# Prevalence and risk factors of poor indoor air quality and sick house syndrome symptoms in Dubai

# إنتشار و عوامل الخطر لفقر الهواء الداخلي وأعراض متلازمة البيت المريض في دبي

**by**

**MUNA IBRAHIM ALI**

**A thesis submitted in fulfilment**

**of the requirements for the degree of**

**DOCTOR OF PHILOSOPHY IN ARCHITECTURE**
**AND SUSTAINABLE BUILT ENVIRONMENT**

**at**

**The British University in Dubai**

**April 2019**

# Declaration

I warrant that the content of this research is the direct result of my own work and that any use made in it of published or unpublished copyright material falls within the limits permitted by international copyright conventions.

I understand that a copy of my research will be deposited in the University Library for permanent retention.

I hereby agree that the material mentioned above for which I am author and copyright holder may be copied and distributed by The British University in Dubai for the purposes of research, private study or education and that The British University in Dubai may recover from purchasers the costs incurred in such copying and distribution, where appropriate.

I understand that The British University in Dubai may make a digital copy available in the institutional repository.

I understand that I may apply to the University to retain the right to withhold or to restrict access to my thesis for a period which shall not normally exceed four calendar years from the congregation at which the degree is conferred, the length of the period to be specified in the application, together with the precise reasons for making that application.

Signature of the student

# Copyright and information to users

# Abstract

Housing environment is a key determinant of health and wellbeing for individuals, communities, and public health at large. Recently, an increasing range of diseases related to poor Indoor Environmental Quality (IEQ) commonly referred to as Sick Building Syndrome (SBS) symptoms – or Sick House Syndrome (SHS) in case of housing related symptoms – which are evolving as a global concern. What exacerbate the concern regarding SHS is its' being a product of intricate interactions between three multivariate factors involving the IEQ factors in addition to building and population characteristics. Due to that complexity; high levels of ambiguity and uncertainty enfold the associations between IEQ and SHS. Globally, previous research focused in investigating the associations between IEQ and health symptoms in offices more than houses. However, housing IEQ and its associated health risks is of growing concern because of the longer exposure to contaminants and its inclusion of vulnerable individuals. In the United Arab Emirates (UAE), poor indoor air quality (IAQ) in housing – which is one of the IEQ factors – is considered as the 2$^{nd}$ environmental health risk. However, few population-based researches were conducted regarding poor housing IEQ and its associations with SHS. None covered a sample including the different nationalities living in UAE. That is important in revealing more realistic results reflecting the present IEQ and SHS in UAE housing. Furthermore, the impact of many building variables on IEQ and SHS is under-researched by previous studies i.e. applied HVAC system, building age and type.

Therefore, this research sought to respond to a number of questions aiming to: (1) Explore the IEQ conditions and prevalent SHS in Dubai housing; (2) Identify the risk factors affecting IAQ and SHS; (3) Investigate the impact of the applied heating, ventilation, and air conditioning (HVAC) system on IEQ and SHS; (4) Assess the sufficiency of provided AERs; and (5) Propose appropriate strategies to mitigate poor IEQ and SHS prevalence. The two major methods employed by this study were a cross-sectional survey and a field study. The survey collected data from 770 Dubai residents. The utilized questionnaire was adopted and adapted from the MM 040 NA questionnaire, EPA IEQ in addition to EPA IAQ and work environment questionnaire. A pilot survey covering 120 Dubai households was conducted to examine the reliability and validity of the proposed questionnaire and to develop it accordingly. SPSS Statistics Version 23 software was used for the survey analysis and it encompassed the conduct of principal component analysis (PCA) and multiple linear regression (MLR) models. Regarding the field study; it was conducted in the living hall of 60

Dubai household and it included measurements, questionnaire, and AERs calculations using $CO_2$ steady-state method. Performed measurements were: (1) Continuous measurement of indoor $PM_{2.5}$, $PM_{10}$, CO, $CO_2$, TVOC, RH, and T levels for 24 hours; (2) A single sample of indoor HCHO drawn for 30 minutes; and (3) A spot measurement of outdoor $CO_2$, CO, TVOC, RH, and T levels.

The survey results revealed that prevalent health symptoms experienced at least 1 – 3 days/week in Dubai households were ergonomic symptoms experienced by about 18% of Dubai households, general (17%), skin (17%), fatigue (17%), nose (17%), neurological (15%), cough (12%), eye (10%), throat (9%), chest symptoms (8%), and fever (5%). Prevalent SHS symptoms – occurred at least once a week and became better outdoors – were about 30%. The most prevalent IEQ conditions at least 1 – 3 days/week was dust and dirt experienced by about 29% then "Too quiet" (22%), "Too hot" (22%), "Too humid" (19%), "Too noisy" (19%), "Too cold" (17%), "Too glary" (13%), "Too dim" (14%), "Little air" (15%), "Too dry" (16%), and "Stuffy bad air" (14%). The most prevalent odors at least 1 – 3 days/week were "Fishy/food odors" reported by approximately 21%, "Body/cosmetics odors" (20%), "Tobacco smoke" (20%), "Incense smoke" (19%), "Chemicals odors" (7%), "Dampness odors" (6%), "Diesel/engine exhaust" (6%), "New carpets' odors" (4%), and "Paint odors" (4%). Moreover, following is a summary characterizing measured indoor IEQ parameters and estimated AERs in the 60 Dubai households:

- $PM_{2.5}$ levels exceeded the 35μg/$m^3$ limit (ASHRAE 2016) in all households.
- $PM_{10}$ levels exceeded the 150μg/$m^3$ limit (DM 2016) in 88% of households.
- TVOC levels exceeded the 300μg/$m^3$ by DM (2016) in 67% of households.
- $CO_2$ levels exceeded the 800ppm limit (DM 2016) in 45% of households.
- T range was not complying with DM (2016) requirements in all households while RH range was not complying with DM (2016) requirements in 60%.
- Estimated AER insufficient as per (ASHRAE 2016) in 38% of households.
- CO and HCHO levels were acceptable as per national and international standards.

According to survey results; perceived IAQ discomfort was significantly associated with: perceived odors, Thermal, Lighting, and Noise comfort, dust allergy, age, migraine, other Africans, in addition to new wall covering. IAQ discomfort was positively associated with all above parameters except the new wall covering. Regarding the signicant associations with prevalent SHS symptoms; the population variables identified as risk factors that had positive association with prevalent SHS symptoms were: dust allergy, migraine, asthma, females, eczema, and other Arabs or MENA Nationals. The following list shows the building and IEQ variables identified as risk factors positively associated with prevalent SHS symptoms. Notably that no significant association was found between any of the three HVAC systems studied by this research with SHS symptoms as per the adjusted MLR models.

- Dimness with all SHS symptoms.
- Stuffy air, dust, dirt, paint odors, dampness odors, in addition to attached kitchen with Eye, Nose, Throat, and Chest symptoms.
- High humidity, incense smoke, water leakage, in addition to Dubai Sector 1 with General, Ergonomic, Nervous, and Skin symptoms.

The above results revealed the great opportunities in mitigating prevalent SHS symptoms in Dubai housing when controlling the identified risk factors. To achieve that, collaborative efforts are required from all related bodies i.e. governmental and academic institutions, building industry, and even occupants. Following are the major practical implications and recommendations that can be derived from findings of this research:

- Developing related regulations by:
    - Mandating an appropriate exposure limit for indoor $PM_{2.5}$ concentration.
    - Establishing rigorous policies to enforce compliance with mandated limits.
    - Establishing convenient policies to manage probable environmental risk of incense burning and new paints.
    - Incorporating the needs of atopic individuals and females in related policies.
- Increasing public awareness about below risk factors and how to manage them:
    - The risk of having unacceptable indoor levels of $PM_{2.5}$, $PM_{10}$, TVOC, $CO_2$, T, RH, and AERs that threatens a substantial number of Dubai housing.
    - The identified IEQ and building risk factors associated with SHS symptoms which were: indoor dimness, dust and dirt, stuffy air, paint odors, high humidity, water leakage, dampness odors, incense smoke, attached kitchens, and Dubai Sector 1. While population risk factors were: dust allergy, migraine, asthma, gender, eczema, and other Arabs or MENA Nationals.
- Employing efficient management methods for the above identified risk factors i.e. indoor lighting solutions, moisture control methods, dust prevention strategies … etc.
- Conducting further research to fill available theoretical gaps i.e. in-depth researches regarding identified risk factors exploring their sources and management methods.

# مُلخص

تُعْتَبَر البيئة السكنية من العوامل الرئيسية المحددة للصحة و الرفاهية لما لها من تأثيرٌ كبيرٌ على الصحة العامة للأفراد و المجتمعات. فى الآونة الأخيرة، هناك قلق متنامى عالمياً من التزايد الملحوظ فى معدل الأعراض المرضية المرتبطة بتردى نوعية البيئة الداخلية التى يُطلق عليها أعراض متلازمه المبنى المريض – أو أعراض متلازمة البيت المريض فى حالة حدوثها داخل المبانى السكنية. إحدى الأسباب وراء هذا القلق المتزايد من أعراض متلازمة البيت المريض أنها نتاج تفاعل عالى التعقيد بين ثلاثة عوامل متعددة المتغيرات وهى نوعية البيئة الداخلية, خصائص المبنى, و خصائص السكان. نتيجة لهذا التفاعلات المعقدة, تكتنف العلاقات بين أعراض متلازمة البيت المريض و نوعية البيئة الداخلية قدر عال من الغموض. على الصعيد العالمى, كان تركيز معظم البحوث السابقة على دراسة العلاقة بين أعراض متلازمة المبنى المريض ونوعية البيئة الداخلية فى المبانى المكتبية أكثر من المبانى السكنية. إلا أن نوعية البيئة الداخلية فى المبانى السكنية فى حوجة ماسة للمزيد من البحث و الدراسة نسبةً لتعرض مستخدميها لملوثات الهواء الداخلى لفترات أطول و لإحتوائها على الأفراد ضعيفى المقاومة مثل الأطفال, المرضى, و كبار السن. فيما يتعلق بدولة الإمارات العربية المتحدة, تم تصنيف التردى فى نوعية الهواء الداخلى– و هو أحد عوامل نوعية البيئة الداخلية – فى المبانى السكنية كثانى المخاطر الصحية البيئية. بالرغم من ذلك, أُجريت القليل من الدراسات التى تبحث عن العلاقة بين بيئة المسكن الداخلى و أعراض متلازمة البيت المريض من عينات سكانية ممثلة لسكان الدولة. من بين هذه الدراسات القليلة, لا يوجد بحث واحد يتناول دراسة هذه الظاهرة على مستوى الجنسيات المختلفة التى تقطن بالإمارات العربية المتحدة. مثل هذه الدراسات فى غاية الضرورة لأنها تعكس نتائج أكثر مطابقة للواقع بخصوص الوضع الحالى لبيئة المساكن الداخلية و أعراض متلازمة البيت المريض فى الإمارات. علاوةً على ذلك, لم تتناول أيٍ من هذه الدراسات البحث عن تأثير المتغيرات الوسيطة مثل نوعية التهوية التى يمكن من خلالها تحسين بيئة المساكن الداخلية وتقليص أعراض متلازمة البيت المريض المرتبطة به فى دولة الإمارات العربية.

لذلك سعى هذا البحث الى الإجابة على عدد من الأسئلة التى هدفت إلى: (1) إستكشاف الأوضاع الحالية لنوعية البيئة الداخلية فى مبانى دبى السكنية و مدى إستشراء أعراض متلازمة البيت المريض فيها وسط قاطنيها, (2) تعريف عوامل الخطر التى تؤثر على نوعية الهواء الداخلى و أعراض متلازمة البيت المريض التى يعانى منها السكان, (3) التحقق من تأثير أنظمة التكييف و التهوية المستخدمة على نوعية الهواء الداخلى و أعراض متلازمة البيت المريض, (4) تقييم مدى كفاية معدلات التهوية فى المنازل, (5) إقتراح إستراتيجيات مناسبة للتخفيف من تردى البيئة الداخلية للمنازل والمشاكل الصحية المترتبة عليها. لتحقيق هذه الأهداف إستخدمت الدراسة إسلوبى بحث رئيسين هما مسح و دراسة ميدانية. جمع المسح بيانات من 770 فرد من سكان دبى خلال الفترة من يوليو 2017 إلى يونيو 2018. إعتمد الإستبيان المستخدم فى تصميمه على إستبيان MM 040 NA و إستبيانى EPA – IEQ و EPA – IAQ. كما أُجريت دراسة تجريبية شملت 120 فرد من سكان دبى قبل الشروع فى الإستبيان الرئيسى بغرض التأكد من صلاحية الإستبيان المقترح كأداة بحث موثوقٌ بها وتطويره تبعا لذلك. تم التحليل الإحصائى للبيانات بإستخدام برنامج SPSS Statistics 23 و شمل إجراء تحليل المكون الأساسى Principal component analysis (PCA) و نماذج الإنحدار الخطى المتعدد Multiple linear regression (MLR) models. بخصوص الدراسة الميدانية, فقد تم

تطبيقها فى صالة المعيشة فى 60 مسكن فى دبى خلال الفترة من سبتمبر 2017 إلى يونيو 2018 و شملت عمل قياسات ميدانية, إستبيان, وحساب معدلات التهوية بإستخدام CO$_2$ steady state method . شملت القياسات الميدانية الآتى: (1) قياس مستمرلمدة يوم كامل لمستويات PM$_{10}$, PM$_{2.5}$, CO, CO$_2$, TVOC, T, RH, (2) قياس مستويات الـ HCHO لمدة 30 دقيقة, (3) قياس لحظى Spot measurement لمستويات CO, CO$_2$, TVOC, T, RH فى الهواء الخارجى المحيط بالمنزل.

أظهرت نتائج المسح أن الأعراض الصحية السائدة فى مساكن دبى بمعدل 1 – 3 أيام في الأسبوع على الأقل هى: Ergonomic symptoms التي عانى منها حوالي 18٪ من الأسر؛ العامة (17٪)؛ الجلد (17٪)؛ الإرهاق (17٪)؛ والأنف (17٪)؛ والعصبية (15 ٪)؛ السعال (12 ٪)؛ العين (10 ٪)؛ الحنجرة (9 ٪)؛ أعراض الصدر (8 ٪)؛ و الحمى (5%). فيما يتعلق بأعراض متلازمة البيت المريض الأكثر شيوعاً, و هى التى حدثت بمعدل 1 – 3 أيام في الأسبوع على الأقل و التى تحسنت خارج المنزل، فهى متواجدة بنسبة 30% فى منازل دبى. أما بالنسبة للأوضاع البيئة الداخلية الأكثر شيوعاً و التى تتواجد بمعدل 1 – 3 أيام في الأسبوع على الأقل فهى الغبار و الأوساخ التى يعاني منها حوالى 29% من سكان دبى متبوعة بـ "هادئ جدًا" (22٪) ، "حار جدًا" (22٪) ، "رطب جدًا" (19٪), "شديدة الصخب" (19٪) ، "شديد البرودة" (17٪) ، "شديد التوهج" (13٪) ، "شديد التعتيم" (14٪) ، "قليل للهواء" (15٪) ، "جاف للغاية "(16 ٪) ،و" هواء سيئ "(14 ٪). أمَا الروائح الأكثر شيوعًا التي أبلغ عنها بمعدل 1 – 3 أيام في الأسبوع على الأقل هي " روائح سمك أو أطعمة أخرى" و التى عانى منها حوالي 21٪ من سكان دبى، "روائح الجسم / مستحضرات التجميل" (20٪) ، "دخان التبغ" (20٪) ، "دخان البخور" ( 19٪) ، "روائح كيماويات" (7٪) ، "روائح الرطوبة" (6٪) ، "روائح صادرة عن عادم الديزل / المحرك" (6٪) ، "روائح السجاجيد الجديدة" (4٪) ، و "روائح الدهان" (4%). بالإضافة الى ذلك, النقاط القادمة تمثل ملخص لنتائج القياسات الميدانية وتقديرات معدلات التهوية المتوفرة فى الـ 60 مسكن بدبى:

- مستويات PM$_{2.5}$ تعدت حد الـ 35µg/m$^3$ المنصوص عليه حسب (ASHRAE 2016) فى كل المساكن.
- مستويات PM$_{10}$ تعدت حد الـ 150µg/m$^3$ المنصوص عليه حسب (DM 2016) فى 88% من المساكن.
- مستويات TVOC تعدت حد الـ 300µg/m$^3$ المنصوص عليه حسب (DM 2016) فى 67% من المساكن.
- مستويات CO$_2$ تعدت حد الـ 800µg/m$^3$ المنصوص عليه حسب (DM 2016) فى 88% من المساكن.
- درجات الحرارة تعدت المدى المنصوص عليه حسب (DM 2016) فى كل المساكن.
- مستويات الرطوبه النسبية تعدت المدى المنصوص عليه حسب (DM 2016) فى 60% من المساكن.
- معدلات التهوية المتوفرة غير كافية حسب (ASHRAE 2016) فى 38% من المساكن.
- مستويات كل من CO and HCHO مقبولة حسب المقاييس المحلية و العالمية.

وفقاً لنتائج المسح, إرتبط الإنزعاج من نوعية الهواء الداخلى إرتباطاً ملحوظاً بـ: الروائح المحسوسة؛ الإنزعاج من نوعية البيئة الداخلية حراريا, ضوئيا, وصوتيا؛ و تجديد غطاء الجدران بالإضافة الى العوامل المرتبطه بالسكان و هى التحسس من الغبار, العمر, الصداع النصفى، و الجنسيات الأفريقية الأخرى. كل هذه العوامل تؤثر بشكل إيجابى على مدى الإنزعاج من نوعية الهواء الداخلى ما عدا تجديد غطاء الجدران. أيضاً, حسب نتائج المسح, العوامل السكانية التى تم تعريفها كعوامل خطر لإرتباطها الوثيق بأعراض متلازمة البيت المريض السائدة في مساكن دبى هى:

حساسية الغبار ، الصداع النصفي ، الربو ، والأكزيما, الإناث, بالإضافة الى سكان دبى من الجنسيات العربية الأخرى/ الشرق الأوسط و شمال أفريقيا. كما توضح القائمة بالأسفل عوامل نوعية البيئة الداخلية التى تمَ تعريفها كعوامل خطر لإرتباطها الوثيق و الإيجابى بأعراض متلازمة البيت المريض السائدة في مساكن دبى. و تجدر الإشارة هنا أنه لم يتم العثور على أي إرتباط وثيق بين أعراض متلازمة البيت المريض و أنظمة التكييف و التبريد المستخدمة فى مساكن دبى حسب نتائج الإنحدار الخطى المتعدد المعدلة Adjusted MLR models .

- العتمة الداخلية مرتبطة إرتباط وثيق مع كل أعراض متلازمة البيت المريض.
- الهواء السئ، الغبار، الأوساخ، روائح الطلاء، روائح الرطوبة، بالإضافة إلى المطبخ المرفق بالمنزل مرتبطة إرتباط وثيق مع أعراض متلازمة البيت المريض المتعلقة بالأنف, الأذن, الحنجرة, و الصدر.
- الرطوبة العالية, دخان البخور, تسرب المياه ، بالإضافة إلى قطاع دبي 1 مرتبطة إرتباط وثيق مع أعراض متلازمة البيت المريض العامة, العصبية, الجلدية, و الـ Ergonomic.

كشفت النتائج أعلاه عن الإمكانيات العالية المتاحة بخصوص تخفيف أعراض متلازمة البيت المريض السائدة فى مساكن دبى فى حال التحكم الجيد على عوامل الخطر المرتبطة به. يستلزم تحقيق ذلك بذل الجهد والتنسيق بين جميع الهيئات و الجهات ذات الصلة مثل المؤسسات الحكومية و الأكاديمية بالإضافة الى تلك المرتبطة بصناعة البناء وحتى السكان. فيما يلي ملخص للآثار العملية والتوصيات الرئيسية التي يمكن استخلاصها من نتائج هذا البحث:

- تطوير اللوائح ذات الصلة من خلال:
  - فرض حد مناسب لتركيز $PM_{2.5}$ داخل المساكن.
  - وضع سياسات صارمة لفرض الإمتثال للحدود المنصوص عليها بخصوص نوعية البيئة الداخلية فى المساكن.
  - وضع سياسات ملائمة لإدارة المخاطر البيئية المحتملة للدهانات و لحرق البخور.
  - وضع احتياجات الإناث بالإضافة الى الأفراد ضعيفى المناعة فى الإعتبار عند سن سياسات جديدة ذات الصلة.
- زيادة الوعي العام بعوامل الخطر الآتية وكيفية إدارتها:
  - المخاطر المترتبة على تواجد $PM_{10}$, CO, $CO_2$, TVOC, T, RH بمستويات عالية و غير مقبولة و التى تهدد عدداً كبيراً من مساكن دبى.
  - عوامل الخطر التى تمَ تعريفها و المتعلقة بنوعية البيئة الداخلية والمبنى التى إرتبطت إرتباط وثيق مع أعراض متلازمة البيت المريض و هى: العتمة ، الرطوبة العالية, تسرب المياه, روائح الرطوبة, روائح الطلاء، الهواء السئ، دخان البخور، الغبار، الأوساخ, المطابخ المرفقة، دبى قطاع 1. بالإضافة الى عوامل الخطر من المتغيرات السكانية وهى: حساسية الغبار، الصداع النصفي، الربو، الإناث، الأكزيما، والجنسيات العربية الأخرى/الشرق الأوسط و شمال أفريقيا.
- استخدام أساليب إدارة فعالة لعوامل الخطر التى تم تعريفها أعلاه مثل حلول الإضاءة الداخلية، طرق التحكم في الرطوبة, استراتيجيات منع الغبار, و أساليب لإدارة الغازات الناتجه عن الإحتراق من المواقد و البخور.
- إجراء مزيد من البحوث لملء الفجوات العلمية الموجودة مثل البحوث المتعمقة بغرض إستكشاف مصادر أو مسببات عوامل الخطر المعرَفة أعلاه و البحث عن الطرق المناسبة لإدارتها و التحكم بها.

# Dedication

*To the soul of my father; the first who urged me to search for knowledge.*

*To my mother; who kept on inspiring me throughout my life.*

*To my husband; without whose support, this would've never been accomplished.*

*To my children; for whom I am still struggling.*

# Acknowledgement

Firstly, I would like to express my sincere gratitude to my director of studies Prof. Bassam Abu-Hijlah for his wise directions, patience, and immense knowledge. My gratitude is extended to Dr. Hasim Altan for his valuable guidance, motivation, and continuous support. Their supervision helped me throughout my research and writing of this thesis. Besides, I would like to thank all the staff in the British University in Dubai for being so cooperative and helpful throughout my PhD study. The conduct of this research would have been very difficult without their precious support and cooperation. My sincere thanks also goes to all Dubai residents who participated in the survey and to those who offered me the opportunity to perform the field study in their households. This study would have never been accomplished without their valuable participation.

# Table of Contents

# List of Figures

# List of Tables

# Nomenclature

| | |
|---|---|
| AC | Air conditioning |
| ACGIH | American Conference of Governmental Industry Hygienists |
| AD | Abu Dhabi |
| AD EHSMS | Abu Dhabi Environmental, Health and Safety Management System |
| AD OSHAD | Abu Dhabi Occupational, Safety, and Health Center |
| AD UPC | Abu Dhabi Urban Planning Council |
| AER | Air exchange rate |
| AERA | American Educational Research Association |
| AIHA | American Industrial Hygienic Association |
| ALARA | As low as reasonably achievable |
| ALTER | Acceptable long-term exposure range |
| ANSI | American National Standards Institute |
| APHA | American Public Health Association |
| AQG | Air quality guideline |
| ASA | American Standards Associations |
| ASHRAE | American Society of Heating, Refrigerating and Air Conditioning Engineers |
| ASHVE | American Society of Heating and Ventilating Engineers |
| ASTER | Acceptable short-term exposure ranges |
| ASTM | American Society for Testing and Materials |
| AV | Active ventilation |
| BREEAM | Building Research Establishment Environmental Assessment Method |
| BRI | Building related illness |
| BUiD | British University in Dubai |
| CAV | Constant air ventilation |
| CCOHS | Canadian Centre for Occupational Health and Safety |
| $C_6F_6$ | Hexafluorobenzene |
| CI | Confidence interval |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| COHb | carboxyhaemoglobin |
| DM | Dubai Municipality |
| DSC | Dubai Statistics Center |
| DV | Dependent variable |
| EAD | Environmental Agency – Abu Dhabi |
| EBD | Environmental burden of disease |
| ECA | European Collaborative Action |
| ENT | Ear, nose, and throat |
| EPA | Environmental Protection Agency – USA |
| EPA BASE | EPA Building Assessment Survey and Evaluation |
| ETS | Environmental tobacco smoke |

| | |
|---|---|
| GFC | Gas filter correlation |
| HAAD | Health Authority – Abu Dhabi |
| HCHO | Formaldehyde |
| $H_2S$ | Hydrogen sulphide |
| HVAC | Heating, ventilation, and air conditioning systems |
| IA | Illness absence |
| IAQ | Indoor air quality |
| IEA | International Energy Agency |
| IEQ | Indoor environmental quality |
| ISO | International Organization for Standardization |
| IV | Independent variable |
| JFS | Japan for sustainability |
| KMO MSA | Kaiser-Meyer-Olkin Measure of Sampling Adequacy |
| LCCA | Life cycle cost analysis |
| LEED | Leadership in Energy and Environmental Design |
| LOD | Limit of detection |
| MEM | Micro – environmental exposure monitor |
| MCS | Multiple chemical sensitivities |
| MLR | Multiple linear regression |
| MMVF | Man-made vitreous fibres |
| MoPWs | Ministry of Public Works - UAE |
| NDIR | Non-dispersive infrared |
| NIOSH | National Institute for Occupational Safety and Health |
| $NO_2$ | Nitrogen dioxide |
| NOAA | National Oceanic and Atmospheric Administration |
| $NO_x$ | Nitrogen oxides |
| NV | Natural ventilation |
| $O_3$ | Ozone |
| OECD | Organisation for Economic Co-operation and Development |
| OSHA | United States Occupational Safety and Health |
| PBRS | Pearl Building Rating System |
| PCA | Principal component analysis |
| PEL | Permissible exposures limit |
| PEM | Personal exposure monitor |
| PID | Photoionization detector |
| $PM_{2.5}$ | Particulate matter of with an aerodynamic diameter of ≤ 2.5 micrometers |
| $PM_{10}$ | Particulate matter of with an aerodynamic diameter of ≤ 10 micrometers |
| POST | Parliamentary Office of Science and Technology |
| PSD | Passive sampling device |
| REL | Recommended exposure limit |
| RH | Relative humidity |
| Rn | Radon |
| SBS | Sick building syndrome |
| $SF_6$ | Sulphur hexafluoride |
| SHS | Sick house syndrome |

| | |
|---|---|
| $SO_2$ | Sulphur dioxide |
| $SO_x$ | Sulphur oxides |
| SOP | Standard operating procedure |
| SPSS | Statistical package for the social sciences |
| STEL | Short – term exposure limit |
| T | Temperature |
| TBS | Tight building syndrome |
| TEA | Triethanolamine |
| TEC | The Executive Council _ UAE |
| TLV | Threshold limit value |
| TVOC | Total volatile organic compounds |
| TWA | Time weighted average |
| UAE | United Arab Emirates |
| UFP | Ultrafine particulate matter |
| UN | United Nations |
| US / USA | United States of America |
| US CIA | United States Central Intelligence Agency |
| USGBC | United States Green Building Council |
| VAV | Variable air ventilation |
| VOC | Volatile organic compound |
| WHO | World Health Organization |

# Chapter 1 : Introduction

## 1.1 Background of the problem

The whole world is experiencing an increasing range of diseases related to poor IEQ conditions collectively referred to as SBS (Kishi et al. 2018; Wang et al. 2013; Guo et al. 2013; Jurado et al. 2014; Ndwiga et al. 2014; Takigawa et al. 2012; Sahlberg 2012, Kanazawa et al. 2010; Gomzi & Bobic 2009; and Yang et al. 2009). SBS symptoms were also called as SHS when occurring in indoor housing spaces (Kishi et al. 2018; Runeson-Broberg & Norbäck 2013; Eastin & Mawhinney 2011; Kanazawa et al. 2010; JFS 2007; Tanabe 2003). SBS or SHS involves multiple health effects ranging from mild disorders to acute, chronic, and probably life-threatening illnesses i.e. cardiovascular disease and cancer (EPA 2015; WHO 2010a, 2006, 2000; Health Canada 2006, 2010, 2011, 2012, 2013, 2016). According to Engvall et al. (2004); SBS or SHS symptoms is affected by three major factors which are indoor environmental qualities (IEQ), building, and population characteristics whereas the IEQ encompass four factors which are the IAQ, Thermal, Lighting, and Noise quality (Figure 1-1). According to (EPA 2015; Hess-Kosa 2011), poor IAQ is one of the IEQ factors that of growing concern as it is evolving as one of the top global health hazards. IAQ encompass all indoor air attributes affecting occupants' health and comfort (ASHRAE 2007; EAD 2014). In UAE, poor IAQ was identified as the second environmental health risk (Willis et al. 2010; Gibson et al. 2013; Gibson & Farah 2012).

As per Turpin (2014), the SBS term emerged and popularly used in the 1990s and the causes of the significant escalation of similar health problems were attributed by many references to the 1970s in the United States of America (USA) (Hess-Kosa 2011; Gomzi & Bobic 2009; OSHA 1999a). However, it is important to note that health problems resulting from poor IAQ are prevailing due to a wide range of sources throughout history. For instance, combustion of biomass fuels such as wood, crop residues, and animal dung for heating and cooking significantly contributed in poor IAQ prior industrialization age. The generated smoke caused many adverse health impacts on occupants (Zhang & Smith 2003). Unfortunately, solid fuels are still being used worldwide and its resultant indoor smoke is causing high indoor air pollution (WHO 2018; IEA 2017; Apte and Salvi 2016). As demonstrated by (Ndwiga et al. 2014; Butz et al.  2011), exposure to such levels adversely affects occupants health particularly women and young children who spend the majority of their time near their dwellings' hearth. Notably that, as declared by (Nicole 2014; Logue et al. 2014; WHO 2007; Zhang & Smith 2003), even the use of natural gas cooking burners (NGCBs) were estimated to increase indoor air pollution levels and is also associated with health risks in lower levels than using solid fuels.

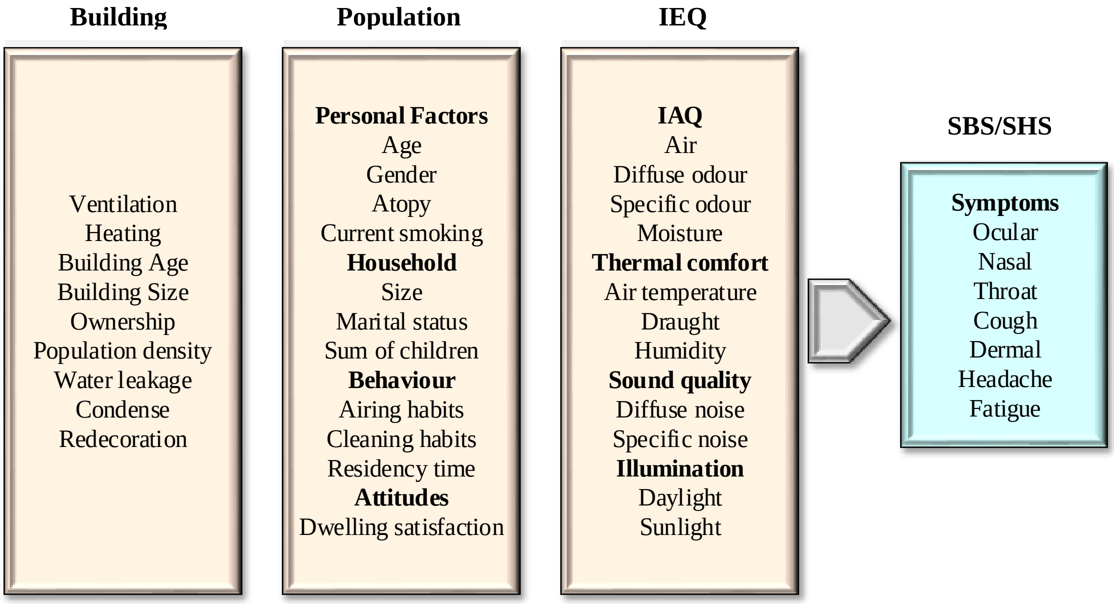


Figure 1-1: SBS/SHS major factors (Engvall et al. 2004, p.26)

Then in the 1970s, in an attempt to save energy due to the energy crisis, modern building became more airtight with inoperable windows to reduce AERs than those provided in traditional buildings (Hess-Kosa 2011; Zhang & Smith 2003; OSHA 1999a). Reference to (Hess-Kosa 2011), the higher exchange rates in traditional buildings dilute and clean indoor air contaminants more than in energy-efficient ones. One of the subsequent results of the decreased AERs in modern buildings is the increase of indoor air pollution by 2-5 times more than outdoors. Moreover, indoor air pollution was ranked as one of top environmental risks in USA. That was strongly correlated with the 85% increase of Chronic bronchitis and emphysema between 1970 – 1987; 60% increase in Asthma incidence during 1996-2011 among school children; and 8% of all school-aged children were asthma diagnosed in 2011 (Hess-Kosa 2011). Noteworthy that, after 1970s, new challenges evolved in modern houses. Reference to (EPA 2016a; EAD 2014; OSHA 2011a, 2011; WHO 2010a, 2010b; POST 2010), chemical and synthetic products were extensively used in modern air-tight buildings such as furnishings, upholstery, adhesives, manufactured wood products, paints, sealants, copy machines, carpeting, cleaning products, pesticides … etc. Indoor airborne contaminants generated from occupants presence or/and activity may also affect the IAQ i.e. cooking methods, smoking habits, incense burning, human metabolic activity, hobbies, craft activities, cleaning methods, … etc. According to (Hess-Kosa 2011; Zhang & Smith 2003); the net result of the lower AERs provided in new air-tight buildings compared with traditional ones was the entrapment of several airborne pollutants indoors. This was highlighted as a key contributor in increasing SBS complaints in both developed and developing countries.

## 1.2 Problem statement

Poor IAQ in residential spaces was classified as the second environmental health risk in UAE by three recent studies commissioned by the Environmental Agency – Abu Dhabi (EAD) (Willis et al. 2010; Gibson et al. 2013; Gibson & Farah 2012). Healthcare visits attributable to poor IAQ were estimated by (Gibson et al. 2013; Gibson & Farah 2012) as 49% and 439% more than that of polluted outdoor; respectively. Annual fatalities were also estimated as 150 – 290 deaths by the previous two studies; respectively. That means at least 12 deaths monthly are attributed to poor IAQ in UAE housing spaces. Attaining such higher number of healthcare visits and deaths attributable to poor residential IAQ is a concerning indication of the long-term latency diseases due to the exposure to harmful indoor air contaminants in UAE future. That is because, according to EPA (2015), poor IAQ is considered as a hazardous risk of considerable uncertainties regarding the determination of the potential negative impact of poor IAQ on occupants' health due to the high levels of ambiguity and ignorance enfolding the phenomenon. The ambiguity stems from the difficulty in predicting the probability of negative health impacts due to the complex factors influencing its occurrence. That is because SHS depends on three multivariate factors that encompass diversified number of parameters which are IEQ, building, and population parameters (Figure 1-1). The interaction between these parameters is very complex and differs from context to another. For example, a particular contaminant might cause different symptoms by different people which make it very difficult to identify the pollution source. Also, related ignorance to that is attributed to the insufficient data identifying the acceptable IAQ pollutants concentrations and acceptable exposure limits to IAQ pollutants in all indoor spaces generally and in residential spaces in particularly.

According to Yeatts et al. (2012a), although the globally increasing recognition of IAQ as a prime parameter influencing occupants' health; limited number of large population-based studies assessed the health impacts of indoor air contamination particularly in residential spaces. Such researches are beneficial in identifying the levels and sources of potential hazards threatening the majority of population. This is essentially required particularly in the first stages of IAQ risk management. That is exactly what had been done by (OSHA 1999a) to address the rising concerns regarding the increasing complaints of employees towards the healthiness of their office buildings. Results of 500 IEQ investigations revealed that 52%, 16%, 10%, 5%, 4%, and 13% of health complaints were attributed to inadequate ventilation, indoor pollutants, outdoor pollutants, microbial pollutants, and building materials; respectively (Figure 1-2). Many technical, administrative and work practice recommendations were established reference to these findings. Moreover, huge number of IAQ researches were built on or inspired by those findings worldwide and still revisited recently (Hess-Kossa 2011; Wang & Zhang 2010a).

In UAE, only one population-based study was conducted regarding poor housing IAQ (Yeatts et al. 2012a; Funk et al. 2014). One of the major limitations of that study was the non-representativeness of the sample of UAE population due to its non-inclusion of expatriates who forms the majority of UAE residents. Another limitation was the insufficient information provided by that study regarding the duration of some unacceptable concentrations due to the use of passive samplers which were incapable to identify short-term peak concentrations. More research is needed to provide sufficient details regarding these contaminants' concentrations in UAE housing. Furthermore, no study assessed the influential factors on IAQ and SHS from a general prospect. Even the only one available study; discussed in more details in Section 2.6, focused on assessing the impact of IEQ parameters as independent variable (IV) on SHS as dependent variable (DV). The assessment did not include the impact of the applied ventilation system on poor IAQ and SHS prevalence. According to (Sundell et al. 2011; Hess-Kosa 2011; OSHA 1999a), the sufficiency and quality of provided ventilation is one of the most important mediating variables that was strongly associated by many contemporaneous studies with the IAQ conditions (IV) and SHS prevalence (DV). In this introductory stage of knowledge, it is essential to address the IAQ and SHS phenomenon from a broad perspective that allows assessing a wide range of parameters. Moreover, ranking these factors forms the first step to highlight what needs to be controlled and managed. That is why this study is aiming to prioritize the influencing factors on IAQ and SHS in UAE housing. Due to the extensive dependence of UAE housing on mechanical ventilation particularly in summer, Dubai emirate is not an exception, this study intends to have more focus on exploring the correlations between the applied heating, ventilation, and air conditioning (HVAC) system with IAQ and SHS conditions.

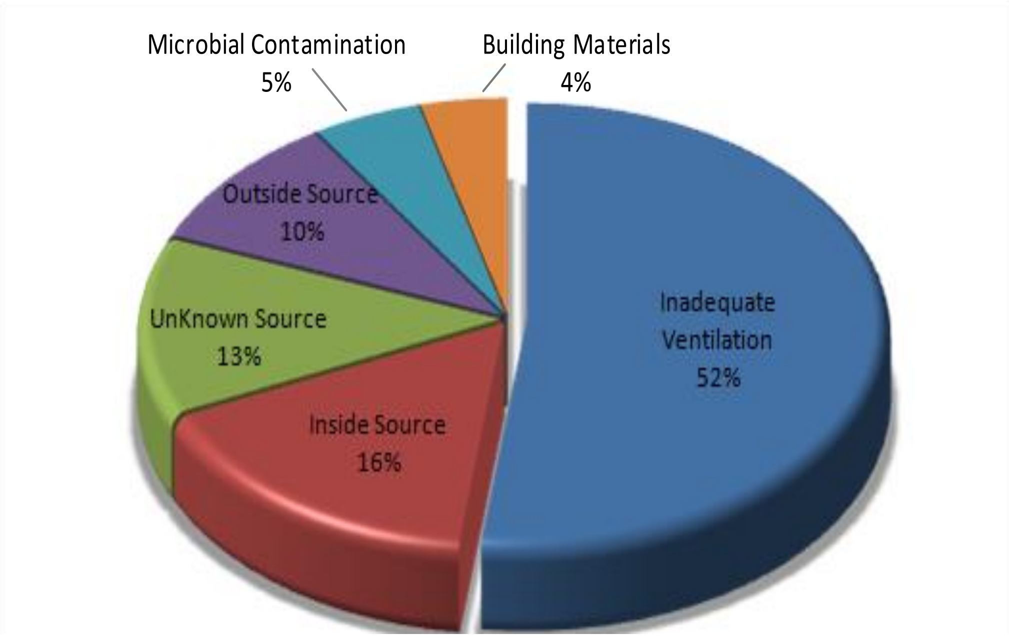


Figure 1-2: Probable causes of poor IAQ and health problems (OSHA 1999a)

## 1.3 Motivation

Based on literature review (Chapter 2), the following theoretical gaps were identified:

- Large scale population-based researches regarding the health impacts of poor IAQ, particularly in residential buildings, is globally lacking and little is known about such impacts in the Middle East (Yeatts et al. 2012a).
- SHS is dominated by diversified and interrelated variables classified into three factors: IEQ, building, and population characteristics (Gomzi & Bobic 2009). Thus, SHS prevalence greatly differs responding to the context characteristics.
- In UAE, the few relevant studies did not sufficiently address the associations between SHS and residential IEQ in the following aspects:
  - Reference to the first population-based UAE study by (Yeatts et al. 2012a), the study sample only covered Emirati nationals whereas the expatriates representing the majority of UAE residents were not included.
  - Previous studies focused on measuring residential contamination levels and sources in relations with prevalent SHS. None studied the impact of applied HVAC systems, ventilation rates, building age and humidity levels that act as confounding variables affecting both the independent variable (IV) which is IEQ conditions and dependent variable (DV) which is SHS levels. Controlling such variables might mitigate or even eliminate the impact of IV on DV.
  - Prevalent SHS and residential IEQ conditions in UAE was not clearly and fully characterized.

To fill the above gaps, this study is aiming to explore the risk factors affecting SHS prevalence and IEQ conditions in general and IAQ in particular in Dubai/UAE housing. The study addressed that from a broader perspective allowing the coverage of the prominently cited variables of the three SHS dimensions rather than focusing on limited number of variables in a specific context. Subsequently, the anticipated results were of general nature. Moreover, this study paid particular consideration to investigate the impact of three commonly applied HVAC systems in Dubai households on IAQ conditions and SHS prevalence. That was because ventilation sufficiency particularly that provided by mechanical systems was significantly associated with health complaints. Also, the dependence of UAE houses in general on mechanical ventilation throughout the year was another reason behind focusing in assessing its impact.

## 1.4 Research questions, aims and objectives

This study intended to answer the following questions:

1. What are the current IEQ conditions and prevalent SHS in Dubai housing?
2. What are the risk factors associated with prevalent SHS symptoms and IAQ conditions in Dubai housing?
3. What is the impact of the applied HVAC system on IAQ and SHS prevalence in Dubai housing?
4. Are the provided AERs sufficient in Dubai housing?
5. What are the potentially appropriate solutions to mitigate or control poor IAQ and SHS in Dubai housing?

In answering the previous questions, this research aimed to:

1. Explore the current IEQ conditions and prevalent SHS in Dubai housing.
2. Identify the risk factors affecting IAQ and SHS in Dubai housing.
3. Investigate the impact of HVAC systems on IAQ and SHS in Dubai housing.
4. Assess the sufficiency of provided AERs in Dubai housing.
5. Propose appropriate strategies that can be used to mitigate poor IAQ and SHS prevalence in Dubai housing.

To fulfill the above aims, the following three objectives were concurrently set. Each objective is linked with the applied methods to achieve it:

1. Identifying the IEQ conditions and SHS prevalence in Dubai housing was achieved by:
    a) Providing descriptive statistics of perceived IEQ conditions and prevalent SHS symptoms measured by self-reported questionnaires.
    b) Providing descriptive statistics of indoor measurements of T, RH, $PM_{10}$, $PM_{2.5}$, CO, $CO_2$, TVOC, and HCHO concentrations in addition to outdoor CO, $CO_2$, and TVOC. Descriptive statistics of estimated AERs provided in the living room during measurement period was also provided.
    c) Compliance assessment of above measured parameters on field in addition to estimated AERs with local and international standards.
2. Identifying the risk factors affecting IAQ and SHS in Dubai housing was achieved by performing multiple linear regression (MLR) models of:
    a) Building and population variables on self-reported SHS symptoms.
    b) Building and population variables on self-reported IEQ perceptions.
    c) Self-reported IEQ perceptions on self-reported SHS symptoms.
    d) Other self-reported IEQ perceptions on self-reported IAQ perceptions.
3. Based on the above findings; appropriate solutions were proposed to mitigate and control poor IEQ and SHS symptoms in Dubai housing.

## 1.5 Research design

This study can be classified as an applied social research as it targeted: (i) knowledge expansion regarding IEQ and SHS in UAE housing, (ii) developing suitable resolution strategies i.e. appropriate ventilation rates, and (iii) explaining particular behavioral patterns within a social context. Like most investigations in this domain; it fell within the quantitative paradigm characterized by its numerical outcome that quantified the variations and predicted associations between variables. For this research, the non-experimental approach was suggested as more congruent one. That is because the complexity and ambiguity concerning the associations between the IEQ variables and SHS symptoms makes the assumption of having full control on all confounders unattainable. Hence, conducting an experimental study under incompletely controlled conditions threatens the experiment internal validity. Thus, this study opted to utilize non-experimental methods to achieve its aims. It was found that a survey was required to reflect current IEQ conditions and prevalent SHS symptoms in Dubai housing and to explore the associations between them. A survey is an appropriate research method in answering "who, what, where, how many, and how much" questions. Also, it is a feasible research method due to their relative low cost and wide coverage. Also, the precedence of understanding the associations between various SHS parameters is fundamental when launching investigations regarding the associations between IEQ conditions and SHS symptoms or prior conducting an experimental study.

However, a survey as a sole instrument is insufficient in revealing clear information regarding measured parameters and contextual characteristics because its major focus is reflecting population trends and generalizability issues. Contrarily, despite their higher cost compared with questionnaires; field measurements were widely used in similar investigations as they reveal clearer information regarding the measured parameter and contextual characteristics. Therefore, it was decided to conduct field measurements for some prominent IEQ variables as part of a field study in which questionnaires and AERs calculation were also performed. The main aim of the field study was to provide clear information regarding the prevalence of measured parameters in Dubai housing and their compliance with national and/or international standards. Thus, the two major research methods employed by this study were: (i) a cross-sectional survey collecting data from 770 Dubai residents, and (ii) a field study that included field measurements of some IEQ parameters, a questionnaire, and estimated AERs provided in 60 households in Dubai. A pilot survey covering 120 households in Dubai was conducted prior the conduct of the main survey. The major aims from conducting the pilot survey were to examine the reliability in addition to the face and content validity of the proposed questionnaire and to develop it accordingly.

Field measurements for indoor HCHO, $PM_{2.5}$, and $PM_{10}$, CO, $CO_2$, TVOC, RH, and T levels were performed in 60 households. Measured parameters were the focus of many contemporaneous studies (Lee et al. 2018; Mečiarová et al. 2017; Funk et al. 2014; Fadeyi et al. 2014; Yeatts et al. 2012a, 2012b; EAD 2014). $PM_{2.5}$ and $PM_{10}$ were continuously measured for 24 hours in each household using the Optical Particle Sizer (OPS) Model 3330. Also, continuous measurement of CO, $CO_2$, TVOC, RH, and T levels was conducted for 24 hours in each household using the DirectSense IQ – 610. Moreover, a spot measurement for a single sample drawn during 30 minutes was conducted to measure the HCHO concentrations in each household. HCHO was measured using the gas detector Model FP 30. Outdoor $CO_2$, CO, TVOC, RH, and T levels were monitored by performing a spot sample using the DirectSense IQ – 610. Outdoor $CO_2$ measurements were employed along with the indoor ones to estimate the provided AERs. The above measurements were performed over 9 months starting from Thursday 14th September 2017 up to Monday 11th June 2018. Notably that the three utilized monitoring devices were manufacturer calibrated prior launching the field measurements.

Moreover, this research adopted $CO_2$ steady-state method in the field study to calculate provided AERs in the living room of the participating households where measurement equipment was installed. $CO_2$ peak analysis approach or equilibrium analysis was commonly employed by contemporaneous relevant studies due to its relatively low-cost, time-efficient, and convenience (Haverinen-Shaughnessy et al. 2015; Kapalo et al. 2014; Turanjanin et al. 2014; You et al. 2012; Haverinen-Shaughnessy et al. 2011; You et al. 2007; Shaughnessy et al. 2006). It was also validated by many researches and considered as effective methods in estimating AERs (Kapalo et al. 2014; You et al. 2007). For attaining more accurate estimations of provided AERs; occupancy profiles during the measurement period in the living room was recorded by the household head in a diary note According to recorded occupancy profiles; provided AER was calculated during the occupancy period of peak $CO_2$ concentration. $CO_2$ generation rate in the peak period was calculated based on recorded number of occupants in the living hall during that period.

# Chapter 2 : Literature review

## 2.1 SBS and SHS definition

Nowadays, the whole world is experiencing an increasing range of diseases strongly correlated with poor IEQ conditions referred to as SBS, tight building syndrome (TBS), building related illness (BRI), and multiple chemical sensitivities (MCS) (Turpin 2014; Hess-Kosa 2011; Gomzi & Bobic 2009; OSHA 1999a). OSHA (1999a) classified building-related health problems into two main categories which are sick building syndrome (SBS) and building-related illnesses (BRI). According to (Turpin 2014; OSHA 1999a), SBS describes health disorders or discomfort symptoms that occur indoors and often disappear or not develop outdoors. SBS is defined by many studies as health disorders which are frequently experienced at least 1 day per week monthly and that usually disappear or not develop outdoors (Ung-Lanki et al. 2017; Azuma et al. 2015; Reijula & Sundman-Digert 2004). The term of sick house syndrome (SHS) was coined from SBS and it is used for SBS symptoms that experienced in housing environments (Kishi et al. 2018; Runeson-Broberg & Norbäck 2013; Eastin & Mawhinney 2011; Kanazawa et al. 2010; JFS 2007; Tanabe 2003). The exact causes of SHS symptoms are usually unknown and sometimes are referred to the exposure to toxic substance/s or to individual vulnerability even to low contamination levels (Turpin 2014; OSHA 1999a). SHS symptoms encompass a wide range of symptoms including headache, nausea, dizziness, dermatitis, respiratory irritation; coughing; difficulty concentrating; sensitivity to odors, muscle pain, fatigue, in addition to eye, nose, and throat related symptoms (Kishi et al. 2018; Kanazawa et al. 2010; OSHA 1999a).

On the other hand, BRI is an allergic infection of specific symptoms that continue after leaving the building and caused by a known cause such as bacteria, virus or fungus. According to EPA (1991b), BRI was another vital potential health problem among employees caused by specified building-related reasons. For instance, bioaerosols caused by microbial contaminated HVAC systems, furniture, and/or rugs might lead to hypersensitivity pneumonitis. This is a respiratory sickness which can be diagnosed by chest x-ray. Other BRI can be caused by the overexposure to toxic substances such as CO with initial symptoms i.e. headaches and nausea. These symptoms might occur for other reasons not related to buildings. That is why proper diagnosis of BRI is the output of a physician's assessmEye, nose, throat, and awareness of environmental pollutants (EPA 1991b). As explained by (Turpin 2014), BRI symptoms include cough, chest tightness, fever, chills, and muscle aches, legionnaires disease, skin rashes, hyper-sensitivity pneumonitis and any other symptoms attributed to virus, bacteria, and/or fungus are usually classified as BRI not SBS or SHS. What differentiate SBS or SHS from BRI is that illness cause in case of BRI is clinically identified by physical signs and/or laboratory results i.e. legionellosis and hypersensitivity diseases.

As per (Turpin 2014), the SBS term is coined and popularly used in the 1990s and the causes of the significant escalation of similar health problems were attributed by many references to the 1970s in the USA (Hess-Kosa 2011; Gomzi & Bobic 2009; OSHA 1999a). However, it is important to note that health problems resulting from poor IAQ are prevailing in varying degrees throughout history. Historically, as explained by Zhang & Smith (2003), heating and cooking prior industrialization era depended on combusting biomass fuels such as wood, crop residues, and animal dung. The generated smoke caused many adverse health impacts on occupants. Then, during industrialization; coal was extensively used for heating indoor spaces. The emitted coal smoke from London households' chimneys was the major reason behind the Great London Smog 1952 that caused thousands of deaths over a week. Banning domestic use of coal in many developed cities was one of the implications of that episode. Unfortunately, domestic coal and/or biomass combustion is still taking place worldwide and their resultant indoor smoke is adversely affecting about 50% of the world's population (Zhang & Smith 2003). Reference to (EPA 1991a; WHO 2008; POST 2010; OSHA 2011a; EPA 2016a), poorly ventilated and maintained gas stoves may increase indoor concentrations of combustion gases such as CO, $NO_2$, $SO_2$ in addition to alleviating respirable particles. According to (WHO 2007), the use of liquefied petroleum (LPG) or natural gas for cooking purposes was associated with lower risk than using coal or kerosene. However, according to recent research (Nicole

2014; Logue et al. 2014) in California houses, natural gas cooking burners (NGCBs) were estimated to increase the weekly-averaged indoor $NO_2$ levels about 35 – 39% in winter and 25–33% in summer. It was also estimated that NGCBs added about 21% and 30% to the indoor CO concentration in winter and summer, respectively.

Then in the 1970s, in an attempt to save energy due to the energy crisis, building became more airtight with inoperable windows to reduce AERs than those provided in traditional buildings (Hess-Kosa 2011; Zhang & Smith 2003; OSHA 1999a). According to (Hess-Kosa 2011), the higher exchange rates in traditional buildings dilute and clean indoor air contaminants more than in energy-efficient ones. One of the subsequent results of this is polluted indoor air 2-5 times more than outdoor. Moreover, indoor air pollution was ranked one of top environmental risks in USA. That is strongly correlated with the 85% increase of Chronic bronchitis and emphysema between 1970 – 1987; 60% increase in Asthma incidence during 1996-2011 among school children; and 8% of all school-aged children were asthma diagnosed in 2011 (Hess-Kosa 2011). After 1970s, new challenges evolved in the new air-tight buildings as worrying concerns arise from exposure to chemical and synthetic substances commonly utilized in modern buildings i.e. furnishings, upholstery, adhesives, manufactured wood products, paints, sealants, copy machines, carpeting, cleaning products, pesticides (Zhang & Smith 2003). Moreover, indoor airborne contaminants generated from occupants presence or/and activity may also affect the IAQ i.e. cooking methods, smoking habits, incense burning, human metabolic activity, hobbies, craft activities, cleaning methods (EPA 2016a; EAD 2014; OSHA 2011a; OSHA 2011; WHO 2010a, 2010b; POST 2010). The net result of lower AERs and the presence of several sources of chemical substances was the entrapment of these substances and their emissions indoors. This was highlighted as a key contributor in increasing SBS complaints in both developed and developing countries (Hess-Kosa 2011; Zhang & Smith 2003).

According to EPA (2015), health impacts from indoor air contaminants might be experienced directly after exposure or after years. That is because some health effects might immediately appear after a sole or frequent exposure to a contaminant such as throat and sensory irritation, dizziness, fatigue, and headaches. Those immediate impacts are often treatable and short-term. Sometimes the cure is just removing the pollution source if it can be recognized. Other health impacts might appear either after lengthy exposure durations, up to years, or after repeated durations of exposure. These impacts may include some heart, respiratory diseases, and cancer that might be severely fatal or incapacitating. That is why it is vital to enhance residential IAQ even if symptoms are unrecognizable. Many factors dominate the reaction towards IAQ contaminants such as exposure duration, pollutant's toxicity, pollutant's concentration and other personal characteristics i.e. health conditions, sensitivity, age, and gender. In other cases, different individuals might experience different symptoms when exposed to similar indoor air contaminant. Furthermore, after frequent or high level exposures, some individuals can become sensitive to chemical and/or biological contaminants (EPA 2015). Reference to (EPA 2015; Turpin 2014), some SBS immediate symptoms are analogous to those from viral, bacterial and/or fungus diseases such as flu and colds. That is why it is usually hard to identify SBS symptoms from other viral infections. Hence, the diagnosis of SBS symptoms and causes is difficult due to the: (i) similarity between certain immediate symptoms and those of viral infections makes it difficult to identify SBS, and the (ii) different reactions demonstrated by different individuals towards same pollutant.

Reference to EPA (1991b), due to the rising concerns regarding poor IEQ in EPA office buildings; an extensive survey was conducted on 3955 employees inquiring about the demographic, personal, space characteristics, and prevalent health complaints. A follow-up survey covering 384 was also performed to report prevalent work-related health symptoms in monitored sites. According to EPA (1991b), the reported health symptoms includes 30 health symptoms that can be grouped into 11 components listed in Table 2-1. However, SBS symptoms are differently clustered by different scholarly-reviewed studies. For instance, Andersson (1998) examined IAQ problems employing a practical approach called as Orebro model that involves using the standardized MM questionnaires when launching an IAQ investigation followed by technical measurements if needed. That approach was recommended by WHO in 1980s and practically adopted by Nordic countries (WHO 1983). Reference to (Andesson et al. 1988), significant SBS symptoms were divided into 3 components which are general, mucousal, and skin symptoms.  Table 2-2 shows the three work-related health symptoms groups along with the environmental factors significantly correlated with.

Table 2-1: Classification of work-related health symptoms (EPA 1991b)

| Cluster | Cluster definition | Included symptoms |
|---|---|---|
| H1 | Headache or nausea | Headache<br>Nausea |
| H2 | Nasal and cough symptoms | Runny nose<br>Stuffy nose/ sinus congestion<br>Sneezing<br>Cough |
| H3 | Chest-related symptoms | Wheezing/ whistling in chest<br>Breath shortness<br>Chest tightness |
| H4 | Eye-related symptoms | Dry/ itching/ tearing eyes<br>Sore/ strained eyes<br>Blurry/ double vision<br>Burning eyes |
| H5 | Throat-related symptoms | Sore throat<br>Hoarseness<br>Dry throat |
| H6 | Tiredness | Unusual fatigue or tiredness<br>Sleepiness or drowsiness |
| H7 | Chills or fever | Chills<br>Fever |
| H8 | Ergonomic symptoms | Aching muscles or joints<br>Lower back pain or stiffness<br>Shoulder/ neck pain/ numbness<br>Hand/ wrist pain/ numbness |
| H9 | Mental or nerve symptoms | Difficulty in remembering<br>Feeling depressed<br>Tension or nervousness<br>Difficulty concentration |
| H10 | Dizziness/light-headedness | Dizziness/ light-headedness |
| H11 | Dry or itchy skin | Dry/ itchy skin |

Table 2-2: Index groups for IEQ variables and SBS symptoms (Andersson et al. 1988)

| Health effect | Symptoms | Environmental experience |
|---|---|---|
| **General symptoms** | Fatigue<br>Heavy-headedness<br>Headache<br>Nausea<br>Concentration problems | Stuffy “bad” air<br>Unpleasant smell<br>Dry air |
| **Mucous membrane symptoms** | Irritated, stuffy or runny nose<br>Frequent colds<br>Sinus problems<br>Dry, hoarse, sore throat<br>Hacking cough | Low temperature<br>Draught<br>Draught from floor |
| **Skin problems** | Facial dry skin<br>Hands dry skin<br>Scaling, itching scalp/ears<br>Facial itching or burning | Noise<br>Lighting |

## 2.2 SHS factors

Similar to SBS factors; SHS factors can be classified into three constructs: IEQ characteristics, building characteristics, and population characteristics (Engvall et al. 2004 & EPA 1991b) (Figure 2-1). IEQ has four dimensions that act as independent variables (IVs) including IAQ, thermal conditions, sound, and illumination qualities. These IVs directly causes SHS symptoms which are the dependent variables (DVs). According to EPA (1991b), models relating employee-reported health symptoms and thermal comfort concerns can be influenced by many potential confounding variables that might affect the associations between the health and IEQ conditions i.e. individual’s age, gender, exposure duration, furniture, carpets, …etc. According to EPA (1991b), the IEQ parameters was considered as the IV of their study, SBS was the DV while all building and personal parameters can be dealt with as potential confounders that might have an impact on both IV and DV (Figure 2-1). As this study addressed similar associations; it adopted above constructs identified by EPA (1991b).

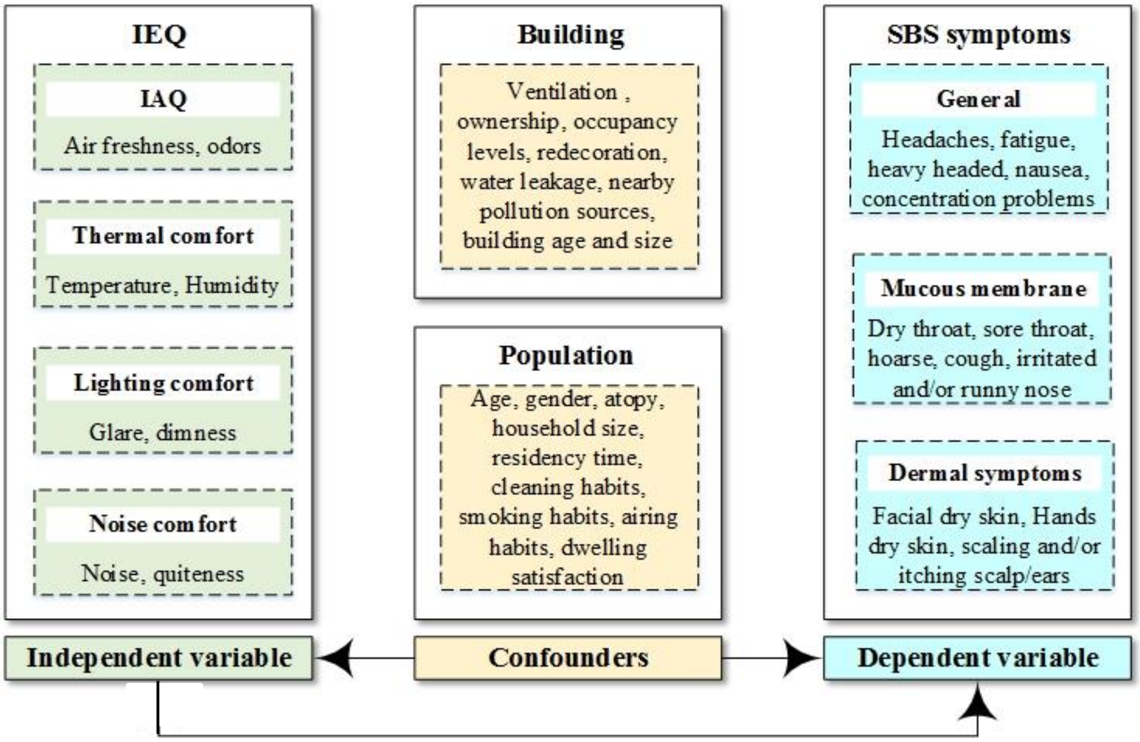


Figure 2-1: Study constructs (Adopted from EPA (1991b))

Concerning SHS associations with the IEQ factors; indoor noise was significantly associated with skin and general symptoms (Niven et al. 2000; Ooi et al. 1998). While poor lighting in work environments had significant association with SBS symptoms that included eye and nose irritation, stuffy nose, dry throat, and shortness of breath in addition to the general or neurotoxic symptoms that included headache, fatigue, dizziness, drowsiness, nausea, and vomiting (Ooi et al. 1998). According to EPA (1991a); thermal comfort is directly affected by indoor temperature and humidity levels. They may also provide indirect indications of HVAC condition and the potential for airborne contamination from biological or organic compounds. Comparison of indoor and outdoor temperature and humidity levels measured during complaint periods can indicate whether thermal discomfort might be due to extreme conditions beyond the design capacity of HVAC equipment or the building envelope. Readings showing large variations within the space may indicate improper air distribution or mixing problem whereas highly variable readings over time may indicate control or balance problems with the HVAC systems. According to EPA (1991b); high temperature might lead to sleepiness and fatigue while low temperatures might cause muscle pain. Moreover, large temperature variations might result in difficulties in adjusting body temperature and subsequently lead to chills and fever.

Concerning indoor humidity; there is considerable debate among researchers, IAQ professionals, and health professionals regarding acceptable humidity levels. However, the humidity levels recommended by different organizations generally range between 30% - 60% RH as that required by DM (2016). Reference to (Hellgren 2012; Nevalainen et al. 1991), the growth of mold and dust mites may be encouraged in case of excess humidity. Also, significant association was found between high humidity and general symptoms (Wang et al. 2013; Kanazawa et al. 2010); mucousal symptoms (EPA 2013; Wang et al. 2013; Kanazawa et al. 2010); increased skin symptoms (Kanazawa et al. 2010; Reinikainen & Jaakkola 2003). Moreover, higher humidity and dampness were significantly associated with odor perception (Wang et al. 2013; Reinikainen & Jaakkola 2003). Furthermore, significant association between mold odors and mucousal symptoms was revealed by (Wang et al. 2013; Sun et al. 2011). While (Sahlberg 2012; Zhang et al. 2012) found significant association between an increased incidence of SBS symptoms and a decreased remission of SBS symptoms with molds, moldy odor, and/or dampness.

In terms of the IAQ; it refers to air characteristics within occupational spaces that is strongly related with occupants’ health and comfort. Reference to ASHRAE (2016), acceptable IAQ describes air characteristics in which there are no harmful concentrations of toxic substances identified by recognized institutions and within which not less than 80% of space occupants are satisfied. Health Canada (1989) identified acceptable domestic IAQ as that free of chemical, biological, and physical pollutants to assure that there is an insignificant amount of risk threatening the safety and health of occupants. And according to The Centre for Australian Weather and Climate Research (2010), IAQ is the output of five aspects:

i. Outdoor pollution sources that might penetrate indoors via infiltration or ventilation,
ii. Indoor pollution sources related to the building characteristics,

iii. Indoor pollution sources related to occupants' activities,
iv. Air exchange rates (AERs) and its impact in replacing indoor air by outdoor air,
v. Processes and materials removing indoor contamination.

Despite the globally increasing recognition of IAQ as a prime factor influencing occupants' health status; comprehensive global data is lacking. That is because many countries are recently experiencing the transition from traditional health risks of household fuel combustion to modern risks of airtight building and building materials. Although the rapid pace of development in some middle east and Arab Gulf countries, little is known regarding the impact of this transition on IAQ status. Knowledge regarding IAQ pollutants and their health impacts is evolving and has not been fully characterized yet. Moreover, limited number of large population-based studies assessed the health impacts of poor IAQ (Yeatts et al. 2012a). Such researches are beneficial in identifying the levels and sources of potential hazards threatening the majority of population. This is essentially required particularly in the first stages of IAQ risk management. That is exactly what had been done by (OSHA 1999a) to address the rising concerns regarding the increasing complaints of employees towards the healthiness of their office buildings. Results of 500 IAQ investigations revealed that 52%, 16%, 10%, 5%, 4%, and 13% of IAQ problems was attributed to inadequate ventilation, indoor pollutants, outdoor pollutants, microbial pollutants, building materials, and unknown sources; respectively (Figure 1-2). Many technical, administrative and work practice recommendations were established reference to these findings focused on providing appropriate air exchange rates (AERs) as a major contributor in attaining better IAQ conditions. Actually, huge number of IAQ researches were built on or inspired by those findings worldwide and still revisited recently (Hess-Kossa 2011; Wang & Zhang 2010a).

Recently, the associations between AER and occupants' health problems were investigated in a review for 27 peer-reviewed articles published since 2005 (Sundell et al. 2011). The review found that literature did not afford clear evidence proving the causality relationship between the two parameters. However, the associations of health problems with AERs were biologically plausible. For instance, higher AERs of more than 25 l/s per person were associated with less SBS symptoms. The review has also highlighted the need for more studies investigating the associations between occupants' health problems and AERs particularly in harsh climates and in other building types than offices. According to Hess Kosa (2011), insufficient AERs in USA were usually correlated with modern airtight buildings that depend on mechanical ventilation. As per (Mudari & Fisk 2007), the reliance on electricity to operate those mechanical systems has led to more ambient air pollution that might negatively affect the quality of indoor air. Besides, as declared by Awbi (2008), these mechanical systems turn to be a source of indoor contamination when they are badly-maintained or installed.

HVAC systems can be classified into three types: (i) Supply-only, (ii) Extract-only; and (iii) Supply and exhaust systems (Awbi 2008). Reference to Ali (2014) research investigating the impact of the applied AC system on IAQ and SHS in Dubai housing, the three most popularly utilized HVAC systems in UAE is the central, split and window HVACs. According to Stein et al. (2000), each one of these three systems utilizes different technology in terms of their provision of fresh air and the number of served zones. Generally, both split and window HVAC serves one zone while the central HVACs serves more than one zone. That characteristic has an important implication on IAQ conditions. Reference to (Awbi 2008), the amount of re-circulated air applied in some central HVAC systems is a major concern affecting IAQ because this practice transfers produced contaminants between different zones. Also, concerns might also be raised regarding whether the provided amount of fresh air via natural infiltration is sufficient particularly when using the Split HVAC system. That is because, unlike the central HVACs and the window HVAC in which indoor air can be exchanged by outdoor one, the split HVAC technology has not that capability (Stein et al. 2000).

HVAC systems can also be categorized into: (i) centralized including all-air systems, all-water systems and air-water systems; (ii) Terminal units i.e. fan coils, radiators, inductors, and diffusors; and (ii) individual unitary AC systems i.e. window units, split units and heat pumps. Centralized all-air systems can further be categorized into constant air ventilation (CAV) or variable air ventilation (VAV) systems (Bhatia 2012). It is important to note that most residential spaces utilize CAV systems due to their simplicity and convenience (Xiaoshu et al. 2011). CAV systems provide constant supply air flow at different temperatures that vary in response with a space thermostat while VAV systems provide different air flow rates at pre-set temperature responding to a space thermostat. While CAV systems are appropriate in spaces with similar cooling profiles, VAV are suitable with densely-occupied spaces of diversified cooling loads i.e. lecture halls, churches, gymnasiums, etc (Murphy & Bakkum 2013). Similarly, most of the terminal units and individual unitary AC systems that are widely used in residential spaces provide fixed air flow rates (Bhatia 2012). Reference to Ali (2014), about 41% of the surveyed UAE households utilizes window and split HVAC systems classified as CAV systems. The determination of acceptable AERs by HVAC systems has been evolving since 1836 when Tredgold had published the first estimated AER (Klauss et al. 1970). Throughtout all estimated minimum required AERs in USA, the highest one was 30 cfm/person in 1895 by the American Society of Heating and Ventilating Engineer (ASHVE) later developed into ASHRAE (Figure 2-2). A minimum AER of 10 cfm/person was recommended by ASHVE for the American Standards Association (ASA) Lighting Standard in 1946 (Janssen 1999). The first ASHRAE guidelines "Standard 62-1973" recommended minimum AER ranging between 5 – 50 cfm/person (Stanke 1999). Due to the increasing complaints regarding poor IAQ, minimum 15 cfm/person AERs were recommended by "ANSI/ASHRAE Standard 62-1989" based on consistent research findings (Tucker 1993; Mendell 1993). It was only in 1999 "Addendum n to BSR/ASHRAE Standard 62-1989" when AERs calculations combined both occupant-related and building-related minimum required AERs. Within this version, outdoor air intake could also be calculated to indicate for the efficiency of the ventilation system (Stanke 1999).

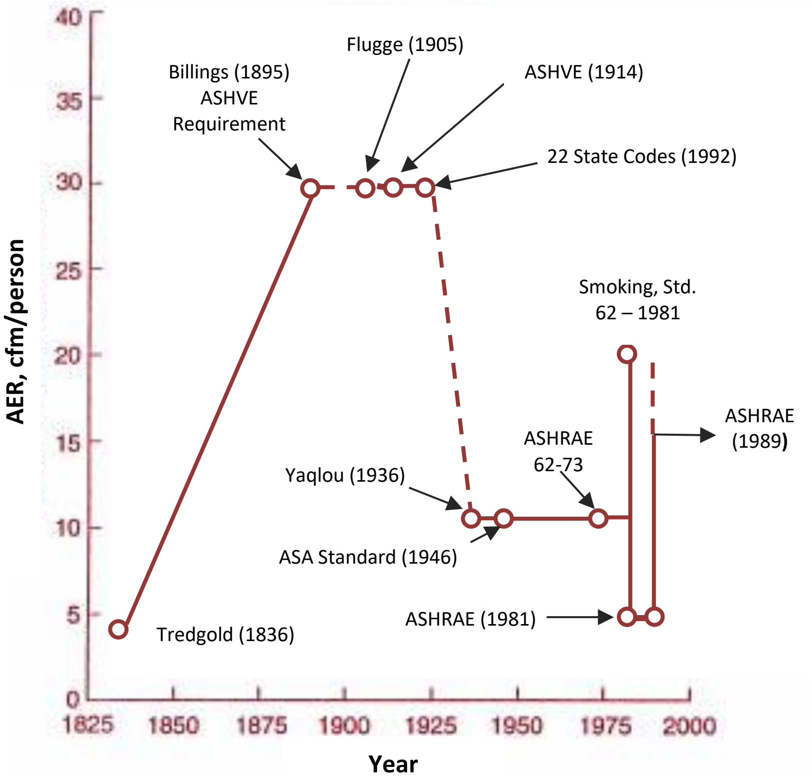


Figure 2-2: Minimum recommended AERs during 1825-2000 (Stanke 1999, p. 51)

One of the most important mandated IAQ requirements on all new and existing buildings in Dubai emirate is that provided AERs should comply with ASHRAE 62 (DM 2016). Reference to (ASHRAE 2016), the first edition of ANSI/ASHRAE Standard 62.1-2007 is published in 1973 that is updated on a regular basis using ASHRAE's continuous maintenance procedures. According to these procedures, Standard 62.1 is continuously revised by addenda that are publicly reviewed, approved by ASHRAE and ANSI, and published in a supplement approximately 18 months after each new edition of the standard. A new, complete edition of the standard is published every three years. Standard 62.1 has undergone some key changes over the years, reflecting the ever-expanding body of knowledge, experience, and research related to ventilation and air quality. While the purpose of the standard has remained consistent, to specify minimum AERs and other measures intended to provide IAQ that is acceptable to human occupants and that minimizes adverse health effects; the means of achieving this goal have evolved. For instance, in its first edition the standard adopted a prescriptive approach to ventilation by specifying both minimum and recommended outdoor airflow rates to obtain acceptable IAQ for a variety of indoor spaces. However, ASHRAE 1981 edition had reduced minimum outdoor airflow rates and introduced an alternative performance-based approach, the IAQ Procedure, which allowed for the calculation of the amount of outdoor air necessary to maintain the levels of indoor air contaminants below recommended limits. Today the standard still retains the two procedures for ventilation design, the IAQ Procedure and the Ventilation Rate Procedure. In its 1989 edition, and in response to a growing number of buildings with apparent IAQ problems, the standard increased minimum outdoor airflow rates significantly and introduced a requirement for finding outdoor air intake flow requirements for multiple-zone, recirculating systems. The 1999 and 2001 editions made several minor changes and clarifications that did not impact the minimum required outdoor airflow rates. In its 2004 edition, the last time the standard was published in its entirety, the standard modified the IAQ Procedure to improve enforceability, but more significantly, it modified the Ventilation Rate Procedure, changing both the minimum outdoor airflow rates and the procedures for calculating both zone-level and system-level outdoor airflow rates. The updated versions of (ASHRAE 62. 1) standard in 2004, 2007, 2010, 2013, and 2016 have provided some significant updates but the changes are primarily focused on usability and clarity (ASHRAE 2016).

## 2.3 Indoor air contaminants

As discussed in Section 2.1, contaminated indoor air poses many health concerns. A considerable risk level is involved when managing poor IAQ problems because of the diversified nature of indoor air contaminants. An indoor contaminant can be an allergen or a carcinogen. A carcinogen chemical may not have any warning signs of exposure but may cause cancer in future. Allergens results in immediate infections with insignificant long-term impacts. However, after lengthy exposure, carcinogenic chemicals might lead to cancer. Indoor air consists of complex substances and a significant negative health impacts may occur in case of being infected by different irritants causing different symptoms. Proper diagnosis depends on proper identification of all contributing contaminants (EPA 2015; Hess-Kossa 2011). Thus; understanding, defining and controlling indoor air contaminants might help in mitigating the risk of negative health impacts. The three sources of indoor air pollution as explained by the Parliamentary office of science and technology "POST" (2010) are:

i. Indoor sources including both building-related and occupants-related ones as exemplified in Table 2-3 to Table 2-5. According to Health Canada (1989), internally produced airborne contaminants can be generated from 3 major sources. The 1st source is combustion appliances for heating and cooking i.e. stoves, furnaces, and other combustion appliances especially improperly vented. Contaminants associated with such appliances include CO, $NO_x$ and sulphur, aldehydes and polycyclic aromatic hydrocarbons. The 2nd is generated from construction materials and furnishings i.e. synthetic polymers used in furnishings and decorative materials, draperies, rugs, fabrics, and the majority of man-made fibres. HCHO is released from wood laminates and particle board in which formaldehyde-containing resins have been used. Urea-formaldehyde foam insulation is a significant source of HCHO and possibly other gaseous products. The 3rd is generated from occupants' activity or presence. Tobacco smoking is a major source of indoor air pollution. While smokers subject themselves to mainstream smoke, bystanders can be involuntarily exposed to significant amounts of PM, CO and $NO_x$, and other organic contaminants. Respiration, perspiration, and food preparation add water vapour and odors to the indoor atmosphere. Also, various practices or activities may generate airborne contaminants i.e. cleaning habits, craft activities, hobbies, air fresheners, pesticides, frequently used deodorants. Incense burning is commonly performed indoors in UAE houses which; according to findings by Cohen et al. (2013) when testing two UAE incense types; has exceeding CO, $NO_x$, and PM emissions than mandated government regulation levels and emissions previously seen from environmental tobacco smoke (ETS). That may contribute in poor IAQ and could cause harmful health impacts on exposed occupants.

ii. Outdoor sources i.e. ambient air pollutants infiltrating indoors through openings or ventilation systems such as contaminants from vehicles exhausts; building exhausts, plumbing vents, as well as combustion substances entering from adjacent parking lots, garages, and factories (POST 2010). Examples of such pollutants are PM, $O_3$, $NO_x$, $SO_x$, and CO which was highlighted as concerning ambient air pollutants in Abu Dhabi-UAE by EAD (2014). Reference to Health Canada (1989), a continuous air exchange occurs between indoor and outdoor air. Therefore, outdoor pollutants can probably be transferred indoors. Largely, indoor levels is expected to be similar or less than outdoors when indoor pollutant's sources are absent (Health Canada 1989).

iii. Radon (Rn) gas infiltration from ground into the building (POST 2010). Reference to Health Canada (1989), Rn is a naturally occurring radioactive gas that decays to non-gaseous radioactive species which can be adsorbed onto suspended particulate matter and hence be deposited in the lung. Underlying soil and domestic well water are the most likely potential sources of radon in buildings

Table 2-3: Building-related potential pollutants & their sources (Wang & Zhang 2010b)

| Potential pollutants | Source |
|---|---|
| Asbestos | Shells, façades, cement roofing, siding and shingles.<br>Fibers in insulation; |
| Chemicals odors | Paints, sealants, adhesives, coatings;<br>Used in levelling concrete floors prior application of finishing materials;<br>Collected by wallboards that adsorbed fumes and odors;<br>Asphalt and tar on roofing; |
| VOC emissions | Paints, sealants, adhesives, coatings;<br>Insecticides, fungicides, and germicides occasionally added to building materials to prevent mold;<br>Asphalt and tar on roofing;<br>Some membrane roofing systems; |
| HCHO and other aldehydes | Drywalls or wallboards;<br>Fiberglass and foam insulation;<br>Decorative panels produced of pressed wood;<br>Plywood and particleboards;<br>Some membrane roofing systems; |
| Polyvinyl chloride (PVC) | Most common plastic used in construction and flooring. |
| Solvents | Paints, sealants, adhesives, coatings;<br>Trapped solvents in plastic panels; |

Table 2-4: Occupant-related pollution sources (Wang & Zhang 2010b)

| **Source** | **Potential pollutants** |
|---|---|
| Human breath | CO, $CO_2$, moisture, ammonia, $H_2S$, isoprene, acetone, ethanol, |
| Skin metabolism | CO, $CO_2$, ammonia, acetone, toluene, methane, |

Table 2-5: Common indoor contaminants in US homes (EPA 2016a; OSHA 2011a)

| **Contaminants** | **Sources/Causes** | **Health impacts** |
|---|---|---|
| ETS | Tobacco products | Trigger asthma and other respiratory diseases, … |
| CO | Car exhaust, gas stoves, ETS, poorly maintained combustion devices, … | Confusion, headaches, dizziness, lethal at very high concentrations, … |
| $CO_2$ | Highly occupied spaces | Hypercarbia ranging from headache to unconsciousness up to death. |
| VOCs | Cleaning and building products, furnishings, office equipment, … | Respiratory irritations, possible effects with asthma, some linked with cancer, … |
| Pesticides | insecticides, fungicides, herbicides, and other pests control products | Headache, irritations, vomiting, might cause seizures and death |
| Radon | Radioactive gas infiltrates via cracks from surfaces adjacent to the ground. | Leading reason of lung cancer amid non-smokers. |
| Biological contaminants | Pets hair and dandruff, pollen, plants, microbes, … | Trigger asthma. |
| Legionella | Stagnant warm water | Legionella disease |
| Mold | Humidity and moisture problems. | Allergic responses, asthma, and other respiratory diseases, … |
| Dust mites | Dust, poor cleaning habits, … | Trigger allergic reactions and asthma. |

According to Hess-Kosa (2011), the number of substances identified as toxic reaches up to 100,000. Therefore, the study will focus in assessing the impact of the most commonly cited in relevant literature as of greater risk. The most prominent contaminants that should be included when monitoring IAQ are bioaerosols as declared by (EPA 1991a; Abu Dhabi Emirate Environment, Health and Safety Management System "AD EHSMS" 2012) are CO, $CO_2$, HCHO, $PM_{10}$, $PM_{2.5}$, Rn, relative humidity (RH), temperature (T), and VOCs. That is in great agreement with the most important indoor air contaminants identified by POST (2010) as $NO_2$, CO, PM, Rn, ETS, VOCs and ozone ($O_3$). In AD – UAE, according to EAD (2014), the most common indoor air contaminants are $SO_2$, NO, $NO_2$, $O_2$, CO, $CO_2$, $NH_2$, PB, HCN, PMs, hydro-carbonates, Rn, HCHO, mercury, sulphates, organics, odours, fluorocarbons, and vinyl chloride hydrocarbons. Based on the above, this research will monitor the indoor concentrations of the following substances: $CO_2$, CO, TVOC, $PM_{2.5}$, $PM_{10}$, and HCHO (Table 2-6 & Table 2-7). The selected contaminants are some of the most frequently monitored in IAQ investigations locally and internationally (Derbez et al. 2018; Singleton et al. 2017; Fadeyi et al. 2014; Funk et al. 2014; Yeatts et al. 2012a). Detailed description of selected substances monitored indoors by this study is provided in Sections 2.3.1 to 2.3.5 .

Table 2-6: Proposed indoor air pollutants to be monitored, their sources and health impacts (POST 2010; EAD 2014; WHO 2010a; OSHA 1999a)

| **Pollutant** | **Sources** | **Health impacts** |
|---|---|---|
| CO | Wood burning, fuel combustion, cooking and heating machines | Probable chronic health disorders at low concentrations, fatal at high concentrations |
| $CO_2$ | Combustion products, occupants' exhalation, unvented gas | Concentration difficulties, drowsiness, respiratory problems |
| $PM_{2.5}$ & $PM_{10}$ | Sand storms, cooking, fuel combustion, chemical reactions, aerosols, | More risk of respiratory and heart problems, decreased function of lungs, premature mortality |
| TVOC | Paints, cleaning products, printers | Probable impacts on Asthmatics, respiratory tract irritation |
| HCHO | Fuel combustion, wood burning, wooden & cleaning products, furniture, paints, adhesives | Respiratory problems, sensory irritations, probable cancer causation |

Table 2-7: Acceptable exposure limits by recognized institutions for selected contaminants

| | Long exposure | Short exposure | Guideline/Reference |
|---|---|---|---|
| **PM$_{2.5}$** | 12µg/m$^3$ – 1 year [a] | 35µg/m$^3$ – 24 hours [b] | ASHRAE (2016) |
| | 10µg/m$^3$– 1 year [c] | 25µg/m$^3$ – 24 hours [p] | WHO (2006) |
| | Keep as low as possible [i] | Health Canada (2012) | |
| **PM$_{10}$** | 50µg/m$^3$ – 1 year [c] | 150µg/m$^3$ – 24 hours [d] | ASHRAE (2016) |
| | 20µg/m$^3$ – 1 year [c] | 50µg/m$^3$ – 24 hours [p] | WHO (2006) |
| | | 150µg/m$^3$ – 8 hours [s] | DM (2016) |
| **CO** | | 25ppm – 1 hour [i] | Health Canada (2010) |
| | | 10ppm – 24 hours [i] | Health Canada (2010) |
| | | 50ppm – 8 hours [e, f] | OSHA (2011a) |
| | | 35ppm - 10 hours [e, g] | NIOSH in (OSHA 2011a) |
| | | 25ppm – 8 hours [e, h] | ACGIH in (OSHA 2011a) |
| | | 35ppm – 1 hour [d] | ASHRAE (2016) |
| | | 9ppm – 8 hours [d] | ASHRAE (2016) |
| | | 10ppm – 8 hours | WHO (2010a) |
| | | 9ppm – 8 hours | DM (2016) |
| **CO$_2$** | 5,000ppm – 8 hour [e, f, k] | 30,000ppm – 15 min [l, m] | OSHA (2011a)<br>(NIOSH 2005) |
| | | 30,000 ppm – 10 min [l, m] | (NIOSH 2005) |
| | | 800 ppm – 8 hours | DM (2016) |
| **HCHO** | | 123µg/m$^3$ – 1 hour [i] | Health Canada (2006) |
| | | 50µg/m$^3$ – 8 hours [i] | Health Canada (2006) |
| | | 100µg/m$^3$ (0.08 ppm)– 30 min [j] | WHO (2010a) |
| | 0.75ppm – 8 hours [q, e]<br>0.5ppm – 8 hours [r] | 2ppm – 15 min [i, e] | OSHA (2011b) |
| | | 0.08ppm – 8 hours or<br>9.82µg /m$^3$ – 8 hours | DM (2016) |
| **TVOC** | | 300µg /m$^3$ – 8 hours | DM (2016) |

[a] Three years average of the annual arithmetic mean.
[b] 98th percentile – averaged over 3 years.
[c] Annual arithmetic mean.
[d] Not to be exceeded more than once annually.
[e] Time – weighted average.
[f] Permissible exposure limit (PEL).
[g] Recommended exposure limit (REL).
[h] Threshold exposure limit.
[i] Acceptable short-term exposure ranges (ASTER) in residential spaces.
[j] Average concentrations.
[k] Applicable on concentration in the office space.
[i] Short – term exposure limit (STEL).
[m] 10 min duration for NIOSH (REL) and 15 min duration for ACGIH (TLV) and OSHA (PEL). TLV = Threshold limit value.
[n] Recommended WHO air quality guideline (AQG).
[o] Previous WHO guideline and Interim Target – I (IT – I) for developing countries while a goal of 50µg/m$^3$ for 24 hours is (IT – II) towards achieving the recommended AQG of 20µg/m$^3$.
[p] 99th percentile (3days/year).
[q] Permissible exposure limit (PEL).
[r] Action level increased industrial hygiene monitoring.
[s] 8 hours– weighted average .

### 2.3.1 Particulate matter ($PM_{10}$ & $PM_{2.5}$):

Reference to (WHO 2006), particulate matter ($PM_{10}$) is a term represents suspended particles in air of ≤ 10 µm aerodynamic diameter while $PM_{2.5}$ represents suspended particles in air of ≤ 2.5 µm aerodynamic diameter. Regarding $PM_{10}$ and $PM_{2.5,}$ according to WHO (2006); they are composed of a mixture of solid and/or liquid constituents varying in shape, size, surface area, density, and chemical composition. $PM_{10}$ represents the particle mass that enters the respiratory tract and it includes both the course (particle size between 2.5 and 10µm) and $PM_{2.5}$ (measuring less than 2.5µm). $PM_{10}$ is primarily produced by mechanical processes such as construction activities, road dust and wind whereas $PM_{2.5}$ results from infiltrating $PM_{2.5}$ from outdoor air as well as indoor sources such as cooking, smoking, and cleaning. Reference to (Health Canada 2012), average indoor $PM_{2.5}$ levels in homes with smokers were higher (< 35µg/m$^3$) than those without smokers (< 15µg/m$^3$). Generally, indoor $PM_{2.5}$ concentrations in homes without smokers were lower than those measured in adjacent outdoor spaces.

The health effects of $PM_{2.5}$ and $PM_{10}$ due to short or long exposure were well documented and they included respiratory and cardiovascular morbidity; aggravation of asthma and respiratory symptoms; mortality from respiratory and cardiovascular diseases in addition to lung cancer (POST 2010; EAD 2014; WHO 2010a, 2013; OSHA 1999a). Literature provided good evidence regarding the impacts of short-term exposure to $PM_{10}$ on respiratory health. However, in terms of mortality, $PM_{2.5}$ poses a higher risk factor than $PM_{10}$ particularly in case of long term exposure (WHO 2013; Health Canada 2012). Some evidence has demonstrated relationship between indoor $PM_{2.5}$ concentrations and declined lung function, increased exhaled $NO_2$, and a marker of airway inflammation in asthmatic children. Also, correlations between indoor $PM_{2.5}$ and subtle alterations in markers of cardiovascular disease had also been reported in elderly individuals. Based on available literature; no recognized threshold below which negative health impacts of exposure to indoor or outdoor $PM_{2.5}$ concentrations (Health Canada 2012; WHO 2006; EPA 2010). Actually, growing evidence that adverse health effects can occur when exposed to $PM_{2.5}$ levels even less than the established levels by WHO (Table 2-7). However, available evidence is insufficient to identify the levels below which negative health impacts might not occur (WHO 2010a, 2006). That is why (Health Canada 2012) required that indoor $PM_{2.5}$ levels should be kept as low as possible. It is impossible to completely eradicate $PM_{2.5}$ indoors because it is caused by sources and/or activities considered as daily life essentials i.e. cooking, cleaning, and ambient air infiltration. However, any reduction in $PM_{2.5}$ levels is expected to lead to better health conditions particularly for individuals with sensitivities, children and the elderly. Two of the recommended methods to mitigate indoor $PM_{2.5}$ concentrations are not to smoke indoors in addition to using a stove top fan during cooking. Adequate ventilation might also help in reducing $PM_{2.5}$ concentrations in case of higher indoor $PM_{2.5}$ concentrations compared with outdoor concentrations. Some existing evidence illustrates that some portable air cleaners and in-duct air filters with filters might assist in mitigating indoor $PM_{2.5}$ concentrations.

### 2.3.2 Carbon monoxide (CO):

CO is an odourless, colorless and tasteless gas that results from incomplete combustion of organic or carbon substances. Common CO sources are: (i) ETS and incense burning; (ii) leakage from vented and unvented combustion devices; and (iii) exhaust from generators and other gasoline-powered equipment i.e. vehicles, snowmobiles, parking lots (OSHA 2011a; Health Canada 2010). Indoor CO levels are generally nearly typical or less than outdoor levels when having sufficient AERs, properly vented combustion devices, when ETS level is less than 100 ppm; or acceptable generation of CO levels during cooking (Health Canada 1989, 2010). Exposure to unacceptable CO levels might cause mild headache, breath shortness, nausea, brain damage, and death. Poisoning symptoms due to exposure to CO can be confusing since they resemble influenza and food poisoning symptoms. That is why deliberate diagnosis is required for such symptoms because exposure to even low levels of CO might lead to a long-term health risks if not properly attended. Long-term exposure to high concentrations of CO can result in reduction of access to oxygen, aggravation of heart disease (EAD 2014), brain damage and death (OSHA 2011a; POST 2010). Groups that may be at particular risk from the effects of CO exposure include pregnant women, new-borns, individuals living at high altitude, in addition to those having cerebrovascular, peripheral vascular and cardiovascular diseases (Health Canada 1989, 2010). Table 2-7 shows some identified regulations and recommendations of CO exposure limits.

### 2.3.3 Carbon dioxide ($CO_2$):

$CO_2$ is an odourless, tasteless, and colorless gas. $CO_2$ is the by-product of complete combustion and biological respiration. Examples of $CO_2$ sources are human respiration and combustion operations and processes (OSHA 2011a, 1999a; Health Canada 1989). Reference to (Health Canada 1989), the average $CO_2$ concentration in the atmosphere is ≈ 340 ppm (620 mg/m$^3$) at variable levels according to location and time. According to (OSHA 2011a; ASHRAE 2016); the acceptable $CO_2$ range in ambient air is usually between 300 to 500 ppm. As per ASHRAE (2016), high $CO_2$ levels in ambient air may be an indicator of combustion and/or other pollution sources. According to Health Canada (1989); indoor $CO_2$ concentrations tend to be more than outdoor ones and that unvented kerosene heaters and gas stoves are major sources of indoor $CO_2$. In rooms with poor ventilation, $CO_2$ levels might exceed 3000 ppm (5400 mg/m$^3$) from occupants' metabolism alone.

As per (OSHA 2011a; ASHRAE 2016); $CO_2$ levels can be used as an indicator of AERs sufficiency. $CO_2$ production increases in occupied spaces with higher occupancy levels and can be diluted or removed by ventilation. That is why assessing $CO_2$ levels can furnish data regarding occupancy levels and AERs. According to (OSHA 1999a); occupants' comfort had been associated with $CO_2$ concentrations in many studies. Together, these studies suggested that $CO_2$ concentrations higher than 1000 ppm as an indication of inadequate fresh air supply. Reference to them, complaints has been reported at $CO_2$ concentrations as low as 600ppm. Although that, complaints regarding poor IAQ observed at $CO_2$ concentrations between 600 – 1,000ppm are not clearly interpreted. However, at 1,000ppm complaints of fatigue, headaches, throat and eye irritations are more prevalent. Noteworthy that exceeding $CO_2$ levels than 1,000ppm does not certainly indicate the hazardousness of the building and that the building should be evacuated. It is only a guideline that should be exploited to assist in increasing occupants' health and comfort indoors.

As declared by (Health Canada 1989); the acceptable long-term exposure range for $CO_2$ in housing indoor air is ≤ 3500ppm. Reference to (OSHA 2011a), at higher $CO_2$ concentrations than 15,000ppm, cases of loss of mental acuity had been reported. Also, Health Canada (1989) stated that $CO_2$ increase in ambient air implied a rise in blood acidity and an increase in breathing rate and depth. Exposures to $CO_2$ levels higher than 50,000ppm have led to effects on human cardiovascular and central nervous system. Moreover, concentrations of 500 – 3200ppm has been associated with fatigue, headaches, increased unpleasant odours, and increased perception of warmth. The lowest $CO_2$ concentrations at which harmful health impacts have been reported in humans is 7,000ppm at which higher blood acidity have occurred after continuous exposure over several many weeks (Health Canada 1989). Furthermore, according to NIOSH (2005), $CO_2$ concentrations at 2 – 3% had been associated with breath shortness and deep breathing. At 7.5% it has been linked with dizziness, breathlessness, blood pressure, higher heart rate, visual distortion while vomiting, nausea, and consciousness loss occurs at 10%. Concentrations higher than 30% had been associated with convulsion, coma, and death. Table 2-7 demonstrates acceptable exposure limits for $CO_2$ by some recognized agencies worldwide.

### 2.3.4 Total volatile organic compounds (TVOC)

VOCs include all organic chemical compounds with substantial vapour pressures and which can cause adverse impacts on environmEye, nose, throat, and human health. VOCs are vapors emitted from a diversified number of solids and liquids substances estimated as thousands i.e. paints, lacquers, paint strippers, cleaning supplies, pesticides, building materials and furnishings, copiers, printers, correction fluids and carbon-less copy paper, and graphics and craft materials, glues, adhesives, permanent markers, and photographic solutions. VOC concentrations are consistently higher indoors, sometimes ten times higher, compared with outdoors. The most common VOCs are benzene, HCHO, methylene chloride, trichloroethylene, and tetra-chloroethylene. Exposure to VOCs can lead to acute and chronic health impacts depending on the level and duration of exposure (OSHA 2011a). VOCs have been associated with acute health effects i.e. dizziness; headache; fatigue; nausea; eye, mucous membrane and respiratory tract irritation (OSHA 1999a). Few VOCs like benzene have been associated with cancer in humans while others are suspected to cause cancer (OSHA 2011a).

Reference to (Graywolf Sensing Solutions LLC 2016, OSHA 1999a), individual VOCs have different concentrations at which health concerns might arise. For instance, OSHA's recent allowed exposure levels to Benzene, Toluene, and Acetone for 8 hour are 1 ppm, 200 ppm, and 1,000 ppm; respectively. Notably that the identified levels are based on healthy adult workers. Lower limits are recommended by Health Canada for Benzene and Toluene in residential space by Health Canada (2013, 2011). According to Health Canada (2013), Benzene should be kept as low as possible in residential spaces while Health Canada (2011) stated that Toluene should not exceed the 4.0ppm as short-term exposure limit (8 hours) and 0.6 ppm as long-term exposure limit (24 hours). Regarding the TVOC limit, several Asian countries and few others worldwide have established maximum indoor concentrations. For instance a concentration limit of 600 μg/m$^3$ has been established in Portugal and China (Portugal Ministério das Obraspúblicas 2007) (Standardization Administration of the People's Republic of China 2002). While Dubai and Singapore have set a limit (< 300μg/m$^3$) and 3ppm (≈1.5ppm isobutylene), respectively (DM 2016; Singapore Public Health Ministry of the Environment 1996). Moreover, the recognized IEQ flush-out test by US Green Building Council/Leadership in Energy and Environmental Design (USGBC LEED) necessitates TVOC concentrations not to exceed the 500μg/m$^3$ prior occupancy (USGBC 2005).

Reference to (ECA 1997), the widespread usage of new materials and products implied increased levels of indoor air contaminants particularly VOCs. There is a tendency in many scientific researches not to individually report measured VOCs concentrations but to demonstrate the total VOCs concentrations (TVOCs). That is because, it is easier and simpler to interpret one single parameter rather than a long list of VOCs normally found indoors. Identifying and quantifying all indoor air VOCs is challenging and practically impossible. Moreover, recording data for all individual VOCs is cumbersome because analysis is required for a huge number of samples. For that, simplified approaches of assessing the findings of VOCs measurements in the form of TVOC have been established and adopted by many researchers. Different processes have been used by those researchers when analysing and integrating individual VOCs. That is why reported TVOC assessments in present literature are incomparable in most cases. However, clearly defining the TVOCs increases comparability.

Reference to ECA (1997), TVOC definition is controversial as the compounds included to form the TVOC mixture are not agreed on. The analysis and assessment of indoor VOCs can be done via three main approaches. The simplest approach does not separate the VOC composition into individual constituents while in the second approach constituents are separated then the individual responses are summed but no identification of individual components is provided. The third approach separates the mixture components and provides an identification of individual constituents. Reference to ECA (1997); the health and comfort impacts of a composition of 22 VOCs were assessed. An almost similar mixture was assessed at the EPA laboratories; consecutively. The results of those studies had been based on relatively limited number of VOCs forming specified compositions. Therefore, it cannot be assumed that the reported health and comfort effects might also occur with another TVOC composition even if concentrations of the two mixtures are nearly similar.

According to (ECA 1997), the major purpose of TVOC value is to attain an indicator of the total exposure to many VOCs commonly prevailing indoors. TVOCs value should carefully be dealt with and it cannot be concluded that specific TVOCs might be more powerful in causing harmful impacts on humans. In such cases, they should individually be evaluated and a list of similar VOCs should be inaugurated. That is why Establishing acceptable exposure limits of TVOCs based on toxicological foundations has been challenging (ECA 1997). Consequently, few guidelines are inaugurated identifying acceptable exposure limits of TVOC (Levin 2010). One of them was established by

(Mølhave 1990) who identified the following four exposure ranges in relation to TVOCs: comfort range (<0.2mg/m$^3$), discomfort range (0.2 – 3mg/m$^3$), multifactorial exposure range (3 – 25mg/m$^3$), and a toxic range (>25mg/m$^3$). Notably that TVOC guideline limit comfort range of 0.2mg/m$^3$ established by Mølhave (1990) is widely adopted by IAQ experts. Seifert (1990) suggested another approach in which empirical data was collected on field from German residences to assess an upper TVOC limit that is not usually exceeded. Based on the collected data, Seifert (1990) recommended an average concentration of 300 µg/m$^3$ of TVOC as the concentration that appears to be readily realizable in German residences that should not be exceeded. The 300 µg/m$^3$ was divided into the following chemical groups: alkanes (100µg/m$^3$), aromatics (50µg/m$^3$), terpenes (30µg/m$^3$), halocarbons (30µg/m$^3$), esters (20µg/m$^3$), and carbonyls not including HCHO (20µg/m$^3$), and others (50µg/m$^3$). No one of the individual compounds within the above groups should be more than 50% of the average amount of its group or 10% of the assessed TVOC value. Notably that the above values are not derived from toxicological considerations but are based on what levels could be logically realizable or traceable.

### 2.3.5 Formaldehyde (HCHO):

The major sources of the aldehydes include ETS, space heaters, and gas stoves. Characteristics of all the aldehydes created during incomplete combustion of organic fuels are not yet fully identified. However, studies have shown that HCHO, acrolein and acetaldehyde are the main present aldehydes. The common impact of airborne aldehydes on human health is eye, nose and throat irritations (Health Canada 1989; 2015, 2006). Reference to (WHO 2001, 2010a), HCHO is the most common aldehyde. HCHO is a colourless, flammable, reactive gas with a pungent odour which is easily polymerized at room temperature and pressure. It is soluble in water, diethyl ether, and ethanol and is utilized in both solution or polymerized form. Under atmospheric conditions, it is also readily photo-oxidized in sunlight to $CO_2$ and it reacts relatively rapidly with trace substances and air contaminants in a way that its presence in ambient air, under sunlight influence, is short. When $NO_2$ is absent, the half-life of HCHO is (≈ 50 minutes) during daytime and (≈ 35 minutes) in the presence of $NO_2$.

HCHO is naturally formed in the air during the hydrocarbons oxidation. It is one of the VOCs formed in the preliminary stages of plant residuals decomposition in soil. The major anthropogenic source of HCHO encompasses combustion and the decomposition of HCHO-based resins utilized in textiles, wood, paper, or urea-formaldehyde foam insulation (UFFI). Other sources encompass direct emissions from the production and use of HCHO i.e. particle board and HCHO-based resins and off-gassing of urea–HCHO insulation foam. The main anthropogenic HCHO sources affecting human health are within the indoor environments. That is due to the common use of products containing HCHO indoors i.e. ETS, vehicles exhaust from engines not built-in with catalytic converters, heating and cooking in addition to chipboard, resins, plywood, glues, insulating materials, and fabrics. Generally, indoor air HCHO concentrations are usually higher than outdoors (WHO 2001, 2010a). Moreover, HCHO concentrations in buildings is variable according to:(i) building age since HCHO release decreases with time, (ii) T and RH, (iii) AERs, (iv) season (WHO 2010). According to (WHO 2001, 2010a), HCHO is a sensory irritant affecting eyes, nasal passages, respiration and it is probable cancer causation. The minimum concentration associated with throat and nose irritation in humans after short-term exposure is 0.1mg/m$^3$. However, some people can feel the HCHO presence at lower levels. Table 2-7 demonstrates established acceptable exposure limits for HCHO by some recognized agencies worldwide.

## 2.4 Poor IAQ as a global hazard

Poor IAQ is evolving as one of the top global health hazards. A considerable risk level is involved when managing poor IAQ problems because of the diversified nature of IAQ contaminants and the difficulty in predicting their negative health impacts (Hess-Kossa 2011). EPA (2015) considered poor IAQ as a hazardous risk of considerable uncertainties in terms of determining its potential negative impact on occupants' health due to the:

i. Ambiguity regarding predicting its probable negative health impacts attributed to the complex factors influencing its occurrence i.e. different people may demonstrate different symptoms caused by similar contaminant that makes the identification of the pollution source very difficult (EPA 2015).
ii. Ignorance regarding identifying the acceptable exposure limits to indoor air pollutants. Although concentration limits of many contaminants within which well-defined health impacts become evident, definition of exposure limits of the subtle health impacts were not well-researched (EPA 2015). According to Hess-Kosa (2011), recommended exposure limits were identified in USA – the country from where many IAQ guidelines are adopted worldwide – for less than 400 out of the 100,000 toxic substances to which building occupants are potentially exposed.

Residential IAQ is of recent growing concerns globally due to the deficiency of regulations regarding residential exposure limits. As declared by Hess-Kosa 2011 – even in USA from where related regulatory standards and guidelines were adopted in UAE and other countries – OSHA regulates workplace environments including office, industry and construction exposures while EPA regulates outdoor ambient air. No regulatory agencies control residential exposure limits. This is concerning because the exposure duration in housing spaces is longer than the 8 – 10 exposure hours in office or industrial buildings. Moreover, houses include vulnerable individuals to contaminants i.e. infants, elderly, and sick. One of the examples demonstrating that deficiency is in determining exposure limits of $PM_{2.5}$. According to (WHO 2006), the annual mean $PM_{2.5}$ concentrations should not exceed $10\mu g/m^3$ or $25\mu g/m^3$ as daily mean concentrations. However, Health Canada (2012) recommended that $PM_{2.5}$ concentrations to be kept as low as possible because emerging evidence illustrated that long-term exposure to even $10\ \mu g/m^3$ was associated with mortality and other chronic impacts. However, available information does not allow a judgment to be made of concentrations below which no effect would be expected. Moreover, reference to POST (2010), the impact of contaminants other than gaseous ones are yet not fully identified because of inadequate monitoring of indoor air contamination levels and inadequate studies on health effects. However, the maximum risk of indoor pollution falls on vulnerable individuals i.e. elder, children and sick individuals having cardiovascular or/and respiratory illnesses. As stated by Hess-Kosa (2011), to address the rising IAQ health problems in USA, recognized guidelines were recommended i.e. American Conference of Governmental Industrial Hygienists (ACGIH) and American Society of Heating, Refrigerating and Air conditioning Engineers (ASHRAE). Hence, residential IAQ have yet to be regulated, standardized and managed. Therefore, those performing investigation should develop strong knowledge base and pursue each new case with a flexible and detective mind.

## 2.5 Value of good IEQ

Fisk et al. (2011) assessed the costs and benefits of employing some simple and feasible scenarios that enhance IEQ of US office buildings sector. The scenarios encompassed increasing AERs lower than 10 – 15l/s.person, providing outdoor air economizers and controls, setting winter indoor temperatures not more than 23º C, and decreasing mold and dampness problems. The collective potential financial benefits of the set of non-overlapping scenarios were estimated as $20 billion annually. Additionally; Sivunen et al. (2014) aimed to furnish novel insights on the economic benefits of good IEQ reference on contemporary research results. Reference to their findings, the asset value of buildings with better IEQ conditions were 10% higher than standard buildings and an increase on that was predicted over the following 5 years. Moreover, the occupancy rate and rental yields of buildings of better IEQ conditions were 10% and 5% higher compared with standard buildings, respectively. Also, Kajander et al. (2014) declared many potential benefits attained from good IAQ not only on human well-being but also financial benefits such as better work performance, lower healthcare expenses, less turnover of workers, less sick leaves, and less IAQ complaints, and subsequently less maintenance costs.

According to (Mendell et al. 2013; Fisk et al. 2011; Seppänen et al. 2013; Sundell et al. 2011; Singh et al. 2011), several existing procedures and/or technologies can enhance

IAQ in a way that improves health, performance, and financial benefits. For instance, Mendell et al. (2013) suggested that increasing AERs can lessen occupant illness absence (IA). They assessed correlations between IA and AERs over two academic years in 162 classrooms of 3rd – 5th grades in 28 California elementary schools in three districts. According to their results; increasing classroom AERs from 4 to 7.1l/s. person might achieve 3.4% less IA and $33 million annual increase of attendance-linked finance to schools with an only $4 million increase in costs. Additional benefits might be attained when increasing AERs more than that. Also, Logue et al. (2011) estimated the costs and benefits of whole-house mechanical ventilation system on new Californian houses. Results showed that health benefits attained from minimizing exposure to indoor contaminants were worthy compared with the costs of providing additional mechanical ventilation complying with ASHRAE Standard 62.2 recommendations.

However, according to Seppänen et al. (2013), tenants were usually reluctant to pay additional money for rent while owners were unwilling to invest more money to attain better IAQ particularly in the public realm. According to Kajander et al. (2014), it is a fact that potential economic advantages of good IAQ are not deliberately considered. Only few feasibility studies related to building investments included quantitative analysis of the life cycle economic costs and benefits of improving IAQ (Elf & Malmqvist 2009; Zimina et al. 2012). For instance, the choice of ventilation system is usually considered based on initial costs, maintenance, and energy costs. That might implies adverse health impacts and low profitability when not accounting the potential economic losses due to poor IAQ. Practically, there is a crucial need to employ the best present IAQ technologies and procedures. To achieve that, it is essential to demonstrate the economic benefits of good IAQ to guide investors, decision-makers and design managers in the construction industry. Moreover, although the impacts of IAQ on health and performance was subjected to comprehensive research for many decades; studies directed to quantitatively analyze the economic benefits of good IAQ is yet very limited. Pioneering scholars (Fisk et al. 2011; Mendell et al. 2013; Seppänen et al. 2006) have recently recommended establishing new methods to assess the economic benefits of IAQ investments under uncertainty. They highlighted the obvious need to develop approaches or tools enabling the integration of

IAQ economic outcomes of better health and productivity in the initial cost benefit calculations of building projects along with energy and maintenance costs.

## 2.6 SHS & IAQ status in UAE housing

UAE is located in the Middle East/southwest Asia and is surrounded by Oman Gulf, the Arab Gulf, Oman, Saudi Arabia, and Qatar (Figure 2-3). It is situated between 22°50′ and 26° north latitude and between 51° and 56°25′ east longitude. UAE is a federation of seven emirates which are Abu Dhabi, Ajman, Al Fujayrah, Shariqah, Dubai, Umm al Quwain, and Ra's al Khaymah. As being part of the Arabian Desert, its climate is generally very hot and sunny. July and August are the hottest months with average maximum temperature higher than 40°C. The coldest months are January and February with average minimum temperature range between 10 – 14°C (Dubai Metrological Office 2016). During the end of summer, a humid south-eastern wind called as Al Sharqi prevails at UAE coastal region leading to unpleasantly higher humidity levels. The average annual rainfall is less than 120 mm in coastal region and it often reaches 350mm in some mountain areas (Wikipedia 2016). According to The Official Portal of UAE Government, UAE population was about 8,300,000 by the end of 2010 of which about 11% were UAE citizens while the remaining are expatriates of different nationalities (Government.ae 2019). This statistics was also supported by a recent study that estimated UAE citizens as only 11% of total UAE residents (Snoj 2015).

UAE has witnessed a rapid transition during the last 60 years from a nomadic trading economy to an evolving industrialized economy. This was accompanied by large-scale development in transportation, industrial and the urban fabric infrastructure. The dramatic change in the built environment from naturally ventilated to highly sealed mechanically cooled houses is accompanied by higher potentiality of exposure to indoor contaminants accumulating inside. Few environmental health-related studies have been conducted on the Arab Gulf region despite the rapid environmental changes. Recently, a PubMed search for environmental health topics performed in 2010 in UAE, Oman, KSA, Kuwait, and Bahrain identified 300 articles. However, 30000 articles obtained from the same search in USA which equals twelve times what was published in the Arabian Gulf region on per capita calculations (Yeatts et al. 2012b).

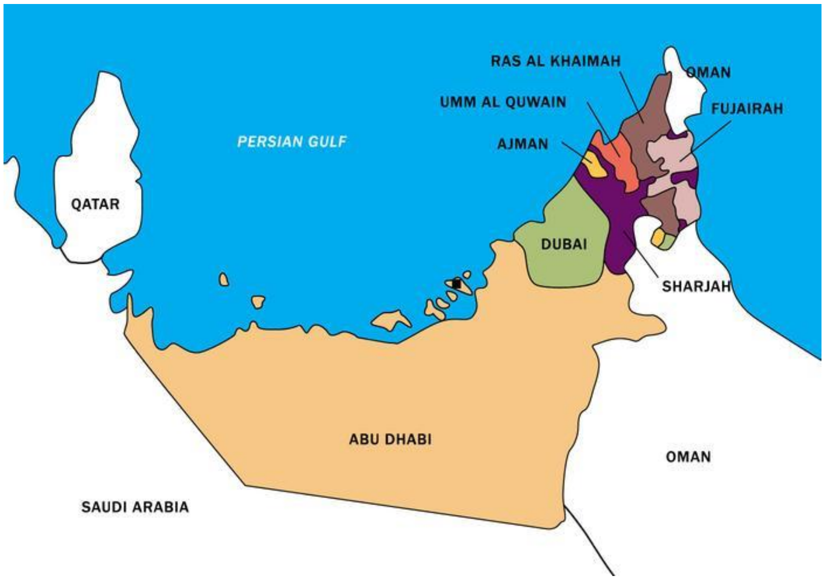


Figure 2-3: UAE map (Dubai Business Guide 2018)

UAE ambient air in the Arabian Peninsula is formed by high levels of PM, dust storms, industrial, and transportation emissions, and meteorological-linked smog formation. The infiltration of ambient air pollution in addition to other indoor contaminants might increase indoor air pollution (Yeatts et al. 2012a). Reference to (EAD 2014, 2017), the high $PM_{10}$ and ground level $O_3$ concentrations in Abu Dhabi (AD) ambient air is one of the major concerns regarding ambient air quality. According to EAD (2014), average $PM_{10}$ levels in AD was higher than the 20 µg/m$^3$ guideline identified by (WHO 2006) by seven times with peak levels equals 14 times WHO guideline occurring during dust storms. The major contributors for that high $PM_{10}$ levels were natural sources, combustion processes and transportation. Also, reference to EAD (2014), ground level $O_3$ concentrations were usually higher than AD acceptable limit of 200µg/m$^3$ for an hour, of 120µg/m$^3$ for 8 hours, and the WHO guideline of 100 µg/m$^3$ for 8 hours. Ground level $O_3$ in the atmosphere is formed from the reactions of some air pollutants such as $NO_x$, and VOCs under sunlight presence. The major sources of precursor pollutants are industry and transportation (EAD 2014). Regarding $PM_{2.5}$ concentrations in AD, about 54 – 67% was a result of anthropogenic activities. About 41 – 48% is by-product of oil manufacturing and refining procedures in UAE and the Gulf region. About 26% of $PM_{2.5}$ was formed from mineral dust while 13 – 15%, 11%; 4 – 9% is from traffic, shipping or industry, and marine salt respectively (EAD 2014).

Regarding related local regulations, the “Green Building Guidelines” for UAE was collaboratively developed by the Ministry of Public Works (MoPWs) along with The Executive Council (TEC) of Dubai Government to be carried out for new buildings at federal level (UAE Ministry of EnvironmEye, nose, throat, and Water 2014). The guidelines were mandated since 2009 on all new buildings related to the Ministry of Public Works (MoPWs) (TEC & MoPWs 2009). The Green Building Guidelines – UAE included eight IEQ guidelines, seven of them are mandatory while one is optional. The optional requirement is the insulation and shading of water tanks while the other seven mandatory requirements are regarding: (1) Operable Windows, (2) Ventilation Systems and Ceiling Fans, (3) Indoor Air Quality, (4) Low-emitting (VOCs) Materials, (5) Clean Materials and Chemical Pollutions, (6) Smoking and Non-smoking Zones, in addition to (7) Noise and Acoustics Controls. Following that guideline, IAQ in all new buildings should follow the latest version of ASHRAE 62.2. The guideline also identifies the allowable air construction levels which are adopted from USEPA in Table 2-8. Technical tests should be performed prior occupancy and flush out procedure should be conducted in case of buildings with higher levels than prescribed.

Table 2-8: Allowable air construction levels (TEC & MoPWs 2009)

| | **Indoor contaminants** | **Allowable air construction levels** |
|---|---|---|
| **1** | CO | < 9ppm |
| **2** | $CO_2$ | < 800ppm |
| **3** | Airborne mold and mildew | Simultaneous indoor/outdoor readings |
| **4** | Formaldehyde | <20µg/m$^3$ (Above outside air concentration) |
| **5** | Total TVOC | <200µg/m$^3$(Above outside air concentration) |
| **6** | 4 phenyl cyclohexene (4 – PC) | < 3µg/m$^3$ |
| **7** | Total particulates (PM) | < 20µg/m$^3$ |
| **8** | Regulated pollutants | < NAAQS |
| **9** | Other pollutants | < 5% of TLV-TWA |

Additionally to the federal requirements, green building regulations including IAQ requirements in UAE are initiated and developed by individual emirates. Abu Dhabi and Dubai are the two pioneering emirates in UAE in terms of mandating and encouraging more stringent building codes in general including the IEQ regulations. For instance, Abu Dhabi emirate established the Pearl Building Rating System (PBRS) in 2010 as part of Estidama Program established by Abu Dhabi Urban Planning Council (AD UPC 2010). In Dubai emirate, the Green Building Regulations and Specifications was established in 2011 and was initially mandated in only Dubai government sector then on all Dubai buildings in 2014 (DM 2011, 2016). During 2011 – 2014; building types other than governmental were awarded an IAQ certificate from DM when voluntarily complying below requirements (DM 2011, 2014). DM (2016) had recently mandated pre-occupancy indoor air testing for that must be conducted in all new buildings including residential ones to ensure that the maximum limit for TVOCs, HCHO, and suspended particulates have not being exceeded (Table 2-9).

Table 2-9: Maximum acceptable levels for pre-occupancy test by DM (DM 2016)

| | **Contaminant** | **Exposure limit (TWA)** |
|---|---|---|
| 1 | HCHO | < 0.08ppm per 8 hours |
| 2 | TVOC | < 300µg /m$^3$ per 8 hours |
| 3 | Suspended particulate | < 150µg/m$^3$ per 8 hours |

Additionally, DM (2016) mandated indoor air testing that must be conducted every five years in specified existing building types to ensure that the maximum limit for TVOCs, HCHO, $O_3$, $CO_2$, CO, $PM_{10}$, bacteria, and fungi have not being exceeded (Table 2-10). Included existing building types to comply with the above requirement are governmental buildings, educational buildings, health care buildings, hotels, shopping malls …etc. However, the mandated indoor air testing every 5 years was not enforced on existing residential buildings. Also, one of the most important mandated requirements on Dubai emirate is that all buildings should comply with ASHRAE 62 in terms of AERs provision (DM 2016). In 2016, Dubai Municipality introduced Al Sa'fat- Dubai Green Building Evaluation System which is an evaluation system for green buildings (DM 2016). Prior to the inauguration of Dubai Green Building Regulations and Specifications in 2011, the prevailing rating systems voluntarily utilized in regulating IAQ in Dubai were LEED or Building Research Establishment Environmental Assessment Method (BREEAM) which are an American and British rating systems, respectively (Salama & Al Saber 2013). Presently, residential IAQ for inhabited buildings is not regularly monitored by UAE government bodies because houses are private properties. However, in Abu Dhabi emirate, there is a scope of enhancing IAQ monitoring through voluntary procedures from conscious and aware residents as part of Enhancing Air Quality in Abu Dhabi policy (EAD 2014).

Table 2-10: Maximum acceptable levels on all existing buildings by DM (DM 2016)

| | **Contaminant** | **Exposure limit (TWA)** |
|---|---|---|
| 1 | HCHO | < 0.08ppm per 8 hours |
| 2 | TVOC | < 300µg /m$^3$ per 8 hours |
| 3 | $PM_{10}$ | < 150µg/m$^3$ per 8 hours |
| 4 | $O_3$ | 0.06ppm per 8 hours |
| 5 | $CO_2$ | 800ppm per 8 hours |
| 6 | CO | 9ppm per 8 hours |
| 7 | Bacteria | 500CFU/m$^3$ (Algar plate) |
| 8 | Fungi | 500CFU/m$^3$(Algar plate) |

Concerning IAQ in residential spaces in UAE; poor IAQ was classified by (Willis et al. 2010) as the second highest risk after ambient air pollution whilst the occupational exposure in industry was the third. These results were part of a comparative environmental risk-ranking for 14 categories of environmental risks to health conducted in UAE to inform a strategic planning process led by EAD. Willis et al. (2010) was the first study at national level of a deliberative method of comparative risk-ranking that encompassed a five stage process including a quantitative risk assessment by experts and deliberations by five groups of stakeholders. Based on that study, illness and premature incidence deaths in 2008 attributable to these environmental risks revealed 650, 290, and 10 annual deaths caused by ambient air pollution, indoor air pollution in residential spaces, and occupational exposures in industry; respectively. The 290 annual deaths were attributed to Asthma, lung cancer, leukemia, cardiovascular and respiratory diseases due to residential exposure to ETS, Bioaerosols, $PM_{10}$, $PM_{2.5}$, Rn, Benzene, HCHO, and incense use. Among the three risks, healthcare facilities visits in 2008 attributable to indoor air pollution in residential spaces was the highest reaching up to 89,000 compared those 15,000 and 79,000 visits ascribed to ambient air pollution and occupational exposure in industry. The study also demonstrated that although environmental health problems in UAE are quite low based on global levels, it is comparable to that in western countries. Annual incidence of deaths related to ambient air pollution is 0.14 per 1000 persons which was similar to that attributed to particulate matter (PM) in ambient air in USA and less than the 0.19 of Japan and UK (Gibson & Farah 2012).

Another major study in UAE was conducted by (Gibson et al. 2013) in which EAD and the Health Authority–Abu Dhabi (HAAD) commissioned a team of international specialists in environmental and public health to quantify the environmental burden of disease (EBD) in UAE. The major aim of that research was to assess the probable health improvements attainable in UAE with enhanced environmental pollution controls. Disease burden ascribed to exposure to six environmental hazards was assessed using a spatially resolved Monte Carlo simulation model that integrates environmental and public health data. The assessment covers all UAE population estimated as 4.5 million at the analysis year (2008). Results revealed that outdoor air pollution is the first environmental hazard in UAE followed by indoor air then occupational exposures causing about 650, 153, and 46 annual deaths; respectively. Among the three, healthcare facility visits related to poor IAQ were the highest reaching about 21,800 visits compared with those 17,200 and 14,600 attributed to occupational exposure and outdoor air pollution; respectively (Gibson et al. 2013).

One of the important conclusions confirmed by the above two major studies (Gibson et al. 2013; Gibson & Farah 2012) was that indoor air pollution in residential spaces is the second highest risk after outdoor air pollution. Furthermore, healthcare visits attributable to poor IAQ was estimated as 49% and 439% more than that of polluted outdoor by Gibson et al. (2013) and Gibson & Farah (2012); respectively. Attaining such higher number of healthcare visits is a concerning indication of the long-term latency diseases due to the exposure to harmful indoor air contaminants in UAE future. Reference to Section 2.3, some contaminants might be irritants with temporal health impacts or they might be sensitizing chemicals for which future exposures may lead to an extreme immune response. Moreover, both studies provided similar estimations regarding annual deaths and healthcare facility visits attributable to polluted outdoor air. Contrarily, the estimated potential impacts of polluted residential IAQ were greatly different.  For instance, about 90% more annual deaths were attributed to poor IAQ by (Gibson & Farah 2012) compared with that of (Gibson et. al 2013). This percentage is even more regarding healthcare visits attributed by (Gibson & Farah 2012) to poor residential IAQ that is about 308% more than that stated by (Gibson et. al 2013). The illustrated fluctuating results raised susceptibility, regarding the measurement of EBD of poor IAQ in UAE houses, in terms of determining which one is more reliable. That is a strong indication for the need of more intensive and comprehensive research. As explained by (Yin 2014), high reliability could only be attained by re-conducting the research utilizing typical methodological procedures which is not yet available for the above described findings.

Regarding other related research conducted in UAE, Barakat-Haddad et al. (2015) examined the associations between IAQ and asthma, chronic bronchitis, wheeze, dry cough, and emphysema among 6,363 school adolescents from 9 UAE areas. Demographic, residential, socio-economic and behavioral data was collected i.e. residence location, outdoor air quality, smoking, exposure to tobacco, and ethnicity. Additionally, regarding the unconventional drug use, participants were asked whether they ever intentionally smelled gasoline fumes, car exhaust, glues, correctors or burning black ants. These unconventional forms of substance use are commonly known among the UAE adolescent population. Results revealed that 12.3%, 1.8%, and 0.5% of the sample reported asthma, chronic bronchitis, and emphysema; respectively. A total of 34.8% and 12.2% reported a dry nocturnal cough and wheeze during last year. Multivariate analyses highlighted gender as a significant predictor of dry cough and asthma. Exposure to tobacco in addition to the exposure to arts/ crafts ceramics/stained glass work were found to be significant predictors of respiratory health. Tobacco smoking in addition to intentionally smelling gasoline fumes/ car exhaust/ correctors/glues/ burning black ants were found to significant predictors of dry cough and wheeze (Barakat-Haddad et al. 2015).

Moreover, there is rising concerns regarding the adverse respiratory health impacts of incense burning recently reported by literature. For instance, Cohen et al. (2013) performed a hazard assessment of exposure to incense burning to explore its adverse health impacts. Incense burning is a mutual practice in Gulf Countries that stands as a potential source of indoor air pollution. PMs, CO, $SO_2$, $NO_x$, HCHO, and carbonyls were measured and analyzed in an environmental chamber representing a typical UAE living room in which two types of UAE incense were burnt. Peak concentrations were of 1.42 mg/$m^3$, 122 pm, 0.3ppm, 85ppb, 71.9µg/$m^3$, 84.8µg/$m^3$ were detected for PMs, CO, $NO_x$, HCHO, pentanal, and glyoxal; respectively. Results revealed that time-weighted averages of PM, $NO_x$, and CO exceeded acceptable government regulation limits and emissions previously seen from ETS. The main contributor of high $NO_x$ and CO concentrations was charcoal emissions. A significant cell inflammatory reaction was reported in response to smoke constituents formed from examined incense types. Their study suggested that incense burning resulted in indoor air pollution and might be dangerous to human health. Also, reference to related research conducted in Oman, Al-Rawas et al. (2009) investigated the contribution of Arabian incense smoke on asthma prevalence or triggers. A cross sectional survey following a multi-stage cluster sampling method was conducted on 2441 Omani children of 10 years old. Results revealed that 15.4% of the sample had current asthma. Moreover, children breathing was three times more affected when burning incense more than twice a week than those not burning incense. The impact of burning incense more than twice a week on children breathing was 2.55 times more likely to affect asthmatics than non-asthmatics. Incense burning contributed in increasing wheezing in 38% of asthmatics and it was classified as the fourth trigger parameter following dust, weather and respiratory tract infections that contributed in worsening it by about 49.2%, 47.6%, and 42.2%, respectively. They also concluded that incense smoke might represent a potential environmental pollutant with negative health impact on humans after long-term exposure.

Moreover, research in residential IAQ and SHS status in UAE is at its preliminary stages. The first and the only large-scale population-based study was recently conducted when EAD commissioned a multi-disciplinary health study including epidemiologic, nutritional and indoor air constituents. As part of that study, Yeatts et al. (2012a) conducted a cross-sectional study of a 628 Emarati households from UAE seven emirates. Data collection instruments were questionnaires and field measurements for $SO_2$, $NO_2$, $H_2S$, HCHO, CO, $PM_{2.5}$, $PM_{2.5\text{-}10}$, and $PM_{10}$. Moreover, health information was collected from 1,590 household members. Data was collected during two visits for each household throughout 8 months period from October 2009 to May 2010. It is one of the few large international and one of the first in the region exploring the correlations between some indoor air pollutants and health symptoms. Results of the study showed that 13%, 9%, 8%, 4%, and 12% of the population had ever wheezing, current wheezing, and ever having doctor-diagnosed asthma, speech-limiting wheeze, and chest tightness/difficulty breathing; respectively. The most reported neurologic symptom was headache during the last 12 months whereas dizziness was the least accounting of about 46% and 12%, respectively. Moreover, measured $SO_2$, HCHO, $NO_2$, and $H_2S$ levels ranged between (0.010 – 0.507ppm), (0.006 – 0.137ppm), (0.006 – 0.048ppm), and (0.060 – 1.098ppm); respectively. $SO_2$, $NO_2$, and $H_2S$ concentrations in these houses were strongly associated with reported Asthma and wheezing symptoms whereas HCHO was associated with neurologic symptoms and difficulty in concentration. These results were comparable with the findings of other contemporaneous studies. Burning incense was associated with headaches, difficulty in concentration and forgetfulness. However, the study did not find increased respiratory symptoms due to burning incense. This result is contradicting with the limited recent research findings illustrating strong associations between incense burning and asthma incidence in the gulf region. Hence, further investigation is needed to understand variable incense components, their emissions and potential health impacts in this region.

As demonstrated in Table 2-11, the range of measured CO concentrations in the 625 households was low compared with established exposure limits. However, the data shown in (Appendix A – Table A-1) might be concerning regarding the following: (i) the 75th percentile of $SO_2$ measurements was 36.68μg/m$^3$ which is higher than the 20μg/m$^3$ recommended by WHO (2006); (ii) the 75th percentile of $PM_{10}$ concentrations was 62.1μg/m$^3$ which is above the 50 μg/m$^3$ mean concentrations for 24 hours recommended by WHO (2006); (iii) the 95th percentile of $H_2S$ was 208.5μg/m$^3$ that exceeded the WHO

(2000) limit of 150 μg/m$^3$ limit for 24 hours; in addition to (iv) the 95th percentile of $NO_2$ measurements was 22.6 μg/m$^3$ which is concerning when compared with the 20μg/m$^3$ mean for 24 hours established by (Health Canada 2016) as safe exposure limit in residential spaces. Detailed data regarding the duration of these measurements and in which houses they occurred is missing. As informed by one of the authors of Yeatts et al. (2012a) study via personal emails, the utilized passive samplers has not the capability to identify the duration of those concentrations (Yeatts 2015). Having insufficient details regarding the duration of the above highlighted readings, there is a probability of their being unacceptable limits when compared with recognized standards. For instance, the above highlighted concerning data might be an indication of having at least 25% of the sample houses with $PM_{10}$ and $SO_2$ exceeding the WHO (2006) limits. Also, it might be an indication of having at least 5% of the sample houses with $H_2S$ and $NO_2$ exceeding the WHO (2000) and (Health Canada 2016) limits. Furthermore, it is important to highlight the great local concerns regarding indoor PM concentrations due to the prevailing high PM levels in UAE ambient air (EAD 2014) and the infiltration threat of outdoor air PM (Gibson & Farah 2012) to indoor air. Moreover, the study found no associations between respiratory symptoms and the measured PM concentrations which are contradicting with relevant research (WHO 2006; Health Canada 2012). Hence, there is a critical need of more research aggregating knowledge regarding PM concentrations in UAE housing and their correlations with health problems.

Thus, one of the limitations of (Yeatts et al. 2012a) is the incapability of the utilized passive samplers to identify the duration of these measurements and their compliance with recognized standards. Moreover, the number of houses where these peak measurements occurred is also missing. Hence, more research is needed to convey more detailed quantification of indoor air contaminants concentrations in UAE houses via utilizing an appropriate sampling technique. Moreover, the non-inclusion of (Yeatts et al. 2012a) sample of expatriates' households is another limitation. Expatriates are estimated to be about 89% of UAE population (Government.ae 2019; Snoj 2015). They encompass many nationalities of different socio-economic status and lifestyles that greatly differ from Emirati nationals. That might have its consequent implications on residential IAQ levels and SHS perceptions. For instance, building types – having an attached kitchen, residents' behaviors, and applied cooling techniques – might greatly influence IAQ levels. Noteworthy that, unlike UAE nationals, the majority of expatriates lives in houses with attached kitchens. As presented by this study, having an attached kitchen has strong association with $SO_2$, CO, $PM_{10}$, and $PM_{2.5}$ concentrations. Thus, the non-inclusion of that study sample might not reveal realistic and valid results regarding the present IAQ conditions and the prevalence of SHS in UAE housing. Moreover, the study did not find significant correlation between PM concentrations and respiratory problems despite the well documentation of that association by relevant research (WHO 2000, 2006). Of particular importance was $PM_{2.5}$ concentrations that recommended to be kept as low as possible (Health Canada 2012). That finding highlights the need for further research to aggregate the knowledge regarding PM concentrations in UAE housing and their correlations with health problems.

Additional results than that of Yeatts et al. (2012a) regarding the correlations between indoor and outdoor pollutants concentrations were demonstrated in (Funk et al. 2014). That was based on extra measurements of outdoor air quality ultrafine PM concentrations in 23 households and elemental PM concentrations were conducted in 14 homes to assess indoor/outdoor pollution ratios. Indoor/outdoor ratios of ultrafine particulate matter (UFP), $PM_{2.5}$, and $PM_{10}$ were 0.44, 0.41, and 0.38, respectively. Funk et al. 2014 compared their study's results with another contemporaneous study conducted in 134 Detroit homes during 3 summer months. The comparison revealed that $PM_{2.5}$ indoor/outdoor ratio was 2.5 times lower in UAE's study than that of Detriot's. This was occurring although outdoor $PM_{2.5}$ concentration by UAE study was $15.4\mu g/m^3$ which was relatively similar to the $14\mu g/m^3$ in Detroit's study. That was attributed to the infiltration of outdoor polluted air in passively ventilated Detroit houses whereas the tightly sealed mechanically conditioned UAE houses allow less infiltration. The unattached kitchens in 69% of UAE houses might also be a reason of their lower indoor $PM_{2.5}$ concentrations. Indoor $PM_{10}$, $PM_{2.5}$ were significantly correlated with vehicles parking within 5 m, central air `conditioning, attached kitchens. These findings raise many questions regarding the contribution of a specific IAQ variable within different contexts. More questions arise even when assuming the positive impact of the UAE tightly sealed HVAC houses on PM infiltration indoors; what is the impact of different HVAC systems and the provided AERs on other contaminants concentrations. Also, one of the most important results revealed by (Funk et al. 2014) was that gained from indoor-outdoor elemental composition analysis of the PM samples in 14 houses. The composition profiles of indoor and outdoor PM were similar indicating a common source and that ambient air infiltration was a great contributor of indoor PM concentrations. One of this study conclusions were that the pollutant concentration patterns are evidently complex and therefore definitive and general statements about causative factors cannot be made.

Table 2-11: Measured indoor air pollutants by (Yeatts et al. 2012a) compared with established exposure limits standards/guidelines

| | **Measured by (Yeatts et al. 2012a)** | **Long exposure** | **Short exposure** | **Guideline/Reference** |
|---|---|---|---|---|
| **$PM_{2.5}$** | NA[*]-167.3µg/m$^3$ | 12µg/m$^3$ – 1 year | 35µg/m$^3$ – 24 hours | ASHRAE (2016) |
| | | 10µg/m$^3$– 1 year | 25µg/m$^3$ – 24 hours | WHO (2006) |
| | | To be kept as low as possible[i] | | Health Canada (2012) |
| **$PM_{10}$** | NA[*]- 421.9µg/m$^3$ | 50µg/m$^3$ – 1 year | 150µg/m$^3$ – 24 hours | ASHRAE (2016) |
| | | 20µg/m$^3$ – 1 year | 50µg/m$^3$ – 24 hours | WHO (2006) |
| | | | 150µg/m$^3$ – 8 hours | DM (2016) |
| **CO** | 0.30 – 5.8ppm | 10ppm – 24 hours | 25ppm – 1 hour | Health Canada (2010) |
| | | | 50ppm – 8 hours | OSHA (2011a) |
| | | | 35ppm – 1 hour | ASHRAE (2016) |
| | | | 9ppm – 8 hours | ASHRAE (2016) |
| | | | 10ppm – 8 hours | WHO (2010a) |
| | | | 9ppm – 8 hours | DM (2016) |
| **HCHO** | 7.37 – 168.2µg/m$^3$ or | | 123µg/m$^3$ – 1 hour | Health Canada (2006) |
| | 0.006 – 0.14ppm | | 50µg/m$^3$ – 8 hours | Health Canada (2006) |
| | | | 100µg/m$^3$ – 30 min | WHO (2010a) |
| | | | 0.75ppm – 8 hours | OSHA (2011b) |
| | | | 0.08ppm – 8 hours | DM (2016) |
| **$SO_2$** | 26.2 – 1,327 µg/m$^3$ or | | 75pbb– 1 hour | ASHRAE (2016) |
| | 0.010 – 0.507 ppm | 20µg/m$^3$ – 24 hours | 500µg/m$^3$ – 10 min | WHO (2006) |
| **$H_2S$** | 83.4–1,527µg/m$^3$ | 150µg /m$^3$ – 24 hours | | WHO (2000) |
| | | | 30000µg /m$^3$ – 10 min | OSHA (1978) |
| | | | 75000µg /m$^3$ – 10 min | |
| | | | 15000µg /m$^3$ – 10 min | |
| **$NO_2$** | 11.3 – 90.3µg/m$^3$ or | 100µg/m$^3$ – 1 year | 0.10ppm – 1 hour | ASHRAE (2016) |
| | 0.006 – 0.048ppm | 20µg/m$^3$ – 24 hours | 170µg/m$^3$ – 1 hour | Health Canada (2010) |
| | | 40µg/m$^3$ – 1 year | 200µg/m$^3$ – 1 hour | WHO (2006) |

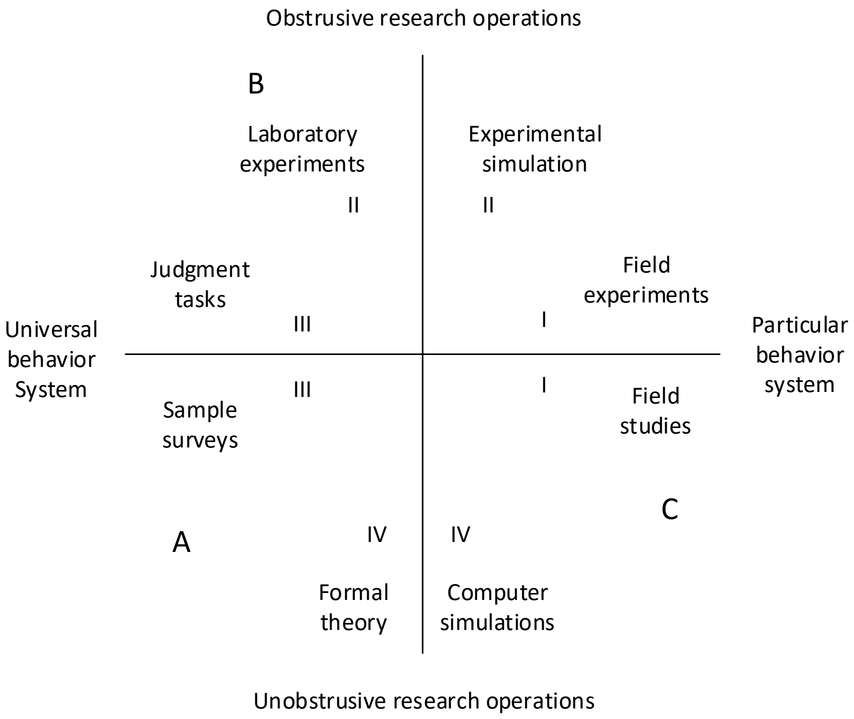
[*] Not available

# Chapter 3 : Methodology

## 3.1 Prevailing research approaches and methods

According to prevailing research approaches and methods employed in relevant studies; the majority of IEQ and SBS studies were empirical ones depending on observed and sensual experiences as fundamental source of knowledge in answering its questions, developing and examining theories (Punch 2009). They also fell within the quantitative paradigm since the expected outcome was numerical quantifying the variations and predicting correlations between variables. That differentiates them from the qualitative research describing the variations and explaining relationships in rich texts (Mack & Woodsong 2005). The two quantitative methods are experimental and non-experimental. Experimental designs establish cause-and-effect relationships and encompass at least one treatment (Miller & Yang 2008). For instance, Li et al. (2010) examined the potentiality of improving thermal comfort and perceived IAQ by 30 human subjects when utilizing a combined under-floor air distribution system and personalized ventilation in a field chamber. Interventions were provision of different temperatures and ventilation rates. Norbäck & Nordstrm, K. (2012) assessed the influence of $CO_2$ demand-controlled ventilation system on SBS and IAQ in 4 classes in which air supply was manipulated. The aim of such experimental designs is testing the impact of a particular treatment (Creswell 2014).

Conversely, non-experimental approach that encompasses surveys and field measurements studies do not encompass a treatment (Miller & Yang 2008). A survey is an extensive approach collecting data via questionnaires to describe population characteristics (Creswell 2012). Questionnaires are commonly used to in relevant investigations. For example, Kielb et al. (2014) utilized questionnaires to assess perceived SBS and IAQ conditions by 500 teachers in 23 classrooms. Prevalent SBS complaints were significantly associated with dust, dust reservoirs, paint odors, and moldy odors. Questionnaires were also used by Ndwiga et al. (2014) to assess the health effects of utilizing biomass fuel on 202 Kenyan women. It was found that the third phase of biomass fuel chain was significantly associated with prevalent SBS symptoms. According to Andersson (1998); questionnaires is an appropriate method when launching IAQ and SBS investigations. However, Mohle et al. (2003) debated that questionnaire as a sole instrument is insufficient in revealing clear information regarding measured parameters and contextual characteristics. As illustrated in Figure 3-1, although survey can produce correlational results, its major focus is on reflecting the population trends and generalizability issues (Cresswell 2012). Contrarily, despite its higher cost compared with questionnaires (Mohle et al. 2003), field measurements were widely used in similar investigations because they reveal clearer information regarding the measured parameters and contextual characteristics (Miller & Yang 2008) (Figure 3-1).



I. Settings in natural systems.
II. Contrived and created settings
III. Behavior not setting dependent.
IV. No observation of behavior required.
A. Point of maximum concern with generality over factors.
B. Point of maximum concern with precision of measurement behavior.
C. Point of maximum concern with system character context.

Figure 3-1: McGrath’s research strategies (Miller & Yang 2008, p. 149)

According to Wang et al. (2016), variables in non-experimental studies utilizing questionnaires and/or field measurements are simultaneously measured but without being manipulated as in experiments, Cresswell (2012) explained that such designs investigate associations between variables and predict outcomes utilizing statistical tests to measure the co-variance between variables (Cresswell 2012). Field studies were popularly utilized in SBS and IAQ investigations because, unlike experiments, they allow investigating more than one variable in the real phenomenon setting not a manipulated one (Cohen et al. 2011). For instance, Elia & Micheal (2009) conducted a field study investigating the effect of mechanical ventilation on IAQ conditions in 6 hospitality venues in USA and UK where smoking was allowed. Data was collected by field measurements for AERs, ETS, $CO_2$, CO, TVOC, T, and RH. Results revealed that mechanical ventilation plays an important role in hospitality venues in attaining IAQ conditions comparable to air quality outdoors. Also, Haverinen-Shaughnessy et al. (2015) examined associations between various IAQ parameters and students' health, absenteeism, and performance in 70 USA schools. Data was collected by field measurements of $CO_2$, RH, T, and settled dust in addition to school records. Significant correlations were found between reading and mathematics scores with indoor T and AERs. Also, Gao et al. (2014) performed a field study investigating IAQ, window opening behaviours, and students' SBS perceptions in 4 classrooms differently ventilated in Denmark. Classes were ventilated by manual and automatic operable windows with and without exhaust fans or balanced ventilation system. Indoor T, RH, and $CO_2$ were continuously measured over a summer and a winter. Window opening was also monitored during measurements and questionnaires were employed to assess pupils' perceptions. $CO_2$ measurements were used to estimate provided AERs. Results revealed that $CO_2$ and T levels were the highest in the manually operable windows during both seasons. The class with automatically operable windows provided the highest AERs. Based on pupils' perception and the number of reported SBS cases, the IAQ in the class with automatically operable windows was better than that with manual ones.

Additionally many relevant contemporary researches had performed field studies throughout a specific climatic season/s which helped them in achieving their set objectives. For instance, Less et al. (2015) assessed IAQ conditions and AERs in 24 Californian houses designed as high performance homes of which twelve were new and the other 12 were retrofit. Utilized methods included houses inspections, surveys, AERs measurements in addition to monitoring the following parameters for 6 days: T, RH, $CO_2$, CO, NO, $NO_2$, $NO_x$, and UFP. To accurately assess the efficiency of the houses' designs, whether naturally or mechanically ventilated, measurements were performed during winter that witnesses the highest runtime of HVAC systems and least window opening practices. Also, Park et al. (2014) quantified the impact of three ventilation systems on indoor PM concentrations in fifteen residential flats from three Seoul locations. The three ventilation systems were: natural ventilation, balanced and unbalanced mechanical ones. PMs, $CO_2$, and T levels were continuously monitored indoors and outdoors for 24 hours in each apartment. Since the natural ventilation was one of the studied ventilation systems, the study opted to conduct measurements during a thermally comfortable period in Seoul between (April – June 2012).

Moreover, Takigawa et al. (2012) examined whether indoor chemicals represent potential environmental risk factors on SHS in new houses less than 6 years age on 6 Japanese cities. Longitudinal questionnaires in addition to RH, T, 13 types of aldehydes, and 29 types of VOCs measurements were performed on 260 households in 2004 and 2005. The study was performed during autumn which was the season of least HVAC usage. Environmental monitoring was conducted once a year and samples were collected for 24 hours from the living hall. Moreover, Yang et al. (2009) investigated IAQ conditions according to building age in 55 Korean naturally-ventilated schools. Indoor and outdoor CO, $CO_2$, $PM_{10}$, Total microbial count (TMC), TVOCs, and HCHO were measured from a laboratory, classroom, and a computer classroom in each school. Measurements were taken for 24 hours during winter, summer, and autumn. Also, Dorizas et al. (2015) assessed indoor air contaminants and ventilation rates in 6th-grade classrooms naturally ventilated in nine Greece schools. Field measurements of RH, T, CO, $CO_2$, VOCs, $PM_{0.5}$, $PM_1$, $PM_{2.5}$, $PM_{10}$, and UFP continued for approximately 7 hours daily. Since the study investigated the impact of natural ventilation on IAQ conditions, measurements were performed during spring season only.

The majority of IEQ conditions and SBS symptoms studies intensively focused on examining the associations between IEQ conditions and SBS symptoms in particular contextual settings. As an example, Zamani et al. (2013) assessed SBS prevalence among 170 workers in an old and new Malaysian office building. 85 questionnaires were performed in each building in addition to field measurements for AERs, T, RH, $CO_2$, CO, TVOC, UFP, $PM_{10}$, and $PM_{2.5}$. Results demonstrated significant associations between the old building and all contaminants except UFP which was significantly correlated with the new one. However, no significant associations were found between AERs and SBS in both buildings. Also, Mishra & Ramgopal (2015) assessed the impact of thermal comfort of students on learning. The thermal perceptions and academic performance of 50 students were monitored using surveys and grades records. One class was naturally ventilated while the other was mechanically ventilated. Findings demonstrated insignificant difference between students' academic performance in the two classes. That was attributed to the pupils' ability to adapt with a range of thermal conditions that helped them in sustaining long-term average performance. Another example by Jurado et al. (2014) who evaluated IAQ comparing between 15 naturally-ventilated (NV) classes with 15 air-conditioned (AC) ones in five Brazilian universities. Results of the 802 questionnaires revealed that mold concentrations were less in AC than NV classes. Moreover, $CO_2$ levels in NV were significantly below the AC ones. Above results were attained from a sample selected within a particular context i.e. 200 students from one or two primary schools instead of randomly selecting the sample from all similar contexts i.e. 200 students from all primary schools. That might raise many concerns regarding results' generalizability and whether the sample is representative for the whole population (Creswell 2012, 2014).

## 3.2 Utilized research methods

Reference to this study aims described in Section 1.4; this research was an applied social one because it targeted: (i) knowledge expansion regarding IEQ and SHS in Dubai housing, (ii) developing suitable resolution strategies i.e. appropriate ventilation rates, and (iii) explaining particular behavioral patterns within social contexts that encompassed prevalent health symptoms in the housing sector (Roll-Hansen 2009; Punch 2009). Like most investigations in this domain demonstrated in Section 3.1; it fell within the quantitative paradigm characterized by its numerical outcome that quantified the variations and predicted associations between variables (Mack & Woodsong 2005). Regarding this study constructs comprehensively explained in Section 2.2 (Figure 2-1), the IEQ variables were the IVs whereas SHS variables were the DVs. Due to the insufficient evidence regarding the causal relationship between building and population characteristics (EPA 2015; Sundell et al. 2011; ASHRAE 2007); they were assumed as confounders that might affect both IV and DV (Engvall et al. 2004; EPA 1991b; Andersson 1998; Andersson & Stridh 1991). For this research, the non-experimental approach was suggested as more congruent one due to the complexity and ambiguity concerning the associations between the IEQ variables and SBS symptoms (EPA 2015; ASHRAE 2007). That made the assumption of having full control on all confounders – which is required in experimental research – unattainable. Hence, conducting an experimental study under incompletely controlled conditions threatens the experiment internal validity (Miller & Yang 2008). Thus, this study opted to utilize non-experimental methods to achieve its aims.

Also, according to described aims (Section 1.4); it was found that a survey was required to reflect current IEQ conditions and prevalent SHS symptoms in Dubai housing and to explore the associations between them. As explained in Section 3.1, a survey is an appropriate research method in answering “who, what, where, how many, and how much” questions (Yin 2014). According to Gillham (2007), a survey is a feasible research method due to their relative low cost and wide coverage. Also, reference to Carrer & Wolkoff (2018), the precedence of understanding the associations between various SBS parameters is fundamental prior conducting an experimental study that examines a particular variable. Predictive correlational research designs are appropriate in investigating the associations between variables (Cohen et al. 2011). Furthermore, when launching investigations regarding the associations between IEQ conditions and SBS symptoms, performing questionnaires was proposed by Andersson (1998) as the most appropriate method. As explained in 0 2.6, large population based studies investigating those associations in the housing sector were insufficient globally and locally (Yeatts et al. 2012a). That necessitates extensive research method such as questionnaires to investigate the phenomenon from the general population. However, Mohle et al. (2003) debated that questionnaires as a sole instrument are insufficient in revealing clear information regarding measured parameters and contextual characteristics. That is because, although survey can produce correlational results, its major focus is on reflecting the population trends and generalizability issues (Cresswell 2012). On the other hand, despite their higher cost compared with questionnaires (Mohle et al. 2003); field measurements were widely used in similar investigations as they reveal clearer information regarding the measured parameter and contextual characteristics (Miller & Yang 2008). Based on the above, it was decided to conduct field measurements for some prominent IEQ variables as part of a field study in which questionnaires and AERs calculation were also performed. The main aim of the field study was to provide clear information regarding the prevalence of measured parameters in Dubai housing and their compliance with national and/or international standards.

Thus, this study opted to utilize non-experimental methods to achieve its aims. The two major research methods employed by this study were: (i) a cross-sectional survey collecting data from 770 Dubai residents, and (ii) a field study conducted in 60 households in Dubai that included field measurements of some IEQ parameters, a questionnaire, and estimated provided AERs. A pilot survey covering 120 households in Dubai was conducted prior the conduct of the main survey. The main aims from conducting the pilot survey were to examine the reliability in addition to the validity of the proposed questionnaire and to develop it accordingly. In terms of surveys, performing a pilot survey is a crucial step for attaining a good questionnaire design. As explained by Bullen (2014; Viechtbaur et al. (2015), one of the goals of a pilot survey is to identify unforeseen problems, such as ambiguous inclusion or exclusion criteria or misinterpretations of questionnaire items. Additionally, they can greatly help in testing the validity and reliabilty of the questionnaire as a research instrument.

To illustrate the sufficiency of the methods in achieving its objectives, this research's objectives are linked with the employed methods to achieve them as follows:

1. Identifying current IEQ conditions and prevalent SHS symptoms in Dubai housing was achieved by the provision of descriptive statistics of self-reported IEQ conditions and self-reported SHS symptoms collected by the main survey. Also, descriptive statistics of measured T, RH, CO, $CO_2$, HCHO, $PM_{2.5}$, $PM_{10}$ in addition to estimated AERs were provided by the field study.
2. Identifying the influence of building and population characteristics on current IEQ conditions and prevalent SHS symptoms was achieved by performing regression tests to predict the influence of population and building parameters on self-reported IEQ conditions and SHS symptoms collected by the main survey.
3. Identifying the influence of IEQ factors on prevalent health symptoms was achieved by performing regression tests to explore associations and

predict the influence of self-reported IEQ measures on self-reported SHS symptoms collected by the main survey

4. Identifying the influence of other IEQ parameters on IAQ was achieved by performing regression tests to explore associations and predict the influence of other self-reported IEQ conditions on self-IAQ conditions collected by the main survey.
5. Based on the above findings, appropriate solutions were proposed to mitigate and control poor IEQ and prevalent SHS problems in Dubai housing.

## 3.3 Pilot survey

Reference to literature, the term “pilot studies” is identified as:

> [M]ini versions of a full-scale study to assess the feasibility and/or pre-test a particular research instrument such as a questionnaire or interview schedule (Teijlingen & Hundley 1998, p.1).
>
> [A] trial study carried out before a research design is finalized to assist in defining the research question or to test the feasibility, reliability and validity of the proposed study design (Thabane et al. 2010, p.2).
>
> [A] small scale test of a research project to evaluate its design. Pilot studies are frequently conducted in order to minimize the risks and correct for potential errors involved in large-scale survey research or other types of labor intensive fieldwork (Oxford University Press 2017).

A closer look at the pilot study definitions reveals that it is a feasibility study intended to guide the planning of a large-scale investigation. According to (Thabane et al. 2010; Leon et al. 2012; Alznafer 2014), the main goal of pilot studies is to assess feasibility so as to avoid potentially disastrous consequences of embarking on a large study which could undermine the whole research effort. However, reference to Teijlingen & Hundley (1998), conducting a pilot study does not guarantee success in the main study, but it does increase the likelihood. According to Thabane et al. (2010), the rationale for a pilot study falls under four broad classifications: (i) assessing the feasibility of the planned steps in the main study (ii) assessing time and budget problems that can occur during the main study (iii) investigating potential human and data optimization problems, and (iv) scientific rationale i.e. assessment of treatment safety and determination of dose levels and response. That classification is in congruence with the probable purposes of pilot study listed by Hertzog (2008): (i) feasibility, (ii) adequacy of instrumentation, (iii) problems of data collection strategies and proposed methods; (iv) answering methodological questions; (v) planning a larger study; and/or (vi) obtaining sufficient preliminary data to justify a grant award. In terms of surveys, a pilot survey is a crucial element of a good questionnaire design. As declared by (Bullen 2014; Viechtbaur et al. 2015), testing a survey questionnaire before using it to collect data is important. Piloting can help identifying unforeseen problems such as ambiguous inclusion or exclusion criteria or misinterpretations of questionnaire items. Additionally, pilot surveys can greatly help in testing the validity and reliabilty of the questionnaire as a research instrument. Reference to Parsian & Dunning (2009), to validate and develop a questionnaire it is essential to assess its reliability in addition to its face and content validity.

The face validity indicates the questionnaire appears to be appropriate to the study purpose and content area. It is the easiest validation process to undertake and it evaluates the appearance of the questionnaire in terms of feasibility, readability, consistency of style and formatting, language clarity, and the likelihood the target audience would be able to answer the questions (Parsian & Dunning 2009, DeVon et al. 2007; Trochim 2001; Haladyna 1999). Whereas, reference to (Pilot & Hunger 1999; DeVon et al. 2007), the content or logical validity of a questionnaire can be evaluated by a pilot study involving a group of scientists or experts to ascertain the content relevance to the study purpose and inclusion of a sufficient range of relevant attributes. According to (Engvall et al. 2004), adopting standard questionnaires administered by scholars in related fields, tested and retested for validity might enhance the potentiality of having better measures in terms of both contEye, nose, throat, and face validity. Reference to (O’Rourke & Hatcher 2014; Beaumont 2012; Chumney 2012; Suhr 2005; Grimm & Yarnold 1995), the content validity of a questionnaire can also be tested by performing the principal component analysis (PCA). PCA is useful in identifying the principal components accounting for most of the variance in the observed variables. It is also useful in identifying which items make up each componEye, nose, throat, and how strongly they relate to the component. That’s why PCA is most useful when used as a descriptive tool for the process of measure development as it contributes to the researcher’s understanding of the strengths and weaknesses of the measure. Furhermore, a pilot survey might also be used to examine the reliability of the questionnaire. Post examining the validity of the questionnaire, it is essential to assess the reliability or the inter-item consistency of the instrument. Reliability refers to the ability of a questionnaire to consistently measure an attribute and how well the items fit together, conceptually (Nunnally & Bernstein 1994; Haladyna 1999; DeVon et al. 2007). Reference to (Trochim 2001; DeVon et al. 2007; Parsian & Dunning 2009), the internal consistency of a questionnaire items can statistically be measured in two ways: Split-Half reliability and Cronbach's alpha correlation coefficient.

### 3.3.1 Pilot survey objectives

This pilot survey was performed to:

i. Examine the reliability of the measures used in the proposed questionnaire by computing their Cronbach's alpha.
ii. Examine the face validity of the questionnaire items. This was achieved by:
    - Asking participants about the clarity of the wording and their understanding of the questionnaire items.
    - Reporting participants' behaviors in filling the questionnaire items i.e. their provision of no answer, multiple answers, qualified answers or unanticipated answers to the study questions.
    - Evaluating time required to fill the questionnaire and the likelihood the target audience would be able to answer the questions.
iii. Develop the questionnaire accordingly. The utilized methods to develop the questionnaires involved:
    - Rewording or rephrasing the unclear items.
    - Providing sufficient options to choose the answer from.
    - Changing the scale in which responses are reported.
    - Excluding items measuring similar variable but written in different forms.
    - Performing PCA to reduce the health and odor measures and to assess the content validity of the resultant ones.

### 3.3.2 Pilot survey sample size

Reference to Sincero (2012), a pilot survey is an approach used to pre-test the questionnaire using a smaller sample compared to the planned sample size. In a pilot survey, the questionnaire is administered to a percentage of the total sample population or in more informal cases just to a convenient sample. Reference to (Viechtbaur et al. 2015; Hertzog 2008; Nieswiadomy 2002; Lackey & Wingate 1998), the sample size for the pilot study is controversial and it depends on many factors that varies from one study to another. Generally, literature provided recommendations regarding obtaining approximately 10 participants (Nieswiadomy 2002) or 10% of the final study size (Lackey & Wingate 1998) but the final decision to be guided by cost, time constraints, as well as population size (Hulley et al. 2001). According to Thabane et al. (2010), based on a common formula for obtaining a 95% CI (Confidence Interval), the required sample for the pilot study would be at least 75 subjects if the main study is designed to include ≥ 70% of eligible subjects and using a 95% CI for the proportion of eligible cases, a margin of error (ME) of 0.05, and an expected completion rate of 75%. Viechtbaur et al. (2015) debated that, none of the proposed calculation methods of sample sized for pilot studies are directed at the goal of problem detection. Thus, in their article, they presented a simple formula to calculate the sample size needed to be able to identify problems that may arise with a given probability. According to Viechtbaur et al. (2015), if a problem exists with 5% probability in a potential study participant, the problem will almost certainly be identified with 95% CI in a pilot study including 59 participants.

However, according to (Hertzog 2008), the general guideline of providing 10% of the sample required for the main study may be inadequate for aims such as assessment of the adequacy of instrumentation or providing statistical estimates for a larger study. Also, required sample size for pilot studies may be different depending on their objectives. For instance, a sample of 10 or even fewer may be sufficient to assess clarity of instructions or item wording, acceptability of formatting, or ease of administration. However, it may be inadequate the pilot aims to estimate internal consistency or test–retest reliability. One of the conclusions of that study was that a sample range from 10 to 40 per group are evaluated as adequate in providing precise estimates to meet a variety of possible aims.

Thus, the sample size for the current pilot study was calculated based on the above recommendations. The calculated sample size was based on two considerations: (i) the intention to test the questionnaire reliability; and (ii) the inclusion of three major groups in the questionnaire design as described later in more details (Section 3.4.1 & Table 3-28). Based on above suggestions, the sample size for this pilot study can range from 38 – 50 samples when providing the 10% of the proposed sample size (380 – 500) assumed as sufficient for the main survey (Section 3.4.1). Or it can range between 30 – 120 cases based on number of samples per the three major groups (Table 3-28). According to (Hertzog 2008), when evaluating item performance using Cronbach's alpha for pilot samples of 25 – 40 per group, observed alpha should probably be at least 0.75 in order to have reasonable confidence on the measure reliability. Samples having fewer than 25 participants per group need observed alpha to be close to 0.80. Thus, this study intended to provide 40 cases per group leading to a sample of 120 cases that was high compared with other recommendations that require 59 cases (Viechtbaur et al. 2015) or 10% of the main sample (Lackey & Wingate 1998).

Regarding the sample size required to obtain reliable results when performing PCA; the minimal number of participants should be at least 100 participants or 5 times the number of variables being analyzed (O'Rourke & Hatcher 2014; Chumney 2012; Bryman & Cramer 2005; Munro 2005; Suhr 2005; Field 2003). However, reference to (Parsian & Dunning 2009; Costello & Osbourne 2005; Field 2003), the number of participants required to undertake a reliable PCA remains under debate. Stevens (2002) debated that the number of observations required for PCA to be reliable depend on the data particularly on how well the variables load on the different components. Following Steven's (2002) rules of thumb, variables loading should not be less than 0.722 when the sample size is 50. However, the acceptable variables loading should not be less than 0.512 when the sample size is 100 cases. Notworthy that the the valid cases to be analysed from the covered 120 cases were 91, 94, and 96 cases for the IEQ, health symptoms, and odors perceptions' scales; respectively. That implies in accepting variable loading greater than 0.512 as recommended by Steven (2002) and followed by many contemperaneous studies (Suliman & Al Kathairi 2013; Suliman et al. 2010;

Parsian & Dunning 2009). Moreover, to ensure an appropriate sample size was obtained for the pilot study to enable PCA to be undertaken, Bartlett test of Sphericity and the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy (MSA) was deliberately considered. Reference to (Beaumont 2012; Parsian & Dunning 2009; Field 2005; Kaiser 1974), it is important to consider the Bartlett test of Sphericity and KMO MSA to ensure an appropriate sample size was obtained for the pilot study to enable PCA to be undertaken. KMO statistic varies between 0 and 1. A value of 0 indicates that PCA is inappropriate while a value close to 1 indicates that the PCA will yield distinct and reliable components. According to (Beaumont 2012; Parsian & Dunning 2009; Kaiser 1974); the adequacy of the sample size to perform a valid PCA can be assured when KMO is greater than 0.5 and the Bartlett test of Sphericity is associated with a $p$ value less than 0.05.

### 3.3.3 Pilot questionnaire design

Regarding the pilot questionnaire design shown in Appendix B and Appendix C, it is important to mention that it was adapted from the following three standardized questionnaires initially established to assess SBS and IEQ in office spaces which are the: (i) Indoor environmental quality questionnaire that was developed by (EPA 2003) generically referred to it as EPA Questionnaire (A) in this study (Appendix G), (ii) Indoor air quality and work environment survey developed by (EPA 1991b) generically referred to it as EPA Questionnaire (B) in this study (Appendix H); and (iii) MM 040 NA questionnaire developed by the Örebro Model (Andersson 1998; Andersson & Stridh 1991) (Appendix I). The above standardized questionnaires were commonly employed by recent related studies (Azuma et al. 2015; Ung-Lanki et al. 2017; Chirico et al. 2017; Carrer & Wolkoff 2018; Syazwan et al. 2013; Hellgren 2012; Peretti & Schiavon 2011; Kanazawa et al. 2010; Eriksson & Stenberg 2006). The use of standardized questionnaires that were tested and retested enhances their inter-item consistency and reliability (Dillman et al. 2009). One of the major targets when designing this study questionnaire was to develop a comprehensive but short one. That was very essential because, reference to (Ali 2014), long questionnaires tend to discourage UAE residents from participation.

Fortunately the above criterion was satisfied in terms of its comprehensiveness and shortness (Andersson 1998; Andersson & Stridh 1991). However, reference to (EPA 1991b), items measuring IEQ conditions in EPA questionnaire (B) are more detailed. For instance, only one item is measuring odors in the MM 040 NA questionnaires whereas odors are measured by 15 items in EPA questionnaire (B). Although there are differences in the levels of details in the three questionnaires, they are similarly divided into four sections: (i) personal characteristics, (ii) building parameters, (iii) IEQ parameters; and (iv) health symptoms. Based on that, this study intended to adopt a similar structure to that provided by them in terms of dividing the questionnaire into the above 4 sections. When designing the questionnaire, it was intended to keep it as short as possible to encourage UAE individuals to respond. Hence, the pilot questionnaire adopted the brief MM 040 NA questionnaire measures. However, some changes were made following that of EPA in terms of injecting more items measuring a specific parameter or in the scale in which data was collected as detailed in the following paragraphs. The resultant questionnaire from such a hybrid approach is a 2-page questionnaire similar to the MM 040 NA questionnaires but more comprehensive. At the same time, it is simpler and shorter when compared to the 13 and 20 pages EPA questionnaire (A) and (B); respectively.

As shown in Appendix B and Appendix C, the pilot questionnaire was divided into the following 4 sections: Section (I) collected data regarding population characteristics; Section (II) collected data regarding building characteristics; Section (III) collected data regarding IEQ; while Section (IV) collected data regarding SHS symptoms. Table 3-1 illustrates the number of covered variables in each section. It is important to note that the perceived IEQ involves some self-reported comfort measures, self-reported odor measures in addition to self-reported IAQ rating. Reference to EPA (1991b), those IEQ measures are subjective ones considered as outcome/dependent variables (DVs) in some statistical models. That is mainly because they are affected by population, building variables in addition to other objective IEQ parameters such as T, RH, air contaminants, lighting quality … etc. Whereas in other statistical models, self-reported IEQ measures are considered as (IVs) that affect the health symptoms which are considered as (DVs) (EPA 1991b).

Table 3-1: Pilot questionnaire design

| Section | Item no. | Variable | Variable code |
|---|---|---|---|
| **I** | 1 - 10 | Population | P1 – P10 |
| **II** | 11 – 23 | Building | B1 – B13 |
| **III** | | Perceived IEQ | |
| | 24 – 39 | Odor perceptions | O1 – O16 |
| | 40 - 57 | Comfort perceptions | C1 – C18 |
| | 58 | IAQ rating | A1 |
| **IV** | 59 - 88 | Health symptoms | H1 – H30 |

The first section of the questionnaire was directed to collect data regarding population characteristics. The included variables within this section are (P1 – P10) (Table 3-2). Participants were asked about their gender, age, smoking habits, passive smoking, and health status. All these variables, except age, were binary in which data was collected in two categories i.e. gender was answered by either “females or males” while smoking habits and allergic diseases were answered either by “Yes” or “No”. However, the age was continuous variable as participants were asked to specify their age in numbers. All the parameters from P1 – P7 were used by (Andersson 1998; EPA 1991b, 2003). Similarly to (Andersson 1998), the pilot questionnaire adopted the first three allergic diseases or symptoms measured by P5 – P7 which were asthma, hay fever, and eczema (2nd page – Item no. 1 to 4). Whereas the P8 – P10 were other important parameters measuring participant health status adopted from (EPA 1991b, 2003) inquiring about having migraine, allergy to dust, and allergy to molds.

Table 3-2 : Measured population variables in pilot questionnaire

| Item | Code | Variable | Data type | Source |
|---|---|---|---|---|
| 1 | P1 | Gender | Binary | (EPA 2003)<br>(EPA 1991b)<br>(Andersson 1998) |
| 2 | P2 | Age | Continuous | |
| 3 | P3 | Being a smoker | Binary | |
| 4 | P4 | Being a passive smoker | Binary | |
| 5 | P5 | Having asthma | Binary | |
| 6 | P6 | Having hay fever | Binary | |
| 7 | P7 | Having eczema | Binary | |
| 8 | P8 | Having migraine | Binary | (EPA 2003)<br>(EPA 1991b) |
| 9 | P9 | Having allergy to dust | Binary | |
| 10 | P10 | Having allergy to mold | Binary | |

The second section of the questionnaire was directed to collect data regarding the building characteristics. As shown in Table 3-3, the pilot questionnaire involved 13 building variables (B1 – B13) measured by items no. (11 – 23) that inquired about house type, occupancy levels, residency duration, house age, kitchen type, applied AC system, water leaks, new carpets, new curtains, new furniture, new devices, walls painted, and rearranged walls. Parameters (B1 – B6) measured by items no. (11 – 16) were not found in the three standardized questionnaires. One of the reasons of not introducing them in those questionnaires was that they were originally directed towards work spaces not residential buildings. However, they were included in this study questionnaire due to their probable impact on poor IAQ and SHS as discussed in Chapter 2. Variables (B7 – B13) measured by items no. (17 – 23) inquiring regarding having water leaks, new carpets, new curtains, new furniture, new devices, walls painted, and rearranged walls in the house which were adopted from EPA questionnaire (A) in Part I (Item no. 14) and EPA questionnaire (B) in Part I (Item no. 11 & 12). Residency duration (Item no. 15) coded as B4 in the pilot questionnaire was also adopted and adapted from EPA questionnaire (A) in Part I (Item no. 1) and EPA questionnaire (B) following (Part I/ Item no. 4) in which participants were asked about the duration working in the building. As discussed in Section 2.2 and reference (EPA 1991b), all these variables were confounders because of their probable impact on both IV and DV. Also, all of them were categorical or nominal data of which some were binary such as house type, having an attached kitchen, having water leaks, or having new changes while others were categorical such as house age, occupants' number per age, and AC type.

The third section of the questionnaire measured perceptions regarding the four IEQ factors which were: IAQ, thermal, lighting and noise qualities. Noteworthy that, constrained by the 2nd aim and objective of this study (Section 1.4); the inclusion of some variables to measure perceived thermal, lighting and noise qualities was not intended to eventually characterize those qualities but to identify the IEQ risk factors that affect both perceived IAQ and SHS symptoms in Dubai housing. Concerning odor items utilized by the above three questionnaires; only two items measures odors in the MM 040 NA questionnaire which are items no. (34 and 36) inquiring about having "Unpleasant odors" or "Passive smoke". Whereas in EPA questionnaire (A), odors perceptions were measured by three items which are "Tobacco smoke odors", "Unpleasant chemicals odors" and "Unpleasant odors" in Part III - 1. In EPA questionnaire (B), fifteen types of odors are used to measure perceptions regarding IAQ

(Items no. Part III/ Q2/a – o). In addition to these 15 odor items, participants are asked to specify any other unpleasant odor in (Items no. Part III/ Q2/p). All these items are related to this study except one (Items no. Part III/ Q2/a – k) inquiring about odors caused by printing processes such as pressing and binding materials which is more related to office spaces than residential ones. Hence, in order to explore and identify prevailing odors perceptions in Dubai, the related 14 items identified by EPA questionnaire (B) were adopted in the pilot questionnaire as items no. (25 – 38) coded as (O2 – O15) in Table 3-4. Moreover, another odor measure was used inquiring about the frequency of experiencing smoke of incense burning (Item no. 24 or O1). Reference to related discussion in Section 2.6, incense burning is one of the variables that might have potential negative impact on both IAQ and SHS. That is why the study included it as one of the IAQ items in order to assess its correlations with IAQ and SHS in Dubai housing. The last item (Item no. 39) coded as O16 explored the prevalence of any odor type other than the mentioned ones.

Table 3-3: Measured building variables in pilot questionnaire

| **Item** | **Code** | **Variable** | **Variable type** | **Source** |
|---|---|---|---|---|
| 11 | B1 | House type | Binary | Author |
| 12 | B2 | House age | Ordinal | |
| 13 | B3 | Kitchen type | Binary | |
| 14 | B4 | Residency duration | Continuous | Adapted from<br>(EPA 2003)<br>(EPA 1991b)<br>(Andersson 1998) |
| 15 | B5 | Occupancy levels | Ordinal | Author |
| 16 | B6 | AC type | Categorical | |
| 17 | B7 | Having water leaks | Binary | (EPA 2003)<br>(EPA 1991b) |
| 18 | B8 | Having new carpet | Binary | |
| 19 | B9 | Having new curtains | Binary | |
| 20 | B10 | Having new furniture | Binary | |
| 21 | B11 | Having new devices | Binary | |
| 22 | B12 | Having walls painted | Binary | |
| 23 | B13 | Having rearranged walls | Binary | |

Also, another two IAQ items measured the frequency of experiencing “dust and dirt” in addition to “stuffy bad air”, respectively (Item no. 40 & 41 coded as C1 – C2) (Table 3-5). The two items were similarly employed as those (1st page, Items no. 32 and 39) in the MM 040 NA questionnaires and as (Items no. Part III/ Q1/ j & m) in the EPA questionnaire (B). According to (EPA 1991b; Andersson 1998), those two items (C1 – C2) were considered as important measures reflecting their IAQ comfort perceptions. Moreover, participants were asked to provide their judgement regarding the overall IAQ of their house by choosing one of four categories: excellent, good, fair, and poor (Item no. 58 coded as A1). Hence, IAQ was measured by 3 variables that involved 2 comfort measures, and an IAQ rating (Table 3-5). Similarly as in EPA questionnaire (B), from where the majority of items were adopted, data for all IEQ – except A1 – in addition to health items were recorded on a 5-points Likert scale. The frequency at which the measured item occurs was identified as “Never”, “Rarely”, “Sometimes”, “Often”, and “Always”. Likert scale was commonly used in contemporary research for quantifying personality traits and attitudes. Identifying the data collected by Likert scale as ordinal or interval is controversial. However, many recent researches tend to deal with such data as interval or continuous data similarly as done by (EPA 1991b; Norman 2010; Brown 2011; Harry & Boone 2012; Sullivan & Artino 2013).

Table 3-4: Odor measures in the pilot questionnaire

| **Item** | **Code** | **Odor description** | **Data type** | **Source** |
|---|---|---|---|---|
| **24** | O1 | Smoke from incense burning | 5 points scale | Author |
| **25** | O2 | Body odors | ,, ,, ,, | (EPA 2003)<br>(EPA 1991b) |
| **26** | O3 | Cosmetics odors | ,, ,, ,, | |
| **27** | O4 | Tobacco smoke odors | ,, ,, ,, | (EPA 2003)<br>(EPA 1991b)<br>(Andersson 1998) |
| **28** | O5 | Fishy smells | ,, ,, ,, | (EPA 1991b) |
| **29** | O6 | Other food smells | ,, ,, ,, | |
| **30** | O7 | Musty damp basement smells | ,, ,, ,, | |
| **31** | O8 | Odors from new carpet | ,, ,, ,, | |
| **32** | O9 | Odors from curtains or drapes | ,, ,, ,, | |
| **33** | O10 | Odors from diesel | ,, ,, ,, | |
| **34** | O11 | Odors from equipment | ,, ,, ,, | |
| **35** | O12 | Odors from cleaning products | ,, ,, ,, | |
| **36** | O13 | Odors from pesticides | ,, ,, ,, | |
| **37** | O14 | Odors from chemicals | ,, ,, ,, | (EPA 2003)<br>(EPA 1991b) |
| **38** | O15 | Odors from paint | ,, ,, ,, | (EPA 1991b) |
| **39** | O16 | Other odors | ,, ,, ,, | |

Table 3-5: IAQ measures in pilot questionnaire

| Items | Code | Item description | Data type | Source |
|---|---|---|---|---|
| **58** | A1 | IAQ rating | 4 points scale | (EPA 1991b) |
| **40** | C1 | Dust and dirt | 5 points scale | (EPA 1991b)<br>(Andersson 1998) |
| **41** | C2 | Stuffy “bad” air | ,, ,, ,, | |

Thermal, Lighting, and Noise measures are shown in Table 3-6 as (C3 – C11), (C12 – C16), and (C17 – C18); respectively. They were typically adopted from EPA questionnaire (B). The thermal comfort was measured using the same 9 items of EPA’s (Items no. Part III/ Q1/ a – i); the two noise measures followed (Items no. Part III/ Q1/ k – l); while the 5 items measuring the lighting comfort are adopted from (Items no. Part III/ Q4). Perceptions regarding thermal comfort (C3 – C11) and noise comfort (C17 – C18) were reported on 5-points Likert scale as in EPA questionnaire. However, the study slightly changed that of lighting comfort measures (C12 – C16) to be recorded into 5-points Likert scale similar to other IEQ comfort measures instead of asking respondents to rate the item. The adopted comfort measures were more detailed in EPA questionnaire compared with those employed in MM 040 NA questionnaire (1st page, Items no. 28 – 31, 37, and 38) which were only 6 items to measure the Thermal, Lighting, and Noise qualities altogether. Since the IEQ factor represented the major IV in this study, it was intended to exploit as much measures as possible to detect the associations between IEQ parameters and SHS. That is why extensive IEQ measures used in EPA questionnaire (B) were adopted by this study.

The fourth section was oriented to report the prevalent SHS symptoms among Dubai residents. Reference to EPA questionnaire (B), the significant employee – reported health symptoms includes 30 health symptoms listed in Table 3-7. The symptoms measures used in the MM 040 NA questionnaire were only 12 symptoms and in EPA questionnaire (A) were 19 symptoms (Part II/ 8). Notably that the 30 symptoms in EPA questionnaire (B) included those in the other two questionnaires. Thus, following EPA questionnaire (B), these 30 measures of health symptoms were typically adopted as (Items: H1 – H30) and similarly reported on a 5-points Likert scale. Further information was required from a participant when reporting the prevalence of a particular symptom (Items no. Part II/Q8a) in EPA questionnaire (A), and (Items no. Part II/Q7) in EPA questionnaires (B). Similar information was requested by the MM

040 NA questionnaires (2nd page. Items no. 7 – 30). As explained in Section 2.1, identifying how an experienced health symptom changes outside the house is essential in identifying it as SHS symptom or no. That is why this study adopted similar measure from EPA questionnaire (B) and the MM 040 NA questionnaire to record the variation in symptom intensity when leaving the house in terms of whether the symptom "gets more", "stay same", or "gets less". For instance, if the experienced symptom gets less outside the house that might indicate an IAQ problem in the house.

Table 3-6: Thermal, Lighting, and Noise measures in the pilot questionnaire

| Factor | Items | Code | Item description | Data type | Source |
|---|---|---|---|---|---|
| Thermal | 42 | C3 | Too much air move- | 5 points scale | (EPA 2003)<br>(EPA 1991b) |
| | 43 | C4 | Too little air move- | ,, ,, ,, | |
| | 44 | C5 | Need to adjust air | ,, ,, ,, | |
| | 45 | C6 | Too hot | ,, ,, ,, | (EPA 2003)<br>(EPA 1991b)<br>(Andersson 1998) |
| | 46 | C7 | Too cold | ,, ,, ,, | (EPA 2003)<br>(EPA 1991b)<br>(Andersson 1998) |
| | 47 | C8 | Need to adjust T | ,, ,, ,, | (EPA 1991b) |
| | 48 | C9 | Too much humidity | ,, ,, ,, | (EPA 2003)<br>(EPA 1991b) |
| | 49 | C10 | Too much dryness | ,, ,, ,, | (EPA 2003)<br>(EPA 1991b)<br>(Andersson 1998) |
| | 50 | C11 | Need to adjust humid- | ,, ,, ,, | (EPA 1991b) |
| Lighting | 51 | C12 | Too much dim | 5 points scale | (EPA 2003)<br>(EPA 1991b)<br>(Andersson 1998) |
| | 52 | C13 | Little dim | ,, ,, ,, | (EPA 2003)<br>(EPA 1991b) |
| | 53 | C14 | Too much glare | ,, ,, ,, | |
| | 54 | C15 | Little glare | ,, ,, ,, | |
| | 55 | C16 | Need to adjust lighting | ,, ,, ,, | (EPA 1991b) |
| Noise | 56 | C17 | Too noisy | 5 points scale | (EPA 2003)<br>(EPA 1991b)<br>(Andersson 1998) |
| | 57 | C18 | Too quiet | ,, ,, ,, | (EPA 1991b) |

Table 3-7: Items measuring SHS symptoms in the pilot questionnaire

| Item no. | Code | Description | Data type |
|---|---|---|---|
| **59** | H1 | Headache | 5 points scale |
| **60** | H2 | Nausea | ,, ,, ,, |
| **61** | H3 | Runny nose | ,, ,, ,, |
| **62** | H4 | Stuffy nose | ,, ,, ,, |
| **63** | H5 | Sneezing | ,, ,, ,, |
| **64** | H6 | Cough | ,, ,, ,, |
| **65** | H7 | Wheezing/whistling in chest | ,, ,, ,, |
| **66** | H8 | Breath shortness | ,, ,, ,, |
| **67** | H9 | Chest tightness | ,, ,, ,, |
| **68** | H10 | Dry/itching/tearing eyes | ,, ,, ,, |
| **69** | H11 | Sore/strained eyes | ,, ,, ,, |
| **70** | H12 | Blurry/double vision | ,, ,, ,, |
| **71** | H13 | Burning eyes | ,, ,, ,, |
| **72** | H14 | Sore throat | ,, ,, ,, |
| **73** | H15 | Hoarseness | ,, ,, ,, |
| **74** | H16 | Dry throat | ,, ,, ,, |
| **75** | H17 | Unusual fatigue or tiredness | ,, ,, ,, |
| **76** | H18 | Sleepiness or drowsiness | ,, ,, ,, |
| **77** | H19 | Chills | ,, ,, ,, |
| **78** | H20 | Fever | ,, ,, ,, |
| **79** | H21 | Aching muscles or joints | ,, ,, ,, |
| **80** | H22 | Feeling depressed | ,, ,, ,, |
| **81** | H23 | Lower back pain or stiffness | ,, ,, ,, |
| **82** | H24 | Shoulder/ neck pain/ numbness | ,, ,, ,, |
| **83** | H25 | Hand/ wrist pain/ numbness | ,, ,, ,, |
| **84** | H26 | Difficulty in remembering | ,, ,, ,, |
| **85** | H27 | Dizziness/ light-headedness | ,, ,, ,, |
| **86** | H28 | Tension or nervousness | ,, ,, ,, |
| **87** | H29 | Difficulty concentration | ,, ,, ,, |
| **88** | H30 | Dry/ itchy skin | ,, ,, ,, |

Noteworthy that the recall period for all IEQ and health were different in the three standardized questionnaires as it was 4 weeks in the EPA Questionnaire (A) (EPA 2003); three months in the MM questionnaire (Andersson 1998); whereas it was 1 year in EPA Questionnaire (B) (EPA 1991b). Reference to (Andersson 1998); recall periods up to 12 months for health symptoms were used in other relevant standardized questionnaires such as the Royal Society of Health (RSH) questionnaires. Reference to (EPA 1991b; OECD 2011), one of the advantages of using a recall period of 12 month is the avoidance of seasonal variations and subsequently collecting data that represent typical conditions. However, according to (Andersson 1998), a recall period of 3 month is an appropriate one to avoid memory effects and to efficiently follow up remedial interventions. Concerning this study, and since the expected period during which the required sample size was undefined; using the 12 month as recall period was more appropriate as it enables avoiding the effect of probable seasonal variations during collecting questionnaires.

### 3.3.4 Pilot survey results & modifications

#### 3.3.4.1 Reliability results of pilot questionnaire

Cronbach’s alpha was computed to examine the reliability of the questionnaire. Regarding the global DV items measuring the health symptoms (Table 3-7), Cronbach’s alpha was 0. 950. Regarding the global IV which was the IEQ measures that include IAQ, thermal, lighting and odor measures (Table 3-4 to Table 3-6); computed Cronbach’s alpha was 0.905. Moreover, computed Cronbach’s alpha was 0.776 for odor measures. Also, it was 0.877 for IEQ comfort measures that include the IAQ, Thermal, Lighting, and Noise measures. According to (Suliman & Al Kathairi 2013; Tavakol & Dennick 2011; Suliman et al. 2010; Parsian & Dunning 2009; DeVon et al. 2007; DeVellis 1991), an alpha of 0.70 is acceptable. According to (DeVellis 1991), Cronbach alpha below 0.60 is considered as unacceptable while values between 0.60 – 0.65 are undesirable, 0.65 – 0.70 is minimally acceptable, 0.70 – 0.80 is respectable, 0.8 – 0.90 is very good, while Cronbach alpha much above 0.90 suggests redundancies and indicates that test might need shortening.

Thus, the alpha computed for the global IV and DV in addition to the subscales exceeded the 0.70. That indicates a high correlation between the items and that the measures are consistently reliable. Also, according to (Hertzog 2008), when evaluating item performance using Cronbach’s alpha for pilot samples of 25–40 per group as in this one, observed alpha should probably be at least 0.75 in order to have reasonable confidence on the measure reliability. Thus, having Cronbach’s alpha for the global DV and the global IV highly above 0.8 indicated that the pilot sample size was sufficient. However, Cronbach alpha value for the health symptoms (Global DV) and for the odor measures is 0.95 and 0.905 respectively. Reference to (DeVellis 1991; Tavakol & Dennick 2011), such values indicated having redundant items and there was a need to shorten the questionnaire particularly for the health symptoms which was highly above 0.9. The concern regarding having redundant items and highlighted the need to shorten the questionnaire are further discussed and dealt with in the following sections.

### 3.3.4.2 Face validity of pilot questionnaire

Face validity indicates the questionnaire appears to be appropriate to the study purpose and content area. It is the easiest validation process to undertake and it evaluates the appearance of the questionnaire in terms of feasibility, readability, consistency of style and formatting, and the clarity of the language used (Haladyna 1999; Trochim 2001; DeVon et al. 2007). The face validity of this pilot questionnaire items was assessed by:

i. Asking participants about the clarity of the wording and their understanding of the questionnaire items;
ii. Reporting participants' behavior in filling the items i.e. commonly unanswered questions, multiple answers, qualified answers or unanticipated answers to the study questions …. etc.
iii. Evaluating the time required to fill the questionnaire and the likelihood the target audience would be able to answer the questions.

Following are the reported participants' inquiries, observations, and behaviors along with suggested modifications:

i. Many participants reported that (Q15: How many persons in your house are within the following range) in the pilot questionnaire (Appendix B and Appendix C), inquiring about the number of occupants within particular age groups as unclear. Few participants, only 57 out of 107, answered it. Most participants did not report the number of individuals in the box provided for each group but just ticked in it. Regarding this, a note was provided asking participants to indicate a number in the provided box in case of manually filled questionnaire. In case of electronic questionnaire, a drop down menu displaying numbers from 1 – 10 so as to select from. Hence, Q15 (Appendix B and Appendix C) was amended and provided as Q9 (Appendix D and Appendix E) in the revised questionnaire shown in.
ii. It was noticed that participants gave similar answers for (Q12: House age) and (Q14: How many years you are living in this house) (Appendix B and Appendix C). It was probable that participants had provided relevant answers. However, it was also probable that participants were

confused between the two questions and subsequently gave similar answers for both. One of the justifications of that confusion was that the respondents might not have the knowledge to answer Q12. To solve that confusion and to ensure that the accuracy of collected data, (Q12: House age) (Appendix B and Appendix C) was rephrased to be (Q11: For how long your house is built) (Appendix D and 0Appendix E). Moreover, an optional answer “Not aware/ Not sure” was added in addition to the provided age groups in Q11 in the revised questionnaire Appendix D. Moreover, another question inquiring about the residential area was provided in the main questionnaire as (Q7: In which area are you living in Dubai) (Appendix D and 0Appendix E). When the building age was not provided by the participant, it was estimated based on the approximate age of the majority of the buildings on the defined residential area.

iii. Q39 in the pilot questionnaire (Appendix B and Appendix C), inquiring about the existence of other odors than the mentioned in the questionnaire, was one of the least answered questions. Only 55 participants, out of the 107, answered the question of whom a number of 43 participants reported that they had never experienced other types of odors. Therefore, (Q39: other odors) was deleted in the main questionnaire.

iv. Some participants inquired whether the described smells on (Q30: Musty damp basement smells) was exclusively used for smells coming from basements or it was an inclusive description of musty dampness smells originated from other types of occupational spaces. Noting their inquiry, it was important to record that having a basement floor as part of residential buildings was rare in UAE. However, due to the high RH levels with a mean daily maximum reaching up to 83% (NOAA 2013), experiencing moldy and musty dampness smells was probable. Therefore, to have a relevant measure to the local setting of Dubai environmEye, nose, throat, and residences, (Q30: Musty damp basement smells) was changed to (Q22: Musty/mouldy dampness smells).

v. Some participants inquired about the accurate definition of the utilized 5-points likert scale that utilized (“Never”, “Rarely”, “Sometimes”, "Always", and "Often"). They preferred having an explanation of each point in terms of duration or frequency. Accordingly, the description of the above 5 points was changed to ("Never", "1 – 3 days/year", "1 – 3 days/month", "1 – 3 days/week", "Everyday/ Almost every day"). The description of the above 5 points was adopted and adapted from the 4 – point scale used in EPA BASE questionnaire (EPA 2003) which was ("Never", "1 – 3 days/month", "1 – 3 days/week", "Everyday/ Almost every day"). The pilot 5 – points scale originally adopted from EPA (1991b) was retained due to two reasons. The 1st reason was that participants in EPA (1991b) are asked to report their perceptions for the whole last year while in EPA (2003) they are asked to report perceptions for the last month only. Noting that participation in this study main survey might last for several months over different climatic conditions; it was better to report perceptions for the whole last year not only the last month. The 2nd reason was that the 5 – points scale affords a wider range of options for participants to select from. Hence, an additional point "1 – 3 days/year" was added to EPA's (EPA 2003) 4 – points scale. Thus, the 1st point in the main questionnaire is "Never"; the 2nd is "1 – 3 days/year" instead of "Rarely"; "1 – 3 days/month" instead of "Sometimes"; "1 – 3 days/week" instead of "Always"; and "Everyday/ Almost every day" instead of "Always". The revised 5 – points scale was used in reporting the odors (Q20 – Q28), IEQ comfort (Q29 – Q41); and health symptoms measures (Q42 – Q52) (Appendix D and Appendix E).

vi. Many participants assessed the questionnaire as long one. Participants' behaviors in completing the questionnaire confirmed that. As previously mentioned, one of the least answered questions were (Q15: How many persons in your house are within the following range), (Q39: Other odors), (Q13: Is your kitchen attached), and (Q17: Last year, do you notice any water leaks from the ceiling, floor, walls, or pipes in your house) in which there were 57, 46, 11, and 11 missed items; respectively. When excluding Q15 and Q39; only 52 participants completely answered the four questionnaire sections covering the population, building, IEQ, and health symptoms. That means the fully completed questionnaires was only 43%. This low percentage of completion in addition to participants' remarks highlighted the great need to shorten the questionnaire. Fortunately, it was found that 94, 96, 100 participants completed the whole section of the health; odors; and IEQ section when excluding Q39. That number was sufficient in this pilot study for the purpose of running PCA and reliability tests for the each individual section. However, the questionnaire should be shortened to alleviate the probability of having it completed by participants in the main survey.

vii. During the conduct of the pilot, it was revealed that it is legally not allowed to perform the initially proposed random stratified sampling method. Following a non-probability sampling method suggests the probability of having a sample not representing all nationalities living in UAE. Thus, Q2 is added in the main survey inquiring about participants' nationalities (Appendix D and Appendix E) to inform regarding the sample demographics. Reference to the above modifications; measured population and building parameters in the main survey are shown in Table 3-8 and Table 3-9.

Table 3-8: Population parameters measured in the main questionnaire

| Item | Code | Variable | Data type |
|---|---|---|---|
| 1 | P1 | Gender | Binary |
| 2 | P2 | Being UAE/ GCC National | Binary |
|  | P3 | Being other Arabs/ MENA National | ,, ,, ,, |
|  | P4 | Being Indian Subcontinent National | ,, ,, ,, |
|  | P5 | Being other Asian | ,, ,, ,, |
|  | P6 | Being Other African | ,, ,, ,, |
|  | P7 | Being Europeans, Oceanians, North or South American | ,, ,, ,, |
| 3 | P8 | Age | Ordinal |
| 4 | P9 | Smoking Habits | Binary |
| 5 | P10 | Passive Smoking | Binary |
| 6 | P11 | Asthma | Binary |
|  | P12 | Hay Fever | ,, ,, ,, |
|  | P13 | Eczema | ,, ,, ,, |
|  | P14 | Migraine | ,, ,, ,, |
|  | P15 | Allergy to dust | ,, ,, ,, |
|  | P16 | Allergy to molds | ,, ,, ,, |

Table 3-9: Building parameters measured in the main questionnaire

| Item | Code | Variable | Data type |
|---|---|---|---|
| 7 | B1 | Dubai Sector 1 | Binary |
| | B2 | Dubai Sector 2 | ,, ,, ,, |
| | B3 | Dubai Sector 3 | ,, ,, ,, |
| | B4 | Dubai Sector 4 | ,, ,, ,, |
| | B5 | Dubai Sector 5 | ,, ,, ,, |
| | B6 | Dubai Sector 6 | ,, ,, ,, |
| | B7 | Dubai Sector 7 | ,, ,, ,, |
| | B8 | Dubai Sector 8 | ,, ,, ,, |
| 8 | B9 | House Type | Binary |
| 9 | B10 | No of occupants less than 18 years old | Continuous |
| | B11 | No of occupants (18 – 34) years old | ,, ,, ,, |
| | B12 | No of occupants (35 – 54) years old | ,, ,, ,, |
| | B13 | No of occupants (55 – 74) years old | ,, ,, ,, |
| | B14 | No of occupants 75 years or older | ,, ,, ,, |
| 10 | B15 | Residency duration | Ordinal |
| 11 | B16 | House age | Ordinal |
| 12 | B17 | Separate Kitchen unit | Binary |
| | B18 | Attached open kitchen | ,, ,, ,, |
| | B19 | Attached kitchen with interior walls | ,, ,, ,, |
| 13 | B20 | Central HVAC | Binary |
| | B21 | Split HVAC | ,, ,, ,, |
| | B22 | Window HVAC | ,, ,, ,, |
| 14 | B23 | New carpets | Binary |
| 15 | B24 | New furniture | ,, ,, ,, |
| 16 | B25 | Walls painted | ,, ,, ,, |
| 17 | B26 | New wall arrangement | ,, ,, ,, |
| 18 | B27 | New wall covering | ,, ,, ,, |
| 19 | B28 | Water leakage | ,, ,, ,, |

### 3.3.4.3 Content validity of pilot questionnaire

Content validity is usually undertaken by seven or more experts and it indicates appropriateness of the content to the study purposes and its inclusion of sufficient attributes relevant to the research (Pilot & Hunger 1999; DeVon et al. 2007). As described in Section 3.3.3, the utilized pilot questionnaire Appendix B and Appendix C was adopted and adapted from three standardized questionnaires which were tested and retested for reliability and validity by scholars in this domain (EPA 1991b; EPA 2003; Andersson 1998). The questionnaire was designed to cover the major SHS constructs in the simplest and shortest form as possible. The content of the resultant pilot questionnaire was in the middle between the two standard questionnaires in terms of length and comprehensiveness. However, reference to the participants comments and the number of fully completed questionnaires, it was clear that the questionnaire needed shortening to enhance the potentiality of having higher response rate and completed number of questionnaires. One of two approaches taken to reduce the questionnaire items was to exclude those measure similar variable but written in different forms. Deleting such items carrying the above criteria might not affect the content validity of the questionnaire and might help in shortening the questionnaire. Based on that, the following IEQ items were deleted in the main questionnaire:

- Deleting (Q44: Need to adjust air movement), (Q47: Need to adjust temperature), and (Q50: Need to adjust humidity) (Appendix B & Appendix C). It is assumed that the retained air movement items (Q42: Too much air movement & Q43: Too little air movement), temperature items (Q45: Too hot & Q46: Too cold), and humidity items (Q48: Too much humidity & Q49: Too much dryness) are sufficient to report whether there is a need to adjust the above conditions.

- Excluding the three lighting items (Q52: Little dim), (Q54: Little glare); and (Q55: Need to adjust lighting) (Appendix B & Appendix C) from the main questionnaire. Only lighting items (Q51: Too much dim) and (Q53: Too much glare) was retained. It was assumed that data collected from the two retained lighting measures would be sufficient. That was because participants were asked to report the frequency of experiencing items (Q51: Too much dim) which was simultaneously the opposite of (Q52: Little dim) and (Q54: Little glare); respectively. As shortening the questionnaire was required, excluding Q52 and Q54 might not affect the questionnaire content validity. Also, the reported responses on (Q51: Too much dim) and (Q53: Too much glare) would simultaneously indicate whether the lighting quality was balanced or there was a need to adjust it. Hence, Q55 inquiring about the need to adjust lighting could also be deleted without affecting the content validity of the questionnaire.

Based on the above, thermal measures were reduced to 6 measures instead of the 9 pilot measures while lighting was reduced to 2 measures instead of 5 measures employed in the pilot questionnaire. Table 3-10 shows the final IAQ, Thermal, Lighting, and Noise measures that was utilized in the main survey. Table 3-11 demonstrates a comparison between the revised Thermal, Lighting, and Noise measures against those used by the MM questionnaire (1998) and EPA BASE questionnaire (2003). One of the important conclusions from this comparison is that the content of the revised measures was sufficiently covering the content addressed by EPA BASE and MM questionnaires.

Table 3-10: IAQ, Thermal, Lighting, and Noise items in the main questionnaire

| **Factor** | **Item** | **Code** | **Item description** | **Data type** | **Source** |
|---|---|---|---|---|---|
| IAQ | 58 | A1 | IAQ rating | 4 points scale | (EPA 1991b) |
| | 40 | C1 | Dust and dirt | 5 points scale | (EPA 1991b)<br>(Andersson 1998) |
| | 41 | C2 | Stuffy “bad” air | ,, ,, ,, | |
| Thermal | 42 | C3 | Too much air move- | 5 points scale | (EPA 2003)<br>(EPA 1991b) |
| | 43 | C4 | Too little air move- | ,, ,, ,, | |
| | 45 | C5 | Too hot | ,, ,, ,, | (EPA 2003)<br>(EPA 1991b)<br>(Andersson 1998) |
| | 46 | C6 | Too cold | ,, ,, ,, | (EPA 2003)<br>(EPA 1991b)<br>(Andersson 1998) |
| | 48 | C7 | Too much humidity | ,, ,, ,, | (EPA 2003)<br>(EPA 1991b) |
| | 49 | C8 | Too much dryness | ,, ,, ,, | (EPA 2003)<br>(EPA 1991b)<br>(Andersson 1998) |
| Lighting | 51 | C9 | Too much glare | 5 points scale | (EPA 2003)<br>(EPA 1991b) |
| | 55 | C10 | Too much dim | | (EPA 2003)<br>(EPA 1991b)<br>(Andersson 1998) |
| Noise | 56 | C11 | Too noisy | 5 points scale | (EPA 2003)<br>(EPA 1991b)<br>(Andersson 1998) |
| | 57 | C12 | Too quiet | ,, ,, ,, | (EPA 1991b) |

Table 3-11: A comparison of Thermal, Lighting, and Noise items between this study's main questionnaire against EPA BASE and MM questionnaires

| | **EPA BASE** | | **This study** | | **MM Survey** |
|---|---|---|---|---|---|
| 1 | Too much air movement | 1 | Too much air movement | | |
| 2 | Too little air movement | 2 | Too little air movement | | |
| 3 | Too hot | 3 | Too hot | 1 | Room temperature too high |
| 4 | Too cold | 4 | Too cold | 2 | Room temperature too low |
| | | | | 3 | Varying room temperature |
| 5 | Too much humidity | 5 | Too much dryness | 4 | Draught |
| 6 | Too much dryness | 6 | Too much humidity | | |
| 7 | Rating the lighting | 7 | Too much glare | 5 | Light is dim or causes glare and/or reflections |
| | | 8 | Too much dim | | |
| 8 | Distracting noise | 9 | Too noisy | 6 | Noise |
| | | 10 | Too quiet | | |

The 2nd approach taken by the study to shorten the questionnaire was reducing the number of items measuring the odors (Q21 – Q36) and health symptoms (Q56 – Q114) using PCA method. It is important to note that odors and health symptoms cannot be reduced following the logical procedure applied in the previous IEQ items. However; reference to hypothesized constructs of health symptoms and odors furnished by previous studies, some measured variables might be strongly correlated. For instance, items measuring sore throat, dry throat, and hoarseness might be measures for similar construct which is throat-related symptoms as hypothesized by (EPA 1991b, 2003). As explained by (O'Rourke & Hatcher 2014; Suhr 2005), it would be advantageous to reduce the number of variables in a dataset if responses actually display redundancy. In this case, redundancy means that some of the variables are correlated with each other possibly because they are measuring the same construct. Because of this redundancy, performing PCA is particularly useful in reducing the observed variables into a smaller number of principal components accounting for most of the variance in the observed variables (Beaumont 2012; Chumney 2012; Suhr 2005; Grimm & Yarnold 1995).

Additionally, PCA is most useful when used as a descriptive tool in pilot studies as it contributes to the researcher's understanding of the strengths and weaknesses of the measures (O’Rourke & Hatcher 2014; Beaumont 2012; Chumney 2012; Suhr 2005; Grimm & Yarnold 1995). It is a prevailing statistical method that was utilized by many contemporary researches (O’Rourke & Hatcher 2014; De Winter & Dodou 2014; Parsian & Dunning 2009; Bryman & Cramer 2005). For instance, EPA (1991b) performed PCA to minimize the large number of odor and health symptoms to a manageable number of components. Although hypothetical constructs of both odors and health symptoms were provided by literature, it might be inaccurate to assume that similar correlations exists in Dubai housing. That is why this study opted to conduct PCA on odors and health symptoms variables as follows:

- First, conducting PCA to identify the major components accounting for the most variance of health symptoms and odors items.
- Second, performing PCA for the items included within each defined major component to identify its sub components.

#### 3.3.4.4 PCA of pilot questionnaire

PCA is a variable reduction procedure employed by this study in both the pilot and the main survey to reduce their items to a smaller number of components accounting for the most observed variance. PCA that is similar in many aspects to the factor analysis (FA) which involves both the exploratory factor analysis (EFA) and the confirmatory factor analysis (CFA). Reference to (Beaumont 2012, Albright & Park 2009), a factor in this context is a latent variable, unobservable variable or a construct. A latent variable is a variable that cannot be measured directly but is measured indirectly through several observable or manifest variables i.e. questions/items in a questionnaire. For instance, scores on multiple tests may be observed variables of intelligence that represent the latent or unobserved variable. As explained by (Beaumont 2012; Chumney 2012; Brown 2006; and Brown et al. 1998); the PCA, EFA, and CFA are used to analyze multiple variables for the purposes of data reduction in addition to the scale construction, improvement, and validation. They can help in data restructuring by reducing the number of variables in an approach often called as “data reduction” or “dimension reduction” technique. The basic definition of the term “data reduction” is the process in which the large number of observed variable is reduced to a smaller number that still reflect a large proportion of the information contained in the original dataset.

Many similarities exist between the three methods and particularly between EFA and PCA. EFA and PCA are frequently used in statistical practices in social science (O'Rourke & Hatcher 2014; Parsian & Dunning 2009; Bryman & Cramer 2005), psychological, educational, marketing, and organizational research journals with PCA appearing to be the most popular (De Winter & Dodou 2014). According to reviews in exploratory data analyses use, 40 to 67% of the studies use PCA while 12 to 34% use CFA (De Winter & Dodou, 2014). However, there are significant conceptual differences between the three methods. As explained by (O'Rourke & Hatcher 2014; Chumney 2012; Beaumont 2012; Albright & Park 2009; Suhr 2005), one of the major conceptual differences between the above three methods is the assumption of having or not having an underlying causal structure. EFA assumes that co-variation among the observed variables is due to the presence of one or more latent variables that exert directional influence on these observed variables. These factors are latent in the sense that it is assumed respondents hold specific beliefs that cannot be measured directly. However, these beliefs do influence participants' responses to the items. That is why researchers use EFA when they believe that one or more latent factors exert directional influence on participants' responses. EFA helps the researcher identify the number and nature of such latent factors. In contrast, PCA makes no assumptions about underlying causal structures; it is simply a variable reduction procedure that typically results in a relatively small number of components accounting for or capturing the most variance in a set of observed variables. Simply, PCA is a process that involves groupings of observed variables while the EFA involves grouping of latent constructs.

On the other hand, CFA is a statistical method appropriate for testing whether a theoretical model of relationships is consistent with a given set of data. When performing CFA, it is assumed that the relationships observed between variables exist because they are influenced by a hypothesized underlying construct. CFA enables the testing of hypotheses about a particular structure or relationships between the observed variables and factors/latent variables and between the factors themselves (Chumney 2012; Albright & Park 2009; Suhr 2006; Brown 2006). In determining the appropriate analytical method between the three, it is important to note that this study had no assumption regarding the existence of latent variables that exerted directional influence on observed variables. Subsequently, using EFA to identify the latent factors is not intended. Also, the use of CFA is not appropriate because the study did not intend to test a particular hypothesized structure of the observed and unobserved variables. Hence, PCA was an appropriate analytical method for this study since the study was interested in reducing the number of the questionnaire items by identifying the components accounting for most variation in the dataset. The method is also capable to identify which items make up each componEye, nose, throat, and how strongly they relate to the component. PCA is a useful descriptive tool for pilot studies, particularly at the development stage, since it might help in assessing the strengths and weaknesses of its measures in terms of content validity.

In determining the number of principal components to be retained; the following four criteria are popularly employed (Jolliffe et al. 2016; O’Rourke & Hatcher 2014; Beaumont 2012; Suhr 2006, 2005; Field 2003):

i. Kaiser criterion (Eigenvalue > 1): When applying Kaiser Criterion, each principal component explains at least as much variance as 1 observed variable.
ii. Scree Plot: According to the Scree plot, it is preferred to take the number of factors corresponding to the last Eigenvalue before they start to level off.
iii. Proportion of variance for each component or the cumulative proportion of variance explained: According to Field (2003), there is no general consensus and one should check what is common in his field. It seems reasonable that any decent model should have at least 50% of the variance in the variables explained by the common factors (Parsian & Dunning 2009; Field 2003).
iv. Interpretability which is defined in this context as the conceptual meaning represented by the created principal components. Reference to (Suhr 2005, 2006), interpretability involves having at least 3 observed variables per component, common conceptual meaning, measuring different constructs, and having a rotated factor pattern with simple structure that has no cross loading.

In practice, as explained by (Suhr 2005; Suhr 2006; Field 2003), there is no single best rule to use and a combination of the above criteria is often used. Hence, to create statistically and conceptually meaningful components; a combination of the four criteria is considered when determining the number of retained components. When computing a principal component, each variable is given a weight that is called a variable loads on that component (O’Rourke & Hatcher 2014; Chumney 2012). For example, if the item/variable “Went out of my way to do a favor for a coworker” is given a lot of weight on the “helping others” component; it means that this item “loads” on that component. Reference to (O’Rourke & Hatcher 2014; Suhr 2005; Field 2003; Stevens 2002), it is highly desirable to have a minimum of three and preferably more variables loading on each retained component when the PCA is complete. Reference to (Chumney 2012; Costello & Osbourne 2005; Grimm & Yarnold 1995), researchers often rely on a general rule of thumb that a variable loading on a component should be ≥ 0.32 in order to be retained as an item on the component. According to Hair et al. (1998) guideline for practical significance, a loading of ±0.3 means the item is of minimal significance, ±0.4 indicates it is more important, and ±0.5 indicates the item is significant. On the basis of these tests, items were eliminated from the component pattern matrix when the factor loading was < ±0.5. However, reference to (Chumney 2012; Field 2003; Stevens 2002), these rules of thumb may not be a good practice in all instances because a variable loading coefficient is affected by the sample size. Reference to Steven (2002) Guideline relates between the sample size and statistically acceptable loading. According to Steven (2002), the statistically acceptable loading for 50 participants is 0.72, for 100 participants 0.51, and for 200 – 300 participants 0.29 – 0.38. Notably that the valid cases analysed for the health and odor measures is 94 and 96 cases; respectively. That implies in accepting variable loading > 0.512 as recommended by Steven (2002) and followed by many contemperaneous studies (Suliman & Al Kathairi 2013; Suliman et al. 2010; Parsian & Dunning 2009).

Regarding the 30 items measuring the health symptoms, retaining a number of 6 components was recommended when following Kaiser’s criterion. Whereas, based on the Scree plot, a number of 2 – 6 components were recommended to be retained. Therefore, among a lot of 2 – 6 solutions examined; a four component solution shown in (Table 3-12) was deemed to be the most statistically and conceptually appropriate to the classifications of health symptoms in related studies (EPA 1991b; Andersson 1998; EPA 2003). The retained four components accounted for 64.24 % of the total variance which is acceptable (Parsian & Dunning 2009; Field 2003). Moreover, following the recommendations of (Beaumont 2012; Parsian & Dunning 2009; Field 2005; Kaiser 1974); Bartlett test of Sphericity and KMO MSA were performed to ensure an appropriate sample size was obtained for the pilot study to enable PCA to be undertaken. KMO MSA for the health symptoms solution was 0.852 and the Bartlett test of Sphericity result was highly significant at *p* value < 0.001. According to the above references, the value of this KMO MSA is assessed as great and it indicated that the sample size was adequate to run PCA that might yield distinct and reliable components. However, a number of 6 items were deleted in the final four components which were: (Q84: Hoarseness); (Q92: Chills); (Q98: Feeling depressed); (Q102: Shoulder or neck pain); (Q106: Difficulty in remembering); and (Q108: Dizziness or light-headedness). Eaqch deleted item had either a loading < 0.5 or highly loading > 0.5 in more than one component. Since the sample size used in the health symptoms PCA process was 94 cases; variables with a loading <0.5 is preferred to be deleted (Steven 2002; Suliman & Al Kathairi 2013; Suliman et al. 2010; & Parsian & Dunning 2009). Also, according to (Beaumont 2012; Costello & Osbourne 2005), it is preferred to drop cross loaded items that are highly loading in more than one component particularly when there are other items measuring similar construct that are successfully loaded.

Table 3-12: Loadings of health symptoms on the four components

| | **1** | **2** | **3** | **4** |
|---|---|---|---|---|
| Sore or strained eyes | .755 | | | |
| Dry or itching eyes | .716 | | | |
| Burning eyes | .678 | | | |
| Blurry or double vision | .646 | | | |
| Fatigue or tiredness | .620 | | | |
| Sleepiness or drowsiness | .606 | | | |
| Dry or itchy skin | .474 | | | |
| Runny nose | | .836 | | |
| Stuffy nose | | .810 | | |
| Sneezing | | .796 | | |
| Cough | | .752 | | |
| Fever | | .618 | | |
| Sore throat | | .607 | | |
| Dry throat | | .506 | | |
| Tension or nervousness | | | .832 | |
| Difficulty in concentration | | | .818 | |
| Back pain | | | .787 | |
| Hand or wrist pain | | | .577 | |
| Aching muscles or joints | | | .527 | |
| Nausea | | | | .747 |
| Breath shortness | | | | .690 |
| Wheezing chest | | | | .636 |

| | |
|---|---|
| Chest tightness | .606 |
| Headache | .441 |

However, two items with loading < 0.5 were retained which were (Q56: Headache) and (Q114: Dry/ itchy skin). The 1st reason for retaining those two measures was that their loading was a bit less than 0.5 reaching about 0.474 and 0.441; respectively (Table 3-12). Reference to (Chumney 2012; Costello & Osbourne 2005; Grimm & Yarnold 1995), some researchers rely on a general rule of thumb that a variable loading on a component should be ≥ 0.32 in order to be retained as an item on the component. Moreover, according to (Hair et al. 1998; Field 2003), items with loading ±0.4 are considered as of practical importance. Secondly, the dry/itchy symptom item was the only one measuring the prevalence of skin irritations as identified by both (EPA 1991b; Andersson 1998). Similarly, the item measuring headache was retained because it was one of only two items measuring the general symptoms or non-specific IAQ symptoms as identified by Andersson (1998) or EPA (1991b); respectively. Thus, the two items were kept to allow measuring the two symptoms in the main survey and to assess their importance accordingly. Such an exceptional decision, of retaining items with loading < 0.5; was acceptably taken by other contemporary and scholarly reviewed studies as in (Parsian & Dunning 2009).

Also, the 2nd component included 7 variables of which the first three variables measures runny nose, stuffy nose and sneezing which was considered as nasal symptoms (EPA 1991b; Andersson 1998; Yeatts et al 2012a; & Funk et al. 2014). Cough was also included within this component similar to the PCA results performed by EPA (1991b) in which nasal and cough symptoms were included in one component. Moreover, two throat-related items were also included within this component in addition to fever. According to EPA (1991b; Yeatts et al 2012a; Funk et al. 2014), fever was classified as a flu-like symptom. Reference to the PCA results performed by EPA (1991b); dry throat in addition to sore throat and hoarseness formed one component called throat-related symptoms. Also, one of the classifications of related health symptoms by EPA (1989); dry throat in addition to runny and stuffy nose were identified as one group as mucous membrane symptoms. Hence, strong associations were revealed between included symptoms within this component by this study and others. This component was called “Nasal, throat, cough and fever symptoms” and it accounted for 11.24% of the variance.

As illustrated in Table 3-13, the 1$^{st}$ health symptoms component includes 7 variables of which the first five represented eye and skin related symptoms that could be considered as one cluster. Reference to the questionnaire utilized by (Yeatts et al 2012a; Funk et al. 2014), both eye and skin related symptoms can be identified as allergies/irritations i.e. itchy/watery eyes, dry irritated eyes, itchy skin with rash, and irritated skin without rash. The remaining two variables measuring "Fatigue and tiredness" and "Sleepiness and drowsiness" were dealt with as items measuring fatigue and tiredness by (EPA 1991b). Thus, the 1$^{st}$ component was called "Eye/skin irritations and tiredness symptoms". According to that PCA result, Eye/skin irritations and tiredness symptoms accounted for 41.82% of the variance in the dataset.

Also, the 2$^{nd}$ component included 7 variables of which the first three variables measures runny nose, stuffy nose and sneezing which was considered as nasal symptoms (EPA 1991b; Andersson 1998; Yeatts et al 2012a; & Funk et al. 2014). Cough was also included within this component similar to the PCA results performed by EPA (1991b) in which nasal and cough symptoms were included in one component. Moreover, two throat-related items were also included within this component in addition to fever. According to EPA (1991b; Yeatts et al 2012a; Funk et al. 2014), fever was classified as a flu-like symptom. Reference to the PCA results performed by EPA (1991b); dry throat in addition to sore throat and hoarseness formed one component called throat-related symptoms. Also, one of the classifications of related health symptoms by EPA (1989); dry throat in addition to runny and stuffy nose were identified as one group as mucous membrane symptoms. Hence, strong associations were revealed between included symptoms within this component by this study and others. This component was called "Nasal, throat, cough and fever symptoms" and it accounted for 11.24% of the variance.

Table 3-13: Percentage of variance explained by identified health components

| Component name | Included items | % of Variance |
|---|---|---|

| | | | |
|---|---|---|---|
| 1 | Eye/skin irritations and tiredness | Sore or strained eyes<br>Dry or itching eyes<br>Burning eyes<br>Blurry or double vision<br>Dry or itchy skin<br>Fatigue or tiredness<br>Sleepiness or drowsiness | 41.84% |
| 2 | Nasal, throat, cough and fever symptoms | Runny nose<br>Stuffy nose<br>Sneezing<br>Sore throat<br>Dry throat<br>Cough<br>Fever | 11.24% |
| 3 | Ergonomic and neurological symptoms | Back pain<br>Hand or wrist pain<br>Aching muscles or joints<br>Tension or nervousness<br>Difficulty in concentration | 5.97% |
| 4 | Chest-related and general symptoms | Breath shortness<br>Wheezing chest<br>Chest tightness<br>Nausea<br>Headache | 5.20% |

The 3rd component included five variables. Three of them measures back pain, hand or wrist pain, and aching muscles or joints. These three symptoms were considered as ergonomic symptoms in EPA (1991b). The other two items were tension/ nervousness and difficulty in concentration which were included within the mental and nervous cluster in (EPA1991b). However, in the questionnaire utilized by (Yeatts et al 2012a; Funk et al. 2014), the above two symptoms were identified as neurological symptoms. Hence, this component was identified as the “Ergonomic and neurological symptoms” component. Regarding the 4th component, it was composed of 5 variables. Three of them were considered as chest-related symptoms which were breath shortness, wheezing chest, and chest tightness (EPA 1991b) while in the questionnaire utilized by (Yeatts et al 2012a; Funk et al. 2014) they were identified as respiratory symptoms. The other two variables measuring headache and nausea were considered as general symptoms by (Andersson 1998). Headache and nausea were considered as one cluster based on PCA results performed by EPA (1991b). Thus, the 4th component was called as “Chest related and general symptoms”.

After identifying the principal components of the health symptoms, the study intended to identify the sub scales within each component. For instance, which of the identified items of the eye/skin irritations and tiredness component were more related? To identify that, PCA was performed on the items included within each component. Similar to EPA (1991b), the resultant components of this step was referred to as clusters so as not to be confused with the major components identified in Table 3-13. Each cluster used as an item or a measure in the main questionnaire. Table 3-14 shows the PCA results of the "Eye/skin irritations and tiredness symptoms" component. All items were highly loaded above 0.7 indicating that they were practically and statistically significant measures (Stevens 2002; Field 2003; Parsian & Dunning 2009). KMO MSA was 0. 859 which was a great value and the Bartlett test of Sphericity result was highly significant at *p* value < 0.001. The high variables loading > 0.5 and the KMO MSA results indicated that the sample size was adequate to run PCA and that it might yield distinct and reliable clusters (Beaumont 2012; Parsian & Dunning 2009; Field 2005; Steven 2002; Kaiser 1974). Three clusters were identified which were: (i) eye-related symptoms accounted for 60.64% and included sore/strained eyes, dry/itching eyes, burning eyes, and blurry double vision; (ii) tiredness symptoms accounted for 12.65% and included sleepiness or drowsiness in addition to fatigue or tiredness; and (iii) dry-itchy skin that accounted for 8.13% of the variation.

Table 3-14: PCA for the Eye, skin irritations and tiredness component

| | **1** | **2** | **3** |
|---|---|---|---|
| Sore or strained eyes | .857 | | |
| Burning eyes | .848 | | |
| Dry itching eyes | .821 | | |
| Blurry double vision | .706 | | |
| Sleepiness or drowsiness | | .839 | |
| Fatigue or tiredness | | .778 | |
| Dry or itchy skin | | | .890 |

The obtained PCA result for "Nasal, throat, cough, and fever symptoms" component is demonstrated in Table 3-15. All items were highly loaded above 0.7 indicating that they were significant measures (Stevens 2002; Field 2003; Parsian & Dunning 2009). Moreover, KMO MSA was 0. 862 which is a great value and the

Bartlett test of Sphericity result was highly significant at *p* value < 0.001. The high variables loading > 0.5 and KMO MSA results indicate that the sample size was adequate to run PCA and that it might yield distinct and reliable clusters (Beaumont 2012; Parsian & Dunning 2009; Field 2005; Steven 2002; Kaiser 1974). The identified four clusters within the above component were: (i) nasal symptoms accounted for 62.52% of the variance and included sneezing, stuffy nose, and runny nose; (ii) Throat-related symptoms accounted for 11.33% and included dry and sore throat; (iii) fever that accounted for 9.50% of the variation; and (iv) cough that accounted for 5.40% of the variation.

Table 3-15: PCA results for the “Nasal, throat, cough and fever symptoms” component

| | **1** | **2** | **3** | **4** |
|---|---|---|---|---|
| Sneezing | .892 | | | |
| Stuffy nose | .762 | | | |
| Runny nose | .700 | | | |
| Dry throat | | .878 | | |
| Sore throat | | .832 | | |
| Fever | | | .926 | |
| Cough | | | | .853 |

The obtained PCA results for the “Neurological and ergonomic symptoms” component is demonstrated in Table 3-16. All items were highly loaded above 0.65 indicating that they were significant measures (Stevens 2002; Field 2003; Parsian & Dunning 2009). Moreover, KMO MSA was 0. 810 which was a great value and the Bartlett test of Sphericity result was highly significant at *p* value < 0.001. The high variables loading > 0.5 and KMO MSA results indicated that the sample size was adequate to run PCA and that it might yield distinct and reliable clusters (Beaumont 2012; Parsian & Dunning 2009; Field 2005; Steven 2002; Kaiser 1974). As shown in Table 3-16, two main clusters were identified within this component: (i) neurological symptoms accounted for 67.11% and included difficulty in concentration in addition tension and/or nervousness; and (ii) Ergonomic symptoms accounted for 13.76% and included aching muscles and joints, back pain, and hand/wrist pain.

Table 3-16: PCA results for the “Neurological and ergonomic symptoms” component

| | **1** | **2** |
|---|---|---|

| | | |
|---|---|---|
| Difficulty in concentration | .918 | |
| Tension or nervous | .858 | |
| Aching muscles or joints | | .914 |
| Back pain | | .713 |
| Hand or wrist pain | | .656 |

The obtained PCA results for the “Chest related and general symptoms” component is demonstrated in Table 3-17. All items were highly loaded above 0.7 indicating that they are significant measures (Stevens 2002; Field 2003; Parsian & Dunning 2009). Moreover, KMO MSA was 0. 717 which was a good value and the Bartlett test of Sphericity result was highly significant at *p* value < 0.001. The high variables loading > 0.5 and KMO MSA results indicated that the sample size was adequate to run PCA and that might yield distinct and reliable clusters (Beaumont 2012; Parsian & Dunning 2009; Field 2005; Steven 2002; Kaiser 1974). As shown in Table 3-17, two main clusters were identified within this component: (i) chest-related symptoms accounted for 52.9% and included breathing shortness, chest tightness, and wheezing in chest; (ii) general symptoms that included headache and nausea accounted for 21.06% of the variation.

Table 3-17: PCA results for the “Chest related and general symptoms” component

| | **1** | **2** |
|---|---|---|
| Breath shortness | .880 | |
| Chest tightness | .792 | |
| Wheezing chest | .786 | |
| Headache | | .939 |
| Nausea | | .709 |

Thus, based on the above PCA results, 11 clusters were identified.

Table 3-18 illustrates those clusters in comparison with EPA’s clusters. Resulting clusters were almost similar except in the following:

- Dizziness or light-headedness was considered as a separate cluster by EPA (1991b) but in this study it was dropped because of its being poorly loaded.

- Chills was included with fever in one cluster by PEA (1991b), but in this study it was dropped because of its being poorly loaded.
- Nasal and cough symptoms were included in one cluster by EPA (1991b) but in this study each one form a separate cluster.

Table 3-18: Identified health clusters by this pilot study compared with EPA's (1991b)

|  | **Pilot study** |
|---|---|
| 1 | Eye-related symptoms |
| 2 | Tiredness symptoms |
| 3 | Dry itchy skin |
| 4 | Ergonomic symptoms |
| 5 | Chest-related symptoms |
| 6 | Throat-related symptoms |
| 7 | Headache and nausea |
| 8 | Neurological symptoms |
| 9 | Fever |
| 10 | Nasal symptoms |
| 11 | Cough |

|  | **EPA 1991b** |
|---|---|
| 1 | Eye-related symptoms |
| 2 | Tiredness symptoms |
| 3 | Dry itchy skin |
| 4 | Ergonomic symptoms |
| 5 | Chest-related symptoms |
| 6 | Throat-related symptoms |
| 7 | Headache and nausea |
| 8 | Mental, nervous, & psychological symptoms |
| 9 | Dizziness or light-headedness |
| 10 | Fever and chills |
| 11 | Nasal and cough symptoms |

Based on the attained results, the identified clusters was used as measures in the main survey as demonstrated in Table 3-19. As shown in Appendix D, all health items (Q42 - Q52) are preceded by the following inquiry "During last year, how often have you or any of your family members suffered from the following symptoms?". Furthermore, a comparison between items measuring health symptoms by this study's main questionnaire with both EPA BASE questionnaire (EPA 2003) and the MM questionnaire (Andersson 1998) is illustrated in Table 3-20. One of the important conclusions that can be derived from this comparison is that the utilized content of the two other standardized questionnaires was sufficiently covered by the health symptoms items in this study main questionnaire.

Table 3-19: Health symptoms parameters in the main questionnaire

|  | **Item description** |
|---|---|
| **Q42** | Headache or nausea |
| **Q43** | Nasal symptoms i.e. Runny, stuffy nose, or sneezing |
| **Q44** | Chest-related symptoms i.e. Breath shortness, wheezing chest, or chest tightness |
| **Q45** | Cough |
| **Q46** | Eye-related symptoms i.e. Sore, itching, tearing, burning eyes, or blurry vision |
| **Q47** | Throat-related symptoms i.e. Sore or dry throat |

| | |
|---|---|
| **Q48** | Tiredness symptoms i.e. Unusual fatigue, tiredness, sleepiness, or drowsiness |
| **Q49** | Fever |
| **Q50** | Ergonomic symptoms i.e. Back, hand, wrist, muscles, or joints pain |
| **Q51** | Neurological symptoms i.e. Tension, nervousness, or difficulty in concentration |
| **Q52** | Dry itchy skin |

Table 3-20: Items measuring health symptoms by the main questionnaire compared with the EPA BASE and MM questionnaires

| | **EPA BASE questionnaire** | | **This study main questionnaire** | | **MM questionnaire** |
|---|---|---|---|---|---|
| 1 | Dry, itching, or irritated eyes | 1 | Eye-related symptoms i.e. Sore, strained, dry, itching, tearing, burning eyes, blurry … | 1 | Itching, burning, or irritated eyes |
| 2 | Tired or strained eyes | | | | |
| 3 | Stuffy or runny nose, or sinus congestion | 2 | Nasal symptoms i.e. Stuffy, runny nose, sinus congestion, or sneezing. | 2 | Irritated, stuffy, or runny nose |
| 4 | Sneezing | | | | |
| 5 | Sore or dry throat | 3 | Throat-related symptoms i.e. sore or dry throat | 3 | Hoarse, dry throat |
| 6 | Cough | 4 | Cough | 4 | Cough |
| 7 | Unusual tiredness, fatigue, ` | 5 | Tiredness symptoms i.e. fatigue, … | 5 | Fatigue |
| 8 | Headache | 6 | Headache or nausea | 6 | Headache |
| | | | | 7 | Feeling heavy-headed |
| 9 | Nausea or upset stomach | | | 8 | Nausea/dizziness |
| 10 | Difficulty remembering or concentrating | 7 | Neurological symptoms i.e. nervousness, tension, concentration problems, … | 9 | Difficulty in concentration |
| 11 | Tension, irritability, or nervousness | | | | |
| 18 | Feeling depressed | | | | |
| 12 | Dry, or itchy skin | 8 | Dry, or itchy skin | 10 | Dry, or flushed facial skin |
| | | | | 11 | Scaling/itchy scalp or ears |
| | | | | 12 | Hands dry, itchy, red skin |
| 13 | Shortness of breath | 9 | Chest-related symptoms i.e. breath shortness, chest tightness, or wheezing | | |
| 14 | Chest tightness | | | | |
| 15 | Wheezing | | | | |
| 16 | Pain or stiffness in back, shoulders, or neck | 10 | Ergonomic symptoms i.e. Back, hand, wrist, muscles, or joints pain | | |
| 17 | Numbness in hands or wrists | | | | |
| | | 11 | Fever | | |

Similar reduction procedure as that performed on the health symptoms variables was applied to lessen the number of odor items. On the 1st PCA run for the 15 odor measures, the Scree plot criterion suggested retaining 2 – 6 components while Kaiser criterion (Eigen value > 1) suggested retaining 5 components. One of the meaningful configurations was attained by 3 components which was a medium number of components between those suggested by the above criteria (Table 3-21). Total variance explained by the three components was 53.8% which was reasonable according to (Parsian & Dunning 2009; Field 2005; Field 2003). KMO MSA was 0.715 which was a good value and the Bartlett test of Sphericity result was highly significant at *p* value < 0.001. KMO MSA results indicated that the sample size was adequate to run PCA and that it might yield distinct and reliable clusters (Beaumont 2012; Parsian & Dunning 2009; Field 2005; Kaiser 1974). Since the valid cases to perform PCA for the odor measures was 96 cases; variables with loading > 0.512 were retained as recommended by Steven (2002) in case of having 100 observations. That recommendation was followed by many contemperaneous studies such as (Suliman & Al Kathairi 2013; Suliman et al. 2010; Parsian & Dunning 2009).

Table 3-21: PCA of odor measures

| | **1** | **2** | **3** |
|---|---|---|---|
| Odors from new carpet | .870 | | |
| Odors from new curtain | .842 | | |
| Smoke from incense | .536 | | |
| Body odors | .550 | | |
| Musty damp basement | | .716 | |
| Odors from chemicals | | .685 | |
| Odors from paint | | .660 | |
| Odors from pesticides | | .628 | |
| Odors from diesel | | .490 | |
| Tobacco smoke | | .327 | |
| Other foods odors | | | .812 |
| Fishy smells | | | .761 |
| Odors from cosmetics | | | .722 |

Following that recommendation, two items < 0.5 were deleted: (i) odors from equipmEye, nose, throat, and (ii) odors from cleaning product. Two reasons were behind their exclusion. First, their poor loading indicated that they were practically and statistically insignificant measures (Beaumont 2012; Chumney 2012; Field 2003; Stevens 2002; Hair et al. 1998). The second reason had relation with the nature of the measured variable. Odor from equipment was more related to office building than houses. It is important to note that the original EPA questionnaire was oriented to measure IAQ in work environments (EPA 1991b). The cleaning products item was also deleted due to its poor loading and because other items measuring the same construct "Chemicals odors" were successfully loaded above 0.5. However, two items loaded < 0.5 but were retained which were: (i) Diesel exhaust odors, and (ii) Tobacco smoke. The 1st reason to retain them was that they were loaded > 0.3 which, although poor, was an acceptable loading for an item of minimal practical significance (Chumney 2012; Costello & Osbourne 2005; Grimm & Yarnold 1995). Secondly, the two items represented types of odors of different nature that were not measured by other variables. That is why they were kept to be reassessed in the main survey.

As shown in Table 3-22, the 1st component included 3 variables which were: (i) Odors from new carpet, (ii) Odors from new curtain, and (iii) Smoke from incense. Thus, this component was called "Carpet, drapes and incense odors" and it accounted for 28.4% of the variance in the dataset. The 2nd component included 6 variables which were: (i) Odors from chemicals, (ii) Odors from paint, (iii) Odors from pesticides, (iv) Odors from diesel, (v) Tobacco smoke, and (vi) Mouldy damp basement odors. This component was called "Chemicals, diesel, tobacco, and mouldy odors" and it accounted for 14.55% of the variance in the dataset. The 3rd component includes 4 variables which were: (i) Fishy smells, (ii) Other foods smells, (iii) Cosmetics odors, and (iv) Body odors. This component was called "Food, body and cosmetics odors" and it accounted for 10.9% of the variance in the dataset.

Similar to the applied analytical procedure on the health symptoms, the sub scales within each major odor component were identified by performing PCA on the items included within each component. Similar to EPA (1991b), the resultant components of this PCA results was referred to as clusters so as not to be confused with the major components identified in Table 3-22. Each cluster formed an item or a measure that was used in the main questionnaire. Table 3-23 illustrated the PCA results of the "Carpet, drapes, and incense odors" component. All items were highly loaded above 0.7 indicating that they were significant measures (Stevens 2002; Field 2003; Parsian & Dunning 2009). Moreover, KMO MSA was 0. 572 which was an acceptable value and the Bartlett test of Sphericity result was highly significant at *p* value < 0.001. The high variables loading > 0.5 and KMO MSA results indicated that the sample size was adequate to run PCA and that it might yield distinct and reliable clusters (Beaumont 2012; Parsian & Dunning 2009; Field 2005; Steven 2002; Kaiser 1974). Two main clusters were identified: (i) carpet and drapes cluster that accounted for 49.7% and included odors from new curtains and new carpets; and (ii) smoke from incense and accounted for 28.7% of the variation. Both clusters accounted for 78.37% of variance in this data set.

Table 3-22: Percentage of variance explained by the identified odor components

| | **Component name** | **Included items** | **Variance** |
|---|---|---|---|
| 1. | Carpet, drapes, and incense odors | Odors from new carpet<br>Odors from new curtain<br>Smoke from incense | 28.391% |
| 2. | Chemicals, diesel, tobacco, and mouldy odors | Odors from chemicals<br>Odors from paint<br>Odors from pesticides<br>Odors from diesel<br>Tobacco smoke<br>Musty damp basement smells | 14.551% |
| 3. | Food, body and cosmetics odors | Fishy smells<br>Other foods odors<br>Cosmetics odors<br>Body odors | 10.854% |

Table 3-23: PCA for the "Carpet, drapes, and incense odors" component

| | **1** | **2** |
|---|---|---|
| New curtain | .870 | |
| New carpet | .740 | |
| Smoke from incense | | .974 |

Table 3-24 shows the clusters identified within the “Chemicals, diesel, tobacco, and mouldy odors” component. All items were highly loaded above 0.7 indicating that they were significant measures (Stevens 2002; Field 2003; Parsian & Dunning 2009). Moreover, KMO MSA was 0. 767 which was a great value and the Bartlett test of Sphericity result was highly significant at *p* value < 0.001. The high variables loading > 0.5 and KMO MSA results indicated that the sample size was adequate to run PCA and that it might yield distinct and reliable clusters (Beaumont 2012; Parsian & Dunning 2009; Field 2005; Steven 2002; Kaiser 1974). One of the meaningful grouping of this component items includes five clusters which were: (i) Two items measuring odors from pesticides and chemicals like glue, adhesives…etc that accounted for 41.99% of the variation; (ii) Odors from paint that accounts for 17.51%; (iii) Musty damp basement smells that accounted for 12.31% of the variation; (iv) Odors from diesel exhaust that accounted for 11.20% of the variation; and (v) Odors tobacco smoke that accounted for only 9.29% of the variation. The five clusters accounted for 92.29% of variance in this data set.

Table 3-24: PCA for Chemicals, diesel, tobacco, and mouldy odors component

| | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| Odors from chemicals | .850 | | | | |
| Odors from pesticides | .741 | | | | |
| Odors from paint | | .913 | | | |
| Musty damp basement | | | .926 | | |
| Odors from diesel | | | | .955 | |
| Tobacco smoke | | | | | .995 |

Table 3-25 shows the clusters identified within the “Food, body and cosmetics odors” component. All items were highly loaded above 0.7 indicating that they were significant measures (Stevens 2002; Field 2003; Parsian & Dunning 2009). Moreover, KMO MSA was 0. 697 which was an acceptable and the Bartlett test of Sphericity result was highly significant at *p* value < 0.001. The high variables loading > 0.5 and KMO MSA results indicated that the sample size was adequate to run PCA and that it might yield distinct and reliable clusters (Beaumont 2012; Parsian & Dunning 2009; Field 2005; Steven 2002; Kaiser 1974). Two main clusters were identified: (i) Food odors that includes two items measuring the existence of fishy smells and other food odors and accounted for the most variation (52.94%); (ii) Body and cosmetics odors cluster that included two items measuring the existence of odors from body and cosmetics and accounted for 20.00% of the variation. Both clusters accounted for 72.94% of variance in this data set.

Table 3-25: PCA for “Food, body and cosmetics odors” component

| | **1** | **2** |
|---|---|---|
| Fishy smells | .891 | |
| Other foods odors | .803 | |
| Body odors | | .863 |
| Odors from cosmetics | | .722 |

Thus, based on the above PCA results, a number of 9 clusters were identified. Table 3-26 illustrates those clusters in comparison with EPA’s clusters. The first three clusters were similar in both: (i) Carpet and drapes; (ii) Tobacco smoke; and (iii) Diesel exhaust. The differences in identified clusters were: (i) All food smells loaded together; (ii) Paint odors did not load in the same cluster that included other chemical odors as in EPA’s cluster of chemicals odors that included cleaning products, paint, pesticides, glues and adhesives; (iii) One more cluster that included incense smoke which was not measured in EPA (1991b). One of the important conclusions that can be derived from this comparison is that the content of the main questionnaire was sufficiently covering that addressed by EPA. Moreover, it was measuring an additional variable “Incense smoke” which was considered as potential IAQ hazard in local environments by recent studies as discussed in Section 2.6. Based on the attained results, the identified clusters was used as measures in the main questionnaire (Table 3-27). Instead of the 15 initial odor items of the pilot questionnaire, a reduction of 6 items was achieved. As shown in Appendix D, all odor items (Q20 – Q28) were preceded by the following question “During last year, how often have you or any of your family members experience one of the following at your house?”.

Table 3-26: A comparison between this study and EPA's (1991b) odors clusters

| | **This study's main questionnaire** | | **EPA questionnaire** |
|---|---|---|---|
| 1 | Carpet and drapes odors | 1 | Carpet and drapes odors |
| 2 | Tobacco smoke | 2 | Tobacco smoke |
| 3 | Diesel exhaust | 3 | Diesel exhaust |
| 4 | Body and cosmetics odors | 4 | Body, cosmetics, and other food smells |
| 5 | Musty damp basement smells | 5 | Musty damp basemEye, nose, throat, and fishy smells |
| 6 | Fishy and other food smells | 6 | Chemical odors |
| 7 | Paint odors | | |
| 8 | Other chemical odors | | |
| 9 | Incense smoke | | |

Table 3-27: Odors parameters in the main questionnaire

| | **Item description** |
|---|---|
| **Q20** | Incense smoke |
| **Q21** | Odors from new carpet, curtains or drapes |
| **Q22** | Musty/Mouldy dampness odors |
| **Q23** | Fishy or other food smells |
| **Q24** | Body or cosmetics odors i.e. perfumes, after shave, … etc. |
| **Q25** | Odors from paint |
| **Q26** | Odors from other chemicals i.e. pesticides, adhesives, cleansers ... etc. |
| **Q27** | Tobacco smoke |
| **Q28** | Odors from Diesel or engine exhaust |

## 3.4 Main survey

This study main survey was a cross-sectional one in which data was collected from individuals once at a particular time (Mann 2012). The cross-sectional design was adopted in the survey aiming to report IAQ conditions and SHS prevalence in Dubai households. It is a popularly used design and sufficient one for characterizing these conditions (Hellgren et al. 2011; Yeatts et al. 2012a, 2012b; Ghosh et al. 2013; Mongkolsawat et al. 2014; Dorizas et al. 2015). Following sections provided detailed description of this cross-sectional survey sample size, sampling strategy, questionnaire design, in addition to the analytical approach and procedures.

### 3.4.1 Main survey sample size

Regarding the sample size of the cross-sectional survey, Cohen et al. (2011) stated that a 384 sample size is required for random sampling to attain 95% confidence level at 5% CI for a population ≥1,000,000. According to (McCormack & Hill 1997), the rule of thumb of having adequate sample size is 500 and that rule was based on past research experiences. However, both (Cohen et al. 2011; McCormack & Hill 1997) explained that survey design affects required sample and that another way of calculating the required sample size depends on the population subgroups in which the study is interested. That is because data of those groups will be analysed individually and compared with each other and expected to yield representative and reliable results. They declared that each major subgroup requires ≥ 100 and each minor subgroup requires 20 – 50 cases. The required sample size is also affected by the proposed analytical procedure. Regarding this study, the analytical procedure involved performing PCA and multiple linear regression (MLR) tests. Reference to (Bujang et al. 2017; Knofczynski & Mundfrom 2008), one of the guidelines suggested by (Pedhazur & Schmelkin 1991) requires 30 observations for each predictor and another suggested by (Miller & Kunce 1973) requires 10 cases per each predictor. According to Bujang et al. (2017) recommendations, a minimum required sample size for conducting MLR is 300 to attain approximately close estimations to the parameters of the population.

Concerning the major and minor subgroups of this study; and as discussed in Chapter 2, many studies correlated poor IEQ with ventilation problems. That's why the study particularly focused in investigating the impact of the commonly utilized HVAC systems on IEQ and SHS prevalence as part of its objectives (Section 1.4). Therefore, this survey design targeted houses of three major subgroups defined according to the applied HVAC systems which were: central, split, and window HVAC systems (Table 3-28). According to Ali (2014), the three HVAC systems are the most commonly employed HVAC systems in UAE houses. Also, building age was correlated by some researches as an important factor affecting both IEQ and SHS conditions. For instance, Zamani et al. (2013) assessed SBS prevalence among 170 workers in an old and new Malaysian office building. The age of the old building was (< 15 years) while the new one was (> 4 years). 85 questionnaires were performed in each building in addition to field measurements for AERs, T, RH, $CO_2$, CO, TVOC, UFP, $PM_{10}$, and $PM_{2.5}$. Results demonstrated significant associations between the old building and all contaminants except UFP which was significantly correlated with the new one. However, no significant associations were found between AERs and SBS in both buildings. Takigawa et al. (2012) examined whether indoor chemicals represented potential environmental risk factors on SHS in new houses (< 6 years) on 6 Japanese cities. Questionnaires in addition to RH, T, 13 types of aldehydes, and 29 types of VOCs measurements were performed on 260 households in 2004 and 2005. Reported SHS cases were strongly correlated, by both questionnaires and environmental monitoring, with the aliphatic hydrocarbons and aldehydes levels in new buildings. That result was in accordance with (WHO 1986) estimation that about 30% of new and refurbished constructions encompassed excessive complaints correlated with IAQ. Also, Yang et al. (2009) investigated IAQ conditions according to building age in 55 Korean naturally-ventilated schools. Indoor and outdoor CO, $CO_2$, $PM_{10}$, Total microbial count (TMC), TVOCs, and HCHO were measured from a laboratory, classroom, and a computer classroom in each school. The 55 schools were selected from six areas and were divided into four groups: (≤ 1 year), (1 – 3 years), (3 – 5 years), and (10+ years). Measurements were taken for 24 hours during winter, summer, and autumn. Results revealed that chemical emissions from the building and furniture in addition to insufficient AERs were the reasons behind indoor air contamination. The I/O of HCHO during autumn was 6.32 and indoor

HCHO in schools of ( ≤ 1 year) was significantly higher than Korean IAQ standards reaching a mean of 0.16 ppm. For enhancing the IAQ of schools, the study recommended increasing the AERs by utilizing HVAC in addition to using building low-emissions materials and furniture.

Therefore, in order to measure the impact of building age on IAQ and SHS, the study covered four minor subgroups of houses: (1 – 3 years), (4 – 6 years), (7 – 10 years), and (10+ years) (Table 3-28). Notably that the classification criteria for the above groups was not only based on the building age but also on the applicable Dubai building regulations at the time of construction described in Section 2.6. Based on that, the (1 – 3 years) households represented those following the mandated IEQ requirements by Dubai Green Building Regulations and Specifications since 2014. While the (4 – 6 years) represented houses built during the voluntary period that started in 2011. The other two groups represented the households prior the inauguration of the Green Building Regulations and Specifications. Thus, the survey design will have three technical major subgroups (central, split and window HVAC systems) and four temporal/historical minor subgroups (building age of 1-3, 4-6, 7-10 and 10+ years) (Table 3-28). The calculation of the required sample size for this study was based on its major and minor subgroups as explained by (Cohen et al. 2011; McCormack & Hill 1997). Accordingly, about 300 cases were needed for major subgroups and about (80 – 200) for minor subgroups. Based on that, a sample size of (380 – 500) cases was expected to be sufficient. To reduce the sampling error (Creswell 2014), the study distributed 770 questionnaires of which 543 cases were valid to be used for further statistical analysis. As per calculated range of sample size, the attained 543 valid cases were considered as sufficient.

Table 3-28: Survey major subgroups (HVAC Systems on Top) and minor subgroups (Building age on LHS)

| | **Central HVAC** | **Split HVAC** | **Window HVAC** |
|---|---|---|---|
| **1 – 3 years** | Group (1) | Group (5) | Group (9) |
| **4 – 6 years** | Group (2) | Group (6) | Group (10) |
| **7 – 10 years** | Group (3) | Group (7) | Group (11) |
| **10+ years** | Group (4) | Group (8) | Group (12) |

### 3.4.2 Main survey sampling strategy

This study's survey was a cross-sectional one distributed for 770 residents in Dubai. As discussed in Section 2.6, different building regulations related to IAQ are applied at individual UAE emirates. Due to the wide dispersion of UAE population in its seven emirates, it was unfeasible to perform this study in each of the seven emirates individually. That is why this study was conducted in Dubai emirate only. Survey sampling strategy followed a non-probability sampling method in which the questionnaires were distributed via the internet or through personal communications. Notably that non-probability sampling was one of the limitations of this study because the sample was not randomly selected and allowed participation for only those who have convenient access to participate i.e. internet access or having social relation with the researcher. According to (Cresswell 2014; Cohen et al. 2011; Dillman 2009; Alreck & Settle 2004), probability sampling strategies has better potentiality than non-probability ones in yielding a representative sample and generalizable results. The known population size, sampling frame, sample size, and response rate are essential in calculating the sampling error and the approximate accuracy of results (Cresswell 2014). The concerns regarding the sample representativeness of non-probability strategies threatens the external validity since the sample describes a specific sector that has convenient access or interest (Cohen et al 2011). Moreover, the sampling error in a non-probability design could not be estimated because of the unknown population size, sampling frame and response rate (Dillman 2009).

However, adopting random sampling which is the most rigorous probability design was not feasible in this research due to the: (i) difficulty of compiling a list of all UAE residents of whom 89% are mobile expatriates (Government .ae 2019; Snoj 2015), and (ii) lack of a fixed contact method for each household i.e. mail, phone numbers, or emails. It is also important to highlight that the study initially proposed a multi-stage cluster and stratified random sampling method as an appropriate one demonstrated in more details in Appendix W. That sampling strategy involves listing all Dubai regions, randomly selecting 12 of them following the explained criteria. Then households of the selected regions were proposed to be listed from which the 600 participants are proposed to be selected following the described stratified random sampling method. Although less rigorous than random sampling, performing such a probability sampling method affords higher potentiality of attaining a representative sample and generalizable results compared with non-probability sampling. However, as informed by Dubai Statistics Center (DSC) (DSC 2017a), conducting a survey that involves random visits to Dubai households by individuals is prohibited by law for safety, security, and privacy reasons.

Based on the above, distributing the questionnaires via the internet or personal communication was the only feasible way to report residents' perceptions regarding IEQ and SHS prevalence in Dubai residential buildings. Although the growing popularity of online surveys recently, their low response rate has been concerning. According to (Saleh & Bista 2017), the estimated response rate for online surveys is 11% less than other survey methods. Reference to (Linderman 2018), response rate for face to face surveys is the best with an average 56% response rate while the average response rate for online surveys 29%. One of the suggested methods to boost a survey response rate is to perform mixed methods approach (Saleh & Bista 2017). That is why the study adopted a mixed methods approach in collecting questionnaires combining between both face to face and online surveys.

### 3.4.3 Statistical analysis procedure of the main survey

To fulfill the aims of this study, a multivariate statistical analysis of multiple outcomes was performed. Following were the analytical methods concurrently set to achieve the described objectives in Section 1.4:

1. Descriptive statistics were provided to report IEQ conditions and SHS symptoms in Dubai housing.
2. PCA was performed to examine the interrelationships among self-reported IAQ measures, other IEQ comfort measures, odors measures, and self-reported SHS symptoms.
3. MLR models were employed to predict the influence of:
    a) Population and building variables on health symptoms components. The significantly identified population and building variables were further used in adjusted MLR models to predict the influence of:
        i. Self-reported IEQ components on health symptoms components.
        ii. Self-reported IEQ variables on health symptoms components.
    b) Predict the influence of population and building variables on IEQ components. The significantly identified population and building variables on IAQ component was further used in adjusted MLR models to predict the influence of:
        i. Other self-reported IEQ components on self-reported IAQ component.
        ii. Other self-reported IEQ variables on self-reported IAQ components.

The Statistical Package for the Social Sciences (SPSS Statistics 23) software was used to statistically analyze the data. Figure 3-2 illustrates the statistical analytical procedure followed in analyzing this study's main survey data. It is important to note that it was adopted from Model C in (EPA 1991b) study that had similar analytical objectives as this one in terms of investigating the associations between building, population and IEQ parameters with health symptoms. Following is the description of this study analytical procedure:

1. Data reliability was tested, initially and after performing PCA, using Cronbach alpha test.
2. Normality of data distribution was tested using Kolomogrov-Smirnov test.
3. Significantly correlated IEQ and SHS variables were identified by conducting PCA.
4. Significantly associated confounding variables with SHS symptoms and IEQ components was identified by developing the following stepwise regression models:
    i. Population parameters were used as predictors (IVs) to predict the health symptoms and IEQ components.
    ii. Building parameters were used as predictors (IVs) to predict the health symptoms and IEQ components.
5. Performing the following MLR tests:
    i. IEQ components were used in MLR models to predict the health symptoms components. Then, IEQ components adjusted for the pertinent confounders identified in steps (4.i) and (4.ii) were used in MLR models to predict the health symptoms components.
    ii. Other IEQ components, not including IAQ, were used in MLR models to predict the IAQ component. Then, other IEQ comfort components adjusted for the pertinent confounders identified in steps (4.i) and (4.ii) were used in MLR models to predict the IAQ component.

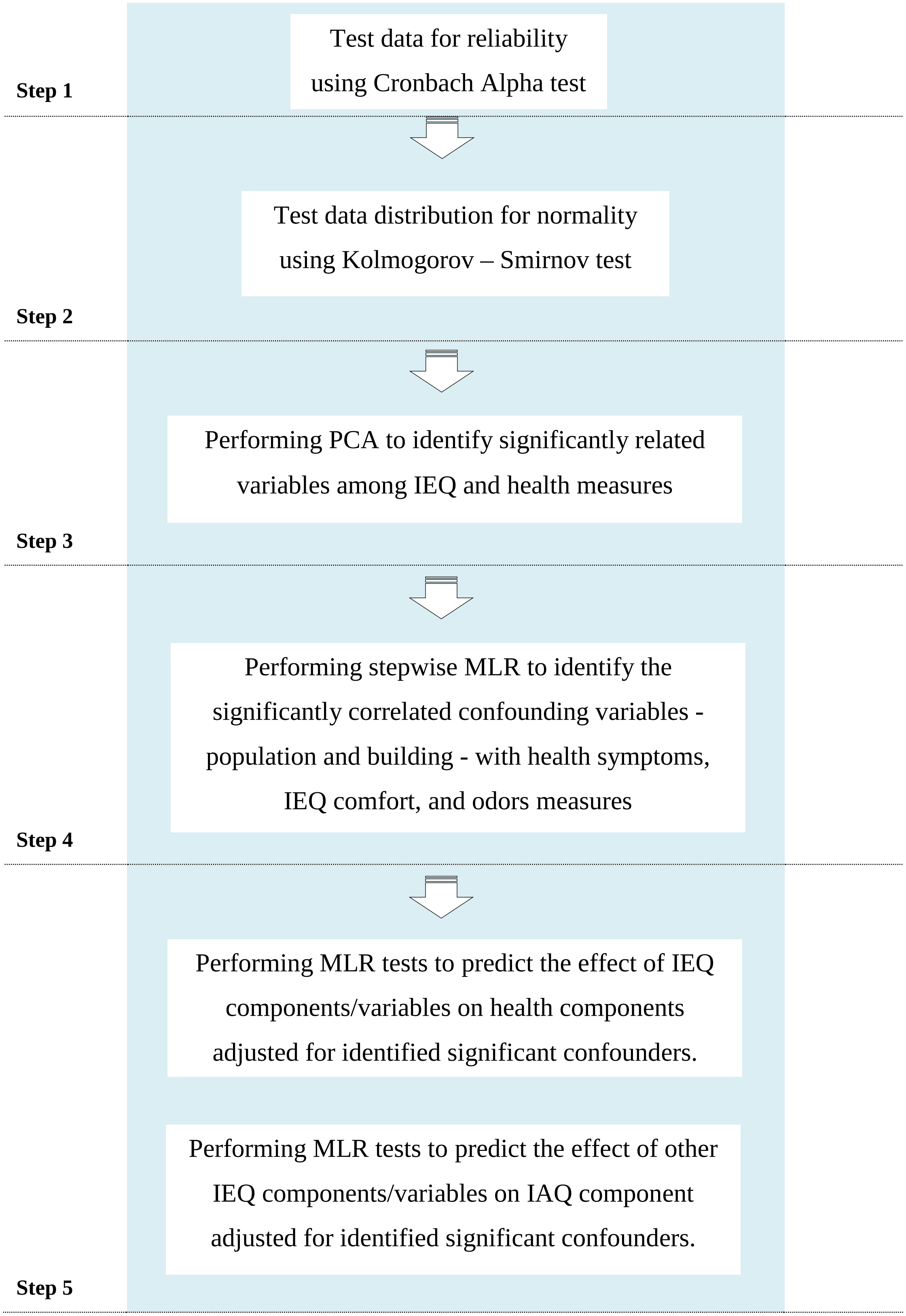


Figure 3-2: Statistical analysis procedures of the main survey

As described in Section 3.3.4.4, PCA is a variable reduction procedure employed by this study in both the pilot and the main survey to reduce their items to a smaller number of components accounting for the most observed variance. The criteria followed when performing the PCA for the pilot study was similarly followed for the main survey. As described in Figure 3-2, MLR models were conducted following the PCA. MLR models were commonly employed in relevant studies examining the associations between prevalent health symptoms and IEQ conditions (Norback et al. 1990; EPA 1991b; Runeson et al. 2006; Sahlberg 2012; Zhang et al. 2012; Syazwan et al. 2013; Egondi et al. 2013; Chang et al. 2015; Herbig et al. 2016; Yang et al. 2018; Argunhan & Avci 2018). MLR test is a type of parametric tests that have more statistical power and are more likely to detect a significant outcome compared with nonparametric tests (Ogee et al. 2015). Reference to Field (2016), the three MLR methods are the hierarchical, forced entry, and stepwise. Predictors in the hierarchical method are orderly entered into the model based on past work or available literature. After entering known predictors, the researcher can add other new predictors into the model. In MLR models applying the forced entry method, all predictors are simultaneously forced into the model. Both hierarchical and forced entry methods rely on good theoretical justifications for including the selected predictors. When using the hierarchical method, it is required from the researcher to make decisions regarding the order of entered predictors based on literature. However, that is not a requirement when using the forced entry method (Field 2016).

Stepwise linear regression is a regression method in which the value of the outcome variable is predicted from multiple variables while simultaneously eliminating unimportant ones. The stepwise regression basically performs multiple regressions for a number of intervals. Stepwise regression test iterates as per the following steps:(i) search for the predictor contributing most in predicting the outcome variable and locate it in the regression model when its statistical significance ($p$ value) is under a specified threshold (commonly $p \leq 0.05$), (ii) find the second predictor of highest significant contribution among the other predictors (IVs) and retain it in the model; (iii) this procedure is repeated until all insignificant predictors, of p values above a specified threshold (commonly 0.10), are excluded from the model and only significant ones are retained (Field 2016, Watson

2017, SPSS Tutorials 2018). Many researchers debated that stepwise regression method deprive them from taking important methodological decisions out of their hands. That is because decisions about included variables are based upon slight statistical variances. Their concern is that these slight statistical variations sometimes dramatically contradict with the theoretical significance of a predictor in the model. However, it is the only practical method when little theory is available regarding the included variables in the model (Field 2016). As discussed in Section 2.2, population and building parameters are considered as potential confounders that might affect both the IEQ variables (IV) and the health symptoms (DV) and that the associations between them differs from a particular context and population to another. Therefore, stepwise regression test is an appropriate method to identify the important confounders within measured population and building parameters that significantly contribute in predicting health, IEQ comfort, and odor components (EPA 1991b; Runeson et al. 2006). Then, MLR tests using the forced entry method were employed to predict the effect of the IEQ parameters (IV) on the health symptoms (DV) adjusted for the significant confounders previously identified. Also, due to the high level of ambiguity and complex interaction regarding the IEQ variables (IV) and health symptoms discussed in Section 2.1 – 2.4, the forced entry multiple regression method is more appropriate than the hierarchical one. That is because the forced entry method does demand entering the predictors in order based on their importance explained in available literature (Field 2016).

MLR is based on the following assumptions: (i) having a linear relationship between the outcome variable and the predictors; (ii) homogeneity of variance or homoscedasticity that means having constant error variance; (iii) having normal distribution of residuals which are the differences between the observed outcome values (DV) and the predicted values by the regression model; and (iv) the independence of error. These assumptions are to be satisfied for linear regression models to produce valid standard error (*SE*), confidence interval (*CI*), and *p* values (Barker & Shaw 2015; Mangiafico 2016; McCarthy 2016; UCLA 2018). It is important to note that, the residuals are assumed to be normally distributed in linear regression models but not the data nor the outcome as commonly mistaken (UCLA 2018; Barker & Shaw 2015; Petr Keil 2013).

Furthermore, reference to (Field 2016; Barker & Shaw 2015; UCLA 2018); there are some issues – but not assumptions – that should be considered during analysis which are of great concern. The first issue is multicollinearity that happens when predictors are highly correlated with each other. The primary concern of multicollinearity is the instability in estimating regression coefficients and the inflation in *SE*. The second issue is the data inclusion of outliers, leverages, and influential data points. An outlier is defined as a data point that appears to be inconsistent or isolated from the remainder points in that dataset. An outlier is also defined as an observation with huge residual or which its dependent variable value or the Y value is unusual. Outliers may highlight a sample's uniqueness, an error in data entry or other issues. On the other hand, a point with high leverage is an observation that has an extreme predictor variable or X value. Influential observations are those substantially change the coefficient estimate when removed. Notably that not all outliers or points with high leverage are influential points. An outlier or a point with high leverage does affect the regression line but to a far lesser degree than the influential point (Field 2016; Barker & Shaw 2015; UCLA 2018).

Regarding the violation of normality assumption in linear regression models, as explained by Ogee et al. (2015), parametric tests can work well with not normally distributed and skewed data if the required sample size for the test is satisfied. Also, (Schmidt & Finan 2018; Mangiafico 2016; & UCLA 2018) stated that linear regression models are not very sensitive to deviations from normality. Schmidt & Finan (2018) debated that the normality of residuals distribution is essential to obtain accurate standard error (*SE*), confidence interval (*CI*) and *p* values. However, based on their study findings, they claimed that regression models with normality violation often still yield valid results particularly when having a large sample size. Violation to normality of residuals in large samples does not impact bias and often has unnoticeably impacts on the results in case of large sample size where the number of observations per variable is more than 10. They also debated that, reference to Gauss-Markov theorem, that the ideal linear regression estimates, that are both unbiased and having the least amount of variance, have a property called "Best linear unbiased estimators" abbreviated as (BLUE). Based on that theorem, estimates are qualified as BLUE when the errors are uncorrelated, homoscedastic and have a zero mean. Subsequently, the normal distribution of the residuals is not a requirement to obtain estimates qualified as BLUE. However, in small sample size studies, the *SE* estimates might be affected or biased and subsequently the *CI* and the *p* values will be affected when residuals are not normally distributed.

According to Oyeyemi et al. (2015), detected outliers are indicators for unusual data that may lead to model misspecification, incorrect variable estimation and biased results. Assuming that the errors are normally distributed, it is expected that 95% of the standardized residuals to be within ±1.96 and 99% of them to be within ±2.58. Moreover, 99.9% of the standardized residuals or almost all of them should be between ±3.29 ( Simonof 2016; Field 2016). Reference to (Field 2016), having standardized residuals greater than ±3.29 are concerning because such high value is unlikely to happen in an average sample. Also, standardized residuals more than 5% larger than ±1.96 or more than 1% larger than ±2.58 is an evidence of an unacceptable error and that the model is a poor fit of the sample data. According to (Simonof 2016), a good guideline that an observation above ±2.5 should be examined as a potential outlier since its occurrence is randomly expected for less than 1% of the time. However, surveys with large sample size could have many observations that have standardized residuals ±2.5 but not outliers. Such observations should be investigated and dismissing them is not justified only because it is expected to randomly happen less than 1% of the time (Simonof 2016).

Reference to Eberly College of Science (2018a), a data point with a standardized residual greater than 3 is considered by some as an outlier. Others adopt a little conservative approach and consider any data point with a standardized residual greater than 2 as an outlier. However, researchers are advised not to literally follow the rule of thumb of either 2 or 3 but to simply consider them as an indicator for further investigation. According to (Schutte & Violette 1991; Nelson 2007), when dealing with outliers, there is neither consensus on what is the right analytical approach to follow nor specific cut offs to employ. According to them, it is difficult if not impossible to obtain an absolute set of criteria or procedures that is appropriate to all situations. Also, Muller & Mock (2009) advised statistical analysts to cautiously deal with data and not to simply exclude troublesome observations in order to slightly improve the model fit in most cases. In terms of identifying data points with high leverage, Imon & Apu (2016) listed the three rules of thumb commonly used in research. The first was proposed by Huber (1981) who defined a range of possible leverage values between 0 and 1 and divided that range into three intervals: (i) safe values below 0.2, (ii) risky values between 0.2 to 0.5, and (ii) values above 0.5 should be avoided. The second guideline is size adjusted cutoff value of 2p/n suggested by Hoaglin & Welsch (1978) where p equals the number of parameters and n equals the observations' number. SAS Institute Inc. (2015) and Hamilton (2013) follow the 2p/n guideline as size adjusted one. The third guideline is also size adjusted one suggested by Velleman & Welsch (1981) and considers any point exceeding 3p/n as of high leverage (Imon & Apu 2016). Similar rules of thumb of 2p/n and 3p/n regarding high leverage were declared by (Eberly College of Science 2018b; Montero Ledezma 2017; Comuzzi et al. 2003; Liang & Kvalheim 1996) as recommended size adjusted guidelines.

Regarding the identification of the influential data points, many statistics can be used to detect them such as Cook's distance and DFBETAS which were employed in this study. Reference to Eberly College of Science (2018a), Cook's distance is a measure of how much all the predicted values by the regression model varies when deleting an observation. According to SAS Institute Inc. (2015), Cook's distance is very similar to DFFITS statistic which is a measure of how the predicted value of an observation is affected when the observation itself is deleted. According to (Simonof 2016; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011; Chatterjee et al 2000); a general rule of thumb is that Cook's value greater than 1 indicates that a point might be influential. As per Eberly College of Science (2018a) and Oyeyemi et al. (2015), another commonly followed guideline is that any observation of Cook's value greater than 0.5 needs to be investigated since it might be influential and better to be examined. If Cook's value is greater than 1, then the observation is very likely to be influential. Reference to Meyers et al. 2010, for regressions of more than 6 predictors, the cutoff Cook's distance is less than 1. According to (Algur & Biradar 2017; Mehamet & Jacobsen 2017; Hamilton 2013), a size adjusted guideline is that an observation of Cook's distance greater than 4/n, where n equals the sample size, is considered as influential. Whereas, Jayakumar & Sulthan (2015) considered any point of Cook's distance greater than 4/n-p as influential.

Reference to (Simonof 2016), Cook's value measures a particular criterion of influence and must not be dealt with as the only standard when investigating about a point influence. That is why this study employed DFBETAS as another statistic to detect influential points. Reference to Schutte & Violette (1991), DFBETAS is a measure of how the regression intercept and coefficients estimates of each predictor vary when an observation is omitted. Reference to SAS Institute Inc. (2015) and Schutte & Violette (1991), a general cutoff value of 2 indicates that the point is influential. Another rule of thumb is declared by (Field 2016; Nelson 2007) which is cutoff value of 1. Following that guideline, any data point that pulls the regression coefficient estimates at least one standard error is considered as influential. Also, according to (SAS Institute Inc. 2015; UCLA 2018; Nelson 2007; Schutte & Violette 1991); recommended a size-adjusted cutoff of 2/sqrt(n) which was initially suggested by Belsley et al. (1980).

In checking for bias or violations regarding above assumptions and procedural concerns, the following steps were performed:

- Examining error independence, linearity, and homoscedasticity:

  They were graphically checked by using scatter plots of standardized residuals against standardized predicted values. For testing linearity, UCLA (2018) suggests fitting Loess Curve which is a nonlinear best fit line through the scatter plot. Linear relationship between the outcome and the predictor can be assumed if the fitted Loess Curve is linear or roughly linear around zero. Reference to (Field 2016; SPSS Tutorials 2018; UCLA 2018; Ballance 2015; Barker & Shaw 2015); independence of errors and homoscedasticity can also be assumed when the dots in the scatter plot follows a random pattern. Randomly and evenly scattered dots are an indication that the variance of the residuals is homogeneous across levels of the predicted values. In homoscedastic models, the residual trend is centred around the zero and that the variance around zero is randomly and uniformly scattered. If the model is well-fitted, there should be no pattern to the residuals plotted against the predicted values. Oppositely, having a pattern such as a funnel or v-shape, pie-wedge or fan shape means that the variance of the residual is variable. If the variance of the residuals is non-constant around the zero, then the residual variance is said to be heteroscedastic (Field 2016; SPSS Tutorials 2018; UCLA 2018; Ballance 2015; Barker & Shaw 2015).

- Examining the normality of distribution of the residuals:

  It was detected by histograms of the standardized residuals, normal probability plots (P-P plots) and the Q-Q plots that compare the theoretical quantile with the observed quantile of a normal distribution. Normal distribution of the residuals can be assumed when the histogram of the standardized residuals is bell shaped (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013; Eberly College of Science 2018c). Q-Q plots are better in comparing distributions that vary on scale and location and it is highly sensitive to tail distributions. Normality of distribution can be assumed if the residuals in the plots, P-P plot or the Q-Q plot, are not significantly deviating from line. Contrarily, a curved line suggests a departure from normality (Field 2016; Barker & Shaw 2015; UCLA 2018).

- Examining multicollinearity:

  It was examined by considering the tolerance and the variance inflation factors (VIF). The tolerance is an indicator of the amount of variance in the predictor not accounted for by other predictors. Thus, the smaller the tolerance is the higher the redundancy of the predictors. Oppositely is the VIF that equals (1/tolerance). Reference to (Field 2016; Ballance 2015; Ghani & Ahmad 2010), VIF values below 5 indicates that multicollinearity is not serious, above 5 indicates that multicollinearity is substantial, while above 10 indicates multicollinearity is more serious.

- Examining outliers, points of high leverage, and influential points:

  Reference to (Muller & Mock 2009; Schutte & Violette 1991; Nelson 2007), when dealing with unusual data points, there is no agreed on analytical approach to follow nor a particular procedure that fits all situations. Muller & Mock (2009) advised statistical analysts to cautiously deal with data and not to simply exclude troublesome observations to slightly improve the model fit in most cases. Muller & Mock (2009) had some conservations regarding employing Cook's distance, following Obenchain (1977), and advised not to employ it and to focus in its basic components instead which are the residual and the leverage. That is because, based on their experience, Cook's distance only highlights points already highlighted by the residual and leverage analysis. Another reason is the uncertainty in which cutoff to use. Also, reference to (Mehamet & Jacobsen 2017), it is better to follow the general or absolute cutoff rather than the size adjusted one debating that data points of high influence are also part of the dataset. Hence, in this study, a particular focus was paid to standardized residuals and leverage analysis. Reference to (Oyeyemi et al. 2015; Simonof 2016; Field 2016), based on the assumption of having normally distributed residuals; it is expected that: (i) 95% of the standardized residuals to be within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. Not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data (Simonof 2016; Field 2016; Oyeyemi et al. 2015). To avoid that, any data point not following the above criteria was deleted. Also, examining data points of high leverage employed the size adjusted cutoff value of 2p/n and 3p/n (Imon & Apu 2016; Eberly College of Science 2018b; Montero 2017; Comuzzi et al. 2003; Liang et a. 1996). Any data point above the cutoff values was further examined in scatter plots of regression standardized residuals and centered leverage values. However, based on having no consensus and uncertainty regarding which cutoff to use to identify influential observations, this study employed the general cutoff values in examining points of influence. Regarding Cook's distance, a cutoff value of 1 is followed (Simonof 2016; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011). In terms of DFBETAS, a cutoff value of 1 is also followed (Field 2016; Nelson 2007).

## 3.5 Field study

As explained in Section 3.1 – 3.2, field studies are more appropriate than surveys in reflecting clearer information regarding measured variables and in describing contextual characteristics (Cresswell 2012; Miller & Yan 2008; Mohle et al. 2003). The aim of this field study was to investigate regarding some IEQ variables identified by previous studies as strongly associated with prevalent SHS and assess their compliance with national and/or international standards. To achieve that, a field study was conducted in 60 Dubai households that encompassed the performance of continuous measurements for indoor T, RH, $CO_2$, CO, TVOC, $PM_{2.5}$, and $PM_{10}$ concentrations for 24 hours while indoor HCHO concentrations was measured for 30 minutes. Spot measurements were also performed outdoors for T, RH, $CO_2$, CO, and TVOC. Measured parameters were the focus of many contemporaneous studies (Yeatts et al. 2012a, 2012b; EAD 2014). The above measurements were performed during 9 months starting from Thursday 14th September 2017 up to Monday 11th June 2018. Self–administered questionnaires were utilized to report occupants' perceptions regarding IEQ and SHS symptoms. Additionally, AERs were calculated following $CO_2$ steady state method. Moreover, the diary notes illustrated in Appendix K was filled by the participating household member to report occupancy profiles occurring in the living hall where monitoring equipment were installed. On those diary notes, participants were asked to report their activities, their durations in addition to any relevant observations that might have an effect on the measurements i.e. number of occupants, smoking, cooking, cleaning, practicing hobbies such as arts & crafts, weather condition, … etc. Also, a walk through check list (Appendix J) was filled by the researcher on the measurement day to record any related observations such building and HVAC characteristic i.e. building's construction materials; characteristics of the applied HVAC i.e. manufacturer, maintenance company and procedure; observed interior or exterior pollution sources i.e. having pets or nearby construction sites; weather conditions i.e. dust storms, rain.

The sample size of the field study is acceptable as per (Cohen et al. 2011; Delice et al 2010) who stated that a sample size of 30 – 500 cases is generally acceptable by researchers. As declared by Mohle et al. (2003), performing field measurements is considered a demanding method in terms of financial and human resources. Thus, it was decided to conduct the field study in 60 households which was a feasible and acceptable sample size that considered the available resources oriented to the study in terms of having a limited number of air monitoring devices utilized by a sole researcher. As in the main survey, SPSS software was used to statistically analyze the collected data. Descriptive statistics was provided regarding self- reported IEQ perceptions and self - reported SHS symptoms in the sampled households as collected by the questionnaires. Also, descriptive statistics was furnished concerning measured T, RH, $CO_2$, CO, TVOC, HCHO, $PM_{2.5}$, and $PM_{10}$ along with an assessment of their compliance with local and international standards. The following sub-sections 3.5.1 – 3.5.3 comprehensively explain the utilized methods in this field study. The protocol integrating all the utilized methods in the study is described in Section 03.6.

### 3.5.1 Field measurements

#### 3.5.1.1 Prevailing indoor air sampling methods

A wide variety of sampling methods are utilized in measuring some IEQ chemical and physical characteristics. Therefore, a researcher should be very prudent in selecting the appropriate sampling techniques that in congruence with research anticipated results and available resources. Basic understanding of different sampling methods, their advantages and limitations is crucial in taking such decisions. Indoor air sampling methods can be identified according to three criteria: (i) sampling collection technique, (ii) anticipated data output, and (iii) instantaneousness of the results. For example, air sampling methods can be divided into (i) active and (ii) passive ones based on sampling collection technique. Active sampling instruments utilize a pump, vacuum or hand pumps, to draw air into the sampler and subsequently power is needed for pump operation. In case of the vacuum pump, air is drawn into sampling devices features such as: (i) filters that capture airborne contaminants, (ii) sorbent tubes that collect particular substances vapors on a powder; or (iii) impingers that infringe the contaminant on a solution. The hand pump is usually connected with an uncapped detector tube containing chemicals that might react with targeted air substance. Air is sucked into the detector manually by the hand pump and the reaction intensity determines the substance concentration (Figure 3-3). The personal monitoring devices carried or worn by individuals to measure that individual's exposure to particular chemical(s), sometimes referred to as dosimeters, is one example of active samplers (EPA1991a).

Figure 3-3: Hand-pump tube based detectors (OSHA 2014)

Active sampling techniques have being used as the method of choice for monitoring many indoor air substances (Wimberry et al 1990; EPA 1991a). Utilizing a pump allows collecting larger air volumes and subsequently measuring lower concentrations within shorter time. Active samplers' limitations are their relatively high-cost, need for routine calibration maintainance, power, and highly-experienced personnel. It can also generate noise, heat, and safety problems (US Committee on Indoor Pollutants 1981; Turk et al. 2007; Yu et al. 2008). Comparatively, passive sampling devices (PSD) collect air by diffusion-based methods instead of a mechanical pump (Figure 3-4). PSDs are frequently used to measure contaminants of high-concentrations within short periods. PSDs need longer periods to collect sufficient sample of low-concentrations (Wimberry et al 1990; Nash & Leith 2010). However, PSDs are of growing popularity due to their low-cost and easy use even by not highly-trained personnel. Moreover, PSDs are small, noiseless and are largely accepted by occupants as unobtrusive (Yu et al. 2008; Turk et al. 2007). Reference to Nash & Leith (2010), despite the relatively inaccurate/ imprecise results compared with real-time measurement devices, PSDs are of considerable value when other trade-off factors intervene.

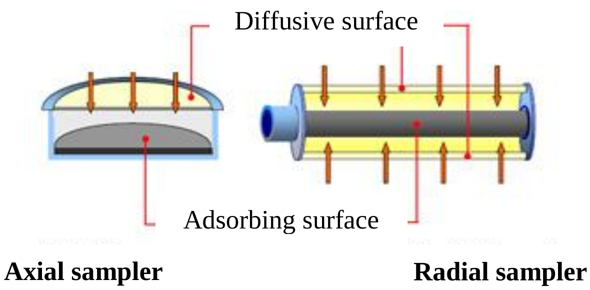


Figure 3-4: Passive diffusive samplers (Sigma-Aldrich 2016)

Moreover, sampling methods can be categorized according to the anticipated results into: (i) continuous, (ii) integrated, and (iii) spot sampling. Continuous sampling affords real-time measurements of a substance concentrations that enable observing the temporal variations in concentrations throughout measurement periods. Therefore, it has 3 advantages: (i) measuring peak short-term concentrations, (ii) calculating average concentrations during any period, and (iii) correlating concentration variations at specific timing with other IAQ characteristics i.e. ventilation, contamination source generation, …. etc. Integrated sampling affords an average of measured concentrations over a specific period and it is assumed as desirable method when the mean concentration is adequate for the measurement objective. Integrated sampling method are of lower cost and less personnel while their limitatons are the non illustration of peak short-term measurements. Spot sampling affords single samples measured at particular intervals. It is the cheapest with least-demand of manpower and appropriate for large-scale surveys when the knowledge of average substance concentrations or temporal fluctuations during a specified period is not important. However, such measurements might be affected by a simple factor i.e. opened doors or windows (US Committee on Indoor Pollutants 1981).

Sampling techniques can also be classified according to the instantaneousness of results into: (i) direct-measuring methods, and (ii) methods requiring laboratory analysis. Direct-measuring methods present the results in short time without laboratory testing (AD EHSMS 2012). They include hand-pump detector tubes and real-time instruments such as photoionization detecors, mercury analyzers, detector tubes, combustible gas monitors, infrared analyzers, and dust/particulate monitors (EPA 1991a; OSHA 2014). Some of them provide continuous readings while others afford time-weighted average (TWA). Regular calibration and maintenance is required to assure the proper functioning of instruments parts i.e. batteries, sensors, … etc. Comparatively, samplers are collected in the second method to be analysed in a laboratory. This method includes both active samplers such as charcoal adsorbent tubes, cowl samplers in addition to passive ones i.e. PSDs and canisters (AD EHSMS 2012).

#### 3.5.1.2 Utilized indoor air sampling methods

As per previous discussion regarding prevailing indoor air sampling methods, this study proposed active sampling methods as more appropriate than passive sampling devices (PSD). Utilizing a pump allows active samplers collecting larger air volumes and subsequently measuring lower concentrations within shorter time. That is why such methods have the capability to report peak short-term concentrations. On the other hand, PSDs collect air by diffusion-based methods instead of a mechanical pump. According to (Wimberry et al 1990; Nash & Leith 2010), PSDs are frequently used to measure contaminants of high-concentrations within short periods. Generically, PSDs provide TWA readings for longer durations because they need longer periods to collect sufficient sample of low-concentrations. Subsequently, the peak short-term concentrations occurring during the measured period is not reported. The issue of measuring the peak short-term concentrations is of particular importance in fulfilling this research objective to characterize current IEQ of UAE housing. As explained in Section 2.6, readings of some contaminants' concentrations measured by Yeatts et al. (2012a) in a sample of UAE households were high indicating the potentiality of having some exposure limits that exceeds those identified by international standards (WHO 2006; Health Canada 2016). Unfortunately, the duration of the concentrations' measurements were not reported because they utilized passive samplers recorded average readings and thus were incapable to report the duration of these concentrations.

Active sampling methods were commonly used in contemporary relevant research such as that employed by Park et al. (2014). They quantified the impact of three ventilation systems on indoor PM concentrations in fifteen residential flats from three Seoul locations. The three ventilation systems were: natural ventilation, balanced and unbalanced mechanical ones. Field measurements for PMs, $CO_2$, and T were monitored indoors and outdoors for 24 hours in each apartment using active sampling devices. Since the natural ventilation was one of the studied ventilation systems, the study opted to conduct measurements during a thermally comfortable period in Seoul between April to June 2012. PM of ($0.3\mu m \leq$ diameter $\leq 10\mu m$) and $PM_{2.5}$ were measured by optical particle counters and TSI Dust Trak photometers, respectively. $CO_2$, RH, T was measured by IAQ monitors. Results revealed that I/O ratios of sub-microns particles in the naturally ventilated flats ranged between 0.56 – 0.72 and between 0.25 – 0.60 for particles of more than 1.0μm diameter. Moreover, I/O ratios of sub-micron particles were 26% reduced by the two mechanical systems and 65% reduction of fine particles were achieved compared with the natural ventilation. That pointed to the higher capability of mechanical ventilation in mitigating the penetration of outdoor PM into residential buildings.

Behzadi & Fadeyi (2012) investigated IAQ conditions at a classroom on four Dubai-UAE elementary schools. TVOC, $CO_2$, CO, $O_3$, TPM, HCHO, RH, and T are measured by active samplers for during a working day (6-7 hours) in the four studied classes. HCHO was measured by RK-FP 30; while TPM was measured by Thermo Scientific pDR-1500 (Accuracy ±5%, Range 0.001 – 400 $mg/m^3$). Direct Sense IAQ-IQ Probe 610 was used to measure CO, $CO_2$, TVOCs, $O_3$, RH, and T with (Accuracy ±5%, Range 0 – 10,000ppm), (Accuracy ±3%rdg ± 50ppm, Range 0 – 500ppm), (Range 0 – 20,000ppb), (Accuracy ±2%RH, Range 0 – 100%RH), and (Accuracy ±3ºC, Range -10 – +70ºC). Provided AERs were calculated assuming that outdoor $CO_2$ was 380ppm. Results revealed that TPM, TVOC, and $CO_2$ levels were unacceptable compared with international standards and that might imply health or discomfort problems. Moreover, all the calculated AERs are insufficient to dilute indoor contamination.

Also, Chatzidiakou et al. (2015) conducted a research that aimed to (i) examine the environmental and behavioral parameters affecting IAQ of eighteen classrooms in six London schools, and to (ii) assess the capability of $CO_2$ as an inclusive IAQ predictor. Indoor/outdoor measurements utilizing active sampling methods continued for five working days at each case. Calibration of continuous real-time instruments were done by the manufacturers. Parameters that were continuously measured by active sampling devices were T, RH, $CO_2$, $PM_{10}$, $PM_{2.5}$, $PM_1$, and TVOCs. $CO_2$ was measured using non-dispesive infrared spectrometry (Acurracy ±3%, Range 1 - 20,000ppm), PMs by optical method (LOD > 1μg/m$^3$), while T and RH were measured using a rotronic sensor (T: Accurracy ±5ºC, Range 30 – 65°C, RH: Accuracy ±1.5%RH), and TVOCs was measured by photo-ionization detector (Acurracy ±5%, Range 1 - 20,000ppm). Results revealed that keeping the temperatures lower than 22°C along with mitigating indoor air contamination sources might keep TVOC concentrations below its associated levels with sensory irritations. It also suggested that keeping $CO_2$ levels lower than 1000 ppm by increasing ventilation rates might keep indoor airborne PM levels lower than WHO (2010a) recommendations. Generally, $CO_2$ concentrations were a beneficial predictor for IAQ except for traffic-related contaminants.

Dorizas et al. (2015) assessed indoor air contaminants and ventilation rates in 6th grade classrooms naturally ventilated in nine Greece schools. Field measurements of RH, T, CO, $CO_2$, VOCs, $PM_{0.5}$, $PM_1$, $PM_{2.5}$, $PM_{10}$, and UFP by active sampling methods continued for approximately 7 hours daily. AERs were calculated utilizing a tracer gas decay method. $CO_2$, CO, VOCs were measured by a multi-gas monitor (0±20% accuracy); indoor $PM_{0.5}$, $PM_1$, $PM_{2.5}$, and $PM_{10}$ by Handheld 3016 (100% counting efficiency for particles larger than 0.45μm); outdoor $PM_1$, $PM_{2.5}$, and $PM_{10}$ by an airborne particular monitor (Range 0.1 – 6000μg/m$^3$); UFP by portable condensation particle counter (Accuracy 95% and 3% - 12% precision); RH and T by Tiny Tag data loggers (RH: Accuracy ±3.0%RH, T: Accuracy ±0.6°C at 25°C). All instruments were calibrated prior the beginning of the sampling. Results revealed that average $CO_2$ levels are negatively correlated with ventilation rates and in the majority of the classes were a little higher than recommended ones. $PM_{10}$ levels were 10 times higher in all cases than the recommended limits and $PM_{2.5}$ exceeded the limits in many of them. Moreover, the ratio of indoor to outdoor (I/O) concentrations was more than one pointing to higher indoor contamination sources.

According to (EPA 1991a), many factors greatly affect the selection of appropriate sampling instruments such as: (i) Ease of use i.e. portability, noise, vibration, direct-reading vs. laboratory analysis required, ruggedness, time required for each measurement; (ii) Quality assurance i.e. availability of service and customer support, maintenance, and calibration requirements; (iii) Output i.e. time-averaged vs. instantaneous readings, sensitivity, compatibility with computer or data logging accessories; (iv) Cost i.e. commercial availability, single use only vs. reusable, purchase vs. rental. Those factors were deliberately considered when determining the appropriateness of the monitoring instruments for measuring this study's parameters. Accordingly, the criteria utilized in determining the appropriate monitoring instruments for this study were the: (i) provision of peak short-term readings; (ii) convenience i.e. easiness of use, commercial availablity, avialability in the British University in Dubai (BUiD), quietness, portability, ….etc; (iii) quality assurance i.e. certifications from internationally recognized bodies, availability of service and customer support, maintenance and calibration requirements; (iv) output quality i.e. directness of results, sensitivity, and consistency with computer accessories; in addition to (v) cost.

Based on above criteria, the sampling methods shown in (Table 3-29) were utilized. $PM_{2.5}$ and $PM_{10}$ were continuously measured for 24 hours in each household using the Optical Particle Sizer (OPS) Model 3330 (Size resolution ±5% @ 0.5µm, Range 0.3 – 10 µm). Moreover, a spot measurement for a single sample drawn during 30 minutes was conducted to measure the indoor HCHO concentrations in each household. HCHO was measured using the gas detector Model FP 30 (Accuracy ±10%rdg, Range 0.01 – 1.0ppm). Additionally; CO, $CO_2$, TVOC, RH, and T were continuously measured for 24 hours in each household using DirectSense IQ – 610. The device was also used to perform a spot measurement of outdoor $CO_2$, CO, TVOC, RH, and T levels. $CO_2$ was measured using non-dispersive infrared (NDIR) sensor (Accuracy ±3%rdg ±50ppm, Range 0 – 10,000ppm); CO was measured using electrochemical sensor (Accuracy ±2ppm<50ppm, ±3%rdg >50ppm; Range 0 – 500ppm); TVOC was measured using photoionization detector (PID) (Resolution 1ppb, Range 5 – 20,000ppb); while T and RH were measured using electronic sensors (T: Accuracy ±0.3°C, Range -25° to +70°C; RH: Accuracy: (±2%RH <80%RH) and (±3%RH>80%RH ); Range 0 – 100 %RH). Following sub sections discuss how the above criteria had influenced the selection of the selected sampling methods. Noteworthy that three monitoring devices were calibrated prior the conduct of measurements (Appendix P).

Table 3-29: Proposed air sampling methods and instruments

| | **Method** | **Device** |
|---|---|---|
| **HCHO** | Colorimetric detection tablet | FP - 30 |
| **$PM_{10}$ & $PM_{2.5}$** | Continuous particulate mass monitor | OPS 3330 |
| **$CO_2$** | Non dispersive infrared sensor | DirectSense IQ- 610 |
| **CO** | Electrochemical oxidation sensor | |
| **TVOCs** | Photoionization detector | |
| **T & RH** | Electronic sensor | |

### 3.5.1.3 HCHO measurement method

As previously mentioned, the following criteria had influenced the study decision regarding the suitable instrument to measure HCHO which were: (i) provision of peak short-term readings; convenienc; quality assurance; output quality; in addition to the cost and commercial availablity. According to EPA (1991a), measuring the peak short-term concentrations is the most ideal method for evaluating acute irritation when monitoring HCHO. Moreover, one of the important guidelines recommended by EPA (1991a) when selecting an HCHO monitoring device is its capability to detect concentrations well below 0.1ppm. Therefore, the portable HCHO gas detector Model FP 30 with its detection range (0.01 – 0.4ppm) was considered as a suitable device for monitoring HCHO levels in Dubai household. Detailed specifications of Model FP 30 is illustrated in Table 3-30 whereas the view and different parts of the device is demonstrated in Appendix Q. This instrument provides direct readings for peak short-term concentrations and it employs colorimetric and photoelectric photometry detection methods (RKI Instruments Inc. 2017). It was used to perform a spot measurement for a single sample drawn during 30 minutes in each household. Resultant measured HCHO concentrations were comparable with WHO acceptable short term exposure limit (WHO 2010a) (Table 2-7).

Table 3-30: Specifications of HCHO detector Model FP 30 (RKI Instruments Inc. 2017)

| | **Specification** |
|---|---|
| **Detection method** | Colorimetric tablet |
| **Detection principle** | Photoelectric photometry |
| **Sampling method** | Sample drawing with built-in pump |
| **Detection range** | 0.01 – 0.4ppm |
| **Detection time** | 30 minutes |
| **Accuracy** | ± 10% of reading or ± 5% of full scale (whichever is greater) |
| **Display** | Digital LCD |
| **Operating conditions** | -10 ~ 40ºC (14 ~ 104ºF), below 90% RH |
| **Memory** | Up to 99 points |
| **Power Source** | AA size Alkaline batteries (quantity 4) |
| **Battery life** | ≈ 12 hours |
| **Dimensions** | ≈ 85(W) x 190(H) x 40(D)mm, 3.35(W) x 7.48(H) x 1.57(W), |
| **Weight** | 500g, 17.6 oz |

Model FP 30 is commonly utilized in contemporary research such as that performed by Asadi et al. (2011) used the device to measure CO, $CO_2$, TVOCs, RH, and T. The aim of their study was to establish and demonstrate the comprehensive IAQ audit approach for hotel buildings based on Portugal national laws. Also, Hirst et al. (2011) compared the performance of two commercially available direct-reading instruments which were an RKI Instruments Model FP-30 and a PPM Technology Formaldemeter™ htV with NIOSH Method 2016 in different test environments to determine if these direct-reading instruments can accurately measure HCHO. That study was sponsored by NIOSH and the US National Center for Environmental Health. The PPM Technology Formaldemeter™ htV instrument uses electrochemical sensing technology. NIOSH Method 2016 is an integrated sampling method that collects formaldehyde on silica gel coated with 2, 4- dinitrophenyl hydrazine and then the derivitized product (2, 4-dinitrophenylhydrazone) is analyzed using high performance liquid chromatography with UV detection. Forty-seven 1-hour integrated air samples were collected and analyzed for formaldehyde using NIOSH Method 2016. Measurements were made simultaneously with both direct-reading instruments and with the NIOSH Method. Although the direct-reading instruments differed from NIOSH Method

2016, scatter plots and correlation tests showed that the 1-hour integrated sample collected with the direct-reading instruments correlated with those from the laboratory- based method. Moreover, sensitivity and specificity tests demonstrated that 1-hour integrated samples with the PPM Technology Formaldemeter™ htV was more accurate at measuring formaldehyde concentrations greater than 0.2ppm, while the RKI Instruments Model FP-30 was better at measuring concentrations less than 0.2ppm. Reference to measured HCHO concentrations in 625 UAE houses (Table 2-11); the maximum measured concentration was 0.14ppm. Based on all the above, the HCHO gas detector FP 30 is a credible and appropriate instrument for monitoring HCHO concentrations in Dubai houses. Detailed description of this device SOP is demonstrated in Appendix T.

As explained by RKI Instruments Inc. (2012) (Figure 3-5), the HCHO gas detector Model FP 30 has a gas detection tablet test paper, referred to as TAB, that is treated with special chemicals and an illuminating agent. When gas is blown onto the TAB paper face, the paper emits illumination by chemical reaction that causes the paper to change color. When HCHO contacts the paper, chemicals impregnated into the paper combine with HCHO to form compounds and these compounds change the paper from white to yellow color. The amount of color change is determined by the level of HCHO exposure and the time of exposure. Then the device utilizes a photoelectric photometry technology to create a light beam that reflects off the test paper. The intensity of the light beam is affected by the color or darkness of the detection TAB paper and this intensity is measured by a light sensor. The level of light intensity measured is correlated, from an exposure curve stored in the instrument, to a particular level of HCHO exposure to the tab. This concentration is then directly displayed at the end of the detection cycle on an LCD display.

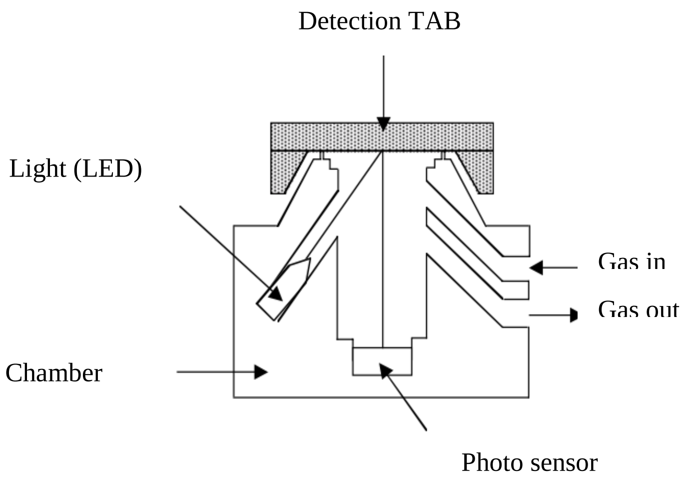


Figure 3-5: HCHO gas detector Model FP 30 (RKI Instruments Inc. 2012, p. 20)

FP 30 is produced by RKI Instruments and it has an IS0 14001 and an ISO 9001 certificates (RKI Instruments Inc. 2016). The IS0 14001 is developed by ISO Technical Committee ISO/TC 207 to provide practical tools for companies and organizations of all kinds looking to manage their environmental responsibilities. It sets out the criteria for an environmental management system and maps out a framework that a company or organization can follow to set up an effective environmental management system. ISO 14001 certification can provide assurance to company managemEye, nose, throat, and employees as well as external stakeholders that environmental impact is being measured and improved (ISO 2015a). Moreover, RKI Instruments has an ISO 9001 certificates (RKI Instruments Inc. 2016) that provide guidance and tools for companies and organizations who want to ensure that their products and services consistently meet customer's requirements and that quality is consistently improved. In fact, there are over one million companies and organizations in over 170 countries certified to ISO 9001. ISO 9001 certification can ensure that customers get consistent, good quality products and services, which in turn brings many business benefits (ISO 2015b).

#### 3.5.1.4 $PM_{2.5}$ and $PM_{10}$ measurement method

Regarding measuring $PM_{2.5}$ and $PM_{10}$, as discussed in the beginning of this section 3.5.1, a variety of collection and analytical techniques are available. As exemplified by (EPA 1991a), they can be collected by using active samplers that utilizes a pump to draw air through a filter. The filter can then be weighed, a gravimetric analysis, or examined under a microscope. Direct readouts of $PM_{2.5}$ and $PM_{10}$ are also available such as meters equipped with scattered light detectors. As discussed in Section 2.6, measuring the peak short-term concentrations of $PM_{2.5}$ and $PM_{10}$ was a core need in this study. That is because, the 25% percentile of $PM_{10}$ measurements in (Yeatts et al. 2012a) indicated the potentiality of having unacceptable levels in UAE houses compared with recommended exposure limits by WHO (2006). However, due to the use of PSD that provided average readings, the duration of these measurements were not identified. That is why this study measured $PM_{2.5}$ and $PM_{10}$ using a method capable of recording peak short-term concentrations in Dubai households. In addition to the provision of peak short-term readings the following criteria had also influenced the study decision regarding the suitable instrument to measure $PM_{2.5}$ and $PM_{10}$ which were: (i) convenience; (ii) quality assurance; (iii) output quality; in addition to (iv) cost and commercial availablity. Accordingly, this study measured $PM_{2.5}$ and $PM_{10}$ using the TSI Optical Particle Sizer (OPS) Model 3330 which is a light, portable unit that provides direct and continuous measurement of particle concentration and particle size distribution using single particle counting technology. Detailed specification of this instrument is shown in Table 3-31 while different views and parts of this device are illustrated in Appendix R.

Reference to (TSI Inc. 2011, 2012) (Figure 3-6), the OPS Model 3330 operates by drawing the aerosol sample straight into the measurement region of the OPS Model 3330 to reduce particle losses due to transport. A sheath flow surrounds the sample, focusing the aerosol to enhance size resolution, and keeping the optics clean for improved reliability and low maintenance. The flow rates in the OPS are carefully controlled using real-time feedback to ensure concentration accuracy. In the optical chamber, the aerosol crosses a laser beam creating a light pulse. The intensity of the flash is used detect the particles' number and size. The shape of the laser beam, the size of the viewing volume, the type of detector and the signal processing algorithms in the Model 3330 were designed to provide optimal resolution over the size range of 0.3 to 10µm. After being sized, the sample flows from the optics chamber to the filter cartridge where it is collected on a 37mm filter, for gravimetric analysis or further chemical or microscopic sample investigation.

Table 3-31: Specifications of TSI OPS Model 3330 (TSI Inc. 2011, 2012)

| | **Specifications** |
|---|---|
| **Particle size range** | 0.3 to 10µm |
| **Size channels** | Up to 16 |
| **Size resolution** | 5% @ 0.5 µm per ISO 21501-1 |
| **Flow rate & accuracy** | Sample flow of 1.0 L/min ± 5% accuracy |
| **Operational temperature** | -20º to 60ºC |
| **Operational humidity** | 0 to 95% RH, non-condensing |
| **Data logging** | 5MB on-board memory (30,000 samples) |
| **Log interval** | User adjustable, 1 second to 24 hours |
| **Physical size (HWD)** | 13.5 x 21.6 x 22.4 cm |
| **Weight** | 2.8 Kg – with 2 battery |
| **Gravimetric Sampling** | 37 mm filter inside standard removable filter cartridge |
| **Vacuum Source** | Internal pump |
| **Power AC (AC adapter)** | 100 – 240 VAC 50 – 60 Hz |
| **Power – DC** | 24V DC at 2.5 A |
| **Screen** | 5.7 in. VGA color touchscreen with graphical display |
| **Software** | Supplied with Aerosol Instrument Manager software |

Many contemporary researches utilized this instrument when monitoring wide range of PM concentrations. For instance, Chen et al (2014) investigated the level of protection provided by the HVAC system in Singapore office building during both hazy and clear outdoor conditions. The indoor and outdoor particle concentrations were simultaneously monitored using the OPS Model 3330 to evaluate the impacts of the HVAC system on them. Results revealed that the HVAC system mitigated migration of outdoor originated particles into indoor environments. The removal efficiency was size dependEye, nose, throat, and was more effective for the larger particles. The protection effect provided by the building was not satisfactory for the particles <1.117µm during the haze episode. Also, Cha et al. (2016) performed on-board monitoring on a commuter train stopping at underground and aboveground stations. The concentration and size distribution of particulates were monitored using the OPS Model 3330 for both indoor and outdoor levels. The results showed that the levels of $PM_{10}$ and $PM_{2.5}$ inside the train were about one-fifth of the outdoor levels. Significant increases in indoor particulate number concentrations were observed in tunnel environments and there was a slight increase when the doors were open. Differences in the size distributions of micro and nano-sized particulates could be identified for different tunnels. Results revealed that outdoor particulate mass and particulate number levels increased significantly during braking by 12 and three times, respectively. Also, particulate concentration measured inside the compartment showed increments of 5–25% when the train door opened. Moreover, inside long tunnels the $PM_{2.5}$ and $PM_{10}$ levels inside the compartment increased by a factor of 1.5 and 1.8 respectively compared to the results obtained from aboveground measurements.

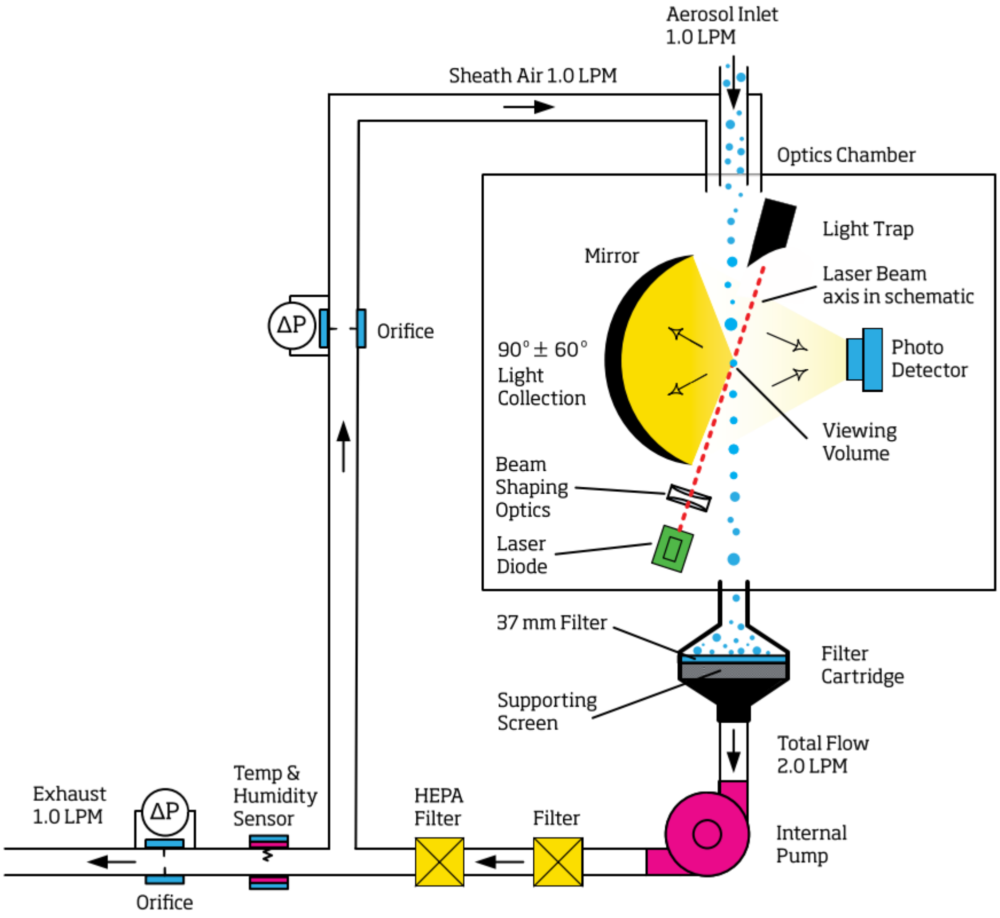


Figure 3-6: Schematic of OPS Model 3330 operation (TSI Inc. 2012, p. 2)

Backed by over 40 years of aerosol instrumentation design experience, the OPS uses state-of-the-art optics with 120° light collection and sophisticated electronics processing resulting in precision, high quality data. Rigorous factory calibration standards ensure measurement accuracy. The Model 3330 is manufactured at TSI's ISO 9001 certified facility that, as discussed in the previous section, can ensure that customers get consistent, good quality products and services, which in turn brings many business benefits (ISO 2015b). Other safety certifications awarded to the device is shown in Appendix O. Moreover, The OPS Model 3330 is calibrated using NIST traceable PSL spheres and TSI's accredited Electrostatic Classifier and Condensation Particle Counters. PSL is the industry wide calibration aerosol of choice because it has properties close to many real world aerosols and is traceable to national standards throughout the world. Based on all the above, the OPS Model 3330 is a reliable and appropriate instrument for this research to continuously measure $PM_{2.5}$ and $PM_{10}$ for 24 hours in each household. Detailed description of the OPS Model 3330 SOP is illustrated in Appendix U.

#### 3.5.1.5 $CO_2$, CO, TVOCs, T, and RH measurement methods

As previously mentioned in the beginning of this section 3.5.1, the criteria utilized in selecting the appropriate monitoring instrument for this study parameters were the: (i) provision of peak short-term readings; (ii) convenience; (iii) quality assurance; (iv) output quality; in addition to (v) cost and commercial availablity. Complying with the above criteria, the study used the DirectSense IQ – 610 sensors to continuously measure indoor CO, $CO_2$, TVOCs, T, and RH for 24 hours in each household. Spot measurement was also performed using it for outdoor CO, $CO_2$, TVOCs, T, and RH concentrations in each household. Detailed description for the specifications of DirectSense probes are showed in Table 3-32. A non-dispersive infrared (NDIR) sensor was used to monitor $CO_2$ concentrations while CO and TVOCs were monitored using an electrochemical sensor and a photoionization detector (PID); respectively. T and RH were measured by electronic sensors. Detailed specification of the instrument is illustrated in Table 3-32 while different views and parts of the instrument are shown in Appendix S.

Table 3-32: Specifications of DirectSense IQ – 610 (Davenport 2016, GrayWolf Sensing Solutions LLC 2014)

| | **Specification** |
|---|---|
| **$CO_2$** | NDIR sensor, range: 0 to 10,000ppm, accuracy: ±3%rdg ±50ppm) |
| **CO** | Electrochemical sensor, range: 0 – 500ppm, accuracy ±2ppm <50ppm, ±3%rdg >50ppm |
| **TVOCs** | PID, range: 5 to 20,000ppb, resolution 1ppb, L.O.D. <5ppb<br>10.6 eV PIDs respond to the majority of VOCs but not to VOCs with ionization potentials >10.6. Standard calibration is to Isobutylene. Users may calibrate to alternative VOCs |
| **T** | Range: -25° to +70°C, accuracy: ±0.3°C |
| **RH** | Range: 0 to 100 %RH, accuracy: ±2%RH <80%RH (±3%RH>80%RH ) |
| **Response time** | All sensors exhibit 90% response <1 minute |
| **Operating range** | VOCs (PID) sensors: 0 to 90%RH, -15 to 60°C<br>Other sensors: 0 to 98%RH (non-condensing), -15 to 60°C |
| **Data storage** | 32GB for data-logging (millions of readings) |
| **Probe dimensions** | 5cm dia. x 30cm length. |
| **Probe weight** | w/batteries 0.7kg |

Reference to (AD OSHAD 2016; EPA 1991a); it is recommended to measure $CO_2$ with either a direct reading meter or a detector tube kit. Direct-reading meters estimate air concentrations through one of several detection principles. These may report specific chemicals e.g. (i) $CO_2$ by infrared light or chemical methods; (ii) certain VOCs by photoionization (PID) method; (iii) or PMs by scattered light. Detector tube kits are generally active methods that include a hand pump which draws a known volume of air through a chemically treated tube intended to react with certain contaminants. The length of color stain resulting in the tube correlates to chemical concentration. According to (Wimberry et al. 1990), the non-dispersive infrared (NDIR) systems have several advantages over these monitoring techniques because they are: (i) insensitive to flow rates, (ii) require no wet chemicals, (iii) independent of room temperature change, (iv) sensitive over a wide concentration range, (v) quick responding, and (vi) operable by non-technical personnel. The proposed non-dispersive infrared (NDIR) sensor included within the DirectSense IQ – 610 is capable to provide direct and continuous $CO_2$ readings. Hence, the device was used to perform a spot measurement for outdoor $CO_2$ concentrations while indoor measurements of $CO_2$ will continuously be performed in each household for 24 hours. Reference to EPA (1991a), it is recommended to record the relative occupancy and weather for each period of $CO_2$ testing. Such data was collected via the walk through check list – illustrated in Appendix J – which was filled by the author in the 1st visit to each household. Also, according to EPA (1991a) guidelines, $CO_2$ measurements for ventilation was collected away from any source that could directly influence the reading e.g. hold the sampling device away from exhaled breath. Additionally, $CO_2$ outdoor samples were taken as near as possible to the outdoor air intake as recommended by EPA (1991a). This was also considered when determining the location of the devices during the 1st visit to each household as explained in the study protocol (Section 3.6).

Regarding measuring TVOCs, according to (AD OSHAD 2016; Wimberry et al. 1990; EPA 1991a), it is recommended to measure them by a stainless steel canister; solid adsorbent tube, or direct reading instruments. Reference to Wimberry et al. (1990), the stainless steel canister is an active method in which air samples is drawn by a pump into stainless steel canisters. After the air sample is collected, the canister valve is closed, an identification tag is attached to the canister, and the canister is transported to a predetermined laboratory for analysis. The VOCs are separated by gas chromatography (GC) and measured by mass-selective detector or multi-detector techniques that might include the nitrogen- phosphorus detector (NPD), the flame ionization detector (FlO), the electron capture detector (BCD) and the photoionization detector (PID). On the other hand, the solid adsorbent tube is a passive device in which air samples are collected by dispersion that follows similar analysis procedures to the stainless steel canister. According to EPA (1991a), several direct-reading instruments are available that provide TVOCs measurements. One of the commonly used direct reading meters is the photoionization detector that utilizes a screening tool for measuring TVOCs. TVOCs determined from stainless steel canister and solid adsorbent tube can provide more accurate average readings than direct-reading instruments. However, unlike direct- reading instruments, they are unable to distinguish peak exposures during the measurement period. Since this study was interested in identifying the peak short-term concentrations, measuring TVOCs with the PID sensor of the DirectSense IQ – 610 was considered as an appropriate method.

Also, reference to AD OSHAD (2016) and EPA (Wimberry et al. 1990), it is recommended to measure CO using an electrochemical oxidation, non-dispersive infrared (NDIR), or a gas filter correlation (GFC) detection method. All three devices can provide peak short-term concentrations and they are commonly used to measure CO in similar research. However, the CO electrochemical sensor of the DirectSense IQ 610 is more convenient than others for this research because it is available within the BUiD indoor air monitoring devices. Thus, CO concentrations were continuously monitored for 24 hours in each household using the electrochemical sensor of DirectSense IQ 610. Also, reference to (AD OSHAD 2016; Wimberry at al. 1990), T and RH are recommended to be measured using an electronic sensor, thermometer, or a sling psychrometer. In this study, T and RH were measured utilizing electronic sensors not only because their provision of continuous measurements but also due to their compatibility with computer and data login accessories. According to EPA's guidelines, the recommended accuracy when measuring temperature is ±1 ºF. Moreover, a single indoor measurement may not be a good indication of long-term relative humidity in the building. Also, programmable recording sensors can be used to gain better understanding of temperature or humidity conditions as they change over time (EPA 1991a). Reference to the detailed specifications of the DirectSense electronic T sensor in (Table 3-32), the provided accuracy (± 0.3ºC) is better than recommended in (EPA 1991a). Moreover, the continuous measurement of T and RH for a whole day in each household was expected to furnish good understanding of thermal and humidity conditions in them. The standard operating procedure of the DirectSense IQ – 610 probes is demonstrated in Appendix V.

Notably that the device manufacturer, GrayWolf Sensing Solutions LLC, is an accredited one by the American Industrial Hygienic Association (AIHA) for IAQ sampling, analytical, and laboratory equipment (AIHA 2015). Further details regarding the certificates/declarations of conformance and compliance of DirectSense IQ – 610 sensors with recognized standards are demonstrated in Appendix O. Moreover, the device is commonly used by contemporary research such as that done by Asadi et al. (2011) that used the device to measure CO, $CO_2$, TVOCs, RH, and T. The aim of their study was to establish and demonstrate the comprehensive IAQ audit approach for hotel buildings based on Portugal national laws. A 4-star hotel building in Portugal was used as a case study to demonstrate the IAQ audit application and evaluate its comprehensiveness and usefulness to the hotel or facility managers. The systematic approach involved the measurement T, RH, $CO_2$, CO, TVOCs, HCHO, $PM_{10}$ in addition to the measurements of biological indicators (bacteria, fungi, Legionella). DirectSense IQ – 610 sensors was used to measure the T, RH, $CO_2$, CO, and TVOCs. AERS were estimated following $CO_2$ steady state method that used metabolic $CO_2$ as the tracer gas. The comprehensive IAQ audit revealed four main problems in the hotel building: (i) insufficient ventilation rate; (ii) too high particle concentration in some rooms; (iii) contamination by Legionella of the sanitary hot-water circuit; (iv) poor filtration effectiveness in all air handling units (AHUs).

Also, Sulaiman & Mohamed (2011) also utilized the DirectSense IQ 610 to measure T, RH, $CO_2$, CO, and TVOCs in addition to other parametrs in their research aiming to investigate the association between SBS and indoor air pollutants in two Malaysian libraries. Higher prevalence of SBS recorded in Perpustakaan Sultanah Zanriah (PSZ) compared with Perpusttakaan Sultan Ismail (PSI). Significantly higher levels of indoor air pollutants were detected in PSZ compared with PSI for CO, $CO_2$, T, and TVOCs in addition to fungi and bacteria while PSI indicated higher level of RH. The levels of T, RH, TVOCs, and bacteria counts were the possible major factors contributing to SBS complaints among the workers of both libraries. Also, sponsored by the National Science Foundation and by the IEEE Control Systems Society (CSS), the University of North Texas Engineering Department (2013) and conducted a project that aimed to build experimental IAQ $CO_2$ monitoring system with “On Demand” ventilation capabilities. Results revealed that potential hazardous gases in the work place were a critical issue. Too often, these gases were undetected until the employee became ill or a foul odor was reported by building occupants. By the time this occurs, occupants would have been suffered exposure to poor air quality. With an on-demand venting system in place, IAQ issues could be dealt with immediately.

### 3.5.2 AERs calculation methods

#### 3.5.2.1 Prevailing AERs measurement methods

Ventilation rates can be measured by either direct or indirect methods. According to EPA (1991a), AERs can be estimated by multiplying the cross-sectional area and velocity of provided airstream. Air velocity can be measured by an anemometer or a pilot tube while the cross-sectional area can be calculated. The measurement of air velocity is highly difficult due to its considerable variability in an airstream and the best estimate of air velocity is obtained as an average of multiple measurements. Similarly, cross-sectional area of the air-stream is variable from location to another i.e. diffusers, mixing boxes. AERs can also be directly measured by flow hoods at grilles, exhaust outlets, or diffusers. Reference to (You et al. 2007; You et al. 2012; Wang et al. 2016; Zhao et al. 2014), direct methods for measuring AERs are relatively complicated, expensive, and sometimes inconvenient compared with indirect methods. Indirect methods estimate AERs based on measuring another parameter's concentrations by employing relatively easier and cheaper instruments. For instance, AERs can be estimated by measuring the concentrations of specific tracer gas i.e. helium, hydrogen, methane, acetone …etc. For safety reasons, the frequently used ones in recent practice are: sulphur hexafluoride ($SF_6$), perflurocarbons tracers (PFT), hexafluorobenzene ($C_6F_6$), and $N_2O$ (Laussmann & Helm 2011; Zong & Zhang 2012; Chatzidiakou et al. 2015). Dorizas et al. (2015) assessed AERs in nine naturally-ventilated Greece classrooms using the tracer gas decay method that encompassed injecting $SF_6$ as a tracer gas in the space. After $SF_6$ injection, space air was well-mixed using fans. The decay of $SF_6$ was measured by a photo-acoustic multi-gas monitor. The AERs were calculated by the following equation (Dorizas et al. 2015):

$$ACH = \frac{\ln C(t1) - \ln C(t2)}{t2 - t1} \qquad \text{Eq. 2-1}$$

Where

ACH = air changes per hour,

$C(t_1)$ and $C(t_2)$ = $SF_6$ concentrations at times $t_1$ and $t_2$ consequtively,

$t_2 - t_1$ = measurment duration in hours.

Reference to (Xiaoshu et al. 2011), measuring AER based on tracer gas method is powerful but uneconomical and difficult to apply. You et al. (2007) stated that despite the popular utilization of $SF_6$ as a tracer gas; the large size and high-cost of instrumentations in addition to the high-cost of analysis procedures are major limitations. Due to the necessity of employing effective methods of lower-cost and more convenience for measuring AER, many calculation methods are developed to estimate AERs based on measured $CO_2$ concentrations. According to EPA (1991a), $CO_2$ presents a good indicator of ventilation adequacy and an efficient method for estimating AERs under well-studied test procedures. $CO_2$ measurements by real-time sampling method are relatively low-cost, time-efficient, and more convenient due to their smaller sizes, friendly-use and quietness compared with flow hoods or tracer gas methods (You et al. 2007; You et al. 2012; Turanjanin et al. 2014). For example, one of the recommended methods by AD EHSMS (2012) for estimating AERs is a calculation method depending on $CO_2$ concentrations adopting the following equation from EPA (1991a):

$$\textbf{Outdoor air (\%)} = \frac{C_S - C_R}{C_O - C_R} \times 100$$

Eq. 2-2

Where

$C_s$ = $CO_2$ concentratins in the supply air (when measured in a room), or

$CO_2$ concentrations in the mixed air (when measured at AC air handler),

$C_R$ = $CO_2$ concentrations in the return air,

$C_0$ = $CO_2$ concentrations in the outdoor air.

Then, the percentage of outdoor air is converted as follows (EPA 1991a):

$$\textbf{Outdoor air (in cfm)} = \frac{\text{Outdoor air (percent)}}{100} \text{ x total airflow (cfm)}$$

Eq. 2-3

Where

Total airflow = the supplied air quantity to a specific zone or space, or

= the total airflow by a HVAC system, or

= the air handler capacity.

Another prevailing AERs calculation method is based on the mass balance equation and uses measured indoor and outdoor $CO_2$ concentrations (Shaughnessy et al. 2006; Turanjanin et al. 2014; You et al. 2007; You et al. 2012; Kapalo et al. 2014; Haverinen-Shaughnessy et al. 2011; Haverinen-Shaughnessy et al. 2015). According to that equation the change of indoor $CO_2$ concentrations "*dC*" in infinitesimal time "*dt*" can be expressed as follows (Xiaoshu et al. 2011):

$$V\frac{dC}{dt} = Q(C_o(t) - C(t)) + G(t) \qquad \text{Eq. 2-4}$$

Where

$V$ = space volume,

$Q$ = volume of into/out airflow rate,

$C_0(t)$ = outdoor air $CO_2$ concentration at time $t$,

$C(t)$ = indoor air $CO_2$ concentration at time $t$,

$G(t)$ = $CO_2$ generation rate in the space at time $t$.

Based on Eq. 2-4, AER can be calculated by Eq. 2-5 when adopting the following assumptions: (i) constant airflow rate; (ii) the volume of into and out airflow rate are equal; (iii) the space is served by 100% fresh air; (iv) outdoor air $CO_2$ concentrations are constant; (v) indoor air is well-mixed; and (vi) indoor $CO_2$ generation is constant for sufficient duration (Xiaoshu et al. 2011; ASHRAE 2016; Persily & Jonge 2017).

$$Q = \frac{G}{(C_{eq} - C_o)} \qquad \text{Eq. 2-5}$$

Where

$C_{eq}$ = equilibrium $CO_2$ concentration,

$G$= $CO_2$ generation rate in the space.

Based on assumptions (i) to (v) in addition to (vii) having no $CO_2$ generation source, AER can be expressed as follows (Xiaoshu et al. 2011):

$$AER = \frac{1}{t} \ln \frac{(C(0) - C_o)}{(C(t) - C_o)} \qquad \text{Eq. 2-6}$$

Where

$C(0)$ = $CO_2$ concentrations at time $t = 0$.

Eq. 2-5 represents the steady state method – also called as equilibrium analysis or $CO_2$ peak approach – that was commonly used to calculate AER if an equilibrium $CO_2$ levels or a steady-state ($C_{eq} = CO_{2ss}$) is attained (Xiaoshu et al. 2011; ASHRAE 2016; Persily & Jonge 2017). Eq. 2-6 represents the decay method often used to estimate AERs during unoccupied periods (Turanjanin et al. 2014; Kapalo et al. 2014). The use of the steady-state and decay methods for estimating AERs were validated by You et al. (2007) who utilized both laboratory experiments and field measurements in meeting rooms, classrooms, offices, apartments, and dormitories over 3 to 5 days. Results showed acceptable laboratory performance because only 10% differences existed between the two methods, 10% was the range of duplicate precision, and the calculated AERs were about 90 – 120% of the real ones. Furthermore, measured AERs were comparable with those recorded in contemporaneous literature. However, the lack of accurate data regarding indoor $CO_2$ generation during occupied periods implies in imprecise AERs estimations. Despite that, You et al. (2007) considered calculating AERs based on indoor and outdoor $CO_2$ concentrations as an effective method that provides AERs in different indoor spaces. The obtained calculated AERs by the above two methods were also validated by Kapalo et al. (2014) by field measurements from an office case-study and they were almost similar. Shaughnessy et al. (2006); Haverinen-Shaughnessy et al. (2011); and Haverinen-Shaughnessy et al. (2015) relied on the steady-state method in calculating provided AERs and they succeeded in presenting congruent to their research objectives. They Followed a peak analysis approach in which Eq. 2-5 was utilized for calculating AERs and the peak measured $CO_2$ concentrations were assumed as ($CO_{2ss} = C_{eq}$). For attaining more accurate estimations of ventilation rates, occupancy data was collected during measurement periods.

### 3.5.2.2 Utilized AERs calculation method

This study adopted $CO_2$ steady-state method represented in Eq. 2-5, also called as equilibrium analysis or peak $CO_2$ approach, by this field study to calculate provided AER in the living room of the participating households where measurement equipment were installed (Xiaoshu et al. 2011; ASHRAE 2016; Persily & Jonge 2017). Reference to above discussion regarding prevailing AERs estimation methods, this method can yield reliable results in addition to its lower-cost, better time-efficiency; more convenience compared with direct AERs measuremEye, nose, throat, and tracer gas decay methods. Many contemporary studies have found $CO_2$ steady-state method as conveniEye, nose, throat, and sufficient in estimating AERs. For instance, Kapalo et al. 2014 used them to estimate AERs during occupied and unoccupied periods, respectively. Field measurements of indoor T, RH, pressure differences, wind velocity, indoor, and outdoor $CO_2$ were conducted in a real occupied office room. The obtained calculated AERs were validated by those experimental ones and they were almost similar. Findings showed that office buildings should have at least 0.7 l/h fresh ventilation rate instead of the provided one which was only 2.0 l/h. It also recommended that in case of not having sufficient data regarding $CO_2$ concentrations, at least 12.5 l/s. person of fresh airflow should be provided. A similar approach was performed by (Shaughnessy et al. 2006; Haverinen-Shaughnessy et al. 2011; Haverinen-Shaughnessy et al. 2015). Haverinen-Shaughnessy et al. (2011) examined the associations between students' academic performance and provided ventilation rates in classrooms. $CO_2$ concentrations were measured in 100 USA fifth-grade classrooms. AERs were calculated using Eq. (3-3) following the $CO_2$ peak analysis approach. $CO_2$ source generation was calculated according to U.S. EPA (1997) that estimated $CO_2$ generation rates by teachers as 0.0052 l/s. person and 0.0043 l/s. person for students. Linear relationship existed between students' academic performance and ventilation rates within the range of 0.9 – 7.1 L/s. person. Also, Haverinen-Shaughnessy et al. (2015) investigated the associations between some IEQ parameters and pupil's performance, health status and absenteeism. $CO_2$, settled dust, RH, and T were monitored in 70 USA schools throughout two academic years. Students' performance, socioeconomic, absenteeism, and health conditions were collected from the school district and anonymously retrieved. Ventilation rates were calculated based on $CO_2$ concentrations using the previous approach. Significant associations were found between students' scores in reading and mathematics tests and ventilation rates and indoor T. Ventilation rates were also associated with the number of students' visits to the school nurse with respiratory complaints.

For calculating AER using the steady-state method, the following assumptions were made: (i) constant airflow rate; (ii) the volume of into and out airflow rates are equal; (iii) the space is served by 100% fresh air; (iv) outdoor air $CO_2$ concentrations are constant; (v) indoor air is well-mixed; and (vi) indoor $CO_2$ generation is constant for sufficient duration (Xiaoshu et al. 2011). According to assumption (i), this method is only appropriate for calculating AER in spaces served with fixed airflow rates. For residential spaces, this method is largely convenient. As explained in Section 2.2, CAV systems and most of other terminal and individual units widely utilized in residential units provide fixed air flow rates (Xiaoshu et al. 2011; Bhatia 2012; Murphy & Bakkum 2013; Ali 2014). Assumption (ii) is based on the concept that exfiltration or infiltration rates are practically insignificant compared with mechanically supply and return ones. Referring to assumption (iii), Eq. 2-5 is only suitable for spaces with natural ventilation or with mechanical ventilation that provide 100% fresh air supply. To estimate the AER of fresh air when the space is served with mixed air, the percentage of outdoor air intake should be identified before applying Eq. 2-5. As the attainment of such information was difficult; the provision of 100% fresh air supply by applied ventilation systems was assumed in all participating households. One of the implications of that assumption is that percentage of fresh air in calculated AERs may be higher than what is really provided.

As previously explained, Eq. 2-5 is usually used to calculate AER if an equilibrium $CO_2$ levels or a steady-state ($CO_{2ss}= C_{eq}$) is attained (Xiaoshu et al. 2011; ASHRAE 2016; Persily & Jonge 2017). Following a peak analysis approach similar to (Shaughnessy et al. 2006; Haverinen-Shaughnessy et al. 2010; Haverinen-Shaughnessy et al. 2015); the measured peak average of $CO_2$ concentrations were utilized as the $CO_{2ss}$ value. For attaining more accurate estimations of provided AERs; occupancy profiles during the measurement period in the living room – where monitoring equipment were installed – was recorded by the household head in the diary note shown in Appendix K. According to recorded occupancy profiles; provided AER was calculated during the occupancy period of peak $CO_2$ concentration. Reference to (ASHRAE 2016; Persily & Jonge 2017; ASHRAE 2016; Szczepanik-ścisło 2018; Persily 2016), estimated $CO_2$ generation rate as per the ASTM Standard for an averaged size adult practicing office work at 1.2 met units is 0.0052 L/s. Whereas it is 0.0029 L/s for a child engaged in similar physical activity level (Persily & Jonge 2017). Thus, $CO_2$ generation rate in the peak period was calculated based on those values as per recorded number of occupants in the living hall during that period. Reference to (ASHRAE 2016; Persily & Jonge 2017; Persily 2016); reliable studies have found that an AER of about 7.5 l/s. per person (15 cfm) of fresh air for sedentary occupants is sufficient to dilute odors from human bioeffluents or body odors for the substantial majority of unadapted visitors. Reference to ASHRAE (2016), attaining an indoor steady-state $CO_2$ ($CO_{2ss}$) concentration not more than about 700 ppm of ambient air levels can be considered as an indication that provided AER is sufficient for a substantial majority of visitors (80%) with respect to human bioeffluents. Also, according to ASHRAE (2016), the acceptable range of outdoor $CO_2$ is from 300 to 500 ppm and that higher concentrations than that may be considered as indicator for combustion and/or other pollution sources. Based on that, the range of indoor $CO_2$ concentrations that can be considered as an indication of sufficient AERs is from 1000 – 1200 ppm.

### 3.5.3 Field study survey

As explained in Section 3.5.1, self-administered questionnaires shown in Appendix F were distributed to participants to be filled after 24 hours from launching measurements. The utilized questionnaire was similar to that used in the cross-sectional survey shown in (Appendix D & Appendix E) in terms of their inclusion of similar variables in both. Following the main survey, the field study survey was divided into four sections: (i) personal characteristics, (ii) building parameters, (iii) IEQ parameters; and (iv) health symptoms (Table 3-33). Building and population variables and their measuring items were typical to those utilized in the main questionnaire (Table 3-8 & Table 3-9).

Table 3-33: Sections of the field study questionnaire

| | Item no. | Variable | Variable code |
|---|---|---|---|
| **I** | 1 - 6 | Population | P1 – P6 |
| **II** | 7 – 19 | Building | B7 – B19 |
| **III** | | Perceived IEQ | |
| | 20 – 28 | Odor perceptions | O1 – O9 |
| | 31 – 36 | Thermal comfort perceptions | C3 – C8 |
| | 37 – 38 | Lighting comfort perceptions | C9 – C10 |
| | 39 – 40 | Noise comfort perceptions | C9 – C10 |
| | 29 – 30 | IAQ comfort perceptions | C1 – C2 |
| | 41 | IAQ rating | A1 |
| **IV** | 42 - 52 | Health symptoms | H1 – H30 |

However, a change was made in the items measuring the IEQ and SHS symptoms variables which was adopted from EPA's "Indoor Air Quality and Work Environment Follow up Survey" (EPA 1991b). One of the major differences between the two questionnaires utilized by this research was that the 1st survey was not accompanied with field measurements and it reported IEQ perceptions and the prevalence of SHS symptoms over the whole last year. Contrarily, the questionnaire utilised in the field study was accompanied with field measurements of some IEQ parameters and it reported IEQ perceptions and the prevalence of SHS symptoms during the measurement day only. Hence, this field study questionnaire and EPA's follow up questionnaire was similar in terms of their interest to report participants' perceptions on measurement day only. Based on that, the following difference existed between the two questionnaires; the main survey and the field study. The difference existed in (Items no. 20 – 40 & 42 – 52) reported in 5-point Likert scale in the main survey inquiring about IEQ perceptions and prevalent SHS throughout the whole past. The 5-point Likert scale afforded participants 5 ranges to report the frequency of the measured variable during the long year duration. However, the above items in the field study survey were binary in which participants were asked to report whether they had experienced the variable during the measurement day only (Table 3-34 & Appendix F).

Table 3-34: Items measuring IEQ variables in the field study questionnaire

| Item no. | Variable | Variable code | Variable type |
|---|---|---|---|
| 20 – 28 | Odor perceptions | O1 – O9 | Binary |
| 31 – 36 | Thermal comfort perceptions | C3 – C8 | ,, ,, |
| 37 – 38 | Lighting comfort perceptions | C9 – C10 | ,, ,, |
| 39 – 40 | Noise comfort perceptions | C9 – C10 | ,, ,, |
| 29 – 30 | IAQ comfort perceptions | C1 – C2 | ,, ,, |
| 41 | IAQ rating | A1 | Ordinal |
| 42 - 52 | Health symptoms | H1 – H30 | Binary |

## 3.6 Research protocol

The conduct of this research involved the performance of the pilot survey, main survey, in addition to the field study described in Section 3.30, 3.4, and 3.50; respectively. The conduct of this research fieldwork followed the below procedures:

1. Conduct the pilot survey using the questionnaire illustrated in Appendix B and Appendix C. 120 questionnaires were distributed via internet and personal communications. Participants were completely informed about the implications, responsibilities, and rights of their inclusion in the study via a consent letter (Appendix L). Along with collecting questionnaires, collected data was entered in SPSS. Both the validity and reliability of the questionnaire was tested. Moreover, modifications on the questionnaire were performed based on derived recommendations from the pilot survey.

2. Conduct the main survey using the questionnaire illustrated in Appendix D and Appendix E. 770 questionnaires were distributed via internet and personal communications. Participants were completely informed about the implications, responsibilities, and rights of their inclusion in the study via a consent letter (Appendix L). They were also be informed about the field study and asked about their interest to participate in it. Along with collecting questionnaires; collected data was entered in SPSS.

3. Analyzing collected data from the questionnaires as per proposed statistical procedures.

4. Conduct the field study on 60 Dubai households that positively answered requests sent manually or via emails to voluntarily participate in the field study. Participants were completely informed about the implications, responsibilities, and rights of their inclusion in the study via a consent letter (Appendix M). The field study encompassed the conduct of three methods which were field measurements of

HCHO, $PM_{2.5}$, $PM_{10}$, $CO_2$, CO, TVOC, T, and RH; calculating provided AERs; and a self – administered questionnaire (Appendix F). Performing the above methods involved two visits to each household. Performing the field study was accomplished following below steps:

i. Performing the 1st visit to the 1st household during which the following duties were executed:

  - Filling the walkthrough check list demonstrated in Appendix J that collected general data regarding the building and applied ventilation system i.e. age, construction, occupancy levels, HVAC type, maintenance procedure, outdoor air percentage … etc. The proposed checklist was adopted and adapted from the standardized protocol building and HVAC check lists (EPA 1991a).

  - Determining the outdoor sampling point where outdoor $CO_2$ was conducted following recommended guidelines by EPA (1991a) (Section 3.5.1). Accordingly, the sampling point for measuring outdoor $CO_2$ concentrations was at a suitable nearest point to where fresh outdoor air intake occurs.

  - Determining the location where indoor sampling point. Regarding this, and as agreed by the majority of relevant research (Yeatts et al. 2012a; Turanjanin et al. 2014; Park et al. 2014), the study intended to fix the devices at a central point at breathing zone height (4 – 6ft ≈ 1.2 – 1.8m) in a room where household members usually spend most of their time. The particular location for indoor sampling point was decided case by case in consultation with participants. A table of 1.2 m with a plane area sufficient to accommodate the monitoring instruments was available in each field visit to be used if needed and accepted by the participant.

- Handing the self - administered questionnaires shown in Appendix F to the participating household head to be filled and returned back on the 2nd visit. Each participant was fully informed about the implications, responsibilities, and rights of their inclusion in the study via direct communication and a consent letter shown in Appendix M .

- Affording a diary note demonstrated in Appendix K to the participant to record variations in occupancy profiles in terms of occupants’ number, performed activities, window opening behaviors, in addition to and the HVAC system operation status in the living room throughout the measurement period.

- Conducting field measurements of the specified IEQ variables indoors and outdoors following the SOPs demonstrated in Appendix T, Appendix U, and Appendix V.

ii. Performing the 2nd visit to the 1st household after 24 hours or when it was convenient for the participant. During this visit, all instruments utilized in air monitoring were reinstalled and took out from the 1st household.

iii. Collected data from field measurements were properly saved and backed up.

iv. Repeating Steps (i – iii) for the remaining households.

5. Analyzing collected data from field study as per proposed statistical procedures.

## 3.7 Summary of research methodology

Reference to research aims (Section 1.4); this study can be classified as an applied social research because it targeted: (i) knowledge expansion regarding IEQ and SHS in UAE housing, (ii) developing suitable resolution strategies i.e. appropriate ventilation rates, and (iii) explaining particular behavioral patterns within a social context. Like most investigations in this domain; it fell within the quantitative paradigm characterized by its numerical outcome that quantified the variations and predicted associations between variables. Most of IAQ and SBS investigations are quantitative ones utilizing both experimental and non-experimental approaches. Experimental designs establish rigorous cause-and-effect relationships between few variables and require full control on confounders. For this research, the non-experimental approach was suggested as more congruent one. That is because the complexity and ambiguity concerning the associations between the IEQ variables and SBS symptoms makes the assumption of having full control on all confounders unattainable. Hence, conducting an experimental study under incompletely controlled conditions threatens the experiment internal validity.

Thus, this study opted to utilize non-experimental methods to achieve its aims. The non-experimental approaches encompass surveys and field studies. It was found that a survey was required to reflect current IEQ conditions and prevalent SHS symptoms in Dubai housing and to explore the associations between them. A survey is an appropriate research method in answering “who, what, where, how many, and how much” questions. It is a feasible research method due to their relative low cost and wide coverage. Also, the precedence of understanding the associations between various SBS parameters is fundamental when launching investigations regarding the associations between IEQ conditions and SBS symptoms or prior conducting an experimental study. However, conducting a survey as a sole instrument is insufficient in revealing clear information regarding measured parameters and contextual characteristics as its major focus is reflecting population trends and generalizability issues. On the other hand, despite their higher cost compared with questionnaires; field measurements were widely employed in similar investigations as they reveal clearer information regarding measured parameters and contextual characteristics. Based on the above, it was decided to conduct field measurements for some prominent IEQ variables as part of a field study in which questionnaires and AERs calculation were also performed. The main aim of the field study was to provide clearer information regarding the prevalence of measured parameters in Dubai housing and their compliance with national and/or international standards. Thus, the two major research methods utilized by this study were: (i) a cross-sectional survey collecting data from 770 Dubai residents, and (ii) a field study that included field measurements of some IEQ parameters, a questionnaire, and estimated AERs provided in 60 households in Dubai. A pilot survey covering 120 households in Dubai was conducted prior the conduct of the main survey. The pilot survey was conducted to examine the reliability and validity of the proposed questionnaire and to develop it accordingly.

According to relevant researches, various sampling methods are utilized in measuring IAQ chemical and physical characteristics. They can be identified as: (i) continuous, integrated, and spot methods based on data output; (ii) active and passive methods based on sampling collection technique; and (iii) direct-measuremEye, nose, throat, and laboratory-required analysis methods based on results' instantaneousness. Each category has its advantages and advantages. For instance, continuous sampling affords real-time measurements of a substance concentrations that enables observing peak short-term concentrations. Integrated sampling affords an average of measured concentrations over a specific period. They are of lower cost and requires less personnel while their limitatons are the non-demonstration of peak short-term measurements. Spot sampling affords single samples measured at particular intervals. It is the cheapest with least-demand of manpower and appropriate for large-scale surveys when the knowledge of average substance concentrations or temporal fluctuations during a specified period is not important. The selection of the appropriate sampling instruments depends on many factors such as: (i) Ease of use i.e. portability, noise, vibration, direct-reading vs. laboratory analysis required, ruggedness, time required for each measurement; (ii) Quality assurance i.e. availability of service and customer support, maintenance, and calibration requirements; (iii) Output i.e. time-averaged vs. instantaneous readings, sensitivity, compatibility with computer or data logging accessories; (iv) Cost i.e. commercial availability, single use only vs. reusable, purchase vs. rental.

Reference to the previously described sampling methods; this study proposed active sampling methods as more appropriate than passive sampling devices (PSDs). Active samplers have the capability to continuously measure contaminants of low and high-concentrations and to report peak short-term concentrations. Comparatively, PSDs are frequently used to provide TWA readings for contaminants of high-concentrations within short periods but they need longer periods to collect sufficient sample of low-concentrations. Subsequently, the peak short-term concentrations occurring during the measured period is not reported by PSDs. The issue of measuring the peak short-term concentrations is of particular importance in fulfilling this research objective to characterize current IEQ of UAE housing. Field measurements for indoor HCHO, $PM_{2.5}$, and $PM_{10}$, CO, $CO_2$, TVOC, RH, and T levels were performed in 60 households. The proposed parameters to be measured were the focus of many contemporaneous studies. $PM_{2.5}$ and $PM_{10}$ were continuously measured for 24 hours in each household using the Optical Particle Sizer (OPS) Model 3330 (Size resolution ±5% @ 0.5 µm, range 0.3 – 10µm). Moreover, a spot measurement for a single sample drawn during 30 minutes was conducted to measure the indoor HCHO concentrations in each household. HCHO was measured using the gas detector Model FP 30 (Accuracy ±10%rdg, Range 0.01 – 1.0ppm). Additionally; CO, $CO_2$, TVOC, RH, and T were continuously measured for 24 hours in each household using DirectSense IQ – 610. The device was also used to perform a spot measurement of outdoor $CO_2$, CO, TVOC, RH, and T levels. $CO_2$ was measured using non-dispersive infrared (NDIR) sensor (Accuracy ±3%rdg ±50ppm, Range 0 to 10,000ppm); CO was measured using electrochemical sensor (Accuracy ±2ppm<50ppm, ±3%rdg >50ppm; Range 0 – 500 ppm); TVOC was measured using photoionization detector (PID) (Resolution 1ppb, Range 5 to 20,000ppb); while T and RH were measured using electronic sensors (T: Accuracy ±0.3°C, Range -25 to +70°C; RH: Accuracy: ±2%RH <80%RH (±3%RH>80%RH ); Range 0 to 100 %RH). The above measurements were performed during 9 months starting from Thursday 14th September 2017 up to Monday 11th June 2018. Notably that the three utilized monitoring devices were manufacturer calibrated prior launching the field measurements.

Concerning provided AERs, they can be measured by direct or indirect methods. Direct AERs measuring methods such as flow hoods are relatively complicated, expensive, and sometimes inconvenient. Comparatively, indirect methods estimate AERs based on measuring another parameter's concentrations by employing relatively easier and cheaper instruments. For example, AERs can be estimated by using the tracer gas method decay that encompasses injecting a specific tracer gas in the space, measuring its concentrations and calculating AERs accordingly. Measuring AER based on tracer gas method is powerful but uneconomical and difficult to apply. Another prevailing AERs calculation method is based on the steady state and decay methods that uses measured indoor and outdoor $CO_2$ concentrations. Real-time $CO_2$ measurements are relatively low-cost, time-efficient, and more convenient due to their smaller sizes, friendly-use and quietness compared with flow hoods or tracer gas methods. The two methods were validated by many researches and considered as effective methods in estimating AERs. However, the lack of accurate data regarding $CO_2$ indoor generation might imply in imprecise estimations. Based on mentioned advantages; this study adopted $CO_2$ steady-state method in the field study to calculate provided AER in the living room of the participating households where measurement equipment was installed. Following a peak analysis approach; the measured peak average of $CO_2$ concentrations were utilized as the $CO_{2ss}$ value. For attaining more accurate estimations of provided AERs; occupancy profiles during the measurement period in the living room was recorded by the household head in a diary note According to recorded occupancy profiles; provided AERs were calculated during the occupancy period of peak $CO_2$ concentration. $CO_2$ generation rate in the peak period was calculated based on recorded number of occupants in the living hall during that period. Reference to ASHRAE (2016); an AER of about 7.5 l/s. person of fresh air for sedentary occupants is considered as sufficient to dilute odors from human bioeffluents or body odors for the substantial majority (80%) of unadapted visitors. Also, attaining an indoor steady-state $CO_2$ ($CO_{2ss}$) concentration $\leq$ 700 ppm of ambient air can be considered as an indicator of having sufficient provision of AER indoors.

# Chapter 4 : Results, analysis, and discussions

## 4.1 Main survey

As per calculations performed in Section 3.4.1, a sample size of 380 – 500 cases was suggested as sufficient for this study. However, to reduce the sampling error, it was initially proposed to distribute 600 questionnaires. At the beginning, the questionnaires were sent to 170 participants. However, due to the low online response rate and in a trial to boost it; face to face method was utilized in distributing 600 questionnaires. Thus, 770 questionnaires were distributed during 1st July 2017 – 15th June 2018. As discussed in Section (3.4.2), survey sampling strategy followed a non-probability sampling method that allowed participation for only those who have convenient access i.e. internet access or having social relation with the researcher (Alreck & Settle 2004; Cohen et al 2011). The population size, sampling frame, sample size, and response rate were unknown in such a case (Cresswell 2014). Although the survey was not randomly distributed nor it had a sampling frame, a rough estimation of the response is provided based on the number of responses out of the whole number of distributed questionnaires. According to (Morton et al. 2012; Centers for Disease Control and Prevention 2010), response rate can be estimated by dividing the number of completed cases by the number of cases asked to participate. The final valid cases used in the statistical analysis was 543 cases of which 66 were answered online while 477 were collected face to face. Only 80 out of the 170 online questionnaires were answered while only 66 questionnaires were completed resulting in about 39% response rate. The response rate for the face to face questionnaire was better because 477 questionnaires were completed out of 600 distributed ones resulting in about 80% response rate. The response rate for all distributed questionnaires whether face to face or online was 71% which is an acceptable rate (Linderman 2018; Nulty 2008; Fincham 2008). References to recent studies, these response rates were consistent with other contemporaneous studies. According to (Linderman 2018), although the growing popularity of online surveys recently, their low response rate has been concerning. The estimated response rate for online surveys as per Saleh & Bista (2017) was 11% less than other survey methods. Reference to (Linderman 2018; Nulty 2008), response rate for face to face surveys is the best as its average response rate is approximately 56%. Whereas, average response rates for online surveys ranges between 29 to 33%. According to Fincham (2008), an approximate 60% response rate is expected to be achieved by most research to avoid non-response bias and the non-representativeness of the sample.

### 4.1.1 Data preparation

All population, building, odors, comfort, and health variables shown in Table 3-8, Table 3-9, Table 3-10, Table 3-19, and Table 3-27 are included in the analysis except Q9 in Table 3-8 regarding the number of occupants per age. That is because the majority of participants did not indicate the number of their family members within specified age group. Regarding Q7 inquiring about participants' living area in Dubai, the provided areas were categorized as per Dubai Sectors shown in Appendix X. Each sector was then dealt with as binary variable. Coding for binary variables, except gender and house type, was ("No" = 0, "Yes" =1). Coding for gender was ("Male" = 0, "Female"=1) while for house type was ("Flat" = 0, "Villa" = 1). All ordinal population and building parameters were coded as ("1st option" = 0, "2nd option" = 1, "3rd option" = 2 ….etc.). Coding for the 5 point Likert scale used in measuring the odor, comfort, and health symptoms variables was ("Never" = 0, "1 – 3 days/Year" = 1, "1 – 3 days/Month" = 2, "1 – 3 days/Week" = 3, "Daily/ Almost daily" = 4).

Notably that the health symptoms questions had two parts. The first part was inquiring about the frequency of experiencing a particular health symptom reported in 5 point Likert scale and coded as previously explained. The second part inquired about how the experienced symptom develop when going outdoors and it had 3 optional answers which were "Gets more", "Stay same", and "Gets less". As per SHS syndrome definition (Section 2.1); symptoms frequently experienced that became less outdoors can be considered as SHS symptoms (Turpin 2014; Hess-Kosa 2011; Gomzi & Bobic 2009; OSHA 1999). In practice, according to (Andersson 1998; Raw et al. 1996), the positive answer in the MM 040 NA questionnaire is the "Yes, often" while "Yes, sometimes" and "No, Never" are considered as negative. Reference to (EPA 2003), "Fairly often" is equivalent to 1 - 3 days per month while “Very often” is equivalent to daily or almost every day. Similarly, the positive answer interpreted from the 5 point Likert scale used in EPA questionnaire (EPA 1991b) was “Often” and “Always” while other points which are “Never”, “Rarely”, and “Sometimes” were considered as negative. Based on that, the equivalent points to “Often” and “Always” in this study questionnaire are “1 – 3 days/ Week” and “Daily/ Almost daily”. Subsequently, descriptive statistics of SHS cases in this study were calculated based on those symptoms that occurred at least once a week and became better outdoors. Worth noting that the MLR analysis was not performed in only the identified ones as SHS symptoms following the above definition but it involved all reported health symptoms. This approach was followed by (EPA 1991b; Runeson et al. 2006; Wang et al. 2008; Kanazawa et al. 2010; Wang et al. 2013; Syazwan et al. 2013; Chang et al. 2015). According to (EPA 1991b), some building related symptoms might worsen when going out of them such as back or muscle pain. Other symptoms that are building related ones might stay same for long period even when going outside the building. Whereas some non-building related symptoms might improve when leaving the building because of natural causes i.e. headaches that start in the morning before going to work and gets better after leaving the office. One of the observations in this study was that substantial number of participants noted that they experienced some health symptoms but the pattern on which those symptoms develop was indefinite or inconstant. Chang et al. (2015) and Wang et al. (2008) suggested employing the broader definition of SHS symptoms that encompass all symptoms whether continuously or sporadically occurring so as to reveal more potential risk factors. Based on that, it was decided to run the MLR analysis on all reported health symptoms in order to avoid situations that might lead to misclassification and subsequently result in concealing some potential risk factors. In future, further analysis of only identified SHS may be performed and a comparison between the two results may be provided.

### 4.1.2 Reliability and distribution tests

Cronbach’s alpha was computed to examine the reliability or the internal consistency of the data collected by the survey. Regarding the health symptoms measures (Global DV), Cronbach’s alpha is 0.890. Computed Cronbach alpha is 0.864 for all IEQ measures (Global IV) that include odor measures in addition to IAQ, Thermal, Lighting, and Noise measures. Regarding the reliability of the subscales, Cronbach alpha is 0.828 for IEQ comfort factor that include IAQ, thermal, light, and noise items. For odors measures, Cronbach alpha is 0.734. As discussed in Section 3.3.4.1, an alpha of 0.70 is acceptable (Suliman & Al Kathairi 2013; Tavakol & Dennick 2011; Suliman et al. 2010; Parsian & Dunning 2009; DeVon et al. 2007). According to DeVellis (1991), Cronbach alpha values for the Global DV, Global IV, and IEQ comfort measures are classified as very good and it is respectable for the odors measures. Thus, the alpha computed for the global IV and DV in addition to the subscales indicates a high correlation between the items and that the measures are consistently reliable. Regarding the collected data distribution; global DV factor, global IV, IEQ comfort, and odors factors were tested for normality using the Kolmogorov-Smirnov one-sample test. Results shows that data was not normally distributed for all above factors since the test result was highly statistically significant at $p < 0.001$ for the global DV, global IV, and odors factor and $p < 0.01$ for the IEQ comfort measures.

### 4.1.3 Descriptive statistics

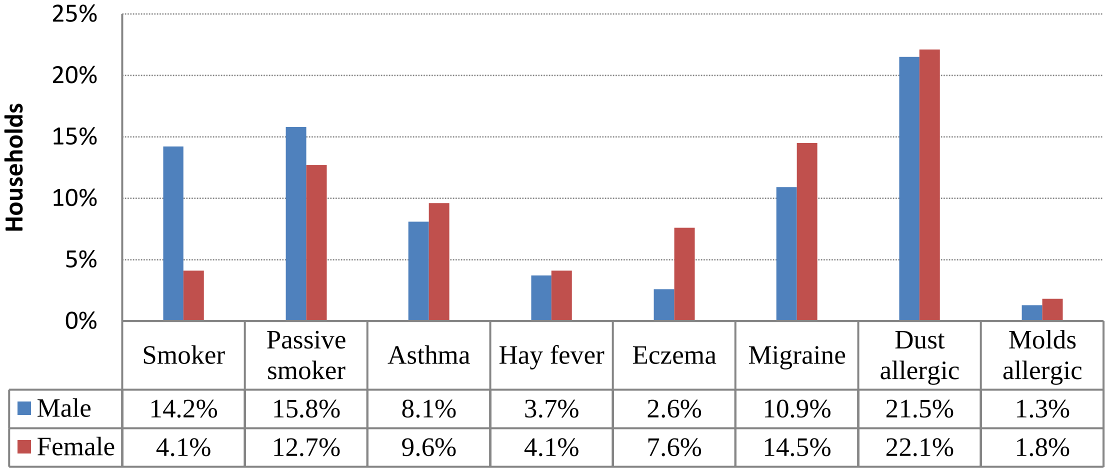
The demographic characteristics of the sample are illustrated in Table 4-1. 54% of the participants were male while the females were 46%. The nationality of the highest participation in this study was the Indian Subcontinent Nationals who were 51.4% followed by the other Africans (18.8%), Arabs or MENA Nationals (14.5%), UAE or GCC Nationals (10.9%), Europeans, Oceanians, and South/North Americans (3.7); and other Asians (0.7%). 62% of the participants were 18 – 34 years old while 33.3% were between 35 – 54 years old. Thus, the participation in this questionnaire is relatively equal gender wise. That is not matching with Dubai demographics being highly male skewed comprised of 70%

male and 30% female (DSC 2016). That is not considered as concerning because participants in this survey were asked to report the IAQ and SHS experiences of the whole household's members. Regarding the sample representation of UAE population, the UAE Nationals represents 8% of Dubai population while others are non UAE Nationals (DSC 2017b). And according to (US CIA 2018) estimation of UAE population, the South Asians are 59.4%; Emiratis are 11.6%; Egyptians are 10.2%; while other nationalities are 12.8%. Also, reference to (AbuDhabi2 2018), South Asians in UAE are estimated as 53.5%, UAE Nationals 11.5%, other Arabs as 12%, South East Asians as 6.5%, Westerners as 3.5%, and others about 13%. Based on that, the sample is relatively representing the UAE population in terms of nationalities particularly for the Indian Subcontinent nationals; Arabs or MENA Nationals; UAE or GCC Nationals; and Europeans, Oceanians, and South/North Americans. The only group that is not well represented by the sample is the "Other Asians".

Table 4-1: Population demographic characteristics

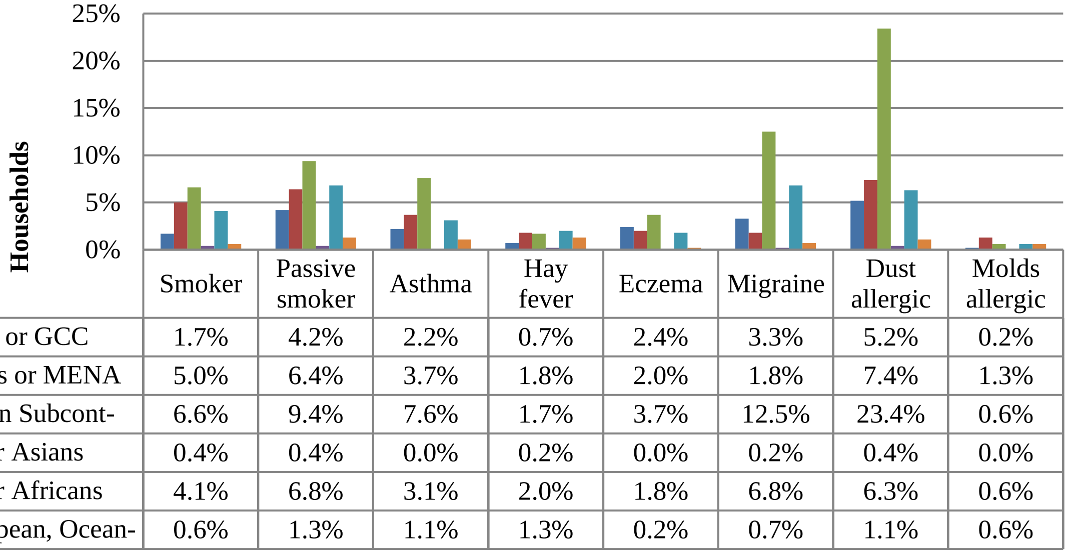
| | **Gender** | | **Nationality** | |
|---|---|---|---|---|
| | N | % | N | % |
| Male | 293 | 54 | | |
| Female | 250 | 46 | | |
| UAE or GCC National | | | 59 | 10.9 |
| Arabs or MENA National | | | 79 | 14.5 |
| Indian Subcontinent National | | | 279 | 51.4 |
| Other Asians | | | 4 | 0.7 |
| Other Africans | | | 102 | 18.8 |
| European, Oceanians, North or South American | | | 20 | 3.7 |
| Total | 543 | 100 | 543 | 100 |

Regarding the population smoking habits shown in Table 4-2, about 18% are smokers while passive smokers are more than the first hand smokers by 10%. 14% of the smokers are male and only 4% are females (Figure 4-1). As shown in Table 4-2, the most prevalent health disorder among UAE residents was having dust allergy reaching up to about 44% followed by migraine (25%), asthma (18%), eczema (10%), hay fever (8%), and the least prevalent was being mold allergic (3%). Females suffered more than male from all those health disorders. As per nationality, being dust allergic was the most prevalent among all nationalities except for the “Other Africans” and “Europeans, Oceanians, and North/South Americans” (Figure 4-2). Having migraine is the most prevalent disorder among “Other Africans” while hay fever among the “Europeans, Oceanians, and North/South Americans” while allergy to dust was the second. On the other hand, the least prevalent health disorder among all nationalities except for the “Europeans, Oceanians, and North/South Americans” was having allergy to mold.



| | Smoker | Passive smoker | Asthma | Hay fever | Eczema | Migraine | Dust allergic | Molds allergic |
|---|---|---|---|---|---|---|---|---|
| 🟦 Male | 14.2% | 15.8% | 8.1% | 3.7% | 2.6% | 10.9% | 21.5% | 1.3% |
| 🟥 Female | 4.1% | 12.7% | 9.6% | 4.1% | 7.6% | 14.5% | 22.1% | 1.8% |

Figure 4-1: Population health characteristics as per gender



| | Smoker | Passive smoker | Asthma | Hay fever | Eczema | Migraine | Dust allergic | Molds allergic |
|---|---|---|---|---|---|---|---|---|
| 🟦 UAE or GCC | 1.7% | 4.2% | 2.2% | 0.7% | 2.4% | 3.3% | 5.2% | 0.2% |
| 🟥 Arabs or MENA | 5.0% | 6.4% | 3.7% | 1.8% | 2.0% | 1.8% | 7.4% | 1.3% |
| 🟩 Indian Subcont- | 6.6% | 9.4% | 7.6% | 1.7% | 3.7% | 12.5% | 23.4% | 0.6% |
| 🟪 Other Asians | 0.4% | 0.4% | 0.0% | 0.2% | 0.0% | 0.2% | 0.4% | 0.0% |
| 🟦 Other Africans | 4.1% | 6.8% | 3.1% | 2.0% | 1.8% | 6.8% | 6.3% | 0.6% |
| 🟧 European, Ocean- | 0.6% | 1.3% | 1.1% | 1.3% | 0.2% | 0.7% | 1.1% | 0.6% |

Figure 4-2: Population health characteristics as per nationality

Table 4-2: Population smoking habits and health characteristics

| | **Smoking** | | **Passive Smoking** | | **Asthma** | | **Hay fever** | | **Eczema** | | **Migraine** | | **Dust allergy** | | **Molds allergy** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | % | N | % | N | % | N | % | N | % | N | % | N | % | N | % |
| Non smoker | 444 | 82% | | | | | | | | | | | | | | |
| Smoker | 99 | 18% | | | | | | | | | | | | | | |
| No passive smoke | | | 388 | 72% | | | | | | | | | | | | |
| Passive smoke | | | 155 | 28% | | | | | | | | | | | | |
| Not having asthma | | | | | 447 | 82% | | | | | | | | | | |
| Having asthma | | | | | 96 | 18% | | | | | | | | | | |
| Not having hay fever | | | | | | | 501 | 92% | | | | | | | | |
| Having hay fever | | | | | | | 42 | 8% | | | | | | | | |
| Not having eczema | | | | | | | | | 488 | 90% | | | | | | |
| Having eczema | | | | | | | | | 55 | 10% | | | | | | |
| Not having migraine | | | | | | | | | | | 405 | 75% | | | | |
| Having migraine | | | | | | | | | | | 138 | 25% | | | | |
| Not having dust allergy | | | | | | | | | | | | | 306 | 56% | | |
| Having dust allergy | | | | | | | | | | | | | 237 | 44% | | |
| Not having molds allergy | | | | | | | | | | | | | | | 526 | 97% |
| Having molds allergy | | | | | | | | | | | | | | | 17 | 3% |
| Total | 543 | 100% | 543 | 100% | 543 | 100% | 543 | 100% | 543 | 100% | 543 | 100% | 543 | 100% | 543 | 100% |

Regarding the location of the participating households, and reference to Dubai Statistics Centre (DSC 2017c), Dubai is categorized into 9 sectors. The participation was from households located in 8 sectors in Dubai (Table 4-3). The highest participation was from participants residing in Dubai Sector 3 reaching up to about 28% followed by Sector 6 from which 26% had participated then 23% of the participation was from Dubai Sector 2. Participants from Sector 1, Sector 4, Sector 5, Sector 8, and Sector 7 were 8.3%, 3.1%, 0.6%, 0.4%, and 0.2%; respectively. Appendix W exhibit lists of the 74 Dubai communities of participating households categorized per sector. Regarding the building characteristics of the sample shown in Table 4-4, about 423 (78%) were flats while the other 120 houses are villas (22%). Approximately half of those houses (51%) were built more than 10 years backwards while about 25%, 13%, and 11% were 7 – 10 years, 4 – 6 years, and less than 3 years; respectively. On the other hand, about half of the participants were living in their houses for less than 3 years. The majority of the houses (59%) had attached closed kitchen, 26% have open kitchens while only 15% had unattached Kitchen that is locally called as Mulhag. The applied HVAC system in 71% of the houses was the central system while 19% of the houses had a split HVAC and 9% had window HVAC systems. Only 5 houses (0.9%) applied both central and split HVAC whereas 3 houses (0.6%) applied split and window HVAC systems.

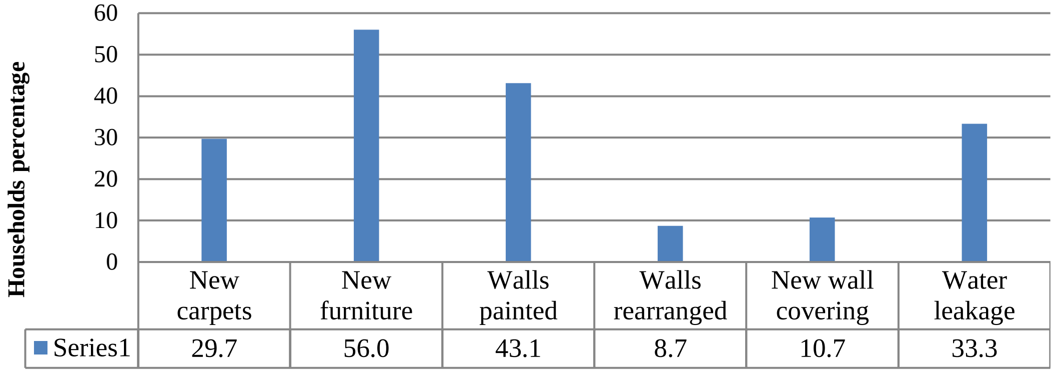
Table 4-3: Participating households per Dubai sectors

| | **Sector** | **Frequency** | **% of Total** |
|---|---|---|---|
| 1 | Sector 1 | 45 | 8.3 |
| 2 | Sector 2 | 125 | 23.0 |
| 3 | Sector 3 | 150 | 27.6 |
| 4 | Sector 4 | 17 | 3.1 |
| 5 | Sector 5 | 3 | 0.6 |
| 6 | Sector 6 | 139 | 25.6 |
| 7 | Sector 7 | 1 | 0.2 |
| 8 | Sector 8 | 2 | 0.4 |
| | Missing | 61 | 11.2 |
| | Total | 543 | 100 |

In terms of the events that took place during last year, about one third of the households (33.3%) reported having water leakage (Figure 4-3). Moreover, more than half of the households (56%) had new furniture while 43.1% had walls painted and 29.7% had new carpets. The least occurring change was having rearranged walls (8.7%). Figure 4-4 sheds more light on the magnitude of odors experienced as sufficiently often. The most prevalent odors experienced sufficiently often were “Fishy and food odors”, “Body and cosmetics odors”, “Tobacco smoke”, and “Smoke from incense burning” that occurred in 20.8%, 19.7%, 19.5%, and 19% of the population at least 1 – 3 days/ week. Odors from chemicals, dampness odors, diesel or engine exhaust, odors from new carpets, and odors from paint were sufficiently often experienced in 6.4%, 6.1%, 5.4%, 4.4%, and 4.2% of the households (Figure 4-4). Regarding IEQ discomfort measures illustrated in Figure 4-5, the most prevalent one was dust and dirt that experienced by 28.9% of the population at least 1 -3 days/ week. The next three sufficiently prevalent IEQ discomfort measures were “Too quiet”, “Too hot”, “Too humid”, and “Too noisy” that occurred in 22%, 21.9%, 18.8%, and 18.6%. Whereas “Too cold” was sufficiently frequently experienced by 17%, “Too glary” by 13%, “Too dim” by 11%, “Little air” by 15%, “Too dry” by 16%, and “Stuffy bad air” was sufficiently frequently experienced by 14% of the households at least 1 -3 days/ week.

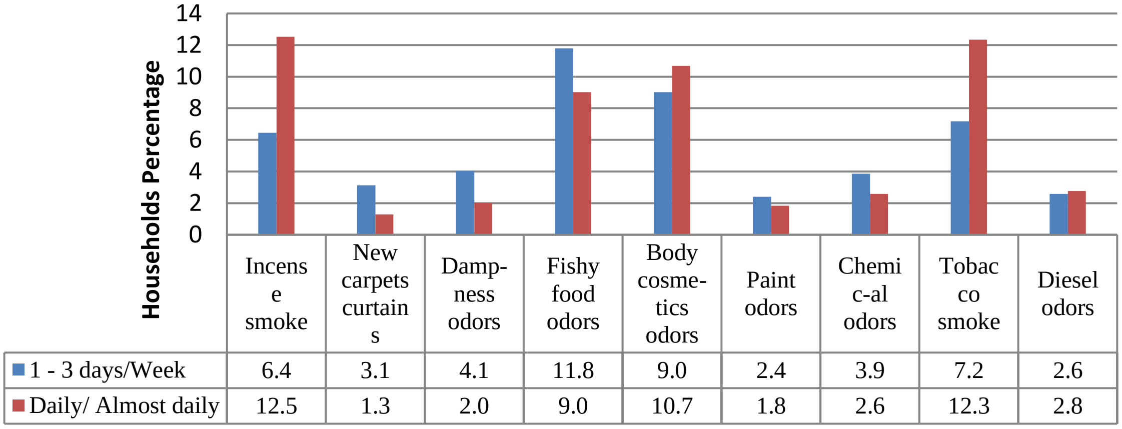
Table 4-4: Building characteristics of the sample

| | **House type** | | **Residency duration** | | **Building age** | | **Kitchen type** | | **AC type** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | % | N | % | N | % | N | % | N | % |
| Flat | 423 | 77.9% | | | | | | | | |
| Villa | 120 | 22.1% | | | | | | | | |
| Less than 3 yrs | | | 283 | 52.1% | | | | | | |
| 4 – 6 yrs | | | 124 | 22.8% | | | | | | |
| 7 – 10 yrs | | | 68 | 12.5% | | | | | | |
| More than 10 yrs | | | 68 | 12.5% | | | | | | |
| Less than 3 yrs | | | | | 60 | 11% | | | | |
| 4 – 6 yrs | | | | | 69 | 12.7% | | | | |
| 7 – 10 yrs | | | | | 135 | 24.9% | | | | |
| More than 10 yrs | | | | | 279 | 51.4% | | | | |
| Separate kitchen | | | | | | | 79 | 14.5% | | |
| Open kitchen | | | | | | | 143 | 26.3% | | |
| Closed kitchen | | | | | | | 321 | 59.1% | | |
| Central AC | | | | | | | | | 385 | 70.9% |
| Split AC | | | | | | | | | 101 | 18.6% |
| Window AC | | | | | | | | | 49 | 9.0% |
| Central & split AC | | | | | | | | | 5 | 0.9% |
| Split & window AC | | | | | | | | | 3 | 0.6% |
| Total | 543 | 100% | 543 | 100% | 543 | 100% | 543 | 100% | 543 | 100% |



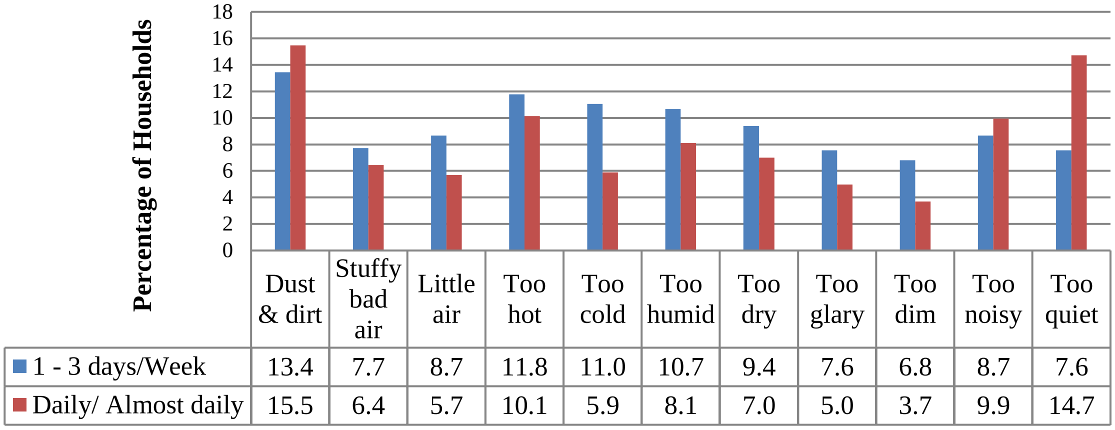
| | New carpets | New furniture | Walls painted | Walls rearranged | New wall covering | Water leakage |
|---|---|---|---|---|---|---|
| 🟦 Series1 | 29.7 | 56.0 | 43.1 | 8.7 | 10.7 | 33.3 |

Figure 4-3: Reported last year households' events



| | Incense smoke | New carpets curtains | Damp-ness odors | Fishy food odors | Body cosme-tics odors | Paint odors | Chemic-al odors | Tobacco smoke | Diesel odors |
|---|---|---|---|---|---|---|---|---|---|
| 🟦 1 - 3 days/Week | 6.4 | 3.1 | 4.1 | 11.8 | 9.0 | 2.4 | 3.9 | 7.2 | 2.6 |
| 🟥 Daily/ Almost daily | 12.5 | 1.3 | 2.0 | 9.0 | 10.7 | 1.8 | 2.6 | 12.3 | 2.8 |

Figure 4-4: Percentage of households experiencing sufficiently "Often" odors



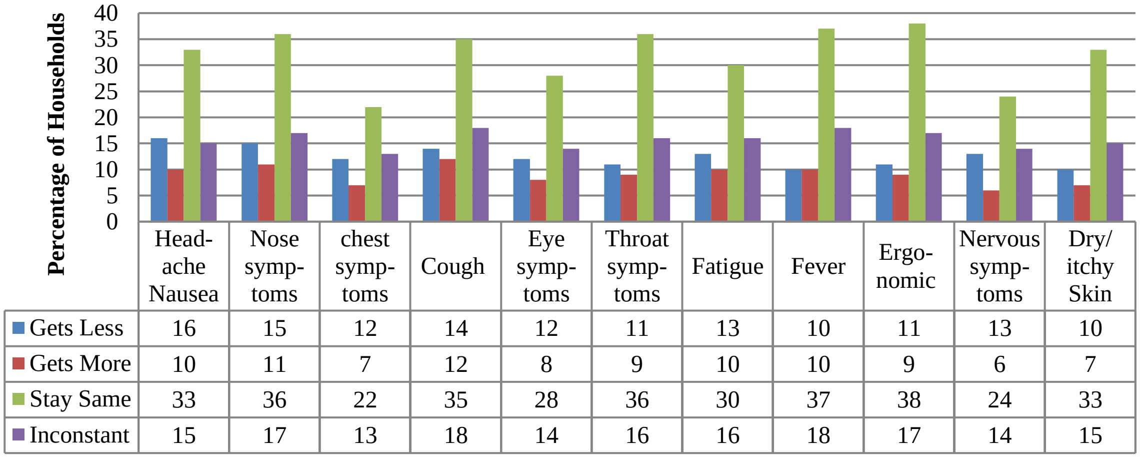
| | Dust & dirt | Stuffy bad air | Little air | Too hot | Too cold | Too humid | Too dry | Too glary | Too dim | Too noisy | Too quiet |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 🟦 1 - 3 days/Week | 13.4 | 7.7 | 8.7 | 11.8 | 11.0 | 10.7 | 9.4 | 7.6 | 6.8 | 8.7 | 7.6 |
| 🟥 Daily/ Almost daily | 15.5 | 6.4 | 5.7 | 10.1 | 5.9 | 8.1 | 7.0 | 5.0 | 3.7 | 9.9 | 14.7 |

Figure 4-5: Percentage of households experiencing sufficiently "Often" IEQ discomfort conditions

Figure 4-6 shows how the experienced symptoms illustrated in Appendix AA develop outdoors by classifying them into four categories: (i) symptoms that became less when going outdoors, (ii) symptoms that became more, (iii) symptoms that stood same, and (iv) inconstantly or variably changing symptoms as they sometimes became less while other times became more or stood same. The percentage of health disorders that became less when going outdoors was: About 16% for headache and nausea symptoms; 15% for experienced nose related symptoms; 12% for chest related symptoms; 14% for cough symptoms, 12% for eye related symptoms; 11% for throat related symptoms; 13% for unusual fatigue symptoms; 10% for fever, 11% for ergonomic symptoms; 13% for neurological symptoms; and 10% for dry itchy skin symptoms. Notably that the percentage of experienced symptoms that gets less when going outdoors was more than that gets more in all symptoms except fever in which they were equal. In terms of the frequently prevalent health symptoms (Figure 4-7), following is the percentage of households that sufficiently often experienced health disorders for at least 1 -3 days weekly: (1) the ergonomic symptoms were 17.7%, (2) headache and nausea were 17.1%, (3) dry skin symptoms were 16.9%, (4) unusual fatigue was 16.8%, (5) nose related symptoms were 16.6%, (6) neurological symptoms were 15.3%, (7) cough was 12.2%, (8) eye related symptoms were 9.9%, (9) throat related symptoms were 9.4%, (10) chest related symptoms were 7.9%, and (11) fever was 5.3% .

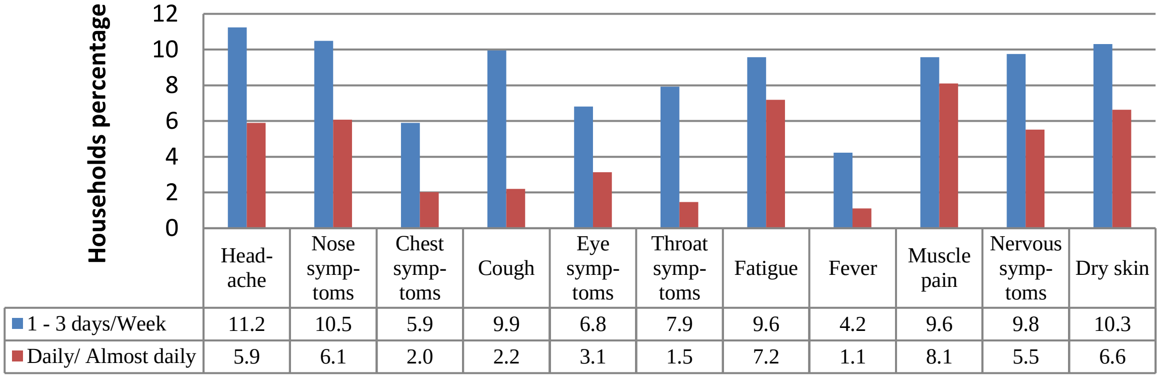
Figure 4-8 shows the percentage of households that sufficiently often experienced health disorders along with those which became less when going outdoors. Following is the percentage of households that frequently experienced health disorders that became less outdoors: (1) headache and nausea were 5%, (2) nose related symptoms and neurological symptoms were 4%, (3) unusual fatigue, chest related, and ergonomic symptoms were 3%, (4) cough, eye related, throat related, and dry itchy skin were 2%, (5) fever was 1%. As per SHS definition (Section 2.1), the cases of frequently experienced health disorders at least 1 day per week in the month and that disappear or not develop outdoors could be considered as SHS symptoms (Azuma et al. 2015; Turpin 2014; Hess-Kosa 2011; Gomzi & Bobic 2009; OSHA 1999). Based on that, the total percentage of households that experienced SHS symptoms was approximately 30% in the main survey. Noteworthy that prevalent

SHS in Dubai housing might be higher than this percentage considering the substantial number of participants who reported symptoms compatible to SHS but the way in which those symptoms developed outdoors was variable or inconstant.



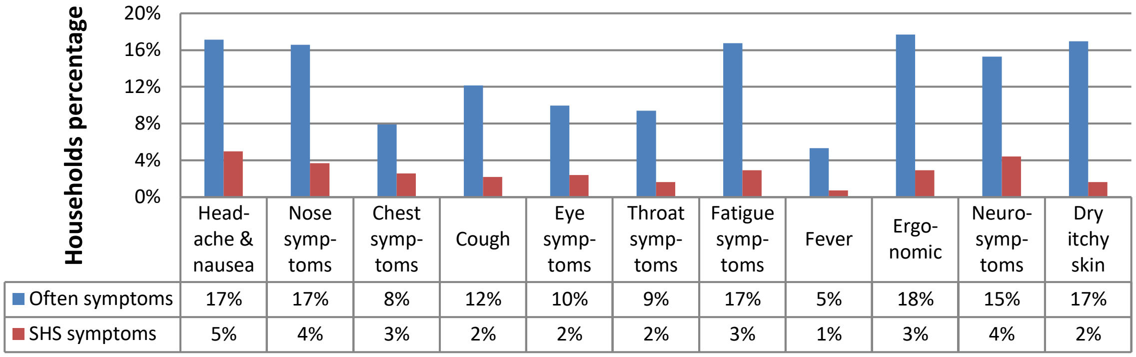
| | Head-ache Nausea | Nose symp-toms | chest symp-toms | Cough | Eye symp-toms | Throat symp-toms | Fatigue | Fever | Ergo-nomic | Nervous symp-toms | Dry/ itchy Skin |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 🟦 Gets Less | 16 | 15 | 12 | 14 | 12 | 11 | 13 | 10 | 11 | 13 | 10 |
| 🟥 Gets More | 10 | 11 | 7 | 12 | 8 | 9 | 10 | 10 | 9 | 6 | 7 |
| 🟩 Stay Same | 33 | 36 | 22 | 35 | 28 | 36 | 30 | 37 | 38 | 24 | 33 |
| 🟪 Inconstant | 15 | 17 | 13 | 18 | 14 | 16 | 16 | 18 | 17 | 14 | 15 |

Figure 4-6: Percentage of households according to how experienced health symptoms developed outdoors



| | Head-ache | Nose symp-toms | Chest symp-toms | Cough | Eye symp-toms | Throat symp-toms | Fatigue | Fever | Muscle pain | Nervous symp-toms | Dry skin |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 🟦 1 - 3 days/Week | 11.2 | 10.5 | 5.9 | 9.9 | 6.8 | 7.9 | 9.6 | 4.2 | 9.6 | 9.8 | 10.3 |
| 🟥 Daily/ Almost daily | 5.9 | 6.1 | 2.0 | 2.2 | 3.1 | 1.5 | 7.2 | 1.1 | 8.1 | 5.5 | 6.6 |

Figure 4-7: Percentage of households that sufficiently “Often” experienced health problems



| | Head-ache & nausea | Nose symp-toms | Chest symp-toms | Cough | Eye symp-toms | Throat symp-toms | Fatigue symp-toms | Fever | Ergo-nomic | Neuro-symp-toms | Dry itchy skin |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 🟦 Often symptoms | 17% | 17% | 8% | 12% | 10% | 9% | 17% | 5% | 18% | 15% | 17% |
| 🟥 SHS symptoms | 5% | 4% | 3% | 2% | 2% | 2% | 3% | 1% | 3% | 4% | 2% |

Figure 4-8: Percentage of households that sufficiently “Often” experienced health problems along with SHS symptoms

### 4.1.4 PCA results

PCA was performed in both the pilot questionnaire and main survey to examine the relations between measures in order to minimize them to a smaller number of components accounting for the most observed variance. Similar to the PCA procedure and criteria followed in the pilot questionnaire (Section 3.3.4.4) was applied in the main survey. In the main survey, PCA was performed on health and IEQ comfort measures but not performed on the odors items. That was because, based on the conducted reliability test in Section 4.1.2; Cronbach Alpha was 0.734 which is an acceptable value (Suliman & Al Kathairi 2013; Tavakol & Dennick 2011; Suliman et al. 2010; Parsian & Dunning 2009; DeVon et al. 2007). However, the reliability of the odors scale would be unacceptable if items were to be reduced. Therefore, PCA was only conducted on IEQ comfort and health items.

Regarding the 11 items measuring the health symptoms, retaining a number of 2 components was recommended by both Kaiser’s criterion and the Scree plot (Figure 4-9). The PCA result of 2 components’ solution is shown in

Table 4-5. Only one variable was excluded because of its low loading (< ±0.5) indicating that fever variable was of minimal significance (Hair et al. 1998; Stevens 2002; Suliman & Al Kathairi 2013; Suliman et al. 2010; Parsian & Dunning 2009). The retained two components composed of the 10 retained items accounted for 56% of the total variance in the data set (Table 4-6). The first component was called as "Eye, Nose, Throat, and Chest symptoms" component while the second one was called as "General, Ergonomic, Nervous, and Skin symptoms" component. According to (Parsian & Dunning 2009; Field 2003), the cumulative proportion of variance explained by the retained two components was acceptable. Moreover, following (Beaumont 2012; Parsian & Dunning 2009; Field 2005; Kaiser 1974) recommendations; Bartlett test of Sphericity and the KMO MSA were performed to ensure an appropriate sample size was obtained for the pilot study to enable PCA to be undertaken. KMO MSA for the health symptoms solution was 0.898 and the Bartlett test of Sphericity result was highly significant at *p* value < 0.001. According to the above references, the value of this KMO MSA was assessed as great and it indicated that the sample size was adequate to run PCA that would yield distinct and reliable components.

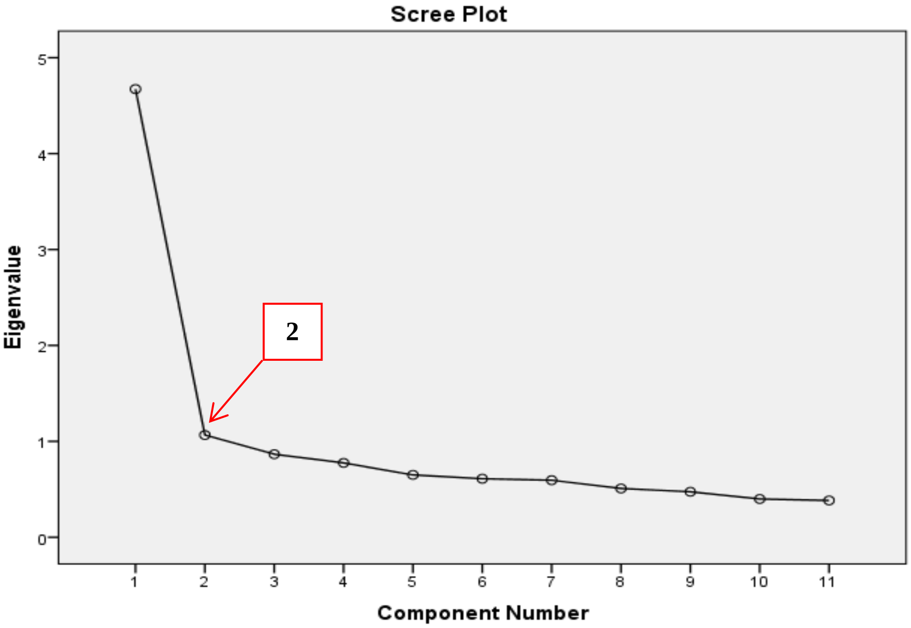


Figure 4-9: Scree plot of health symptoms PCA

Table 4-5: Variables loading in the PCA solution of health symptoms

| | Variable | **1** | **2** |
|---|---|---|---|
| 1. | Nose related symptoms | .796 | |
| 2. | Cough | .748 | |
| 3. | Chest related symptoms | .680 | |
| 4. | Throat related symptoms | .666 | |
| 5. | Eye related symptoms | .500 | |
| 6. | Ergonomic symptoms | | .820 |
| 7. | Neurological or nervous symptoms | | .719 |
| 8. | Fatigue/sleepiness | | .716 |
| 9. | Dry/ itchy skin | | .602 |
| 10. | Headache, nausea | | .516 |

Table 4-6: Variance explained by health symptom components

| | **Component** | **Variables included** | **Explained variance** |
|---|---|---|---|
| 1 | Eye, Nose, Throat & Chest symptoms | Nose related symptoms<br>Cough<br>Chest related symptoms<br>Throat related symptoms<br>Eye related symptoms | 45% |
| 2 | General, Ergonomic, Nervous, & Skin symptoms | Ergonomic symptoms<br>Neurological or nervous symptoms<br>Fatigue/sleepiness<br>Dry/ itchy skin<br>Headache, nausea | 11% |

In terms of the PCA of the 13 IEQ comfort measures, retaining a number of 3 components was recommended by Kaiser's criterion while the Scree plot recommended retaining 2 or 3 components (Figure 4-10). The PCA result of 2 components' solution shown in Table 4-7 was considered as more appropriate statistically and conceptually. Two variables which were noisy and too little air were excluded because of their loading (< ±0.5) (Hair et al. 1998; Stevens 2002; Suliman & Al Kathairi 2013; Suliman et al. 2010; Parsian & Dunning 2009). Another two variables which were "Too hot" and "Too much dryness" were also excluded because they were cross loading. "Too hot" loaded as 0.475 and 0.501 while "Too little air" loaded as 0.532 and 0.506 in component 1 and 2, respectively. Those two variables were excluded as recommended by (Costello & Osbourne

2005; Omondi et al. 2014) for the following 3 reasons: (1) they were loading highly above 0.32; (2) the difference between them was minor (< 0.2); and (3) there was adequate number of other items loading above 0.5 in each component. The retained two components composed of the 9 items accounted for 50% of the total variance in the data set (Table 4-8). According to (Parsian & Dunning 2009; Field 2003), the cumulative proportion of variance explained by the retained two components was acceptable. Moreover, following (Beaumont 2012; Parsian & Dunning 2009; Field 2005; Kaiser 1974) recommendations; Bartlett test of Sphericity and the KMO MSA performed to ensure an appropriate sample size was obtained to enable PCA to be undertaken. KMO MSA for the health symptoms solution was 0.779 and the Bartlett test of Sphericity result was highly significant at *p* value < 0.001. According to the above references, the value of this KMO MSA was assessed as acceptable and it indicated that the sample size was adequate to run PCA that would yield distinct and reliable components.

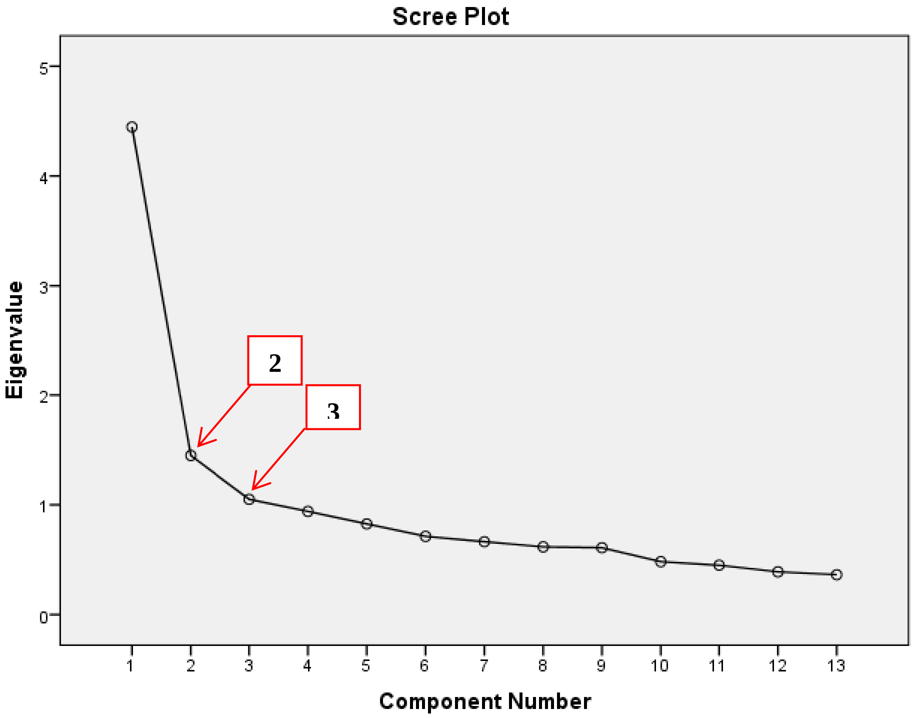


Figure 4-10: Scree plot of IEQ comfort PCA

Table 4-7: Variables loading in the PCA solution of IEQ comfort measures

| | | 1 | 2 |
|---|---|---|---|
| 1 | Too much air movement | .674 | |
| 2 | Too cold | .673 | |
| 3 | Too much humidity | .510 | |
| 4 | Too much glare | .654 | |
| 5 | Too much dim | .622 | |
| 6 | Too quiet | .536 | |
| 7 | Dust and dirt | | .743 |
| 8 | Stuffy "bad" air | | .778 |
| 9 | Overall IAQ | | .732 |

Table 4-8: Variance explained by IEQ comfort components

| | Component | Variables included | Variance explained |
|---|---|---|---|
| 1 | Thermal, Lighting, and Noise | Too much air movement<br>Too cold<br>Too much humidity<br>Too much glare<br>Too much dim<br>Too quiet | 34% |
| 2 | IAQ | Dust and dirt<br>Stuffy "bad" air<br>Overall IAQ | 16% |

The PCA results of the IEQ variables showed that variables measuring perceived thermal, lighting and noise comfort were statistically correlated as they fall within one component that explained 34% of the variance in the dataset. Whereas the IAQ variables formed a 2nd component that explains 16% of the variance in the data set which was not explained by the 1st component. Reference to (Ginazzo et al. 2019; Yang & Moon 2018; Zarrabi et al. 2017); the inclusion of the variables measuring perceived thermal, lighting, and noise comfort within one component was found to be conceptually accetptable as it can be attributed to impact of the simultaneous exposure of occupants to various interlinked IEQ factors. Subsequently, their indoor environmental comfort perceptions depends on the combined impacts and interaction of those factors. For instance, according to results revealed by (Ginazzo et al. 2019), daylight and temperature did affect human responses perceptually rather than physiologically. The interaction effects between daylight and temperature were bi-directional as daylight color and quantity affects thermal perception while temperature influenced visual perception. Also, findings by Garretón et al. (2016) revealed that perceived temperature influenced glare predictions. Additionally, findings by Zarrabi et al. (2017) suggested that the pleasant visual qualities could positively affect perceived thermal comfort. Yang (2017) also found that temperature had an effect on acoustic comfort significantly. According to results shown by Kulve et al. (2018); the change in visual comfort and the change in thermal comfort were positively related under different light conditions. Also, results by Yang & Moon (2019) indicated that acoustic comfort had positive association with thermo-neutrality; thermal comfort had negative association with noise level at 500 lx; while visual comfort had negative association with the noise level at thermo-neutrality. They concluded that indoor environmental comfort increases with a decrease in the noise level at thermo-neutrality in brighter conditions.

### 4.1.5 Reliability of created PCA components

Cronbach's alpha was computed to examine the reliability or the internal consistency of the created PCA components. Computed Cronbach Alpha for the 5 items measuring the Eye, Nose, Throat, and Chest related symptoms component shown in (Table 4-6) was 0.786 which is respecptable (DeVellis 1991; Suliman & Al Kathairi 2013; Tavakol & Dennick 2011; Suliman et al. 2010; Parsian & Dunning 2009; DeVon et al. 2007). Cronbach alpha for the 5 items measuring the General, Ergonomic, Nervous, and Skin symptoms component was 0.787 which is also respectable. Also, computed Cronbach Alpha for the 6 items measuring Thermal, Lighting, and Noise comfort component shown in (Table 4-8) was 0.701 which is acceptable. However, computed Cronbach Alpha for the three items measuring IAQ comfort component was 0.671 which is minimally acceptable (DeVellis 1991; Suliman & Al Kathairi 2013; Tavakol & Dennick 2011; Suliman et al. 2010; Parsian & Dunning 2009; DeVon et al. 2007). When deleting the item measuring the overall IAQ; the reliability of the IAQ component substantially increased to 0.725. Thus, the overall IAQ rating item was excluded from analysis while retaining the other two items which were "Dust and dirt" and "Stuffy bad air". Computed Cronbach alpha for all health items (Global DV) was 0.859 while it was 0.825 for all IEQ items (Global IV) which were very good values. Thus, as illustrated in (Table 4-9) and reference to computed alpha value of 0.734 for the odors scale in Section 4.1.2, all scales utilized in this questionnaire were consistently reliable.

Table 4-9: Reliability results for questionnaire scales

| | **Scale** | | **Cronbach alpha** |
|---|---|---|---|
| 1 | Global DV: Health symptoms | | 0.859 |
| | 1.1 | Eye, Nose, Throat, and Chest related symptoms | 0.786 |
| | 1.2 | General, Ergonomic, Nervous, and Skin symptoms | 0.787 |
| 2 | Global IV: IEQ conditions | | 0.826 |
| | 2.1 | Thermal, Lighting, and Noise comfort | 0.701 |
| | 2.2 | IAQ comfort | 0.725 |
| | 2.3 | Odors | 0.734 |

### 4.1.6 MLR results

In order to answer this research questions, the multivariate statistical analysis involved the conduct of 24 MLR models. An overview table summarizing the performed MLR models is illustrated in Table 4-10. Ten MLR models were performed to identify significant population and building variables. Five models of them used the 16 population variables (Table 3-8) and the other five models used the 23 building variables (Table 3-9 excluding B10 to B14) to predict the five subscales in this study; the three IEQ and two health symptoms factors. Also four MLR models were conducted to investigate the associations between IEQ factors and health symptoms. Two models of them were performed using the IEQ factors to predict each health symptoms factor and then the two models were adjusted to the significant population and building variables. Furthermore, six MLR models were performed to investigate the associations between the variables of each of the three IEQ subscales with each health symptoms factor. Another two MLR models were performed to investigate the associations between all IEQ variables with each health symptoms factor adjusted for significant population and building variables. Moreover, two MLR models were conducted to investigate the associations between other IEQ factors with IAQ factor. An MLR model used the other two IEQ factors to predict the IAQ factor and then the model was adjusted for significant population and building variables. Following is detailed description of above described models.

Table 4-10: An overview of performed MLR models

| Model | Independent parameter/s | Dependent parameter | Significantly associated parameters |
|---|---|---|---|
| 1 | Population variables | Eye, Nose, Throat, & Chest symptoms | Dust allergy, migraine, & asthma |
| 2 | Population variables | General, Ergonomic, Nervous, & Skin symptoms | Gender, migraine, dust allergy, Other Arabs/MENA, & eczema |
| 3 | Population variables | Thermal, Lighting, & Noise discomfort | Migraine, dust allergy, & passive smoking |
| 4 | Population variables | IAQ discomfort | Migraine, dust allergy, age, & other African |
| 5 | Population variables | Odors | Passive smoking, dust allergy, & migraine |
| 6 | Building variables | Eye, Nose, Throat, & Chest symptoms | Water leakage, new carpets, & attached closed kitchen |
| 7 | Building variables | General, Ergonomic, Nervous, & Skin symptoms | Water leakage, new furniture, new carpets, central HVAC, & Dubai Sector 1 |
| 8 | Building variables | Thermal, Lighting, & Noise discomfort | New carpets & water leakage |
| 9 | Building variables | IAQ discomfort | New wall covering & water leakage |
| 10 | Building variables | Odors | New carpets, water leakage, & split HVAC |
| 11 | IEQ factors | Eye, Nose, Throat, & Chest symptoms | Odors, IAQ discomfort, and Thermal, Lighting, & Noise discomfort |
| 12 | IEQ factors adjusted for population & building variables | Eye, Nose, Throat, & Chest symptoms | Odors, IAQ discomfort; Thermal, Lighting, & Noise; migraine, attached kitchen with interior walls, new carpets, & asthma. |
| 13 | IEQ factors | General, Ergonomic, Nervous, & Skin symptoms | Odors; Thermal, Lighting, & Noise discomfort factors; & IAQ discomfort |
| 14 | IEQ factors adjusted for population & building variables | General, Ergonomic, Nervous, & Skin symptoms | Odors; Thermal, Lighting, & Noise discomfort; gender; migraine, water leakage, other Arabs & MENA, IAQ discomfort, eczema, new carpets, & central HVAC |
| 15 | Thermal, lighting, noise discomfort & odors factors | IAQ discomfort | Odors and Thermal, Lighting, & Noise discomfort. |

| | | | |
|---|---|---|---|
| 16 | Thermal, Lighting, Noise discomfort; & odors factors adjusted for population & building variables | IAQ discomfort | Odors, Thermal, Lighting, & Noise discomfort; age, other Africans, dust allergy, new wall covering, & migraine. |
| 17 | Thermal, Lighting, & Noise discomfort variables | Eye, Nose, Throat, & Chest related symptoms | Too much dim & Too much humidity |
| 18 | IAQ discomfort variables | Eye, Nose, Throat, & Chest related symptoms | Dust and dirt & Stuffy bad air |
| 19 | Odors variables | Eye, Nose, Throat, and Chest related symptoms | Odors from other chemicals i.e. pesticides, glues, or cleaning products, Odors from new carpet, curtains, or drapes; Odors from paint, Tobacco smoke, Smoke from incense burning, & Musty/mouldy dampness odors |
| 20 | Thermal, Lighting, & Noise discomfort variables | General, Ergonomic, Nervous, & Skin symptoms | Too much humidity, Too much dim, & Too cold |
| 21 | IAQ discomfort variables | General, Ergonomic, Nervous, & Skin symptoms | Stuffy "bad" air” & Dust and dirt |
| 22 | Odors variables | General, Ergonomic, Nervous, & Skin symptoms | Smoke from incense burning, Fishy smells or other food smells, Body odors or cosmetics odors, Odors from paint, Odors from other chemicals i.e. pesticides, glues, or cleaning products |
| 23 | IEQ variables adjusted for population & building variables | Eye, Nose, Throat, & Chest related symptoms | Musty/mouldy dampness odors; Allergy to dust; Too much dim; Migraine; Stuffy "bad" air; Odors from paint, Asthma, Attached kitchen with interior walls; & Dust and dirt. |
| 24 | IEQ variables adjusted for population and building variables | General, Ergonomic, Nervous, & Skin symptoms | Too much humidity, Too much dim, Smoke from incense burning, Gender, Migraine, Other Arabs/ MENA, Eczema, Water leakage, Dubai Sector 1, & Allergy to dust. |

#### 4.1.6.1 MLR model of population variables on Eye, Nose, Throat, and Chest related symptoms

As explained in Section 3.4.3, population and building variables considered as confounders in this study were used in stepwise regression tests to predict the health symptoms, comfort, and odors components. The 1st MLR model followed the stepwise method and used the 16 population variables listed in (Table 3-8) to predict Eye, Nose, Throat, and Chest symptoms (Table 4-6). Appendix BB describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this stepwise regression model. This prediction model contained three of the 16 population variables and was reached in three steps with no variables removed. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-11. The model was statistically significant, F (3, 527) = 19.571, $p < .001$, and accounted for approximately 10% of the variance of Eye, Nose, Throat, and Chest related symptoms ($R^2$= .10, Adjusted $R^2$ = .095).

Table 4-11: Stepwise regression results examining population variables on Eye, Nose, Throat, and Chest symptoms

| | | | | | | 95% CI Interval for B | |
|---|---|---|---|---|---|---|---|
| | B | *SE-B* | Beta | Sig. | $sr^2$ | Lower Bound | Upper Bound |
| (Constant)*** | 4.39 | .22 | | .000 | | 3.96 | 4.82 |
| Dust allergy*** | 1.52 | .29 | .22 | .000 | .05 | 0.95 | 2.10 |
| Migraine*** | 1.68 | .33 | .22 | .000 | .04 | 1.02 | 2.33 |
| Asthma* | .83 | .38 | .09 | .029 | .01 | .084 | 1.58 |

Note. The dependant variable was Eye, Nose, Throat, and Chest symptoms.
$R^2$ = 0.10, Adjusted $R^2$ = 0.095.
$sr^2$ is the squared semi-partial correlation.
*$p \leq .05$, **$p \leq .01$, *** $p \leq .001$

Eye, Nose, Throat, and Chest related symptoms were statistically significantly predicted by having allergy to dust, migraine, and asthma. The three predictors were positively predicting the DV. Both allergy to dust and migraine received similar weights in the model while having asthma received the lower weight. Participants having allergy to dust have 1.52 higher frequency of experiencing Eye, Nose, Throat, and Chest symptoms than those not having after controlling for migraine and asthma. Participants having migraine and asthmatics have 1.68 and 0.83 higher frequency of experiencing those symptoms; respectively. The unique variances explained by the variables indexed by squared semi-partial correlations were: having allergy to dust, migraine, and asthma uniquely accounted for approximately 5%, 4%, and 1% of the variance of Eye, Nose, Throat, and Chest related symptoms.

#### 4.1.6.2 MLR model of population variables on General, Ergonomic, Nervous, and Skin symptoms

The 2nd MLR model followed the stepwise method and used the 16 population variables listed in (Table 3-8) to predict General, Ergonomic, Nervous, and Skin symptoms (Table 4-6). Appendix CC describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this stepwise regression model. This prediction model contained 5 of the 16 population variables and was reached in five steps with no variables removed. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-12. The model was statistically significant, F (5, 534) = 18.695, $p \leq .001$, and accounted for approximately 15% of the variance of General, Ergonomic, Nervous, and Skin symptoms ($R^2$= .149, Adjusted $R^2$ = .141). The General, Ergonomic, Nervous, and Skin symptoms were statistically significantly predicted by gender, migraine, allergy to dust, being other Arabs/ MENA, and having eczema. All the five predictors were positively predicting the DV. Having migraine received the highest weights in the model followed by gender and then having allergy to dust while being other Arab or MENA national and having eczema received the lowest weight. People who had migraine had 2.09 higher frequency of experiencing the General, Ergonomic, Nervous, and Skin symptoms than those who didn’t have after controlling for gender, dust allergy, being Arabs/ MENA, and having eczema.

Females, people who have eczema, Arabs or MENA nationals, and dust allergic had 1.66, 1.52, 1.40, and 1.33 higher frequency of experiencing those symptoms; respectively. The unique variances explained by the variables indexed by squared semi-partial correlations were: migraine, gender, allergy to dust, being other Arabs/ MENA, and having eczema uniquely accounted for approximately 4%, 3%, 2%, 1%, and 1% of the variance of was General, Ergonomic, Nervous, and Skin symptoms.

Table 4-12: Stepwise regression results examining population variables on General, Ergonomic, Nervous, and Skin symptoms

| | | | | | | 95% CI for B | |
|---|---|---|---|---|---|---|---|
| | B | *SE-B* | Beta | Sig. | $sr^2$ | Lower Bound | Upper Bound |
| (Constant)*** | 4.25 | .30 | | .000 | | 3.665 | 4.844 |
| Gender*** | 1.66 | .36 | .19 | .000 | .03 | .953 | 2.366 |
| Migraine*** | 2.09 | .41 | .21 | .000 | .04 | 1.290 | 2.880 |
| Allergy to dust*** | 1.33 | .35 | .15 | .000 | .02 | .634 | 2.021 |
| Other Arabs/ MENA** | 1.40 | .50 | .11 | .005 | .01 | .418 | 2.380 |
| Eczema** | 1.52 | .59 | .11 | .010 | .01 | .362 | 2.681 |

Note. The dependant variable was General, Ergonomic, Nervous, and Skin symptoms.
$R^2$ = 0.149, Adjusted $R^2$ = 0.141.
$sr^2$ is the squared semi-partial correlation.
*$p \leq .05$, **$p \leq .01$, *** $p \leq .001$

#### 4.1.6.3 MLR model of population variables on Thermal, Lighting, and Noise discomfort

The 3rd MLR model followed the stepwise method and used the 16 population variables listed in (Table 3-8) to predict the Thermal, Lighting, and Noise discomfort (Table 4-8). Appendix DD describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this stepwise regression model. This prediction model contained 3 of the 16 population variables and was reached in three steps with no variables removed. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-13. The model was statistically significant, F (3, 532) = 8.840, $p \leq .001$, and accounted for approximately 4.7% of the variance of Thermal, Lighting, and Noise discomfort ($R^2$= .047, Adjusted $R^2$ = .042). The Thermal, Lighting, and Noise discomfort was statistically significantly predicted by having migraine, allergy to dust, and being passive smoker. All the 3 predictors were positively predicting the DV. Having migraine received the highest weights followed by allergy to dust while being passive smoker received the lowest weight. Participants having migraine have 1.57 higher frequency of experiencing the Thermal, Lighting, and Noise discomfort than those not having it when controlling for allergy to dust and passive smoking. Dust allergic and passive smokers have 1.20 and 0.92 higher frequency of experiencing Thermal, Lighting, and Noise discomfort; respectively. The unique variances explained by the variables indexed by squared semi-partial correlations were: migraine, allergy to dust, and having eczema uniquely accounted for approximately 2%, 2%, and 1% of the variance of Thermal, Lighting, and Noise discomfort.

Table 4-13: Stepwise regression results examining population variables on Thermal, Lighting, and Noise discomfort

| | | | | | | 95% CI for B | |
|---|---|---|---|---|---|---|---|
| | B | *SE-B* | Beta | Sig. | $sr^2$ | Lower Bound | Upper Bound |
| (Constant)*** | 5.23 | .31 | | .000 | | 4.619 | 5.835 |
| Migraine** | 1.57 | .45 | .15 | .001 | .02 | .679 | 2.459 |
| Allergy to dust** | 1.20 | .40 | .13 | .003 | .02 | .414 | 1.973 |
| Passive Smoking* | .92 | .44 | .09 | .035 | .01 | .064 | 1.780 |

Note. The dependant variable was Thermal, Lighting, and Noise discomfort.
$R^2$ = 0.047, Adjusted $R^2$ = 0.042.
$sr^2$ is the squared semi-partial correlation.
*$p \leq .05$, **$p \leq .01$, *** $p \leq .001$

#### 4.1.6.4 MLR model of population variables on IAQ discomfort

The 4th MLR model followed the stepwise method and used the 16 population variables listed in Table 3-8 to predict the IAQ discomfort (Table 4-8). Appendix EE describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this stepwise regression model. This prediction model contained 4 of the 16 population variables and was reached in four steps with no variables removed. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-14. The model was statistically significant, F (4, 538) = 8.875, $p \leq .001$, and accounted for approximately 6.2% of the variance of IAQ discomfort ($R^2$= .062, Adjusted $R^2$ = .055). The IAQ discomfort was statistically significantly predicted by migraine, allergy to dust, age, and being other African. Allergy to dust received the highest weights in the model followed by being migraine, then age, while being other Africans received the lowest weights. All predictors were positively predicting the DV. Dust allergic have 0.71 higher frequency of experiencing IAQ discomfort than those who haven't when controlling for all other predictors included in the model. Participants having migraine and other Africans have 0.76 and 0.58 higher frequency of experiencing IAQ discomfort; respectively. Participants of older age group have 0.47 higher frequency of experiencing IAQ discomfort than those of younger age group. The unique variances explained by the variables indexed by squared semi-partial correlations were: (1) Allergy to dust, (2) migraine, (3) age, and (4) being other Africans uniquely accounted for approximately 2%, 2%, 2%, and 1% variance of IAQ discomfort; respectively.

Table 4-14: Stepwise regression results examining population variables on IAQ discomfort

| | | | | | | 95.0% CI for B | |
|---|---|---|---|---|---|---|---|
| | B | *SE-B* | Beta | Sig. | $sr^2$ | Lower Bound | Upper Bound |
| (Constant)*** | 1.54 | .27 | | .000 | | 1.000 | 2.078 |
| Migraine** | .76 | .23 | .14 | .001 | .020 | .314 | 1.198 |
| Allergy to dust*** | .71 | .20 | .15 | .000 | .023 | .321 | 1.093 |
| Age** | .47 | .16 | .12 | .004 | .015 | .149 | .785 |
| Other Africans* | .58 | .25 | .10 | .021 | .009 | .086 | 1.081 |

Note. The dependant variable was IAQ discomfort.
$R^2$ = 0.062, Adjusted $R^2$ = 0.055.
$sr^2$ is the squared semi-partial correlation.
*$p \leq .05$, **$p \leq .01$, *** $p \leq .001$

#### 4.1.6.5 MLR model of population variables on odors

The 5th MLR model followed the stepwise method and used the 16 population variables listed in Table 3-8 to predict odors (Table 3-27). Appendix FF describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this stepwise regression model. This prediction model contained 3 of the 16 population variables and was reached in three steps with no variables removed. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-15. The model was statistically significant, F (3, 526) = 18.089, $p \leq .001$, and accounted for approximately 9.4% of the variance of odors ($R^2$= .094, Adjusted $R^2$ = .088). Odors were statistically significantly predicted by passive smoking, dust allergy, and migraine. Passive smoking received the highest weights in the model followed by dust allergy while migraine received the lowest weights. All predictors were positively predicting the DV. Passive smokers have 2.34 higher frequency of experiencing odors after controlling for dust allergy and migraine. Dust allergic have 1.82 higher frequency while participants having migraine have 1.63 higher frequency of experiencing odors. The unique variances explained by the variables indexed by squared semi-partial correlations were: passive smoking, dust allergy, and migraine uniquely accounted for approximately 4%, 3%, and 2% of the variance of experiencing odors.

Table 4-15: Stepwise regression results examining population variables on odors

| | | | | | | 95% CI for B | |
|---|---|---|---|---|---|---|---|
| | B | *SE-B* | Beta | Sig. | $sr^2$ | Lower Bound | Upper Bound |
| (Constant)*** | 4.86 | .346 | | .000 | | 4.174 | 5.536 |
| Passive Smoking*** | 2.43 | .484 | .209 | .000 | .044 | 1.479 | 3.380 |
| Allergy to dust*** | 1.82 | .441 | .171 | .000 | .029 | .951 | 2.683 |
| Migraine*** | 1.63 | .504 | .135 | .001 | .018 | .643 | 2.624 |

Note. The dependant variable was odors.
$R^2$ = 0.094, Adjusted $R^2$ = 0.088.
$sr^2$ is the squared semi-partial correlation.
$*p \leq .05$, $**p \leq .01$, $***\ p \leq .001$

### 4.1.6.6 MLR model of building variables on Eye, Nose, Throat, and Chest related symptoms

The 6th MLR model followed the stepwise method and used the 23 building variables listed in (Table 3-9 excluding B10 to B14) to predict Eye, Nose, Throat, and Chest related symptoms (Table 4-6). Appendix GG describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this stepwise regression model. This prediction model contained 3 of the 23 building variables and was reached in three steps with no variables removed. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-16. The model was statistically significant, F (3, 470) = 8.884, $p \le .001$, and accounted for approximately 5.4% of the variance of Eye, Nose, Throat, and Chest symptoms ($R^2$= .054, Adjusted $R^2$ = .048).

Table 4-16: Stepwise regression results examining building variables on Eye, Nose, Throat, and Chest symptoms

| | | | | | | 95% CI for B | |
|---|---|---|---|---|---|---|---|
| | B | *SE-b* | Beta | Sig. | $sr^2$ | Lower Bound | Lower Bound |
| (Constant)*** | 4.4 | .30 | | .000 | | 3.80 | 4.97 |
| Water leakage*** | 1.1 | .33 | .15 | .001 | .023 | .454 | 1.75 |
| New carpets** | 1.1 | .34 | .14 | .002 | .019 | .388 | 1.74 |
| Attached closed kitchen ** | 0.9 | .32 | .13 | .004 | .017 | .296 | 1.55 |

Note. The dependant variable was Eye, Nose, Throat, and Chest symptoms.
$R^2$ = 0.054, Adjusted $R^2$ = 0.048.
$sr^2$ is the squared semi-partial correlation.
*$p \le .05$, **$p \le .01$, *** $p \le .001$

Eye, Nose, Throat, and Chest symptoms were statistically significantly predicted by water leakage, new carpets, and attached closed kitchen. Water leakage received the highest weights in the model, followed by new carpets while attached closed kitchen received the lowest weights. All predictors were positively predicting the DV. Households experiencing water leakage had 1.1 higher frequency of having Eye, Nose, Throat, and Chest symptoms after controlling for new carpets and attached closed kitchen. Households having new carpets have about 1.1 higher frequency while households with attached closed kitchen had 0.9 higher frequency of having Eye, Nose, Throat, and Chest symptoms. The unique variances explained by the variables indexed by squared semi-partial correlations were: water leakage, new carpets, and attached closed kitchen uniquely accounted for approximately 2.3%, 1.9%, and 1.7% of the variance of Eye, Nose, Throat, and Chest symptoms.

#### 4.1.6.7 MLR model of building variables on General, Ergonomic, Nervous, and Skin symptoms

The 7th MLR model followed the stepwise method and used the 23 building variables listed in (Table 3-9 excluding B10 to B14) to predict General, Ergonomic, Nervous, and Skin symptoms (Table 4-6). Appendix HH describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this stepwise regression model. This prediction model contained 5 of the 23 building variables and was reached in five steps with no variables removed. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-17. The model was statistically significant, F (5, 464) = 10.106, $p \leq .001$, and accounted for approximately 9.8% of the variance of General, Ergonomic, Nervous, and Skin symptoms ($R^2$= .098, Adjusted $R^2$ = .088). General, Ergonomic, Nervous, and Skin symptoms were statistically significantly predicted by water leakage, new furniture, new carpets, central HVAC, and Dubai Sector 1. Having water leakage received the highest weights in the model which was followed by new furniture and then new carpets while central HVAC and Dubai Sector 1 received the lowest weights. All predictors were positively predicting the DV except having central HVAC. Households experiencing water leakage have 1.78 higher frequency of having General, Ergonomic, Nervous, and Skin symptoms after controlling for other predictors included in the model. Households having new furniture, new carpets, and residents of Dubai Sector 1 have about 1.26, 1.20, and 1.42 higher frequency experiencing General, Ergonomic, Nervous, and Skin symptoms. However, households using central HVAC have .94 lower frequency of experiencing those symptoms. The unique variances explained by the variables indexed by squared semi-partial correlations were: water leakage, new furniture, new carpets, central HVAC, and Dubai Sector 1 uniquely accounted for approximately 3.9%, 2%, 1.5%, 1.1%, 0.9% of the variance of General, Ergonomic, Nervous, and Skin symptoms.

Table 4-17: Stepwise regression results examining building variables on General, Ergonomic, Nervous, and Skin symptoms

| | B | SE-B | Beta | Sig. | $sr^2$ | 95% CI for B | |
|---|---|---|---|---|---|---|---|
| | | | | | | Lower Bound | Upper Bound |
| (Constant)*** | 5.26 | .44 | | .000 | | 4.390 | 6.119 |
| Water leakage*** | 1.78 | .40 | .20 | .000 | .039 | .994 | 2.565 |
| New furniture** | 1.26 | .40 | .15 | .002 | .020 | .481 | 2.038 |
| New carpets** | 1.20 | .43 | .13 | .005 | .015 | .358 | 2.050 |
| Central HVAC* | -.98 | .42 | -.10 | .020 | .011 | -1.802 | -.157 |
| Dubai Sector 1* | 1.42 | .66 | .10 | .032 | .009 | .121 | 2.721 |

Note. The dependant variable was General, Ergonomic, Nervous, and Skin symptoms.
$R^2$ = 0.098, Adjusted $R^2$ = 0.088.
$sr^2$ is the squared semi-partial correlation.
* $p \leq .05$**$p \leq .01$, *** $p \leq .001$

### 4.1.6.8 MLR model of building variables on Thermal, Lighting, and Noise discomfort

The 8th MLR model followed the stepwise method and used the 23 building variables listed in (Table 3-9 excluding B10 to B14) to predict Thermal, Lighting, and Noise discomfort (Table 4-8). Appendix II describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this stepwise regression model. This prediction model contained 2 of the 23 building variables and was reached in three steps with no variables removed. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-18. The model was statistically significant, F (2, 476) = 7.646, $p \leq .001$, and accounted for approximately 3.1% of the variance of Thermal, Lighting, and Noise discomfort ($R^2$= .031, Adjusted $R^2$ = .027). Thermal, Lighting, and Noise discomfort were statistically significantly predicted by new carpets and water leakage. New carpets received the highest weights in the model followed by water leakage. The two predictors were positively predicting the DV. Households with new carpets had1.5 higher frequency of experiencing Thermal, Lighting, and Noise discomfort after controlling for water leakage. Households having water leakage had 0.95 higher frequency experiencing Thermal, Lighting, and Noise discomfort. The unique variances explained by the variables indexed by squared semi-partial correlations were: new carpets and water leakage uniquely accounted for approximately 2.1% and 0.9% of the variance of Thermal, Lighting, and Noise discomfort.

Table 4-18: Stepwise regression results examining building variables on Thermal, Lighting, and Noise discomfort

| | | | | | | 95% CI for B | |
|---|---|---|---|---|---|---|---|
| | B | *SE-B* | Beta | Sig. | $sr^2$ | Lower Bound | Upper Bound |
| (Constant)*** | 5.664 | .291 | | .000 | | 5.093 | 6.236 |
| New carpets*** | 1.495 | .463 | .146 | .001 | .021 | .586 | 2.405 |
| Water leakage* | .946 | .448 | .095 | .035 | .009 | .065 | 1.827 |

Note. The dependant variable was Thermal, Lighting, and Noise discomfort.
$R^2$ = 0.031, Adjusted $R^2$ = 0.027.
$sr^2$ is the squared semi-partial correlation.
* $p \leq .05$**$p \leq .01$, *** $p \leq .001$

#### 4.1.6.9 MLR model of building variables on IAQ discomfort

The 9th MLR model followed the stepwise method and used the 23 building variables listed in (Table 3-9 excluding B10 to B14) to predict IAQ discomfort (Table 4-8). Appendix JJ describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this stepwise regression model. This prediction model contained 2 of the 23 building variables and was reached in two steps with no variables removed. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-19. The model was statistically significant, F (2, 479) = 5.507, $p \leq .001$, and accounted for approximately 2.2% of the variance of IAQ discomfort ($R^2$= .022, Adjusted $R^2$ = .018). IAQ discomfort was statistically significantly predicted by new wall covering and water leakage. New wall covering received the highest weights in the model followed by water leakage. Having new wall covering was negatively associated with IAQ discomfort while water leakage was positively associated with IAQ discomfort. Households having new wall covering had 0.89 lower frequency of experiencing IAQ discomfort after controlling for water leakage. Households having water leakage had 0.5 higher frequency experiencing IAQ discomfort. The unique variances explained by the variables indexed by squared semi-partial correlations were: new wall covering and water leakage uniquely accounted for approximately 1% and 1% of the variance of IAQ discomfort.

Table 4-19: Stepwise regression results examining building variables on IAQ discomfort

| | B | SE-B | Beta | Sig. | $sr^2$ | 95% CI for B<br>Lower Bound | Upper Bound |
|---|---|---|---|---|---|---|---|
| (Constant)*** | 2.72 | .13 | | .000 | .013 | 2.456 | 2.979 |
| New wall covering* | -.89 | .35 | -.11 | .012 | .011 | -1.575 | -.197 |
| Water leakage* | .50 | .22 | .10 | .023 | .013 | .069 | .938 |

Note. The dependant variable was IAQ discomfort.
$R^2$ = 0.022, Adjusted $R^2$ = 0.018.
$sr^2$ is the squared semi-partial correlation.
* $p \leq .05$**$p \leq .01$, *** $p \leq .001$

#### 4.1.6.10 MLR model of building variables on odors

The 10th MLR model followed the stepwise method and used the 23 building variables listed in (Table 3-9 excluding B10 to B14) to predict odors (Table 3-27). Appendix KK describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this stepwise regression model. This prediction model contained 3 of the 23 building variables and was reached in 3 steps with no variables removed. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-20. The model was statistically significant, F (3, 462) = 10.350, $p \leq .001$, and accounted for approximately 6.3% of the variance of odors ($R^2$= .063, Adjusted $R^2$ = .057). Odors were statistically significantly predicted by new carpets, water leakage, and split HVAC. New carpets received the highest weights in the model followed by water leakage, then split HVAC. The three predictors were positively associated with odors. Households having new carpets had 2.00 higher frequency of experiencing odors after controlling for the other two predictors in the model. Households having water leakage and split HVAC had 1.37 and 1.50 higher frequency experiencing odors; respectively. The unique variances explained by the variables indexed by squared semi-partial correlations were: new carpets, water leakage, and split HVAC uniquely accounted for approximately 3%, 2%, and 1%; respectively.

Table 4-20: Stepwise regression results examining building variables on odors

| | | | | | | 95% CI for B | |
|---|---|---|---|---|---|---|---|
| | B | SE-B | Beta | Sig. | $sr^2$ | Lower Bound | Upper Bound |
| (Constant)*** | 5.25 | .34 | | .000 | | 4.574 | 5.919 |
| New carpets*** | 2.00 | .52 | .17 | .000 | .030 | .975 | 3.007 |
| Water leakage** | 1.37 | .50 | .13 | .006 | .016 | .398 | 2.332 |
| Split HVAC** | 1.50 | .57 | .12 | .009 | .014 | .376 | 2.622 |

Note. The dependant variable was odors.
$R^2$ = 0.063, Adjusted $R^2$ = 0.057.
$sr^2$ is the squared semi-partial correlation.
* $p \leq .05$**$p \leq .01$, *** $p \leq .001$

#### 4.1.6.11 MLR model of IEQ factors on Eye, Nose, Throat, and Chest symptoms

The 11th MLR model followed the forced entry method described in Section 3.4.3. The model used the two comfort factors (Table 4-8) and odors factor (Table 3-27) to predict Eye, Nose, Throat, and Chest symptoms (Table 4-6). Appendix LL describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this MLR model. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-21. The model was statistically significant, F (4, 522) = 59.482, $p \leq .001$, and accounted for approximately 25.5% of the variance of Eye, Nose, Throat, and Chest related symptoms ($R^2$= .255, Adjusted $R^2$ = .250). Eye, Nose, Throat, and Chest related symptoms were statistically significantly predicted by the three parameters entered into the model. Predictors ordered according to their weights in the model are as follows: (1) Odors received the highest weights in the model; (2) IAQ discomfort the 2nd weight; and (3) Thermal, Lighting, and Noise discomfort received the 3rd weight. The three predictors were positively associated with Eye, Nose, Throat, and Chest related symptoms. For every unit increase in the frequency of experiencing odors; the model predicts an increase of 0.16 units in the frequency of experiencing Eye, Nose, Throat, and Chest related symptoms after controlling for the other two parameters included in the model. While for every unit increase in the frequency of IAQ discomfort; the model predicts an increase of 0.33 units in the frequency of experiencing Eye, Nose, Throat, and Chest related symptoms. Whereas, an increase of 0.12 units in the frequency of experiencing Eye, Nose, Throat, and Chest related symptoms is predicted for each unit increase in the frequency of experiencing Thermal, Lighting, and Noise discomfort.

Table 4-21: MLR results examining IEQ factors on Eye, Nose, Throat, and Chest symptoms

| | | | | | | 95% CI for B | |
|---|---|---|---|---|---|---|---|
| | B | *SE-B* | Beta | Sig. | $sr^2$ | Lower Bound | Upper Bound |
| (Constant)*** | 2.91 | .25 | | .000 | | 2.430 | 3.393 |
| Thermal, Lighting, and Noise discomfort*** | .12 | .03 | .16 | .000 | .020 | .055 | .180 |
| IAQ discomfort*** | .33 | .07 | .22 | .000 | .035 | .200 | .460 |
| Odors*** | .16 | .03 | .25 | .000 | .044 | .101 | .211 |

Note. The dependant variable was Eye, Nose, Throat, and Chest symptoms.
$R^2 = 0.255$, Adjusted $R^2 = 0.250$.
$sr^2$ is the squared semi-partial correlation.
*$p \le .05$, **$p \le .01$, *** $p \le .001$

In order to identify which predictor had the highest predictive power, the squared structure coefficient ($r_s^2$) was also calculated for each (Ziglari 2017; Ray-Mukherjee et al. 2014; Kraha et al. 2012). Variables ordered as per their calculated $r_s^2$ and predictive power were: (1) odors, $r_s^2 = 0.7$; (2) IAQ discomfort, $r_s^2 = 0.6$; and (3) Thermal, Lighting, and Noise, $r_s^2 = 0.5$; respectively. The proportions of the total variance uniquely and non-uniquely explained by each of the above ordered factors were also calculated based on their $r_s^2$. The proportion of the total variance explained by a variable is the output of multiplying the $r_s^2$ by the total variance explained by the model. The proportion of the total variance explained by a variable is the sum of: (i) the variance uniquely explained by the particular variable and not explained by any other variable, and (ii) the variance that non uniquely or commonly explained by the particular variable and other ones. The proportions of the total variance of the above listed factors were approximately 18.5%, 16.1%, and 12.8% of the explained variance of Eye, Nose, Throat, and Chest related symptoms; respectively. The unique variance explained by each of the factors was calculated based on $sr^2$ (Newsom 2015; Meyers et al. 2006). According to calculated $sr^2$ (Table 4-21); it was found that: (1) odors, (2) IAQ discomfort; and (3) Thermal, Lighting, and Noise discomfort uniquely accounted for approximately 4.4%, 3.5%, and 2.0% of the variance of Eye, Nose, Throat, and Chest related symptoms. It is important to note that the model explained about 26% of the variance in the Eye, Nose, Throat, and Chest related symptoms. However, the total variance uniquely explained by each of the statistically significant predictors was approximately 10%. The remaining 16% of the variance in Eye, Nose, Throat, and Chest related symptoms was non-uniquely explained variance by a particular predictor or the common variance explained by the relationship between the 3 predictors. Considering the uniquely explained variance, the non-uniquely variance or common variance explained by (1) odors, (2) IAQ discomfort, and (3) Thermal, Lighting, and Noise was 14.1%, 12.6%, and 10.8%; respectively (Figure 4-11).

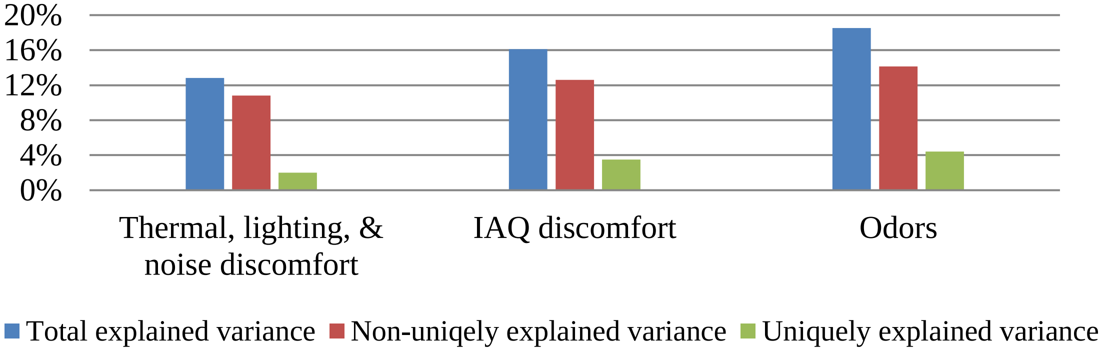


Figure 4-11: Total, uniquely and non-uniquely explained variance by IEQ factors in Eye, Nose, Throat, and Chest symptoms

### 4.1.6.12 MLR model of IEQ factors on Eye, Nose, Throat, and Chest symptoms adjusted for population and building

The 12th MLR model followed the forced entry method described in Section 3.4.3. The model used the two comfort factors (Table 4-8) and odors factor (Table 3-27) to predict Eye, Nose, Throat, and Chest symptoms (Table 4-6). The model was adjusted for population and building variables identified as predictors for Eye, Nose, Throat, and Chest symptoms at statistically significant level illustrated in Table 4-11 and Table 4-16 which are: dust allergy, migraine, asthma, water leakage, new carpets, and attached closed kitchen. Appendix MM describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this MLR model. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-22. The model was statistically significant, F (9, 519) = 23.563, $p \leq .001$, and accounted for approximately 29% of the variance of Eye, Nose, Throat, and Chest related symptoms ($R^2$= .290, Adjusted $R^2$ = .278). Eye, Nose, Throat, and Chest related symptoms were statistically significantly predicted by all parameters entered into the model except for water leakage.

Predictors ordered according to their weights in the model were as follows: (1) odors; (2) IAQ discomfort; (4) Thermal, Lighting, and Noise; (5) both migraine and attached kitchen with interior walls; (6) new carpets; (7) asthma. The eight predictors were positively associated with Eye, Nose, Throat, and Chest related symptoms. An increase of 0.13 units in the frequency of experiencing Eye, Nose, Throat, and Chest related symptoms was predicted for each unit increase in the frequency of experiencing odors after controlling for all other parameters included in the model. For every unit increase in the frequency of experiencing IAQ discomfort; the model predicted an increase of 0.30 units in the frequency of experiencing Eye, Nose, Throat, and Chest related symptoms. While for every unit increase in the frequency of experiencing thermal, lighting, noise discomfort; the model predicted an increase of 0.08 units in the frequency of experiencing Eye, Nose, Throat, and Chest related symptoms. Dust allergic, participants having migraine, and asthmatics had 0.91, 0.81, and 0.82 higher frequency of experiencing Eye, Nose, Throat, and Chest related symptoms than others; respectively. Residents of households having attached closed kitchen and new carpets had 0.71 and 0.68 higher frequency of experiencing Eye, Nose, Throat, and Chest related symptoms.

Table 4-22: MLR results examining IEQ factors on Eye, Nose, Throat, and Chest symptoms adjusted for significant population and building parameters

| | | | | | | 95% CI for B | |
|---|---|---|---|---|---|---|---|
| | B | *SE_B* | Beta | Sig. | $sr^2$ | Lower Bound | Upper Bound |
| (Constant)*** | 1.87 | .317 | | .000 | | 1.245 | 2.489 |
| Thermal, lighting, noise discomfort** | .08 | .031 | .113 | .009 | .009 | .020 | .141 |
| IAQ discomfort*** | .30 | .066 | .202 | .000 | .029 | .172 | .431 |
| Odors*** | .13 | .028 | .207 | .000 | .028 | .072 | .181 |
| Allergy to dust*** | .91 | .260 | .132 | .000 | .017 | .400 | 1.422 |
| Migraine** | .81 | .301 | .102 | .008 | .010 | .215 | 1.399 |
| Asthma* | .82 | .339 | .090 | .016 | .008 | .153 | 1.486 |
| Water leakage | .50 | .273 | .069 | .068 | .005 | -.036- | 1.038 |
| New carpets** | .68 | .290 | .091 | .019 | .008 | .110 | 1.248 |
| Attached kitchen with interior walls** | .71 | .262 | .102 | .007 | .010 | .192 | 1.222 |

Note. The dependant variable was Eye, Nose, Throat, and Chest symptoms.
$R^2$ = 0.290, Adjusted $R^2$ = 0.278.
$sr^2$ is the squared semi-partial correlation.
*$p \leq .05$, **$p \leq .01$, *** $p \leq .001$

In order to identify which predictor had the highest predictive power, $r_s^2$ was also calculated for each (Ziglari 2017; Ray-Mukherjee et al. 2014; Kraha et al. 2012). Variables ordered as per their calculated $r_s^2$ and predictive power were: (1) odors, $r_s^2 = 0.579$; (2) IAQ discomfort, $r_s^2 = 0.505$; (3) Thermal, Lighting, and Noise, $r_s^2 = 0.367$; (4) allergy to dust, $r_s^2 = 0.157$; (5) migraine, $r_s^2 = 0.125$; (6) new carpets, $r_s^2 = 0.059$; (7) asthma, $r_s^2 = 0.055$ ; and (8) attached kitchen with interior walls, $r_s^2 = 0.035$. The proportions of the total variance uniquely and non-uniquely explained by each of the above ordered factors based on their $r_s^2$were approximately 16.8%, 14.7%, 10.6%, 4.6%, 3.6%, 1.7%, 1.9%, and 1.0%; respectively. The unique variance explained by each of the factors was calculated based on $sr^2$ (Newsom 2015; Meyers et al. 2006). According to calculated $sr^2$ (Table 4-22); it was found that: (1) IAQ discomfort; (2) odors; (3) dust allergy; (4) migraine; (5) attached kitchen with interior walls; (6) Thermal, Lighting, and Noise; (7) new carpets; and (8) asthma uniquely accounted for approximately 2.9%, 2.8%, 1.7%, 1%, 1%; 0.9%, 0.8%, and 0.8% of the variance Eye, Nose, Throat, and Chest related symptoms. It is important to note that the model explained about 29% of the variance in the Eye, Nose, Throat, and Chest related symptoms. However, the total variance uniquely explained by the included parameters in the model was approximately 12%. The remaining 17% of the variance in Eye, Nose, Throat, and Chest related symptoms was non-uniquely explained variance by a particular parameter or that explained by the relationship between the parameters. Considering the uniquely explained variance, the non-uniquely variance or common variance explained by (1) odors; (2) IAQ discomfort; (3) Thermal, Lighting, and Noise, (4) allergy to dust, (5) migraine, (6) new carpets, (7) asthma, and (8) attached kitchen with interior walls were 14%, 11.7%, 9.7%, 2.8%, 2.6%, 0.9%, 0.7%, and 0.0%; respectively (Figure 4-12).

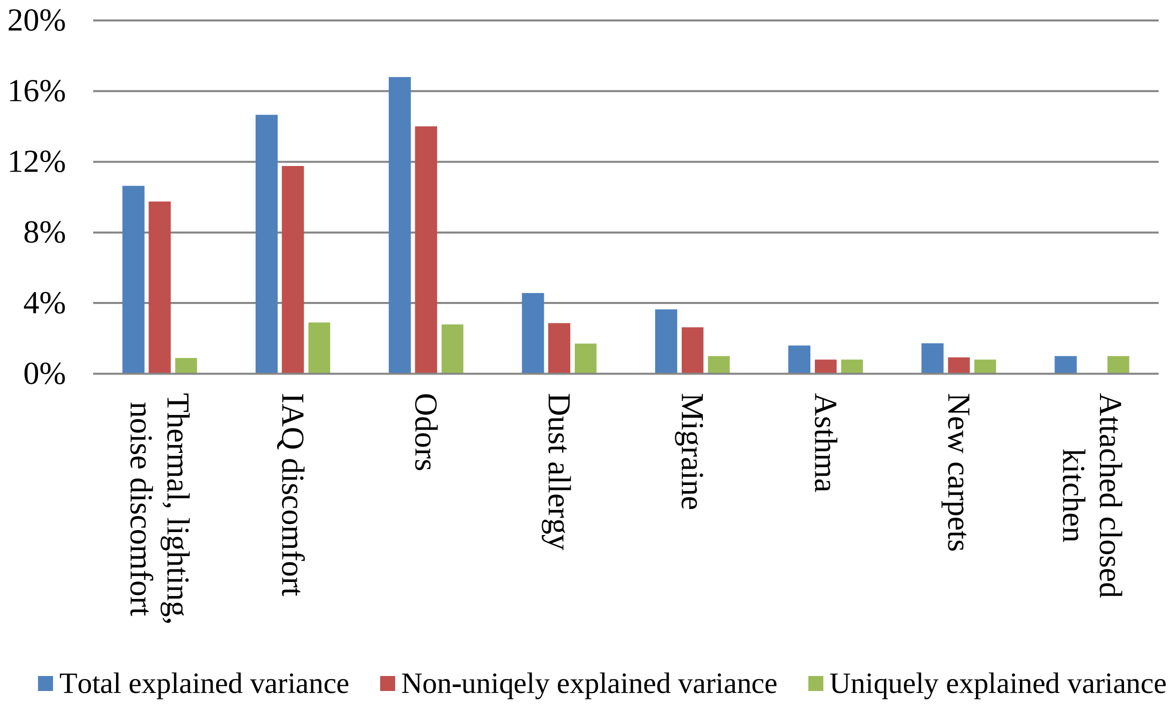


Figure 4-12: Total, uniquely and non-uniquely explained variance of IEQ factors of the variance in Eye, Nose, Throat, and Chest symptoms when adjusted to significant population and building variables

#### 4.1.6.13 MLR model of IEQ factors on General, Ergonomic, Nervous, and Skin symptoms

The 13th MLR model followed the forced entry method described in Section 3.4.3. The model used the two comfort factors (Table 4-8) and odors factor (Table 3-27) to predict general, ergonomic, nervous, and skin symptoms (Table 4-6). Appendix NN describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this MLR model. The raw and standardized regression coefficients of the predictors, *SE-B*, $p$ values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-23. The model was statistically significant, F (3, 519) = 69.541, $p \leq .001$, and accounted for approximately 28.7% of the variance of General, Ergonomic, Nervous, and Skin symptoms ($R^2$= .287, Adjusted $R^2$ = .283). General, Ergonomic, Nervous, and Skin symptoms were statistically significantly predicted by all parameters entered into the model.

Table 4-23: MLR results examining IEQ factors on General, Ergonomic, Nervous, and Skin symptoms

| | | | | | | 95% CI for B | |
|---|---|---|---|---|---|---|---|
| | B | *SE-B* | Beta | Sig. | $sr^2$ | Lower Bound | Upper Bound |
| (Constant)*** | 2.82 | .29 | | .000 | | 2.26 | 3.38 |
| Thermal, lighting, noise discomfort*** | .24 | .04 | .28 | .000 | .057 | .16 | .31 |
| IAQ discomfort* | .18 | .08 | .10 | .017 | .008 | .03 | .33 |
| Odors*** | .20 | .03 | .28 | .000 | .054 | .14 | .27 |

Note. The dependant variable was General, Ergonomic, Nervous, and Skin symptoms.
$R^2$ = 0.287, Adjusted $R^2$ = 0.283.
$sr^2$ is the squared semi-partial correlation.
*$p \leq .05$, **$p \leq .01$, *** $p \leq .001$

Predictors ordered according to their weights in the model were as follows: (1) odors in addition to the Thermal, Lighting, and Noise discomfort factors; then (2) IAQ discomfort factor. The three predictors were positively associated with General, Ergonomic, Nervous, and Skin symptoms. For every unit increase in the frequency of experiencing Thermal, Lighting, and Noise discomfort; the model predicted an increase of 0.24 units in the frequency of experiencing General, Ergonomic, Nervous, and Skin symptoms after controlling for all other parameters included in the model. An increase of 0.20 units in the frequency of experiencing General, Ergonomic, Nervous, and Skin symptoms was predicted for each unit increase in the frequency of experiencing odors. While for every unit increase in the frequency of experiencing IAQ discomfort; the model predicted an increase of 0.18 units in the frequency of experiencing General, Ergonomic, Nervous, and Skin symptoms.

In order to identify which predictor had the highest predictive power, $r_s^2$ was also calculated for each (Ziglari 2017; Ray-Mukherjee et al. 2014; Kraha et al. 2012). Variables ordered as per their calculated $r_s^2$ and predictive power were: (1) odors, $r_s^2 = 0.73$; (2) Thermal, Lighting, and Noise discomfort, $r_s^2 = 0.67$; and (3) IAQ discomfort, $r_s^2 = 0.42$; respectively. The proportions of the total variance uniquely and non-uniquely explained by each of the above ordered factors based on their $r_s^2$ were approximately 21%, 19.7%, and 11.9%; respectively. The unique variance explained by each of the factors was calculated based on $sr^2$ (Newsom 2015; Meyers et al. 2006). According to calculated $sr^2$ (Table 4-23); it was found that: (1) Thermal, Lighting, and Noise discomfort; (2) odors; and (3) IAQ discomfort uniquely accounted for approximately 5.7%, 5.4%, and 0.8%; respectively of the variance of General, Ergonomic, Nervous, and Skin symptoms. It is important to note that the model explained about 29% of the variance in the General, Ergonomic, Nervous, and Skin symptoms. However, the total variance uniquely explained by the included parameters in the model was approximately 12%. The remaining 17% of the variance in General, Ergonomic, Nervous, and Skin symptoms was non-uniquely explained by a particular parameter or that explained by the relationship between the parameters. Considering the uniquely explained variance, the non-uniquely variance or common variance explained by (1) odors; (2) Thermal, Lighting, and Noise discomfort; and (3) IAQ discomfort were approximately 15.6%, 14.0%, and 11.1%, respectively (Figure 4-13).

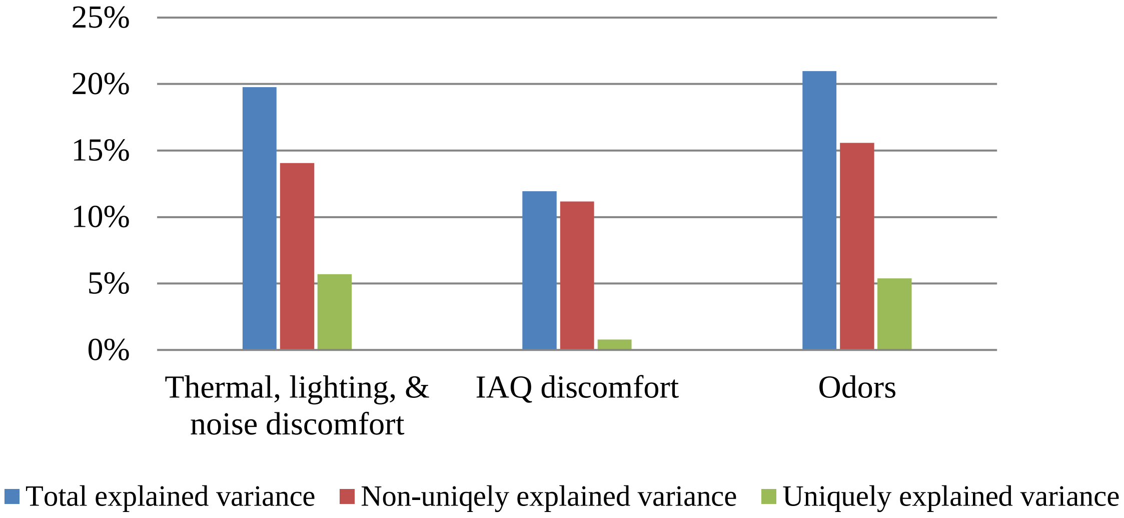


Figure 4-13: Total, uniquely and non-uniquely explained variance by IEQ factors in General, Ergonomic, Nervous, and Skin symptoms

#### 4.1.6.14 MLR model of IEQ factors on General, Ergonomic, Nervous, and Skin symptoms adjusted for significant population and building variables

The 14th MLR model followed the forced entry method described in Section 3.4.3. The model used the two comfort factors (Table 4-8) and odors factor (Table 3-27) to predict general, ergonomic, nervous, and skin symptoms (Table 4-6). The model was adjusted for population and building parameters identified as predictors for General, Ergonomic, Nervous, and Skin symptoms at statistically significant level illustrated in Table 4-12 and Table 4-17 which are: gender, migraine, dust, other Arabs or MENA National, eczema, water leakage, new furniture, new carpets, central HVAC, and Dubai Sector 1. Appendix OO describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this MLR model. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-24. The model was statistically significant, F (13, 464) = 21.602, $p \leq .001$, and accounted for approximately 37.7% of the variance of General, Ergonomic, Nervous, and Skin symptoms ($R^2$= .377, Adjusted $R^2$ = .360). General, Ergonomic, Nervous, and Skin symptoms were statistically significantly predicted by all parameters entered into the model except for: (1) dust allergy; (2) new furniture; and (3) Dubai Sector 1. Predictors ordered according to their weights in the model were as follows: (1) Odors; (2) Thermal, Lighting, and Noise discomfort received; (3) gender; (4) migraine, water leakage, and other Arabs and MENA; (5) IAQ discomfort; (6) eczema; (7) new carpets; and (8) central HVAC. All predictors except central HVAC were positively associated with General, Ergonomic, Nervous, and Skin symptoms.

Table 4-24: MLR results examining IEQ factors on General, Ergonomic, Nervous, and Skin symptoms adjusted for significant population and building variables

| | | | | | | 95% CI for B | |
|---|---|---|---|---|---|---|---|
| | B | SE-B | Beta | Sig. | *sr*$^2$ | Lower Bound | Upper Bound |
| (Constant)** | 1.29 | .49 | | .009 | | .319 | 2.255 |
| Thermal, lighting, noise discomfort*** | .19 | .04 | .20 | .000 | .030 | .109 | .266 |
| IAQ discomfort** | .22 | .09 | .11 | .010 | .009 | .052 | .385 |
| Odors*** | .17 | .04 | .22 | .000 | .031 | .099 | .236 |
| Gender*** | 1.45 | .35 | .16 | .000 | .023 | .770 | 2.133 |
| Migraine** | 1.25 | .40 | .12 | .001 | .014 | .489 | 2.020 |
| Allergy to dust | .64 | .34 | .07 | .061 | .005 | -.029 | 1.302 |
| Other Arabs/ MENA*** | 1.48 | .46 | .12 | .001 | .014 | .579 | 2.386 |
| Eczema* | 1.39 | .55 | .10 | .011 | .009 | .315 | 2.472 |
| Water leakage** | 1.09 | .35 | .12 | .002 | .013 | .398 | 1.788 |
| New furniture | .31 | .35 | .04 | .371 | .001 | -.374 | 1.000 |
| New carpets* | .48 | .39 | .05 | .215 | .002 | -.280 | 1.239 |
| Central HVAC* | -.23 | .37 | -.02 | .531 | .001 | -.962 | .496 |
| Dubai Sector 1 | 1.18 | .56 | .08 | .036 | .006 | .079 | 2.289 |

Note. The dependant variable was General, Ergonomic, Nervous, and Skin symptoms.
$R^2$ = 0.377, Adjusted $R^2$ = 0.360.
*sr*$^2$ is the squared semi-partial correlation.
*$p \leq .05$, **$p \leq .01$, *** $p \leq .001$

An increase of 0.17 units in the frequency of experiencing General, Ergonomic, Nervous, and Skin symptoms was predicted for each unit increase in the frequency of experiencing odors after controlling for all other parameters included in the model. For every unit increase in the frequency of experiencing Thermal, Lighting, and Noise discomfort; the model predicted an increase of 0.19 units in the frequency of experiencing General, Ergonomic, Nervous, and Skin symptoms. While for every unit increase in the frequency of experiencing IAQ discomfort; the model predicted an increase of 0.22 units in the frequency of experiencing General, Ergonomic, Nervous, and Skin symptoms. Females, participants having migraine, participants having eczema, or other Arabs and MENA nationals had 1.45, 1.25, 1.39, and 1.48 higher frequency of experiencing General, Ergonomic, Nervous, and Skin symptoms than others; respectively. Residents of households having water leakage or new carpets had 1.09 and 0.48 higher frequency of experiencing General, Ergonomic, Nervous, and Skin symptoms; respectively. Residents of households using central HVAC had 0.23 lower frequency of experiencing General, Ergonomic, Nervous, and Skin symptoms.

In order to identify which predictor had the highest predictive power, $r_s^2$ was also calculated for each (Ziglari 2017; Ray-Mukherjee et al. 2014; Kraha et al. 2012). Variables ordered as per their calculated $r_s^2$ and predictive power: (1) Odors, $r_s^2 = 0.50$; (2) Thermal, Lighting, and Noise discomfort, $r_s^2 = 0.45$; (3) IAQ discomfort, $r_s^2 = 0.30$; (4) migraine, $r_s^2 = 0.16$; (5) gender, $r_s^2 = 0.15$; (6) water leakage, $r_s^2 = 0.11$; (7) eczema, $r_s^2 = 0.10$; (8) new carpets, $r_s^2 = 0.08$; (9) other Arabs and MENA nationals, $r_s^2 = 0.04$; and (10) central HVAC, $r_s^2 = 0.01$; respectively. The proportions of the total variance uniquely and non-uniquely explained by each of the above ordered factors based on their $r_s^2$ were approximately 18.8%, 17.1%, 11.4%, 5.9%, 5.7%, 4.1%, 3.8%, 3.1%, 1.4%, and 0.4%; respectively. The unique variance explained by each of the factors was calculated based on the squared semi- partial correlations ($sr^2$) (Newsom 2015; Meyers et al. 2006). According to calculated $sr^2$ (Table 4-24); it was found that: (1) Odors; (2) Thermal, Lighting, and Noise discomfort; (3) gender; (4) migraine; (5) other Arabs and MENA nationals; (6) water leakage; (7) IAQ discomfort; (8) eczema; (9) new carpets; and (10) central HVAC uniquely accounted for approximately 3.1%, 3.0%, 2.4%, 1.4%, 1.4%, 1.3%, 0.9%, 0.9%, 0.2%, and 0.1% of the variance of General, Ergonomic, Nervous, and Skin symptoms; respectively. It is important to note that the model explains about 37.7% of the variance in the General, Ergonomic, Nervous, and Skin symptoms. However, the total variance uniquely explained by the included parameters in the model was approximately 16%. The remaining 22% of the variance in General, Ergonomic, Nervous, and Skin symptoms was non-uniquely explained by a particular parameter or that explained by the relationship between the parameters. Considering the uniquely explained variance, the non-uniquely variance or common variance explained by 1) Odors; (2) Thermal, Lighting, and Noise discomfort; (3) IAQ discomfort; (4) migraine; (5) gender; (6) water leakage; (7) eczema; (8) new carpets; (9) other Arabs and MENA nationals; and (10) central HVAC were approximately 15.7%, 14.1%, 10.5%, 4.5%, 3.4%, 2.9%, 2.9%, 2.9%, 0.0%, and 0.3%; respectively (Figure 4-14).

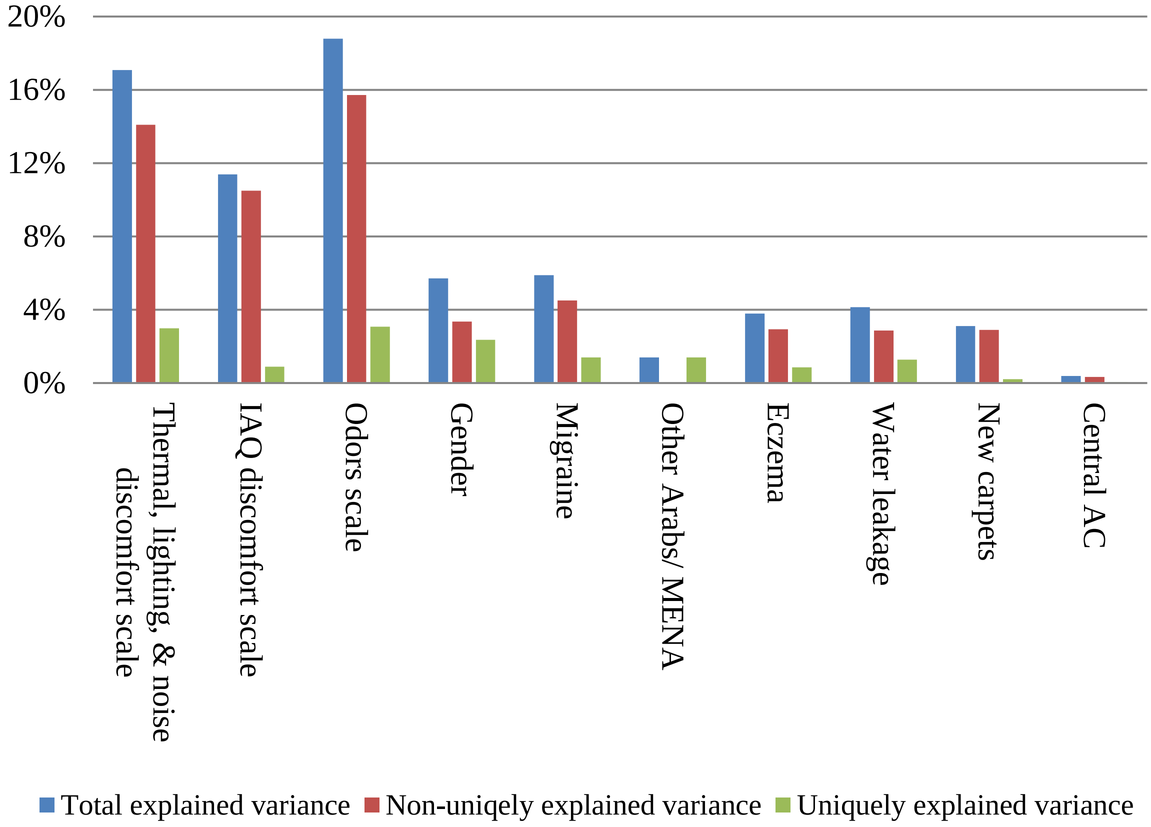


Figure 4-14: Total, uniquely and non-uniquely explained variance in the General, Ergonomic, Nervous, and Skin symptoms by IEQ factors adjusted for significant population and building variables

#### 4.1.6.15 MLR model of other IEQ factors on IAQ discomfort

The 15th MLR model followed the forced entry method described in Section 3.4.3. The model used the Thermal, Lighting, and Noise discomfort factor (Table 4-8) and odors factor (Table 3-27) to predict IAQ discomfort (Table 4-8). Appendix PP describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this MLR model. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-25. The model was statistically significant, F (2, 522) = 126.107, $p \leq .001$, and accounted for approximately 32.6% of the variance of IAQ discomfort ($R^2$= .326, Adjusted $R^2$ = .323). IAQ discomfort was statistically significantly predicted by two parameters entered into the model. Predictors ordered according to their weights in the model were as follows: (1) odors; (2) Thermal, Lighting, and Noise discomfort. The two predictors were positively associated with IAQ discomfort. An increase of 0.17 units in the frequency of experiencing IAQ discomfort was predicted for each unit increase in the frequency of experiencing odors. And for every unit increase in the frequency of experiencing Thermal, Lighting, and Noise discomfort; the model predicted an increase of 0.11 units of the frequency of experiencing IAQ discomfort after controlling for all other parameters included in the model.

Table 4-25: MLR results examining thermal, lighting, noise discomfort and odors factors on IAQ discomfort

| | | | | | | 95% CI for B | |
|---|---|---|---|---|---|---|---|
| | B | SE-B | Beta | Sig. | $sr^2$ | Lower Bound | Upper Bound |
| (Constant)*** | .75 | .147 | | .000 | | .465 | 1.043 |
| Thermal, lighting, noise discomfort*** | .11 | .019 | .239 | .000 | .045 | .075 | .151 |
| Odors*** | .17 | .016 | .419 | .000 | .137 | .137 | .201 |

Note. The dependant variable was IAQ discomfort.
$R^2$ = 0.326, Adjusted $R^2$ = 0.323.
$sr^2$ is the squared semi-partial correlation.

In order to identify which predictor had the highest predictive power, $r_s^2$ was also calculated for each (Ziglari 2017; Ray-Mukherjee et al. 2014; Kraha et al. 2012). Variables ordered as per their calculated $r_s^2$ and predictive power were: (1) Odors, $r_s^2 =$ 0.86; and (2) Thermal, Lighting, and Noise discomfort, $r_s^2 =$ 0.58; respectively. The proportions of the total variance uniquely and non-uniquely explained by each of the above ordered factors based on their $r_s^2$ were approximately 28.1% and 18.8%; respectively. The unique variance explained by each of the factors was calculated based on $sr^2$ (Newsom 2015; Meyers et al. 2006). According to calculated $sr^2$ (Table 4-25); it was found that: (1) odors; and (2); Thermal, Lighting, and Noise discomfort uniquely accounted for approximately 13.7%, and 4.5%; respectively of the variance of IAQ discomfort. It is important to note that the model explains about 32.6% of the variance in the IAQ discomfort. However, the total variance uniquely explained by the included parameters in the model was approximately 18%. The remaining 14% of the variance in IAQ discomfort was non-uniquely explained by a particular parameter or that explained by the relationship between the parameters. Considering the uniquely explained variance, the non-uniquely variance or common variance explained by (1) Odors; and (2) Thermal, Lighting, and Noise discomfort were approximately 14.4% and 14.4; respectively (Figure 4-15).

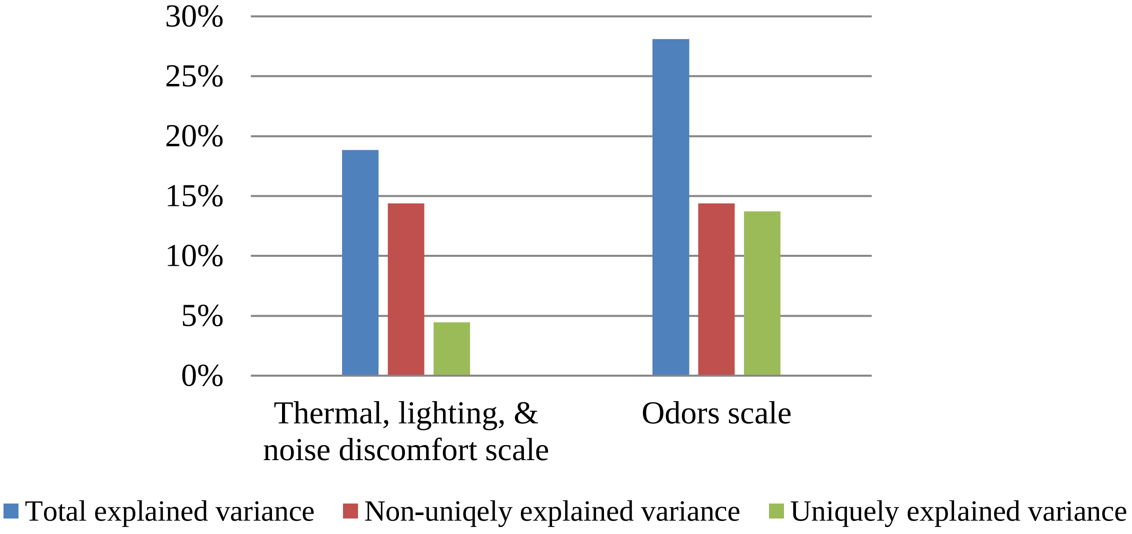


Figure 4-15: Total, uniquely and non-uniquely explained variance by odors and Thermal, Lighting, and Noise discomfort factors in IAQ discomfort

#### 4.1.6.16 MLR model of other IEQ factors on IAQ discomfort adjusted for population and building variables

The 16th MLR model followed the forced entry method described in Section 3.4.3. The model used the Thermal, Lighting, and Noise discomfort factor (Table 4-8) and odors factor (Table 3-27) to predict IAQ discomfort (Table 4-8). The model was adjusted for population and building variables identified as predictors IAQ discomfort at statistically significant level illustrated in Table 4-14 and Table 4-19 which were: UAE or GCC National, migraine, dust allergy, age, asthma, water leakage, and new wall covering. Appendix QQ describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this MLR model. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-26. The model was statistically significant, F (8, 518) = 41.655, $p \leq .001$, and accounted for approximately 39.3% of the variance of IAQ discomfort ($R^2$= .391, Adjusted $R^2$ = .382). IAQ discomfort was statistically significantly predicted by all parameters entered into the model except for water leakage.

Table 4-26: MLR results examining Thermal, Lighting, and Noise discomfort and odors factors on IAQ discomfort adjusted for significant population and building parameters

| | | | | | | 95% CI for B | |
|---|---|---|---|---|---|---|---|
| | B | *SE-B* | Beta | Sig. | $sr^2$ | Lower Bound | Upper Bound |
| (Constant) | -.31 | .252 | | .219 | | -.805 | .185 |
| Thermal, lighting, noise discomfort*** | .09 | .018 | .194 | .000 | .029 | .055 | .126 |
| Odors*** | .17 | .016 | .432 | .000 | .146 | .142 | .203 |
| Migraine* | .37 | .182 | .072 | .042 | .005 | .014 | .727 |
| Allergy to dust** | .47 | .157 | .104 | .003 | .010 | .157 | .775 |
| Age*** | .58 | .129 | .157 | .000 | .023 | .321 | .829 |
| Other Africans*** | .71 | .201 | .124 | .000 | .015 | .314 | 1.104 |
| New wall covering** | -.70 | .257 | -.096 | .006 | .009 | -1.209 | -.198 |
| Water leakage | .20 | .165 | .041 | .239 | .002 | -.130 | .519 |

Note. The dependant variable was IAQ discomfort.
$R^2$ = 0.391, Adjusted $R^2$ = 0.382.
$sr^2$ is the squared semi-partial correlation.

Predictors ordered according to their weights in the model were as follows: (1) odors; (2) Thermal, Lighting, and Noise discomfort; (3) age; (4) other Africans; (5) dust allergy; (6) new wall covering; and (7) migraine. All predictors were positively associated with IAQ discomfort except for new wall covering. For every unit increase in the frequency of experiencing odors; the model predicted an increase of 0.17 units in the frequency of experiencing IAQ discomfort after controlling for all other parameters included in the model. An increase of 0.09 units in the frequency of experiencing IAQ discomfort was predicted for each unit increase in the frequency of experiencing Thermal, Lighting, and Noise discomfort. People of an older age group had 0.58 higher frequency of experiencing IAQ discomfort than those of the younger age group. Other Africans, dust allergic, and those having migraine had 0.71, 0.47, and 0.37 higher frequency of experiencing IAQ discomfort than others; respectively. However, participants living in households with new wall covering have 0.7 lower frequency of experiencing IAQ discomfort than those who hadn't.

In order to identify which predictor had the highest predictive power, $r_s^2$ was also calculated for each (Ziglari 2017; Ray-Mukherjee et al. 2014; Kraha et al. 2012). Variables ordered as per their calculated $r_s^2$ and predictive power were : (1) odors, $r_s^2 = 0.8$; (2) Thermal, Lighting, and Noise discomfort,$r_s^2 = 0.4$; (3) dust allergy,$r_s^2 = 0.07$; (4) age and migraine,$r_s^2 = 0.06$; (5) other Africans,$r_s^2 = 0.04$; and (6) new wall covering,$r_s^2 = 0.02$; respectively. The proportions of the total variance uniquely and non-uniquely explained by each of the above ordered factors based on their $r_s^2$ were approximately 30%, 16%, 2.7%, 2.3%, 1.5%, and 1%; respectively. The unique variance explained by each of the factors was calculated based on $sr^2$ (Newsom 2015; Meyers et al. 2006). According to calculated $sr^2$ (Table 4-26); it was found that: (1) odors; (2) Thermal, Lighting, and Noise discomfort; (3) age; (4) other Africans; (5) dust allergy; (6) new wall covering; and (7) migraine uniquely accounted for approximately 14.6%, 2.9%, 2.3%, 1.5%, 1%, 0.9%, and 0.5% of the variance of IAQ discomfort; respectively. It is important to note that the model explained about 39% of the variance in the IAQ discomfort. However, the total variance uniquely explained by included parameters in the model was approximately 24%. The remaining 15% of the variance in IAQ discomfort is non-uniquely explained by a particular parameter or that explained by the relationship between the parameters. Considering the uniquely explained variance, the non-uniquely variance or common variance explained by (1) odors; (2) Thermal, Lighting, and Noise discomfort; (3) dust allergy; (4) age; (5) migraine; (6) other Africans; and (7) new wall covering were approximately 15.3%, 13.2%, 1.7%, 0%, 1.8%, 0%, and 0.1%; respectively (Figure 4-16).

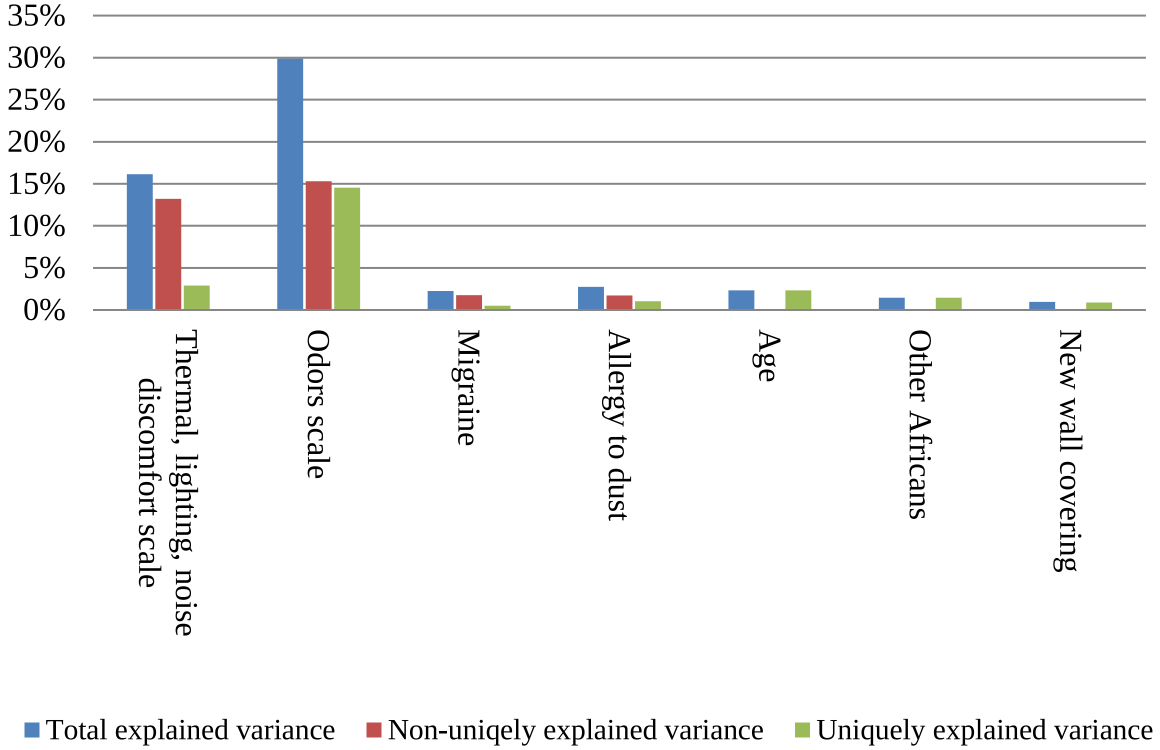


Figure 4-16: Total, uniquely and non-uniquely explained variance by odors and Thermal, Lighting, and Noise discomfort factors in IAQ discomfort adjusted for population and building variables

#### 4.1.6.17 MLR model of Thermal, Lighting, and Noise variables on Eye, Nose, Throat, and Chest related symptoms

The 17th MLR model followed the forced entry method described in Section 3.4.3. The model used the Thermal, Lighting, and Noise discomfort variables (Table 4-8) to predict Eye, Nose, Throat, and Chest related symptoms (Table 4-6). Appendix RR describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this MLR model. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-27. The model was statistically significant, F (6, 536) = 13.496, $p \leq .001$, and accounted for approximately 13.3% of the variance of Eye, Nose, Throat, and Chest related symptoms ($R^2$= .133, Adjusted $R^2$ = .123). Eye, Nose, Throat, and Chest related symptoms were statistically significantly predicted by two variables in the model which were “Too much humidity” and “Too much dim”. Predictors ordered according to their weights in the model were as follows: (1) “Too much dim” and (2) “Too much humidity”. The two predictors were positively associated with Eye, Nose, Throat, and Chest related symptoms. For every unit increase in the frequency of experiencing “Too much dim”; the model predicted an increase of 0.653 units in the frequency of experiencing Eye, Nose, Throat, and Chest related symptoms after controlling for all other parameters included in the model. An increase of 0.290 units in the frequency of experiencing Eye, Nose, Throat, and Chest related symptoms was predicted for each unit increase in the frequency of experiencing “Too much humidity”.

Table 4-27: MLR results examining Thermal, Lighting, and Noise discomfort variables on Eye, Nose, Throat, and Chest related symptoms

|  |  |  |  |  |  | 95% CI for B |  |
|---|---|---|---|---|---|---|---|
|  | B | *SE-B* | Beta | Sig. | $sr^2$ | Lower Bound | Upper Bound |
| (Constant)*** | 4.255 | .249 |  | .000 |  | 3.766 | 4.744 |
| Too much air movement | .094 | .123 | .035 | .445 | .001 | -.147 | .335 |
| Too cold | -.002 | .132 | -.001 | .991 | .000 | -.261 | .258 |
| Too much humidity* | .290 | .127 | .105 | .022 | .009 | .041 | .539 |
| Too much glare | .269 | .151 | .090 | .076 | .005 | -.029 | .567 |
| Too much dim*** | .653 | .159 | .203 | .000 | .028 | .341 | .964 |
| Too quiet | .196 | .102 | .081 | .057 | .006 | -.006 | .397 |

Note. The dependant variable was Eye, Nose, Throat, and Chest related symptoms.
$R^2$ = 0.133, Adjusted $R^2$ = 0.123.
$sr^2$ is the squared semi-partial correlation.
*$p \leq .05$, **$p \leq .01$, *** $p \leq .001$

In order to identify which of the two statistically significant predictors had the highest predictive power, $r_s^2$ was also calculated for each (Ziglari 2017; Ray-Mukherjee et al. 2014; Kraha et al. 2012). Variables ordered as per their calculated $r_s^2$ and predictive power were: (1) “Too much dim”, $r_s^2 = 0.75$ and (2) “Too much humidity”, $r_s^2 = 0.44$; respectively. The proportions of the total variance uniquely and non-uniquely explained by each of the above ordered factors based on their $r_s^2$ were approximately 10% and 6%; respectively. The unique variance explained by each of the factors was calculated based on $sr^2$ (Newsom 2015; Meyers et al. 2006). According to calculated $sr^2$ (Table 4-27); it was found that: (1) “Too much dim” and (2) “Too much humidity” uniquely accounted for approximately 3% and 1% of the variance of Eye, Nose, Throat, and Chest related symptoms; respectively. It is important to note that the model explained about 13% of the variance in the Eye, Nose, Throat, and Chest related symptoms. However, the total variance uniquely explained by included parameters in the model is approximately 5%. The remaining 8% of the variance in Eye, Nose, Throat, and Chest related symptoms was non-uniquely explained by a particular parameter or that explained by the relationship between the parameters. Considering the uniquely explained variance, the non-uniquely variance or common variance explained by (1) “Too much dim” and (2) “Too much humidity” were approximately 7 and 5%; respectively (Figure 4-17).

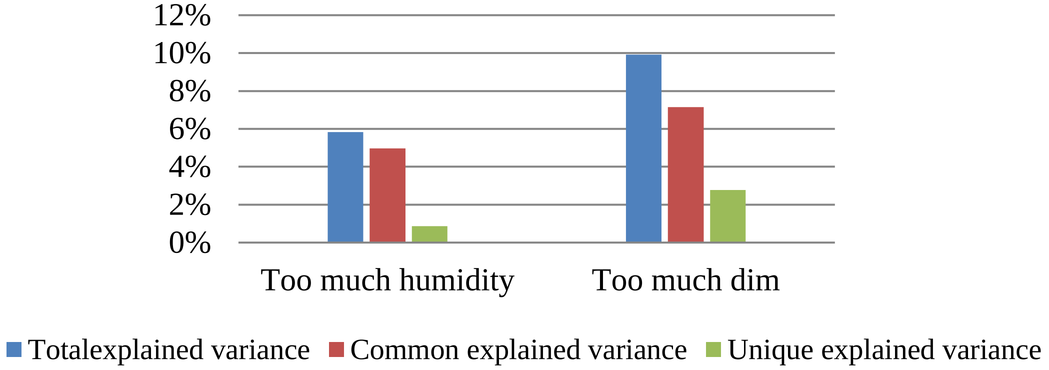


Figure 4-17: Total, uniquely and non-uniquely explained variance by statistically significant variables of Thermal, Lighting, and Noise discomfort in Eye, Nose, Throat, and Chest symptoms

### 4.1.6.18 MLR model of IAQ discomfort variables on Eye, Nose, Throat, and Chest related symptoms

The 18th MLR model followed the forced entry method described in Section 3.4.3. The model used the IAQ discomfort variables (Table 4-8) to predict Eye, Nose, Throat, and Chest related symptoms (Table 4-6). Appendix SS describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this MLR model. The raw and standardized regression coefficients of the predictors, the standard error of B (*SE-B*), *p* values, the squared semi- partial correlations ($sr^2$) between the predictors and the DV, and the lower and upper values of 95% Confidence Interval (CI) are shown in Table 4-28. The model was statistically significant, F (2, 534) = 43.172, $p \leq .001$, and accounted for approximately 13.9% of the variance of Eye, Nose, Throat, and Chest related symptoms ($R^2$= .139, Adjusted $R^2$ = .136). Eye, Nose, Throat, and Chest related symptoms were statistically significantly predicted by the two variables in the model which were “Dust and dirt” and “Stuffy bad air”.

Table 4-28: MLR results examining IAQ discomfort variables on Eye, Nose, Throat, and Chest related symptoms

| | | | | | | 95% CI for B | |
|---|---|---|---|---|---|---|---|
| | B | SE-B | Beta | Sig. | $sr^2$ | Lower Bound | Upper Bound |
| (Constant)*** | 4.163 | .227 | | .000 | | 3.717 | 4.609 |
| Dust and dirt *** | .458 | .124 | .180 | .000 | 0.022 | .214 | .702 |
| Stuffy "bad" air*** | .686 | .140 | .240 | .000 | 0.039 | .411 | .960 |

Note. The dependant variable was Eye, Nose, Throat, and Chest related symptoms.
$R^2$ = 0.139, Adjusted $R^2$ = 0.136.
$sr^2$ is the squared semi-partial correlation.
*$p \leq .05$, **$p \leq .01$, *** $p \leq .001$

Predictors ordered according to their weights in the model were as follows: (1) “Stuffy bad air” and (2) “Dust and dirt”. The two predictors were positively associated with Eye, Nose, Throat, and Chest related symptoms. For every unit increase in the frequency of experiencing “Stuffy bad air”; the model predicted an increase of 0.686 units in the frequency of experiencing Eye, Nose, Throat, and Chest related symptoms after controlling for “Dust and dirt”. An increase of 0.458 units in the frequency of experiencing Eye, Nose, Throat, and Chest related symptoms is predicted for each unit increase in the frequency of experiencing “Dust and dirt”. In order to identify which of the two statistically significant predictors had the highest predictive power, $r_s^2$ was also calculated for each (Ziglari 2017; Ray-Mukherjee et al. 2014; Kraha et al. 2012). Variables ordered as per their calculated $r_s^2$ and predictive power were: (1) “Stuffy bad air”, $r_s^2 = 0.8$ and (2) “Dust and dirt”, $r_s^2 = 0.7$; respectively. The proportions of the total variance uniquely and non-uniquely explained by each of the above ordered factors based on their $r_s^2$ were approximately 12% and 10%; respectively. The unique variance explained by each of the factors was calculated based on $sr^2$ (Newsom 2015; Meyers et al. 2006). According to calculated $sr^2$ (Table 4-28); it was found that: (1) “Stuffy bad air” and (2) “Dust and dirt” uniquely accounted for approximately 4% and 2% of the variance of Eye, Nose, Throat, and Chest related symptoms; respectively. It is important to note that the model explained about 14% of the variance in the Eye, Nose, Throat, and Chest related symptoms. However, the total variance uniquely explained by included parameters in the model was approximately 6%. The remaining 8% of the variance in Eye, Nose, Throat, and Chest related symptoms was non-uniquely explained by a particular parameter or that explained by the relationship between the two variables. Considering the uniquely explained variance, the non-uniquely variance or common variance explained by (1) “Stuffy bad air” and (2) “Dust and dirt” were approximately 7.8% and 7.8%; respectively (Figure 4-18).

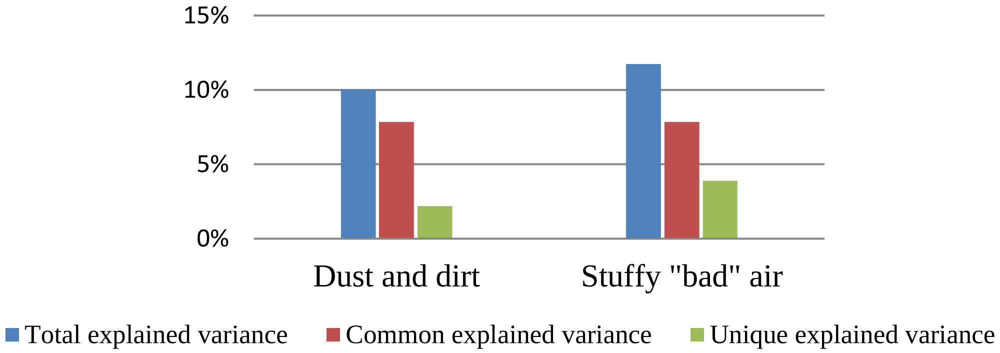


Figure 4-18: Total, uniquely and non-uniquely explained variance by statistically significant variables of IAQ discomfort in Eye, Nose, Throat, and Chest related symptoms

### 4.1.6.19 MLR model of odors variables on Eye, Nose, Throat, and Chest related symptoms

The 19th MLR model followed the forced entry method described in Section 3.4.3. The model used the odors variables (Table 3-27) to predict Eye, Nose, Throat, and Chest related symptoms (Table 4-6). Appendix TT describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this MLR model. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-29. The model was statistically significant, F (9, 492) = 17.153, $p \leq .001$, and accounted for approximately 23.9% of the variance of Eye, Nose, Throat, and Chest related symptoms ($R^2$= .239, Adjusted $R^2$ = .225). Eye, Nose, Throat, and Chest related symptoms were statistically significantly predicted by the following six variables in the model ordered according to their weights: (1) “Odors from other chemicals i.e. pesticides, glues, or cleaning products”; (2) “Odors from new carpet, curtains, or drapes”; (3) “Odors from paint”; (4) “Tobacco smoke”; (5) “Smoke from incense burning”; and (6) “Musty/mouldy dampness odors”.

All predictors were positively associated with Eye, Nose, Throat, and Chest related symptoms. For every unit increase in the frequency of experiencing “Odors from other chemicals i.e. pesticides, glues, or cleaning products”; the model predicts an increase of 0.43 units in the frequency of experiencing Eye, Nose, Throat, and Chest related symptoms after controlling for other variables included in the model. An increase of 0.72 units in the frequency of experiencing Eye, Nose, Throat, and Chest related symptoms were predicted for each unit increase in the frequency of experiencing “Odors from new carpet, curtains, or drapes”. And for every unit increase in the frequency of experiencing “Odors from paint”; the model predicted an increase of 0.60 units in the frequency of experiencing Eye, Nose, Throat, and Chest related symptoms. An increase of 0.30 units, 0.28 units, and 0.41 in the frequency of experiencing Eye, Nose, Throat, and Chest related symptoms was predicted for each unit increase in the frequency of experiencing “Tobacco smoke”, “Smoke from incense burning”, and “Musty/mouldy dampness odors”; respectively.

Table 4-29: MLR results examining odors variables on Eye, Nose, Throat, and Chest related symptoms

| | | | | | | 95% CI for B | |
|---|---|---|---|---|---|---|---|
| | B | SE-B | Beta | Sig. | *sr*$^2$ | Lower Bound | Upper Bound |
| (Constant)*** | 3.5 | .21 | | .000 | | 3.091 | 3.929 |
| Smoke from incense burning** | .28 | .09 | .12 | .003 | .013 | .091 | .458 |
| Odors from new carpet/ curtains*** | .72 | .21 | .15 | .001 | .018 | .300 | 1.133 |
| Musty/mouldy dampness odors* | .41 | .16 | .11 | .012 | .010 | .092 | .724 |
| Fishy smells or other food smells | .15 | .11 | .06 | .194 | .003 | -.076 | .373 |
| Body odors or cosmetics odors | .03 | .11 | .01 | .783 | .000 | -.191 | .253 |
| Odors from paint** | .60 | .20 | .14 | .002 | .014 | .213 | .984 |
| Odors from other chemicals ** | .43 | .16 | .17 | .009 | .011 | .109 | .745 |
| Tobacco smoke** | .30 | .10 | .13 | .003 | .014 | .101 | .494 |
| Odors from diesel/ engines exhaust | .32 | .17 | .08 | .062 | .005 | -.017 | .651 |

Note. The dependant variable was Eye, Nose, Throat, and Chest related symptoms.
$R^2 = 0.239$, Adjusted $R^2 = 0.225$.
*sr*$^2$ is the squared semi-partial correlation.
$*p \leq .05$, $**p \leq .01$, $*** p \leq .001$

In order to identify which of the six statistically significant predictors had the highest predictive power, $r_s^2$ was also calculated for each (Ziglari 2017; Ray-Mukherjee et al. 2014; Kraha et al. 2012). Variables ordered as per their calculated $r_{s2}$ and predictive power were: (1) “Odors from paint”, $r_s^2 = 0.41$; (2) “Odors from new carpet, curtains, or drapes”, $r_s^2 = 0.$; (3) “Odors from other chemicals i.e. pesticides, glues, or cleaning products”, $r_s^2 = 0.32$; (4) “Musty/mouldy dampness odors”, $r_s^2 = 0.27$; (5) “Smoke from incense burning”, $r_s^2 = 0.23$; and (6) “Tobacco smoke”, $r_s^2 = 0.13$; respectively. The proportions of the total variance uniquely and non-uniquely explained by each of the above ordered factors based on their $r_s^2$) were approximately 9.7%, 9.5%, 7.6%, 6.4%, 5.6%, and 3.1%; respectively. The unique variance explained by each of the factors was calculated based on *sr*$^2$ (Newsom 2015; Meyers et al. 2006). According to calculated *sr*$^2$ (Table 4-29); it was found that: (1) “Odors from new carpet, curtains, or drapes”; (2) “Odors from paint”; (3) “Tobacco smoke”; (4) “Smoke from incense burning”; (5) “Odors from other chemicals i.e. pesticides, glues, or cleaning products”; and (6) “Musty/mouldy dampness odors” uniquely accounted for approximately 1.8%, 1.4%, 1.4%, 1.3%, 1.1%, and 1.0% of the variance of Eye, Nose, Throat, and Chest related symptoms; respectively. It is important to note that the model explained about 24% of the variance in the Eye, Nose, Throat, and Chest related symptoms. However, the total variance uniquely explained by included parameters in the model was approximately 9%. The remaining 15% of the variance in Eye, Nose, Throat, and Chest related symptoms was non-uniquely explained by a particular parameter or that explained by the relationship between the variables. Considering the uniquely explained variance, the non-uniquely variance or common variance explained by (1) “Odors from paint”; (2) “Odors from new carpet, curtains, or drapes”; (3) “Odors from other chemicals i.e. pesticides, glues, or cleaning products”; (4) “Musty/mouldy dampness odors”; (5) “Tobacco smoke” ; (6) “Smoke from incense burning” was approximately 8.3%, 7.7%, 6.5%, 5.4%, 4.2% and 1.8%; respectively (Figure 4-19).

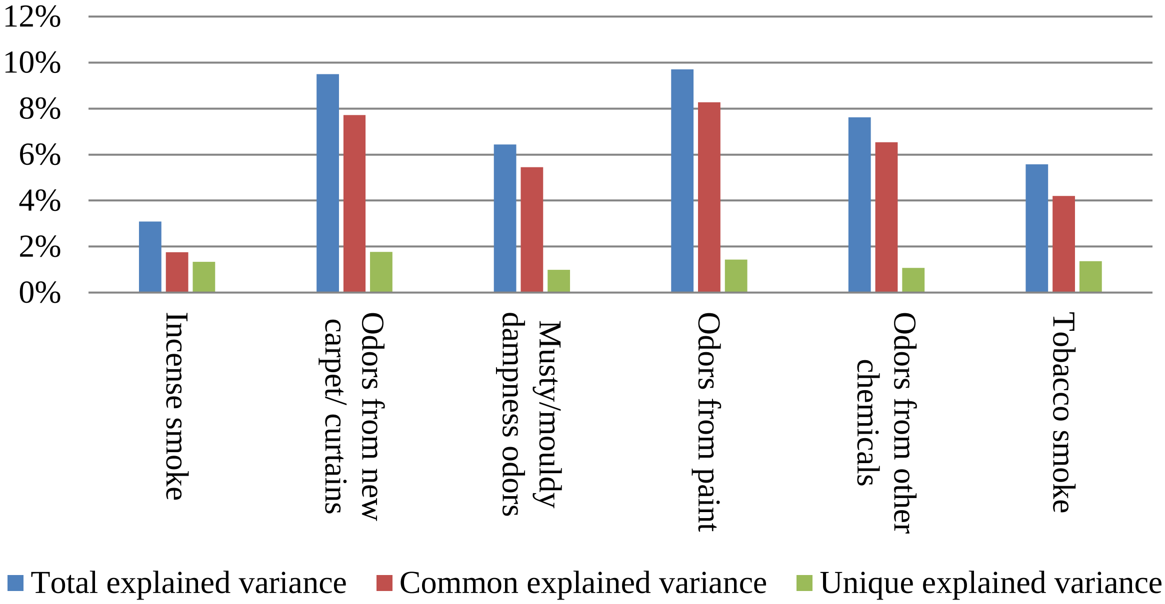


Figure 4-19: Total, uniquely and non-uniquely explained variance by statistically significant odors variables in Eye, Nose, Throat, and Chest related symptoms

#### 4.1.6.20 MLR model of Thermal, Lighting, and Noise discomfort variables on General, Ergonomic, Nervous, and Skin symptoms

The $20^{th}$ MLR model followed the forced entry method described in Section 3.4.3. The model used the Thermal, Lighting, and Noise discomfort variables (Table 4-8) to predict the general, ergonomic, nervous, and skin symptoms (Table 4-6). Appendix UU describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this MLR model. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-30. The model was statistically significant, F (6, 514) = 27.402, $p \leq .001$, and accounted for approximately 24.2% of the variance of General, Ergonomic, Nervous, and Skin symptoms ($R^2$= .242, Adjusted $R^2$ = .234). General, Ergonomic, Nervous, and Skin symptoms were statistically significantly predicted by three variables in the model ordered according to their weights in the model were as follows: (1) "Too much humidity"; (2) "Too much dim" and (3) "Too cold". The three predictors were positively associated with General, Ergonomic, Nervous, and Skin symptoms. For every unit increase in the frequency of experiencing "Too much humidity"; the model predicted an increase of 0.83 units in the frequency of experiencing General, Ergonomic, Nervous, and Skin symptoms after controlling for the other parameters included in the model. An increase of 0.89 units and 0.31 units in the frequency of experiencing General, Ergonomic, Nervous, and Skin symptoms were predicted for each unit increase in the frequency of experiencing "Too much dim" and "Too cold"; respectively.

Table 4-30: MLR results examining Thermal, Lighting, and Noise discomfort variables on General, Ergonomic, Nervous, and Skin symptoms

| | | | | | | 95% CI for B | |
|---|---|---|---|---|---|---|---|
| | B | *SE-B* | Beta | Sig. | $sr^2$ | Lower Bound | Upper Bound |
| (Constant)*** | 4.01 | .29 | | .000 | | 3.447 | 4.566 |
| Too much air movement | -.20 | .14 | -.06 | .161 | .003 | -.478 | .080 |
| Too cold* | .31 | .15 | .09 | .043 | .006 | .010 | .615 |
| Too much humidity*** | .83 | .15 | .25 | .000 | .048 | .545 | 1.120 |
| Too much glare | .37 | .19 | .10 | .053 | .006 | -.006 | .754 |
| Too much dim*** | .89 | .21 | .21 | .000 | .025 | .465 | 1.308 |
| Too quiet | .16 | .12 | .05 | .179 | .003 | -.073 | .388 |

Note. The dependant variable was General, Ergonomic, Nervous, and Skin symptoms.
$R^2$ = 0.242, Adjusted $R^2$ = 0.234.
$sr^2$ is the squared semi-partial correlation.
$*p \leq .05$, $**p \leq .01$, $***\ p \leq .001$

In order to identify which of the statistically significant predictors had the highest predictive power, $r_s^2$ was also calculated for each (Ziglari 2017; Ray-Mukherjee et al. 2014; Kraha et al. 2012). Variables ordered as per their calculated rs2 and predictive power were: (1) “Too much dim”, $r_s^2 = 0.7$; (2) “Too much humidity”, $r_s^2 = 0.6$; and (3) “Too cold”, $r_s^2 = 0.2$; respectively. The proportions of the total variance uniquely and non-uniquely explained by each of the above ordered factors based on their ($r_s^2$) were approximately16%, 15.5%, and 5.4%; respectively. The unique variance explained by each of the factors was calculated based on the $sr^2$ (Newsom 2015; Meyers et al. 2006). According to calculated $sr^2$ (Table 4-30); it was found that: (1) “Too much humidity”; (2) “Too much dim”; and (3) “Too cold” uniquely accounted for approximately 4.8% 2.5% and 0.6% of the variance of General, Ergonomic, Nervous, and Skin symptoms; respectively. It is important to note that the model explains about 24% of the variance in the General, Ergonomic, Nervous, and Skin symptoms. However, the total variance uniquely explained by included parameters in the model is approximately 9%. The remaining 15% of the variance in General, Ergonomic, Nervous, and Skin symptoms was non-uniquely explained by a particular parameter or that explained by the relationship between the parameters. Considering the uniquely explained variance, the non-uniquely variance or common variance explained by (1) “Too much dim”; (2) “Too much humidity”; and (3) “Too cold” were approximately 13.5%, 10.7%, and 4.8%; respectively (Figure 4-20).

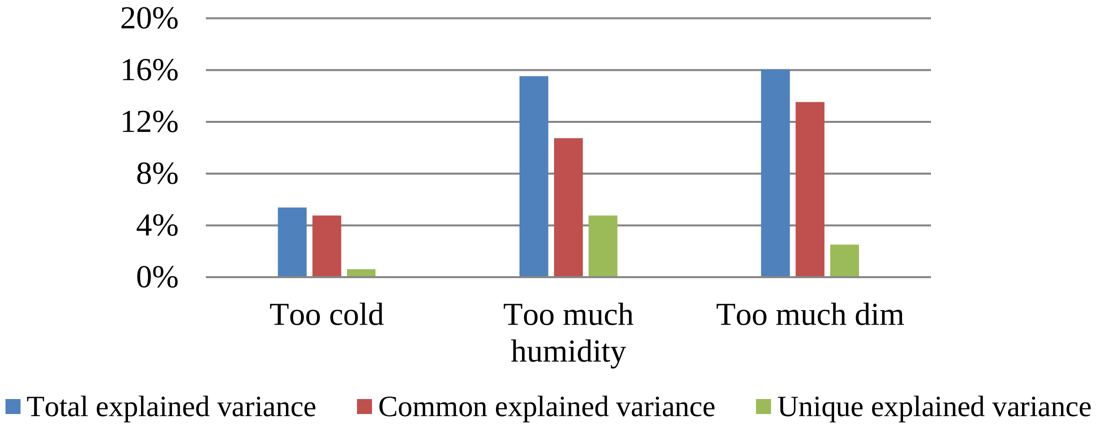


Figure 4-20: Total, uniquely and non-uniquely explained variance by statistically significant variables of Thermal, Lighting, and Noise discomfort in General, Ergonomic, Nervous, and Skin symptoms

#### 4.1.6.21 MLR model of IAQ discomfort variables on General, Ergonomic, Nervous, and Skin symptoms

The 21st MLR model followed the forced entry method described in Section 3.4.3. The model used the IAQ discomfort variables (Table 4-8) to predict the general, ergonomic, nervous, and skin symptoms (Table 4-6). Appendix VV describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this MLR model. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-31. The model was statistically significant, F (2, 531) = 36.748, $p \leq .001$, and accounted for approximately 12.2% of the variance of General, Ergonomic, Nervous, and Skin symptoms ($R^2$= .122, Adjusted $R^2$ = .118). General, Ergonomic, Nervous, and Skin symptoms were statistically significantly predicted by two variables in the model ordered according to their weights in the model were as follows: (1) “Stuffy "bad" air” and (2) “Dust and dirt”. The two predictors were positively associated with General, Ergonomic, Nervous, and Skin symptoms. For every unit increase in the frequency of experiencing “Stuffy "bad" air”; the model predicted an increase of 0.70 units in the frequency of experiencing General, Ergonomic, Nervous, and Skin symptoms after controlling for “Dust and dirt”. An increase of 0.19 units in the frequency of experiencing General, Ergonomic, Nervous, and Skin symptoms was predicted for each unit increase in the frequency of experiencing “Dust and dirt”.

Table 4-31: MLR results examining IAQ discomfort variables on General, Ergonomic, Nervous, and Skin symptoms

| | | | | | | 95% CI for B | |
|---|---|---|---|---|---|---|---|
| | B | *SE-B* | Beta | Sig. | $sr^2$ | Lower Bound | Upper Bound |
| (Constant)*** | 4.64 | .28 | | .000 | | 4.099 | 5.178 |
| Dust and dirt*** | .56 | .15 | .19 | .000 | .023 | .268 | .859 |
| Stuffy "bad" air*** | .70 | .17 | .21 | .000 | .029 | .369 | 1.030 |

Note. The dependant variable was General, Ergonomic, Nervous, and Skin symptoms.
$R^2$ = 0.122, Adjusted $R^2$ = 0.118.
$sr^2$ is the squared semi-partial correlation.
$^*p \leq .05$, $^{**}p \leq .01$, $^{***}\ p \leq .001$

In order to identify which of the two statistically significant predictors had the highest predictive power, $r_s^2$ was also calculated for each (Ziglari 2017; Ray-Mukherjee et al. 2014; Kraha et al. 2012). Variables ordered as per their calculated rs2 and predictive power were: (1) “Stuffy "bad" air”, $r_s^2 = 0.80$ and (2) “Dust and dirt”, $r_s^2 = 0.76$; respectively. The proportions of the total variance uniquely and non-uniquely explained by each of the above ordered factors based on their $r_s^2$ were approximately 10% and 9%; respectively. The unique variance explained by each of the factors was calculated based on $sr^2$ (Newsom 2015; Meyers et al. 2006). According to calculated $sr^2$ (Table 4-31); it was found that: (1) “Stuffy "bad" air” and (2) “Dust and dirt” uniquely accounted for approximately 3% and 2% of the variance of General, Ergonomic, Nervous, and Skin symptoms; respectively. It is important to note that the model explained about 12% of the variance in the General, Ergonomic, Nervous, and Skin symptoms. However, the total variance uniquely explained by included parameters in the model was approximately 5%. The remaining 7% of the variance in General, Ergonomic, Nervous, and Skin symptoms was non-uniquely explained by a particular parameter or that explained by the relationship between the parameters. Considering the uniquely explained variance, the non-uniquely variance or common variance explained by (1) “Stuffy "bad" air” and (2) “Dust and dirt” was approximately 7% for each (Figure 4-21).

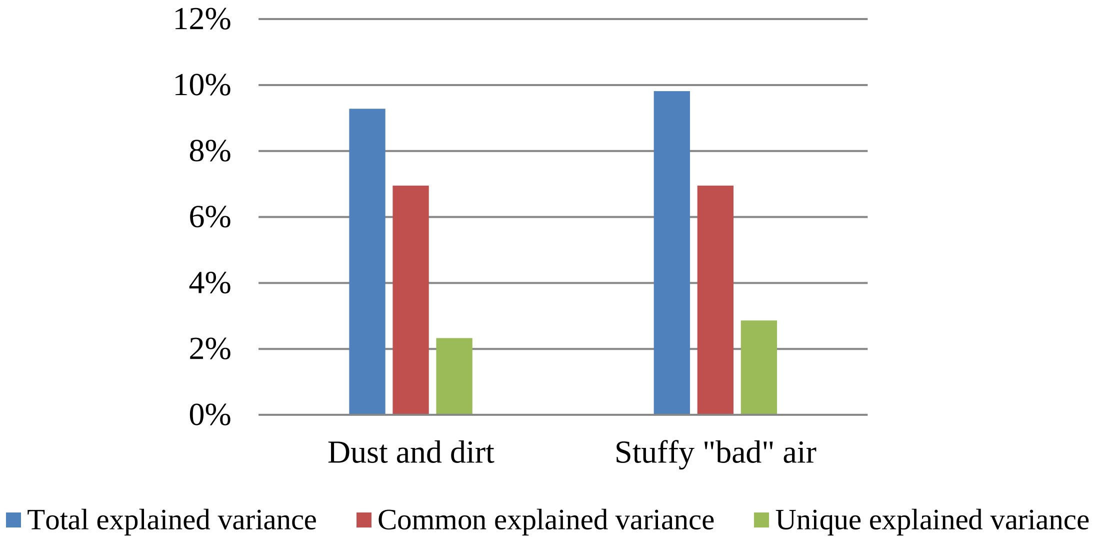


Figure 4-21:Total, uniquely and non-uniquely explained variance by statistically significant variables of IAQ discomfort in General, Ergonomic, Nervous, and Skin symptoms

#### 4.1.6.22 MLR model of odors variables on General, Ergonomic, Nervous, and Skin symptoms

The 22nd MLR model followed the forced entry method described in Section 3.4.3. The model used the odors variables (Table 3-27) to predict the general, ergonomic, nervous, and skin symptoms (Table 4-6). Appendix WW describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this MLR model. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-32. The model was statistically significant, F (9, 523) = 14.311, $p \leq .001$, and accounted for approximately 19.8% of the variance of General, Ergonomic, Nervous, and Skin symptoms ($R^2 = .198$, Adjusted $R^2 = .184$). General, Ergonomic, Nervous, and Skin symptoms were statistically significantly predicted by five variables in the model ordered according to their weights in the model were as follows: (1) “Smoke from incense burning”; (2) “Fishy smells or other food smells” and “Body odors or cosmetics odors”; (3) “Odors from paint”; (4) “Odors from other chemicals i.e. pesticides, glues, or cleaning products”.

The five predictors were positively associated with General, Ergonomic, Nervous, and Skin symptoms. For every unit increase in the frequency of experiencing “Smoke from incense burning”; the model predicted an increase of 0.51 units in the frequency of experiencing General, Ergonomic, Nervous, and Skin symptoms after controlling for all other variables included in the model. An increase of 0.42, 0.39, 0.64, and 0.47 units in the frequency of experiencing General, Ergonomic, Nervous, and Skin symptoms were predicted for each unit increase in the frequency of experiencing “Fishy smells or other food smells”, “Body odors or cosmetics odors i.e. perfumes, after shave”, “Odors from paint”, and “Odors from other chemicals i.e. pesticides, glues, or cleaning products”; respectively. In order to identify which of the statistically significant predictors had the highest predictive power, $r_s^2$ was also calculated for each (Ziglari 2017; Ray-Mukherjee et al. 2014; Kraha et al. 2012). Variables ordered as per their calculated $r_{s2}$ and predictive power were: (1) “Body odors or cosmetics odors i.e. perfumes, after shave”, $r_s^2 = 0.49$; (2)

"Fishy smells or other food smells", $r_s^2$ = 0.44; (3) "Odors from paint", $r_s^2$ = 0.39; (4) "Odors from other chemicals i.e. pesticides, glues, or cleaning products", $r_s^2$ = 0.35; and (5) "Smoke from incense burning", $r_s^2$ = 0.29.

Table 4-32: MLR results examining odors variables on General, Ergonomic, Nervous, and Skin symptoms

| | B | *SE-B* | Beta | Sig. | $sr^2$ | 95% CI for B Lower Bound | 95% CI for B Upper Bound |
|---|---|---|---|---|---|---|---|
| (Constant)*** | 4.05 | .27 | | .000 | | 3.520 | 4.587 |
| Smoke from incense burning*** | .51 | .12 | .17 | .000 | .029 | .280 | .745 |
| Odors from new carpet/ curtains | .15 | .23 | .03 | .509 | .001 | -.301 | .607 |
| Musty/mouldy dampness odors | -.01 | .19 | -.00 | .943 | .000 | -.394 | .366 |
| Fishy smells or other food smells** | .42 | .15 | .13 | .005 | .012 | .128 | .702 |
| Body odors or cosmetics odors** | .39 | .14 | .13 | .007 | .011 | .106 | .671 |
| Odors from paint** | .64 | .23 | .12 | .005 | .012 | .190 | 1.081 |
| Odors from other chemicals* | .47 | .20 | .11 | .019 | .008 | .076 | .853 |
| Tobacco smoke | .11 | .13 | .04 | .387 | .001 | -.140 | .361 |
| Odors from diesel/ engines exhaust | .08 | .21 | .02 | .702 | .000 | -.324 | .480 |

Note. The dependant variable was General, Ergonomic, Nervous, and Skin symptoms.
$R^2$ = 0.198, Adjusted $R^2$ = 0.184.
$sr^2$ is the squared semi-partial correlation.
*$p \leq .05$, **$p \leq .01$, *** $p \leq .001$

The proportions of the total variance uniquely and non-uniquely explained by each of the above ordered factors based on their ($r_s^2$) were approximately 10%, 9%, 8%, 7%, and 6%; respectively. The unique variance explained by each of the factors was calculated based on $sr^2$ (Newsom 2015; Meyers et al. 2006). According to calculated $sr^2$ (Table 4-32); it was found that: (1) "Smoke from incense burning"; (2) "Fishy smells or other food smells" and "Odors from paint"; (3) "Body odors or cosmetics odors"; and (4) "Odors from other chemicals i.e. pesticides, glues, or cleaning products" uniquely accounted for approximately 3%, 1%, 1%, 1%, and 1% of the variance of General, Ergonomic, Nervous, and Skin symptoms; respectively. It is important to note that the model explained about 20% of the variance in the General, Ergonomic, Nervous, and Skin symptoms. However, the total variance uniquely explained by included parameters in the model was approximately 8%. The remaining 12% of the variance in General, Ergonomic, Nervous, and Skin symptoms was non-uniquely explained by a particular parameter or that explained by the relationship between the parameters. Considering the uniquely explained variance, the non-uniquely variance or common variance explained by: (1) “Body odors or cosmetics odors i.e. perfumes, after shave”; (2) “Fishy smells or other food smells”; (3) “Odors from paint”; (4) “Odors from other chemicals i.e. pesticides, glues, or cleaning products”; and (5) “Smoke from incense burning” were approximately 9%, 7%, 6%, 6%, and 3%; respectively (Figure 4-22).

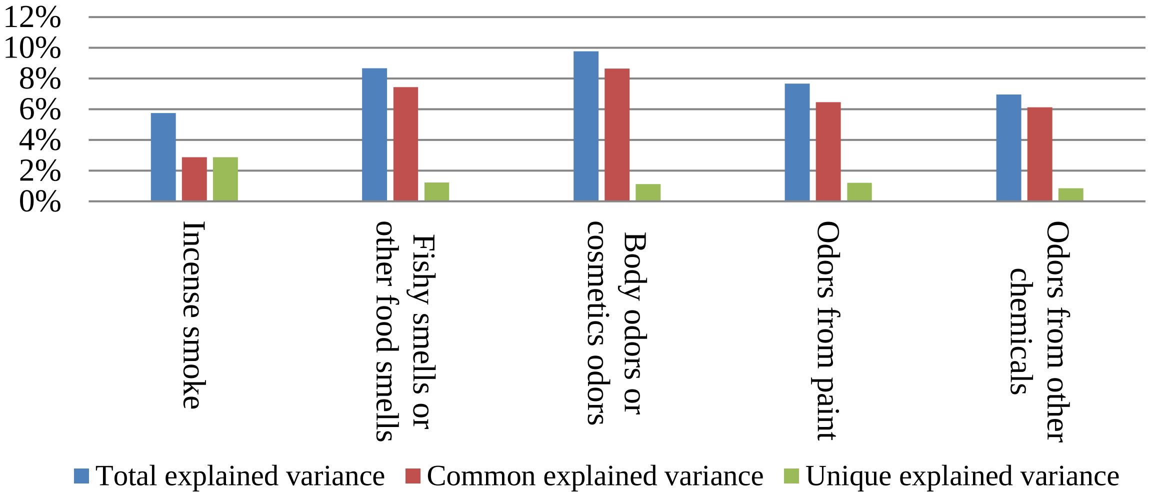


Figure 4-22: Total, uniquely and non-uniquely explained variance by statistically significant odors variables in General, Ergonomic, Nervous, and Skin symptoms

#### 4.1.6.23 MLR model of IEQ variables on Eye, Nose, Throat, and Chest related symptoms

The 23rd MLR model followed the forced entry method described in Section 3.4.3. The model used the seventeen variables of IEQ shown in Table 3-27 and Table 4-8 to predict the Eye, Nose, Throat, and Chest related symptoms (Table 4-6). The model was adjusted for statistically significant population and building variables in predicting Eye, Nose, Throat, and Chest related symptoms (Table 4-11 and Table 4-16). Appendix XX describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this MLR model. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-33. The model was statistically significant, F (23, 536) = 10.992, $p \le .001$, and accounted for approximately 33% of the variance of Eye, Nose, Throat, and Chest related symptoms ($R^2$= .330, Adjusted $R^2$ = .300). Eye, Nose, Throat, and Chest related symptoms were statistically significantly predicted by nine variables in the model ordered according to their weights in the model were as follows: (1) “Musty/mouldy dampness odors”; (2) “Allergy to dust”; (3) “Too much dim”; (4) “Migraine”; (5) “Stuffy "bad" air”; (6) “Odors from paint”, “Asthma”, and “Attached kitchen with interior walls”; and (7) “Dust and dirt” .

Table 4-33: MLR results examining IEQ variables on Eye, Nose, Throat, and Chest related symptoms adjusted for population and building variables

| | | | | | | 95% CI for B | |
|---|---|---|---|---|---|---|---|
| | B | *SE-B* | Beta | Sig. | $sr^2$ | Lower Bound | Upper Bound |
| (Constant) | 1.93 | .34 | | .000 | | 1.264 | 2.599 |
| Smoke from incense burning | .14 | .10 | .06 | .143 | 0.00 | -.048 | .335 |
| Odors from new carpet/ curtains | -.10 | .19 | -.02 | .596 | 0.00 | -.469 | .270 |
| Musty/mouldy dampness odors*** | .61 | .16 | .16 | .000 | 0.02 | .298 | .911 |
| Fishy smells or other food smells | -.06 | .12 | -.02 | .620 | 0.00 | -.296 | .177 |
| Body odors or cosmetics odors | .08 | .12 | .03 | .518 | 0.00 | -.152 | .301 |
| Odors from paint* | .43 | .18 | .10 | .020 | 0.01 | .067 | .790 |
| Odors from other chemicals | .14 | .16 | .04 | .409 | 0.00 | -.186 | .458 |
| Tobacco smoke | .08 | .10 | .03 | .417 | 0.00 | -.120 | .288 |
| Odors from diesel/ engines exhaust | -.01 | .17 | -.00 | .975 | 0.00 | -.329 | .318 |
| Dust and dirt* | .24 | .12 | .09 | .049 | 0.01 | .001 | .482 |
| Stuffy "bad" air* | .31 | .18 | .11 | .037 | 0.01 | .019 | .598 |
| Too much air movement | .10 | .11 | .035 | .395 | 0.00 | -.126 | .319 |
| Too cold | -.21 | .12 | -.07 | .085 | 0.00 | -.458 | .030 |
| Too much humidity | .11 | .12 | .04 | .345 | 0.00 | -.120 | .344 |
| Too much glare | -.02 | .14 | -.01 | .905 | 0.00 | -.292 | .259 |
| Too much dim** | .42 | .15 | .13 | .004 | 0.01 | .132 | .716 |
| Too quiet | .16 | .09 | .07 | .086 | 0.00 | -.023 | .347 |
| Asthma** | .98 | .36 | .10 | .006 | 0.01 | .282 | 1.681 |
| Migraine** | 1.01 | .32 | .12 | .002 | 0.01 | .384 | 1.640 |
| Allergy to dust*** | 1.03 | .27 | .14 | .000 | 0.02 | .498 | 1.568 |
| Attached closed kitchen ** | .74 | .27 | .10 | .007 | 0.01 | .202 | 1.275 |
| New carpets | .57 | .31 | .07 | .066 | 0.00 | -.038 | 1.182 |
| Water leakage | .55 | .29 | .07 | .056 | 0.00 | -.014 | 1.109 |

Note. The dependant variable was Eye, Nose, Throat, and Chest related symptoms.
$R^2$ = 0.330, Adjusted $R^2$ = 0.300.
$sr^2$ is the squared semi-partial correlation.
*$p \le .05$, **$p \le .01$, *** $p \le .001$

The nine predictors were positively associated with Eye, Nose, Throat, and Chest related symptoms. For every unit increase in the frequency of experiencing “Musty/mouldy dampness odors”; the model predicted an increase of 0.61 units in the frequency of experiencing Eye, Nose, Throat, and Chest related symptoms after controlling for all other variables included in the model. An increase of 0.43, 0.42, 0.31, and 0.24 units in the frequency of experiencing Eye, Nose, Throat, and Chest related symptoms were predicted for each unit increase in the frequency of experiencing “Odors from paint”, “Too much dim”, “Stuffy "bad" air”, and “Dust and dirt”; respectively. Dust allergic, those who had migraine and asthmatics had 1.03, 1.01, and 0.98 higher frequency of experiencing Eye, Nose, Throat, and Chest related symptoms than others; respectively. Participants living in households that had an attached kitchen with interior walls had 0.74 higher frequency in experiencing Eye, Nose, Throat, and Chest related symptoms than others.

In order to identify which of the statistically significant predictors had the highest predictive power, $r_s^2$ was also calculated for each (Ziglari 2017; Ray-Mukherjee et al. 2014; Kraha et al. 2012). Variables ordered as per their calculated $r_s^2$ and predictive power were: (1) “Stuffy "bad" air”, $r_s^2 = 0.4$; (2) “Dust and dirt” and “Too much dim”, $r_s^2 = 0.3$; (3) “Odors from paint $r_s^2 = 0.29$; (4) “Musty/mouldy dampness odors”, $r_s^2 = 0.26$; (5) “Allergy to dust”, $r_s^2 = 0.16$; (6) “Migraine”, $r_s^2 = 0.14$; (7) “Asthma”, $r_s^2 = 0.06$; and (8) “Attached kitchen with interior walls”, $r_s^2 = 0.03$. The proportions of the total variance uniquely and non-uniquely explained by each of the above ordered factors based on their ($r_s^2$) were approximately 13%, 11%, 10%, 8%, 5.4%, 4.5%, 2%, and 1%; respectively (Figure 4-23). The unique variance explained by each of the factors was calculated based on $sr^2$ (Newsom 2015; Meyers et al. 2006).

According to calculated $sr^2$ (Table 4-33); it was found that: (1) Each of “Musty/mouldy dampness odors” and “Allergy to dust”; (2) “Migraine”; (3) “Too much dim”; (4) Each of “Asthma” and “Attached kitchen with interior walls”; (5) “Odors from paint”, (6) “Stuffy "bad" air”; while (7) “Dust and dirt” uniquely accounted for approximately 2%, 1.3%, 1.1%, 1.0%, 0.7%, 0.6%, and 0.5% of the total variance of Eye, Nose, Throat, and Chest related symptoms; respectively (Figure 4-23). It is important to note that the model explained about 33% of the variance in the Eye, Nose, Throat, and Chest related symptoms. However, the total variance uniquely explained by included variables in the model was approximately 12%. The remaining 21% of the variance in Eye, Nose, Throat, and Chest related symptoms was non-uniquely explained by a particular parameter or that explained by the relationship between the parameters. Considering the uniquely explained variance, the non-uniquely variance or common variance explained by: (1) “Stuffy "bad" air”; (2) “Dust and dirt”; (3) each of “Too much dim” and “Odors from paint”; (4) “Musty/mouldy dampness odors”; (5) “Allergy to dust”; (6) “Migraine”; (7) “Asthma”; while (8) “Attached kitchen with interior walls” were approximately 12%, 10%, 9%, 7%, 4%, 1%, and 0% of Eye, Nose, Throat, and Chest related symptoms; respectively (Figure 4-23).

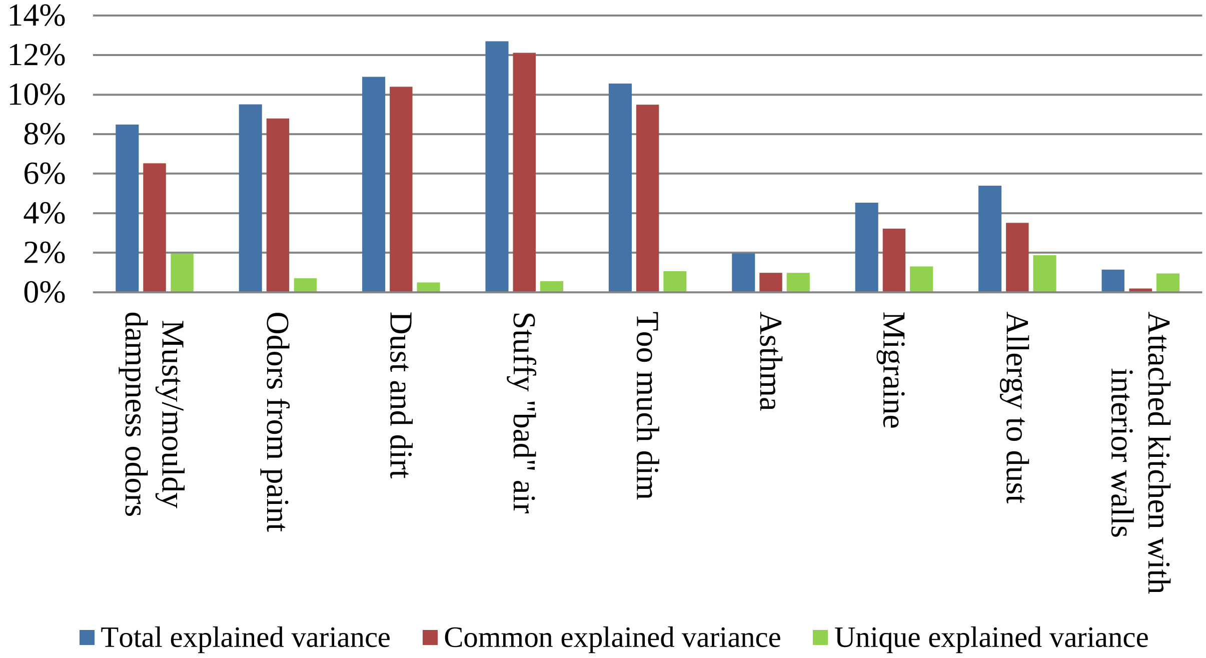


Figure 4-23: Total, uniquely and non-uniquely explained variance by statistically significant IEQ variables in Eye, Nose, Throat, and Chest related symptoms adjusted for population and building variables

#### 4.1.6.24 MLR model of IEQ variables on General, Ergonomic, Nervous, and Skin symptoms

The 24th MLR model followed the forced entry method described in Section 3.4.3. The model used the seventeen variables of IEQ shown in Table 3-27 and Table 4-8 to predict the General, Ergonomic, Nervous, and Skin symptoms (Table 4-6). The model was adjusted for statistically significant population and building variables in predicting the General, Ergonomic, Nervous, and Skin symptoms (Table 4-12 & Table 4-17). Appendix YY describes in details the steps explained in Section 3.4.3 to check for bias or violations regarding the assumptions and procedural concerns related to this MLR model. The raw and standardized regression coefficients of the predictors, *SE-B*, *p* values, $sr^2$ between the predictors and the DV, and the lower and upper values of 95% CI are shown in Table 4-34. The model was statistically significant, F (27, 449) = 12.898, $p \leq .001$, and accounted for approximately 43.7% of the variance of General, Ergonomic, Nervous, and Skin symptoms ($R^2$= .437, Adjusted $R^2$ = .403). General, Ergonomic, Nervous, and Skin symptoms were statistically significantly predicted by ten variables in the model ordered according to their weights in the model were as follows: (1) “Too much humidity”; (2) “Too much dim”; (3) “Smoke from incense burning” and “Gender”; (4) “Migraine”; (5) “Other Arabs/ MENA”; (6) “Eczema”; (7) “Water leakage”; and (8) “Dubai Sector 1” and “Allergy to dust”.

The ten predictors were positively associated with General, Ergonomic, Nervous, and Skin symptoms. For every unit increase in the frequency of experiencing “Too much humidity”; the model predicted an increase of 0.76 units in the frequency of experiencing General, Ergonomic, Nervous, and Skin symptoms after controlling for all other variables included in the model. An increase of 0.59 and 0.42 units in the frequency of experiencing General, Ergonomic, Nervous, and Skin symptoms was predicted for each unit increase in the frequency of experiencing “Too much dim” and “Smoke from incense burning; respectively. Participants having migraine, other Arabs/ MENA, females, those having migraine, and dust allergic had 1.42, 1.39, 1.24, 1.22, and 0.71 higher frequency of experiencing General, Ergonomic, Nervous, and Skin symptoms than others; respectively. Participants living in households in Dubai Sector 1 and those having water leakage had

1.27 and 0.87 higher frequency in experiencing General, Ergonomic, Nervous, and Skin symptoms than others; respectively.

Table 4-34: MLR results examining IEQ variables on General, Ergonomic, Nervous, and Skin symptoms adjusted for population and building variables

| | | | | | | 95% CI for B | |
|---|---|---|---|---|---|---|---|
| | B | *SE-B* | Beta | Sig. | $sr^2$ | Lower Bound | Upper Bound |
| (Constant) | 1.26 | .49 | | .011 | | .292 | 2.219 |
| Smoke from incense burning*** | .42 | .12 | .14 | .000 | .016 | .184 | .645 |
| Odors from new carpet/ curtains | -.07 | .23 | -.01 | .752 | .000 | -.535 | .386 |
| Musty/mouldy dampness odors | .11 | .19 | .02 | .563 | .000 | -.265 | .485 |
| Fishy smells or other food smells | .17 | .15 | .05 | .253 | .002 | -.121 | .458 |
| Body odors or cosmetics odors | .21 | .14 | .07 | .134 | .003 | -.066 | .495 |
| Odors from paint | .23 | .22 | .04 | .303 | .001 | -.209 | .672 |
| Odors from other chemicals | .21 | .20 | .05 | .301 | .001 | -.187 | .603 |
| Tobacco smoke | .02 | .13 | .01 | .896 | .000 | -.233 | .266 |
| Odors from diesel/ engines | -.02 | .20 | .00 | .927 | .000 | -.419 | .381 |
| Dust and dirt | .11 | .15 | .03 | .464 | .001 | -.184 | .404 |
| Stuffy "bad" air | .27 | .18 | .07 | .141 | .003 | -.088 | .617 |
| Too much air movement | -.12 | .14 | -.04 | .402 | .001 | -.403 | .162 |
| Too cold | .11 | .16 | .03 | .474 | .001 | -.194 | .417 |
| Too much humidity *** | .76 | .14 | .22 | .000 | .036 | .478 | 1.037 |
| Too much glare | .10 | .17 | .03 | .554 | .000 | -.232 | .433 |
| Too much dim ** | .59 | .18 | .15 | .001 | .014 | .244 | .945 |
| Too quiet | -.10 | .11 | -.03 | .376 | .001 | -.325 | .123 |
| Gender *** | 1.24 | .35 | .14 | .000 | .016 | .561 | 1.928 |
| Other Arabs/ MENA ** | 1.39 | .46 | .11 | .003 | .011 | .484 | 2.297 |
| Eczema ** | 1.42 | .54 | .10 | .009 | .008 | .350 | 2.486 |
| Migraine ** | 1.22 | .39 | .12 | .002 | .012 | .458 | 1.979 |
| Allergy to dust * | .71 | .33 | .08 | .033 | .006 | .057 | 1.359 |
| Dubai Sector 1 * | 1.27 | .55 | .08 | .021 | .007 | .190 | 2.354 |
| Central AC | -.05 | .36 | -.01 | .900 | .000 | -.760 | .668 |
| New carpets | .58 | .39 | .06 | .133 | .003 | -.178 | 1.342 |
| New furniture | .24 | .34 | .03 | .495 | .001 | -.440 | .909 |
| Water leakage * | .87 | .35 | .09 | .013 | .008 | .183 | 1.549 |

Note. The dependant variable was General, Ergonomic, Nervous, and Skin symptoms.
$R^2 = 0.437$, Adjusted $R^2 = 0.403$.
$sr^2$ is the squared semi-partial correlation.
$*p \leq .05$, $**p \leq .01$, $***\ p \leq .001$

In order to identify which of the statistically significant predictors had the highest predictive power, $r_s^2$ was also calculated for each (Ziglari 2017; Ray-Mukherjee et al. 2014; Kraha et al. 2012). Variables ordered as per their calculated rs2 and predictive power were:

(1) “Too much dim”, $r_s^2$ = 0.38; (2) “Too much humidity”, $r_s^2$ = 0.35; (3) “Smoke from incense burning”, $r_s^2$ = 0.15; (4) “Gender” and “Migraine”, $r_s^2$ = 0.14; (5) “Water leakage” and “Eczema”, $r_s^2$ = 0.09; (6) “Allergy to dust”, $r_s^2$ = 0.08; and (7) “Other Arabs/ MENA” and “Dubai Sector 1”, $r_s^2$ = 0.03. The proportions of the total variance uniquely and non-uniquely explained by each of the above ordered factors based on their $r_s^2$ were approximately 16.5%, 15.1%, 6.3%, 6.0%, 4.0%, 3.5%, and 1% of the total variance in the General, Ergonomic, Nervous, and Skin symptoms; respectively (Figure 4-24). The unique variance explained by each of the factors was calculated based on $sr^2$ (Newsom 2015; Meyers et al. 2006). According to calculated $sr^2$ (Table 4-34); it was found that: (1) “Too much humidity; (2) Each of the “Smoke from incense burning” and “Gender”; (3) “Too much dim”; (4) “Migraine”; (5) “Other Arabs/ MENA”; (6) Each of “Water leakage” and “Eczema”; (5) “Dubai Sector 1”, and (6) “Allergy to dust” uniquely accounted for approximately 3.6%, 1.6%, 1.4%, 1.2%, 1.1%, 0.8%, 0.7%, and 0.6% of the total variance in the General, Ergonomic, Nervous, and Skin symptoms (Figure 4-24).

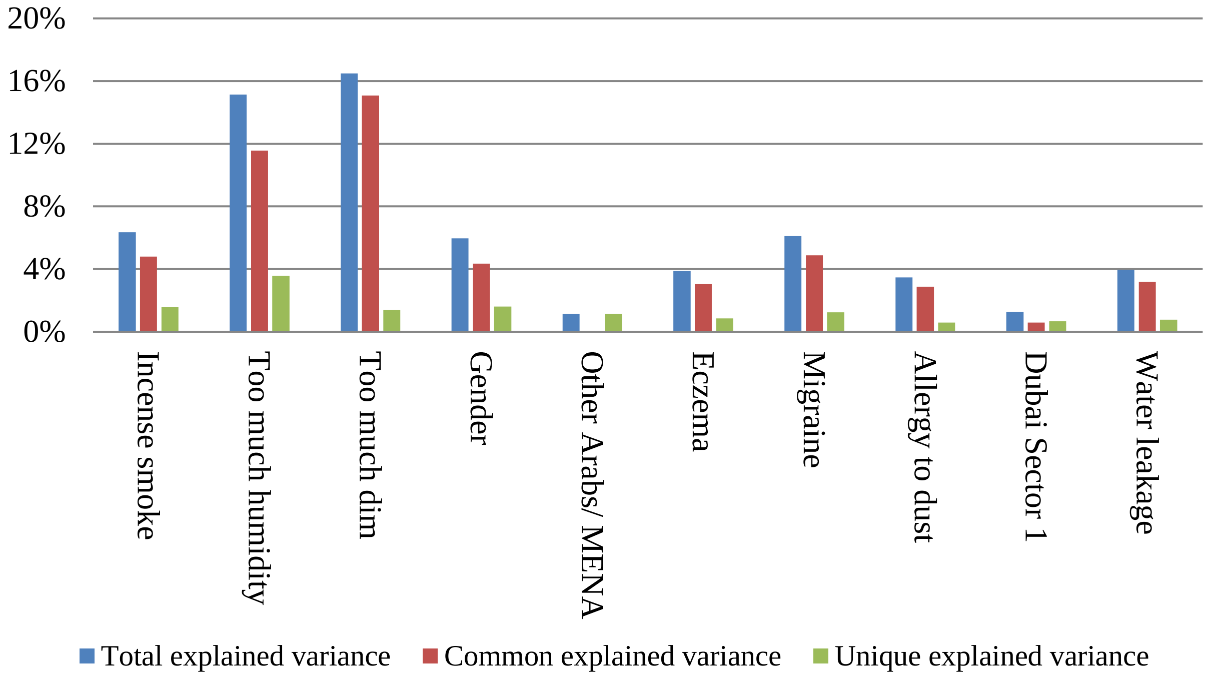


Figure 4-24: Total, uniquely and non-uniquely explained variance by statistically significant IEQ variables in General, Ergonomic, Nervous, and Skin symptoms adjusted for population and building variables

It is important to note that the model explained about 43% of the variance in the General, Ergonomic, Nervous, and Skin symptoms. However, the total variance uniquely explained by included variables in the model was approximately 15%. The remaining 28% of the variance in in the General, Ergonomic, Nervous, and Skin symptoms was non-uniquely explained by a particular parameter or that explained by the relationship between the parameters. Considering the uniquely explained variance, the non-uniquely variance or common variance explained by: (1) “Too much dim”; (2) “Too much humidity”; (3) each of “Smoke from incense burning” and “Migraine”; (4) “Gender”; (5) Each of “Water leakage”, “Eczema”, and “Allergy to dust”; (6) each of “Dubai Sector 1”and “Asthma”; and (7) “Other Arabs/ MENA” were approximately 15%, 12%, 5%, 4%, 3%, 0.6%, and 0% of the total variance in the General, Ergonomic, Nervous, and Skin symptoms (Figure 4-24).

### 4.1.7 Summary of MLR results

#### 4.1.7.1 Associated population variables with health and IEQ

As per results shown in Section 0, about 10% of the variance in the Eye, Nose, Throat, and Chest symptoms was explained by the model using the sixteen population variables. Three out of them were statistically significantly associated with Eye, Nose, Throat, and Chest related symptoms ordered as per their weights and predictive power in the unadjusted model as: (1) dust allergy and migraine similarly received higher weights in the model, while (2) asthma received lower weight. The three variables are positively predicting the Eye, Nose, Throat, and Chest related symptoms. Dust allergic, those having migraine, and asthmatics had higher frequency of experiencing Eye, Nose, Throat, and Chest related symptoms. The three variables accounted for approximately 10% of the variance of Eye, Nose, Throat, and Chest related symptoms of which 5%, 4%, and 1% was explained by dust allergy, migraine, and asthma; respectively. When adjusting the model for all IEQ variables (Section 4.1.6.23); the three population variables were still statistically significantly associated with Eye, Nose, Throat, and Chest related symptoms. Ordering those variables as per their predictive power in the adjusted model is as follows: (1)

"Allergy to dust" had the 5th predictive power and it explained about 5.4% of the total variance; (2) "Migraine" had the 6th predictive power and it explained about 4.5% of the total variance; while (3) "Asthma" had the 7th predictive power and it explained about 2% of the total variance in Eye, Nose, Throat, and Chest related symptoms.

As per results shown in Section 4.1.6.2, about 15% of the variance in the General, Ergonomic, Nervous, and Skin symptoms was explained by the model using the sixteen population variables. Five out of them were statistically significantly associated with General, Ergonomic, Nervous, and Skin symptoms ordered as per their weights and predictive power in the unadjusted model as: (1) migraine that explained about 4% of the variance of General, Ergonomic, Nervous, and Skin symptoms, (2) gender that explained about 3% of the variance, (3) dust allergy that explained about 2% of the variance, (4) Other Arab or MENA national that explained about 1% of the variance, and (5) eczema that explained about 1% of the variance. The five variables were positively predicting the General, Ergonomic, Nervous, and Skin symptoms. Participants having migraine, dust allergy, and eczema in addition to females and other Arab or MENA nationals had higher frequency of experiencing the General, Ergonomic, Nervous, and Skin symptoms. When adjusting the model for all IEQ variables (Section 4.1.6.24), the five population variables were still statistically significantly associated with the General, Ergonomic, Nervous, and Skin symptoms. Ordering the five statistically significant variables as per their weights in the adjusted model was as follows: (1) "Gender" received the 3rd weight; (4) "Migraine" received the 4th weight; (5) "Other Arabs/ MENA" received the 5th weight; (6) "Eczema" received the 6th weight; (8) "Allergy to dust" received the 8th weight in the model. Ordering those variables as per their predictive power in the adjusted model for IEQ factors was as follows: (1) "Gender" and "Migraine" had the 4th predictive power in the adjusted model and they explained about 6% of the total variance; (2) "Eczema" had the 5th predictive power and it explained about 4% of the total variance; (3) "Allergy to dust" had the 6th predictive power and it explained about 3.5% of the total variance; while (3) "Other Arabs/ MENA" had the 7th predictive power and it explained about 1% of the total variance in the General, Ergonomic, Nervous, and Skin symptoms.

As per results shown in Section 4.1.6.4, about 6% of the variance in the IAQ discomfort was explained by the model using the sixteen population variables. Four out of them were statistically significantly associated with IAQ discomfort ordered as per their weights and predictive power in the unadjusted model as: (1) Allergy to dust had the highest weights and predictive power and explained about 2% of the variance in IAQ discomfort, (2) migraine had the 2nd weights and predictive power and explained about 2% of the variance, (3) age had the 3rd weights and predictive power and explained about 1.5% of the variance, and (4) being other Africans had the 4th weights and predictive power and explained about 0.9% of the variance in IAQ discomfort. Reference to results in Section 4.1.6.16; when adjusting the model for other IEQ factors, the four variables were statistically significantly associated with IAQ discomfort. Ordering those variables as per their predictive power in the adjusted model was as follows: (1) dust allergy had the 3rd predictive power in the adjusted model and explained about 3% of the variance in IAQ discomfort; (2) age and migraine had the 4th predictive power and explained about 2% of the variance; and (3) other Africans has the 5th predictive power and explained about 2% of the variance in IAQ discomfort.  Whereas ordering them as per their weights in the adjusted model was as follows: (1) age had the 3rd weights in the adjusted model; (2) other Africans the 4th weights; (3) dust allergy the 5th weights; while (4) migraine the received the 7th weight in the adjusted model. They uniquely accounted for approximately 2.3%, 1.5%, 1%, and 0.5%; respectively.

Regarding associated population variables with the odors; as per results shown in Section 4.1.6.5, about 9% of variance in odors perceptions was explained by the model using the sixteen population variables. Three out of them were statistically significantly associated with odors ordered as per their weights and predictive power in the model as: (1) Passive smoking received the highest weights and predictive power and it explained about 4% of the variance in the odors perceptions; (2) dust allergy received the 2nd weights and predictive power and it explained about 3% of the variance; while (3) migraine received the 3rd weights and predictive power and it explained about 2% of the variance. The three variables were positively associated with the odors perceptions. Passive smokers; dust allergic, and those having migraine had higher levels of experiencing odors.

Regarding associated population variables with the Thermal, Lighting, and Noise discomfort; as per results shown in Section 4.1.6.3, about 2% of variance in the Thermal, Lighting, and Noise discomfort was explained by the model using the sixteen population variables. Three out of them were statistically significantly associated with Thermal, Lighting, and Noise discomfort ordered as per their weights and predictive power in the model as: (1) migraine had the highest weights and predictive power and it explained about 2% of the variance in the Thermal, Lighting, and Noise discomfort; (2) dust allergy had the 2nd weights and predictive power and it explained about 2% of the variance; and (3) passive smoker received the 3rd weight and predictive power and it explained about 1% of the variance. The three variables were positively associated with the Thermal, Lighting, and Noise discomfort. Participants having migraine, dust allergic, and passive smokers had higher levels of experiencing the Thermal, Lighting, and Noise discomfort.

#### 4.1.7.2 Associated building variables with health and IEQ

Reference to Section 4.1.6.6, about 5.4% of the variance in the Eye, Nose, Throat, and Chest symptoms was explained by the model using twenty three building variables. Three out of them were statistically significantly associated with Eye, Nose, Throat, and Chest related symptoms ordered as per their weights and predictive power in the unadjusted model as: (1) water leakage that uniquely accounted for approximately 2.3% of the variance of Eye, Nose, Throat, and Chest related symptoms; (2) new carpets that uniquely accounted for approximately 1.9% of the variance, while (3) attached kitchen with interior walls that uniquely accounted for approximately 1.7% of the variance. The three variables were positively predicting the Eye, Nose, Throat, and Chest related symptoms. Participants living in households having water leakage, new carpets, and attached kitchen with interior walls had higher frequency of experiencing Eye, Nose, Throat, and Chest related symptoms. However, when adjusting the model for IEQ factors (Section 4.1.6.23), only attached kitchen with interior walls was statistically significantly associated with Eye, Nose, Throat, and Chest related symptoms. The “Attached kitchen with interior walls” had the 6th weight and the 8th predictive power in the adjusted model and it explained about 1% of the total variance in the Eye, Nose, Throat, and Chest related symptoms.

Reference to Section 4.1.6.7, about 10% of the variance in the General, Ergonomic, Nervous, and Skin symptoms was explained by the model using twenty three building variables. Five out of them were statistically significantly associated with the General, Ergonomic, Nervous, and Skin symptoms ordered as per their weights and predictive power in the unadjusted model as: (1) water leakage that accounted for approximately 4% of the variance in the General, Ergonomic, Nervous, and Skin symptoms; (2) new furniture that accounted for approximately 2% of the variance ; (3) new carpets that accounted for approximately 1.5% of the variance; (4) central HVAC that accounted for approximately 1.1% of the variance; then (4) Dubai Sector 1 that accounted for approximately 0.9% of the variance. The five variables except central HVAC were positively predicting the General, Ergonomic, Nervous, and Skin symptoms. Participants living in households having water leakage, new furniture, new carpets, and those living in Dubai Sector 1 had higher frequency of experiencing the General, Ergonomic, Nervous, and Skin symptoms. However, households using central HVAC have lower frequency in experiencing those symptoms. When adjusting the model for IEQ factors (Section 4.1.6.24); only water leakage and Dubai Sector 1 became statistically insignificantly associated with General, Ergonomic, Nervous, and Skin symptoms. Ordering the two statistically significant variables as per their predictive power in the adjusted model for IEQ factors was as follows: (1) “Water leakage” had the 5th predictive power and it explained about 4% of the total variance; (2) “Dubai Sector 1” had the 6th predictive power and it explained about 1% of the total variance in the General, Ergonomic, Nervous, and Skin symptoms. Ordering the two variables as per their weights in the adjusted model was as follows: (1) “Water leakage” received the 7th weight in the model and it uniquely accounted for approximately 0.8% of the total variance; while (2) “Dubai Sector 1” received the 8th weight in the model it uniquely accounted for approximately 0.7% of the total variance in the General, Ergonomic, Nervous, and Skin symptoms.

As per results shown in Section 4.1.6.9, about 2% of the variance in the IAQ discomfort was explained by the model using the twenty three building variables. Two out of them were statistically significantly associated with IAQ discomfort ordered as per their weights and predictive power in the unadjusted model as: (1) New wall covering received the highest weights and predictive power and it explained about 1% of the variance in IAQ discomfort, (2) water leakage had the 2nd weights and predictive power and it explained about 1% of the variance. Reference to results in Section 4.1.6.16; when adjusting the model for other IEQ factors, only the new wall covering was statistically significantly associated with IAQ discomfort. The total and unique variance explained in IAQ discomfort by new wall covering was approximately 1%.

In terms of associated building variables with the odors; as per results shown in Section 4.1.6.10, about 6% of the variance in the odors perceptions was explained by the model using the twenty three building variables. Three out of them were statistically significantly associated with odors ordered as per their weights and predictive power in the model as: (1) New carpets received the highest weights in the model and predictive power and it explained about 3% of the variance in the odors perceptions; (2) water leakage received the 2nd weights in the model and predictive power and it explained about 2% of the variance; (3) split HVAC received the 3rd weights in the model and predictive power and it explained about 1% of the variance. The three variables were positively associated with odors perceptions. Participants living in households having new carpets, water leakage, and/or split HVAC had higher levels of experiencing odors.

In terms of associated building variables with the Thermal, Lighting, and Noise discomfort; as per results shown in Section 4.1.6.8, about 3% of the variance in the Thermal, Lighting, and Noise discomfort was explained by the model using the twenty three building variables. Two out of them were statistically significantly associated with Thermal, Lighting, and Noise discomfort ordered as per their weights and predictive power in the model as: (1) New carpets received the highest weights in the model and predictive power and it explained about 2% of the variance in the Thermal, Lighting, and Noise discomfort; while (2) water leakage received the highest weights in the model and predictive power and it explained about 1% of the variance. The two variables were positively predicting the Thermal, Lighting, and Noise discomfort. Participants living in households having new carpets and/or water leakage had higher levels of experiencing the Thermal, Lighting, and Noise discomfort.

#### 4.1.7.3 Associated IEQ parameters with Eye, Nose, Throat, and Chest related symptoms

Results illustrated in Section 4.1.6.11, about 26% of the variance of Eye, Nose, Throat, and Chest related symptoms was explained by the model using IEQ factors. Results revealed that the Eye, Nose, Throat, and Chest related symptoms were statistically significantly and positively associated with the three IEQ factors ordered as per their weights in the unadjusted model as follows: (1) Odors received the highest weights in the model; (2) IAQ discomfort the 2nd weight; and (3) Thermal, Lighting, and Noise discomfort received the 3rd weight. Ordering those factors as per their predictive power in the unadjusted model was: (1) odors factor had the highest predictive power and accounted for approximately 19% of the variance of Eye, Nose, Throat, and Chest related symptoms; (2) IAQ discomfort had the 2nd predictive power and accounted for approximately 16% of the variance, and (3) Thermal, Lighting, and Noise had the 3rd predictive power and accounted for approximately 13% of the variance.  The variance in Eye, Nose, Throat, and Chest related symptoms uniquely explained by: (1) odors, (2) IAQ discomfort; and (3) Thermal, Lighting, and Noise discomfort factor was approximately 4%, 4%, and 2%; respectively.

Reference to results shown in Section 4.1.6.124.1.6.12, about 29% of the variance of Eye, Nose, Throat, and Chest related symptoms was explained by the model using IEQ factors adjusted for significant population and building variables. Even when adjusting the model for the statistically significant population and building variables, the IEQ factors had the highest three predictive power in the adjusted model ordered as follows: (1) odors had the highest predictive power and accounted for approximately 17% of the variance of Eye, Nose, Throat, and Chest related symptoms; (2) IAQ discomfort had the 2nd predictive power and accounted for approximately 15% of the variance of Eye, Nose, Throat, and Chest related symptoms; (3) Thermal, Lighting, and Noise had the 3rd predictive power and accounted for approximately 11% of the variance of Eye, Nose, Throat, and Chest related symptoms (Figure 4-25). Ordering the IEQ factors according to their weights in the adjusted model was: (1) odors received the highest weights in the adjusted model; (2) IAQ discomfort received the 2nd weight; while (3) Thermal, Lighting, and Noise received the 4th weight and they uniquely accounted for approximately 3%, 3%, and 1% of the variance Eye, Nose, Throat, and Chest related symptoms; respectively (Table 4-35). The dominance of the three IEQ factors in predicting Eye, Nose, Throat, and Chest related symptoms is obvious in both the adjusted and unadjusted models (Figure 4-25). The three IEQ factors had the top three predictive powers in both adjusted and unadjusted models ordered as follows: (1) odors, (2) IAQ discomfort, (3) Thermal, Lighting, and Noise discomfort. Odors and IAQ discomfort factors had the top two weights in both the unadjusted and adjusted models while the Thermal, Lighting, and Noise discomfort had the 3rd weight in the unadjusted model and the 4th weight in the adjusted model.

Table 4-35: Statistically significant parameters associated with Eye, Nose, Throat, and Chest related symptoms and explained variance as per adjusted model (Section 4.1.6.12)

| | | | Explained variance | | |
|---|---|---|---|---|---|
| | | Sig. | Total | Unique | Common |
| **IEQ factors** | | | | | |
| 1 | Odors | *** | 17% | 3% | 14% |
| 2 | IAQ discomfort | *** | 15% | 3% | 12% |
| 3 | Thermal, Lighting, and Noise discomfort | ** | 11% | 1% | 10% |
| **Population variables** | | | | | |
| 1 | Dust allergy | *** | 5% | 2% | 3% |
| 2 | Migraine | ** | 4% | 1% | 3% |
| 3 | Asthma | * | 2% | 1% | 1% |
| **Building variables** | | | | | |
| 1 | New carpets | ** | 2% | 1% | 1% |
| 2 | Attached kitchen with interior walls | ** | 1% | 1% | 0% |

Note: *$p \leq .05$, **$p \leq .01$, *** $p \leq .001$

Regarding the associations between odor variables and Eye, Nose, Throat, and Chest related symptoms, about 24% of the variance in the Eye, Nose, Throat, and Chest symptoms was explained by the model using the nine variables of odors factor (Section

4.1.6.19). As shown in (Table 4-36), ordering those odors as per their predictive power is as follows: (1) "Odors from paint" had the highest predictive power and explained about 9.7% of the variance in the Eye, Nose, Throat, and Chest symptoms; (2) "Odors from new carpet, curtains, or drapes" had the 2nd predictive power and explained about 9.5% of the variance; (3) "Odors from other chemicals i.e. pesticides, glues, or cleaning products" had the 3rd predictive power and explained about 7.6% of the variance; (4) "Musty/mouldy dampness odors" had the 4th predictive power and explained about 6.5% of the variance in the Eye, Nose, Throat, and Chest symptoms; (5) "Smoke from incense burning" had the 5th predictive power and explained about 5.6% of the variance; (6) "Tobacco smoke" had the 6th predictive power and explained about 3.1% of the variance in the Eye, Nose, Throat, and Chest symptoms. The amount of variance uniquely explained by: (1) "Odors from new carpet, curtains, or drapes"; (2) "Odors from paint"; (3) "Tobacco smoke"; (4) "Smoke from incense burning"; (5) "Odors from other chemicals i.e. pesticides, glues, or cleaning products"; and (6) "Musty/mouldy dampness odors" was approximately 1.8%, 1.4%, 1.4%, 1.3%, 1.1%, and 1.0% of the variance of Eye, Nose, Throat, and Chest related symptoms; respectively (Table 4-36).

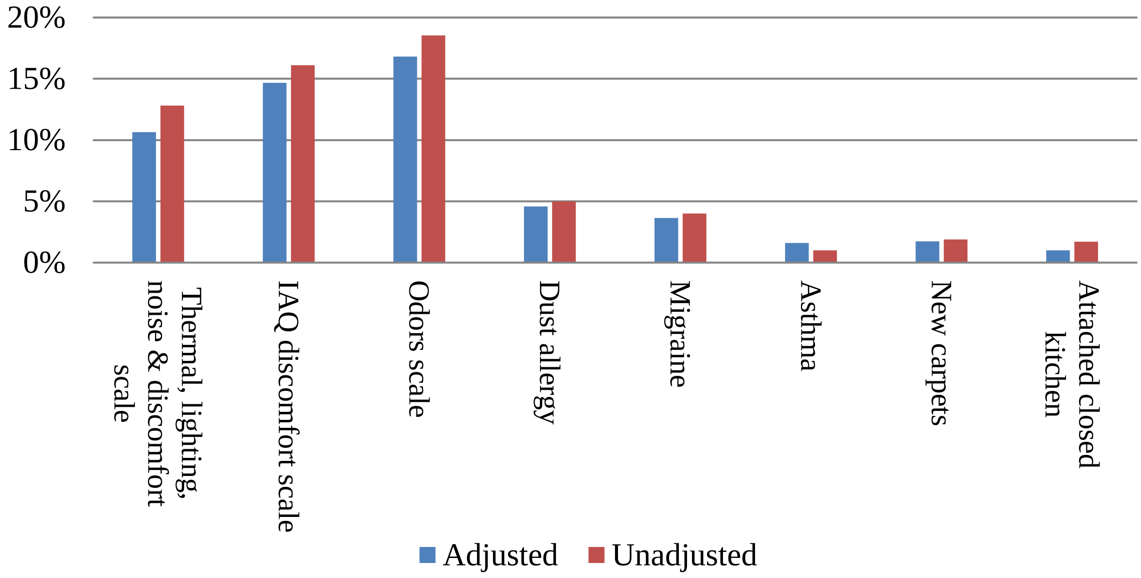


Figure 4-25: Total variance explained in the adjusted and unadjusted MLR models of IEQ factors, population variables, and building variables on Eye, Nose, Throat, and Chest symptoms

However, when adjusting the model using all IEQ variables for significant population and building variables (Section 4.1.6.23); only two odor variables were statistically significant predictors out of the six variables identified in the unadjusted model (Section 4.1.5.19). As shown in Figure 4-26, the two odor variables ordered as per their predictive power in the adjusted model were as follows: (1) “Odors from paint” had the 3rd predictive power and it explained about 10% of the total variance; and (2) “Musty/mouldy dampness odors” had the 4th predictive power and it explained about 8% of the total variance of the Eye, Nose, Throat, and Chest related symptoms. The two variables ordered as per their weights in the adjusted model were: (1) “Musty/mouldy dampness odors” received the highest weights in the model; while (2) “Odors from paint” received the 6th weight. The amount of variance uniquely explained by the above ordered variables was approximately 2% and 1% of the variance of Eye, Nose, Throat, and Chest related symptoms; respectively (Table 4-37).

Table 4-36: Statistically significant IEQ variables associated with Eye, Nose, Throat, and Chest related symptoms and explained variance as per the unadjusted MLR models in Sections 4.1.6.19 to 4.1.6.17

| | | | Explained variance | | |
|---|---|---|---|---|---|
| Model | Variable | Sig. | Total | Unique | Common |
| 4.1.6.19 | **Odors** | | | | |
| | 1 Odors from paint | ** | 10% | 1% | 9% |
| | 2 Odors from new carpet and curtains | *** | 10% | 2% | 8% |
| | 3 Odors from other chemicals | ** | 8% | 1% | 7% |
| | 4 Musty/mouldy dampness odors | * | 6% | 1% | 5% |
| | 5 Smoke from incense burning | ** | 6% | 1% | 5% |
| | 6 Tobacco smoke | ** | 3% | 1% | 2% |
| 4.1.6.18 | **IAQ discomfort** | | | | |
| | 1 Stuffy bad air | *** | 12% | 4% | 8% |
| | 2 Dust and dirt | *** | 10% | 2% | 8% |
| 4.1.6.17 | **Thermal, lighting & noise discomfort** | | | | |
| | 1 Too much dim | *** | 10% | 3% | 7% |
| | 2 Too much humidity | * | 6% | 1% | 5% |

*$p \leq .05$, **$p \leq .01$, *** $p \leq .001$

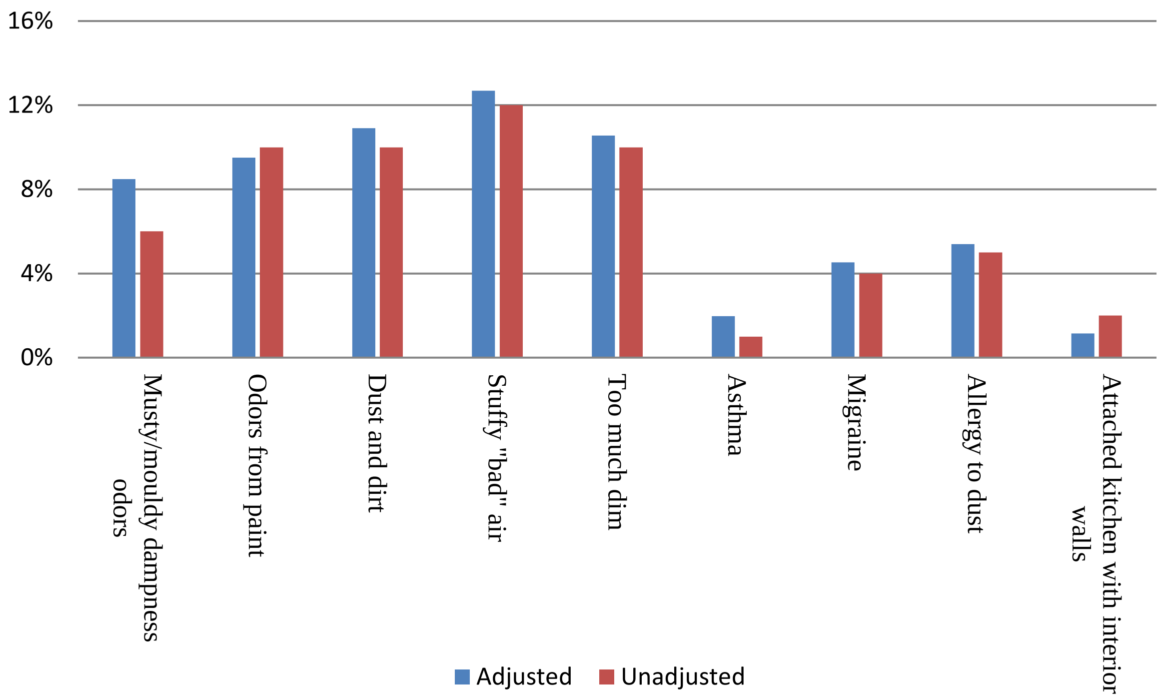


Figure 4-26: Total variance explained in the adjusted and unadjusted MLR models of IEQ, population, and building variables on Eye, Nose, Throat, and Chest related symptoms

Regarding the associations between IAQ discomfort variables and Eye, Nose, Throat, and Chest related symptoms, about 14% of the variance in the Eye, Nose, Throat, and Chest symptoms was explained by the model using IAQ discomfort variables (Section 4.1.6.18). The two IAQ variables that were statistically significantly associated with Eye, Nose, Throat, and Chest related symptoms. “Stuffy bad air” had higher weight and predictive power compared with “Dust and dirt” as they explained about 12% and 10% of the variance in Eye, Nose, Throat, and Chest related symptoms; respectively. The amount of variance uniquely explained by: (1) “Stuffy bad air” and (2) “Dust and dirt” was approximately 4% and 2% of the variance of Eye, Nose, Throat, and Chest related symptoms; respectively (Table 4-36). The two IAQ discomfort variables were statistically significantly associated with Eye, Nose, Throat, and Chest related symptoms even when adjusting the model using all IEQ variables for significant population and building variables (Section 4.1.6.23). As shown in Figure 4-26, the two IAQ discomfort variables had the top two highest predictive powers in the adjusted model ordered as follows: (1)

“Stuffy "bad" air” had the highest predictive power and it explained about 13% of the total variance in Eye, Nose, Throat, and Chest related symptoms; while (2) “Dust and dirt” had the 2nd predictive power and it explained about 11% of the total variance of Eye, Nose, Throat, and Chest related symptoms. The two variables ordered as per their weights in the adjusted model were: (1) “Stuffy "bad" air” received the 5th weight and it uniquely accounted for approximately 0.6% of the total variance; while (2) “Dust and dirt” received the 7th weight in the model and it uniquely accounted for approximately 0.5% of the total variance in Eye, Nose, Throat, and Chest related symptoms (Table 4-37).

Table 4-37: Statistically significant IEQ variables associated with Eye, Nose, Throat, and Chest related symptoms and explained variance as per the adjusted MLR model in Section 4.1.6.23

| | | | Explained variance | | |
|---|---|---|---|---|---|
| | | Sig. | Total | Unique | Common |
| | **Odors** | | | | |
| 1 | Odors from paint* | * | 10% | 1% | 9% |
| 2 | Musty/mouldy dampness odors* | *** | 8% | 2% | 7% |
| | **IAQ discomfort** | | | | |
| 1 | Stuffy "bad" air* | * | 13% | 1% | 12% |
| 2 | Dust and dirt* | * | 11% | 1% | 10% |
| | **Thermal, lighting, noise discomfort** | | | | |
| 1 | Too much dim** | ** | 11% | 1% | 9% |
| | **Population** | | | | |
| 1 | Allergy to dust*** | *** | 5% | 2% | 4% |
| 2 | Migraine** | ** | 5% | 1% | 3% |
| 3 | Asthma** | ** | 2% | 1% | 1% |
| | **Building** | | | | |
| 1 | Attached closed kitchen ** | ** | 1% | 1% | 0% |

*$p \leq .05$, **$p \leq .01$, *** $p \leq .001$

Concerning the associations between Thermal, Lighting, and Noise discomfort variables and Eye, Nose, Throat, and Chest related symptoms, about 13% of the variance in the Eye, Nose, Throat, and Chest symptoms was explained by the model using the six variables of Thermal, Lighting, and Noise discomfort factor (Section 4.1.6.17). The two variables of the Thermal, Lighting, and Noise discomfort factor that were statistically significantly associated with Eye, Nose, Throat, and Chest related symptoms ordered as per their weights and predictive powers were: (1) “Too much dim” and (2) “Too much humidity”. The proportion of the total variance explained ($R^2$) that was explained by each of the above ordered factors based on their ($r_s^2$) was approximately10% and 6%; respectively. The amount of variance uniquely explained by the above two variables was approximately 3% and 1% of the variance of Eye, Nose, Throat, and Chest related symptoms; respectively (Table 4-36). When adjusting the model using all IEQ variables for significant population and building variables (Section 4.1.6.23); only “Too much dim” was statistically significantly associated with Eye, Nose, Throat, and Chest related symptoms. As shown in Figure 4-26, “Too much dim” variable had the 2nd predictive power in the adjusted model and it explained about 11% of the total variance in Eye, Nose, Throat, and Chest related symptoms. “Too much dim” variable received the 3rd weight in the adjusted model and it uniquely accounted for approximately 1.1% of the total variance in Eye, Nose, Throat, and Chest related symptoms (Table 4-37).

#### 4.1.7.4 Associated IEQ parameters with General, Ergonomic, Nervous, and Skin symptoms

Results illustrated in Section 4.1.6.13, about 29% of the variance in the General, Ergonomic, Nervous, and Skin symptoms was explained by the model using the three IEQ factors. Results revealed that the General, Ergonomic, Nervous, and Skin symptoms were statistically significantly associated with the three IEQ factors ordered as per their weights in the model as follows: (1) odors in addition to the Thermal, Lighting, and Noise discomfort factors received the highest weights in the model; then (2) IAQ discomfort factor received the 2nd weight. The three factors were positively associated with General, Ergonomic, Nervous, and Skin symptoms. Ordering those factors as per their predictive power in the model was: (1) odors had the highest predictive power in the model and it explained about 21% of the variance in the General, Ergonomic, Nervous, and Skin symptoms; (2) Thermal, Lighting, and Noise discomfort had the 2nd predictive power and it explained about 20% of the variance; and (3) IAQ discomfort had the 3rd predictive power and it explained about 12% of the variance in the General, Ergonomic, Nervous, and Skin symptoms.

Reference to results shown in Section 4.1.6.14, about 38% of the variance in the General, Ergonomic, Nervous, and Skin symptoms was explained by the model using the three IEQ factors adjusted for population and building variables statistically significantly associated with those symptoms. As illustrated in Figure 4-27, even when adjusting the model for the statistically significant population and building variables, the IEQ factors had the highest three predictive power in the adjusted model. The three factors ordered as per their predictive power in the adjusted model was as follows: (1) Odors had the highest predictive power in the adjusted model and it explained about 19% of the variance in the General, Ergonomic, Nervous, and Skin symptoms; (2) Thermal, Lighting, and Noise discomfort had the 2nd predictive power and it explained about 17% of the variance; and (3) IAQ discomfort had the 3rd predictive power and it explained about 11% of the variance in the General, Ergonomic, Nervous, and Skin symptoms. Ordering the IEQ factors according to their weights in the adjusted model was: (1) Odors had the highest weight, (2) Thermal, Lighting, and Noise discomfort received the 2nd weight; (3) IAQ discomfort had the 5th. The unique variance explained by: (1) Odors; (2) Thermal, Lighting, and Noise discomfort; (3) IAQ discomfort was approximately 3%, 3%, and 1%; respectively (Table 4-38). The dominance of the three IEQ factors in predicting the General, Ergonomic, Nervous, and Skin symptoms is obvious in both the adjusted and unadjusted models (Figure 4-27). The three IEQ factors had the top three predictive powers in both models ordered as follows: (1) odors, (2) Thermal, Lighting, and Noise discomfort, and (3) IAQ discomfort. Odors and the Thermal, Lighting, and Noise discomfort factor had the top two weights in both models while the IAQ discomfort had the 3rd weight in the unadjusted model and the 5th weight in the adjusted model.

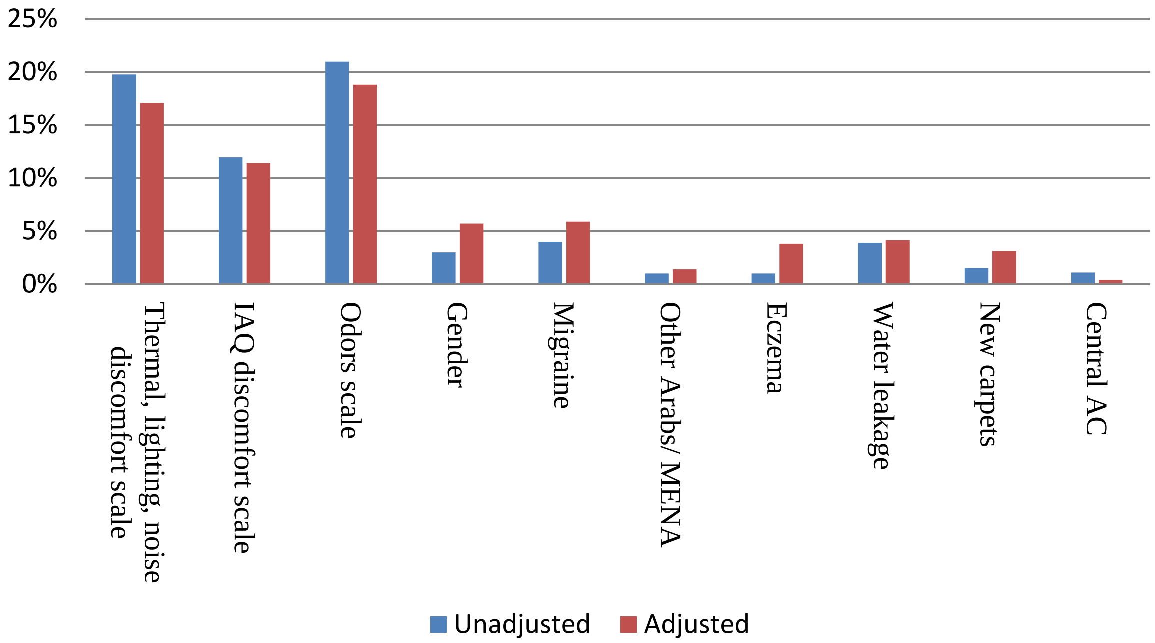


Figure 4-27: Total variance explained in the adjusted and unadjusted MLR models of IEQ factors, population, & building variables on general, ergonomic, nervous & skin symptoms

Table 4-38: Statistically significant parameters associated with General, Ergonomic, Nervous, and Skin symptoms and explained variance as per adjusted model in Section 4.1.6.14

| | | | Explained variance | | |
|---|---|---|---|---|---|
| | | Sig. | Total | Unique | Common |
| **IEQ factors** | | | | | |
| 1 | Odors | *** | 19% | 3% | 16% |
| 2 | Thermal, Lighting, and Noise discomfort | *** | 17% | 3% | 14% |
| 3 | IAQ discomfort | ** | 11% | 1% | 10% |
| **Population variables** | | | | | |
| 1 | Migraine | ** | 6% | 1% | 5% |
| 2 | Gender | *** | 6% | 2% | 4% |
| 3 | Eczema | * | 4% | 1% | 3% |
| 4 | Other Arabs and MENA | *** | 1% | 1% | 0% |
| **Building variables** | | | | | |
| 1 | Water leakage | ** | 4% | 1% | 3% |
| 2 | New carpets | * | 4% | 0.2% | 3.8% |
| 3 | Central HVAC | * | 0.4% | 0.1% | 0.3% |

Note: $*p \leq .05$, $**p \leq .01$, $***\ p \leq .001$

Regarding the associations between odors variables and the General, Ergonomic, Nervous, and Skin symptoms; about 20% of the variance in those symptoms was explained by the model using the nine variables of odors factor (Section 4.1.6.22). Five out of them were statistically significantly associated with General, Ergonomic, Nervous, and Skin symptoms ordered as per their predictive power as follows: (1) "Body odors or cosmetics odors i.e. perfumes, after shave" had the highest predictive power; (2) "Fishy smells or other food smells" had the 2nd; (3) "Odors from paint" had the 3rd; (4) "Odors from other chemicals i.e. pesticides, glues, or cleaning products" had the 4th; while (5) "Smoke from incense burning" had the 5th predictive power. As illustrated in Table 4-39, the proportion of variance that was uniquely and non-uniquely explained by the above ordered five variables was 10%, 9%, 8%, 7%, and 6% of the variance of General, Ergonomic, Nervous, and Skin symptoms; respectively.

Table 4-39: Statistically significant IEQ variables associated with General, Ergonomic, Nervous, and Skin symptoms and explained variance as per unadjusted MLR models in Sections 4.1.6.20 to 4.1.6.22

| | | | | Explained variance | | |
|---|---|---|---|---|---|---|
| Model | Variable | | Sig. | Total | Unique | Common |
| 4.1.6.21 | **Thermal, lighting, & noise discomfort** | | | | | |
| | 1 | Too much dim | *** | 16% | 3% | 13% |
| | 2 | Too much humidity | *** | 16% | 5% | 11% |
| | 3 | Too cold | * | 5% | 1% | 4% |
| 4.1.6.22 | **Odors** | | | | | |
| | 1 | Body odors or cosmetics odors | ** | 10% | 1% | 9% |
| | 2 | Fishy smells or other food smells | ** | 9% | 1% | 8% |
| | 3 | Odors from paint | ** | 8% | 1% | 7% |
| | 4 | Odors from other chemicals | * | 7% | 1% | 6% |
| | 5 | Smoke from incense burning | *** | 6% | 3% | 3% |
| 4.1.6.21 | **IAQ discomfort** | | | | | |
| | 1 | Stuffy bad air | *** | 10% | 3% | 7% |
| | 2 | Dust and dirt | *** | 9% | 2% | 7% |

Note: $*p \leq .05$, $**p \leq .01$, $*** p \leq .001$

As shown in Table 4-39, the unique variance explained by: (1) "Smoke from incense burning"; (2) "Fishy smells or other food smells" and "Odors from paint"; (3)

“Body odors or cosmetics odors”; and (4) “Odors from other chemicals i.e. pesticides, glues, or cleaning products” was approximately 3%, 1%, 1%, 1%, and 1% of the variance of General, Ergonomic, Nervous, and Skin symptoms; respectively. The five odors variables were positively associated with General, Ergonomic, Nervous, and Skin symptoms. However, when adjusting the model using all IEQ variables for significant population and building variables (Section 4.1.6.24); only “Smoke from incense burning” was identified as statistically significant predictor out of the 5 variables identified in the unadjusted model (Section 4.1.6.22). As shown in Figure 4-28, “Smoke from incense burning” had the 3rd highest predictive power in the adjusted model and it explained about 6% of the total variance in the General, Ergonomic, Nervous, and Skin symptoms. Also, “Smoke from incense burning” received the 3rd weight in the in the adjusted model and it uniquely accounted for 1.6% of the total variance in the General, Ergonomic, Nervous, and Skin symptoms (Table 4-40).

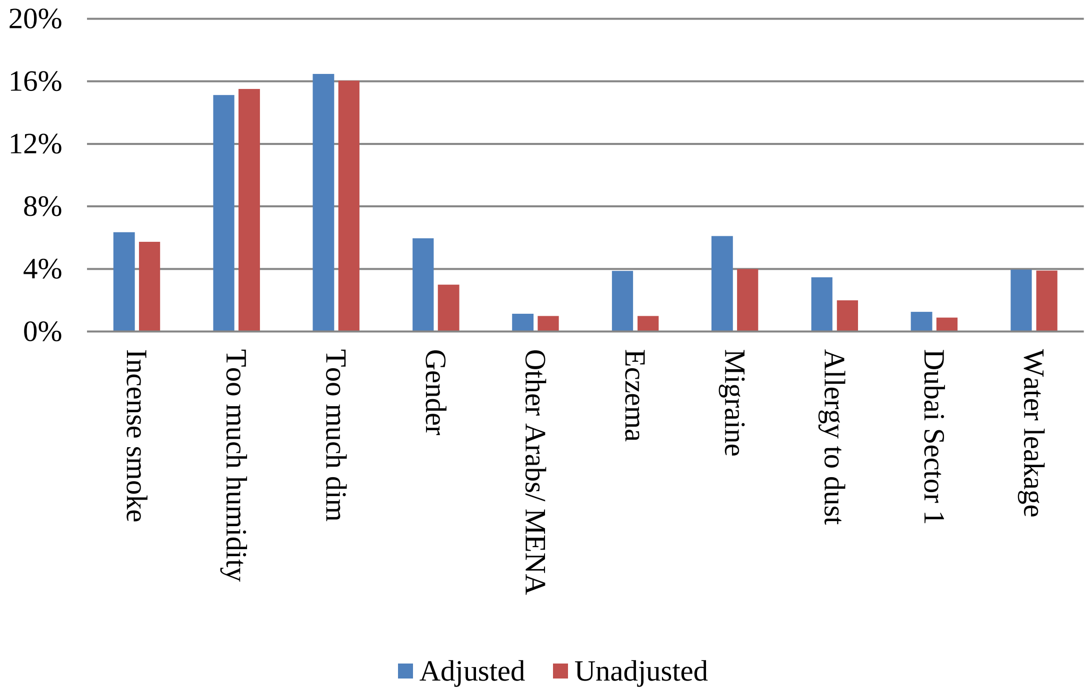


Figure 4-28: Total variance explained in the adjusted and unadjusted MLR models of IEQ, population, and building variables on General, Ergonomic, Nervous, and Skin symptoms

Table 4-40: Explained variance by statistically significant IEQ variables associated with General, Ergonomic, Nervous, and Skin symptoms as per adjusted MLR model in Section 4.1.6.24

| | | | Explained variance | | |
|---|---|---|---|---|---|
| | | Sig. | Total | Unique | Common |
| | **Thermal, lighting, & noise discomfort** | | | | |
| 1 | Too much dim | ** | 16% | 1% | 15% |
| 2 | Too much humidity | *** | 15% | 4% | 12% |
| | **Odors** | | | | |
| 1 | Incense smoke | *** | 6.3% | 1.6% | 4.7% |
| | **Population** | | | | |
| 1 | Gender | *** | 6% | 2% | 4% |
| 2 | Migraine | ** | 6% | 1% | 5% |
| 3 | Eczema | ** | 4% | 1% | 3% |
| 5 | Allergy to dust | * | 3% | 1% | 2% |
| 4 | Other Arabs/ MENA | ** | 1% | 1% | 0% |
| | **Building** | | | | |
| 1 | Water leakage | * | 4% | 1% | 3% |
| 2 | Dubai Sector 1 | * | 1.3% | 0.6% | 0.7% |

*$p \le .05$, **$p \le .01$, *** $p \le .001$

Regarding the associations between the Thermal, Lighting, and Noise discomfort variables and the General, Ergonomic, Nervous, and Skin symptoms; about 24% of the variance in those symptoms was explained by the model using the six variables of Thermal, Lighting, and Noise discomfort factor (Section 4.1.6.20). The three variables of the Thermal, Lighting, and Noise discomfort factor that were statistically significantly associated with the General, Ergonomic, Nervous, and Skin symptoms ordered as per their predictive power were: (1) “Too much dim” had the highest predictive; (2) “Too much humidity” had the 2nd; while (3) “Too cold” had the 3rd predictive power. The proportion of the total variance explained ($R^2$) that was explained by each of the above ordered factors based on their ($r_s^2$) was approximately 16%, 15.5%, and 6%; respectively. The amount of variance uniquely explained by: (1) “Too much humidity”; (2) “Too much dim”; and (3) “Too cold” was approximately 5% 3% and 1% of the variance of General, Ergonomic, Nervous, and Skin symptoms; respectively (Table 4-39). The three variables were positively associated with General, Ergonomic, Nervous, and Skin symptoms.

However, when adjusting the model using all IEQ variables for significant population and building variables (Section 4.1.6.24); only “Too much dim” and “Too much humidity” were statistically significantly associated with General, Ergonomic, Nervous, and Skin symptoms. As shown in Figure 4-28, those two variables had the top two highest predictive powers in the adjusted model as follows: (1) “Too much dim” had the highest predictive power and it explained about 16.5% of the variance; while (2) “Too much humidity” had the 2nd predictive power and it explained about 15.1% of the variance in the General, Ergonomic, Nervous, and Skin symptoms. As shown in (Table 4-40), the unique variance explained by each of the above variables was approximately 4%, and 1% of the total variance in the General, Ergonomic, Nervous, and Skin symptoms; respectively.

Regarding the associations between the IAQ discomfort variables and the General, Ergonomic, Nervous, and Skin symptoms; about 12% of those symptoms were explained by the model using the two variables of IAQ discomfort (Section 4.1.6.21). The two IAQ variables that were statistically significantly associated with the General, Ergonomic, Nervous, and Skin symptoms ordered as per their weights and predictive power were: (1) “Stuffy "bad" air” and (2) “Dust and dirt”. The two variables were positively associated with General, Ergonomic, Nervous, and Skin symptoms. The proportion of the total variance explained by each of the above variables was approximately 10% and 9% while the amount of variance uniquely explained by them was approximately 3% and 2% of the variance in General, Ergonomic, Nervous, and Skin symptoms; respectively (Table 4-39). However, none of those two had statistical significant association with the General, Ergonomic, Nervous, and Skin symptoms when adjusting the model using all IEQ variables for significant population and building variables (Section 4.1.6.24).

#### 4.1.7.5 Associations between other IEQ factors and IAQ discomfort factor

Results illustrated in Section 4.1.6.15, about 33% of the variance of IAQ discomfort was explained by the model using the (1) odors factor and (2) the Thermal, Lighting, and Noise factor. Results revealed that the IAQ discomfort was statistically significantly associated with the two factors. Ordering them as per their weights and predictive power in the unadjusted model was as follows: (1) Odors received the highest weights and predictive power in the model explaining about 28% of the variance in IAQ discomfort; while (2) the Thermal, Lighting, and Noise discomfort factor had the 2nd weight and predictive power explaining about 19% of the variance. The 2 factors were positively associated with IAQ discomfort. The variance in IAQ discomfort uniquely explained by: (1) odors, (2) Thermal, Lighting, and Noise discomfort factor was approximately 14% and 5%; respectively.

Reference to results shown in Section 4.1.6.16, about 49% of the variance of IAQ discomfort was explained by the model using the (1) odors factor and (2) the Thermal, Lighting, and Noise factor adjusted for significant population and building variables. Results revealed that the IAQ discomfort was statistically significantly associated with the following parameters ordered per their predictive power as: (1) odors had the highest predictive power and explained about 30% of the variance in IAQ discomfort; (2) Thermal, Lighting, and Noise discomfort had the 2nd predictive power and explained about 16% of the variance; (3) dust allergy had the 3rd predictive power and explained about 2.7% of the variance; (4) age and migraine had the 4th predictive power and explained about 2.3% of the variance; (5) other Africans had the 5th predictive power and explained about 1.5% of the variance; and (6) new wall covering had the least predictive power and explained about 1% of the variance in IAQ discomfort (Figure 4-29).

As shown in Figure 4-29 and Table 4-41, even after adjusting the model for the statistically significant population and building variables, the odors and the Thermal, Lighting, and Noise factors had the highest two predictive powers in the adjusted model and their explained variance in IAQ discomfort was highly above others. As shown in Table 4-41, within the two IEQ factors, the odors factor uniquely explained about 15% of the variance in IAQ in addition to non-uniquely explaining another 15%. All predictors were positively associated with IAQ discomfort except for new wall covering. Ordering the parameters as per their weights in the adjusted model was: (1) odors received the highest weights; (2) Thermal, Lighting, and Noise discomfort received the 2nd weight; (3) age the 3rd; (4) other Africans the 4th; (5) dust allergy the 5th; (6) new wall covering the 6th; while

(7) migraine the received the least weight. They uniquely accounted for approximately 14.6%, 2.9%, 2.3%, 1.5%, 1%, 0.9%, and 0.5% of the variance of IAQ discomfort; respectively.

Figure 4-29: Total variance explained in the adjusted and unadjusted models of other IEQ factors, population, and building variables on IAQ discomfort (Section 4.1.6.15 & 4.1.6.16)

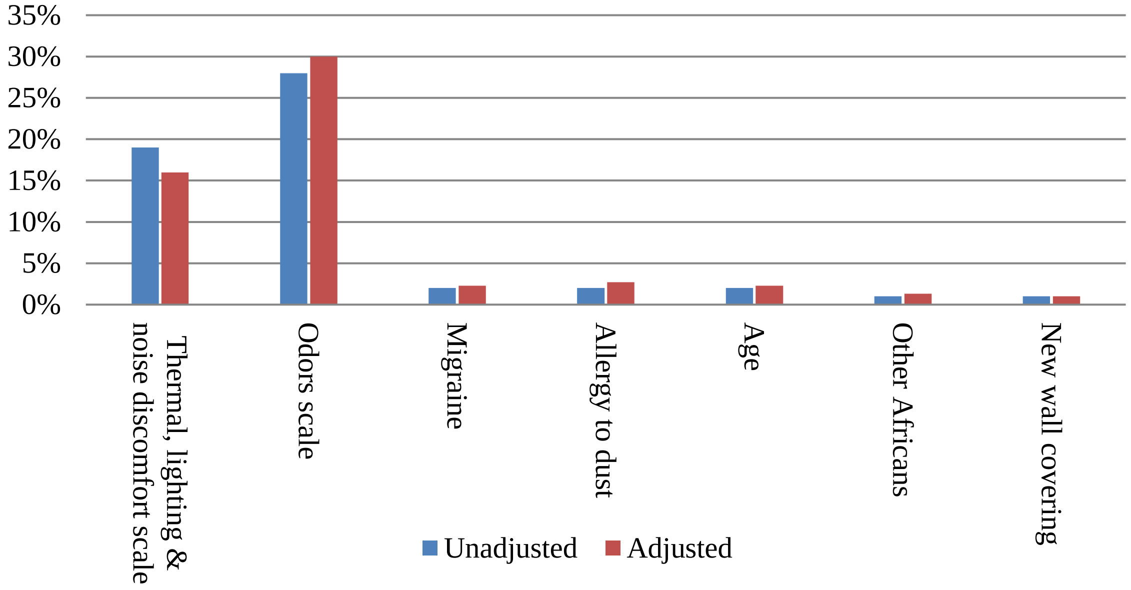


Table 4-41: Parameters statistically significantly associated with IAQ discomfort as per adjusted model (Section 4.1.6.16)

| | | | Explained variance | | |
|---|---|---|---|---|---|
| | | Sig. | Total | Unique | Common |
| | **IEQ factors** | | | | |
| 1 | Thermal, lighting, & noise discomfort | *** | 16% | 3% | 13% |
| 2 | Odors | *** | 30% | 15% | 15% |
| | **Population** | | | | |
| 1 | Migraine | * | 2% | 1% | 1% |
| 2 | Allergy to dust | ** | 3% | 1% | 2% |
| 3 | Age | *** | 2% | 2% | 0% |
| 4 | Other Africans | *** | 2% | 2% | 0% |
| | **Building** | | | | |
| 1 | New wall covering | ** | 1% | 1% | 0% |

Note: *$p \leq .05$, **$p \leq .01$, *** $p \leq .001$

### 4.1.8 Discussions of the main survey results

#### 4.1.8.1 Prevalent IEQ and health complaints in Dubai housing

In terms of the prevalent health symptoms shown in Figure 4-7, the ergonomic symptoms were sufficiently often experienced by approximately 18% at least 1 -3 days/ week. “Headache and nausea”, “Dry itchy skin”, “Unusual fatigue”, and “Nose related symptoms” were sufficiently often experienced by approximately 17% of the participants. “Nervous symptoms, tension, concentration problems” was sufficiently often experienced by approximately 15%, “Cough” by 12%, “Eye related symptoms” by 10%, “Throat related symptoms” by 9%, “Chest related symptoms” by 8%, while the least frequently experienced one is “Fever” by 5% of the households. As illustrated in Figure 4-8, the percentage of households that frequently experienced health disorders that became less outdoors: (1) headache and nausea were experienced by 5%, (2) nose related symptoms and neurological symptoms by 4%, (3) unusual fatigue, chest related, and ergonomic symptoms were experienced by 3%, (4) cough, eye related, throat related, and dry itchy skin by 2%, (5) fever was experienced by 1%. As per SHS syndrome definition (Section 2.1); symptoms frequently experienced that became less outdoors can be considered as SHS symptoms (Turpin 2014; Hess-Kosa 2011; Gomzi & Bobic 2009; OSHA 1999). Thus, the total percentage of households in this study that might be suffering from SHS was about 30%. Prevalent SHS in Dubai housing was higher than the prevalent SBS measured by Azuma et al. (2015) who conducted a nationwide cross-sectional survey in 320 Japanese offices and covering 3335 employees to assess SBS prevalence and identify the risk factors related to the work IEQ environment. Azuma et al. (2015) reported that SBS – defined as symptoms frequently experienced at least one day/ week and became better outdoors - was common in their nationwide sample accounting for 25% of its respondents. Strong associations between self - reported SBS and poor IEQ conditions were found in their study indicating the need for improving those conditions.

According to the reference data of healthy buildings by MM questionnaires, reported complaints of frequently experiencing the following: “Fatigue” is expected to be about 15% in normal conditions, “Feeling heavy headed” 9%, “Headache” 9%, “Nausea/ dizziness” 4%, “Irritation of the eyes” is expected to be about 10%, “Irritated, stuffy, runny nose” is expected to be about 15%, “Hoarse, dry throat” is expected to be about 10%, “Cough” is expected to be about 6%, “Dry or flushed facial skin” was expected to be about 9%, “Scaling/itching scalp or ears” is expected to be about 9%, “Dry hands” is expected to be about 6% in normal conditions (Kjell et al. 2014; Andersson 2010, 1998; Andersson & Stridh 1991). The frequent complaints of “Dry itchy skin” symptoms were about 17% in this study which was less than the expected 24% for all types of skin irritations in the reference data. Also, frequent complaints regarding “Headache and nausea” was about 17% in this study which is less than the expected 22% for frequently experiencing “Headache”, “Nausea/ dizziness”, and “Feeling heavy headed” in the reference data. “Eye related” and “Throat related” symptoms in this study were frequently experienced by 10% which is similar to the reference data. However, frequent complaints regarding “Cough” were 12% which was double the expected normal levels reference data. Also, frequent complaints regarding both “Nose related symptoms” and “Unusual fatigue” were 17% which were above the normally expected 15% by the MM questionnaires reference data.

Regarding IEQ conditions discussed in Figure 4-5, the most prevalent one was dust and dirt experienced by approximately 29% of the population at least 1 -3 days/ week. The next three sufficiently prevalent IEQ conditions were “Too quiet” by 22%, “Too hot” 22%, “Too humid” 19%, and “Too noisy” 19% of the households. Whereas “Too cold” was sufficiently frequently experienced by 17%, “Too glary” by 13%, “Too dim” by 11%, “Little air” by 15%, “Too dry” by 16%, and “Stuffy bad air” was sufficiently frequently experienced by 14% of the households at least 1 -3 days/ week. According to the reference data of healthy buildings by MM questionnaires; reported complaints of frequently experiencing “Dust and dirt” was expected to be about 15%; “Illumination problems” is expected to be about 13%, “Stuffy bad air” is expected to be about 15%, while “Too cold” conditions is expected to be about 9% (Kjell et al. 2014; Andersson 2010, 1998; Andersson & Stridh 1991). Notably that, when comparing between the MM questionnaires reference data, it is important to consider the differences in climatic, individual sensitivities and many other factors that might affect the questionnaire results. Based on MM questionnaires reference data, complaints regarding “stuffy bad air” can be considered as normal. However, complaints regarding “Dust and dirt”; “Too glary”, and “Too dim” can be considered as highly above normal conditions. As per that reference, frequent complaints of dust and dirt up to 15% is considered normal. According to this study results, about 16% of the households experienced dust and dirt on daily or almost daily basis while 13% of them experienced dust at 1 – 3 days weekly. Also, as per MM questionnaires reference data, frequent complaints regarding all “Illumination problems” are expected to be about 13%. However, reported “Too dim” and “Too glary” conditions were sufficiently “Often” experienced by 11% and 13% of the population; respectively. About 4% and 5% of them experienced “Too dim” and “Too glary” conditions on daily or almost daily basis while 7% and 8% of the two conditions 1 – 3 days weekly; respectively. Moreover, complaints regarding “Temperature too low” are expected to be about 9%. However, reported “Too cold” conditions in this study as sufficiently “Often” experienced were by 17% of the population. About 6% of them experienced “Too cold” conditions on daily or almost daily basis while 11% of them experienced dust and dirt 1 – 3 days weekly. In terms of self-reported odors perceptions, results illustrated in Figure 4-4 revealed that the most prevalent odors experienced sufficiently often by approximately 21%, 20%, 20%, and 19% of the population at least 1 – 3 days/ week were “Fishy and food odors”, “Body and cosmetics odors”, “Tobacco smoke”, and “Smoke from incense burning”; respectively. Odors from chemicals, dampness odors, diesel or engine exhaust, odors from new carpets, and odors from paint were sufficiently often experienced by approximately 7%, 6%, 6%, 4%, and 4% of the households. According to the reference data by MM questionnaires (Kjell et al. 2014; Andersson 2010, 1998; Andersson & Stridh 1991), reported complaints regarding frequently experiencing “Unpleasant odors” is expected to be about 9% in normal conditions.

(Reijula & Sundman-Digert 2004) assessed indoor air problems in 122 office environments in Finland using questionnaires that covered 11154 employees. The study was introduced as a reference one for other studies the associations between IEQ and health symptoms (Hellgren 2012). The frequent complaints occurring “every week” in their study was approximately 33% for skin symptoms, 20% for nose symptoms, 17% for each of eye symptoms and general symptoms, 16% for fatigue symptoms, 14% throat symptoms, while 5% for cough. Results of frequent health complaints occurring at least once a week by this study were less than those of (Reijula & Sundman-Digert 2004) regarding eye, nose, throat, and skin symptoms. Frequent fatigue complaints on weekly basis by this study were 17% which was a bit higher than the Finland study. However, frequent cough complaints at least once a week by this study was 12% which was highly above that measured by (Reijula & Sundman-Digert 2004). Concerning the frequently reported IEQ complaints by (Reijula & Sundman-Digert 2004) on weekly basis; about 35% of the complaints were about experiencing dry air, 34% about Stuffy air, 25% about Dust and dirt, 17% about high temperature, 17% about noisiness, 17% about unpleasant odors, 14% for poor lighting, and 13% for low temperature.  Complaints regarding dry and stuffy air was less by this study compared with that of (Reijula & Sundman-Digert 2004). However, frequent complaints regarding dust and dirt, too high and too low temperature, noise, poor lighting, in addition to unpleasant odors were higher than the Finland study.

#### 4.1.8.2 Prevalent associations with IEQ and health in Dubai housing

Table 4-42 and Figure 4-30 illustrates the statistically significant associations between the three IEQ factors and both health factors as per the results of adjusted models for population and building (Section 4.1.6.12 & 4.1.6.14). Odors factor had the highest predictive power and subsequently the highest proportion of explained variance in both health factors. The Thermal, Lighting, and Noise discomfort factor had higher predictive power in the general, ergonomic, nervous & skin symptoms than IAQ discomfort factor. Contrarily, the IAQ factor had higher predictive power in the Eye, Nose, Throat, and Chest related symptoms than Thermal, Lighting, and Noise discomfort factor. This result was in agreement with previous relevant studies. Regarding the associations between odors and health symptoms, Azuma et al. (2015) found significant associations between unpleasant odors (i.e. food odor, body odor, or perfumes) with general and upper respiratory symptoms that included sore or dry throat, sinus congestion, cough, and sneezing. Significant associations between eye, nose, hands, and fatigue with unpleasant odors was found by (Reijula & Sundman-Digert 2004). Also, Wang et al. (2013) found significant associations between general, mucousal, and skin symptoms with perceived odors involving stuffy odor, unpleasant odor, mold odor, pungent odor, and tobacco smoke odor. They also found that the associations between SBS symptoms and those who reported odor perceptions were stronger than those who did not.

Table 4-42: Associations between IEQ factors and health factors as per adjusted models Section 4.1.6.12 and 4.1.6.14

| | | **ENT & chest related** | | | **General, ergonomic, nervous & skin** | | |
|---|---|---|---|---|---|---|---|
| | | Explained variance | | | Explained variance | | |
| | **Factor** | Sig | Total | Unique | Sig. | Total | Unique |
| 1 | Odors | *** | 17% | 3% | *** | 19% | 3% |
| 2 | IAQ | *** | 15% | 3% | ** | 11% | 1% |
| 3 | Thermal, lighting & noise | ** | 11% | 1% | *** | 17% | 3% |

*$p \le .05$, **$p \le .01$, *** $p \le .001$

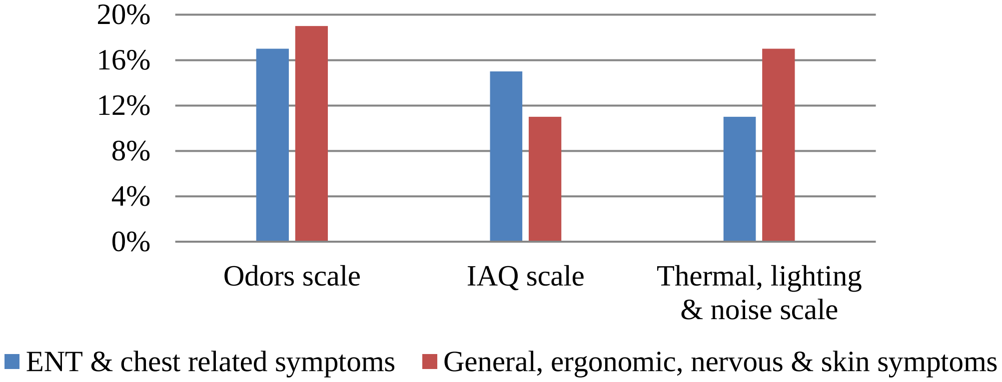


Figure 4-30: Total variance explained by IEQ factors in health symptoms

Concerning the associations between the thermal conditions and health symptoms, results by Azuma et al. (2015) revealed that eye, general, skin, in addition to upper respiratory symptoms that included sore or dry throat, sinus congestion, cough, and sneezing symptoms were significantly associated with the air-conditioning factors that included too little air movement, varying room temperatures, too cold air, too dry air, or excessive airflow from air conditioner. They also found that noise was significantly associated with skin and general symptoms which was consistent with findings by (Niven et al. 2000). Also, Ooi et al. (1998) found highly statistically significant associations ($p \le$

0.001) between high thermal discomfort, poor lighting, and too much noise in work environments and SBS symptoms that included eye irritation, nose irritation, stuffy nose, dry throat, and shortness of breath in addition to the general or neurotoxic symptoms that included headache, fatigue, dizziness, drowsiness, nausea, and vomiting. Significant associations between nose, eyes, hands, or fatigue with drought and room temperature was revealed by (Reijula & Sundman-Digert 2004). Reference to Hellgren (2012), one of the health effects of low RH is skin symptoms. In case of excess humidity, mold growth may be caused by water condensation on cold surfaces. The growth of dust mites is also encouraged in such environments. Also, odor perception is more in environments of high RH (Hellgren 2012). In terms of the associations between IAQ discomfort and health symptoms; significant association was found by Azuma et al. (2015) between dust and dirt with eye irritation, general, skin, in addition to upper respiratory symptoms that includes sore or dry throat, sinus congestion, cough, and sneezing. That is also consistent with (Niven et al. 2000) findings of having significant associations between dust and general, skin and upper respiratory symptoms. Also, Kanazawa et al. (2010) found an association between phosphates in indoor dust with mucousal symptoms that includes eye, nose, throat and respiratory symptoms. Reijula & Sundman-Digert (2004) found significant association between those who reported weekly exposure to stuffy bad air or dust and dirt with those who reported frequent eye, nose, hands, and fatigue symptoms.

Table 4-43 illustrates the population and building variables that were associated with the three IEQ and two health factors as per results in Section (4.1.6.24, 4.1.6.23, 4.1.6.16, 4.1.6.10, 4.1.6.8, 4.1.6.5 and 4.1.6.34.1.6.3). Following is the variables along with the number of the statistically significant associations with each:

- Dust allergy and migraine were statistically significantly associated with the five factors.
- Water leakage was associated with three factors.
- Passive smoking and new carpet were associated with two factors.
- Variables associated with only one factor were asthma, gender, eczema, other Arabs or MENA Nationals, age, other Africans, attached kitchen with interior walls, new wall covering, and split HVAC.

Table 4-43: Associated population and building variables with IEQ and health factors

| | | Eye, Nose, throat, & chest symptoms | General, ergonomic, nervous & skin | Thermal, lighting, & noise discomfort | IAQ discomfort | Odors |
|---|---|---|---|---|---|---|
| **Population** | | | | | | |
| 1 | Dust allergy | *** | * | ** | ** | *** |
| 2 | Migraine | ** | ** | ** | * | *** |
| 3 | Passive Smoking | ▨ | ▨ | * | ▨ | *** |
| 4 | Asthma | ** | ▨ | ▨ | ▨ | ▨ |
| 5 | Females | ▨ | *** | ▨ | ▨ | ▨ |
| 6 | Eczema | ▨ | ** | ▨ | ▨ | ▨ |
| 7 | Other Arabs and MENA | ▨ | ** | ▨ | ▨ | ▨ |
| 8 | Age | ▨ | ▨ | ▨ | *** | ▨ |
| 9 | Other Africans | ▨ | ▨ | ▨ | *** | ▨ |
| **Building** | | | | | | |
| 1 | Water leakage | ▨ | * | * | ▨ | ** |
| 2 | New carpets | ▨ | ▨ | *** | ▨ | *** |
| 3 | Attached kitchen with interior walls | ** | ▨ | ▨ | ▨ | ▨ |
| 4 | New wall covering | ▨ | ▨ | ▨ | ** | ▨ |
| 5 | Split HVAC | ▨ | ▨ | ▨ | ▨ | ** |
| 6 | Dubai Sector 1 | ▨ | * | ▨ | ▨ | |

$*p \leq .05$, $**p \leq .01$, $***\ p \leq .001$

As shown in Figure 4-31 and Table 4-44, in reference to results illustrated by the two adjusted models of IEQ variables on health factors (Section 4.1.6.23 and 4.1.6.24); statistically significant variables with both health factors were: (1) Too much dim, (2) migraine, and (3) allergy to dust. Variables statistically significantly associated with only Eye, Nose, Throat, and Chest related symptoms were: (1) Musty, mouldy or dampness odors, (2) odors from paint, (3) stuffy bad air, (4) dust and dirt; (5) asthma, and (6) attached kitchen with interior walls. Whereas the variables statistically significantly associated with only general, ergonomic, nervous & skin were: (1) Smoke from incense burning, (2) too much humidity, (3) gender, (4) Other Arabs or MENA Nationals, (5) eczema, (6) Dubai Sector 1, and (7) water leakage. As shown in Figure 4-31, the variance explained in the General, Ergonomic, Nervous and Skin by "Too much dim" and migraine was higher than in the Eye, Nose, Throat, and Chest related symptoms. While, the variance explained by dust allergy in the Eye, Nose, Throat, and Chest related symptoms was higher than in the general, ergonomic, nervous & skin symptoms.

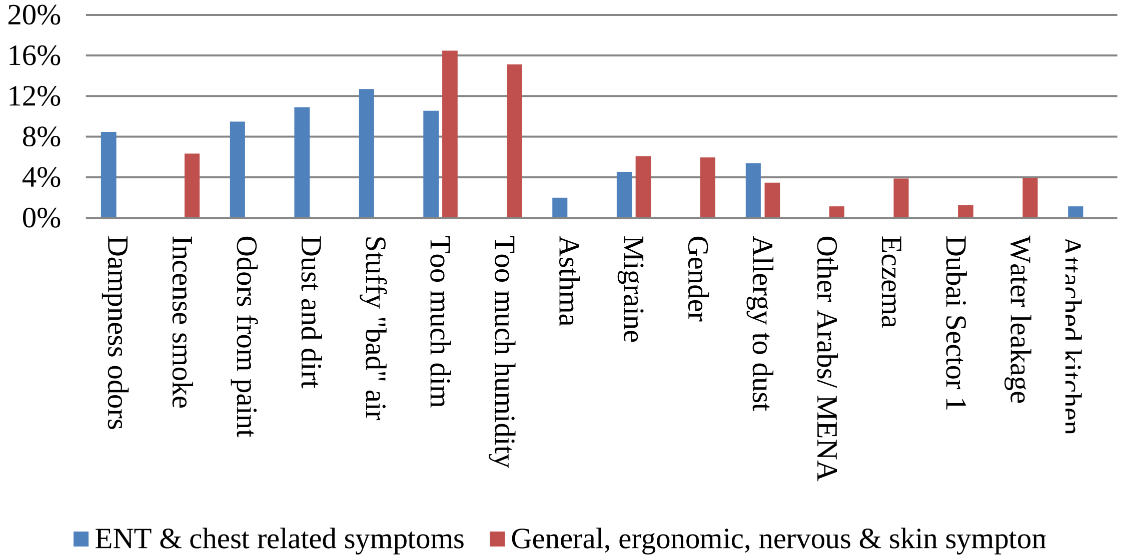


Figure 4-31: Total variance explained by significant variables in health symptoms as per adjusted models (Section 4.1.6.23 and 4.1.6.24)

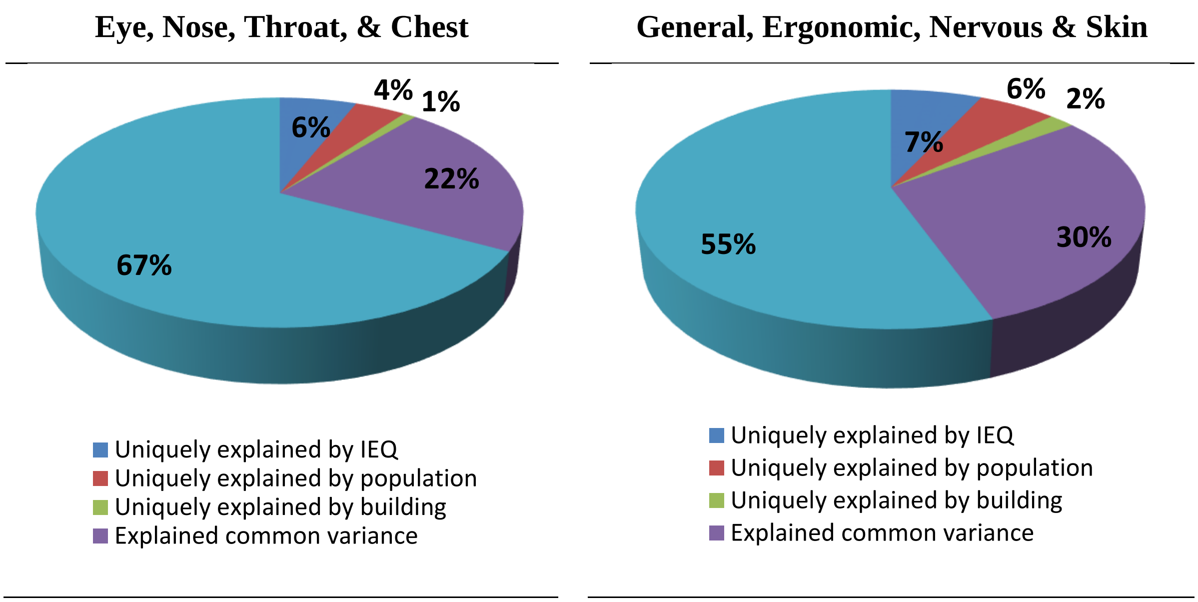
Figure 4-32 illustrates the proportion of explained and unexplained variance in health symptoms as per adjusted models (Section 4.1.6.23 and 4.1.6.24). The total variance explained by the two adjusted models was approximately 44% and 33% of the variance in (1) the general, ergonomic, nervous & skin symptoms and (2) the Eye, Nose, Throat, and Chest related symptoms; respectively. Variables ordered as per the total variance uniquely explained in both health factors were as follows: (1) IEQ variables, (2) population, and then (3) building variables. Noteworthy; about 30% and 22% of the explained variance in both health factors was non-uniquely explained or commonly shared by included variables in the model. This result highlighted the complex interactions between those variables as discussed in Chapter 2. As shown in Table 4-44, the proportion of total variance explained by the IEQ variables was obviously higher than that explained by population and building variables. Subsequently, the IEQ variables had higher proportion of the non-uniquely explained variance than that explained by population and building variables.

Table 4-44: Significantly associated IEQ, population, and building variables with health factors as per adjusted models (Section 4.1.6.23 and 4.1.6.24)

| | **Eye, Nose, Throat, & chest** | | | **General, Ergonomic, Nervous, & Skin** | | |
|---|---|---|---|---|---|---|
| | | Explained variance | | | Explained variance | |
| | Sig. | Total | Unique | Sig. | Total | Unique |
| **Thermal, Lighting, & Noise** | | | | | | |
| 1 Too much dim | ** | 11% | 1% | ** | 16% | 1% |
| 2 Too much humidity | | | | *** | 15% | 4% |
| **IAQ** | | | | | | |
| 1 Stuffy "bad" air | * | 13% | 1% | | | |
| 2 Dust and dirt | * | 11% | 1% | | | |
| **Odors** | | | | | | |
| 1 Odors from paint | * | 10% | 1% | | | |
| 2 Mouldy dampness odors | *** | 8% | 2% | | | |
| 3 Incense smoke | | | | *** | 6.3% | 1.6% |
| **Population variables** | | | | | | |
| 1 Migraine | ** | 5% | 1% | ** | 6% | 1% |
| 2 Gender | | | | *** | 6% | 2% |
| 3 Allergy to dust | *** | 5% | 2% | * | 3% | 1% |
| 4 Eczema | | | | ** | 4% | 1% |
| 5 Asthma | ** | 2% | 1% | | | |
| 6 Other Arabs/ MENA | | | | ** | 1% | 1% |
| **Building variables** | | | | | | |
| 1 Water leakage | | | | * | 4% | 1% |
| 2 Dubai Sector 1 | | | | * | 1.3% | 0.6% |
| 3 Attached closed kitchen | ** | 1% | 1% | | | |

Note: $*p \le .05$, $**p \le .01$, $*** p \le .001$

Figure 4-32: Explained and unexplained variance in health symptoms as per adjusted models (Section 4.1.6.23 and 4.1.6.24)



Eye, Nose, Throat, & Chest

General, Ergonomic, Nervous & Skin

Concerning the associations with population variables (Table 4-43), significant association was found between dust allergic and those having migraine with three IEQ discomfort factors and the two health factors. Asthmatic was significantly associated with Eye, Nose, Throat, and Chest symptoms while participants having eczema were associated with general, ergonomic, nervous & skin symptoms. Results regarding the identified significant associations are in agreement with previous studies. Based on about 100 surveys on SBS, (Andersson 1998, 2010) stated that hypersensitive or atopic individuals – i.e. pollen allergic, pet allergic dust allergic, or those having eczema – reported three to four times higher prevalence of skin and mucous membranes symptoms than non-atopic persons. Allergic individuals may respond to environmental changes earlier than others, and their sensitivity enable them to detect different hazards known to trigger symptoms. Kanazawa et al. (2010) found significant associations between history of allergy with general and skin symptoms at ($p$ = 0.03); while the associations with mucosal symptoms including eye, nose, throat, and respiratory symptoms ($p$ = 0.01). Also, Reijula & Sundman-Digert (2004) found significant associations between allergic individuals and nose, eye related symptoms in addition to dry and hoarse throat. They also found significant associations between allergic individuals and complaints regarding dry and stuffy air, as well as dust or dirt. While Runeson et al. (2006) revealed significant associations between asthmatics and experiencing more Eye, nose, throat, and tiredness symptoms. They also found that nasal symptoms and tiredness more common among those with atopy, such as pet allergy or pollen allergy, than those without atopy. Concerning the relationship between migraine and ENT symptoms; (Sabra et al. 2015) declared that about 11% of 1002 of consecutive patients in an otolaryngology clinic during six month period had migraine as a chief complaint. According to them, migraine may be manifested in typical symptoms (headache and dizziness) and may also be manifested in common atypical symptoms (nasal congestion, facial fullness, ear pain, pressure, and/or tinnitus).

In terms of the association between smoking and health symptoms; significant association was found between exposure to ETS or passive smoking and perceived Thermal, Lighting, and Noise discomfort and odors discomfort (Table 4-43). However, no significant association was found between active or first hand smoking with neither the IEQ nor the health factors. Having no significant association with first hand smoking is inconsistent with findings revealed by Yeatts et al. (2012a) in their UAE study who found significant associations between tobacco smoking and night dry cough, breath shortness, breathing difficulty, increased wheezing, ever having doctor-diagnosed asthma, night dry cough, monthly coughing one or more times. Also, Reijula & Sundman-Digert (2004) found significant associations between first hand smoking and reported IEQ problems and SBS. However, this study results is consistent with that revealed by Kanazawa et al. (2010) who did not find significant associations between first hand smoking with any health symptoms. Also, Zweers et al (1992) did not find any significant association between the first hand smoking and IEQ discomfort nor health complaints. Also, Norback & Edling (1991) did not find any significant association between the first hand smoking and SBS complaints. Noteworthy that this study found significant association was between passive smoking and perceived odors in addition to Thermal, Lighting, and Noise discomfort. However, no significant association was found between passive smokers with any health symptom which is also inconsistent with findings of some previous studies but consistent with others. For instance; according to (Hellgren 2012; Heloma & Jaakkola 2003), environmental tobacco smoke (ETS) was used to be a significant indoor pollutant in Finnish workplaces prior to legislation banning smoking at work (Heloma & Jaakkola 2003). ETS is a major source of more than 4000 chemical substances of which about 50 are carcinogens. The health effects of ETS involve pulmonary disease, chronic obstructive, asthma, stroke, and cancer (Hellgren 2012). Regarding the non-cancer respiratory effects of ETS, Bayard et al. (1992) declared that epidemiologic evidence was provided by previous studies associating between parental smoking and harmful respiratory effects in their infants such as reduced lung function, respiratory irritation that involved cough, wheeze, or sputum production, acute upper respiratory tract infections (colds or sore throats), and acute middle ear infections. However, reference to Godish (2018); the results of studies concerning the association between exposure to ETS and SBS symptoms were variable. That is because several studies indicated the positive significant association between the two (Norback et al. 1990; Hawkins & Wang 1991; Blum et al. 1993). Whereas many other studies did not find significant associations between exposure to ETS with reported SBS symptoms (Trauter et al. 1993; Stenberg et al. 1993; Hedge et al. 1994). According to Godish (2018); the variation in the findings by above studies can be attributed to the influence of many factors that differs from context to context i.e. smoking rates, applied smoking policies, provided AERs.

Also, results of this study revealed significant association between gender and the General, Ergonomic, Nervous, and Skin symptoms (Table 4-43). However, no significant association between Eye, Nose, Throat, and Chest symptoms and gender was found by this study. That is in agreement with previous studies findings. Azuma et al. 2015 found that the general and skin symptoms were significantly higher in females than in males. That significant impact of gender was also found by (Runeson et al. 2006) in eye, nose, throat, skin, headache and tiredness. (Reijula & Sundman-Digert 2004) found significant associations between gender and skin, eye related symptoms, and fatigue. However, results of (Kanazawa et al. 2010) & Norback & Edling 1991) did not find significant association between gender with any health symptoms. This study also revealed significant negative association between participant's age and perceived IAQ comfort and that the younger were more comfortable with their IAQ (Table 4-43). Worth noting that no significant association was found between occupants age with any of the health symptoms factors in this study. Results regarding the association between age and SBS symptoms were variable. Similar to this study finding; no significant association between age and any health symptoms was found by (Sahlberg 2012; Sahlberg & Norbäck 2009; Norback & Edling 1991). However, Azuma et al. (2015) and Ooi et al. (1998) found that reported general symptoms and upper respiratory symptoms significantly increased with age while Sahlberg et al. 2009 found significant increase of general symptoms with age. According to previous studies, age was differently associated with perceived IAQ comfort. For instance, Sakellaris et al. (2016) who assessed the perceived IEQ and comfort reported by 7441 employees in 167 European office buildings (The OFFICAIR Study). According to their study; middle aged participants of 36 to 55 years old were slightly less satisfied of their IAQ compared with the youngest and oldest. Whereas results by Zalejska-Jonsson & Wilhelmsson (2013) revealed that age was positively associated with overall IEQ including IAQ perceptions and that younger participants were more likely to be dissatisfied with their IEQ conditions. Reference to Zalejska-Jonsson & Wilhelmsson (2013), many factors affect the overall satisfaction of occupants with their IEQ such as their expectations, requirements, careers, and previous housing experiences. In most studies, age was employed as proxy for all these factors (Zalejska-Jonsson & Wilhelmsson 2013). The difference in these characteristics may be the reason of having different associations between perceived IEQ satisfaction by occupants as per their ages.

As per above discussions, many population-related factors dominate the reaction towards poor IEQ conditions such as health conditions, sensitivity, age, and gender. Two of the population-related findings of this study was the significant positive association between “Other Arabs and MENA” with the General, Ergonomic, Nervous, and Skin symptoms and the significant positive association between “Other Africans” and perceived IAQ discomfort (Table 4-43). Reference to EPA (2015), a person reaction to a contaminant depends on his personal characteristics that tremendously vary from an individual to another. In some cases, different individuals might experience different symptoms when exposed to similar indoor air contaminant. Furthermore, after frequent or high level exposures, some individuals can become sensitive to chemical and/or biological contaminants (EPA 2015). To the best of my knowledge, this study is one of the first studies in the MENA region and the first in Dubai housing investigating the associations between IEQ and related health symptoms among different nationalities. Due to that, no previous studies were found to validate the above two results.

Regarding the significant association between the attached kitchen with interior walls and Eye, Nose, Throat, and Chest symptoms (Table 4-43), it is important to note that no significant association was found between the attached kitchen without interior walls with any health or IEQ factor. That may be attributed to the occupancy levels of households having attached kitchen without interior walls (Open kitchens). About 26% of this study population lived in houses with open kitchens of which 11% was occupied by only one person, 9% was occupied by 2 persons, and 3% was occupied by 3 persons whereas the remaining 3% was occupied by 4 or more. Based on the low occupancy levels in households with open kitchen; the intensity and duration of cooking is expected to be lower than in households having attached kitchen with interior walls. The significant association between the attached kitchen and Eye, Nose, Throat, and Chest symptoms is consistent with the findings of many previous studies. Reference to (EPA 1991a; WHO 2008; POST 2010; OSHA 2011a; EPA 2016a), gas stoves that are poorly ventilated and maintained may increase the indoor concentrations of combustion gases such as CO, $NO_2$, $SO_2$ in addition to alleviating respirable particles. According to (WHO 2007), the use of LPG gas or natural gas for cooking purposes is associated with lower risk than using coal or kerosene. However, according to recent research (Nicole 2014; Logue et al. 2014) in California houses, natural gas cooking burners (NGCBs) were estimated to increase the weekly-averaged indoor $NO_2$ levels about 35–39% in winter and 25–33% in summer. It was also estimated that NGCBs add about 21% and 30% to the indoor CO concentration in winter and summer, respectively. Guo et al. (2013) found that concentrations of isobutyl ketone, xylene, 1,1,1-trichloroethane, butanol, methyl and styrene in the kitchens or bedrooms of occupants having one or more SBS symptoms during measurement period were significantly higher compared with those without symptoms. They also found that concentrations of HCHO, butanol or 1, 2-dichloroethane in the kitchens or bedrooms of occupants having one or more SBS symptoms in the past were significantly higher compared with those without symptoms. However, the findings of Yeatts et al. (2012a) in their study covering 628 UAE households did not find significant associations of increased respiratory symptoms with attached kitchens. The difference in the result between this study and that of Yeatts et al. (2012a) can be attributed to the difference in the population of each. As discussed in Section 2.6, the whole population of Yeatts et al. (2012a) were UAE nationals of whom about 83% lived in households with unattached kitchen whereas only 17% had attached kitchens. Comparatively, the population of this study involved many nationalities of which about 59% lived in houses with attached kitchen with interior walls (Closed kitchen) while about 15% of them lived in houses with unattached kitchens (Mulhaq). Although that difference, results by Funk et al. (2014) for that population of 628 UAE households suggested the attached kitchens as potential source of indoor CO due to the significant positive association between the two.

In terms of the significant association between participants living in Dubai Sector 1 with the General, Ergonomic, Nervous and Skin (Table 4-43); it is important to note that this sector is the densest one compared with other Dubai sectors. Reference to (City Population 2016), population density in Dubai Sector 1 is approximately 10644/Km$^2$ which is highly above and incomparable with that 4303/Km$^2$, 2844/Km$^2$, 714/Km$^2$, 637/Km$^{2,}$ 480/Km$^2$, 40/Km$^2$, 37/Km$^2$, and 3/Km$^2$ in Dubai Sector 3, Sector 2, Sector 4, Sector 5, Sector 6, Sector 7, Sector 8, and Sector 9; respectively. The result is consistent with that found by (Runeson et al. 2006) who revealed that participants living in larger cities had more fatigue symptoms than others. Runeson et al. (2006) also found significant difference between skin symptoms that were more common in the northern part of Sweden whereas they were least common in the southern part of Sweden. They explained that geographical variation of dermal symptoms might be attributed to different reasons one of which is the lower humidity in that colder region.

Concerning the association between applied HVAC system and the IEQ discomfort and health symptoms in Dubai housing; only the split HVAC was significantly associated with perceived odors (Table 4-43). No other significant association was found between

HVAC systems with any health symptoms or perceived IEQ discomfort in the adjusted MLR models (Section 4.1.6.23 and 4.1.6.24). However, central HVAC had significant negative association with the General, Ergonomic, Nervous, and Skin symptoms in the unadjusted model using building variables as predictors (Section 4.1.6.7). According to many previous studies, one of the major roles of ventilation is the dilution of indoor contaminants and unpleasant odors (OSHA 1991; Sundell 2004; Awbi 2008; Sundell et al. 2011; Persily 2015). The significant association between perceived odors and split HVAC can be attributed to having insufficient amount of fresh air – provided by natural infiltration only when using such systems – to dilute produced odors indoors. That is because, unlike the central HVAC and the window HVAC in which indoor air can be exchanged by outdoor one, the split HVAC technology has not that capability (Stein et al. 2000). The negative impact of the split HVAC on IAQ was also suggested by Funk et al. (2014) in their cross sectional survey study covering 628 UAE households that found significant positive association between CO concentrations and households with split HVACs. On the other hand, their findings revealed significant positive impact of central HVAC systems on IAQ due to significantly lower indoor $PM_{2.5}$ and $PM_{10}$ concentrations in households using central HVAC. The result regarding the insignificant association between the applied HVAC systems and health symptoms is in agreement with some studies while not with others. Reference to OSHA (1999), results of 500 IAQ investigations revealed that about half of IAQ problems were attributed to inadequate ventilation in modern airtight buildings. According to Hess Kosa (2011), insufficient ventilation rates in USA were usually correlated with post energy crisis in 1970s and to the modern airtight buildings that depend on mechanical ventilation. Besides, as declared by Awbi (2008), these mechanical systems may turn to be a source of indoor contamination when they are badly-maintained or installed. According to Sundell et al. (2011) in their review covering 27 peer-reviewed articles published since 2005 concerning the associations between ventilation rates and occupants' health problems found that the associations of health problems with ventilation rates were biologically plausible. However, they declared no clear evidence was afforded by literature proving the causality relationship between the two parameters. Many studies did not find significant relationship between mechanical ventilation systems with health symptoms. For instance, Sahlberg & Norbäck (2009) did not find any significant association between any of the SBS symptoms with the type of ventilation system. Also, Kanazawa et al. (2010) did not find significant relationship between mechanical ventilation systems with the general, skin and mucosal symptoms including eye, nose, throat, and respiratory symptoms in all rooms. Ruotsalainen et al. (1994) did not find consistent associations between the ventilation rates provided by mechanical AC systems with neither health symptoms nor perceived unpleasant odors in 30 Finnish day care centers. They stated that the provision of ventilation in those centers was not totally depending on mechanical systems due to the operable windows. They debated that might be the cause of having insignificant association with those systems although the insufficient ventilation rates provided by them as per standards.

This study also found significant association between smoke from incense burning and the General, Ergonomic, Nervous, and Skin symptoms (Table 4-44). This result is in agreement with findings by Yeatts et al. (2012a) in their UAE study that revealed significant association between incense burning in daily basis with increased headaches, concentration difficulties, and forgetfulness. According to their results, participants living in households in which they were daily exposed to smoke from burned incense were two times more likely to report headaches, three times more likely to report difficulty in concentrating, and three times more likely to report forgetfulness compared with those living in households that burned incense once weekly or not at all. Similar to this study results, Yeatts et al. (2012a) did not find significant associations between incense burning and respiratory symptoms. Reference to (Cohen et al. 2013), time-weighted average of CO, $NO_x$, and PM emissions from burning two types of UAE incense exceeded applied government regulation levels and emissions previously seen from ETS. The main contributor to both $NO_x$ and CO concentrations was charcoal emissions. Their study suggested that incense burning contributed to indoor air pollution and could cause harmful health impacts on exposed occupants.

Results regarding the significant association between “Too dim” with Eye, Nose, Throat, and Chest related symptoms in addition to the general, ergonomic, nervous & skin symptoms (Table 4-44) are consistent with previous studies. Azuma et al. (2015) found that poor lighting was significantly associated with eye related symptoms and upper respiratory symptoms including sore or dry throat, sinus congestion, cough, and sneezing in the model relating between frequent SBS and the work environment. When adjusting the model for other variables; only the association between eye related symptoms was persistent. Reijula & Sundman-Digert (2004) found significant association between poor lighting and eye, nose, and hand symptoms. Furthermore, the significant associations found by this study between “Stuffy "bad" air” and “Dust and dirt” with Eye, Nose, Throat, and Chest related symptoms is consistent with findings of previous relevant studies. For instance, (Kanazawa et al. 2010) found significant associations between stuffy air and mucosal symptoms including eye, nose, throat, and respiratory symptoms. (Reijula & Sundman-Digert 2004) found significant association between stuffy bad air with eye and nose symptoms. Concerning the association with dust and dirt; results by Azuma et al. (2015) revealed significant association between dust and dirt with eye irritation and upper respiratory symptoms that includes sore or dry throat, sinus congestion, cough, and sneezing. Also, Kanazawa et al. (2010) found an association between phosphates in indoor dust with mucousal symptoms that includes eye, nose, throat and respiratory symptoms. Moreover, Reijula & Sundman-Digert (2004) found significant association between dust and dirt with eye, nose, and hands symptoms.

Many significant associations were found related to moisture levels in terms of too much humidity, mouldy dampness odors, and water leakage. Significant association was also found between water leakage and three factors which were the (1) general, ergonomic, nervous & skin symptoms; thermal, (2) Thermal, Lighting, and Noise discomfort; (3) and odors (Table 4-43). Complaints regarding too much humidity were significantly associated with the general, ergonomic, nervous & skin symptoms while those regarding the mouldy dampness odors were significantly associated with the Eye, Nose, Throat, and Chest related symptoms (Table 4-44). Concerning the associations with humidity; (Wang et al. 2013) found significant associations between humid air and the general and mucousal symptoms. Reinikainen & Jaakkola (2003) found significant associations between higher humidity and increased skin symptoms and perception of odor and stuffiness. Reference to (Hellgren 2012), in case of excess humidity, mold growth may be caused by water condensation on cold surfaces. The growth of dust mites is also encouraged in such environments. Regarding the associations with water leakage and dampness odors; according to WHO (2009), indoor dampness and mold were found as predictors of SBS symptoms by many studies. According to (EPA 2013), the associations between damp indoor environments and adverse health effects including upper respiratory symptoms, cough, and asthma symptoms in sensitive individuals were shown by many epidemlogical studies. Wang et al. (2013) also found significant associations between dampness characterized in water damage, mold spots, or condensation on window with many types of odor perceptions. (Kanazawa et al. 2010) found significant associations between moldy odor with general and skin symptoms and mucosal symptoms including eye, nose, throat, and respiratory symptoms. Wang et al. (2013) found significant associations between mold odors and mucousal symptoms. Zhang et al. (2012) found that incidence of SBS symptoms got better outside the workplace and worsen in workplace with moldy odor or any kind of dampness such as water leakage or visible molds. They also revealed that indoor molds and dampness in the work environment were significantly associated with an increased incidence of SBS symptoms and a decreased remission of SBS symptoms. Reference to (Sahlberg 2012), significant association was found between dampness in buildings with mucosal, general, and skin symptoms and that occupants of damp building had a decreased remission of skin and general symptoms. Reference to Zhang et al. (2012), an increased incidence of mucosal symptoms was significantly associated signs of floor dampness. Previous studies also suggested that damp buildings can encourage the growth of mold, bacteria, fungi, yeasts, and wood-rooting (Nevalainen et al. 1991).

Results also revealed that paint odors had significant associations with Eye, Nose, Throat, and Chest related symptoms. Reference to (EPA 2016a; OSHA 2011a; POST 2010; WHO 2000; Health Canada 1989); new paints is considered as one of the common indoor sources of formaldehyde and VOC emissions. According to (EPA 2016a; OSHA 2011a), the health effects of such emissions may involve respiratory irritations, headaches and nausea, loss of coordination, damaging impacts on nervous system, liver, and kidney; some may cause cancer in humans. This result is consistent with many previous studies. Wieslander et al. (1997) found increased asthma prevalence and inflammatory reactions in the airways among occupants with domestic exposure to newly painted surfaces specially the newly painted wood objects and kitchen painting. Indoor TVOC was higher in households painted in the last year. A significant increase in Formaldehyde levels was observed in households with newly painted wooden objects. Norback & Edling (1991) found significant association between domestic exposure to newly painted surfaces in and airway symptoms. Sahlberg & Norbäck (2009) found significant association between indoor painting with mucosal, general, and skin symptoms. Results by Sahlberg et al. (2009) revealed that remission from general symptoms was less in indoor painted dwellings. Sahlberg (2012) suggested that occupants of indoor painted houses had significantly higher prevalence of SBS symptoms.

Results also revealed significant associations between having new carpet with both odors and the Thermal, Lighting, and Noise factors. No significant association was found between having new carpet with any health symptom. Similar to new paint, carpeting was considered as one of the common indoor sources of formaldehyde and VOC emissions that might result in harmful health effects (EPA 2016a; OSHA 2011a; POST 2010; WHO 2000; Health Canada 1989). According to Becher et al. (2018), emitted VOCs from carpets may have odors that may cause irritations particularly in vulnerables. Levels of VOCs emissions from both new carpets and utilized glues are higher from new carpets and they become less over time. Carpets may also act as a sink for indoor air contaminants i.e. particles, allergens and/or other biological contaminants. Many factors can affect pollution levels and subsequent health impact caused by carpets such as design, cleaning protocols, maintenance, and age as well as provided ventilation (Becher et al. 2018). Wall-to-wall carpet was significantly associated by many studies with adverse health symptoms such as respiratory infections and asthma worsening (Jaakkola et al. 2006; Ekici et al. 2008; Tsai 2013; Ferry et al. 2014). However, other studies found that carpets were significantly associated with less asthma prevalence (Zock et al. 2002; Mommers et al. 2005; Behrens et al. 2005; Skorge et al. 2005). Sahlberg & Norbäck (2009) did not find any significant association between wall to wall carpet with any of the SBS symptoms. According to Becher et al. (2018), recent knowledge is insufficient yet to quantify probable health effects of carpet flooring. Though no significant association was found between new carpets and health symptoms by this study; results revealed significant positive association with both perceived odors and the Thermal, Lighting, and Noise discomfort. Reference to (Ceballos & Burr 2012; Hodgson & Levin 2003), some odors in buildings resulted from VOCs even at low concentrations – emitted from carpets or from any other source – may be annoying to some individuals. However, some of VOCs might not be concerning in terms of having toxic health effects.

Furthermore, the thermal and lighting properties of carpets might probably be the cause of the significant positive association between carpets and the Thermal, Lighting, and Noise discomfort. According to (Mcneil 2016; Carpet Institute of Australia Limited 2002), carpets has higher thermal insulation and lower conductivity compared with other types of floors such as concrete, ceramic, PVC, Linoleu, or cork tiles. Radiant heat loss from a room occupant's body to the floor is lower in case of carpet floors compared with others. This thermal property may probably be suitable in cold climate where occupants need heating to attain thermal comfort (Goswami 2018). However, due to UAE hot climate, high levels of cooling need is sought to be satisfied by residents almost throughout the year to attain thermal comfort indoors (Energy Dubai 2018). Within such indoor environment, this thermal property of carpets may probably invoke thermal discomfort in occupants. Also, recalling participants' complaint regarding "Too much dim" indoors, lighting reflectance values (LRV) for flooring surfaces is set within a range of 20% – 50% by recognized institutions (Brembilla et al. 2018). LRV is a measure of the total amount of visible light reflected by a surface from 0% to 100% in which 0% is assumed to an absolutely absorbing black surface while 100 for an absolutely reflecting white surface. According to (Carpet Institute of Australia Limited 2008), carpets are available with satisfactory LRV range from 0.1 – 0.5. However, one of the limitations of carpets of LRV above 0.08 is the high level of required cleaning to retain carpets in acceptable shape. According to (Lavy & Dixit 2012, 2010), one of the criteria of selecting appropriate interior finishing is required cleaning procedure. Following that criterion, carpets of low LRV might be more preferred by customers. Having that limitation, there is a probability of carpets contribution in having "Too much dimness" and subsequently in lighting discomfort if their LRV falls below acceptable levels.

Similar to carpeting, wall covering is considered as one of the indoor sources of formaldehyde and VOC emissions and their subsequent health effects (EPA 2016a; OSHA 2011a; POST 2010; WHO 2000; Health Canada 1989). However, this study results revealed that new wall covering had no significant association with any health symptom. Contrarily, new wall covering was significantly negatively associated with perceived IAQ discomfort indicating that participants living in households with new wall covering were more satisfied regarding their residential IAQ than others. This association can better be understood in relation with other findings by this study concerning participants' complaints of having "Too much humidity", "Mouldy dampness odors", and "water leakage" which had significant associations with health and IEQ discomfort factors. Reference to (Norback et al. 1999; Lavy & Dixit 2012, 2010; Wang et al. 2013); the degradation of wall and floor materials due to dampness in buildings may increase VOCs emission. According to Morse (2017), elevated moisture levels for prolonged periods in building envelope can cause adverse impacts on IAQ and occupants' health in addition to deteriorating building construction.  For instance, prolonged high moisture levels inside a wall assembly can result in the growth of insects as well as microorganisms such as mold and bacteria. The metabolism of bacteria and mold may result in microbiological volatile organic compounds (MVOCs) that negatively affect building IAQ. Musty and moldy smells in damp buildings are a typical result of MVOCs. Such microorganisms can cause adverse health effects and can also generate toxins that can cause health problems. Reference to (Morse 2017; Lavy & Dixit 2012 & 2010; Mortensen et al. 2005), properly designed wall covering may have positive impact in controlling moisture levels and reducing RH indoors as well as attaining better IAQ conditions. Results by Na et al. (2014) suggested that the use of wall paper and flooring made of environmentally friendly materials in housing had minimized formaldehyde levels and improved the severity and pruritus of atopic eczema.

## 4.2 Field study results

As described in Section 0, the aim of this field study was to investigate regarding some IEQ variables identified by previous studies as strongly associated with prevalent SHS and assess their compliance with national and/or international standards. Thus, field measurements for indoor HCHO, $PM_{2.5}$, and $PM_{10}$, CO, $CO_2$, TVOC, RH, and T levels were performed in 60 households. Measured parameters were the focus of many contemporaneous studies. $PM_{2.5}$ and $PM_{10}$ were continuously measured for 24 hours in each household using the Optical Particle Sizer (OPS) Model 3330 produced by TSI Inc. Also, continuous measurement of CO, $CO_2$, TVOC, RH, and T levels was conducted for 24 hours in each household using the AdvancedSense Pro and DirectSense IQ – 610 produced by GrayWolf Sensing Solutions LLC. Moreover, a spot measurement for a single sample drawn during 30 minutes was conducted to measure the HCHO concentrations in each household. HCHO was measured using the gas detector Model FP 30 produced by RKI Inc. Outdoor $CO_2$, CO, TVOC, RH, and T levels were monitored by performing a spot sample using the AdvancedSense Pro and DirectSense IQ – 610. Outdoor $CO_2$ measurements were employed along with the indoor ones to estimate the provided AERs. The above measurements were performed during 9 months starting from Thursday 14th September 2017 up to Monday 11th June 2018. Notably that the three utilized monitoring devices were manufacturer calibrated prior launching the field measurements. Also, noteworthy those continuous measurements intended to last for 24 hours was interrupted in 15 houses resulting in continuously measuring for a period range of 18 hours to 22 hours. It is difficult to predict reasons behind that as the natural field in which measurements were conducted – living halls – involved uncontrolled subjects and activities i.e. children play, household cleaning, visitors … etc. In spite of that, since the least continuously measured period was 18 hours, collected data was considered as sufficient to provide an estimation of prevalent levels of measured parameters.

Concerning detailed results of the field measurements for each house, Appendix ZZ shows descriptive statistics of indoor TVOC, $CO_2$, CO, $PM_{2.5}$, $PM_{10}$, HCHO, T, RH, and estimated AERs in each of the 60 houses. A sample of the field measurements results and analysis of one house is shown in Section 4.2.1. While a summary of field measurements results, analysis, in addition to the discussion for all the 60 houses is shown in Section 4.2.2. To assess the compliance of measured parameters with national and/or international standards, required limits by recognized national and international institutions were drawn above figures illustrating measured indoor levels. The compliance of measured parameters were compared against the following: (i) compliance of T and RH were assessed against requirements set by DM (2016); (ii) compliance of $CO_2$ was assessed against requirements set by DM (2016) and OSHA (1999); (iii) compliance of CO was assessed against requirements set by DM (2016) and WHO (2010a); (iv) compliance of $PM_{10}$ was assessed against requirements set by DM (2016) and WHO (2006); (v) compliance of $PM_{2.5}$ was assessed against requirements set by ASHRAE (2016) and WHO (2006); (vi) compliance of TVOC was assessed against requirements set by DM (2016) and Mølhave (1990); while the (vii) compliance of AERs was assessed against requirements set by ASHRAE (2016). Noteworthy that SHRAE Standard 62 (ASHRAE 2016) is adopted as a reference to comply with its minimum requirements by DM (2016) in terms of the provision of adequate AERs. Also, compliance of HCHO was compared with the exposure limit of 0.08 ppm average concentration for 30 minutes established by WHO (2010a). That is similar to exposure limit of 0.08 ppm as TWA that mandated by DM (2016) but for 8 hours.

### 4.2.1 Sample of measurement results and analysis of a household

Measurements were performed in this house located in Dubai Land area on Wednesday 18th October 2017 starting from 19:20:00. Following the methods explained in Section 3.5.1.3, average HCHO concentrations for 30 minutes were 0.02 ppm. As illustrated in Table 2-7, HCHO average concentrations of 0.08 ppm for 30 minutes is recommended by WHO (2010a) while DM (2016) required compliance with similar levels for 8 hours. Hence, measured HCHO levels in this house may indicate lower levels than those established by WHO (2010a) and DM (2016) if it was constant for set durations. Table 4-45 illustrates minimum, mean, and maximum readings for TVOC, $CO_2$, CO, $PM_{2.5}$, $PM_{10}$, T, and RH while Table 4-46 shows the spot measurements performed outdoors. Figure 4-33 illustrates continuously measured indoor levels of T and RH. Range of indoor

T during measuremnet period was 25 – 29°C which was not complying with the comfortable range (23.5 – 25.5 °C) required by DM (2016). However, the range of indoor RH was 32 – 45% which was acceptable as per required range of 30 – 60% mandated by DM (2016). Hence, as per DM (2016), measured RH in this house would be acceptable if they were persistent for the specified period whereas measured T would be unacceptable if they were persistent for more than 5% of the year

Table 4-45: Levels of continuously measured variables indoors

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m$^3$)** | **$PM_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 432.4 | 664 | 0.9 | 85.9 | 88.5 | 25 | 32 |
| **Mean** | 715.3 | 1082 | 1.804 | 328.6 | 356.4 | 27 | 39 |
| **Max** | 8305.3 | 2116 | 3.6 | 628.8 | 927.0 | 29 | 45 |

Table 4-46: Spot measured variables in outdoor air

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 216 | 590 | 1.0 | 28.5 | 66.2 |

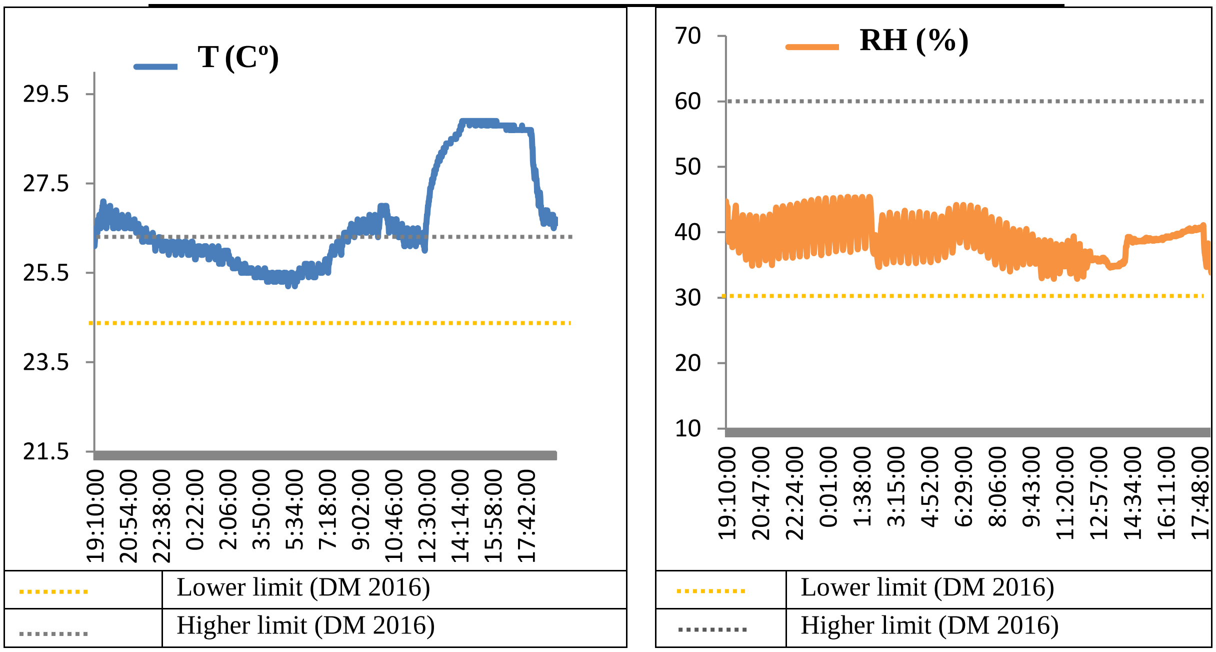


Figure 4-33: Continuously measured indoor levels of T and RH

As shown in Table 4-46, mean $CO_2$ levels in outdoor air were approximately 590 ppm which was higher than the acceptable range of 300 – 500ppm established by ASHRAE (2016). That may be an indication of ambient air pollution. Figure 4-34 shows the continuously measured $CO_2$ and CO indoor levels compared with acceptable concentrations established by recognized institutions. TWA of indoor $CO_2$ concentrations during the whole measurement period was approximately 1082ppm while TWA of CO levels were approximately 1.8ppm. Thus, indoor CO levels during measurement period were within acceptable levels set by (DM 2016; WHO 2010a). Also, TWA of $CO_2$ levels during the measurement period were almost within the acceptable levels set by OSHA (1999) but they were still not complying with required levels mandated by DM (2016).

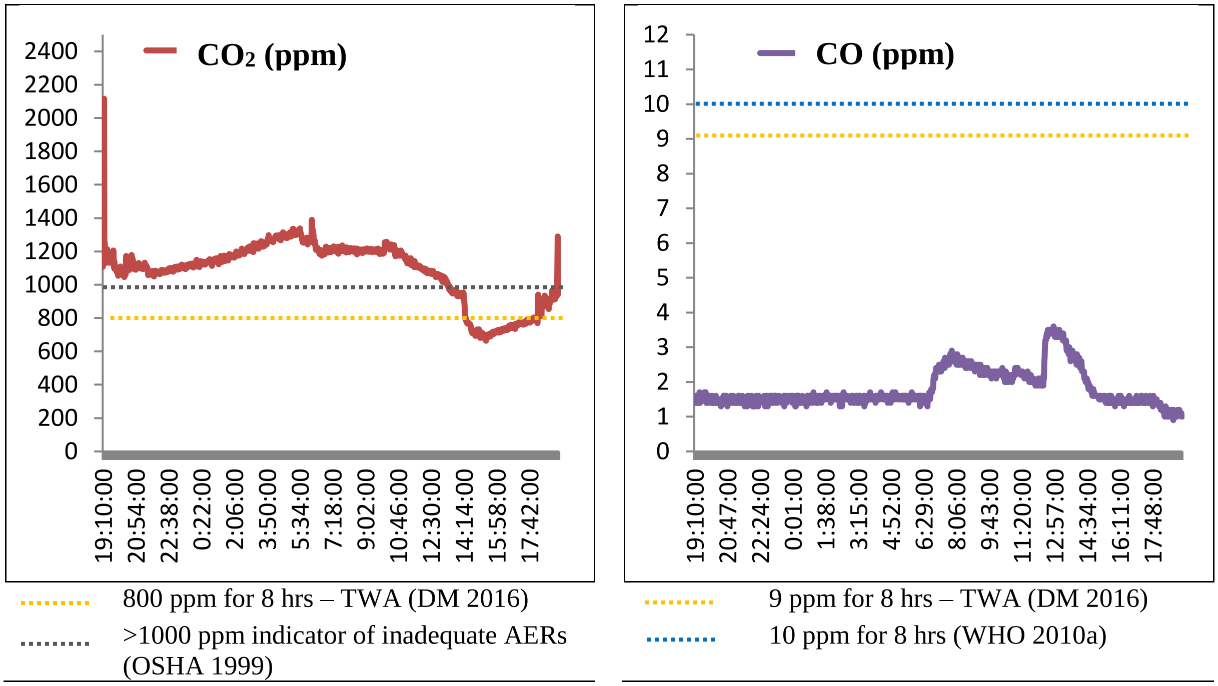


Figure 4-34: Compliance of $CO_2$ and CO levels with established standards

Figure 4-35 shows the occupancy profiles projected on $CO_2$ during measurement period while Table 4-47 describes the occupancy profiles. As explained in Section 0, provided AERs was calculated in the living room where the devices were installed. Peak $CO_2$ levels that occurred during profile P1 was approximately 2116ppm while the TWA average of $CO_2$ over that period was approximately 1082ppm. Calculated AERs based on the TWA of $CO_2$ concentrations during P1 was approximately 8.1L/s. person. According to ASHRAE (2016), provided AERs was sufficient as related studies have found that a sedentary person needs about 7.5L/s of outdoor air to dilute odors resulting from human bioeffluents to satisfactory levels for a substantial majority (80%) of unadapted occupants to a space.

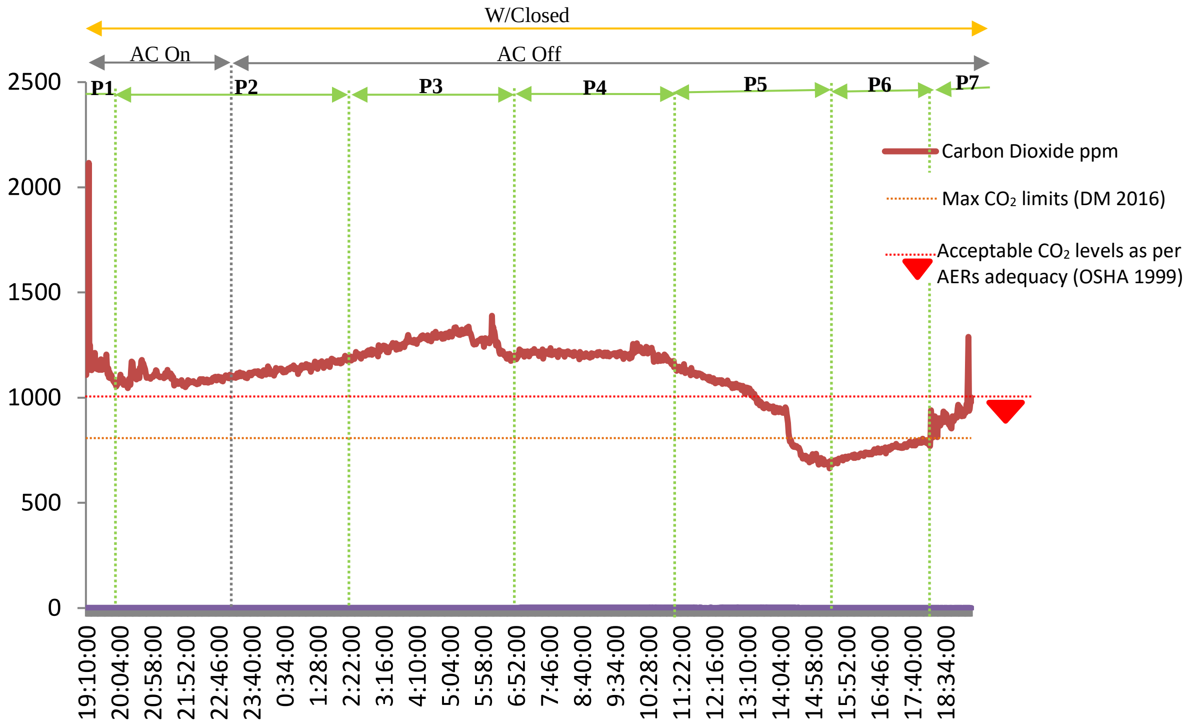
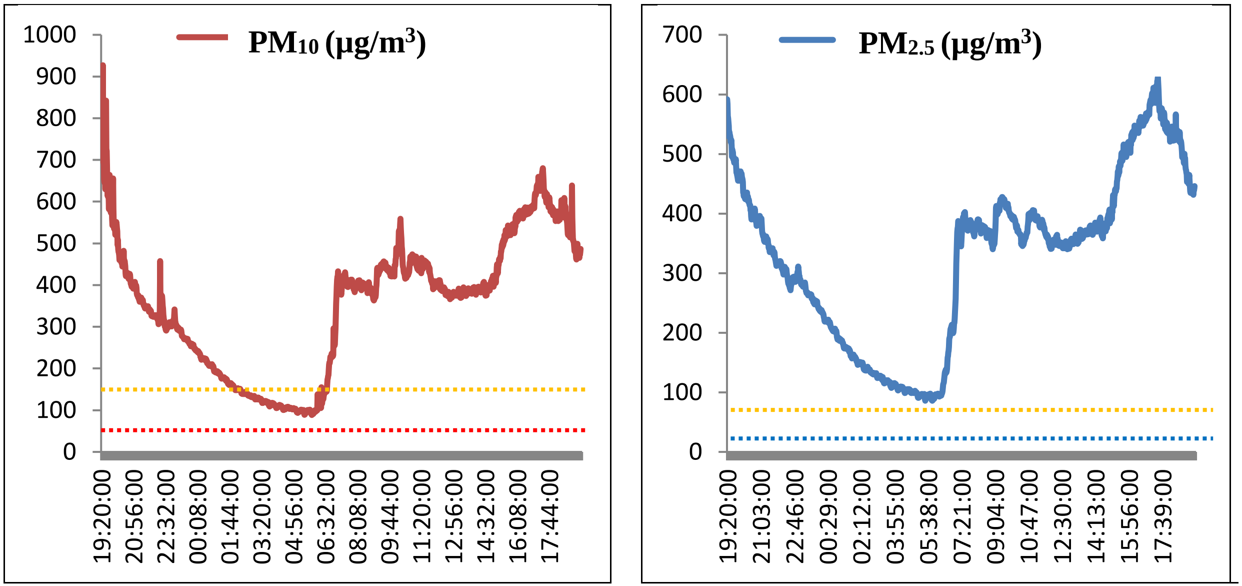


Figure 4-35: Occupancy profiles of the living hall projected on $CO_2$ levels

Table 4-47: Occupancy profiles of the living hall during measurement period

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 19:10 – 19:45 | 7 | Mechanical | Having visitor<br>Sitting |
| **P2** | 19:45 – 02:15 | 4 | Mixed:<br>19:45 – 10:55 Mechanical<br>10:55 – 02:15 Natural (Infiltration) | Sitting |
| **P3** | 02:15 – 06:45 | 0 | Natural (Infiltration) | 5 persons in other room |
| **P4** | 06:45 – 10:50 | 2 | Natural (Infiltration) | Sitting, daily cleaning |
| **P5** | 10:50 – 15:30 | 1 | Natural (Infiltration) | Sitting |
| **P6** | 15:30 – 18:10 | 2 | Natural (Infiltration) | Sitting |
| **P7** | 18:10 – 17:17 | 3 | Natural (Infiltration) | Sitting |

Figure 4-36 shows the continuously measured indoor levels of $PM_{10}$ and $PM_{2.5}$ compared with acceptable concentrations established by recognized institutions. TWA of $PM_{10}$ levels during the measurement period was approximately 356µg /m$^3$ while TWA of $PM_{2.5}$ was approximately 329µg /m$^3$. Hence, $PM_{10}$ concentrations during the measurement period were unacceptable as per DM (2016). Also, the TWA of $PM_{2.5}$ concentrations were exceeding the exposure limit of 35µg /m$^3$ for 24 hours set by ASHRAE (2016). Reference to WHO (2006), exposure limits for 24 hours to $PM_{10}$ and $PM_{2.5}$ is only 50 and 25µg /m$^3$ while their annual average should not exceed 20 and 10µg /m$^3$; respectively. However, measured $PM_{10}$ and $PM_{2.5}$ concentrations were highly above those levels during measurement period. This is a concerning result particularly if measured concentrations are commonly prevelent in this house for longer period than specified by WHO (2006).



| | | | |
|---|---|---|---|
| ········ | 150µg /m$^3$ for 8 hours – TWA (DM 2016) | ········ | 65µg /m$^3$ for 24 hours – 3 years average annual mean (ASHRAE 2016) |
| ········ | 50µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) | ········ | 25µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure 4-36: Compliance of $PM_{10}$ and $PM_{2.5}$ levels with established standards

Figure 4-37 illustrates continuously measured indoor levels of TVOC. TWA of indoor TVOC during measuremnet period was 715µg/m$^3$ which were not complying with the exposure limit of 300µg/m$^3$ for 8 hours mandated by DM (2016) neither with the TVOC guideline limit of comfort range recommended by Mølhave (1990). Notably that outdoor

TVOC measurement was 216 µg/m$^3$ which was below the required 300µg/m$^3$ and also lower than indoor levels indicating the probability of having indoor pollution source or/and insufficient ventilation. However, the assumption of insufficient AERs can be deducted since indoor $CO_2$ levels were within acceptable range as per (ASHRAE 2016; OSHA 2011a). Notably that measured TVOC levels was relatively constant at an average of 500 µg/m$^3$ during night up to 6:45 am. However, after that when occupants had woken up, those levels were higher and that might be attributed to the performed daily activities in the living room during that period. For instance, daily cleaning was reported as taking place during the period (6:45 – 10:50 am) which might have an impact on increasing TVOC levels indoors. Also, a sudden increase in TVOC levels occurred at about 12:30 pm and it took about 3 hours to return to the levels prior that increase. Unfortunately, provided data regarding performed activities during that particular period was insufficient to explore probable reasons justifying that increase. However, based on the acceptable outdoor TVOC levels (Table 4-46), indoor sources in addition to the insufficient AERs throughout most of the measurement (Figure 4-35) was probably major contributors in the unacceptable indoor TVOC in this house.

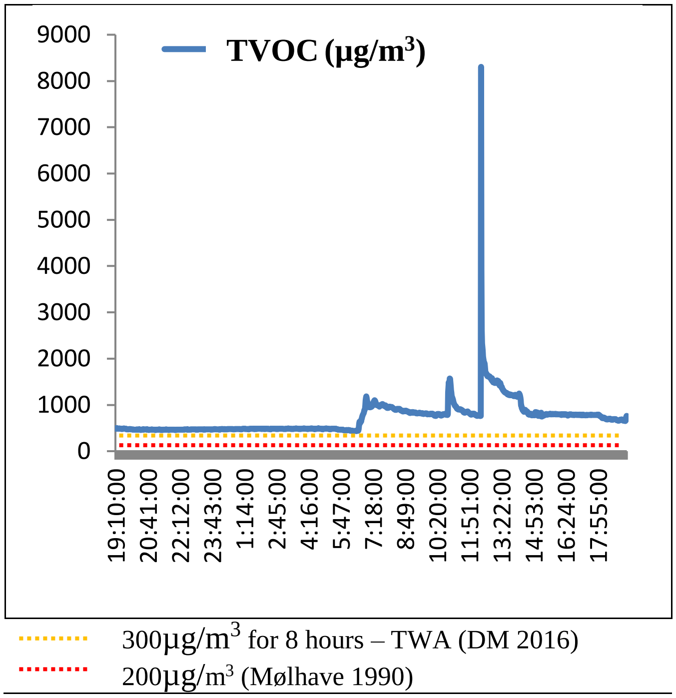


Figure 4-37: Compliance of indoor TVOC levels with established standards

### 4.2.2 Summary of the field study results and discussions

Results of the self-administered questionnaire of the field study revealed that prevalent SHS in the sample was about 39% based on SHS symptoms definition as those frequently experienced health disorders that disappear or not develop outdoors could be considered as SHS symptoms (Azuma et al. 2015; Turpin 2014; Hess-Kosa 2011; Gomzi & Bobic 2009; OSHA 1999). The most prevalent SHS symptoms among participants was the ergonomic symptoms (7%) followed by nose symptoms (6%), neurological or nervous symptoms (5%), cough (4%), fatigue (4%), skin symptoms (4%), headache and nausea (2%), chest symptoms (2%), eye symptoms (2%), throat symptoms (2%), while fever (1%). Noteworthy that prevalent SHS in this sample might be higher than the estimated 39% considering the 8% of participants who reported symptoms compatible to SHS but the way in which those symptoms was variable or inconstant. Compared with revealed results by the questionnaire of the initial study; prevalent SHS symptoms measured in the initial questionnaire was 30% which was less than in the field study sample. However, both studies revealed that prevalent SHS in Dubai housing was higher than the prevalent SBS measured by Azuma et al. (2015) that accounted for 25% of its respondents in their nationwide sample.

Concerning results of the field measurements, Table 4-48 shows the descriptive statistics of indoor TVOC, $CO_2$, CO, $PM_{2.5}$, $PM_{10}$, HCHO, T, RH, and estimated AERs in the 60 houses. Figure 4-38 to Figure 4-43 illustrates TWA for measured indoor concentrations of TVOC, $CO_2$, CO, $PM_{2.5}$, $PM_{10}$, and HCHO in the 60 houses. Figure 4-44 and Figure 4-45 show measured minimum and maximum levels of indoor T and RH. Moreover, estimated AERs for the 60 houses were shown in Figure 4-46. Limits required by DM (2016) were drawn above figures illustrating measured indoor TVOC, $CO_2$, CO, $PM_{10}$, T, and RH levels. Whereas the acceptability of $PM_{2.5}$ and calculated AERs were assessed based on ASHRAE Standard 62 (ASHRAE 2016) that adopted as a reference to comply with its minimum requirements by DM (2016) in terms of the provision of adequate AERs. Compliance of HCHO was compared with the exposure limit of 0.08ppm average concentration for 30 minutes established by WHO (2010a). Notably that DM

(2016) requires compliance with similar exposure limit of 0.08ppm as TWA but for 8 hours. Furthermore, Table 4-49 and Figure 4-47 illustrates a summary of measured indoor concentrations and estimated AERs in the 60 houses in terms of their compliance to mandated or recommended standards.

Table 4-48: Descriptive statistics of indoor concentrations and estimated AERs

| | | | | | Percentile | | |
|---|---|---|---|---|---|---|---|
| | Min | Max | Mean | Median | 75 | 90 | 95 |
| HCHO (ppm) | <0.01 | 0.070 | 0.026 | 0.023 | 0.035 | 0.045 | .055 |
| TVOC (µg/m$^3$) | 123.3 | 4005.5 | 575.4 | 436.8 | 713.1 | 1075.0 | 1891.8 |
| $CO_2$ (ppm) | 505.5 | 7921.8 | 964.2 | 755.6 | 952.7 | 1388.4 | 1835.3 |
| CO (ppm) | 0.0 | 6.7 | 1.5 | 1.04 | 1.9 | 3.1 | 4.4 |
| $PM_{2.5}$ (µg/m$^3$) | 71.9 | 2148.5 | 482.0 | 296.2 | 677.0 | 1065.7 | 1614.8 |
| $PM_{10}$ (µg/m$^3$) | 95.9 | 2600.8 | 558.7 | 371.6 | 761.9 | 1335.1 | 1661.2 |
| T (ºC) | 22.4 | 33.4 | 27.0 | 26.9 | 28.1 | 30.5 | 31.4 |
| RH (%) | 25.8 | 60.3 | 44.6 | 44.7 | 51.4 | 56.0 | 58.5 |
| AERs (L/s. person) | 1.5 | 54.6 | 13.2 | 9.4 | 17.0 | 27.6 | 37.2 |

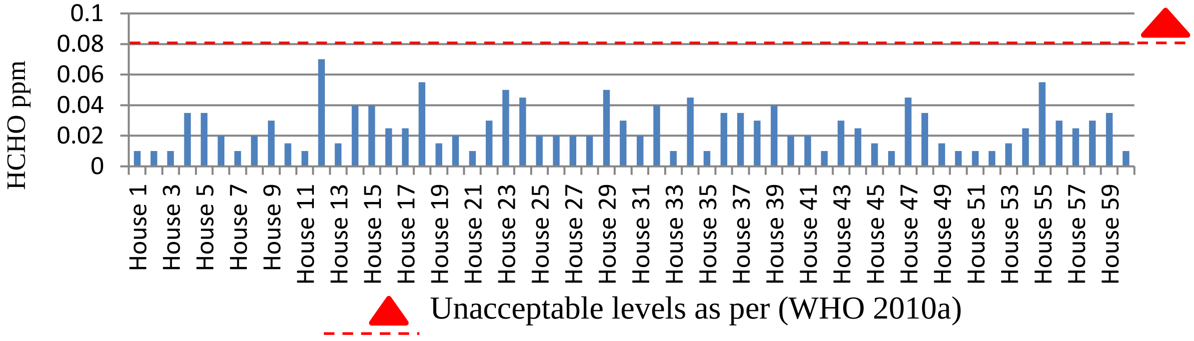


Figure 4-38: Average HCHO concentrations for 30 minutes in the 60 households

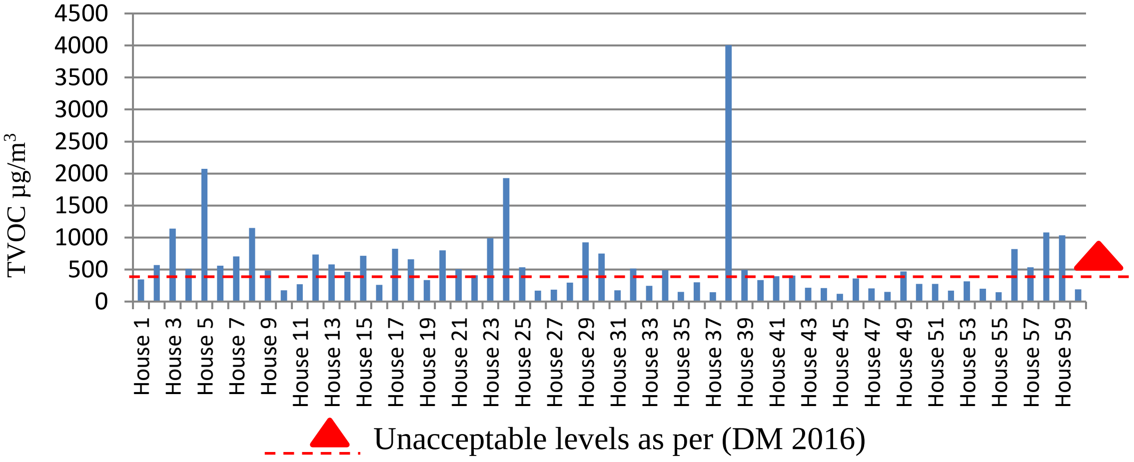


Figure 4-39: TWA of TVOC in the 60 households

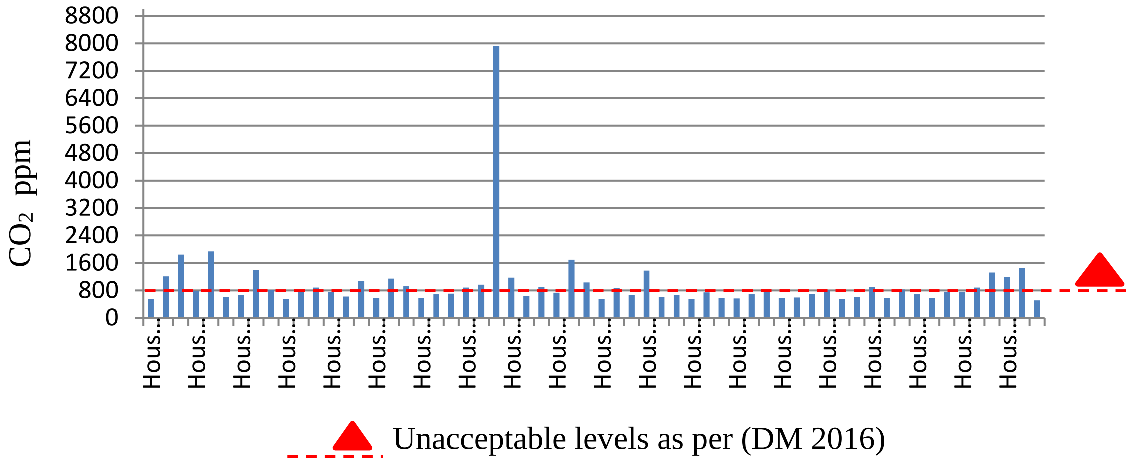


Figure 4-40: TWA of $CO_2$ in the 60 households

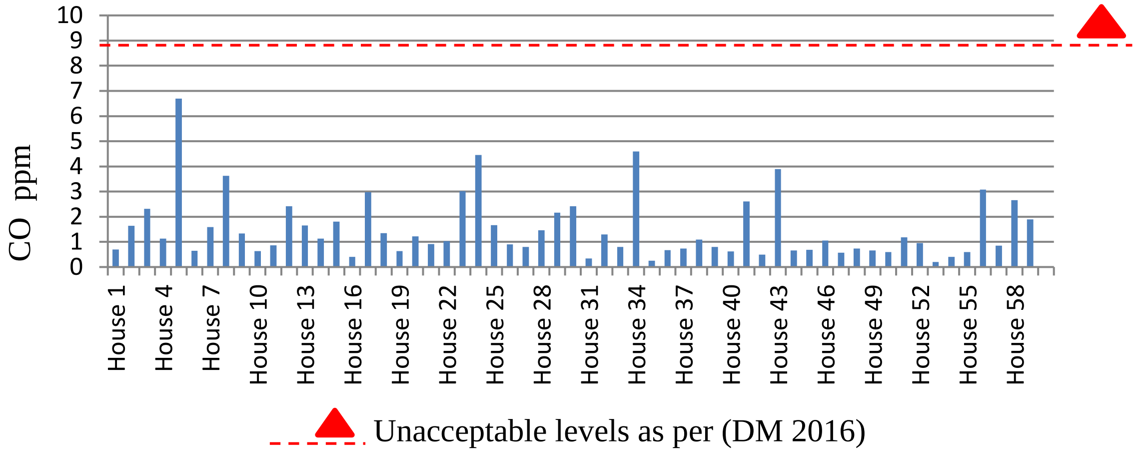


Figure 4-41: TWA of CO in the 60 households

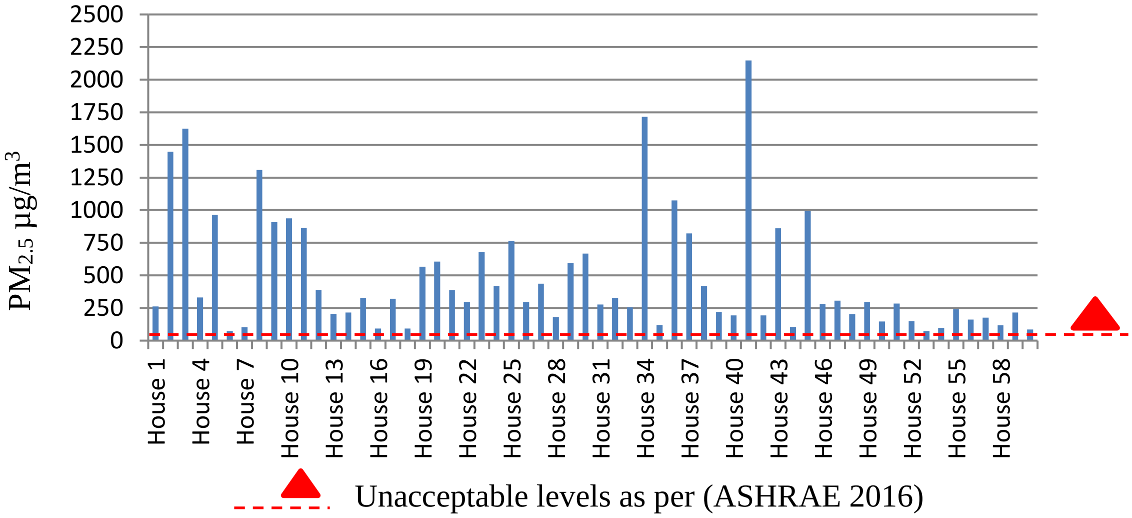


Figure 4-42: TWA of $PM_{2.5}$ in the 60 households

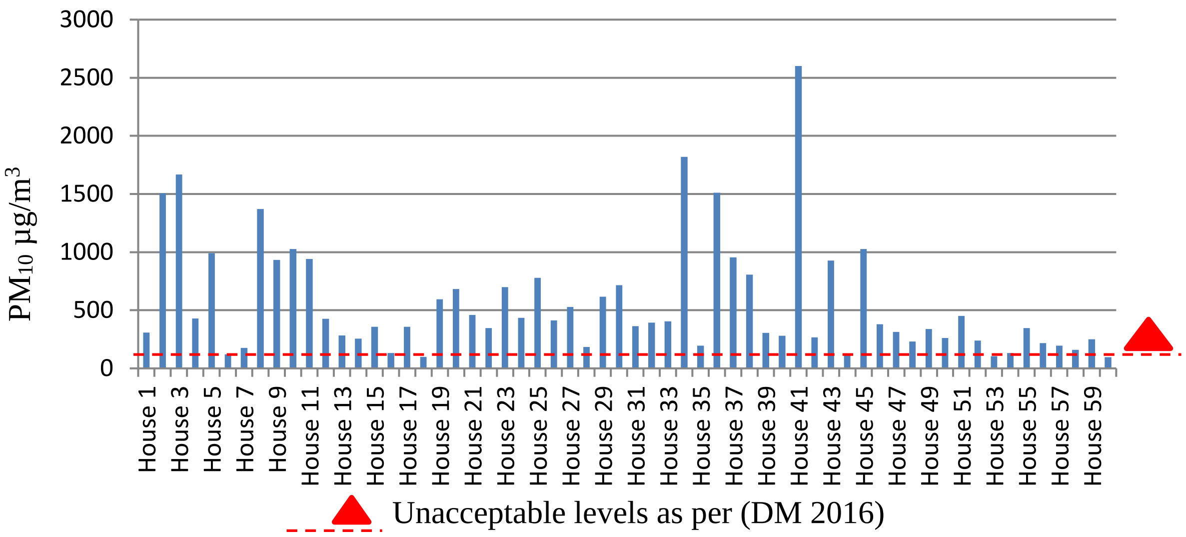


Figure 4-43: TWA of $PM_{10}$ in the 60 households

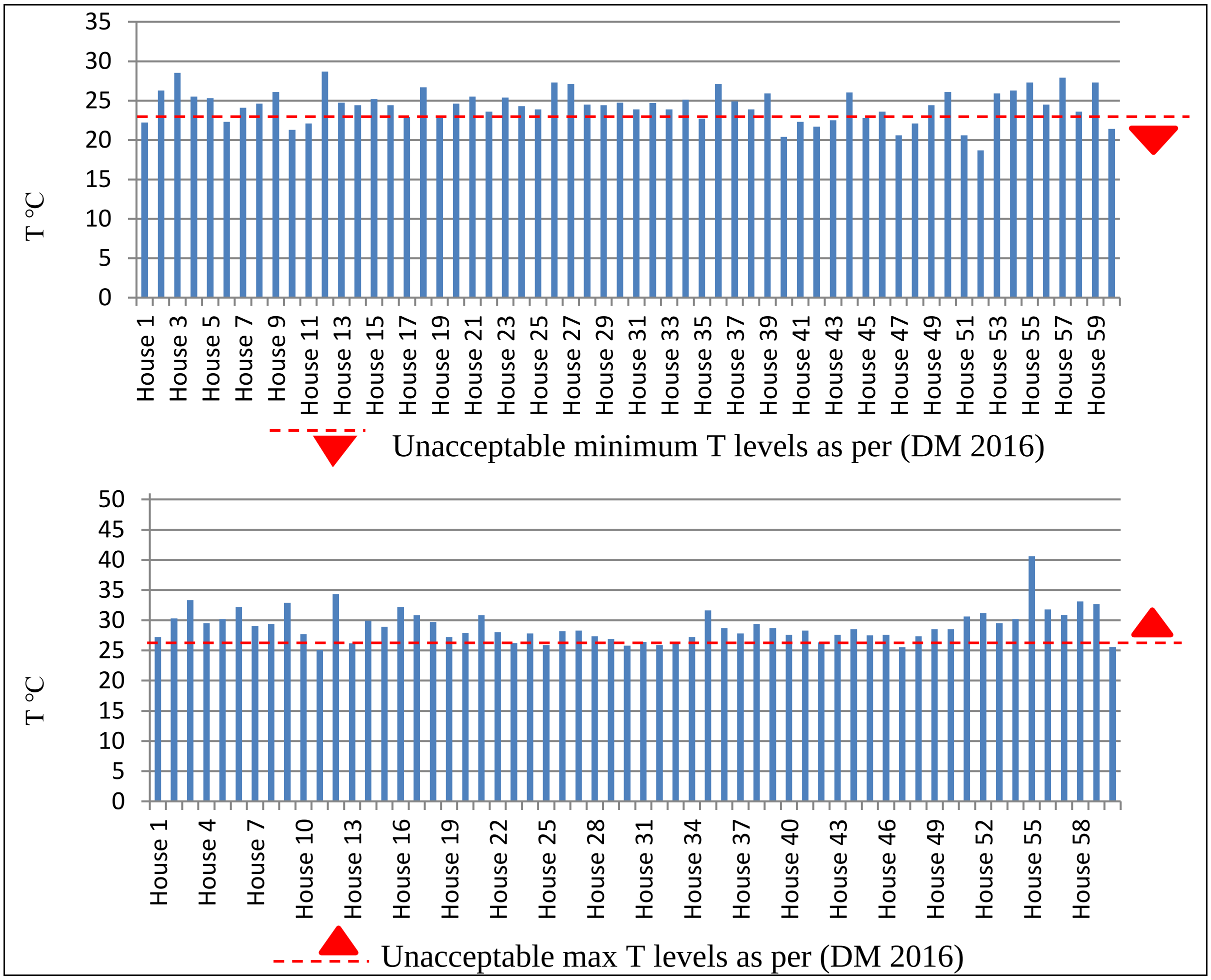


Figure 4-44: Minimum and maximum T levels in the 60 households

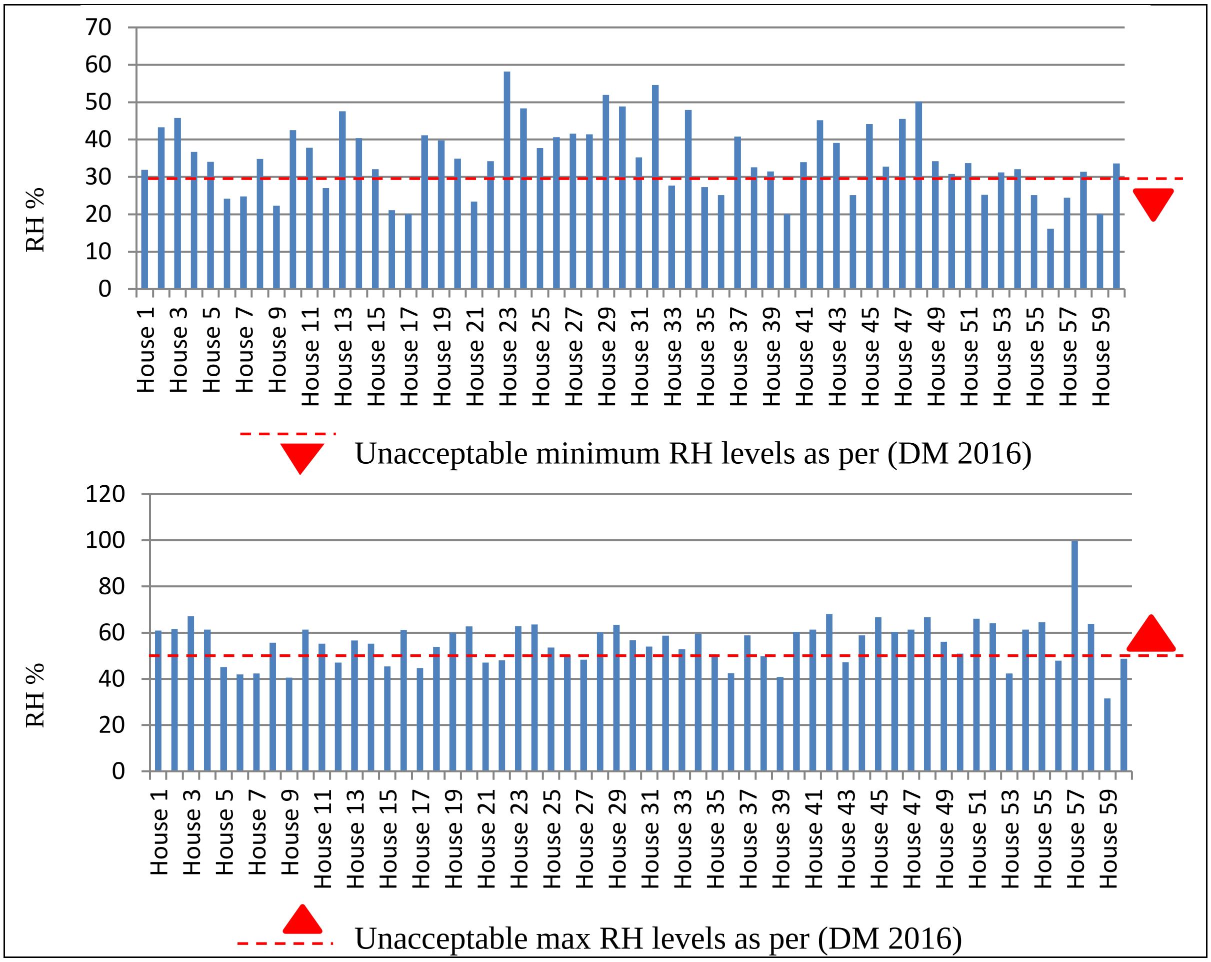


Figure 4-45: Minimum and maximum RH levels in the 60 households

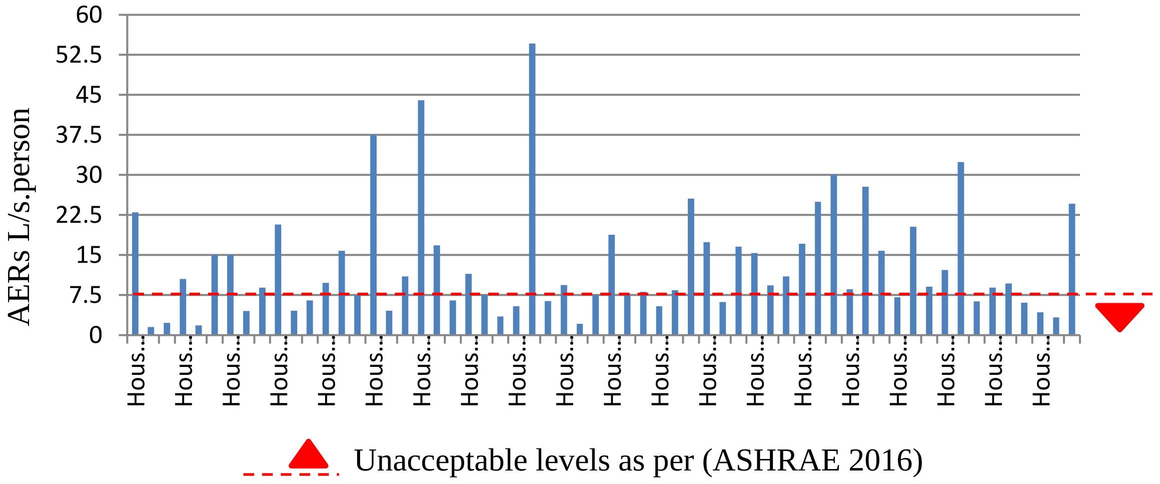


Figure 4-46: Estimated AERs in the 60 households

Table 4-49: Compliance of measured parameters and estimated AERs

| | **Acceptable** | | **Unacceptable** | |
|---|---|---|---|---|
| | N | % | N | % |
| Indoor HCHO compliance with WHO (2010a) | 60 | 100 | 0 | 0 |
| Indoor TVOC compliance with DM (2016) | 20 | 33 | 40 | 67 |
| Indoor $CO_2$ compliance with DM (2016) | 33 | 55 | 27 | 45 |
| Indoor CO compliance with DM (2016) | 60 | 100 | 0 | 0 |
| Indoor $PM_{2.5}$ compliance with ASHRAE (2016) | 0 | 0 | 60 | 100 |
| Indoor $PM_{10}$ compliance with DM (2016) | 7 | 12 | 53 | 88 |
| Indoor T range compliance with DM (2016) | 0 | 0 | 60 | 100 |
| Lower T limit compliance with DM (2016) | 43 | 72 | 17 | 28 |
| Higher T limit compliance with DM (2016) | 1 | 2 | 59 | 98 |
| Indoor RH range compliance with DM (2016) | 24 | 40 | 36 | 60 |
| Indoor RH lower limit compliance with DM (2016) | 43 | 72 | 17 | 28 |
| Indoor RH higher limit compliance with DM (2016) | 36 | 60 | 24 | 40.0 |
| Estimated AERs compliance with ASHRAE (2016) | 37 | 62 | 23 | 38 |

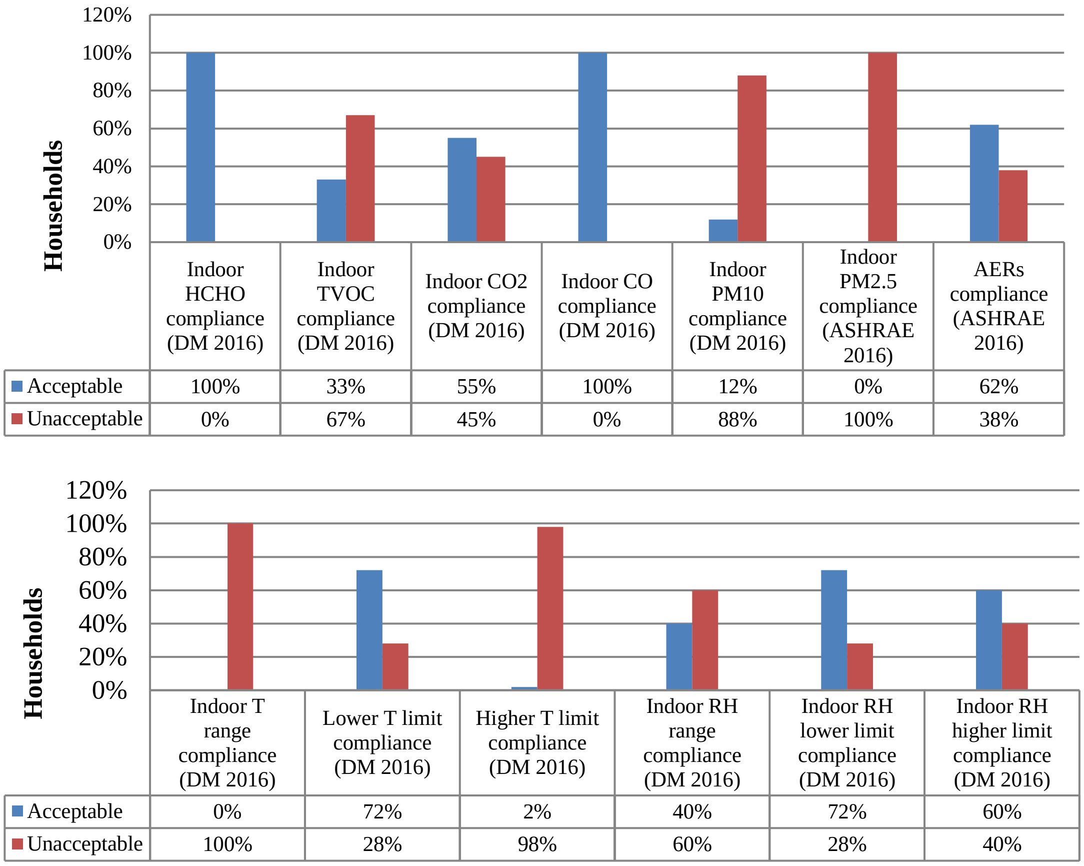


Figure 4-47: Compliance of measured parameters and estimated AERs (DM 2016)

According to measurements results, both indoor CO and HCHO concentrations were acceptable by national and/or international standards. Regarding indoor CO concentrations, they were within a range of 0.0 – 6.7ppm with a mean value of 1.5ppm and a median value of 1.04ppm (Table 4-48). As shown in Figure 4-41 and Table 4-49, the TWA of CO for 8 hours was less than 9ppm in all households which was acceptable as per (DM 2016; ASHRAE 2016). This result is in agreement with previous studies in UAE assessing CO concentrations indoors and outdoors. According to (Yeatts et al 2012a ; Funk et al. 2014), the median of indoor CO concentration was 0.76ppm in 625 UAE houses. Also, reference to Fadeyi et al. (2014), average of indoor CO concentrations in classrooms of 16 elementary schools in UAE was 1.16pm. That is also supported by a recent report by (EAD 2017) stating that CO concentrations in ambient air was in compliance with UAE mandated limits and its trend was decreasing during the period 2007 to 2015. Concerning the average of indoor HCHO levels in the 60 houses, they were within a range of <0.01 – 0.070ppm with a mean value of 0.026ppm and a median value of 0.023ppm (Table 4-48). As shown in Table 4-49 and Figure 4-38, average indoor HCHO for 30 minutes was less than 0.08ppm in all houses which is acceptable as per WHO (2010a). Noteworthy that measured HCHO concentrations would also be acceptable by DM (2016) if they were 0.08ppm or less in average for continuous 8 hours. This result regarding the acceptability of indoor HCHO levels in housing spaces as per WHO guidelines was in agreement with that revealed by (Yeatts et al 2012a; Funk et al. 2014). According to (Yeatts et al 2012a; Funk et al. 2014), median indoor HCHO levels in 625 UAE houses was approximately <0.01ppm. Also, this result is supported Fadeyi et al. (2014) who conducted spot measurements for HCHO in classrooms of 16 elementary schools in UAE. According to Fadeyi et al. (2014), HCHO concentrations in those classrooms were below their instrument level of detection (LOD) which was 0.01.

In terms of the TWA of indoor TVOC, indoor TVOC levels range was from 123.2 to 4005.5μg/m$^3$ with mean value of 575.4μg/m$^3$ and median value of 436.8μg/m$^3$ (Table 4-48). As shown in Table 4-49 and Figure 4-39, the TWA of indoor TVOC was not complying with the 300μg/m$^3$ mandated by DM (2016) in 40 households (67%). Reference to previous studies, measured indoor TVOC concentrations fell within a wide range.

According to Mečiarová et al. (2017), TVOC levels in residential spaces revealed by different studies from different countries were within a range from about 150 to 1300 µg/m$^3$. This finding was lower than that revealed by Fadeyi et al. (2014) who found that mean TVOC concentration was 815µg/m$^3$ in classrooms of 16 elementary schools in UAE. However, indoor TVOC levels by this study was within the range measured by Mečiarová et al. (2017) indicating that mean TVOC concentrations in 35 Slovak villas and apartments were 330.2 and 519.7µg/m$^3$, respectively. Reference to Lee et al. (2018), mean indoor TVOC levels in 30 Korean elderly care centres was about 230 µg/m$^3$ which was lower than that revealed by this study. Also, Chin et al. (2015) found that mean TVOC concentrations in 126 Detriot/USA houses was about 150µg/m$^3$ which was also lower than TVOC levels measured by this study. Regarding the spot measurements of outdoor TVOC in the 60 houses, they were within a range of 0.00 – 1306.4µg/m$^3$ with a mean of 230.4µg/m$^3$ and a median of 156.4µg/m$^3$ (Table 4-50).

As shown in Table 4-51 and Figure 4-48, indoor TVOC concentrations in 40 houses (67%) exceeded the mandated 300µg/m$^3$ by DM (2016) while outdoor TVOC levels exceeded that limit in 13 households (22%). TVOC concentrations exceeded that limit indoors and outdoors in 12 households (20%). Those results indicate the probability of having higher levels of indoor pollution compared with outdoors. Also, the probability of having outdoor and indoor sources of pollution in about 20% of the households can be assumed. Notably that the ratio of indoor TVOC concentations to outdoors was above 1 in almost all the households except one. According to (Gennaro et al. 2013), that might point to having indoor TVOC sources. However, it is important to note the consistent change in outdoor levels following average indoor levels in most of the households that suggests another two probabilities. The first probability supports the suggestion of having indoor TVOC sources that influenced the outdoor levels. Whereas the second suggests outdoor TVOC sources as major contributors influencing indoor TVOC levels accompanied with deficiency in applied processes to remove accumulated TVOCs indoors i.e. insufficient AERs.

Table 4-50: Descriptive statistics of outdoor levels in the 60 houses

| | | | | | Percentile | | |
|---|---|---|---|---|---|---|---|
| | Min | Max | Mean | Median | 75 | 90 | 95 |
| Outdoor TVOC (µg/m$^3$) | 0.00 | 1306.4 | 230.4 | 156.4 | 276.0 | 558.0 | 723.9 |
| Outdoor $CO_2$ (ppm) | 371.0 | 6829.0 | 580.0 | 461.0 | 511.5 | 568.8 | 601.4 |
| Outdoor CO (ppm) | 0.0 | 8.6 | 1.0 | 0.60 | 1.3 | 2.2 | 3.0 |
| Outdoor T (ºC) | 22.6 | 42.4 | 29.3 | 28.6 | 32.6 | 38.7 | 41.2 |
| Outdoor RH (%) | 12.4 | 93.1 | 50.4 | 49.5 | 61.9 | 71.4 | 83.5 |

Table 4-51: Houses with unacceptable TVOC and $CO_2$ concentrations as per DM (2016)

| | Unacceptable TVOC | | Unacceptable $CO_2$ | |
|---|---|---|---|---|
| | N | % | N | % |
| Indoors | 40 | 67% | 27 | 45% |
| Outdoors | 13 | 22% | 19 | 32% |
| Indoors & outdoors | 12 | 20% | 14 | 23% |

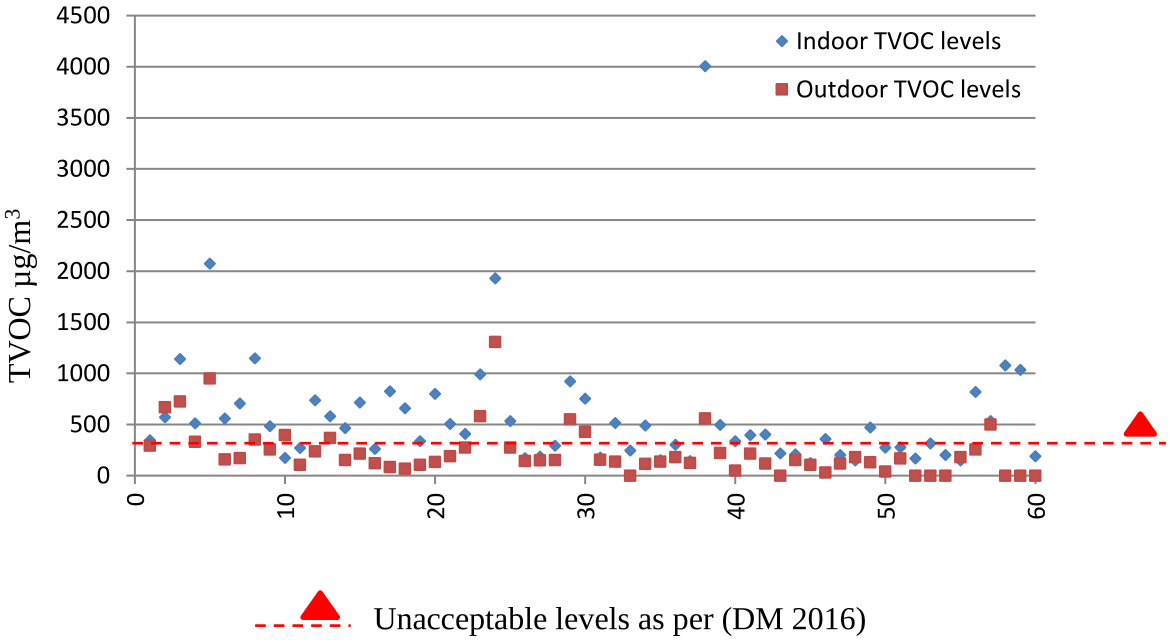


Figure 4-48: TWA of indoor TVOC and spot outdoor TVOC levels in the 60 houses

As illustrated in Figure 4-48, some measurements were found to be remarkably above others. According to (Field 2016; Barker & Shaw 2015; UCLA 2018), similar observations or outliers may highlight a sample's uniqueness, measurement error, data entry error, or other undetected issues. Table 4-52 outlines some of the possible inconsistencies that could have occurred during the measurement which might have affected the accuracy of the results in a house compared with others. When investigating regarding those unusual measurements shown in Figure 4-48; some contextual issues were observed that might probably have contributed in increasing indoor TVOC levels. For instance, reference to Table ZZ-13 & ZZ-14, the TWA of indoor TVOC levels in House (5) was 2073µg/m$^3$ while the outdoor TVOC levels was 949µg/m$^3$. As shown in Figure ZZ-24 & Table ZZ-15, the number of occupants ranged between 7 – 13 occupants while the provided AERs throughout the 5 occupancy profiles was insufficient as per (ASHRAE 2016; OSHA 1999). In case of House (5), the high indoor TVOC levels can be attributed to both outdoor and indoor sources when considering the unacceptable TVOC levels outdoors, reported indoor activities by a relatively large number of occupants that might result in additional TVOC emissions such as cooking and cleaning activities in addition to insufficient AERs. In terms of House (38), the TWA of indoor TVOC levels was also noticeably above remainder measurements reaching up to about 4006 µg/m$^3$ while the outdoor TVOC levels was about 559 µg/m$^3$ (Table ZZ-111 & Table ZZ-112). As shown in (Figure ZZ-189 & Table ZZ-113), the number of occupants ranged between 0 – 4 occupants while the provided AERs throughout the day was sufficient as per (ASHRAE 2016; OSHA 1999) except during P1 when the 4 occupants were in the living room. As shown in Figure ZZ-191, indoor TVOC levels over the period from (13:58 – 0:34) was highly above other durations. One of the probable reasons of that spike was the reported daughter experimenting with chemical games such as making slime and burning substances during P1 (Table ZZ-113). Despite the unacceptable outdoor TVOC and insufficient AERs provided during P1, indoor TVOC sources may probably be a dominant contributor in the noticebly high indoor TVOC levels in House (38). Another extraordinarily high indoor TVOC levels compared with others was reported in House (58). The TWA of indoor TVOC levels reached up to about 1080µg/m$^3$ while the outdoor TVOC levels was below LOD (Table ZZ-171 & Table ZZ-172). As shown in (Figure ZZ-289 & Table ZZ-173), the number of occupants ranged between 0 – 4 occupants while the provided AERs throughout the 7 occupancy profiles was insufficient as per (ASHRAE 2016; OSHA 1999). Considering that, the high indoor TVOC levels can be attributed to indoor issues such as the insufficient AERs, performed cooking and cleaning activities, in addition to having a pet cat living indoors.

Table 4-52: Probable inconsistencies during measurement period

| | **Probable inconsistencies during measurement period** |
|---|---|
| **1** | The proximity of the house to outdoor pollution source/s i.e. nearby parking lots, highways, industrial areas, ongoing construction sites … etc |
| **2** | The proximity of the measuring instrument to indoor pollution source i.e. kitchens |
| **3** | The number of smokers and/or duration of smoking activities |
| **4** | Life style and daily practices i.e. utilized cleaning methods, incense burning, having pets, cooking methods & duration… etc |
| **5** | Weather conditions i.e. dust storms, rain, winds, … etc |

Concerning indoor $CO_2$ concentrations in the 60 houses, they were within a range of 505.5 – 7921.8 ppm with a mean value of 964.2ppm and a median value of 755.6ppm (Table 4-48). As shown in Table 4-49 and Figure 4-40, TWA of $CO_2$ concentrations was not complying with the 800ppm mandated by DM (2016) in about 27 households (45%). Findings by previous studies detected variable ranges of indoor $CO_2$ concentrations. For instance, the measured range of indoor $CO_2$ concentration was in agreement with that found by (McGill et al. 2015) in 8 newly built houses in UK. According to McGill et al. (2015), average of $CO_2$ concentration in the living rooms of the houses was within a range of 548 – 1675ppm. Also, reference to Derbez et al. (2014), the range of mean concentrations in 7 newly built energy-efficient residences in France was 291 – 1013ppm. However, Fadeyi et al. (2014) assessed indoor $CO_2$ concentrations in classes of 16 schools in UAE and found that it was within a range of 786 – 4050ppm but with a higher average value (1605ppm) than that detected by this study. Regarding the spot measurements of outdoor $CO_2$ concentration in the 60 houses, they were within a range of 371 – 6829ppm with a mean of 580.0 ppm and a median of 461ppm (Table 4-50). As shown in Table 4-51 and Figure 4-49, outdoor $CO_2$ concentrations exceeded the expected range of 300 – 500ppm (ASHRAE 2016) in 19 houses (32%). That was lower than the 27 houses (45%) in which indoor $CO_2$ concentration exceeded the mandated 800ppm by DM (2016). Notably that $CO_2$ concentration exceeded the acceptable limit indoors and outdoors in 14 households (23%). This result indicates the probability of having higher levels of indoor pollution compared with outdoors. Also, the probability of having outdoor and indoor sources of pollution in approximately 23% of the households can be assumed.

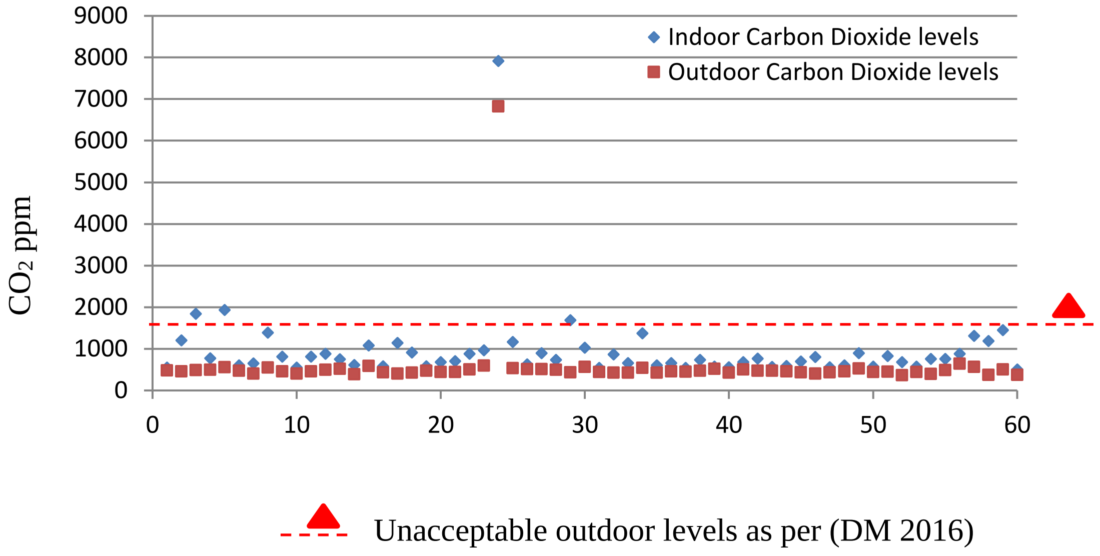


Figure 4-49: TWA of indoor $CO_2$ and spot outdoor $CO_2$ levels in the 60 houses

As shown in Figure 4-49, measured indoor and outdoor $CO_2$ levels of House (24) were noticeably higher than the levels in the other houses. As illustrated in (Table ZZ-70, Table ZZ-71, & Figure ZZ-118), the TWA of indoor $CO_2$ levels was about 7922ppm while the outdoor levels was about 6829ppm. Measurements were conducted in a flat located in Abu Hail Area on 25th December 2017 and it continued for 24 hours starting from 19:00. As illustrated in Table ZZ-72, the number of occupants during measurement day was between 0 – 4 occupants. One of the probable major contributors of having such levels of indoor $CO_2$ was the highly unacceptable outdoor $CO_2$. The noticeably higher ambient $CO_2$ levels can be related with the high population density of Abu Hail Area as it is located in Dubai Sector 1 which is the densest sector in Dubai. Reference to (City Population 2016), population density in Dubai Sector 1 is approximately 10644/Km$^2$ which is highly above and incomparable with that 4303/Km$^2$, 2844/Km$^2$, 714/Km$^2$, 637/Km$^{2,}$ 480/Km$^2$, 40/Km$^2$, 37/Km$^2$, and 3/Km$^2$ in Dubai Sector 3, Sector 2, Sector 4, Sector 5, Sector 6, Sector 7, Sector 8, and Sector 9; respectively. The positive association between population density and $CO_2$ was supported by many studies (Meng & Han 2018; Ohlan, R. 2015). Notably that one of the related findings by this study's survey was the significant positive association between Dubai Sector 1 and the General, Ergonomic, Nervous, and Skin symptoms (Table 4-44).

Based on measured indoor and outdoor $CO_2$ concentrations, AERs were estimated as described in Section 0. Estimated AERs in the 60 houses ranged between 1.5 – 54.6L/s. person with a mean value of 13.2L/s. person and median value of 9.4L/s. person (Table 4-48). As shown in Table 4-49 and Figure 4-46, the estimated AER was above the 7.5L/s. person which was considered as sufficient as per ASHRAE (2016) in 37 households (62%) whereas it was below the 7.5L/s. person was considered as insufficient as per ASHRAE (2016) in 23 households (38%). Table 4-53 shows the percentage of households that had unacceptable indoor concentrations along with those having unacceptable concentrations and insufficient AERs. As per shown results, households that had unacceptable indoor TVOC, $CO_{2,}$ $PM_{2.5,}$ $PM_{10,}$ T range, and RH range levels along with insufficient AERs were 20 (33%), 20 (33%), 23 (38%), 22 (37%), 23 (38.3%), and 12 (20%); respectively. Based on that, insufficient AERs may be one of the causes of attaining unacceptable contaminants' concentrations in those households. In case of dealing with the unacceptable indoor $CO_2$ and TVOC, providing adequate AERs might help in decreasing their indoor levels particularly when considering the lower outdoor $CO_2$ levels in all households and TVOC levels in 59 households than indoor concentrations. However, that might not be the case when dealing with the $PM_{2.5}$ and $PM_{10}$ particulary when considering declarations by local institutions of having unacceptable $PM_{10}$ levels in ambient air (EAD 2017). In such a case, ventilation might increase PM concentrations indoors.

Findings by previous studies regarding provided AERs and the percentage of their adequacy were within variable ranges. For example, EPA BASE Study conducted measurements of volumetric airflow at the air handlers and also measured occupancy levels in 100 randomly selected US office buildings (Persily 2016; Persily & Gorfain 2008; Persily et al. 2005). Findings by EPA BASE Study revealed that the mean AERs was 49 l/s. person while the percentage of households of insufficient AERs was about 17%. Offerman (2009) also measured AERs in 108 houses in California/USA following a steady-state PFT approach in addition to measuring outdoor air intake with hot wire anemometers or flow hoods. The range of AERs for 24 hours as measured by Offerman (2009) was 0.09 to 5.31/h with a median value of 0.261/h. The study also found that about 67% of homes with AERs below the minimum required 0.351/h by California Building Code. Haverinen-Shaughnessy et al. (2011) estimated AERs following the steady-state approach in 100 elementary classrooms and found that provided AERs was within a range of 0.90 – 11.74 l/s. person with a mean value of 4.25l/s. person and a median value of 3.55l/s. person. About 87% of the classes had insufficient AERs as per ASHRAE Standard 62 as of 2004.

Table 4-53: Households having unacceptable concentrations and insufficient AERs

| | Unacceptable levels | | Unacceptable levels & insufficient AERs | |
|---|---|---|---|---|
| | N | % | N | % |
| TVOC | 40 | 66.7 | 20 | 33.3 |
| $CO_2$ | 27 | 45.0 | 20 | 33.3 |
| $PM_{2.5}$ | 60 | 100 | 23 | 38.3 |
| $PM_{10}$ | 53 | 88.3 | 22 | 36.7 |
| T range | 23 | 38.3 | 23 | 38.3 |
| RH range | 36 | 60 | 12 | 20 |

Regarding the TWA of $PM_{2.5}$ concentrations in the 60 houses, they ranged between 71.9 – 2148.5µg/m$^3$ with a mean value of 482µg/m$^3$ and median value of 296.2µg/m$^3$ (Table 4-48). As shown in Table 4-49 and Figure 4-42, TWA of $PM_{2.5}$ concentrations it was exceeding the 35 g/ m$^3$ in all households which was unacceptable as per ASHRAE (2016). In terms of the TWA of $PM_{10}$ concentrations in the 60 houses, they ranged between 95.9 – 2600.8µg/m$^3$ with a mean value of 558.7µg/m$^3$ and median value of 371.6µg/m$^3$ (Table 4-48). The TWA of indoor $PM_{10}$ was not complying with 150µg/m$^3$ exposure limit mandated by DM (2016) in 53 households (88%) (Table 4-49 and Figure 4-43). Noteworthy that, according to WHO (2006), exposure limits of $PM_{10}$ and $PM_{2.5}$ is only 50 and 25µg /m$^3$ for 24 hours while their annual average should not exceed 20 and 10µg /m$^3$; respectively. However, measured $PM_{10}$ and $PM_{2.5}$ concentrations were highly above those levels. This result regarding $PM_{10}$ and $PM_{2.5}$ is concerning particularly if measured concentrations are commonly prevelent in these houses for longer period than specified by (WHO 2006). When comparing those results with others, they are consistent with some studies while inconsistent with others. For instance, the median of $PM_{2.5}$ and $PM_{10}$ concentrations by Funk et al. (2014) in 575 UAE households was 5.7 and 35.2µg/$m^3$, respectively. That result is far lower than this study finding since the median of $PM_{2.5}$ and $PM_{10}$ concentrations was 296.2 and 371.6µg/$m^3$; respectively. However, this study finding is consistent with that found by Fadeyi et al. (2014) who measured mass concentration of PM of 0.3 – 10µm diameter in classrooms of 16 elementary schools in UAE. According to Fadeyi et al. (2014), the range of measured $PM_{0.3–10}$ was 316 – 9828µg/$m^3$ with an average value of 1730µg/$m^3$. Accordingly, $PM_{0.3–10}$ concentrations were highly exceeding the limits of 150µg/$m^3$ for $PM_{10}$ mandated by DM (2016) in those UAE schools.

Also, considering other studies such as (EAD 2017; Al Jallad et al. 2013) illustrating the high levels of $PM_{2.5}$ and $PM_{10}$ in UAE ambient air that exceed the national and international limits; this study findings were consistent. According to Al Jallad et al. (2013), who obtained data from an ambient air quality station in UAE western desert, found that the range of hourly concentrations of $PM_{10}$ was 4 – 3474µg/$m^3$ with a mean value of 128µg/$m^3$. The range of daily mass concentrations of $PM_{10}$ was 14 – 1188µg/$m^3$ of which about 27% were exceeding the mandated 150µg/$m^3$ limit in UAE. Also, reference to the recent report by the Environment Ageny – Abu Dhabi (EAD 2017), $PM_{10}$ that encompass all particulate matter of less than 10 µm in diameter are significantly high in Abu Dhabi Emirate background levels and they were exceeding the national UAE limits. That was attributed by EAD (2017) to the region arid nature in which $PM_{10}$ concentrations alleviate when dust events take place and transport sand and dust into inhabited areas. Moreover, revealed results by this study were comparable with others such as those by (Abdel-Salam 2012; Nasir et al. 2013; Goyal & Kumar 2013 ). According to Nasir et al. (2013), mean concentrations of $PM_{2.5}$ and $PM_{10}$ in the living halls of households using natural gas for cooking in two Pakistanian sites were ranging from (82 – 237µg/$m^3$) and (190 – 359µg/$m^3$); respectively. Reference to Abdel-Salam (2012), mean concentrations of total suspended particles (TSP) in 21 Egyptian homes ranged from 96 to 351µg/ $m^3$. Also, Goyal & Kumar (2013) found that the range of mean $PM_{2.5}$ and $PM_{10}$ concentrations in 9 microenvironments in a commercial building was (16.9 – 102.6µg/$m^3$) and (17.1 – 601.2µg/$m^3$); respectively.

Regarding the indoor thermal conditions, average minimum and maximum T levels in the 60 houses were within a range of 22.4 – 33.4ºC with a mean value of 27.0ºC and a median value of 26.9ºC (Table 4-48). While the average minimum and maximum RH levels range was from 25.8 – 60.3% with a mean value of 44.6% and a median value of 26.9% (Table 4-48). As shown in Table 4-49 and Figure 4-44, measured T levels in 17 households (28%) was below 23.5ºC which was not complying with the lower T limits set by DM (2016). Whereas 59 households (98%) were above 25.5ºC which was not complying with the higher T limits set by DM (2016). As a range, measured T was not complying with the required range (23.5 – 25.5ºC) by DM (2016) in all households. In terms of RH levels (Table 4-49 and Figure 4-45), they were below the 30% in 17 households (28%) which was not complying with the lower RH limits set by DM (2016). Whereas 24 households (40%) were above 60% which was not complying with the higher RH limits set by DM (2016). As a range, measured RH was not complying with the required range (30 – 60%) by DM (2016) in 36 households (60%).

When comparing those results with previous ones, it was found that reported indoor T and RH levels were variable due to many reasons i.e. seasonal variations, utilized HVAC system, occupancy levels, indoor activities, … etc. For example, Indraganti et al. (2016) performed thermal comfort field surveys in eight office buildings in Doha/ Qatar during 4 winter months in 2016 in addition to four office buildings in Tokyo/ Japan during 3 summer months in 2012. As per their findings, mean T and RH levels in the Japanese office buildings were 27.9ºC and 50.8% respectively which were higher than those found by this study. However, mean T and RH levels in the Qatar office buildings were 24.3ºC and 43.3% respectively which were lower than those found by this study. Lower T levels than this study were also found by Amin et al. 2016 who revealed that average minimum and maximum T levels were between 19 – 29ºC in 30 rooms in new residence buildings/ UK measured over the period from December 2014 to May 2015. Noting that measurements of this study were performed over different period (September 2017 – June 2018); seasonal variations in different climatic regions may be a reason behind the difference in measured thermal conditions by above studies.

# Chapter 5 : Conclusions and recommendations

## 5.1 Conclusions

Reference to identified theoretical gaps in the literature review (Chapter 2), this study intended to answer the following questions:

1. What are the current IEQ conditions and prevalent SHS in Dubai housing?
2. What are the risk factors associated with prevalent SHS symptoms and IAQ conditions in Dubai housing?
3. What is the impact of the applied HVAC system on IAQ and SHS prevalence in Dubai housing?
4. Are the provided AERs sufficient in Dubai housing?
5. What are the potentially appropriate solutions to mitigate or control poor IAQ and SHS in Dubai housing?

To respond to the above questions, a cross sectional survey covering 770 Dubai residents was conducted. To the best of our knowledge, this is the first study of its nature covering a large sample size of Dubai households inhabited by different nationalities. Furthermore, a field study was conducted in 60 Dubai households in which field measurements were performed to continuously measure indoor TVOC, CO, $CO_2$, $PM_{2.5}$, $PM_{10}$, RH, and T for 24 hours. Indoor HCHO was also measured in each household for 30 minutes. Moreover, spot measurements were performed for TVOC, CO, $CO_2$, RH, and T in the 60 houses. Provided AERs were calculated using $CO_2$ steady-state method in the living hall where measurement instruments were installed. Additionally, self-reported questionnaires were utilized in the field study to reflect perceived IEQ and prevalent SHS in the sample. In the following Sections 5.1.1 - 5.1.3, each of the above questions were revisited and linked with a summary of the utilized methods to approach it in addition to the main conclusions that can be suggested from the findings of this study. Then, Section 0 represents a summary of the practical implications and recommendations derived from the findings by this study. While the research limitations and ethical considerations were discussed in Section 5.3; respectively.

### 5.1.1 Main findings related to the 1st research question

This thesis demonstrated that the cross sectional survey is an efficiEye, nose, throat, and effective method in answering the 1st research question as provided descriptive statistics reflected the prevalent perceptions regarding IAQ conditions and SHS symptoms in Dubai housing. Moreover, performed field measurements in 60 houses in Dubai revealed clearer information regarding prevalent levels of measured IEQ parameters. The provided descriptive statistics from the field measurements identified concerning IEQ parameters in Dubai housing in terms of their non-compliance with recognized limits established local or/and international institutions. Following are the main conclusions regarding the characterization of current IEQ conditions and prevalent SHS in Dubai housing derived from the study's results:

1. Results of the main survey revealed that the frequently experienced health symptoms at least 1 -3 days/week were ergonomic symptoms experienced by about 18% of Dubai households, general symptoms (17%), skin (17%), fatigue (17%), nose (17%), neurological (15%), cough (12%), eye (10%), throat (9%), chest symptoms (8%), and fever (5%). Noteworthy that reported cough symptoms experienced at least 1 -3 days/week by Dubai residents was double the expected in healthy building as suggested by the reference data of the MM questionnaires (Kjell et al. 2014; Andersson 2010 & 1998). Cough symptoms was also more than double that found by another reference study (Reijula & Sundman-Digert 2004). Also, reported fatigue symptoms experienced health symptoms at least 1 -3 days/week was higher among Dubai residents whereas reported skin symptoms was less than that recorded by the above two reference studies.
2. Concerning prevalent SHS symptoms in Dubai housing – defined as symptoms that occurred at least once a week and became better outdoors – was about 30% as reported by the participants of the main survey. This result is in consistent with the approximately 39% prevalent SHS symptoms reported by the participants of the field study. Noteworthy that the exact magnitude of prevalent SHS in both samples might be higher than the above estimated ones when considering those participants

who reported symptoms compatible to SHS but the way in which those symptoms was variable or inconstant. Compared with another recent study, prevalent SHS in Dubai housing was higher than that revealed by Azuma et al. (2015) who reported that SBS was common in their as it accounted for 25% of their study's sample that covered 3335 employees in 320 Japanese offices.

3. Regarding IEQ conditions frequently experienced at least 1 – 3 days/ week, the most prevalent one is dust and dirt experienced by approximately 29% of the population followed by "Too quiet" (22%), "Too hot" (22%), "Too humid" (19%), and "Too noisy" (19%), "Too cold" (17%), "Too glary" (13%), "Too dim" (14%), "Little air" (15%), "Too dry" (16%), then "Stuffy bad air" (14%). In terms of odors perceptions, the most prevalent odors experienced at least 1 – 3 days/ week was "Fishy and food odors" reported by approximately 21%, "Body and cosmetics odors" (20%), "Tobacco smoke" (20%), "Smoke from incense burning" (19%), "Odors from chemicals" (7%), "Dampness odors" (6%), "Diesel or engine exhaust" (6%), "Odors from new carpets" (4%), and "Odors from paint" (4%). Notably that reported complaints experienced at least 1 – 3 days/week concerning odors, poor lighting conditions, in addition to dust and dirt were highly above the expected in normal conditions as suggested by the MM questionnaires reference data (Kjell et al. 2014; Andersson 2010 & 1998). Similarly, those three IEQ complaints were higher than that reported by Reijula & Sundman-Digert (2004).
4. According to revealed results by the field study, the following is a summarized descriptive statistics that characterize measured IEQ parameters in the 60 Dubai households:
    - The TWA of $PM_{2.5}$ concentrations was between 71.9 – 2148.5µg/m$^3$ with a mean value of 482.0µg/m$^3$ and median value of 296.2µg/m$^3$. TWA of $PM_{2.5}$ concentrations exceeded the 35.0g/µm$^3$ in all households which was unacceptable as per ASHRAE (2016). Regarding the TWA of $PM_{10}$ concentrations, it was between 95.9 – 2600.8µg/m$^3$ with a mean value of 558.7µg/m$^3$ and median value of 371.6µg/m$^{3.}$ The TWA of indoor $PM_{10}$ was not complying with the 150µg/m$^3$ exposure limit mandated by DM (2016) in 53 households (88%). Noteworthy that, according to WHO (2006), exposure limits

of $PM_{10}$ and $PM_{2.5}$ should not exceed the 50 and 25µg/$m^3$ for 24 hours while their annual average should not exceed 20 and 10µg/$m^3$; respectively. However, measured $PM_{10}$ and $PM_{2.5}$ concentrations were highly above those levels. This result regarding $PM_{10}$ and $PM_{2.5}$ is concerning particularly if measured concentrations are commonly prevalent in these houses for longer period than specified by (WHO 2006).

- The TWA of indoor TVOC was between 123.2 to 4005.5µg/$m^3$ with mean value of 575.4µg/$m^3$ and median value of 436.8µg/$m^3$. Regarding the spot measurements of outdoor TVOC in the 60 houses, they were within a range of 0.00 – 1306.4µg/$m^3$ with a mean of 230.4µg/$m^3$ and a median of 156.4µg/$m^3$. Indoor TVOC concentrations in 40 houses (67%) exceeded the mandated 300 µg/$m^3$ by DM (2016) while outdoor TVOC levels exceeded that limit in 13 households (22%). TVOC concentrations exceeded that limit indoors and outdoors in 12 households (20%). Those results indicate the probability of having higher levels of indoor pollution compared with outdoors. Also, the probability of having outdoor and indoor sources of pollution in about 20% of the households can be assumed.
- The TWA of indoor $CO_2$ concentrations was between 505.5 – 7921.8ppm with a mean value of 964.2ppm and a median value of 755.6ppm. Regarding the spot measurements of outdoor $CO_2$ concentration, they were within a range of 371.0 – 6829.0ppm with a mean of 580.0ppm and a median of 461.0ppm. TWA of $CO_2$ concentrations was not complying with the 800 ppm mandated by DM (2016) in about 27 households (45%). Whereas, outdoor $CO_2$ concentrations exceeded the expected range of 300 – 500ppm (ASHRAE 2016) in 19 houses (32%). Notably that $CO_2$ concentration exceeded the acceptable limit indoors and outdoors in 14 households (23%). This result indicates the probability of having higher levels of indoor pollution compared with outdoors. The unacceptable $CO_2$ levels in the 32% of the houses can be attributed to indoor sources or/and insufficient ventilation. Also, the probability of having outdoor and indoor sources of pollution can be assumed in approximately 23% of the households.

- Regarding the indoor thermal conditions, average minimum and maximum T levels in the 60 houses were within a range of 22.4 – 33.4ºC with a mean value of 27.0ºC and a median value of 26.9 ºC. While the average minimum and maximum RH levels range was from 25.8 – 60.3% with a mean value of 44.6% and a median value of 26.9%. Measured T levels in 17 households (28%) were below 23.5ºC which was not complying with the lower T limits set by DM (2016). Whereas 59 households (98%) were above 25.5ºC which was not complying with the higher T limits set by DM (2016). As a range, measured T was not complying with the required range (23.5 – 25.5ºC) by DM (2016) in all households. In terms of RH levels, 24 households (40%) were above 60% which were not complying with the higher RH limits set by DM (2016). Whereas they were below the 30% in 17 households (28%) which were not complying with the lower RH limits set by DM (2016). As a range, measured RH was not complying with the required range (30 – 60%) by DM (2016) in 36 households (60%). Notably that, this finding regarding unacceptably high humidity levels is in accordance with reported complaints in the main survey concerning the high indoor moisture levels.
- Both indoor CO and HCHO concentrations were acceptable by national and/or international standards. Regarding the TWA of indoor CO concentrations, they were within a range of 0.0 – 6.7ppm with a mean value of 1.5ppm and a median value of 1.04ppm. The TWA of CO for 8 hours was less than 9ppm in all households which was acceptable as per (DM 2016; ASHRAE 2016). Concerning the average of indoor HCHO levels in the 60 houses, they were within a range of <0.01 – 0.070ppm with a mean value of 0.026ppm and a median value of 0.023ppm. Average indoor HCHO for 30 minutes was less than 0.08 ppm in all houses which is acceptable as per WHO (2010a).

5. The above described non-compliance of indoor $PM_{2.5}$, $PM_{10}$, $CO_2$, TVOC, T, and RH with local and/or international limits is concerning. That is because, as discussed in the literature review (Section 2.3.1 – 2.3.5); the exposure to unacceptable levels of those parameters was associated with negative health effects as declared by many contemporaneous studies.

### 5.1.2 Main findings related to the $2^{nd}$ research question

To approach this question, PCA was performed in the self-reported health symptoms and perceived IEQ comfort conditions reported by the main questionnaire to minimize them into a smaller number of components accounting for the most observed variance in the dataset. The retained two health symptoms components were: (1) Eye, Nose, Throat, and Chest related symptoms in addition to the (2) General, Ergonomic, Nervous, and Skin symptoms. While the retained two perceived IEQ comfort components were: (1) Thermal, Lighting, and Noise discomfort and the (2) IAQ discomfort. Noteworthy that PCA was not performed on the odors items as any reduction in them would have negatively affected their inter-item consistency and reliability. Thus, perceived SHS symptoms represented the global DV in the main survey that involved the above two health symptoms components. Whereas perceived IEQ represented the global IV involved three subscales; the above two IEQ comfort components in addition to the perceived odors factor. Computed Cronbach alpha for all scales and subscales utilized by this study questionnaire were 0.7 or above indicating their acceptability as reliable and inter-item consistent measures. After PCA, 24 MLR models were employed to identify the potential risk factors on prevalent SHS symptoms and IAQ conditions in Dubai housing. Following are main findings obtained from the MLR models that demonstrated the appropriateness of the conducted multivariate statistical analysis in exploring the risk factors associated with prevalent SHS symptoms and IAQ conditions:

1. The three IEQ factors were statistically significantly associated with both health factors. Odors factor had the highest predictive power ($p \leq .001$) as it accounted for about 17% of the variance in Eye, Nose, Throat, and Chest symptoms and about 19% in the general, ergonomic, nervous & skin symptoms. The Thermal, Lighting, and Noise discomfort factor had higher predictive power ($p \leq .001$) in the general, ergonomic, nervous & skin symptoms than IAQ discomfort factor ($p \leq .01$). The Thermal, Lighting, and Noise discomfort factor explained about 17% of the variance in the general, ergonomic, nervous & skin symptoms while the IAQ discomfort factor explained about 11%. Contrarily, the IAQ factor had higher predictive power

($p \leq .001$) in the Eye, Nose, Throat, and Chest related symptoms than Thermal, Lighting, and Noise discomfort factor ($p \leq .01$). The IAQ discomfort factor explained about 15% in the Eye, Nose, Throat, and Chest related symptoms whereas the Thermal, Lighting, and Noise discomfort factor explained about 11%. This result pointed to the sizeable impact of IEQ factors on health conditions among participating households. It also suggests the great potentiality to mitigate prevalent SHS symptoms when promoting the IEQ conditions of Dubai housing.

2. Concerning the associations between IEQ variables and health factors; "Too much dim" had significant positive association with both health factors ($p \leq .01$). The proportion of total variance explained by "Too much dim" was approximately 11% in the Eye, Nose, Throat, and Chest symptoms and 16% in the general, ergonomic, nervous & skin symptoms. IEQ variables that had significant positive association with only Eye, Nose, Throat, and Chest symptoms were: (1) stuffy bad air ($p \leq .05$) accounting for about 13% of the variance, (2) dust and dirt ($p \leq .05$) accounting for about 11%, (3) odors from paint ($p \leq .05$) accounting for about 10%, and (4) Musty, mouldy or dampness odors ($p \leq .001$) accounting for about 8% of the variance. Whereas IEQ variables that had significant positive association with only general, ergonomic, nervous & skin symptoms were: (1) "Too much humidity" ($p \leq .001$) accounting for about 15%, and (2) Smoke from incense burning ($p \leq .001$) accounting for about 6% of the variance. The total variance explained by the two adjusted models was approximately 44% and 33% of the variance in (1) the General, Ergonomic, Nervous, and Skin symptoms and (2) the Eye, Nose, Throat, and Chest related symptoms; respectively. About 30% and 22% of the explained variance in the two health factors were non-uniquely explained or commonly shared by included variables in the model. Above findings signpost the sophisticated interactions between studied variables which was discussed in Chapter 2. Also, similar to the above; they suggest the potential IEQ risk factors threatening the health conditions of Dubai residents. On the other hand, above identified IEQ risk factors represented great opportunities to mitigate prevalent SHS symptoms in Dubai housing if they are well managed.

3. Concerning population variables that were significantly associated with prevalent health symptoms; the most commonly associated ones were dust allergic and participants having migraine that had significant positive association with the two health factors. Dust allergic participants were significantly associated with Eye, Nose, Throat, and Chest related symptoms ($p \leq .001$) in addition to the general, ergonomic, nervous & skin symptoms ($p \leq .05$). While participants having migraine were significantly associated with the two health factors at $p \leq .01$. Following are other population variables that had significant positive association with one factor: (i) asthmatics were significantly associated with Eye, Nose, Throat, and Chest related symptoms ($p \leq .01$); (ii) females were significantly associated with the general, ergonomic, nervous & skin symptoms ($p \leq .001$); (iii) participants having eczema were significantly associated with the general, ergonomic, nervous & skin symptoms ($p \leq .01$); in addition to the (iv) other Arabs or MENA Nationals who were significantly associated with the general, ergonomic, nervous & skin symptoms ($p \leq .01$).
4. In terms of building variables, three of them were found to have significant association with prevalent health symptoms which were: (i) households having attached kitchen with interior walls had significant positive association with Eye, Nose, Throat, and Chest related symptoms ($p \leq .01$); (ii) households experiencing water leakage had significant positive association with the general, ergonomic, nervous & skin symptoms ($p \leq .05$); in addition to (iii) households located in Dubai Sector 1 had significant positive association with the general, ergonomic, nervous & skin symptoms ($p \leq .05$).
5. Regarding the IAQ discomfort factor; it was significantly associated with the following parameters : (i) odors ($p \leq .001$) that explained about 30% of the variance; (ii) Thermal, Lighting, and Noise discomfort ($p \leq .001$) that explained about 16%; (iii) dust allergic participants ($p \leq .01$) who explained about 2.7%; (iv) elders ($p \leq .001$) and participants having migraine ($p \leq .05$) who explained about 2.3%; (v) other Africans ($p \leq .001$) who explained about 1.5%; in addition to (vi) households having new wall covering ($p \leq .01$) that explained about 1% of the variance. IAQ discomfort factor was positively associated with all above parameters

except with households having new wall covering. Noteworthy that the odors factor had the highest significant association with both prevalent SHS symptoms and perceived IAQ conditions.

### 5.1.3 Main findings related to the 3rd and 4th research questions

1. No significant association was found between any of the three HVAC systems studied by this research with any of the health symptoms as per revealed results by the MLR model using the building variables adjusted for the IEQ parameters in the main survey. Notably that significant negative association was found between households utilizing central HVAC systems with the general, ergonomic, nervous & skin symptoms ($p \leq .05$) by the MLR model using the building variables to predict those symptoms. However, the significance of that association did not sustain after adjusting the MLR model for the IEQ parameters.
2. Based on measured indoor and outdoor $CO_2$ concentrations and following $CO_2$ steady state method; estimated AERs in the living hall of the 60 households provided during measurement period ranged between 1.5 – 54.6L/s. person with a mean value of 13.2L/s. person and median value of 9.4L/s. person. The estimated AER was above the 7.5L/s. person which was considered as sufficient as per ASHRAE (2016) in 37 households (62%). Whereas it was below the 7.5L/s. person in 23 households (38%) which was considered as insufficient AERs as per ASHRAE (2016). Households that had unacceptable indoor TVOC, $CO_2$, $PM_{2.5}$, $PM_{10}$, T range, and RH range levels along with insufficient AERs were 20 (33%), 20 (33%), 23 (38%), 22 (37%), 23 (38.3%), and 12 (20%); respectively. Based on that, insufficient AERs may be one of the causes of attaining unacceptable contaminants' concentrations in those households.

## 5.2 Practical implications and recommendations

Reference to results shown in Section 5.1.1; complaints regarding SHS symptoms and poor IEQ conditions in Dubai housing is concerning. Those findings highlight the great need to promote IEQ conditions and mitigate prevalent SHS symptoms in Dubai housing. Results discussed in Section 5.1.2 suggests the risk factors associated with prevalent health symptoms in Dubai housing. They also revealed the great opportunity to mitigate those health symptoms when controlling the identified risk factors. To achieve that, collaborative efforts are required from all related bodies i.e. governmental establishments, academic institutions, building industry, and even occupants. Such efforts may involve contriving appropriate design and planning solutions, efficient contamination source controls, more stringent regulations, conducting useful research that fills current theoretical gaps, increasing the public awareness regarding the associations between poor housing IEQ conditions and adverse health symptoms, in addition to enhancing occupants' participation in managing related potential risks. Following Sections 5.2.1 – 5.2.4 describes the major practical implications and recommendations that can be derived from findings of this research.

### 5.2.1 Developing regulations and compliance enforcement

1. Concerning the non-compliance of indoor $PM_{2.5}$, $PM_{10}$, $CO_2$, TVOC, T, RH, and provided AERs with local and/or international limits (Section 5.1.1); the following implications can be derived:
    - Inaugurating and mandating an appropriate exposure limit for indoor $PM_{2.5}$ concentration in Dubai housing is of great importance. According to this study findings, indoor $PM_{2.5}$ concentrations is the most concerning as it was not complying with exposure limits established by (WHO 2013 & 2006; Health Canada 2012; EPA 2010) in all the houses in the field study. Reference to those recognized institutions, the non-compliance of $PM_{2.5}$ concentrations with established limits is of growing concern as it represents potential risk that threatens the health conditions of exposed occupants.

Despite that concern by those international in addition to local entities (EAD 2017); an exposure limit for indoor $PM_{2.5}$ concentration has not been regulated yet by DM. Mandating an appropriate exposure limit of $PM_{2.5}$ in housing spaces is crucial as it might help in mitigating probable adverse health effects associated with unacceptable levels in such spaces.

- Regular governmental investigations are crucially needed to monitor the compliance of indoor $PM_{10}$, $CO_2$, and TVOC levels in housing spaces with mandated limits as per DM (2016). Moreover, stringent regulations should be inaugurated to enforce the compliance with mandated limits. An example of similar investigations was launched by the Finland Ministry of Social affairs and Health in 2009 in which a working group was formed to carry on risk assessment programs of exposure to mould in damp buildings (Hellgren 2012). As discussed in Section 2.6, DM (2016) had recently mandated indoor air testing that must be conducted every five years in specified existing building types to ensure that the maximum limit for some IEQ parameters including TVOCs, $CO_2$, and $PM_{10}$ have not being exceeded. Included existing building types to comply with the above requirement are governmental buildings, educational buildings, health care buildings, hotels, shopping malls …etc. However, that testing every 5 years has the following two limitations:
    - Testing was not enforced on existing residential buildings. As per above results indoor TVOC, $CO_2$, and $PM_{10}$ concentrations were not complying with local regulations in substantial number of sampled houses. This indicates that compliance enforcement with such regulations is highly recommended. Regular testing in housing spaces may help in identifying buildings having unacceptable indoor contaminants' concentrations and subsequently launching appropriate contamination control methods
    - Testing should encompass more IEQ parameters than the currently specified ones. That is because revealed results of the field study indicated the non-compliance of T, RH, in addition to the provided

AERs in substantial number of sampled houses with locally mandated requirements by DM (2016). Moreover, the survey results found that poor indoor lighting quality was identified as risk factors that had statistically significant association with prevalent health symptoms in Dubai housing. However, the above parameters were not included in the required ones to be tested indoors every 5 years by DM (2016). The regular investigation regarding the above parameters is essential as it might help in mitigating probable adverse health effects that are associated with them.

2. The needs of hypersensitive or atopic individuals in addition to females should deliberately be considered and incorporated when establishing new regulations and policies related to the healthiness of IEQ conditions in housing spaces. As per attained results from the survey (Section 5.1.2); significant positive associations were found between atopic individuals and females with prevalent health symptoms in Dubai housing. Noteworthy, females and atopic individuals represent a substantial constituent of this study population. That accentuates the crucial need to afford those population groups a comfortable and healthy housing environment that suits their needs as vulnerable individuals.
3. Establishing convenient policies or strategies to manage the probable environmental risk of:
    - Incense burning
    - New paints

   That is because, revealed survey results suggested positive significant associations with the above parameters which is consistent with the findings of other relevant studies. According to (OSHA 2011a), management of pollution sources involves many strategies that either removes, replaces, and/or enfolds the sources i.e. establishing restrictions regarding some activities; replacement or banning of specific painting products; or instituting regulations regarding storage and use of paints and solvents. Example of such programs was that applied by the U.S. Consumer Product Safety Commission recommending the use of carpets with low VOC emissions and encouraging users to inquire about the compliance of the carpet industry with voluntary “green label” program when purchasing new ones (OSHA 2011a).

### 5.2.2 Enhancing public awareness

Attaining adequate level of public awareness regarding prevailing indoor air contaminants, their sources and efficient control methods that prevEye, nose, throat, and/or mitigate IEQ pollution and prevalent SHS is of great benefit. EPA (1991a) considered information, education, training and communication as essential foundations when applying both preventive and remedial IEQ management programs. Building occupants, maintenance, and management personnel can effectively cooperate to prevEye, nose, throat, and resolve poor IEQ problems when they thoroughly understand the reasons and consequences of these problems. Also, according to OSHA (2011a), educating building occupants about IEQ is vital because they can play an essential role in reducing their personal exposure to pollutants when they are well informed about the IEQ conditions and related potential health impacts. Hence, employing the valuable information furnished by this study may contribute in enhancing the public awareness and their participation in managing related potential risks. Following are the major risk factors – which represent good opportunities in attaining better IEQ conditions and mitigating prevalent health symptoms – that the public should acquire adequate knowledge and awareness about them.

1. Increasing public awareness regarding the following IEQ parameters suggested by the field study as concerning due to their indoor prevalence within unacceptable ranges as per local and/or international standards in substantial number of Dubai housing:
   - $PM_{2.5}$ and $PM_{10}$
   - TVOC
   - $CO_2$
   - T and RH
   - Provided AERs

2. Increasing public awareness regarding the following IEQ risk factors suggested by the survey results as concerning due to their significant associations with prevalent health symptoms in Dubai housing:
    - Indoor dimness
    - Dust and dirt
    - Stuffy bad air
    - Incense burning
    - Odors from new paint
3. Adequate public awareness is also required regarding the significant associations between the susceptible individuals – the atopic individuals in addition to females – and prevalent health symptoms. That may greatly help in affording them a comfortable and healthy housing environment that suits their needs as vulnerable individuals.
4. Enhancing the public awareness regarding associated indoor air contaminants with kitchens, their sources and efficient control methods that prevEye, nose, throat, and/or mitigate them i.e. housekeeping practices that encompass preventing dirt filtration from outdoors; removing dirt once entering the house; applying proper cleaning habits; selecting domestic products that reduce indoor pollutants; proper garbage disposal; and proper food storage.

### 5.2.3 Employing appropriate management methods

Reference to (OSHA 2011a and EPA 1991a), pollution source control can be an effective approach to manage poor IAQ and SHS prevalence in case of having identified contamination sources. Findings by this study identified related risk factors that represent good opportunities to mitigate prevalent health symptoms in Dubai housing if well managed. Another implication of the revealed results by this study is the need to employ appropriate and efficient control strategies described below. To satisfy that, all related professionals and stakeholders are expected to contribute in the proposition, development, and employment of practical and efficient methods that may enhance the IEQ conditions and mitigate prevalent health symptoms in Dubai housing.

1. Indoor lighting solutions i.e. adopting efficient and sustainable lighting solutions at city, community and individual buildings proposed by related professionals such as urban planners, architects, interior designers, electrical engineers … etc.
2. Indoor moisture control methods i.e. properly designed and constructed building envelopes, using moisture-tolerant materials capable to withstand repetitive wetting in expected moist spaces, HVAC systems equipped with dehumidification … etc.
3. Prevention techniques of dust and dirt infiltration to indoor spaces i.e. properly installed and maintained filters, proper urban planning strategies that appropriately allocate each zone of the built environment according to its anticipated functions and needs i.e. zoning, density, road networks … etc.
4. Management strategies of indoor combustion gases resulting from kitchen stoves i.e. provision of sufficient ventilation in kitchens, using vented stoves, proper installation, usage, and maintenance of fuel-burning appliances.

### 5.2.4 Need for further research

1. Further research on a representative sample of Dubai households is needed to:
    - Characterize indoor lighting conditions.
    - Explore the nature and concentrations of indoor air contaminants associated with the frequent IEQ and health complaints regarding:
        - Stuffy bad air.
        - Dust and dirt.
        - Smoke of incense burning.
        - Odors from new paints.
        - Indoor moisture levels.
        - Attached kitchens.
    - Measure indoor and outdoor concentrations of prominent contaminants in addition to the provided AERs that may help in
        - Exploring the associations between measured parameters and prevalent health symptoms.

        - Identifying contamination sources whether indoors or outdoors.
        - Assessing the compliance of regulated IEQ parameters with local and/or international standards.

2. Further intensive research is recommended concerning the associations between females and atopic individuals with IEQ comfort and prevalent health symptoms in housing spaces. Also, further research is needed to identify their housing IEQ comfort requirements such as exposure limits to indoor contamination, source control of indoor contamination, acceptable AERs, thermal comfort, noise comfort, and lighting comfort. Investigating housing IEQ comfort requirements for those vulnerable individuals may furnish vital recommendations that can be used as guidelines by professionals, stakeholders or policy makers when reviewing the current practices or proposing new ones.
3. Further research is recommended to fill the knowledge gap regarding the associations between the following building variables with SHS symptoms:
    - New carpets.
    - Split HVAC.
    - New wall covering.
    - Passive smoking

    That is because, despite the significant associations between above variables and the IEQ discomfort factors; no significant association was found between them with health symptoms. Also, findings of previous studies was inconstant regarding their associations with health symptoms as some results supported while others declined it. Hence, provided evidence by recent knowledge is insufficient yet to quantify probable health effects of those variables indicating the need for more research to fill that gap particularly in UAE. For instance, it is recommended to perform in-depth studies investigating the associations between SHS symptoms and carpets of different qualities i.e. organic, having dyes, CRI certified, … etc.

## 5.3 Ethical considerations and limitations

Ethical issues in educational research were directed by guidelines such as the AERA (2011) and BERA (2011). Usually, educational research is discharged by institutional ethical review board when attaining required ethical approval documents (Appendix N). The major ethical issues in empirical research are consent, harm, privacy, deception, and data confidentiality (Punch 2009). For instance, this research survey and field measurements conduct in participants' households implies many ethical practices. For example, respect was paid to the sociocultural background of UAE heterogeneous residents. Reference to research experiences in UAE reported by Yeatts et al. (2012b), acquiring considerable amount of knowledge, awareness, and flexibility are essential to incorporate diversified UAE societal norms. Such issues was deliberately considered and incorporated in this study protocol. For instance, some conservative UAE residents might find it culturally unacceptable for a female researcher to go alone into the men guest/living halls and interview the household men. To solve that, this study female researcher was accompanied by her husband in all field visits in households of which interested participants were males. Moreover, participants were fully informed about the study and their involvement implications via direct conversations and letter of consents. Two letters of consents were delivered to participants, one requesting participation in the cross-sectional survey and the other for the field study (Appendix L & Appendix M). Data confidentiality and anonymity was protected. Moreover, the researcher didn't falsify, fabricate, or plagiarize while suggesting proposals, reviewing data, nor when recording results. It was assured during research conduct that no harm was caused on participants i.e. violating privacy or using intrusive devices (Miller & Yang 2008) (Cohen et al. 2011) (Creswell 2012 & 2014).

Regarding the limitations of this study, one of them is the non-probability sampling strategy followed in the main survey. That is because the sample was not randomly selected as it allowed participation for only those who have convenient access to participate i.e. internet access or having social relation with the researcher. Probability sampling strategies has better potentiality than non-probability ones in yielding a representative sample and generalizable results (Alreck & Settle 2004). The known population size, sampling frame, sample size, and response rate are essential in calculating the sampling error and the approximate accuracy of results (Cresswell 2014). The concerns regarding the sample representativeness of non-probability strategies may threaten the external validity since the sample describes a specific sector that has convenient access or interest (Cohen et al 2011). Moreover, the sampling error in a non-probability design could not be estimated because of the unknown population size, sampling frame and response rate (Dillman 2009). Adopting random sampling, the most rigorous probability design, is not feasible in this research due to the: (i) difficulty of compiling a list of all UAE residents of whom 89% are mobile expatriates (Government .ae 2019; Snoj 2015), and (ii) lack of a fixed contact method for each household i.e. mail, phone numbers, or emails. It was also important to highlight that the study initially proposed a probability sampling strategy which is a multi-stage cluster and stratified random sampling method as an appropriate one demonstrated in Appendix W. Although less rigorous than random sampling, performing such a probability sampling method affords higher potentiality of attaining a representative sample and generalizable results compared with non-probability sampling. However, as informed by Dubai Statistics Center (DSC) (DSC 2017a), conducting a survey that involves visits to households in Dubai emirate is prohibited by law. Based on the above, distributing the questionnaires via the internet or personal communication is the only feasible way to report residents' perceptions regarding IAQ and SHS prevalence in Dubai residential buildings. Therefore, due to its non-probability sampling method, derived results from the main survey may be related to its particular sample and may not be generalizable.

Moreover, another limitiation regarding this study survey was its non-inclusion of any of the socio-economic variables that might have an impact on both the IEQ and SHS symptoms i.e. participants' educational levels, house size, income stratification, … etc. It is also important to note that one of the limitations of the cross sectional was the non inclusion of field measurements of any physical IEQ parameters due to the limited resources oriented to this study i.e. field measurements of T, RH, TVOC, $CO_2$, CO, $PM_{2.5}$, $PM_{10}$, …etc.. Due to that limitation, the associations between the subjective variables measured by the questionnaires and the objective variables measured on field might have been investigated. Additionally, one of the expectations of including the physical measurements in the performed statistical analysis was the probable improvement in the $R^2$ value of conducted MLR models.

Also, concerning the field study, the non-probability sampling strategy followed in it was also one of its limitations. Another limitation was its sample size that covered 60 households in Dubai. According to (Cohen et al. 2011; Delice et al 2010; Punch 2009), a sample size of (≥ 30) cases is acceptable. However, it is generally agreed on that the bigger the sample size, the higher potentiality to yield more rigorous results (Cohen et al. 2011). Similar sample size is capable in providing descriptive statistics regarding measured parameters. However, performing inferential statistical analysis utilizing the statistical tests in commonly used in relevant studies such as multiple linear or logistic regression models requires larger sample size ranging from 10 and 50 samples for each predictor; respectively (Schmidt & Finan 2018 & Josephat & Ame 2018). Though its small sample size, descriptive statistics furnished by the field study succeeded in providing sufficient indications regarding measured IEQ parameters and provided AERs in sampled households particularly in terms of their compliance with local and/or international standards. However, due to its non-probability sampling method and small sample size, derived results from the field study may be related to its particular sample and may not be generalizable.

Another limitation related to the field study was the performed spot measurements of TVOC, CO, and $CO_2$ concentrations in ambient air. Due to limited number of air monitoring equipment in addition to high level of insecurity concerning outdoor measurements; this study opted not to perform continuous measurements outdoor the households. Therefore, it is important to note that conducted spot measurements provided indications regarding TVOC, CO, and $CO_2$ concentrations in ambient air but they were insufficient in reporting the temporal changes over measurement period. Another limitation encountered by the field study was the inclusion of measurements' results of some readings remarkably above others. According to (Field 2016; Barker & Shaw 2015; UCLA 2018), similar observations or outliers may highlight a sample's uniqueness, contextual issues, measurement error, data entry error, or other undetected issues such as those illustrated in Table 4-52 . However, due to three reasons; this study opted neither to remove nor to conduct any other treatment for those readings from the data set. The first reason was the difficulty faced when detecting and confirming the reason of having such readings whether a sample's uniqueness, contextual issues, measurement error, data entry error, or other undetected issues. Thus, considering the probability that measured levels were authentic and that they represent unique observations associated with contextual issues within the sample; provided descriptive statistics of the physical measurements was furnished without conducting any treatments for the outliers. Secondly, this approach of not applying any treatment on the outliers was supported by many researches. For instance, according to (Schutte & Violette 1991; Nelson 2007), when dealing with outliers, there is neither consensus on what is the right analytical approach to follow nor specific cut offs to employ. According to them, it is difficult if not impossible to obtain an absolute set of criteria or procedures that is appropriate to all situations. Also, Muller & Mock (2009) advised statistical analysts to cautiously deal with data and not to simply exclude troublesome observations in order to slightly improve the model fit in most cases. Thirdly, it is important to note that measurement results in the field study were provided as descriptive statistics only but not as inferential statistics that sometimes has specific constraints regarding outliers imposed by the utilized statistical method. For instance, as described in Section 3.4.3 as part of the statistical analysis of the cross sectional survey; the conduct of the MLR models which is one of the inferential statistics methods necessitated treating the outliers because the method itself is based on certain assumptions regarding the outliers. In comparison, the statistical analysis of the field measurements was only descriptive one and did not employ any inferential statistical method that adopts particular assumptions or requirements concerning outliers. However, considering the probability of having those outliers due to a potential measurement error, the recommendation suggested by this study to conduct field measurements on a large and representative sample might not only help in exploring the associations between measured parameters with other IEQ and SHS symptoms but also in investigating the validity and reliability of attained results by this study.

# References

Abdel-Salam, M. (2012). Indoor particulate matter in different residential areas of Alexandria city, Egypt. *Indoor and Built Environment*, vol. 21(6), pp.857–862.

AbuDhabi2. (2018). *Nationality wise population in Seven Emirates of UAE* [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.abudhabi2.com/uae-population-by-nationality/

AD EHSMS. (2012). *Occupational air quality management*. Technical guideline. Version 2.0. Abu Dhabi Environment, Health, and Safety Management System Regulatory Framework 'EHSMS RF'.

AD OSHAD. (2016). *Abu Dhabi Occupational Safety and Health System Framework Code of Practice*. OSHAD-SF Technical guideline. Occupational air quality management. Version 3.0.

AD UPC. (2010). *The pearl rating system for Estidama. Emirate of Abu Dhabi*. Design & construction. Version 1.0 [Online]. [Last accessed 31 August 2018]. Available at: http://estidama.upc.gov.ae/template/estidama/docs/PBRS%20Version%201.0.pdf

AERA. (2011). *AERA code of ethics*. Approved by the AERA Council February 2011. Educational Researcher, vol. 40(3), pp.145-156.

AIHA. (2015). *Buyers' guide for OEHS professionals* [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.aiha.org/publications-and-resources/buyers-guide/Pages/Sampling,-Analytical,-and-Laboratory-Equipment.aspx

Al Jallad, F., Al Katheeri, E., Al Omar, M. (2013). Levels of particulate matter in Western UAE desert and factors affecting their distribution. *WIT Transactions on Ecology and the Environment*, vol. 174, pp.111–122.

Al-Attas, O., Hussain, T., Ahmed, M., Al-Daghri, N., Mohammed, A., De Rosas, E., Gambhir, D., Sumague, T. (2015). Ultra-structural changes, increased oxidative stress, inflammation, and altered cardiac hypertrophic gene expressions in heart tissues of rats exposed to incense. *Environmental Science and Pollution Research*, vol. 22, 13, pp. 10083 – 10093.

Albright, J., Park, M. (2009). Confirmatory Factor Analysis using Amos, LISREL , Mplus , SAS / STAT CALIS *. *The Trustees of Indiana University*, vol. 4724(812), pp. 86.

Algur, S. Biradar, J. (2017). Cooks distance and Mahanabolis distance outlier detection methods to identify review spam. *International Journal of Engineering And Computer Science*, vol. 6(6), pp. 21638-21649.

Ali, M. (2014). *The impact of indoor air quality on the prevalence of sick building syndrome in UAE houses*. A pilot study submitted as part of the PhD in Architecture and Sustainable Built Environment program. Faculty of Engineering & IT. British University in Dubai (BUiD).

Al-Rawas, O.A., Al-Maniri, A.A. & Al-Riyami, B.M. ( 2009). Home exposure to Arabian incense (bakhour) and asthma symptoms in children: a community survey in two regions in Oman. *BMC pulmonary medicine*, 9, p.23 [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2693130&tool=pmcentrez&rendertype=abstract

Alreck, P., Settle, R. (2004). *The survey research handbook*. Chicago: Irwin.

Alznafer, B. (2014). *The impact of neighbourhood geometries on outdoor thermal comfort and energy consumption from urban dwellings*: A case study of the Riyadh City, the Kingdom Of Saudi Arabia. Ph.D. Thesis. Cardiff University.

Amin, R., Telia, D., Jamesa, P., Bourikasa, L. (2016). The influence of a student's "home" climate on room temperature and indoor environmental controls use in a modern hall of residence. *Energy and Buildings*, vol. 119, pp.331–339.

Andersson, K. (1998). Epidemiological Approach to Indoor Air Problems. *Indoor Air*, 8(S4), pp.32-39.

Andersson, K. (2010). Epidemiological Approach to Indoor Air Problems*. *Indoor Air*, 8(S4), pp.32-39

Andersson, K. Stridh, G. (1991). The use of standardized questionnaires in building-related illness (BRI) and sick building syndrome (SBS) survey. In F. Levy & M. Maroni (Eds.), Epidemological and medical management of building-related complaints and illness. *NATA/CCMS pilot study on indoor air quality* (pp. 44-64). Oslow, Norway. Available online at: http://www.inomhusklimatproblem.se/publikations/publikationer/Referens51ny.pdf

Andersson, K., Fagerlund, I., Bodin, L., Ydreborg, B. (1988). Questionnaire as an instrument when evaluating indoor climate. *Healthy Buildings*, Vol. 3 (88), pp. 139-145.

Andersson, K., Stridh, G. (1991). *The use of standardized questionnaires in BRI/SBS surveys*. NATO/CCMS Pilot study on indoor air quality. [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.mmquestionnaire.se/publikations/publications/Reference03.pdf

Andersson, K., Stridh, G., Fagerlund, I., Larsson, B. (1993). *The MM-questionnaire – A tool when solving indoor climate problems*. Department of Occupational and Environment Medicine, Orebro, Sweden.

APHA. (2014). *National Healthy Housing Standard*. [Online]. [Last accessed 5 September 2018]. Avialable at: http://www.nchh.org/portals/0/contents/nhhs_full_doc.pdf.

Apte, K. Salvi, S. (2016). Household air pollution and its effects on health. F1000Research, vol. 5, p.2593. [Online]. [Last accessed 31 August 2018]. Avialable at: https://f1000research.com/articles/5-2593/v1

Argunhan, Z., Avci, A. (2018). Statistical Evaluation of Indoor Air Quality Parameters in Classrooms of a University. *Advances in Meteorology*, v. 2018 [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.hindawi.com/journals/amete/2018/4391579/

Asadi, E., Costa, J. J., & Gameiro da Silva, M. (2011). Indoor air quality audit implementation in a hotel building in Portugal. *Building and Environment*, vol. 46(8), 1617–1623.

ASHRAE. (2007). *ANSI/ASHRAE Standards 62.1-2007*. Ventilation for acceptable indoor air quality. Available online at: http://www.mintie.com/assets/pdf/education/ASHRAE%2062.1-2007.pdf

ASHRAE. (2016). *ANSI/ASHRAE Standards 62.1-2016*. Ventilation for acceptable indoor air quality. Available online at: https://www.ashrae.org/technical-resources/standards-and-guidelines/read-only-versions-of-ashrae-standards

Australian Bureau of Statistics. (2013). *Statistical Language: Measures of Shape*. [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.abs.gov.au/websitedbs/a3121120.nsf/home/statistical+language+-+measures+of+shape

Awbi H. (2008). Ventilation systems. NY: Taylor and Francis.

Azuma, K., Ikeda, K., Kagi, N., Yanagi, U, Osawa, H. (2015). Prevalence and risk factors associated with nonspecific building-related symptoms in office employees in Japan: relationships between work environment, Indoor Air Quality, and occupational stress. *Indoor Air*, vol. 25, pp. 499–511.

Ballance, D. (2015). Assumptions in Multiple Regression: A Tutorial. *Lecture*, pp.1–14. [Online]. [Last accessed 31 August 2018]. Avialable at:http://www.dianneballanceportfolio.com/uploads/1/2/8/2/12825938/assumptions_in_multiple_regression.pdf

Barakat-Haddad, C., Zhang, S., Siddiqua, A., Dghaim, R. (2015). Air Quality and Respiratory Health among Adolescents from the United Arab Emirates. *Journal of Environmental and Public Health*, vol. 2015(284595), pp.1–13.

Barker, E., Shaw, M. (2015). Best (but of t-forgotten) practices: checking assumptions concerning regression residuals. *The American Journal of Clinical Nutrition*, vol. 102(3), 533–539. [Online]. [Last accessed 5 September 2018]. Avialable at: http://doi.org/10.3945/ajcn.115.113498

Baron, R. and Kenny, D. (1986). The moderator-mediator variable distinction in socialpsychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology*, vol.51(6), pp.1173-1182.

Batia, B. (2012). *Design options for HVAC distribution system* [Online]. [Last accessed on 31 August 2018]. Available online at: http://www.pdhonline.org/courses/m147/m147content.pdf

Bayard, S, Jinot, J., Koppikar, A. (1992). Respiratory health effects of passive smoking: lung cancer and other disorders. *Tobacco Control*, vol. 2(1), p.525. [Online]. [Last accessed 31 August 2018]. Avialable at: http://tobaccocontrol.bmj.com/cgi/doi/10.1136/tc.2.1.71.

Beaumont, R. (2012). An introduction to Principal Component Analysis & Factor Analysis Using SPSS 19 and R ( psych package ). *Journal of Geophysical Research*. [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.floppybunny.org/robin/web/virtualclassroom/stats/statistics2/pca1.pdf

Becher, V., Per, S., Steinar, N., Jan, K., Jan, V. (2018). Do Carpets Impair Indoor Air

Quality and Cause Adverse Health Outcomes: A Review. *International Journal of Environmental Research and Public Health*, vol.15(2), p.184. [Online]. [Last accessed 8 Sept 2018]. Avialable at: http://www.mdpi.com/1660-4601/15/2/184

Behrens, T., Maziak, W., Weiland, S.K., Rzehak, P., Siebert, E., Keil, U. (2005). Symptoms of asthma and the home environment. The ISAAC I and III cross-sectional surveys in Münster, Germany. *Int. Arch. Allergy Immunol*. Vol. 137, pp. 53–61.

Behzadi, N., Fadeyi, M. (2012). A preliminary study of indoor air quality conditions in Dubai public elementary schools. *Architectural Engineering and Design Management*, vol.8(3), pp.192-213.

Belsley, A., Kuh, E., Welsch, E. (1980). *Regression diagnostics: Identifying Influential Data and Sources of Collinearity*. John Wiley: New York.

BERA. (2011). *Ethical guidelines for educational research*. London [Online]. [Last accessed 31 August 2018]. Available online at: http://www.bbk.ac.uk/sshp/research/sshp-ethics-committee-and-procedures/BERA-Ethical-Guidelines-2011.pdf

Berglund, L., Gonzalez, R., Gagge, A. (1990). *Predicting human performance decrement from thermal discomfort and ET*. Proceedings of the 5th International Conference on Indoor Air Quality and Climate, Toronto, Canada, vol. 1, pp. 215 – 220.

Bhatia, A. (2012). PDHonline Course M147: Design Options for HVAC Distribution Systems: Study guide. Meadow Estates Drive: PDH Center.

Blom, P., Skåret, E., Levy, F. (1993). The frequency of building related health complaints in Norway. *The 6th International Conference in Indoor Air Quality and climate. Indoor Air,* vol 1, pp. 321-326.

Brasche, S., Bullinger, M., Petrovitch, A., Mayer, E., Gebhardt, H., Herzog, V., & Bischof, W. (2005). Self-reported eye symptoms and related diagnostic findings – comparison of risk factor profiles. *Indoor Air*, 15(Suppl 10), 56–64.

Brembilla, E., Hopfe, C., Mardaljevic, J. (2018). Influence of input reflectance values on climate-based daylight metrics using sensitivity analysis. *Journal of Building Performance Simulation*, vol. 11(3), pp.333–349. [Online]. [Last accessed 31 August 2018]. Avialable at: https://doi.org/10.1080/19401493.2017.1364786

Brown, A. (2006). *Confirmatory factor analysis for applied research*. New York: Guilford Press.

Brown, A., Chorpita, F., Barlow, H. (1998). Structural relationships among dimensions of the DSM-IV anxiety and mood disorders and dimensions of negative affect, positive affect, and autonomic arousal. *Journal of Abnormal Psychology*, vol. 107, pp. 179-192.

Brown, D. (2011). *Likert items and scales of measurement?*. SHIKEN: JALT Testing & Evaluation SIG Newsletter, vol. 15(March), pp. 10–14.

Bryman, A., Cramer, D. (1999). *Quantitative Data Analysis with SPSS Release 8 for Windows*. A Guide for Social Scientists. London: Routledge.

Bryman, A., Cramer, D. (2005). *Quantitative Data Analysis with SPSS12 and 13*. A Guide for Social Scientists. East Sussex Routledge.

Bujang, M., Sa'at, N., Sidik, T. (2017). Determination of minimum sample size requirement for multiple linear regression and analysis of covariance based on experimental and non-experimental studies. Epidemiology Biostatistics and Public Health, vol.14(3), pp.e12117-1-e12117-9

Bullen, P. (2014). *How to pretest and pilot a survey questionnaire* [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.tools4dev.org/wp-content/uploads/how-to-pretest-and-pilot-a-survey-questionnaire.pdf

Butz, A., Breysse, P., Rand, C., Curtin-Brosnan, J., Eggleston, P., Diette, G., Williams, D., Bernert, J., Matsui, E. (2011). Household Smoking Behavior: Effects on Indoor Air Quality and Health of Urban Children with Asthma. *NIH Public Access*, vol. 15(4), pp.460–468.

Campell, M. (2012). *Sensor systems for environmental monitoring*. London: Springer Science & Business Media.

Carpet Institute of Australia Limited. (2002). Thermal Insulation Performance of Carpet. [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.carpetinstitute.com.au/wp-content/uploads/2014/02/factsh_thermal.pdf%0Ahttp://carpetinstitute.com.au/wp-content/uploads/2014/02/factsh_thermal.pdf.

Carpet Institute of Australia Limited. (2008). *Light reflectance*. [Online]. [Last accessed 8

Sept 2018]. Avialable at: https://www.carpetinstitute.com.au/wp-content/uploads/2015/06/Light-Reflectance-Fact-Sheet-FINAL.pdf

Carrer, P., Wolkoff, P. (2018). Assessment of indoor air quality problems in office-like environments: role of occupational health services. *Environmental Research and Public Health*, vol. 15 (741). [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.google.ae/search?safe=strict&ei=iK9cW4_6FcuYafXfubgM&q=stuffy+bad+air+and+chest+problems+mm+questionnaire&oq=stuffy+bad+air+and+chest+problems+mm+quest&gs_l=psy-ab.1.2.33i21k1j33i160k1l2.34076.41361.0.43950.9.9.0.0.0.0.274.1536.0j3j4.7.0....0...1c.1.64.psy-ab..2.4.921....0.GNVFLf9BWS0

Carter, S., Laird, C. (2005). 10 assessmEye, nose, throat, and care of ENT problems. *Emergency Medicine Journal*, vol. 22(2), pp.128–139.

CCOHS. (2019). *Environmental Tobacco Smoke (ETS): General Information and Health Effects*. [Online]. [Last accessed 1 April 2019]. Avialable at: https://www.ccohs.ca/oshanswers/psychosocial/ets_health.html

CDC. (2012). *Section 4: Properties of Frequency Distributions*. US Office of Public Health Scientific Services: Centers for Diseases Control and Prevention. [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.cdc.gov/ophss/csels/dsepd/ss1978/lesson2/section4.html

Ceballos, D., Burr, G. (2012). Evaluating a Persistent Nuisance Odor in an Office Building. *HHS Public Access*, vol.9(1), pp.1–13.

Centers for Disease Control and Prevention. (2010). Increasing questionnaire response rates. *Evaluation Briefs*, vol. 21, pp.1–2. [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.cdc.gov/healthyyouth/evaluation/pdf/brief21.pdf

Cha, Y., Abbasi, S., Olofsson, U. (2016). Indoor and outdoor measurement of airborne particulates on a commuter train running partly in tunnels. Proceedings of the Institution of Mechanical Engineers, Part F: *Journal of Rail and Rapid Transit*, vol. 0(0), 1–11.

Chang, C, Yang, H., Wang, Y., Li, M. (2015). Prevalence of sick building syndrome-related symptoms among hospital workers in confined and open working spaces.

*Aerosol and Air Quality Research*, vol. 15(6), pp.2378–2384.

Chatterjee, S, Hadi, S., Price, B. (2000). *Regression Analysis by Example*. 3rd edn. New York: Wiley.

Chatzidiakou, L., Mumovic, D. and Summerfield, A. (2015). Is $CO_2$ a good proxy for indoor air quality in classrooms? Part 1: The interrelationships between thermal conditions, CO2 levels, ventilation rates and selected indoor pollutants. *Building Services Engineering Research and Technology*, vol. 36(2), pp.129-161.

Chen, A., Cao, Q., Zhou, J., Nazaroff, W., Yang, B., Chang, C. (2014). Indoor/outdoor pollutant relationships in an air-conditioned room during and after the 2013 haze in Singapore. *Indoor Air 2014: 13th International Conference on Indoor Air Quality and Climate*. Hong Kong.

Chin, J., Godwin, C., Parker, E., Robins, T., Lewis, T., Harbin, P., Batterman, S. (2015). *NIH Public Access*. Vol. 24(4), pp.403–415.

Chirico, F., Ferrari, G., Giuseppe Taino, G., Oddone, E., Ines Giorgi, I., Imbriani, M. (2017). Prevalence and risk factors for Sick Building Syndrome among Italian correctional officers: A pilot study Italian Society of Integrative Psychotherapy for Social Development (SIPISS). *Journal of Health and Social Sciences*, vol. 21(March), pp.31–46.

Chumney, F. (2012). *Principal components cnalysis, exploratory factor analysis, and confirmatory factor analysis*. University of West Georgia Research Library.

City Population. (2016). UAE: Division of Dubai. [Online]. [Last accessed 8 September 2018]. Avialable at: https://www.citypopulation.de/php/uae-dubai.php

Cohen, L., Manion, L., Morrison, K. (2011). *Research methods in education*. London:RoutledgeFalmer.

Cohen, R., Sexton, K., Yeatts, K. (2013). Hazard assessment of United Arab Emirates (UAE) incense smoke. *Science of the Total Environment*, vol. 458–460, pp.176–186. [Online]. [Last accessed 31 August 2018]. Avialable at: http://dx.doi.org/10.1016/j.scitotenv.2013.03.101.

Comuzzi, C., Polese, P., Melchior, A., Portanova, R., Tolazzi, M. (2003). SOLVERSTAT: A new utility for multipurpose analysis. An application to the investigation of dioxygenated Co(II) complex formation in dimethylsulfoxide solution. *Talanta*, vol.

59(1), pp.67–80.

Costello, A., Osbourne, J. (2005). Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis. *Practical Assessment, Research & Evaluation*, 10(7), pp.1–9. [Online]. [Last accessed 31 August 2018]. Avialable at: http://graduate.tuiu.edu/res620sum08/Modules/Module03/FactorAnalysis.pdf.

Cracknell, A. and Varotsos, C. (2012). *Remote sensing and atmospheric ozone*. Berlin: Springer Science & Business Media.

Creswell, J. (2012). *Educational research. Upper Saddle River*. N.J.: Pearson/Merrill PrenticeHall.

Creswell, J. (2014). *Research design*. Thousand Oaks, Calif.: Sage Publications.

Davenport, L. (2016). Personal emails with GrayWolf Sensing Solutions LLC on Oct 2016 regarding the AdvancedSense Pro and DirectSense IQ – 610 devices.

Davidson, C., Funk, W., Boundy, M., Leith, D., Popkin, B., Gibson, J., Rusyn, I. and Olshan, A. (2012b). Conducting Environmental Health Research in the Arabian Middle East: Lessons Learned and Opportunities. *Environ Health Perspect*, vol.120(5), pp.632-636.

De Winter, J. C. F., & Dodou, D. (2014). Common factor analysis versus principal component analysis: a comparison of loadings by means of simulations. *Communications in Statistics - Simulation and Computation*, vol. 918 (December 2015), pp. 1–39.

Delice, A. (2010). The sampling issues in quantitative research. *Educational Sciences: Theory & Practice*, vol. 10 (4), pp.2001-2018.

Derbez, M., Berthineau, B., Cochet, V., Lethrosne, M., Pignon, C., Riberon, J., Kirchner, S. (2014). Indoor air quality and comfort in seven newly built, energy-efficient houses in France. *Building and Environment*, vol. 72, pp.173–187.

Derbez, M., Wyart, G., Le Ponner, E., Ramalho, O., Ribéron, J., Mandin, C. (2018). Indoor air quality in energy-efficient dwellings: Levels and sources of pollutants. Indoor Air, vol. 28(2), pp.318–338.

DeVellis, F. (1991). *Scale development*. NJ: Sage Publications.

DeVellis, R. (2012). *Scale development theory and applications*. 3rd edn. Thousand Oaks, CA: Sage.

DeVon, H. A., Block, M. E., Moyle-Wright, P., Ernst, D. M., Hayden, S. J., Lazzara, D. J. et al. (2007). A psychometric Toolbox for testing Validity and Reliability. *Journal of Nursing scholarship*, vol. 39 (2), pp. 155-164.

Dillman, D., Smyth, J., Christian, L. and Dillman, D. (2009). *Internet, mail, and mixed-mode surveys*. Hoboken, N.J.: Wiley & Sons.

DM. (2011). Green buildings regulations and specifications [Online]. [Last accessed 31 August 2018]. Avialable at:http://www.dewa.gov.ae/images/greenbuilding_eng.pdf

DM. (2014). *Dubai Municipality-Circular No.198*. Government of Dubai: Dubai Municipality. [Online]. [Last accessed 31 August 2018]. Avialable at: : https://login.dm.gov.ae/wps/wcm/connect/c87b8361-69ce-4346-bded-9be4f0ac968a/Circular+%28198%29+2014-+Implementation+of+GBRS+-+Arabic-English.pdf?MOD=AJPERES

DM. (2016). Al Sa'fat- Dubai Green Building Evaluation System. Version 1[Online]. [Last accessed 31 August 2018]. Avialable at: https://www.dm.gov.ae/wps/wcm/connect/6e4a9db8-ae3c-418e-918b-82e12d029cfa/Safat+book+english+spread.pdf?MOD=AJPERES

Dorizas, P., Assimakopoulos, M., Helmis, C. and Santamouris, M. (2015). An integrated evaluation study of the ventilation rate, the exposure and the indoor air quality in naturally ventilated classrooms in the Mediterranean region during spring. *Science of The Total Environment*, 502, pp.557-570.

DSC. (2016). Population by Gender - Emirate of Dubai. Government of Dubai: Dubai Statistics Center.

DSC. (2017a). Personal communications with Dubai Statistics Center via emails and phone calls on January and February 2017.

DSC. (2017b). Number of Population Estimated by Nationality- Emirate of Dubai. Government of Dubai: Dubai Statistics Center.

DSC. (2017c). Number of Estimated Population by Sector and Community - Emirate of Dubai. Government of Dubai: Dubai Statistics Center.

Dubai Business Guide. (2018). *United Arab Emirates and Dubai maps*. [Online]. [Last accessed 5 September 2018]. Avialable at:

http://www.dubaimanufacturing.com/united_arab_emirates_maps_gulf_cities_middle_east_territory_map.htm

Dubai Metrological Office. (2016). Dubai Climate [Online]. [Last accessed 31 August 2018]. Avialable at: https://services.dubaiairports.ae/DubaiMet/Met/Climate.aspx

Dunlea, E., Herndon, S., Nelson, D., Volkamer, R., Lamb, B., Allwine, E., Grutter, M., Ramos Villegas, C., Marquez, C., Blanco, S., Cardenas, B., Kolb, C., Molina, L. and Molina, M. (2006). Technical note: Evaluation of standard ultraviolet absorption ozone monitors in a polluted urban environment. *Atmospheric Chemistry and Physics*, vol. 6(10), pp.3163-3180.

EAD. (2014). *Enhancing air quality in Abu Dhabi*. Annual policy brief [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.ead.ae/Publications/Enhancing%20Air%20Quality%20in%20Abu%20Dhabi%202014/Enhancing-Air-Quality-in-Abu-Dhabi-2014.pdf

EAD. (2017). *Abu Dhabi State of Environment Report 2017*. UAE: Environmental Agency – Abu Dhabi.

Eastin, I., Mawhinney, D. (2011). *Japanese f-4star formaldehyde rating process for value-added wood products*. Working Paper 120. Japan: Center for International Trade in Forest Product (CINTRAFOR). [Online]. [Last accessed 8 September 2018]. Avialable at: https://digital.lib.washington.edu/researchworks/bitstream/handle/1773/35408/WP120F4StarRating.pdf?sequence=1

Eberly College of Science. (2018a). *Regression methods: Identifying Outliers (Unusual y Values): Study guideline*. USA: PSU. [Online]. [Last accessed 31 August 2018]. Avialable at: https://onlinecourses.science.psu.edu/stat501/node/339/

Eberly College of Science. (2018b). *Regression methods – Using leverages to help identify extreme x values: Study guideline*. USA: PSU. [Online]. [Last accessed 31 August 2018]. Avialable at: https://onlinecourses.science.psu.edu/stat501/node/338/

Eberly College of Science. (2018c). *Probability theory and mathematical statistics - Shapes of distributions: Study guideline*. USA: PSU. [Online]. [Last accessed 31 August 2018]. Avialable at: https://onlinecourses.science.psu.edu/stat414/node/187/

ECA. (1997). Total Volatile Organic Compounds (TVOC) in Indoor Air Quality

Investigation. *European Communities*, pp.1–45.

Egondi, T., Kyobutungi, C., Ng, N., Muindi, K., Oti, S. (2013). Community perceptions of air pollution and related health risks in Nairobi slums. *International Journal of Environmental Research and Public Health*, vol. 10(10), pp.4851–4868.

Ekici, M., Ekici, A., Akin, A., Altinkaya, V., Bulcun, E. (2008). Chronic airway diseases in adult life and childhood infections. *Respiration*, vol. 75, pp. 55–59.

Elf, M., Malmqvist, I. (2009). An audit of the contEye, nose, throat, and quality in briefs for Swedish healthcare spaces. *Journal of Facilities Management*, Vol. 7(3), pp.198-211

Elia, S., Micheal, G. (2009). Field Studies in the United States and United Kingdom of the effectiveness of mechanical ventilation systems on indoor air quality in hospitality venues where smoking is allowed in relation to outdoor air conditions. *ASHRAE Transactions*, vol. 115 (2), pp. 729 – 736.

Energy Dubai. (2018). *How to save on Energy Consumption*. [Online]. [Last accessed 8 Sept 2018]. Avialable at: http://www.energydubai.com/energy-consumers/save-energy-consumption/

Engvall, K. (2003). A Sociological Approach to Indoor Environment in Dwellings: Risk factors for sick building syndrome (sbs) and discomfort. PhD thesis. Faculty of Medicine. Acta Universitatis Upsaliensis.

Engvall, K., Norrby, C. and Sandstedt, E. (2004). The Stockholm Indoor Environment Questionnaire: a sociologically based tool for the assessment of indoor environmEye, nose, throat, and health in dwellings. *Indoor Air* vol. 14 (1), pp. 24-33.

EPA. (1989). *Indoor air quality and work environment study: EPA Headquarters Buildings*. Volume I: Employee Survey, U.S. Environmental Protection Agency. Research Triangle Park, NC. Atmospheric Research and Exposure Assessment Laboratory.

EPA. (1991a). *Building air quality guide: A guide for building owners and facility managers* [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.epa.gov/sites/production/files/2014-08/documents/iaq.pdf

EPA. (1991b*). Indoor air quality and work environment study*. EPA Headquarters' building. Volume III. Relating employees' responses to the follow-up questionnaire with environmental measurements of indoor air quality. Atmospheric research and expposure assessment laboratory office of research and development, U.S. EPA [Online]. [Last accessed 31 August 2018]. Avialable at: http://nepis.epa.gov/Exe/ZyNET.exe/91014FKP.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1991+Thru+1994&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C91thru94%5CTxt%5C00000027%5C91014FKP.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p%7Cf&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

EPA. (1997). An Office Building Occupant's Guide to Indoor Air Quality. *Indoor Environments Division*, vol. (October), pp.1–11.

EPA. (2001). *Summary and analysis report of the BASE study buildings selection process*. Work assignment V-01, Task 3 of Technical Directive 4. Contract 68D50164 [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.epa.gov/sites/production/files/2014-08/documents/base_building_selection_report.pdf

EPA. (2003). A Standardized EPA protocol for characterizing indoor air quality in large office buildings. *Indoor Environment Division US EPA. Washington, DC*. [Online]. [Last accessed 31 August 2018]. Avialable at: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:A+STANDARDIZED+EPA+PROTOCOL+FOR+CHARACTERIZING+INDOOR+AIR+QUALITY+IN+LARGE+OFFICE+BUILDINGS#7.

EPA. (2003). *A standardized epa protocol for characterizing indoor air quality in large office buildings*. Indoor Environment Division US EPA, Washington, DC, (September 2001).

EPA. (2010). *Integrated Science Assessment for Particulate Matter* [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.arb.ca.gov/research/health/pm-mort/ross.pdf

EPA. (2013). *Moisture control guidance for building design, construction and maintenance* [Online]. [Last accessed 8 September 2018]. Avialable at: www.epa.gov/iaq/moisture

EPA. (2015). *An introduction to indoor air quality* [Online]. [Last accessed 31 August 2018]. Avialable at: http://www2.epa.gov/indoor-air-quality-iaq/introduction-indoor-air-quality

EPA. (2015b). *List of designated reference and equivalent methods*. National exposure research laboratory human exposure & atmospheric sciences division (md-d205-03), Research Triangle Park, NC 27711.

EPA. (2016). *Indoor Particulate Matter*. [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.epa.gov/indoor-air-quality-iaq/indoor-particulate-matter

EPA. (2016a). *Indoor air quality house tour* [Online]. [Last accessed 31 August 2018]. Avialable at:https://www.epa.gov/indoor-air-quality-iaq/text-version-indoor-air-quality-house-tour

EPA. (2016b). *Methodology for the building assessment survey and evaluation study* [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.epa.gov/indoor-air-quality-iaq/methodology-building-assessment-survey-and-evaluation-study

EPA. (2017). *Care for Your Air: A Guide to Indoor Air Quality*. [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.epa.gov/indoor-air-quality-iaq/care-your-air-guide-indoor-air-quality#comb2

EPA. (2018). *Indoor air quality: Second-hand Smoke and Smoke-free Homes*. [Online]. [Last accessed 1 April 2019]. Avialable at: https://www.epa.gov/indoor-air-quality-iaq/secondhand-smoke-and-smoke-free-homes

Eriksson, N., Stenberg, B. (2006). Baseline prevalence of symptoms related to indoor environment. *Scandinavian Journal of Public Health*, vol. 34(4), pp.387–396.

Fadeyi, M., Alkhaja, K., Bin Sulayem, M., Abu-Hijleh, B. (2014). Evaluation of indoor environmental quality conditions in elementary schools' classrooms in the United Arab Emirates. *Frontiers of Architectural Research*, vol. 3(2), pp.166–177.

Ferry, O., Duffy, L., Ferreira, R. (2014). Early life environmental predictors of asthma age-of-onset. *Immun. Inflamm. Dis*, vol. 2, pp. 141–151.

Field, A. (2003). Exploratory factor analysis: Study guide [Online]. USA: University of South Carolina. [Last accessed 9 January 2019]. Avialable at: http://people.stat.sc.edu/habing/courses/530EFA.pdf

Field, A. (2005). *Discovering Statistics using SPSS*. 2nd edn. London: Sage.

Field, A. (2016). Linear models: Looking for bias [Online]. [Last accessed 9 January 2019]. Avialable at: http://www.statisticshell.com/docs/linearmodelsbias.pdf.

Fincham, J. (2008). Response rates and responsiveness for surveys, standards, and the Journal. *American journal of pharmaceutical education*, vol. 72(2), p.43.

Fisk, W.J., Black, D. & Brunner, G. (2011). Benefits and costs of improved IEQ in US offices. *Indoor Air*, vol. 21(5), pp.357–367.

Funk, W.E., Pleil, J.D., Pedit, J.A., Boundy, M.G., Yeatts, K.B., Nash, D.G., Trent, C.B., El Sadig, M., Davidson, C.A. and Leith, D. (2014) Indoor Air Quality in the United Arab Emirates. *Journal of Environmental Protection*, vol.5, pp. 709-722.

Gao, J., Wargocki, P. and Wang, Y. (2014). Ventilation system type, classroom environmental quality and pupils' perceptions and symptoms. *Building and Environment*, vol. 75, pp. 46-57.

Gennaro, G., Farella, G., Marzocca, A., Mazzone, A., Tutino, M. (2013). Indoor and Outdoor Monitoring of Volatile Organic Compounds in School Buildings: Indicators Based on Health Risk Assessment to Single out Critical Issues. *Int J Environ Res Public Health*, vol. 10(12), pp. 6273–6291.

Geology.com. (2008). *United Arab Emirates map and satellite image* [Online]. [Last accessed 31 August 2018]. Avialable at:http://geology.com/world/united-arab-emirates-satellite-image.shtml

Ghani, I., Ahmad, S. (2010). Stepwise multiple regression method to forecast fish landing. *Procedia - Social and Behavioral Sciences*, 8(5), pp.549–554. [Online]. [Last accessed 31 August 2018]. Avialable at: http://dx.doi.org/10.1016/j.sbspro.2010.12.076.

Ghosh, J., Wilhelm, M., Ritz, B. (2013). Effects of Residential Indoor Air Quality and Household Ventilation on Preterm Birth and Term Low Birth Weight in Los

Angeles County, California. *Am J Public Health* 103, vol. (4), pp. 686-694.

Gibson, J., Farah, Z. (2012). Environmental Risks to Public Health in the United Arab Emirates: A Quantitative AssessmEye, nose, throat, and Strategic Plan. *Environ Health Perspect*, vol.20(5), pp.681-686.

Gibson, J., Thomsen, J., Launay, F., Harder, E. and DeFelice, N. (2013). Deaths and Medical Visits Attributable to Environmental Pollution in the United Arab Emirates. *PLoS ONE*, vol. 8(3), p.e57536.

Gillham, B. (2007). *Developing a questionnaire*. London: Continuum.

Gomzi, M., Bobic, J. (2009). Sick building syndrome: Do we live and work in unhealthy environment? UDC 57:61. CODEN PDBIAD. ISSN 0031-5362. *Periodicum Biologorum*, vol. 111(1), pp. 79-84.

Gorsuch, R. L. (1983). *Factor Analysis*. Hillsdale: NJ: Erlbaum.

Goswami, K. (2018). Advances in carpet manufacture. 2nd edn. UK: Elsevier. [Online]. [Last accessed 8 Sept 2018]. Avialable at: https://books.google.ae/books?id=Py5HDgAAQBAJ&pg=PA3&lpg=PA3&dq=insulation+properties+of+carpet&source=bl&ots=WrmsNwBRXn&sig=mz79_9j27eeTlJ7ryXLwIfb_ShA&hl=en&sa=X&ved=2ahUKEwimr5P5tIHdAhUP2qQKHe3gD0o4FBDoATAFegQIBRAB#v=onepage&q=insulation%20properties%20of%20carpet&f=false

Government.ae. (2019). Population and demographic mix. [Online]. [Last accessed 18 March 2019]. Available at: https://www.government.ae/en/information-and-services/social-affairs/preserving-the-emirati-national-identity/population-and-demographic-mix

Goyal, R., Kumar, P. (2013). Indoor-outdoor concentrations of particulate matter in nine microenvironments of a mix-use commercial building in megacity Delhi. *Air Quality, Atmosphere and Health*, vol. 6(4), pp.747–757.

GrayWolf Sensing Solutions LLC. (2014). *AdvancedSense and DirectSense indoor air quality meters*. [Online]. [Last accessed 31 August 2018]. Avialable at: http://wolfsense.com/pdf/GrayWolf-Indoor-Air-Quality-IAQ-Meter-Brochure-lo.pdf

GrayWolf Sensing Solutions LLC. (2016). *AdvancedSense Pro Manual*. USA: 6 Research Dr. Shelton, CT 06484.

GrayWolf Sensing Solutions LLC. (2016). Utilizing PIDs ( for VOCs ) during IAQ Investigations : Photoionization detectors (PIDs) have become an invaluable tool for Indoor Air Quality (IAQ) investigators [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.wolfsense.com/app_notes/PID-IAQ-APP-Note-R2-814S.pdf

Graywolf Sensing Solutions LLC. (2016). Utilizing PIDs ( for VOCs ) during IAQ Investigations. GrayWolf Sensing Solutions LLC [Online]. [Last accessed 31 August 2018]. Avialable at: https://graywolfsensing.com/wp-content/appnotes/PID-IAQ-APP-Note-R2-814S.pdf

Grimm, L. G., & Yarnold, P. R. (1995). *Reading and understanding multivariate statistics*. Washington, DC: American Psychological Association.

Guo, P., Yokoyama, K., Fengyuan Piao, F., Kiyoshi Sakai, K., Khalequzzaman, M., Kamijima, M., Nakajima, T., Kitamura, F. (2013). Sick building syndrome by indoor air pollution in Dalian, China. *International Journal of Environmental Research and Public Health*, vol. 10(4), pp.1489–1504.

Hair, F.; Anderson, E.; Tatham, L.; Black, C. (1998). *Multivariate Data Analysis*. 5th edn. Prentice-Hall: Upper Saddle River.

Haladyna, T. (1999). *Developing and Validating multiple-choice test items*. New Jersey:

Hamilton. L. (2013). *Statistics with STATA: Version 12*. USA: Brooks/ Cole. [Online]. [Last accessed 31 August 2018]. Avialable at: https://books.google.ae/books?id=pUELAAAAQBAJ&pg=PA201&lpg=PA201&dq=which+is+better+the+general+cutoff+or+size+adjused+dfbeta&source=bl&ots=F3osV1MZau&sig=v42thDjWNW3LyE0afN8g_RUaviE&hl=en&sa=X&ved=0ahUKEwi8zo6796bcAhVEBcAKHVffDSE4ChDoAQiGATAJ#v=onepage&q=which%20is%20better%20the%20general%20cutoff%20or%20size%20adjused%20dfbeta&f=false

Harry, N., Boone, Jr. (2012). Analyzing likert data. *Journal of Extension*, vol. 50(2), pp. 1-5.

Haverinen-Shaughnessy, U. Shaughnessy, R., Cole, E., Toyinbo, O., Moschandreas, D. (2015). An assessment of indoor environmental quality in schools and its association with health and performance. *Building and Environment*, vol. 93(P1), pp.35–40. [Online]. [Last accessed 28 December 2018]. Available at: http://dx.doi.org/10.1016/j.buildenv.2015.03.006.

Haverinen-Shaughnessy, U., Moschandreas, J., Shaughnessy, J. (2011). Association between substandard classroom ventilation rates and students' academic achievement. *Indoor Air*, vol. 21(2), pp.121–131.

Hawkins, L., Wang, T. (1991). The office environment and the sick building syndrome. *Proceedings of IAQ 91: Healthy buildings.* ASHRAE. Atlanta.

Health Canada. (1989). *Exposure Guidelines for Residential Indoor Air Quality*. Safe Environments Programme [Online]. [Last accessed 31 August 2018]. Avialable at:http://www.hc-sc.gc.ca/ewh-semt/pubs/air/exposure-exposition/index-eng.php.

Health Canada. (2006). *Residential Indoor Air Quality Guideline – Formaldehyde* [Online]. [Last accessed 31 August 2018]. Canada: Ministry of health. Avialable at: https://www.canada.ca/content/dam/canada/health-canada/migration/healthy-canadians/publications/healthy-living-vie-saine/formaldehyde/alt/formaldehyde-eng.pdf

Health Canada. (2010). *Residential indoor air quality guideline*: *Carbon monoxide* [Online]. [Last accessed 31 August 2018]. Canada: Ministry of health. Avialable at: http://www.healthycanadians.gc.ca/publications/healthy-living-vie-saine/carbon-monoxide-carbone/alt/carbon-monoxide-carbone-eng.pdf

Health Canada. (2011). *Residential Indoor Air Quality Guideline: Toluene.* Canada: Ministry of health [Online]. [Last accessed 31 August 2018]. Canada: Ministry of health. Avialable at: http://www.hc-sc.gc.ca/ewh-semt/pubs/air/toluene/index-eng.php

Health Canada. (2012). Guidance for fine particulate matter ($PM_{2.5}$) in residential indoor air. Canada: Ministry of health. [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.canada.ca/content/dam/canada/health-canada/migration/healthy-canadians/publications/healthy-living-vie-saine/fine-particulate-particule-fine/alt/fine-particulate-particule-fine-eng.pdf

Health Canada. (2012*). Guidance for fine particulate matter* $PM_{2.5}$ *in residential indoor air.* Canada: Ministry of health [Online]. [Last accessed 31 August 2018]. Avialable at:http://healthycanadians.gc.ca/publications/healthy-living-vie-saine/fine-particulate-particule-fine/alt/fine-particulate-particule-fine-eng.pdf

Health Canada. (2013*). Guidance for Benzene in Residential Indoor Air*. Canada: Ministry of health [Online]. [Last accessed 31 August 2018]. Canada: Ministry of health. Avialable at: http://healthycanadians.gc.ca/publications/healthy-living-vie-saine/benzene/index-eng.php

Health Canada. (2016). *Residential indoor air quality guideline*. Canada: Ministry of health [Online]. [Last accessed 31 August 2018]. Canada: Ministry of health. Avialable at: http://healthycanadians.gc.ca/healthy-living-vie-saine/environment-environnement/air/guidelines-lignes-directrices-eng.php

Hedge, A., Erickson, W., Rubin, G. (1994). The effects of alternative smoking policies on indoor air quality in 27 office buildings. *Ann Occup Hyg*, vol. 38(3), pp. 265-278.

Hellgren, U. (2012). *Indoor air problems in Finnish hospitals – from the occupational health perspective*. Academic dissertation. Hjelt Institute. Department of Public Health. University of Helsinki. Finland. [Online]. [Last accessed 31 August 2018]. Avialable at: https://pdfs.semanticscholar.org/b473/55305094921f97aae2f9b901034ab671f43a.pdf

Hellgren, U., Hyvärinen, M., Holopainen, R. and Reijula, K. (2011). Perceived indoor air quality, air-related symptoms and ventilation in Finnish hospitals. *IJOMEH 24*, vol.(1), pp. 48-56.

Heloma A., Jaakkola, M. (2003). Four-year follow-up of smoke exposure, attitudes and smoking behaviour following enactment of Finland's national smoke-free work-place law. *Addiction*, vol. 98(8), pp. 1111–1117.

Heppner, P.P., Heppner, M. J., Lee, D., Wang, Y., Park, H., & W. L. (2006). DevelopmEye, nose, throat, and validation of a Collectivist Coping Style Inventory. *Journal of Counselling Psychology*, vol. 53(1), 107-125.

Herbig, B., Schneider, A., Nowak, D. (2016). Does office space occupation matter? The role of the number of persons per enclosed office space, psychosocial work characteristics, and environmental satisfaction in the physical and mental health of employees. *Indoor Air*, vol. 26(5), pp. 755-767.

Hertzog, M. (2008). Considerations in determining sample size for pilot studies. *Research* *in Nursing & Health*, vol. 31 (2), pp. 180 – 191.

Hess-Kosa, K. (2011). Indoor air quality. 1st ed. Boca Raton, FL: CRC Press.

Hirst, D. V. L., Gressel, M. G., Flanders, W. D., Gressel, Michael G., & Flanders, W. D. (2011). Short-Term Monitoring of Formaldehyde: Comparison of Two Direct-Reading Instruments to a Laboratory-Based Method. *Journal of Occupational and Environmental Hygiene*, vol. 8(6), 357–363.

Hoaglin, C., Welsch, E. (1978). The hat matrix in regression and ANOVA, *The American Statistician*, vol. 32, pp. 17-22.

Hodgson, A., Levin, H. (2003). *Classification of measured indoor volatile organic compounds based on noncancer health and comfort considerations*. USA: Lawrence Berkeley National Laboratory.

Hodgson, A., Rudd, A., Beal, D., Chandra, S. (2000). Volatile organic compound concentrations and emission rates in new manufactured and site-built houses. *Indoor Air*, vol. 10(3), pp. 178 – 192.

Huber, J. (1981). *Robust Statistics*. New York: Wiley.

Hulley, B., Cummings, B., Browner, S., Cummings, R., Hulley, G., Hearst, N. (2001). *Designing clinical research: An epidemiological approach*. Philadelphia: Lippincott, Williams, & Wilkins.

IEA. (2017). WEO-2017 Special Report: Energy Access Outlook 2017 - Executive Summary [Online]. [Last accessed 24 December 2018]. Available at: https://webstore.iea.org/download/summary/274?fileName=English-Energy-Access-Outlook-2017-ES.pdf.

Imon, A., Apu, M. (2016). Detection of High Leverage Points Using a Nonparametric Cut-off Point for the Robust Mahalanobis Distance. *Malaysian Journal of Mathematical Sciences*, vol. 10(3), pp.283–295.

Indraganti, M., Boussaa, D., Ooka, R., Rija, H. (2016). Thermal comfort and adaptation in Qatari and Japanese offices: A comparative overview. *空気調和・衛生工学会大会論文集*, vol. 2012, pp.3–6.

ISO. (2015a). *ISO 14001 key benefits* [Online]. [Last accessed 31 August 2018]. Avialable at:http://www.iso.org/iso/iso_14001_-_key_benefits.pdf

ISO. (2015b). *ISO 9001:2015*. [Online]. [Last accessed 31 August 2018]. Avialable at:

http://www.iso.org/iso/iso_9000

Jaakkola, J., Ieromnimon, A., Jaakkola, M. (2006). Interior surface materials and asthma in adults: A population-based incident case-control study. *American Journal of Epidemiology*, vol. 164(8), pp.742–749.

Janssen, J. (1999). The history of ventilation and temperature control. *ASHRAE Journal*, pp. 47-52. Available online at: file:///C:/Users/Dell/Downloads/2003627102652_326%20(2).pdf

Jayakumar, G., Sulthan, A. (2015). Exact distribution of Cook's distance and identification of influential observations. *Hacettepe Journal of Mathematics and Statistics*, vol. 44(1), pp.165–178.

JFS. (2007). *Study of sick house syndrome to start* [Online]. [Last accessed 8 September 2018]. Avialable at: https://www.japanfs.org/en/news/archives/news_id026636.html

Josephat, K., Ame, A. (2018). Effect of Testing Logistic Regression Assumptions on the Improvement of the Propensity Scores, *International Journal of Statistics and Applications*, vol. 8(1), pp.9–17.

Jurado, S., Bankoff, A. and Sanchez, A. (2014). Indoor Air Quality in Brazilian Universities. *International Journal of Environmental Research and Public Health*, vol.11(7), pp.7081-7093.

Kaiser, H. (1974). An index of factorial simplicity. *Psychometrika*, vol. 39 (1), pp. 31-36.

Kajander, J., Sivunen, M., Junnila, S. (2014). Valuing Indoor Air Quality Benefits in a Healthcare Construction Project with Real Option Analysis. *Buildings*, vol. 4(4), pp.785–805. [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.mdpi.com/2075-5309/4/4/785/

Kanazawa, A., Saito, I., Araki1, A., Takeda1, M., Ma1, M., Saijo, Y., Kishi1, R. (2010). Association between indoor exposure to semi-volatile organic compounds and building-related symptoms among the occupants of residential dwellings. *Indoor Air*, vol. 20(1), pp.72–84.

Kang, D. Kim, J. (2014). Fine, ultrafine, and yellow dust: Emerging health problems in Korea. *Journal of Korean Medical Science*, vol. 29(5), pp.621–622.

Kapalo, P., Domnita, F. and Lojkovics, J. (2014). Methodology for calculating the fresh airventilation airflow rate based on CO2 concentration. *Pollack Periodica*, vol. 9(2), pp.89-97.

Kielb, C., Lin, S., Muscatiello, N., Hord, W., Rogers-Harrington, J. and Healy, J. (2014). Building-related health symptoms and classroom indoor air quality: a survey of school teachers in New York State. *Indoor Air*, vol.25(4), pp.371-380.

Kishi, R., Ketema, R., Bamai, Y., Araki, A., Kawai, T., Tsuboi, T., Saito, I., Yoshioka, E., Saito, T. (2018). Indoor environmental pollutants and their association with sick house syndrome among adults and children in elementary school. *Building and Environment*, vol. 136, pp. 293-301.

Kjell, A., Stridh, G., Fagerlund, I., Aslaksen, W. (2014). *MM questionnaire. Manual: School environment* [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.researchgate.net/publication/228837562_MM_Questionnaire

Klauss, A., Tull, R., Roots, L., and Pfafflin, J. (1970). History of changing concepts of ventilation requirements. *ASHRAE Journal*, vol.12(6), pp. 34-43.

Knofczynski, G., Mundfrom, D. (2008). Sample sizes when using multiple linear regression for prediction. *Educational and Psychological Measurement*, vol. 68(3), pp.431–442.

Kraha, A., Turner, H., Nimon, K., Zientek, L., K. Henson, R. (2012). Tools to support interpreting multiple regression in the face of multicollinearity. *Frontiers in Psychology*, vol. 3(MAR), pp.1–16.

Lackey, R.,Wingate, L. (1998). *The pilot study: One key to research success*. In P.J. Brink & M.J. Wood (Eds.), Advanced design in nursing research. 2nd edn. Thousand Oaks, CA: Sage.

Laussmann, D., Helm, D. (2011). Air Change Measurements Using Tracer Gases: Methods and Results. Significance of air change for indoor air quality, Chemistry, Emission Control, Radioactive Pollution and Indoor Air Quality, Dr. Nicolas Mazzeo (Ed.), ISBN: 978-953-307-316-3, InTech [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.intechopen.com/books/chemistry-emission-control-radioactive-pollution-and-indoor-air-quality/air-change-measurements-using-tracer-gases-methods-and-results-significance-of-air-change-for-indoor

Lavy, S., Dixit, K. (2010). Facility Managers' Preferred Interior Wall Finishes In Acute-Care Hospital Buildings. *W070 - Special Track 18th CIB World Building Congress*, pp.26–39.

Lavy, S., Dixit, K. (2012). Wall finish selection in hospital design: a survey of facility managers. *Herd*, vol. 5(2), pp.80–98.

Lawrence Erlbaum. Hayes, S.C. (2002). Acceptance, Mindfulness, and Science. *American Psychological Association*, D12, pp. 101-105.

Lee, K., Choi, J., Lee, S., Park, H., Oh, Y., Kim, G., Lee, W., Son, B. (2018). Indoor levels of volatile organic compounds and formaldehyde from emission sources at elderly care centers in Korea. *PLoS ONE*, vol. 13(6), pp.1–15.

Leon, C., Davis, L., Kraemer, C. (2012). The role and interpretation of pilot studies in clinical research. *J Psychiatr Res*, vol. 45(5), pp. 626–629.

Less, B., Mullen, N., Singer, B., Walker, I. (2015). Indoor air quality in 24 California residences designed as high-performance homes. *Science and Technology for the Built Environment*, vol. (21), pp. 14-24.

Levin, H. (2010). *National programs to assess IEQ effects of building materials and products (EPA Contractor Report)*. Washington, DC: Indoor Environment Division Office of Radiation and Indoor Air US Environmental Protection Agency.

Li, R., Sekhar, C., Melikov, A. (2010). Thermal comfort and indoor air quality in rooms with integrated personalized ventilation and under-floor air distribution systems. *HVAC&R Research*, vol. 17(5), 829–846.

Liang, Z., Kvalheim, O. (1996). Robust methods for multivariate analysis—a tutorial review. *Chemometrics and intelligent laboratory systems*, vol. 32(1), pp.1–10. Available at: http://linkinghub.elsevier.com/retrieve/pii/0169743995000062.

Linderman, N. (2018). *What's the average survey response rate? [2018 benchmark]*. [Online]. [Last accessed 5 September 2018]. Avialable at: https://surveyanyplace.com/average-survey-response-rate/

Logue, M., Klepeis, N., Lobscheid, A., Singer, B. (2014). Pollutant exposures from natural gas cooking burners: A simulation-based assessment for Southern California. Environmental Health Perspectives, vol. 122(1), pp.43–50.

Logue, M., Price, N., Sherman, H., Singer, C. (2011). Assessment of indoor air quality benefits and energy costs of mechanical ventilation. LBNL Report Number 4945-E. Bekerly Lab. USA: California. [Online]. [Last accessed 31 August 2018]. Avialable at:https://homes.lbl.gov/sites/all/files/assessment-of-indoor-air-quality-lbnl4945e.pdf

Mack, N., Woodsong, C. (2005). *Qualitative research methods*. North Carolina: FLI.

Mangiafico, S. (2016). *Summary and Analysis of Extension Program Evaluation in R*. [Online]. [Last accessed 31 August 2018]. Avialable at: http://rcompanion.org/handbook/I_01.html

Mann, C. (2012). Observational research methods—Cohort studies, cross sectional studies, and case–control studies. *African Journal of Emergency Medicine*, vol. 2(1), pp.38-46.

McCarthy, M. (2016). *Data need to be normally-distributed, and other myths of linear regression* [Online]. [Last accessed 31 August 2018]. Avialable at: https://mickteaching.wordpress.com/2016/04/19/data-need-to-be-normally-distributed-and-other-myths-of-linear-regression/

McCormack, B., Hill, E. (1997). *Conducting a survey*. London: International Thomson Business Press.

McGill, G., Oyedele, O., McAllister, K. (2015). Case study investigation of indoor air quality in mechanically ventilated and naturally ventilated UK social housing. *International Journal of Sustainable Built Environment*, vol. 4(1), pp.58–77.

Mcneil, S. (2016). *The thermal properties of wool carpets*. Technical Bulletin. NZ: AgResearch Limited. [Online]. [Last accessed 8 Sept 2018]. Avialable at: https://www.researchgate.net/publication/298352974_The_Thermal_Properties_of_Wool_Carpets

Mečiarová, L., Vilˇceková, S., Burdová, E., Kiselák, J. (2017). Factors effecting the total volatile organic compound (TVOC) concentrations in slovak households. International Journal of Environmental Research and Public Health, vol. 14(12).

Mehamet, M., Jacobsen, T. (2017). *Applied Statistics Using Stata: A Guide for the Social Sciences*. UK: Sage publications. [Online]. [Last accessed 31 August 2018]. Avialable at: https://books.google.ae/books?id=RvhNDQAAQBAJ&pg=PA156&lpg=PA156&dq=when+to+use+size+adjusted+influential+statistics&source=bl&ots=MnLHAqJCrm&sig=x31f7weJ1f_Y1hflxLJ37TO4FX8&hl=en&sa=X&ved=0ahUKEwjOlOfD-

qbcAhXJfMAKHaGJBeAQ6AEIgwEwBw#v=onepage&q=when%20to%20use%20size%20adjusted%20influential%20statistics&f=false

Mendell, M. (1993). Non-Specific Symptoms in Office Workers: A Review and summary of the epidemiologic literature. *Indoor Air*, vol. 3(4), pp.227-236.

Mendell, M., Eliseeva, E., Davies, M., Spears, M., Lobscheid, A., Fisk, W., Apte, M. (2013). *Association of classroom ventilation with reduced illness absence: A prospective study in California elementary schools*. *Indoor air*, vol.23(6), pp. 515 - 528.

Meng, X., Han, J. (2018). Roads, economy, population density, and $CO_2$: A city-scaled causality analysis. *Resources, Conservation and Recycling*, v. 128, pp. 508-515.

Meyers, S., Gamst, G., Anthony G. (2006). Multiple Regression: Statistical Methods Using IBM SPSS. *Applied multivariate research: Design and interpretation*, pp.366–381.

Miller, E., Kunce, T. (1973). Prediction and statistical overkill revisited. *MeasuremEye, nose, throat, and Evaluation in Guidance*, vol. 6, pp. 157-163.

Miller, G., Yang, K. (2008). *Handbook of research methods in public administration*. New York: CRC Press.

Mishra, A., Ramgopal, M. (2015). A comparison of student performance between conditioned and naturally ventilated classrooms. *Building and Environment* , vol. 84, pp. 181-188.

Mohle, G. Crump, V. Brown, C. Hunter, R. Squire, H. Mann, G. Raw, J. (2003). DevelopmEye, nose, throat, and application of a protocol for the assessment of indoor air quality. *Indoor and Built Environment*, vol. 12(3), pp. 139-149.

Mølhave, L. (1990). *Volatile organic compounds, indoor air quality and health*. Proceedings of the fifth international conference on indoor air quality and climate, Toronto, Canada, July 29–August 3, 1990, Vol. 5, pp. 15–33.

Mommers, M., Jongmans-Liedekerken, W., Derkx, R., Dott, W., Mertens, P., Van Schayck, P., Steup, A., Swaen, M., Ziemer, B., Weishoff-Houben, M. (2005). Indoor environmEye, nose, throat, and respiratory symptoms in children living in the Dutch-German borderland. *Int. J. Hyg. Environ. Health* vol. 208, pp. 373–381.

Mongkolsawat, D., Marmot, A. and Ucci, M. (2014). A comparison of perceived learning performance of Thai university students in fan-assisted naturally ventilated and air-conditioned classrooms. *Intelligent Buildings International*, vol. 6(2), pp. 93-111.

Montero, L. (2017). The growth of world trade: The robustness of the evidence. *Iinvestigacion & desarrollo*, vol. 17(2), pp.5–19. [Online]. [Last accessed 5 September 2018]. Avialable at: http://www.upb.edu/revista-investigacion-desarrollo/index.php/id/article/view/159.

Morse, R. (2017). Indoor air quality and mold prevention of the building envelope. USA: National Institute of Building Sciences. [Online]. [Last accessed 8 September 2018]. Avialable at: https://www.wbdg.org/resources/indoor-air-quality-and-mold-prevention-building-envelope

Mortensen, H., Peuhkuri, R., Rode, C. (2005). Full scale tests of moisture buffer capacity of wall materials. *7th Nordic Symposium on Building Physics*, vol. (May 2016), pp.662–669.

Morton, S., Bandara, D., Robinson, E., Carr, P. (2012). In the 21st Century, what is an acceptable response rate? *Australian and New Zealand Journal of Public Health*, vol. 36(2), pp.106–108.

Mudari, D., Fisk, W. (2007). Public health and economic impact of dampness and mould. *Indoor Air*, vol. 17(3), 226-235.

Muller K., Mock, M. (2009). *Commun stat theory methods*. NIH Public Access, vol. 26(3), pp.389–399.

Munro, H. (2005). *Statistical methods for health care research*. Philadelphia: Lippincott, Williams & Wilkins.

Murphy, J., Bakkum, B. (2013). Understanding single-zone VAV systems. *Trane Engineers Newsletter*, vol. 42(2), pp. 1-9.

Myers, J., Well, A., Lorch, R. (2010). *Research Design and Statistical Analysis*. 3rd edn. New York: Routledge. [Online]. [Last accessed 31 August 2018]. Avialable at: **https://books.google.ae/books?id=7ep8FjCcloYC&pg=PA520&lpg=PA520&dq=cooks+distance+for+over+200+samples&source=bl&ots=RDuVYCzwvy&sig=VsQkSwSnmHP4R_5PqRoahPP5L_4&hl=en&sa=X&ved=0ahUKEwj62rz5zoPcAhWM7xQKHRdFDb4Q6AEIrQEwEA#v=onepage&q=cooks%20distance%20for%20over%20200%20samples&f=false**

Na, J., Byun, S., Jeong, M., Park, K., Huh, C. (2014). The effect of environmentally friendly wallpaper and flooring material on indoor air quality and atopic dermatitis: A pilot study. *Annals of Dermatology*, vol. 26(6), pp.688–692.

Napoli, C., Marcotrigiano, V. and Montagna, M. (2012). Air sampling procedures to evaluate microbial contamination: a comparison between active and passive methods in operating theatres. *BMC Public Health*, vol.12(1), p.594.

Nash, D., Leith, D. (2010). Use of Passive Diffusion Tubes to Monitor Air Pollutants. *Journal of the Air & Waste Management Association*, vol. 60(2), pp.204-209.

Nasir, A., Colbeck, I., Ali, Z., Ahmad, S. (2013). Indoor particulate matter in developing countries: A case study in Pakistan and potential intervention strategies. *Environmental Research Letters*, vol. 8(2).

Ndwiga, T., Kei, R., Jepngetich, H. and Korrir, K. (2014). Assessment of Health Effects Related to the Use of Biomass Fuel and Indoor Air Pollution in Kapkokwon Sub-Location, Bomet Country, Kenya. *Open Journal of Air Pollution*, vol. 03(03), pp.61-69.

Nelson,A. (2007). *Outliers and DFBETA: Study guideline*. USA: Rockefeller College. [Online]. [Last accessed 5 September 2018]. Avialable at: https://www.albany.edu/faculty/kretheme/PAD705/SupportMat/DFBETA.pdf

Nevalainen, A., Pasanen A., Niininen, M., Reponen, T., Jantunen, M. (1991). The indoor air quality in Finnish homes with mold problems. *Environ Int*, vol. 17 (4), 299–302.

Newsom., J. (2015). *Partial and Semipartial Correlation Example: Study guide*. USA: USP 654 Data Analysis II. [Online]. [Last accessed 5 September 2018]. Avialable at: http://web.pdx.edu/~newsomj/da2/ho_partial.pdf

Nicole, W. (2014). Cooking up indoor air pollution: Emissions from natural gas stoves. *Environmental Health Perspectives*, vol. 122(1), p.2103.

Nieswiadomy, M. (2002). Foundations of nursing research. 4th edn. Upper Saddle River, NJ: Pearson Education.

NIOSH . (2005). *Health Risk Evaluation for Carbon Dioxide ($CO_2$) General Information*. Appendix C. USA: NIOSH.

Niven, R., Fletcher, A., Pickering, C., Faragher, E., Potter, I., Booth, W., Jones, T., Potter, P. (2000). Building sickness syndrome in healthy and unhealthy buildings: An epidemiological and environmental assessment with cluster analysis. *Occupational* *and Environmental Medicine*, vol. 57(9), pp.627–634.

NOAA. (2013). *Climate Normals for Dubai* [Online]. [Last accessed 31 August 2018]. Avialable at: ftp://ftp.atdd.noaa.gov/pub/GCOS/WMO-Normals/RA-II/UE/41194.TXT

Norback, D., Edling, C. (1991). Environmental, occupational, and personal factors related to the prevalence of sick building syndrome in the general population. *British journal of industrial medicine*, vol. 48(7), pp.451–462.

Norbäck, D., Michel, I, Widström, J.(1990). Indoor air quality and personal factors related to sick building syndrome. *Scand J Work Environ Health*, vol. 6(2), pp.121-128.

Norback, D., Michel, I., Widstrom, J. (1990). Indoor air quality and personal factors related to the sick building syndrome. *Scandinavian Journal of Work, EnvironmEye, nose, throat, and Health*, vol. 16(2), pp.121–128.

Norbäck, D., Nordstrm, K. (2008). An experimental study on effects of increased ventilation flow on students' perception of indoor environment in computer classrooms. *Indoor Air,* vol.18 (4), pp. 293-300.

Norback,D., Bjornsson, E., Janson, C., Palmgren, U., Boman, G. (1991). Current asthma and biochemical signs of inflammation in relation to building dampness in dwellings. *International Journal of Tuberculosis & Lung Disease*, vol. 3(5), pp.368-76.

Norhidayaha, A., Chia-Kuanga, L., Azharb, Nurulwahidab,S. (2013). Indoor air quality and sick building syndrome in three selected buildings. *Procedia Engineering*, vol. 53(2010), pp.93–98. [Online]. [Last accessed 5 September 2018]. Avialable at: http://dx.doi.org/10.1016/j.proeng.2013.02.014.

Norman, G. (2010). Likert scales, levels of measuremEye, nose, throat, and the "laws" of statistics. *Advances in Health Sciences Education*, vol. 15(5), 625–632.

Nulty, D. (2008). The adequacy of response rates to online and paper surveys: What can be done? *AssessmEye, nose, throat, and Evaluation in Higher Education*, vol. 33(3), pp.301–314.

Nunnally, C., Bernstein, H. (1994). Psychometric theory. New York: McGraw-Hill.

O'Rourke, N., Hatcher, L. (2014). *A Step-by-Step Approach to Using SAS for Factor Analysis and Structural Equation Modeling*. 2nd edn. SAS Institute.

Obenchain, L. (1977). The Editor Technometrics. *Technometrics*, vol. 19(3), pp. 348-349.

OECD. (2011). OECD guide to measuring the information society [Online]. [Last accessed 16 October 2018]. Avialable at: https://books.google.ae/books?id=Q6ML46b4MpsC&pg=PA123&lpg=PA123&dq=12+month+recall+period+advantages&source=bl&ots=ZZYMxz3slt&sig=72WcqgCoOX-KVvF6O7S1JG8bWDw&hl=en&sa=X&ved=0ahUKEwjH5Ku1p5vcAhVF1xQKHbS_B6kQ6AEIUTAD#v=onepage&q=12%20month%20recall%20period%20advantages&f=false

Offerman, F. (2009). *Ventilation and indoor air quality in new homes*. California: California Energy Commission and California Air Resources Board.

Ogee, A., Ellis, M., K. Stone, B., Scibilia, B., Pammer, C., Steele, C. (2015). *Choosing between a nonparametric test and a parametric test*. [Online]. [Last accessed 31 August 2018]. Avialable at: http://blog.minitab.com/blog/adventures-in-statistics-2/choosing-between-a-nonparametric-test-and-a-parametric-test

Ohlan, R. (2015). The impact of population density, energy consumption, economic growth and trade openness on $CO_2$ emissions in India. *Natural Hazards*, v. 79 (2), pp. 1409 – 1428.

Omondi, D., Collins O., Onyango, R., Onyango, M., Bertrand, J. (2014). Systematic monitoring of male circumcision scale-up in Nyanza, Kenya: Exploratory factor analysis of service quality instrumEye, nose, throat, and performance ranking. *PLoS ONE*, vol. 9(7), pp.3–9.

Ooi, L., Goh, T., Phoon, H., Foo, C., Yap, M. (1998). Epidemiology of sick building syndrome and its associated risk factors in singapore. Occupat. Environ. *American Journal of Epidemiology*, vol. 154(9), p.Med., 55: 188-193. DOI: 10.1136/oem.55.3.188. [Online]. [Last accessed 5 September 2018]. Avialable at: http://aje.oupjournals.org/cgi/doi/10.1093/aje/154.9.803.

OSHA. (1978). *Occupational health guideline for hydrogen sulfide* [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.cdc.gov/niosh/docs/81-123/pdfs/0337.pdf

OSHA. (1999a). *OSHA technical manual*. Section III: Chapter 2. Indoor air quality investigation [Online]. [Last accessed 31 August 2018]. Avialable at:

https://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_2.html#footnote1

OSHA. (1999b). *US OSHA 1910.1000 Table Z-1 Limits for air contaminants* [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9992

OSHA. (2011a). *Indoor air quality in commercial and institutional buildings*[Online]. [Last accessed 31 August 2018]. Avialable at: https://www.osha.gov/Publications/3430indoor-air-quality-sm.pdf

OSHA. (2011b). *OSHA Fact sheet. Formaldehyde* [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.osha.gov/OshDoc/data_General_Facts/formaldehyde-factsheet.pdf

OSHA. (2014). *OSHA Technical Manual. Section II: Chapter 3*. Technical Equipment: On-site measurements [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.osha.gov/dts/osta/otm/otm_ii/otm_ii_3.html

Oxford University Press. (2017). *Oxford referene* [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.oxfordreference.com/view/10.1093/oi/authority.20110803100327545

Oyeyemi, M., Bukoye, A., Akeyede, I. (2015). Comparison of Outlier Detection Procedures in Multiple Linear Regressions. *American Journal of Mathematics and Statistics*, vol. 5(1), pp.37–41.

Park, J., Jee, N., Jeong, J. (2014). Effects of types of ventilation system on indoor particle concentrations in residential buildings. *Indoor Air*, vol. 24(6), pp.629-638.

Parsian, N., Dunning, T. (2009). Developing and validating a questionnaire to measure spirituality: A psychometric process. *Global Journal of Health Science*, vol. 1(1), pp. 2–11.

Pedhazur, J., Schmelkin, P. (1991). *Measurement, design, and analysis: An integrated approach*. Hillside. NJ: Lawrence Erlbaum.

Peretti, C., Schiavon, S. (2011). *Indoor environmental quality surveys: A brief literature review*. UC Berkeley: Center for the built Environment. [Online]. [Last accessed 31 August 2018]. Avialable at: https://escholarship.org/uc/item/0wb1v0ss

Persily, A. (2016). Field measurement of ventilation rates. *Indoor Air*, vol. 26(1), pp.97–

111.

Persily, A. (2016). *Indoor carbon dioxide concentrations in ventilation and indoor air quality standards*. USA: National Institute of Standards and Technology.

Persily, A., Gorfain, J. (2008). *Analysis of ventilation data from the US Environmental Protection Agency Building Assessment Survey and Evaluation (BASE) Study*. Gaithersburg, MD: National Institute of Standards and Technology.

Persily, A., Gorfain, J. and Brunner, G. (2005) Ventilation rates in US office buildings from the EPA BASE study, Indoor

Persily, A., Jonge, L. (2017). *Carbon dioxide generation rates for building occupants*. USA: John Wiley & Sons Ltd.

Petr Keil, P. (2013). *Predictors, responses and residuals: What really needs to be normally distributed?*. [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.petrkeil.com/?p=393

Pilot, D., Hunger, B. (1999). *Nursing research: principals and methods*. Philadelphia: Lippincott Williams & Wilkins.

Portugal Ministério das obraspúblicas, transportes e comunicações. (2007). *Accident Investigation Final Report* [Online]. [Last accessed 31 August 2018]. Avialable at: http://lessonslearned.faa.gov/AirTransat236/AirTransat236_AccidentReport.pdf

POST. (2010). *UK indoor air quality*: *Postnote366* [Online]. [Last accessed 31 August 2018]. Avialable at: http://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PN366#fullreport

Punch, K. (2009). *Introduction to research methods in education*. Los Angeles: Sage.

Raw, G., Roys, M., Whitehead, C., Tong, D. (1996). Questionnaire design for sick building syndrome: An empirical comparison of options. *Environment international*, vol. 22(1), pp.61–72. [Online]. [Last accessed 5 September 2018]. Avialable at: http://linkinghub.elsevier.com/retrieve/pii/0160412095001042.

Ray-Mukherjee, J., Nimon, K., Mukherjee1, S., Morris, D., Slotow, R., Hamer, M. (2014). Using commonality analysis in multiple regressions: A tool to decompose regression effects in the face of multicollinearity. *Methods in Ecology and Evolution*, vol. 5(4), pp.320–328.

Reijula, K., Sundman-Digert, C. (2004). Assessment of indoor air problems at work with a questionnaire. *Occup Environ Med*, vol. 61, pp.33–38.

Reinikainen L., Jaakkola J. (2003). Significance of humidity and temperature on skin and upper airway symptoms. *Indoor Air*, vol. 13(4), pp. 344–52.

RKI Instruments Inc. (2003). *Instruction Manual for formaldehyde gas detector Model FP-30/FP-40* [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.rkiinstruments.com/pdf/mfp3040.pdf

RKI Instruments Inc. (2012). *Instruction Manual for formaldehyde gas detector Model FP-30/FP-40. PT0E – 0411*. Japan: RIKEN KEIKI CO., Ltd.

RKI Instruments Inc. (2016). Personal emails with RKI Inc. on July 2016 regarding certificates of Formaldehyde gas detector Model FP 30.

RKI Instruments Inc. (2017). *Formaldehyde gas detector*. Data sheet of FP 30 Model[Online]. [Last accessed 31 August 2018]. Avialable at: http://rkiinstruments.com/pdf/fp30.pdf

Roll-Hansen, N. (2009). *Why the distinction between basic (theoretical) and applied (practical) research is important in the politics of science*. Technical Report 04/09. Centre for the Philosophy of Natural and Social Science [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.lse.ac.uk/CPNSS/research/concludedResearchProjects/ContingencyDissentInScience/DP/DPRoll-HansenOnline0409.pdf

Runeson, R., Norb€ack, D. (2013). Sick building syndrome (SBS) and sick house syndrome (SHS) in relation to psychoso- cial stress at work in the Swedish work-force, Int. Arch. Occup. *Environ. Health*, vol. 86, pp. 915–922.

Runeson, R., Wahlstedt, K., Wieslander, G., Norback, D. (2006). Personal and psychosocial factors and symptoms compatible with sick building syndrome in the Swedish workforce. *Indoor Air*, vol. 16(6), pp.445–453.

Runeson-Broberg, R., Norbäck, D. (2013). Sick building syndrome (SBS) and sick house syndrome (SHS) in relation to psychosocial stress at work in the Swedish workforce. *Int Arch Occup Environ Health*, vol. 86, pp. 915–922.

Ruotsalainen, R., Jaakkola, N., Jaakkola, J. (1994). Ventilation rate as a determinant of symptoms and perceived odors among workers in daycare centers. *Environment*

*International*, vol. 20(6), pp. 731-737

Sabra, O., Maria, I., Al Zayer, M., Saleh, A. (2015). Frequency of migraine as a chief complaint in otolaryngology outpatient practice. *BioMed Research International*, vol. 2015. [Online]. [Last accessed 5 September 2018]. Avialable at: http://dx.doi.org/10.1155/2015/173165

Sahlberg, B., G.Wieslander, G., Norbäck, D. (2009). Sick building syndrome in relation to domestic exposure in Sweden – A cohort study from 1991 to 2001. *Scandinavian Journal of Public Health*, vol.38, pp. 232-238.

Sahlberg, B., Norbäck, D. (2009). Indoor environment in dwellings, asthma, allergies, and sick building syndrome in the Swedish population: a longitudinal cohort study from 1989 to 1997. *Int Arch Occup Environ Health*, vol. 82, pp. 1211-1218

Sahlberg, B., Norbäck, D., Wieslander, G., Gislason, T., Janson C. (2012). Onset of mucosal, dermal and general symptoms in relation to bio-markers and exposures in the dwelling. A cohort study from 1992 to 2002. *Indoor Air 2012* (in press).

Sahlberg, O. (2012). *Indoor environment in dwellings and sick building syndrome (SBS)*. PhD dissertation. Uppsala University: Faculty of Medicine. [Online]. [Last accessed 5 September 2018]. Avialable at: https://www.diva-portal.org/smash/get/diva2:523987/FULLTEXT01.pdf;Indoor

Sakellaris, I., Saraga, D., Mandin, C., Roda, C., Fossati, S., Kluizenaar, Y., Carrer, P., Dimitroulopoulou, S., Mihucz, V., Szigeti, T., Hänninen, O., Fernandes, E., John, B., Philomena, B. (2016). Perceived indoor environmEye, nose, throat, and occupants' comfort in European "Modern" office buildings: The OFFICAIR Study. *International Journal of Environmental Research and Public Health*, vol. 13(5), pp. 1–15.

Salama, M., Al Saber, T. (2013). *Imposing building regulations in Dubai*: 29th Annual ARCOM Conference Proceedings, 24 September 2013. Uk: Reading, Association of Researchers in Construction Management, 1309-1320 [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.arcom.ac.uk/-docs/proceedings/ar2013-1309-1320_Salama_AlSaber.pdf

Saleh, A., Bista,K. (2017). Examining factors impacting online survey response rates in educational research: Perceptions of graduate students. *Journal of Multi*

*Disciplinary Evaluation*, vol. 13(29), pp.63–74. [Online]. [Last accessed 5 September 2018]. Avialable at: http://journals.sfu.ca/jmde/index.php/jmde_1/article/view/487.

SAS Institute Inc. (2015). *SAS/STAT(R) 14.1 User's Guide: The REG Procedure*. [Online]. [Last accessed 31 August 2018]. Avialable at: http://support.sas.com/documentation/cdl/en/statug/68162/HTML/default/viewer.htm#statug_reg_details26.htm

Schmidt, F., Finan, C. (2018). Linear regression and the normality assumption. *Journal of Clinical Epidemiology*, vol. 98, pp.146–151. [Online]. [Last accessed 5 September 2018]. Avialable at: https://doi.org/10.1016/j.jclinepi.2017.12.006

Schutte, M., Violette, M. (1991). The treatment of outliers and influential observations in regression-based impact evaluation how to identify influential. [Online]. [Last accessed 5 September 2018]. Avialable at: https://aceee.org/files/proceedings/1994/data/papers/SS94_Panel8_Paper20.pdf

Seifert B. (1990). *Regulating indoor air*: Proceedings of the fifth international conference of indoor air and climate. 29 July – 3 August. USA: Toronto.

Seppanen, O., Fisk, W. and Mendell, M. (1999). Association of Ventilation Rates and $CO_2$ Concentrations with Health and other Responses in Commercial and Institutional Buildings. *Indoor Air*, vol. 9(4), pp.226-252.

Seppänen, O.; Kurnitski, J. Target Values for Indoor Environment in Energy-Efficient Design. (2013). *In Cost Optimal and Nearly Zero-Energy Buildings (NZEB): Definitions, Calculation Principles and Case Studies*. Kurnitski, J., Ed.; Springer: London, UK, pp. 57–78.

Shaughnessy, R., Haverinen-Shaughnessy, U., Nevalainen, A. Moschandreas, D. (2006). A preliminary study on the association between ventilation rates in classrooms and student performance. *Indoor Air*, vol. 16(6), pp.465-468.

Sigma-Aldrich. (2016). *Passive (Diffusive) Sampling Overview*. [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.sigmaaldrich.com/analytical-chromatography/air-monitoring/passive-sampling.html

Silvia Vilˇceková, S., Burdová, E., Kiselák, J. (2017). Factors effecting the total volatile organic compound (TVOC) concentrations in Slovak households. *International*

*Journal of Environmental Research and Public Health*, vol. 14(12).

Simonof, J. (2016). Regression diagnostics: Study guide. USA:NYU. [Online]. [Last accessed 31 August 2018]. Avialable at: http://people.stern.nyu.edu/jsimonof/classes/2301/pdf/diagnost.pdf

Sincero, M. (2012). *What is a Pilot Survey* [Online]. [Last accessed 31 August 2018]. Avialable at: https://explorable.com/pilot-survey

Singapore Public Health Ministry of the Environment. (1996). *Guidelines for good indoor air quality in office premises* [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.bca.gov.sg/GreenMark/others/NEA_Office_IAQ_Guidelines.pdf

Singapore public health. (1996). *Guidelines for good indoor air quality in office premises*. Ministry of the environment: Institute of Environmental Epidemiology.

Singh, A., Syal, M., Korkmaz, S., and Grady, S. (2011). Costs and Benefits of IEQ Improvements in LEED Office Buildings. *J. Infrastruct. Syst*., 10.1061/(ASCE)IS.1943-555X.0000046, 86-94.

Singleton, R., Salkoski, A., Bulkow, L., Fish, C., Dobson, J., Albertson, L., Skarada, J., Kovesi, T., McDonald, C., Hennessy, T., Ritter, T. (2017). Housing characteristics and indoor air quality in households of Alaska Native children with chronic lung conditions. Indoor Air, vol.27(2), pp.478–486.

Sivunen, M., Kosonen, R. & Kajander, J. (2014). Good Indoor EnvironmEye, nose, throat, and Energy Efficiency Increase Monetary Value of Buildings. *REHVA Journal*, vol 51(4), pp.6–9.

Sivunen, M., Kosonen, R., Kajander, J. (2014). Good indoor environmEye, nose, throat, and energy efficiency increase monetary value of buildings. *REHVA Journal*, vol. 51(4), pp.6–9.

Skorge, D., Eagan, M., Eide, E., Gulsvik, A., Bakke, S. (2005). Indoor exposures and respiratory symptoms in a Norwegian community sample. *Thorax*, vol. 60, pp. 937–942.

Snoj, J. (2015). UAE's population – by nationality. *BQ Magazine* [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.bq-magazine.com/economy/socioeconomics/2015/04/uae-population-by-nationality

SPSS Tutorials. (2018). *SPSS Stepwise Regression – Example 2*. [Online]. [Last accessed 5

September 2018]. Avialable at: https://www.spss-tutorials.com/spss-stepwise-regression-example-2/#ref1

Standardization Administration of the People's Republic of China. (2002). *Indoor air* quality standards, GB/T 18883-2002 [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.mep.gov.cn/image20010518/5295.pdf

Stanke, D. (1999). Ventilation through the years: A perspective. *ASHRAE Journal*, pp. 40-43 [Online]. [Last accessed 31 August 2018]. Avialable at: bookstore.ashrae.biz/journal/download.php?file=stanke.pdf

Stein, B., Reynolds, J., Grondzik, W., Kwok, A. (2000). *Mechanical and electrical equipment for buildings*. NY: Wiley publications.

Sternberg, B., Eriksson, N., Hansson, M. (1993). The office illness project in Northern Sweden – An interdisciplinary study of the sick building syndrome (SBS). *Proceedings of the 6th International Conference on Indoor Air Quality and Climate*, vol. 1, Helsinki.

Stevens, J. (2002). *Applied Multivariate Statistics for the Social Sciences*. 4th edn. Mahwah, NJ: Lawrence Erlbaum Associates.

Strand, S. , Cadwallader, S., Firth, D. (2011). Assumptions for Multiple Regression. University of Southampton: National Centre for Reseaech Methods. [Online]. [Last accessed 5 September 2018]. Avialable at: http://www.restore.ac.uk/srme/www/fac/soc/wie/research-new/srme/modules/mod3/3/index.html

Suhr, D. (2005). Principal component analysis vs. exploratory factor analysis. *SUGI 30 Proceedings*, pp. 203–230. [Online]. [Last accessed 31 August 2018]. Avialable at: http://www2.sas.com/proceedings/sugi30/203-30.pdf

Suhr, D. (2006). Exploratory or confirmatory factor analysis?. *SUGI 31 Proceedings*, pp. 1–17. [Online]. [Last accessed 31 August 2018]. Avialable at: http://www2.sas.com/proceedings/sugi31/200-31.pdf

Sulaiman, Z., Mohamed, M. (2011). Indoor air quality and sick building syndrome study at two selected libraries in Johor Bahru, Malaysia. *EnvironmentAsia*, vol. 4(1), 67–74.

Suliman, A, Abdelrahman, A., Abdalla, A. (2010). Personality traits and work performance in a duty-free industry. *International Journal of Commerce and Management*, vol. 20(1), pp. 64–82.

Suliman, A., Al Kathairi, M. (2013). Organizational justice, commitmEye, nose, throat, and performance in developing countries The case of the UAE. *Employee Relations*, vol. 35(9), 98–115.

Sullivan, G. and Artino, A. (2013). Analyzing and Interpreting Data From Likert-Type Scales. *Journal of Graduate Medical Education*, vol. 5(4), pp.541-542.

Sundell, J. (2004). On the history of indoor air quality and health. *Indoor Air, Supplement*, vol. 14(SUPPL. 7), pp.51–58.

Sundell, J., Levin, H., Nazaroff, W., Cain, W., Fisk, W., Grimsrud, D., Gyntelberg, F., Li, Y., Persily, A., Pickering, A., Samet, J., Spengler, J., Taylor, S. and Weschler, C. (2011). Ventilation rates and health: multidisciplinary review of the scientific literature. *Indoor Air*, vol. 21(3), pp.191-204.

Syazwan, A., Hafizan, J., Baharudin, M., Azman, A., Izwyn, Z., Zulfadhli, I., Syahidatussyakirah, K. (2013). Gender, airborne chemical monitoring, and physical work environment are related to indoor air symptoms among nonindustrial workers in the Klang Valley, Malaysia. *Therapeutics and Clinical Risk Management*, vol. 9(1), pp.87–105.

Szczepanik-ścisło, N. (2018). Measurements and simulation of $CO_2$ concentration in a bedroom of a passive house. *Czasopismo Techniczne*, vol. 9, pp.163–179.

Takigawa, T., Saijo, Y., Morimoto, K., Nakayama, K., Shibata, E., Tanaka, M., Yoshimura, T., Chikara, H. and Kishi, R. (2012). A longitudinal study of aldehydes and volatile organic compounds associated with subjective symptoms related to sick building syndrome in new dwellings in Japan. *Science of The Total Environment*, vol.417-418, pp.61-67.

Tanabe, S. (2003). Material emission and IAQ – recent experiences in Japan. [Online]. [Last accessed 8 September 2018]. Avialable at: http://www.umad.de/infos/cleanair13/pdf/full_9301.pdf

Tavakol, M., Dennick, R. (2011). Making sense of Cronbach's alpha. *International Journal of Medical Education*, vol. 2, pp.53–55. [Online]. [Last accessed 9 January 2019]. Available at:http://www.ijme.net/archive/2/cronbachs-alpha/.

TEC & MoPWs. (2009). *Green Building Guidelines.* UAE: The Executive Council (TEC) and the Goverment of Dubai & Ministry of Public Works (MoPWs). [Online]. [Last accessed 5 September 2018]. Avialable at: www.presidio.gov/.../0/accessibleGreenBuildingGuidelines2002.pdf.

Teijlingen, E., Hundley, V. (1998). The importance of pilot studies. Nursing Standard : Official Newspaper of the Royal College of Nursing, vol.16(40), pp. 33–36.

Thabane, L., Ma, J., Chu, R., Cheng, J., Ismaila, A., Rios, Robson, R., Thabane, M., Giangregorio, L., Goldsmith, H. (2010). A tutorial on pilot studies: the what, why and how. *BMC Med Res Methodol*, vol. 10(1), p. 67.

The Centre for Australian Weather and Climate Research. (2010). *Indoor air project. Part 1: Main report. Indoor air in typical Australian dwellings*. Australia: Commonwealth of Australia [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.environment.gov.au/system/files/resources/87d5dedd-62c2-479c-a001-a667eae21f7c/files/indoor-air-project-dwellings.pdf

Tietjen, G., Khubchandani, J., Ghosh, S., Bhattacharjee, S., Kleinfelder, J. (2012). Headache symptoms and indoor environmental parameters: Results from the EPA BASE study. *Annals of Indian Academy of Neurology*, vol. 15(5), pp. 95-99.

Trauter, M., et al. (1993). Results of a sick building syndrome prevalence study in Johannesburg. *Proceedings of the 6th International Conference on Indoor Air Quality and Climate*, vol. 1. Helsinki.

Trochim, K. (2001). *The Research Methods Knowledge Base*. Cincinnati: Atomic Dog.

Tsai, H., Tung, Y., Su, W., Chiang, L., Chew, T., Kuo, W., Lee, L. (2013). Interleukin-13 genetic variants, household carpet use and childhood Asthma. *PLoS ONE*, vol. 8, e51970.

TSI Inc. (2011). *Model 3330 Optical Particle Sizer Spectrometer*. Operation and service manual. P/N 6004403, Revision E, April 2011. USA: TSI Incorporated.

TSI Inc. (2012). *Optical Particle Sizer Spectrometer Model 3330. Specifications*. P/N 5001323 Rev C, April 2012. USA: TSI Incorporated.

Tucker, W. (1993). *Status of ASHRAE Standard 62- Ventilation for Acceptable Indoor Air Quality*. USA: Air and Engineering Research Laboratory, US Environmental Protection Agency.

Turanjanin, V., Vučićević, B., Jovanović, M., Mirkov, N. and Lazović, I. (2014). Indoor $CO_2$ measurements in Serbian schools and ventilation rate calculation. *Energy*, vol.77, pp.290-296.

Turk, M., Jakšić, J., Vojinović Miloradov, M. and Klanova, J. (2007). Post-war levels of persistent organic pollutants (POPs) in air from Serbia determined by active and passive sampling methods. *Environmental Chemistry Letters*, vol. 5(3), pp.109-113.

Turpin, J. (2014). What happened to sick building syndrome?. Air Conditioning, Heating, Refrigeration News, pp. 18-19.

UAE Ministry of EnvironmEye, nose, throat, and Water. (2014). *UAE State of Green Economy*. 2014 Report [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.moccae.gov.ae/assets/e3bd136a/uae-state-of-green-economy-report-2014.aspx

UCLA. (2018). *Introduction to Regression with SPSS Lesson 2: SPSS Regression Diagnostics*. UCLA: Institute for Digital Research and Education [Online]. [Last accessed 31 August 2018]. Avialable at: https://stats.idre.ucla.edu/spss/seminars/introduction-to-regression-with-spss/introreg-lesson2/

Ung-Lanki, S., Lampi, J. Pekkanen, J. (2017). Analyzing symptom data in indoor air questionnaires for primary schools. *Indoor Air*, vol. 27(5), pp.900–908.

University of North Texas – Engineering Dept. (2013). Indoor air quality: CO2 sensors & demand controlled ventilation [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.teo.unt.edu/ret/pdf2013/IAQ-presentation.pdf

University of North Texas Engineering Department. (2013). [Online]. [Last accessed 13 January 2019]. Available at http://www.teo.unt.edu/ret/pdf2013/IAQ-presentation.pdf

Unkel, S., & Trendafilov, N. T. (2010). Simultaneous parameter estimation in exploratory factor analysis: An expository review. *International Statistical Review*, vol. 78(3), pp. 363-382.

US CIA. (2018). *Middle East: United Arab Emirates*. [Online]. [Last accessed 31 August 2018]. Avialable at: https://www.cia.gov/library/publications/resources/the-world-factbook/geos/print_ae.html

US Committee on Indoor Pollutants. (1981). *Indoor pollutants. Washington*, D.C.: National Academy Press.

USGBC. (2005). LEED ® for New Construction & Major Renovations. Water, (October), p.4 [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.usgbc.org/ShowFile.aspx?DocumentID=5546

Velleman, F., Welsch, E. (1981). Efficient computing in regression diag- nostics, *The American Statistician*, vol. 35, pp. 234-242.

Vicendese, D., Dharmage, C., Tang, K., Olenko, A., Allen, J., Abramson, ,J., Erbas, B. (2015). Bedroom air quality and vacuuming frequency are associated with repeat child asthma hospital admissions. *J Asthma*, vol. 52, pp. 727–731.

Viechtbaur, W., Smits, L., Kotz, D., Bude, L., Spigt, M., Serroyen, J., Crutzen, R. (2015). A simple formula for the calculation of sample size in pilot studies. *Journal of Clinical Epidemiology*, vol. 68 (11), pp. 1375 – 1379.

Waldman, S., Waldman, C., Waldman, J. (2013). Headache pain of ear, nose, throat, and sinus origin. Medical Clinics of North America, vol. 97(2), pp. 309-319

Wang, B., Takigawa, T., Yamasaki, Y., Sakano, N., Wang, D., Ogino, K. (2008). Symptom definitions for SBS (sick building syndrome) in residential dwellings. *International Journal of Hygiene and Environmental Health*, vol.211(1–2), pp. 114-120.

Wang, H., Rosner, L., Goodman, N. (2016). Multiple Regression Using SPSS. *Clinical Trials*, vol. 13(6), pp.621–631. [Online]. [Last accessed 5 September 2018]. Avialable at: http://journals.sagepub.com/doi/10.1177/1740774516649595.

Wang, J., Li1, B., Qin Yang, Q., Yu, W., Han Wang, H., Norback, D., Sundell, J. (2013). Odors and Sensations of Humidity and Dryness in Relation to Sick Building Syndrome and Home Environment in Chongqing, China. *PLoS ONE*, vol. 8(8), pp.1–11.

Wang, J., Zhang, X. (2010a). Influence of ventilation on energy consumption and carbon emissions in high occupant density building. *International Journal of Energy and Environment*, vol. 1(2), pp.351-38.

Wang, J., Zhang, X. (2010b). Recommended concentration limits of indoor air pollution indicators for requirement of acceptable indoor air quality. *International Journal Of Energy And Environment*, vol.1(4), pp.697–704.

Watson, P. (2017). *What is the difference between hierarchical and stepwise regressions?*. University of Cambridge: Cognition and Brain Sciences Unit. [Online]. [Last accessed 5 September 2018]. Avialable at: http://imaging.mrc-cbu.cam.ac.uk/statswiki/FAQ/hier

WHO. (1983). *Indoor air pollutants*. Exposure and health effects. EURO Reports and studies No.78. WHO regional office of Europe, Copenhagen.

WHO. (1986). *Indoor air quality research*. Euro-Reports and Studies No. 103. Copenhagen: World Health Organization Regional Office for Europe.

WHO. (2000). Air quality guidelines for Europe. 2nd edn. WHO Regional Publications, European Series, No. 91 [Online]. [Last accessed 31 August 2018]. Avialable at:http://www.euro.who.int/__data/assets/pdf_file/0005/74732/E71922.pdf

WHO. (2001). *Formaldehyde*. Air Quality Guidelines. 2nd edn, vol.3, pp.1–25.

WHO. (2005). *WHO air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide*. Global update 2005. Summary of risk assessment [Online]. [Last accessed 31 August 2018]. Avialable at: http://apps.who.int/iris/bitstream/10665/69477/1/WHO_SDE_PHE_OEH_06.02_eng.pdf

WHO. (2006). *WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide*. Global update 2005. Summary of risk assessment. Geneva: World Health Organization, pp.1–22 [Online]. [Last accessed 31 August 2018]. Avialable at: http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf?ua=1

WHO. (2007). *Health in the Green Economy: Housing Sector*. [Online]. [Last accessed 8 September 2018]. Avialable at: http://www.who.int/hia/brochure_housing.pdf

WHO. (2008). *Indoor air pollution*. Children's health and the environment. WHO training package for the health sector. [Online]. [Last accessed 8 September 2018]. Avialable at: http://www.who.int/ceh/capacity/Indoor_Air_Pollution.pdf

WHO. (2009). *Guidelines for indoor air quality, dampness and mould*. Copenhagen, Denmark: World Health Organization. [Online]. [Last accessed 8 September 2018]. Avialable at: http://www.euro.who.int/__data/assets/pdf_file/0017/43325/E92645.pdf

WHO. (2010a). *WHO guidelines for indoor air quality: Selected pollutants*. WHO Regional Office of Europe Publications [Online]. [Last accessed 31 August 2018].

Avialable at: http://www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf

WHO. (2010b). Developing guidance for health protection in the built environment - mitigation and adaptation responses Meeting report. International Workshop on Housing, *Health and Climate Change*, pp.1–28. [Online]. [Last accessed 8 Sept 2018]. Avialable at: http://www.who.int/hia/house_report.pdf

WHO. (2013). Health Effects of Particulate Matter: Policy implications for countries in eastern Europe, Caucasus and central Asia. *Journal of the Korean Medical Association*, vol. 50(2), p.20.

WHO. (2018). *Ambient (outdoor) air quality and health*. [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

WHO. (2018). *Household air pollution and health*. [Online]. [Last accessed 5 September 2018]. Avialable at: http://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health

WHO. (2019). *Tobacco Free Initiative (TFI): Second-hand tobacco smoke*. [Online]. [Last accessed 1 April 2019]. Avialable at: https://www.who.int/tobacco/research/secondhand_smoke/en/

Wieslander, G., Norback, D., Bjornsson, E., Janson, C., Boman, G. (1997). Asthma and the indoor environment: the significance of emission of formaldehyde and volatile organic compounds from newly painted indoor surfaces. *International Archives of Occupational & Environmental Health*, vol. 69(2), pp. 115-24.

Wikipedia. (2016). Geography of the United Arab Emirates [Online]. [Last accessed 31 August 2018]. Avialable at: https://en.wikipedia.org/wiki/Geography_of_the_United_Arab_Emirates

Willis, H., Gibson, J., Shih., R., Geschwind, S., Olmstead, S., Hu, J., Curtright, A., Cecchine, G., Moore, M. (2010). Prioritizing Environmental Health Risks in the UAE. *Risk Analysis*, vol.30(12), pp.1842–1856.

Wimberry, T., Forehand, L., Murphy, N., Ceroli, A., Phinney, B., Evans, A. (1990). *Compendium of methods for the determination of air pollutants in indoor air*. US Environmental Protection Agency. Office of Research and Development.

Atmospheric Research and Exposure Assessment Laboratory.

Wu, P., Li, Y., Chiang, C., Huang, C., Lee, C., Li, F. and Su, H. (2005). Changing microbial concentrations are associated with ventilation performance in Taiwan's air-conditioned office buildings. *Indoor Air*, vol. 15(1), pp.19-26.

Xiaoshu, L., Lu, T., Viljanen, M. (2011). Estimation of space air change rates and $CO_2$ generation rates for mechanically-ventilated buildings. Advances in Computer Science and Engineering, Dr. Matthias Schmidt (Ed.), ISBN: 978-953-307-173-2, InTech [Online]. [Last accessed 31 August 2018]. Avialable at: http://www.intechopen.com/books/advancesin-computer-science-and-engineering/estimation-of-space-air-change-rates-and-co2-generation-rates-formechanically-ventilated-buildings.

Yang, W., Sohn, J., Kim, J., Son, B., Park, J. (2009). Indoor air quality investigation according to age of the school buildings in Korea. *Journal of Environmental Management*, vol. (90), pp. 348 – 354.

Yang, Y., Liu, L., Xu, C., Li, N., Liu, Z., Wang,Q., Xu, D. (2018). Source ApportionmEye, nose, throat, and Influencing Factor Analysis of Residential Indoor $PM_{2.5}$ in Beijing. *International Journal of Environmental Research and Public Health*, vol. 15(4), p.686. [Online]. [Last accessed 5 September 2018]. Avialable at: http://www.mdpi.com/1660-4601/15/4/686.

Yeatts, K. (2015). Personal emails with Karmin Yeatts one of the authors of the “Indoor air pollutants and health in the United Arab Emirates” on December 2015.

Yeatts, K., El-Sadig, M., Ali, H., Al-Maskari, F., Campbell, A., Ng, S., Reeves, L., Chan, R., Davidson, C., Funk, W., Boundy, M., Leith, D., Popkin, B., Gibson, J., Rusyn, I. and Olshan, A. (2012b). Conducting Environmental Health Research in the Arabian Middle East: Lessons Learned and Opportunities. *Environ Health Perspect*, vol.120(5), pp.632-636.

Yeatts, K., El-Sadig, M., Leith, D., Kalsbeek, W., Al-Maskari, F., Couper, D., Funk, W., Zoubeidi, T., Chan, R., Trent, C., Davidson, C., Boundy, M., Kassab, M., Hasan, M., Rusyn, I., Gibson, J. and Olshan, A. (2012a). Indoor Air Pollutants and Health in the United Arab Emirates. *Environ Health Perspect*, vol.120(5), pp.687-694.

Yin, R. (2014). *Case study research: Design and methods*. 5th edn. USA: SAGE

Publications.

You, Y., Bai, Z., Jia, C., Wan, Z., Ran, W., Zhang, J. (2007). *Measuring air exchanges rates using continuous $CO_2$ sensors*. In: 9th REHVA World Congress Clima 2007 "Well- Being Indoors"; 2007. Helsinki, Finland.

You, Y., Niu, C., Zhou, J., Liu, Y., Bai, Z., Zhang, J., He, F. and Zhang, N. (2012). Measurement of air exchange rates in different indoor environments using continuous $CO_2$ sensors. *Journal of Environmental Sciences*, vol 24(4), pp.657-664.

Yu, C., Morandi, M., Weisel, C. (2008). Passive dosimeters for nitrogen dioxide in personal/indoor air sampling: A review. *J Expos Sci Environ Epidemiol*, vol. 18(5), pp.441-451.

Zalejska-Jonsson, A., Wilhelmsson, M. (2013). Impact of perceived indoor environment quality on overall satisfaction in Swedish dwellings. *Building and Environment*, vol. 63, pp.134–144. [Online]. [Last accessed 5 September 2018]. Avialable at: http://dx.doi.org/10.1016/j.buildenv.2013.02.005.

Zamani, M., Jalaludin, J., Shaharom, N. (2013). Indoor air quality and prevalence of sick building syndrome among office workers in two different offices in Selangor. *American Journal of Applied Sciences*, vol.10(10), pp.1140-1147.

Zhang, J., Smith, R. (2003). Indoor air pollution: A global health concern. *British Medical Bulletin*, vol. 68, pp.209–225.

Zhang, X., Sahlberg, B., Wieslander, G., Janson, C., Gislason, T., Norback, D. (2012). Dampness and moulds in workplace buildings: Associations with incidence and remission of sick building syndrome (SBS) and biomarkers of inflammation in a 10 year follow-up study. Science of the Total Environment, vol. 430, pp.75–81. [Online]. [Last accessed 5 September 2018]. Avialable at: http://dx.doi.org/10.1016/j.scitotenv.2012.04.040.

Zhao, L., Chen, C., Cao, G. (2014). Influence of Natural Ventilation on Indoor PM2.5 Concentration in Residential Building. *AMM*, vol. 675-677, pp.194-198.

Ziglari, L. (2017). Interpreting multiple regression results: β weights and structure coefficients. *General Linear Model Journal*, vol. 43(2), pp.13–22.

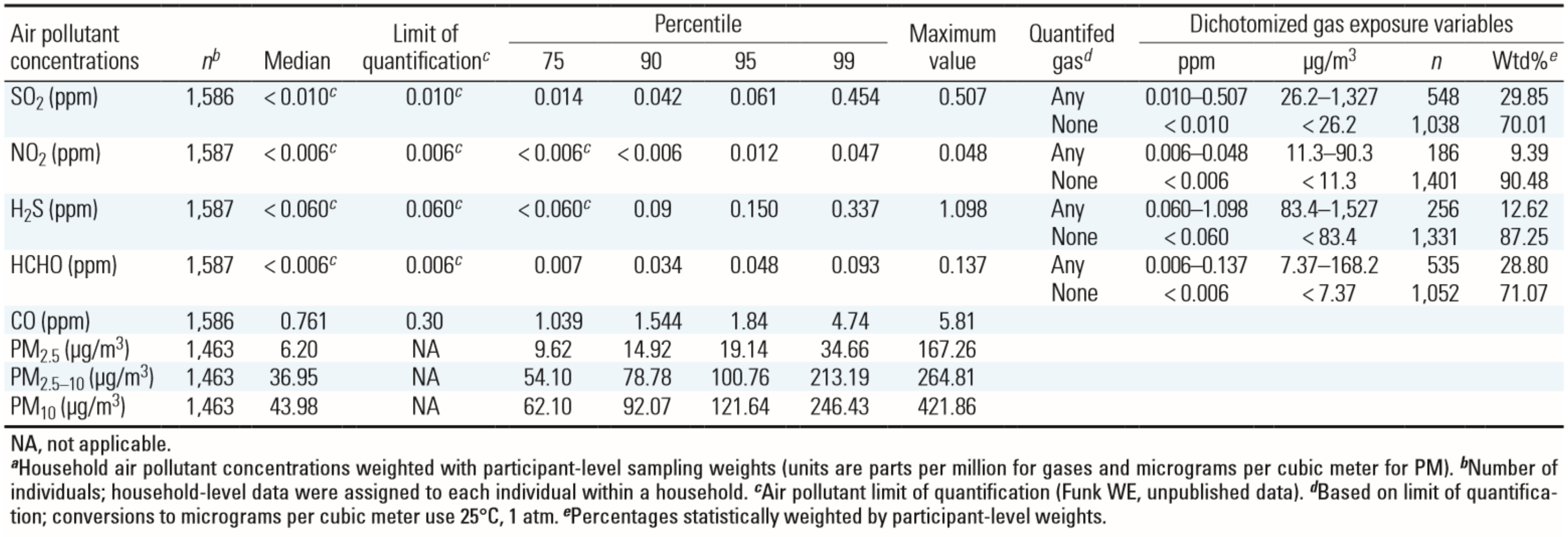
Zimina, D., Ballard, G., Pasquire, C. (2012). Target value design: using collaboration and a lean approach to reduce construction cost. *Construction ManagemEye, nose, throat,* *and Economics*, vol. 30(5), pp. 383-398.

Zock, P., Jarvis, D., Luczynska, C., Sunyer, J., Burney, P. (2002). European Community Respiratory Health Survey. Housing characteristics, reported mold exposure, and asthma in the European Community Respiratory Health Survey. J. Allergy Clin. Immunol, vol. 110, pp. 285–292.

Zweers, T., Preller, L., Brunekreef, B., Boleij, J. Health and indoor climate complaints of 7043 office workers in 61 buildings in the Netherlands. *Indoor Air*, vol. (1992), pp. 127–136.

# Appendix A: Measured concentrations by (Yeatts et al. 2012a)

Table A-1: Measured indoor air pollutants concentrations in 625 UAE houses (Yeatts et al. 2012a, p. 690)



| Air pollutant concentrations | $n^b$ | Median | Limit of quantification$^c$ | Percentile |  |  |  | Maximum value | Quantifed gas$^d$ | Dichotomized gas exposure variables |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | 75 | 90 | 95 | 99 |  |  | ppm | µg/m$^3$ | $n$ | Wtd%$^e$ |
| $SO_2$ (ppm) | 1,586 | < 0.010$^c$ | 0.010$^c$ | 0.014 | 0.042 | 0.061 | 0.454 | 0.507 | Any | 0.010–0.507 | 26.2–1,327 | 548 | 29.85 |
|  |  |  |  |  |  |  |  |  | None | < 0.010 | < 26.2 | 1,038 | 70.01 |
| $NO_2$ (ppm) | 1,587 | < 0.006$^c$ | 0.006$^c$ | < 0.006$^c$ | < 0.006 | 0.012 | 0.047 | 0.048 | Any | 0.006–0.048 | 11.3–90.3 | 186 | 9.39 |
|  |  |  |  |  |  |  |  |  | None | < 0.006 | < 11.3 | 1,401 | 90.48 |
| $H_2S$ (ppm) | 1,587 | < 0.060$^c$ | 0.060$^c$ | < 0.060$^c$ | 0.09 | 0.150 | 0.337 | 1.098 | Any | 0.060–1.098 | 83.4–1,527 | 256 | 12.62 |
|  |  |  |  |  |  |  |  |  | None | < 0.060 | < 83.4 | 1,331 | 87.25 |
| HCHO (ppm) | 1,587 | < 0.006$^c$ | 0.006$^c$ | 0.007 | 0.034 | 0.048 | 0.093 | 0.137 | Any | 0.006–0.137 | 7.37–168.2 | 535 | 28.80 |
|  |  |  |  |  |  |  |  |  | None | < 0.006 | < 7.37 | 1,052 | 71.07 |
| CO (ppm) | 1,586 | 0.761 | 0.30 | 1.039 | 1.544 | 1.84 | 4.74 | 5.81 |  |  |  |  |  |
| $PM_{2.5}$ (µg/m$^3$) | 1,463 | 6.20 | NA | 9.62 | 14.92 | 19.14 | 34.66 | 167.26 |  |  |  |  |  |
| $PM_{2.5–10}$ (µg/m$^3$) | 1,463 | 36.95 | NA | 54.10 | 78.78 | 100.76 | 213.19 | 264.81 |  |  |  |  |  |
| $PM_{10}$ (µg/m$^3$) | 1,463 | 43.98 | NA | 62.10 | 92.07 | 121.64 | 246.43 | 421.86 |  |  |  |  |  |

NA, not applicable.

[a] Household air pollutant concentrations weighted with participant-level sampling weights (units are parts per million for gases and micrograms per cubic meter for PM). [b] Number of individuals; household-level data were assigned to each individual within a household. [c] Air pollutant limit of quantification (Funk WE, unpublished data). [d] Based on limit of quantification; conversions to micrograms per cubic meter use 25°C, 1 atm. [e] Percentages statistically weighted by participant-level weights.

# Appendix B: Pilot questionnaire (English)

Survey about:

# The Influential Factors on Indoor Air Quality and Sick Building Syndrome in Dubai Housing

I.

1 **What is your gender?** ☐ Male ☐ Female

2 **What is your age?** ________ Years

3 **Are you a smoker?** Yes ☐ No ☐

4 **Does your house include a smoker?** Yes ☐ No ☐

**Have you or one of your family ever experienced:**

5 Asthmatic problems ☐

6 Hay fever ☐

7 Eczema ☐

8 Migraine ☐

9 Allergy to dust ☐

10 Allergy to molds ☐

II.

11 **House type:** (1) Flat (2) Villa

12 **House age:**
(1) 1 – 3 years (2) 4 – 6 years
(3) 7 – 10 years (4) more than 10 years

13 **Is your kitchen attached?** Yes ☐ No ☐

14 **How many years living in this house?** ________ Years

15 **How many persons in your house are within the range of:**
(1) 1 – 18 years ☐ (2) 19 – 40 years ☐ (3) Above 40 ☐

16 **AC type:**
(1) Central ☐ (2) Split ☐ (3) Window ☐

17 **Last year, do you notice any water leaks from the ceiling, floor, walls, or pipes in your house?** Yes ☐ No ☐

**Last year, have any of the following changes taken place in your house?**

18 New carpeting Yes ☐ No ☐

19 New curtains Yes ☐ No ☐

20 New furniture Yes ☐ No ☐

21 New devices Yes ☐ No ☐

22 Walls painted Yes ☐ No ☐

23 Rearranged walls Yes ☐ No ☐

III.

**During last year, how often have you experience one of the following at your house?**

| | | Never | Rarely | Some-times | Often | Always |
|---|---|---|---|---|---|---|
| 24 | Smoke from incense burning | ☐ | ☐ | ☐ | ☐ | ☐ |
| 25 | Body odors | ☐ | ☐ | ☐ | ☐ | ☐ |
| 26 | Cosmetics odors i.e. perfumes, | ☐ | ☐ | ☐ | ☐ | ☐ |
| 27 | Tobacco smoke | ☐ | ☐ | ☐ | ☐ | ☐ |
| 28 | Fishy smells | ☐ | ☐ | ☐ | ☐ | ☐ |
| 29 | Other food smells | ☐ | ☐ | ☐ | ☐ | ☐ |
| 30 | Musty damp basement smells | ☐ | ☐ | ☐ | ☐ | ☐ |
| 31 | Odors from new carpet | ☐ | ☐ | ☐ | ☐ | ☐ |
| 32 | Odors from curtains or drapes | ☐ | ☐ | ☐ | ☐ | ☐ |
| 33 | Odors from diesel/ engines exhaust | ☐ | ☐ | ☐ | ☐ | ☐ |
| 34 | Odors from equipment i.e. computer | ☐ | ☐ | ☐ | ☐ | ☐ |
| 35 | Odors from cleaning products | ☐ | ☐ | ☐ | ☐ | ☐ |
| 36 | Odors from pesticides | ☐ | ☐ | ☐ | ☐ | ☐ |
| 37 | Odors from chemicals i.e. adhesives | ☐ | ☐ | ☐ | ☐ | ☐ |
| 38 | Odors from paint | ☐ | ☐ | ☐ | ☐ | ☐ |
| 39 | Other odors (Please specify below) | ☐ | ☐ | ☐ | ☐ | ☐ |
| 40 | Dust and dirt | | | | | |

| | | Never | Rarely | Some-times | Often | Always |
|---|---|---|---|---|---|---|
| 41 | Stuffy "bad" air | ☐ | ☐ | ☐ | ☐ | ☐ |
| 42 | Too much air movement | ☐ | ☐ | ☐ | ☐ | ☐ |
| 43 | Too little air movement | ☐ | ☐ | ☐ | ☐ | ☐ |
| 44 | Need to adjust air movement | ☐ | ☐ | ☐ | ☐ | ☐ |
| 45 | Too hot | ☐ | ☐ | ☐ | ☐ | ☐ |
| 46 | Too cold | ☐ | ☐ | ☐ | ☐ | ☐ |
| 47 | Need to adjust temperature | ☐ | ☐ | ☐ | ☐ | ☐ |
| 48 | Too much humidity | ☐ | ☐ | ☐ | ☐ | ☐ |
| 49 | Too much dryness | ☐ | ☐ | ☐ | ☐ | ☐ |
| 50 | Need to adjust humidity | ☐ | ☐ | ☐ | ☐ | ☐ |
| 51 | Too much dim | ☐ | ☐ | ☐ | ☐ | ☐ |
| 52 | Little dim | ☐ | ☐ | ☐ | ☐ | ☐ |
| 53 | Too much glare | ☐ | ☐ | ☐ | ☐ | ☐ |
| 54 | Little glare | ☐ | ☐ | ☐ | ☐ | ☐ |
| 55 | Need to adjust lighting | ☐ | ☐ | ☐ | ☐ | ☐ |
| 56 | Too noisy | ☐ | ☐ | ☐ | ☐ | ☐ |
| 57 | Too quiet | ☐ | ☐ | ☐ | ☐ | ☐ |

58 How do you judge the overall indoor air quality of your house during last year?

(1) Excellent ☐ (2) Good ☐ (3) Fair ☐ (4) Poor ☐

IV.

**During last year, how often have you or any of your family members suffered from the following symptoms:**

**If the symptom has been experienced, how it changes outside your house?**

| | | Never | Rarely | Some-times | Often | Always | | Gets more | Stay same | Gets less |
|---|---|---|---|---|---|---|---|---|---|---|
| 59 | Headache | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 59b | ☐ | ☐ | ☐ |
| 60 | Nausea | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 60b | ☐ | ☐ | ☐ |
| 61 | Runny nose | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 61b | ☐ | ☐ | ☐ |
| 62 | Stuffy nose | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 62b | ☐ | ☐ | ☐ |
| 63 | Sneezing | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 63b | ☐ | ☐ | ☐ |
| 64 | Cough | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 64b | ☐ | ☐ | ☐ |
| 65 | Wheezing/whistling in chest | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 65b | ☐ | ☐ | ☐ |
| 66 | Breath shortness | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 66b | ☐ | ☐ | ☐ |
| 67 | Chest tightness | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 67b | ☐ | ☐ | ☐ |
| 68 | Dry/itching/tearing eyes | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 68b | ☐ | ☐ | ☐ |
| 69 | Sore/strained eyes | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 69b | ☐ | ☐ | ☐ |
| 70 | Blurry/double vision | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 70b | ☐ | ☐ | ☐ |
| 71 | Burning eyes | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 71b | ☐ | ☐ | ☐ |
| 72 | Sore throat | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 72b | ☐ | ☐ | ☐ |
| 73 | Hoarseness | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 73b | ☐ | ☐ | ☐ |
| 74 | Dry throat | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 74b | ☐ | ☐ | ☐ |
| 75 | Unusual fatigue or tiredness | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 75b | ☐ | ☐ | ☐ |
| 76 | Sleepiness or drowsiness | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 76b | ☐ | ☐ | ☐ |
| 77 | Chills | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 77b | ☐ | ☐ | ☐ |
| 78 | Fever | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 78b | ☐ | ☐ | ☐ |
| 79 | Aching muscles or joints | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 79b | ☐ | ☐ | ☐ |
| 80 | Feeling depressed | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 80b | ☐ | ☐ | ☐ |
| 81 | Lower back pain or stiffness | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 81b | ☐ | ☐ | ☐ |
| 82 | Shoulder/ neck pain/ numbness | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 82b | ☐ | ☐ | ☐ |
| 83 | Hand/ wrist pain/ numbness | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 83b | ☐ | ☐ | ☐ |
| 84 | Difficulty in remembering | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 84b | ☐ | ☐ | ☐ |
| 85 | Dizziness/ light-headedness | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 85b | ☐ | ☐ | ☐ |
| 86 | Tension or nervousness | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 86b | ☐ | ☐ | ☐ |
| 87 | Difficulty concentration | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 87b | ☐ | ☐ | ☐ |
| 88 | Dry/ itchy skin | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ 88b | ☐ | ☐ | ☐ |

**Thanks a lot**

# Appendix C: Pilot questionnaire (Arabic)

استبيان عن:

# العوامل المهيمنه علي تلوث الهواء الداخلي و متلازمة المباني المريضه في المباني السكنية بدبي

I

1 **الجنس:** ذكر ☐ انثى ☐

2 **العمر:** ______ سنه

3 **هل انت مدخن ؟** نعم ☐ لا ☐

4 **هل يوجد بمنزلك شخص مدخن؟** نعم ☐ لا ☐

**هل اصبت انت أو أحد من أفراد عائلتك بواحد او أكثر من الاعراض اللاحقه؟**

5 الربو (Asthma) ☐ 8 الصداع النصفى ☐

6 حمى القش (Hay Fever) ☐ 9 حساسية من الغبار ☐

7 اكزيما (Eczema) ☐ 10 حساسية من العفن ☐

II

11 **نوع المنزل:** (1) شقه (2) فيلا

12 **عمر المنزل:**

(1) 1 – 3 سنوات (2) 4 – 6 سنوات

(3) 7 – 10 سنوات (4) أكثر من 10 سنوات

13 **هل مطبخ المنزل مفصول عن باقي المنزل "مُلحق"؟** نعم ☐ لا ☐

14 **كم سنه تسكن في هذا المنزل؟** ______ سنه

15 **عدد سكان المنزل حسب العمر:**

(1) 1 – 18 سنه ☐ (2) 19 – 40 سنه ☐ (3) فوق الأربعين ☐

16 **نوع تكييف المنزل:**

(1) مركزي ☐ (2) Split ☐ (3) Window ☐

17 **خلال السنه السابقه, هل لاحظت أي تسرب للمياه من السقف, الارضية, الحوائط, أو أنابيب المياه في منزلك؟** نعم ☐ لا ☐

**خلال السنه السابقه, هل حدثت أي من التغييرات التاليه في منزلك؟**

18 سجاده جديده نعم ☐ لا ☐

19 ستائر جديده نعم ☐ لا ☐

20 أثاثات جديده نعم ☐ لا ☐

21 أجهزه جديده نعم ☐ لا ☐

22 طلاء حوائط نعم ☐ لا ☐

23 ترتيب جديد للحوائط نعم ☐ لا ☐

III

**خلال السنه السابقه, هل من المعتاد حصول أحدي الحالات التاليه في بيئة منزلك الداخليه؟**

| | | أبداً | نادراً | أحياناً | كثيرا | دائماً |
|---|---|---|---|---|---|---|
| 24 | دخان من البخور | ☐ | ☐ | ☐ | ☐ | ☐ |
| 25 | روائح من الاجسام | ☐ | ☐ | ☐ | ☐ | ☐ |
| 26 | روائح من أدوات التجميل | ☐ | ☐ | ☐ | ☐ | ☐ |
| 27 | دخان التبغ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 28 | رائحة شبيهه برائحة السمك | ☐ | ☐ | ☐ | ☐ | ☐ |
| 29 | رائحة اطعمه أخري | ☐ | ☐ | ☐ | ☐ | ☐ |
| 30 | روائح عفنه ناتجه عن الرطوبه | ☐ | ☐ | ☐ | ☐ | ☐ |
| 31 | روائح من سجاد جديد | ☐ | ☐ | ☐ | ☐ | ☐ |
| 32 | روائح من ستائر | ☐ | ☐ | ☐ | ☐ | ☐ |
| 33 | روائح ديزل – عوادم الماكينات | ☐ | ☐ | ☐ | ☐ | ☐ |
| 34 | روائح من الأجهزه | ☐ | ☐ | ☐ | ☐ | ☐ |
| 35 | روائح من مواد التنظيف | ☐ | ☐ | ☐ | ☐ | ☐ |
| 36 | روائح من المبيدات | ☐ | ☐ | ☐ | ☐ | ☐ |
| 37 | روائح من المواد اللاصقه | ☐ | ☐ | ☐ | ☐ | ☐ |
| 38 | روائح من الطلاء و الصبغ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 39 | روائح أخري (رجاءً التحديد في الأسفل) | ☐ | ☐ | ☐ | ☐ | ☐ |
| 40 | غبار و أوساخ. | | | | | |

| | | أبداً | نادراً | أحياناً | كثيرا | دائماً |
|---|---|---|---|---|---|---|
| 41 | هواءغير نقي "عفن" | ☐ | ☐ | ☐ | ☐ | ☐ |
| 42 | حركة هواء قويه جداً | ☐ | ☐ | ☐ | ☐ | ☐ |
| 43 | حركة هواء ضعيفه جداً | ☐ | ☐ | ☐ | ☐ | ☐ |
| 44 | إحتياج لظبط حركة الهواء | ☐ | ☐ | ☐ | ☐ | ☐ |
| 45 | درجة حرارة عاليه جداً | ☐ | ☐ | ☐ | ☐ | ☐ |
| 46 | درجة حراره منخفضه جداً | ☐ | ☐ | ☐ | ☐ | ☐ |
| 47 | إحتياج لظبط درجة الحراره | ☐ | ☐ | ☐ | ☐ | ☐ |
| 48 | درجة رطوبه عاليه | ☐ | ☐ | ☐ | ☐ | ☐ |
| 49 | درجة جفاف عاليه | ☐ | ☐ | ☐ | ☐ | ☐ |
| 50 | إحتياج لظبط درجة الرطوبه | ☐ | ☐ | ☐ | ☐ | ☐ |
| 51 | إضاءه قويه جداً | ☐ | ☐ | ☐ | ☐ | ☐ |
| 52 | إضاءه ضعيفه جداً | ☐ | ☐ | ☐ | ☐ | ☐ |
| 53 | وهج قوي جد | ☐ | ☐ | ☐ | ☐ | ☐ |
| 54 | وهج ضعيف جداً | ☐ | ☐ | ☐ | ☐ | ☐ |
| 55 | إحتياج لظبط درجة الإضاءه | ☐ | ☐ | ☐ | ☐ | ☐ |
| 56 | ضجيج عالي جداً | ☐ | ☐ | ☐ | ☐ | ☐ |
| 57 | هدوء شديد جداً | ☐ | ☐ | ☐ | ☐ | ☐ |

58 ما هو تقييمك لنوعية الهواء بداخل منزلك خلال السنه السابقه؟ (1) مُمتازه ☐ (2) جيده ☐ (3) حسنه ☐ (4) سيئه ☐

**IV خلال السنه السابقه, هل من المعتاد أن تُعاني انت او احد من أفراد عائلتك من أحد الأعراض التاليه؟**

**في حالة معاناتك من العرض, هل تتغير حدته خارج المنزل؟**

| | | أبداً | نادراً | أحياناً | كثيرا | دائماً | | تزيد حدته | يظل كما هو | تخف حدته |
|---|---|---|---|---|---|---|---|---|---|---|
| 59 | صداع | ☐ | ☐ | ☐ | ☐ | ☐ | 59b ⇦ | ☐ | ☐ | ☐ |
| 60 | غثيان | ☐ | ☐ | ☐ | ☐ | ☐ | 60b ⇦ | ☐ | ☐ | ☐ |
| 61 | تدفق مخاطي من الأنف | ☐ | ☐ | ☐ | ☐ | ☐ | 61b ⇦ | ☐ | ☐ | ☐ |
| 62 | أنسداد في الأنف | ☐ | ☐ | ☐ | ☐ | ☐ | 62b ⇦ | ☐ | ☐ | ☐ |
| 63 | عطس | ☐ | ☐ | ☐ | ☐ | ☐ | 63b ⇦ | ☐ | ☐ | ☐ |
| 64 | سعال | ☐ | ☐ | ☐ | ☐ | ☐ | 64b ⇦ | ☐ | ☐ | ☐ |
| 65 | صفير في الصدر | ☐ | ☐ | ☐ | ☐ | ☐ | 65b ⇦ | ☐ | ☐ | ☐ |
| 66 | تنفس متسارع | ☐ | ☐ | ☐ | ☐ | ☐ | 66b ⇦ | ☐ | ☐ | ☐ |
| 67 | ضيق في الصدر | ☐ | ☐ | ☐ | ☐ | ☐ | 67b ⇦ | ☐ | ☐ | ☐ |
| 68 | جفاف/ حكه في العيون | ☐ | ☐ | ☐ | ☐ | ☐ | 68b ⇦ | ☐ | ☐ | ☐ |
| 69 | إلتهاب/ إجهاد في العيون | ☐ | ☐ | ☐ | ☐ | ☐ | 69b ⇦ | ☐ | ☐ | ☐ |
| 70 | رؤيه ضبابيه/ مزدوجه | ☐ | ☐ | ☐ | ☐ | ☐ | 70b ⇦ | ☐ | ☐ | ☐ |
| 71 | حرقه في العيون | ☐ | ☐ | ☐ | ☐ | ☐ | 71b ⇦ | ☐ | ☐ | ☐ |
| 72 | إلتهاب في الحلق | ☐ | ☐ | ☐ | ☐ | ☐ | 72b ⇦ | ☐ | ☐ | ☐ |
| 73 | بحه "في الصوت" | ☐ | ☐ | ☐ | ☐ | ☐ | 73b ⇦ | ☐ | ☐ | ☐ |
| 74 | جفاف في الحلق | ☐ | ☐ | ☐ | ☐ | ☐ | 74b ⇦ | ☐ | ☐ | ☐ |
| 75 | تعب / إرهاق غير معتاد | ☐ | ☐ | ☐ | ☐ | ☐ | 75b ⇦ | ☐ | ☐ | ☐ |
| 76 | نعاس / رغبه في النوم | ☐ | ☐ | ☐ | ☐ | ☐ | 76b ⇦ | ☐ | ☐ | ☐ |
| 77 | قشعريره | ☐ | ☐ | ☐ | ☐ | ☐ | 77b ⇦ | ☐ | ☐ | ☐ |
| 78 | حمى | ☐ | ☐ | ☐ | ☐ | ☐ | 78b ⇦ | ☐ | ☐ | ☐ |
| 79 | ألم في العضلات/ المفاصل | ☐ | ☐ | ☐ | ☐ | ☐ | 79b ⇦ | ☐ | ☐ | ☐ |
| 80 | إكتئاب | ☐ | ☐ | ☐ | ☐ | ☐ | 80b ⇦ | ☐ | ☐ | ☐ |
| 81 | ألم/ تصلب في أسفل الظهر | ☐ | ☐ | ☐ | ☐ | ☐ | 81b ⇦ | ☐ | ☐ | ☐ |
| 82 | ألم/ تنميل في الكتف/ الرقبه | ☐ | ☐ | ☐ | ☐ | ☐ | 82b ⇦ | ☐ | ☐ | ☐ |
| 83 | ألم/ تنميل في اليد أو المعصم | ☐ | ☐ | ☐ | ☐ | ☐ | 83b ⇦ | ☐ | ☐ | ☐ |
| 84 | صعوبه في التذكر | ☐ | ☐ | ☐ | ☐ | ☐ | 84b ⇦ | ☐ | ☐ | ☐ |
| 85 | دوخه | ☐ | ☐ | ☐ | ☐ | ☐ | 85b ⇦ | ☐ | ☐ | ☐ |
| 86 | إحساس بالتوتر أو العصبيه | ☐ | ☐ | ☐ | ☐ | ☐ | 86b ⇦ | ☐ | ☐ | ☐ |
| 87 | صعوبه في التركيز | ☐ | ☐ | ☐ | ☐ | ☐ | 87b ⇦ | ☐ | ☐ | ☐ |
| 88 | جفاف أو حكه في البشره | ☐ | ☐ | ☐ | ☐ | ☐ | 88b ⇦ | ☐ | ☐ | ☐ |

**شكــــــراً جزيـــــــــلاً**

# Appendix D: Main questionnaire (English)

Survey about:

# The Influential Factors on Indoor Air Quality and Sick Building Syndrome in Dubai Housing

Thank you for agreeing to take part in this survey.

The survey is conducted to investigate the most influential factors on indoor air quality and its subsequent impacts on occupants' health.

Please answer the questions as accurately and completely as you can, regardless of how satisfied or dissatisfied you are with conditions in the building.

This survey might only take 5 – 10 minutes to be completed.

Be assured that this questionnaire is completely anonymous and that no personally identifiable information is captured.

I.

1 **What is your gender?** ☐ Male ☐ Female

2 **What is your nationality?**

(1) UAE or GCC national

(2) Other Arabs/ MENA (3) Indian Subcontinent

(4) Other Asians (5) Other African

(6) Europeans, Oceanians, North or South American

3 **What is your age?**

(1) Less than 18 years (2) 18–34 years

(3) 35–54 years (4) 55 – 74 years

(5) Older than 74 years

4 **Are you a smoker?**

(1) No (2) Yes

5 **Does your house include a smoker?**

(1) No (2) Yes

6 **Please indicate if you or any one of your family have ever experienced one of the following:**

☐ Asthma ☐ Migraine

☐ Hay fever ☐ Allergy to dust

☐ Eczema ☐ Allergy to molds

II.

7 **Name of Living area in Dubai:** ____________________

8 **House type:** (1) Flat (2) Villa

9 **How many persons in your house within the following age groups (Please indicate a number):**

(1) Less than 18 years ☐ (2) 18–34 years ☐

(3) 35–54 years ☐ (4) 55 – 74 years ☐

(5) 75 years or older ☐

10 **Number of years living in this house:**

(1) Less than 3 years (2) 4 – 6 years

(3) 7 – 10 years (4) More than 10 years

11 **For how long the house is built:**

(1) Less than 3 years (2) 4–6 years

(3) 7 – 10 years (4) More than 10 years

(5) Not aware/ not sure

12 **Please select your kitchen type from the following:**

(1) Unattached (Separate unit)

(2) Attached open kitchen without interior walls

(3) Attached kitchen with interior walls

13 **The applied air conditioning (AC) system in your house is:**

(1) Central ☐ (2) Split ☐ (3) Window ☐

**Last year, please select which of the following events have taken place in your house?**

14 New carpet ☐ 15 New furniture ☐ 16 Walls painted ☐

17 Rearranged walls ☐ 18 New wall covering ☐ 19 Water leakage ☐

III **During last year, how often have you or any one in your family experience one of the following at your house**

| | | Never | 1 – 3 days/ Year | 1 – 3 days/ Month | 1 – 3 days/ week | Daily/ Almost daily |
|---|---|---|---|---|---|---|
| 20 | Smoke from incense burning | ☐ | ☐ | ☐ | ☐ | ☐ |
| 21 | Odors from new carpet or curtains | ☐ | ☐ | ☐ | ☐ | ☐ |
| 22 | Musty/mouldy dampness odors | ☐ | ☐ | ☐ | ☐ | ☐ |
| 23 | Fishy smells or other food smells | ☐ | ☐ | ☐ | ☐ | ☐ |
| 24 | Body odors or cosmetic odors | ☐ | ☐ | ☐ | ☐ | ☐ |
| 25 | Odors from paint | ☐ | ☐ | ☐ | ☐ | ☐ |
| 26 | Odors from other chemicals | ☐ | ☐ | ☐ | ☐ | ☐ |
| 27 | Tobacco smoke | ☐ | ☐ | ☐ | ☐ | ☐ |
| 28 | Odors from diesel or engine exhaust | ☐ | ☐ | ☐ | ☐ | ☐ |
| 29 | Dust and dirt | ☐ | ☐ | ☐ | ☐ | ☐ |
| 30 | Stuffy "bad" air | ☐ | ☐ | ☐ | ☐ | ☐ |

| | | Never | 1 – 3 days/ Year | 1 – 3 days/ Month | 1 – 3 days/ week | Daily/ Almost daily |
|---|---|---|---|---|---|---|
| 31 | Too much air movement | ☐ | ☐ | ☐ | ☐ | ☐ |
| 32 | Too little air movement | ☐ | ☐ | ☐ | ☐ | ☐ |
| 33 | Too hot | ☐ | ☐ | ☐ | ☐ | ☐ |
| 34 | Too cold | ☐ | ☐ | ☐ | ☐ | ☐ |
| 35 | Too much humidity | ☐ | ☐ | ☐ | ☐ | ☐ |
| 36 | Too much dryness | ☐ | ☐ | ☐ | ☐ | ☐ |
| 37 | Too much glare | ☐ | ☐ | ☐ | ☐ | ☐ |
| 38 | Too much dim | ☐ | ☐ | ☐ | ☐ | ☐ |
| 39 | Too noisy | ☐ | ☐ | ☐ | ☐ | ☐ |
| 40 | Too quiet | ☐ | ☐ | ☐ | ☐ | ☐ |

41 **How do you judge the overall indoor air quality of your house during last year?**

(1) Excellent ☐ (2) Good ☐ (3) Fair ☐ (4) Poor ☐

IV.

| | **During last year, how often have you or any one in your family suffered from the following symptoms:** | Never | 1 – 3 days/ Year | 1 – 3 days/ Month | 1 – 3 days/ week | Daily/ Almost daily | | **If experienced, how it changes outside your house?** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | **Gets more** | **Stay same** | **Gets less** |
| 42 | Headache or nausea | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ | ☐ | ☐ | ☐ |
| 43 | Nasal symptoms i.e. runny nose, stuffy nose or sneezing | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ | ☐ | ☐ | ☐ |
| 44 | Chest-related symptoms i.e. tightness, wheezing or short breath | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ | ☐ | ☐ | ☐ |
| 45 | Cough | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ | ☐ | ☐ | ☐ |
| 46 | Eye-related symptoms i.e. sore, itching, burning, tearing or blurry eyes | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ | ☐ | ☐ | ☐ |
| 47 | Throat-related symptoms i.e. sore throat, or dry throat | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ | ☐ | ☐ | ☐ |
| 48 | Unusual fatigue or tiredness, sleepiness or drowsiness | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ | ☐ | ☐ | ☐ |
| 49 | Fever | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ | ☐ | ☐ | ☐ |
| 50 | Pain in muscles, joints, back, neck, or hand | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ | ☐ | ☐ | ☐ |
| 51 | Neurological symptoms i.e. tension, concentration problems, or nervous | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ | ☐ | ☐ | ☐ |
| 52 | Dry or itchy skin | ☐ | ☐ | ☐ | ☐ | ☐ | ⇨ | ☐ | ☐ | ☐ |

**Thanks a lot**

# Appendix E: Main questionnaire (Arabic)

إستبيان عن:

## العوامل المهيمنه علي تلوث الهواء الداخلي و متلازمة المباني المريضه في المباني السكنية بدبي

شكراً على موافقتك المشاركه في هذا الإستبيان.

يبحث الإستبيان عن أكثر العوامل المؤثره علي نوعية الهواء داخل المباني السكنيه بدبي و آثارها على صحة السكان.

قد يأخذ منك ملء هذا الإستبيان 5 – 10 دقائق فقط.

نؤكد على أن هذا الإستبيان لا يبين هوية المشارك و أنه يتم التعامل مع إجاباتك بدرجه عاليه من السريه.

I

1 **الجنس:** ذكر ☐ انثى ☐

2 **ماهى جنسيتك:**
(1) إماراتى/ خليجى
(2) من دول عربية أخرى/ شرق أوسطى (3) هندى/ من دول شبه القاره الهندية
(4) من دول أسيويه أخرى (5) من دول أفريقيه أخرى
(6) أوروبى, أوشيانيان, من شمال أو جنوب أميركا

3 **كم عمرك:**
(1) أقل من 18 سنه (2) 18 – 34 سنه
(3) 35 – 54 سنه (4) 55 – 74 سنه
(5)75 سنه أو أكبر

4 **هل أنت مدخن:**
(1) لا (2) نعم

5 **هل يوجد مدخن بمنزلك؟**
(1) لا (2) نعم

6 **الرجاء توضيح إذا كنت انت أو أى فرد من أفراد عائلتك يعانى من واحده أو أكثر من الأعراض التاليه:**
☐ ربو (Asthma) ☐ صداع نصفى (Migrane)
☐ حمى القش (Hay fever) ☐ حساسيه من الغبار
☐ اكزيما (Eczema) ☐ حساسيه من الفطريات

II

7 **إسم منطقتك السكنية فى دبى:** ..................................................

8 **نوع المنزل:** (1) شقه (2) فيلا

**عدد سكان المنزل حسب العمر (الرجاء كتابة الرقم فى المربع المرفق):**
9 (1) أقل من 18 سنة ☐
(2) 18 – 34 سنة ☐
(3) 35 – 54 سنة ☐
(4) 55 – 74 سنة ☐
(5) 75 سنه أو أكبر ☐

10 **كم سنة تسكن فى هذا المنزل؟**
(1) أقل من 3 سنوات (2) 4 – 6 سنوات
(3) 7 – 10 سنوات (4) أكثر من 10 سنه

11 **منذ متى تمَ بناء هذا المنزل؟**
(1) أقل من 3 سنوات (2) 4 – 6 سنوات
(3) 7 – 10 سنوات (4) أكثر من 10 سنه
(5) غير معلوم لدى / غير متأكد

12 **الرجاء تحديد نوع مطبخك من الخيارات الآتيه:**
(1) مطبخ مفصول عن المنزل (مُلحق)
(2) مطبخ مفتوح (متصل بباقى المنزل من غير حوائط داخلية)
(3) مطبخ متصل بباقى المنزل (لديه حوائط داخلية)

13 **الرجاء تحديد نوع نظام التكييف بمنزلك:**
(1) مكيف مركزى (Central AC)
(2) سبليت (Split AC)
(3) مكيف نافذة (Window AC)

**خلال السنه السابقه, هل حدثت أي من التغييرات التاليه في منزلك؟**

14 سجاده جديده نعم ☐ لا ☐
17 إعادة ترتيب للحوائط نعم ☐ لا ☐

15 أثاثات جديده نعم ☐ لا ☐
18 تشطيبات حوائط جديده نعم ☐ لا ☐

16 طلاء حوائط نعم ☐ لا ☐
19 تسرب مياه نعم ☐ لا ☐

III **خلال السنه السابقه, هل من المعتاد حصول أحدي الحالات التاليه في بيئة منزلك الداخليه؟**

| | | أبداً | 1 - 3 أيام فى السنه | 1 - 3 أيام فى الشهر | 1 - 3 أيام فى الأسبوع | يومياً/ يومياً تقريباً |
|---|---|---|---|---|---|---|
| 20 | دخان من البخور | ☐ | ☐ | ☐ | ☐ | ☐ |
| 21 | روائح من سجاد أو ستائرجديدة | ☐ | ☐ | ☐ | ☐ | ☐ |
| 22 | روائح عفنه ناتجه عن الرطوبه | ☐ | ☐ | ☐ | ☐ | ☐ |
| 23 | رائحة شبيهه برائحة السمك/ أطعمة أخرى | ☐ | ☐ | ☐ | ☐ | ☐ |
| 24 | روائح من الاجسام أو من مواد وأدوات التجميل | ☐ | ☐ | ☐ | ☐ | ☐ |
| 25 | روائح من الطلاء و الصبغ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 26 | روائح من مواد كيميائية أخرى | ☐ | ☐ | ☐ | ☐ | ☐ |
| 27 | دخان التبغ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 28 | روائح ديزل أو من عوادم الماكينات | ☐ | ☐ | ☐ | ☐ | ☐ |
| 29 | غبار و أوساخ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 30 | هواءغير نقي "عفن" | ☐ | ☐ | ☐ | ☐ | ☐ |

| | | أبداً | 1 - 3 أيام فى السنه | 1 - 3 أيام فى الشهر | 1 - 3 أيام فى الأسبوع | يومياً/ يومياً تقريباً |
|---|---|---|---|---|---|---|
| 31 | حركة هواء قويه جداً | ☐ | ☐ | ☐ | ☐ | ☐ |
| 32 | حركة هواء ضعيفه جداً | ☐ | ☐ | ☐ | ☐ | ☐ |
| 33 | درجة حرارة عاليه جداً | ☐ | ☐ | ☐ | ☐ | ☐ |
| 34 | درجة حراره منخفضه جداً | ☐ | ☐ | ☐ | ☐ | ☐ |
| 35 | درجة رطوبه عاليه | ☐ | ☐ | ☐ | ☐ | ☐ |
| 36 | درجة جفاف عاليه | ☐ | ☐ | ☐ | ☐ | ☐ |
| 37 | إضاءة / وهج قوى جداً | ☐ | ☐ | ☐ | ☐ | ☐ |
| 38 | إضاءة / وهج ضعيفه جداً | ☐ | ☐ | ☐ | ☐ | ☐ |
| 39 | ضجيج عالي جداً | ☐ | ☐ | ☐ | ☐ | ☐ |
| 40 | هدوء شديد جداً | ☐ | ☐ | ☐ | ☐ | ☐ |

41 **ما هو تقييمك لنوعية الهواء بداخل منزلك خلال السنه السابقه؟** (1) مُمتازه ☐ (2) جيده ☐ (3) حسنه ☐ (4) سيئه ☐

IV **خلال السنه السابقه, هل من المعتاد أن تُعاني أنتَ أو أى أحد من عائلتك من أحد الأعراض التاليه؟**

**في حالة معاناتك من العرض, هل تتغير حدته خارج المنزل؟**

| | | أبداً | 1 - 3 أيام فى السنه | 1 - 3 أيام فى الشهر | 1 - 3 أيام فى الأسبوع | يومياً/ يومياً تقريباً | | **تزيد حدته** | **يظل كما هو** | **تخف حدته** |
|---|---|---|---|---|---|---|---|---|---|---|
| 42 | صداع أو غثيان | ☐ | ☐ | ☐ | ☐ | ☐ | ⇐ | ☐ | ☐ | ☐ |
| 43 | أعراض مرتبطة بالأنف مثل تدفق مخاطى, إنسداد أنفى, أو عطس | ☐ | ☐ | ☐ | ☐ | ☐ | ⇐ | ☐ | ☐ | ☐ |
| 44 | أعراض مرتبطة بالصدرمثل ضيق أو صفير فى الصدر, أو تنفس متسارع | ☐ | ☐ | ☐ | ☐ | ☐ | ⇐ | ☐ | ☐ | ☐ |
| 45 | سعال | ☐ | ☐ | ☐ | ☐ | ☐ | ⇐ | ☐ | ☐ | ☐ |
| 46 | أعراض مرتبطة بالعين مثل جفاف، حكه، إلتهاب، إجهاد، أو رؤيه ضبابيه | ☐ | ☐ | ☐ | ☐ | ☐ | ⇐ | ☐ | ☐ | ☐ |
| 47 | أعراض مرتبطة بالحلق مثل إلتهاب أو جفاف في الحلق، أو بحه فى الصوت | ☐ | ☐ | ☐ | ☐ | ☐ | ⇐ | ☐ | ☐ | ☐ |
| 48 | تعب أو إرهاق غير معتاد | ☐ | ☐ | ☐ | ☐ | ☐ | ⇐ | ☐ | ☐ | ☐ |
| 49 | حمى | ☐ | ☐ | ☐ | ☐ | ☐ | ⇐ | ☐ | ☐ | ☐ |
| 50 | ألم في العضلات, المفاصل, أسفل الظهر, الكتف, الرقبه, أو اليد | ☐ | ☐ | ☐ | ☐ | ☐ | ⇐ | ☐ | ☐ | ☐ |
| 51 | أعراض مرتبطه بالدماغ مثل صعوبة فى التركيز, عصبية, أو توتر | ☐ | ☐ | ☐ | ☐ | ☐ | ⇐ | ☐ | ☐ | ☐ |
| 52 | بشرة جافة أو حكة جلدية | ☐ | ☐ | ☐ | ☐ | ☐ | ⇐ | ☐ | ☐ | ☐ |

**شكرا جزيـــلا**

# Appendix F : Field study questionnaire

Survey about:

# The Influential Factors on Indoor Air Quality and Sick Building Syndrome in Dubai Housing

Thank you for agreeing to take part in this survey.

The survey is conducted to investigate the most influential factors on indoor air quality and its subsequent impacts on occupants' health.

Please answer the questions as accurately and completely as you can, regardless of how satisfied or dissatisfied you are with conditions in the building.

This survey might only take 5 – 10 minutes to be completed.

Be assured that this questionnaire is completely anonymous and that no personally identifiable information is captured.

I.

1 **What is your gender?** ☐ Male ☐ Female

2 **What is your nationality?**

(1) UAE or GCC national
(2) Other Arabs/ MENA (3) Indian Subcontinent
(4) Other Asians (5) Other African
(6) Europeans, Oceanians, North or South American

3 **What is your age?**

(1) Less than 18 years (2) 18–34 years
(3) 35–54 years (4) 55 – 74 years
(5) Older than 74 years

4 **Are you a smoker?**

(1) No (2) Yes

5 **Does your house include a smoker?**

(1) No (2) Yes

6 **Please indicate if you or any one of your family have ever experienced one of the following:**

☐ Asthma ☐ Migraine
☐ Hay fever ☐ Allergy to dust
☐ Eczema ☐ Allergy to molds

II.

7 **Area of living in Dubai:** ________________________

8 **House type:** (1) Flat (2) Villa

9 **How many persons in your house within the following age groups (Please indicate a number):**

(1) Less than 18 years ☐ (2) 18–34 years ☐
(3) 35–54 years ☐ (4) 55 – 74 years ☐
(5) Older than 74 years ☐

10 **Number of years living in this house:**

(1) Less than 3 years (2) 4 – 6 years
(3) 7 – 10 years (4) More than 10 years

11 **For how long the house is built:**

(1) Less than 3 years (2) 4–6 years
(3) 7 – 10 years (4) More than 10 years
(5) Not aware/ not sure

12 **Please select your kitchen type from the following:**

(1) Unattached (Separate unit)
(2) Attached open kitchen without interior walls
(3) Attached kitchen with interior walls

13 **The applied air conditioning (AC) system in your house is:**

(1) Central ☐ (2) Split ☐ (3) Window ☐

**Last year, please select which of the following events have taken place in your house?**

14 New carpet ☐ 15 New furniture ☐ 16 Walls painted ☐
17 Rearranged walls ☐ 18 New wall covering ☐ 19 Water leakage ☐

III **Have you experienced any of the following at your house yesterday:**

| | | Yes | No |
|---|---|---|---|
| 20 | Smoke from incense burning | ☐ | ☐ |
| 21 | Odors from new carpet or curtains | ☐ | ☐ |
| 22 | Musty/mouldy dampness odors | ☐ | ☐ |
| 23 | Fishy smells or other food smells | ☐ | ☐ |
| 24 | Body odors or cosmetic odors | ☐ | ☐ |
| 25 | Odors from paint | ☐ | ☐ |
| 26 | Odors from other chemicals | ☐ | ☐ |
| 27 | Tobacco smoke | ☐ | ☐ |
| 28 | Odors from diesel or engine exhaust | ☐ | ☐ |
| 29 | Dust and dirt | ☐ | ☐ |
| 30 | Stuffy "bad" air | ☐ | ☐ |

**For the following, please check the response that best describes your house indoor environment yesterday:**

| | | Morning | Afternoon |
|---|---|---|---|
| 31 | Too much air movement | ☐ | ☐ |
| 32 | Too little air movement | ☐ | ☐ |
| 33 | Too hot | ☐ | ☐ |
| 34 | Too cold | ☐ | ☐ |
| 35 | Too much humidity | ☐ | ☐ |
| 36 | Too much dryness | ☐ | ☐ |
| 37 | Too much glare | ☐ | ☐ |
| 38 | Too much dim | ☐ | ☐ |
| 39 | Too noisy | ☐ | ☐ |
| 40 | Too quiet | ☐ | ☐ |

41 **How do you judge the overall indoor air quality of your house yesterday?**

(1) Excellent ☐ (2) Good ☐ (3) Fair ☐ (4) Poor ☐

IV. **Have you suffered from the following symptoms at your house yesterday:**

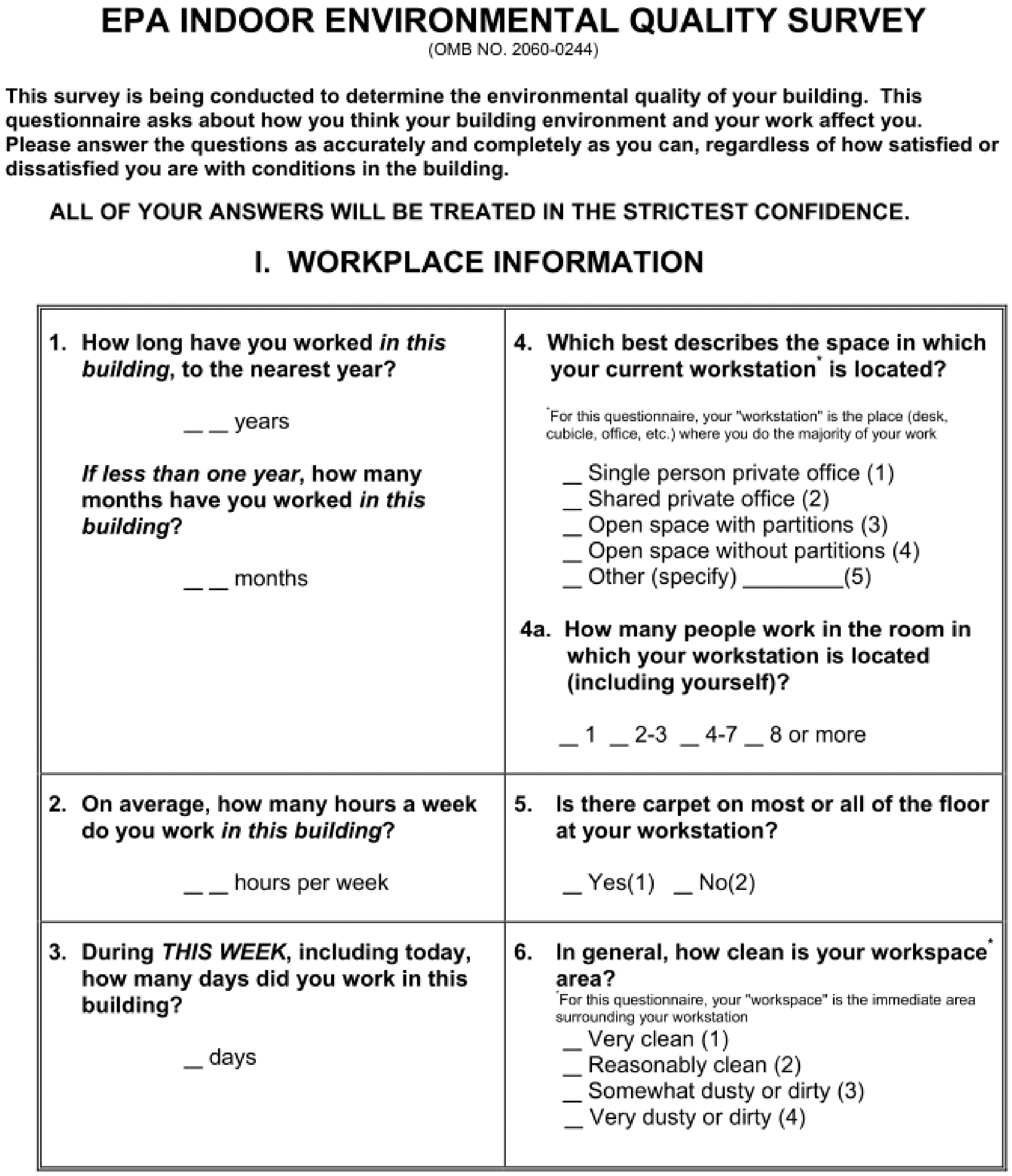
**If experienced, how it changes outside your house?**

| | | Yes | No | | Gets more | Stay same | Gets less | NA | It Varies |
|---|---|---|---|---|---|---|---|---|---|
| 42 | Headache or nausea | ☐ | ☐ | ⇨ | | | | | |
| 43 | Nasal symptoms i.e. runny nose, stuffy nose or sneezing | ☐ | ☐ | ⇨ | | | | | |
| 44 | Chest-related symptoms i.e. tightness, wheezing or short breath | ☐ | ☐ | ⇨ | | | | | |
| 45 | Cough | ☐ | ☐ | ⇨ | | | | | |
| 46 | Eye-related symptoms i.e. sore, itching, burning, or tearing eyes | ☐ | ☐ | ⇨ | | | | | |
| 47 | Throat-related symptoms i.e. sore throat, or dry throat | ☐ | ☐ | ⇨ | | | | | |
| 48 | Unusual fatigue or tiredness, sleepiness or drowsiness | ☐ | ☐ | ⇨ | | | | | |
| 49 | Fever | ☐ | ☐ | ⇨ | | | | | |
| 50 | Pain in muscles, joints, back, neck, or hand | ☐ | ☐ | ⇨ | | | | | |
| 51 | Neurological symptoms i.e. tension, concentration problems | ☐ | ☐ | ⇨ | | | | | |
| 52 | Dry or itchy skin | ☐ | ☐ | ⇨ | | | | | |

## Thanks a lot

# Appendix G : Indoor environmental quality questionnaire

EPA BASE study (EPA 2003)



## EPA INDOOR ENVIRONMENTAL QUALITY SURVEY

(OMB NO. 2060-0244)

**This survey is being conducted to determine the environmental quality of your building. This questionnaire asks about how you think your building environment and your work affect you. Please answer the questions as accurately and completely as you can, regardless of how satisfied or dissatisfied you are with conditions in the building.**

**ALL OF YOUR ANSWERS WILL BE TREATED IN THE STRICTEST CONFIDENCE.**

## I. WORKPLACE INFORMATION

**1. How long have you worked *in this building*, to the nearest year?**

_ _ years

***If less than one year*, how many months have you worked *in this building*?**

_ _ months

**2. On average, how many hours a week do you work *in this building*?**

_ _ hours per week

**3. During *THIS WEEK*, including today, how many days did you work in this building?**

_ days

**4. Which best describes the space in which your current workstation[*] is located?**

[*] For this questionnaire, your "workstation" is the place (desk, cubicle, office, etc.) where you do the majority of your work

_ Single person private office (1)
_ Shared private office (2)
_ Open space with partitions (3)
_ Open space without partitions (4)
_ Other (specify) ________(5)

**4a. How many people work in the room in which your workstation is located (including yourself)?**

_ 1 _ 2-3 _ 4-7 _ 8 or more

**5. Is there carpet on most or all of the floor at your workstation?**

_ Yes(1) _ No(2)

**6. In general, how clean is your workspace[*] area?**

[*] For this questionnaire, your "workspace" is the immediate area surrounding your workstation

_ Very clean (1)
_ Reasonably clean (2)
_ Somewhat dusty or dirty (3)
_ Very dusty or dirty (4)

**7. Please rate the lighting at your workstation.**

__ Much too dim (1)
__ A little too dim (2)
__ Just right (3)
__ A little too bright (4)
__ Much too bright (5)

**8. Do you experience a reflection or "glare" in your field of vision when at your workstation?**

__ Rarely (1)
__ Occasionally (2)
__ Sometimes (3)
__ Fairly often (4)
__ Very often (5)

**9. How comfortable is the chair at your workstation?**

__ Very comfortable (1)
__ Reasonably comfortable (2)
__ Somewhat uncomfortable (3)
__ Very uncomfortable (4)
__ Don't have one specific chair (5)

**10. How comfortable is the current set-up of your desk or work table** (i.e., height and general arrangement of the table, chair, and equipment you work with)**?**

__ Very comfortable (1)
__ Reasonably comfortable (2)
__ Somewhat uncomfortable (3)
__ Very uncomfortable (4)
__ Don't have one specific desk or work table (5)

**11. Do you work with a computer or word processor?**
____ yes(1) ____ no(2)(skip to #12)

**11a. About how many hours a day do you work with a computer or word processor, to the nearest hour?**
__ __ hours per day

**11b. If you use a computer or word processor, do you usually wear glasses when you use these machines?**
__ Yes (1) __ No (2)

**11c. Do you use a glare screen on your computer?**
__ Yes (1) __ No (2)

**12. Which one of the following statements best describes the windows in your work area?**

__ There are no windows in my personal workspace and none in the general area visible from my workspace (when I am either standing or seated). (1)

__ There are no windows in my personal workspace, but I can see one or more windows in the general area. (2)

__ There are one or more windows in my personal workspace. (3)

**13. If there is a window visible from your workspace, how far (in feet) is the closest window from your desk chair?**

______ feet ______ No window

**14. During the PAST THREE MONTHS, have the following changes taken place within 15 feet of your current workstation?**

| | YES (1) | NO (2) |
|---|---|---|
| New carpeting | | |
| Walls painted | | |
| New furniture | | |
| New partitions | | |
| New wall covering | | |
| Water damage | | |

**15. How often do you use the following at work? (Check the appropriate box for each item.)**

| | Several times a day (1) | About once a day (2) | 3-4 times a week (3) | Less than 3 times/week (4) | Never (5) |
|---|---|---|---|---|---|
| Photocopier | | | | | |
| Laser printer | | | | | |
| Facsimile (FAX) machine | | | | | |
| Self-copying (carbonless) copy paper | | | | | |
| Cleanser, glue, correction fluid, or other odorous chemicals | | | | | |

## II. INFORMATION ABOUT HEALTH AND WELL-BEING

**1. Have you ever been told by a doctor that you have or had any of the following?**

| | YES(1) | NO(2) |
|---|---|---|
| Migraine | | |
| Asthma | | |
| Eczema | | |
| Hay fever | | |
| Allergy to dust | | |
| Allergy to molds | | |

**2. What is your tobacco smoking status?**

__ never smoked (1)
__ former smoker (2)
__ current smoker (3)

**3. Do you consider yourself especially sensitive to the presence of tobacco smoke in your workspace?**

__ Yes (1) __ No (2)

**4. Do you consider yourself especially sensitive to the presence of other chemicals in the air of your workspace?**

___ Yes (1) ___ No (2)

**5. What type of corrective lenses do you usually wear at work?**

__ none (1)
__ glasses (2)
__ bifocals(3)
__ contact lenses (4)

**6. How old were you on your last birthday?**

__ under 20(1) __ 20-29 years(2)

__ 30-39 years(3) __ 40-49 years(4)

__ 50-59 years(5) __ over 59 years(6)

**7. Are you:**

__ male (1) __ female (2)

## II. (Cont.) EXAMPLE -- HOW TO ANSWER THE QUESTIONS ON THE NEXT PAGE.

The next page contains questions regarding symptoms you may have experienced while at work during the last 4 weeks. The following **EXAMPLE** shows how an employee might fill out this type of questionnaire.

| 8. During the **LAST FOUR WEEKS YOU WERE AT WORK,** how often have you experienced each of the following symptoms while working in this building?<br>· If you answer "Not in Last 4 Weeks" for a symptom, please move down the page to the next symptom. | | | | | 8a.During the **LAST FOUR WEEKS YOU WERE AT WORK**, what happened to this symptom at times when you were away from work? (eg, holidays, weekends) | | | 8b. During **THIS WEEK**, on how many days did you experience this symptom? |
|---|---|---|---|---|---|---|---|---|
| **SYMPTOMS** | **Not in Last 4 Weeks (1)** | **1-3 days in last 4 weeks (2)** | **1-3 days *per wk* in last 4 wks (3)** | **Every or Almost Every Workday (4)** | **Got Worse (1)** | **Stayed Same (2)** | **Got Better (3)** | **Number of Days This Week** |
| earache | X | | | | | | | |
| hiccups | X | | | | | | | |
| toothache | | X | | | | X | | 0 |
| leg cramps | | | | X | X | | | 3 |

| | |
|---|---|
| **9a. In the LAST FOUR WEEKS how often have any of the symptoms listed above reduced your ability to work?**<br>_6_ **days** | **9b. In the LAST FOUR WEEKS how often have any of the symptoms listed caused you to leave work?**<br>_3_ **days** |

The above responses show that during the last 4 weeks while at work, **THIS EMPLOYEE**:

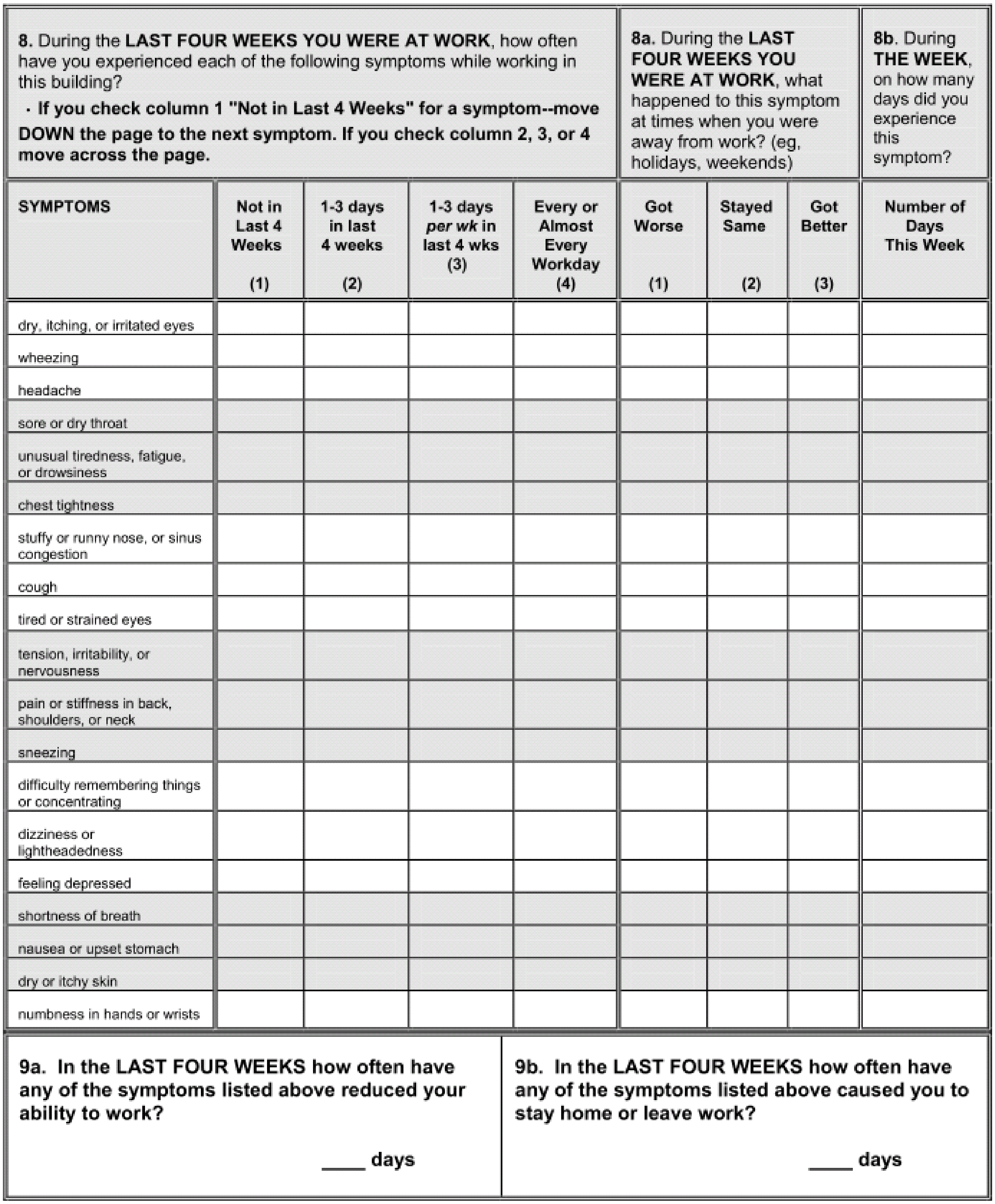
1. Did not experience EARACHE or HICCUPS.

2. Experienced TOOTHACHE 1-3 days. Toothache stayed same when away from work. No toothache this week.

3. Experienced LEG CRAMPS almost every day. Leg cramps got worse when away from work. H leg cramps three days this week.

One or more of the symptoms reduced their ability to work 6 days in the last four weeks. One or more of the symptoms caused them to stay home or leave work 3 days.

**(NOTE that the symptoms in this example are for illustration only and are not the same as those on the following page.)**



| **8.** During the **LAST FOUR WEEKS YOU WERE AT WORK**, how often have you experienced each of the following symptoms while working in this building?<br>· **If you check column 1 "Not in Last 4 Weeks" for a symptom--move DOWN the page to the next symptom. If you check column 2, 3, or 4 move across the page.** | | | | | **8a.** During the **LAST FOUR WEEKS YOU WERE AT WORK**, what happened to this symptom at times when you were away from work? (eg, holidays, weekends) | | | **8b.** During **THE WEEK**, on how many days did you experience this symptom? |
|---|---|---|---|---|---|---|---|---|
| **SYMPTOMS** | **Not in Last 4 Weeks (1)** | **1-3 days in last 4 weeks (2)** | **1-3 days *per wk* in last 4 wks (3)** | **Every or Almost Every Workday (4)** | **Got Worse (1)** | **Stayed Same (2)** | **Got Better (3)** | **Number of Days This Week** |
| dry, itching, or irritated eyes | | | | | | | | |
| wheezing | | | | | | | | |
| headache | | | | | | | | |
| sore or dry throat | | | | | | | | |
| unusual tiredness, fatigue, or drowsiness | | | | | | | | |
| chest tightness | | | | | | | | |
| stuffy or runny nose, or sinus congestion | | | | | | | | |
| cough | | | | | | | | |
| tired or strained eyes | | | | | | | | |
| tension, irritability, or nervousness | | | | | | | | |
| pain or stiffness in back, shoulders, or neck | | | | | | | | |
| sneezing | | | | | | | | |
| difficulty remembering things or concentrating | | | | | | | | |
| dizziness or lightheadedness | | | | | | | | |
| feeling depressed | | | | | | | | |
| shortness of breath | | | | | | | | |
| nausea or upset stomach | | | | | | | | |
| dry or itchy skin | | | | | | | | |
| numbness in hands or wrists | | | | | | | | |

**9a. In the LAST FOUR WEEKS how often have any of the symptoms listed above reduced your ability to work?**

**____ days**

**9b. In the LAST FOUR WEEKS how often have any of the symptoms listed above caused you to stay home or leave work?**

**____ days**

# III. DESCRIPTION OF WORKPLACE CONDITIONS

| 1. During the **LAST FOUR WEEKS YOU WERE AT WORK**, how often have you experienced each of the following environmental conditions while working in this building?<br>· **If you put a check in the column "Not in Last 4 Weeks " -- move down the page to the next condition.** | | | | | 1a. During **THE WEEK**, on how many days did you experience this environmental condition? |
|---|---|---|---|---|---|
| **CONDITIONS** | **Not in** Last 4 **Weeks (1)** | **1-3 days in last 4 weeks (2)** | **1-3 days *per wk* in last 4 wks (3)** | **Every or** Almost Every **Workday (4)** | **Number of Days This Week** |
| too much air movement | | | | | |
| too little air movement | | | | | |
| temperature too hot | | | | | |
| temperature too cold | | | | | |
| air too humid | | | | | |
| air too dry | | | | | |
| tobacco smoke odors | | | | | |
| unpleasant chemical odors | | | | | |
| other unpleasant odors (e.g., body odor, food odor, perfume) | | | | | |

**How satisfied are you with the following aspects of your workstation?**

| **2. Conversational privacy** | **3. Freedom from distracting noise** |
|---|---|
| __ Very satisfied (1)<br>__ Somewhat satisfied (2)<br>__ Not too satisfied (3)<br>__ Not at all satisfied (4) | __ Very satisfied (1)<br>__ Somewhat satisfied (2)<br>__ Not too satisfied (3)<br>__ Not at all satisfied (4) |

# IV. CHARACTERISTICS OF YOUR JOB

**1. What is your job category?**

__ Managerial (1)
__ Professional (2)
__ Technical (3)
__ Secretarial or Clerical(4)
__ Other (specify) _____________(5)

**2. All in all, how satisfied are you with your job?**

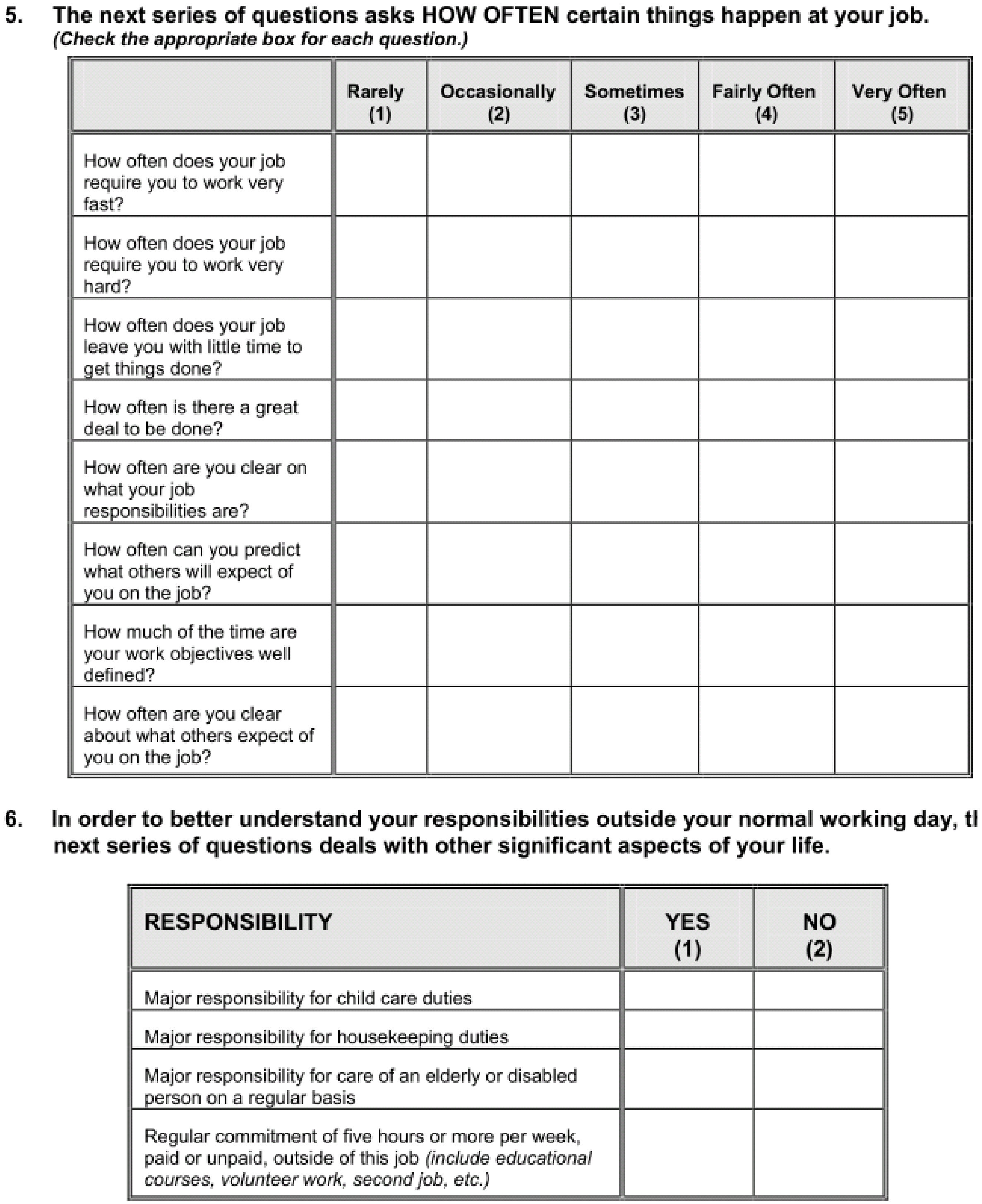
__ Very satisfied (1)
__ Somewhat satisfied(2)
__ Not too satisfied (3)
__ Not at all satisfied (4)

**3. What is the highest level you completed in school?**

__ 8th grade or less (1)
__ Some high school (2)
__ High school graduate (3)
__ Some college (4)
__ College degree (5)
__ Graduate degree (6)

**4.** Conflicts can occur in any job. For example, someone may ask you to do work in a way that is different from what you think best, or you may find that it is difficult to satisfy everyone. **HOW OFTEN do you face problems in your work like the ones listed below? (Check the appropriate box for each statement.)**

| | Rarely or Never (1) | Sometimes (2) | Fairly Often (3) | Very Often (4) |
|---|---|---|---|---|
| Persons equal in rank and authority over you ask you to do things which conflict | | | | |
| People in a good position to see if you do what they ask give you things to do which conflict with one another | | | | |
| People whose requests should be met give you things which conflict with other work you have to do | | | | |



5. **The next series of questions asks HOW OFTEN certain things happen at your job.**
***(Check the appropriate box for each question.)***

| | Rarely (1) | Occasionally (2) | Sometimes (3) | Fairly Often (4) | Very Often (5) |
|---|---|---|---|---|---|
| How often does your job require you to work very fast? | | | | | |
| How often does your job require you to work very hard? | | | | | |
| How often does your job leave you with little time to get things done? | | | | | |
| How often is there a great deal to be done? | | | | | |
| How often are you clear on what your job responsibilities are? | | | | | |
| How often can you predict what others will expect of you on the job? | | | | | |
| How much of the time are your work objectives well defined? | | | | | |
| How often are you clear about what others expect of you on the job? | | | | | |

6. **In order to better understand your responsibilities outside your normal working day, tl next series of questions deals with other significant aspects of your life.**

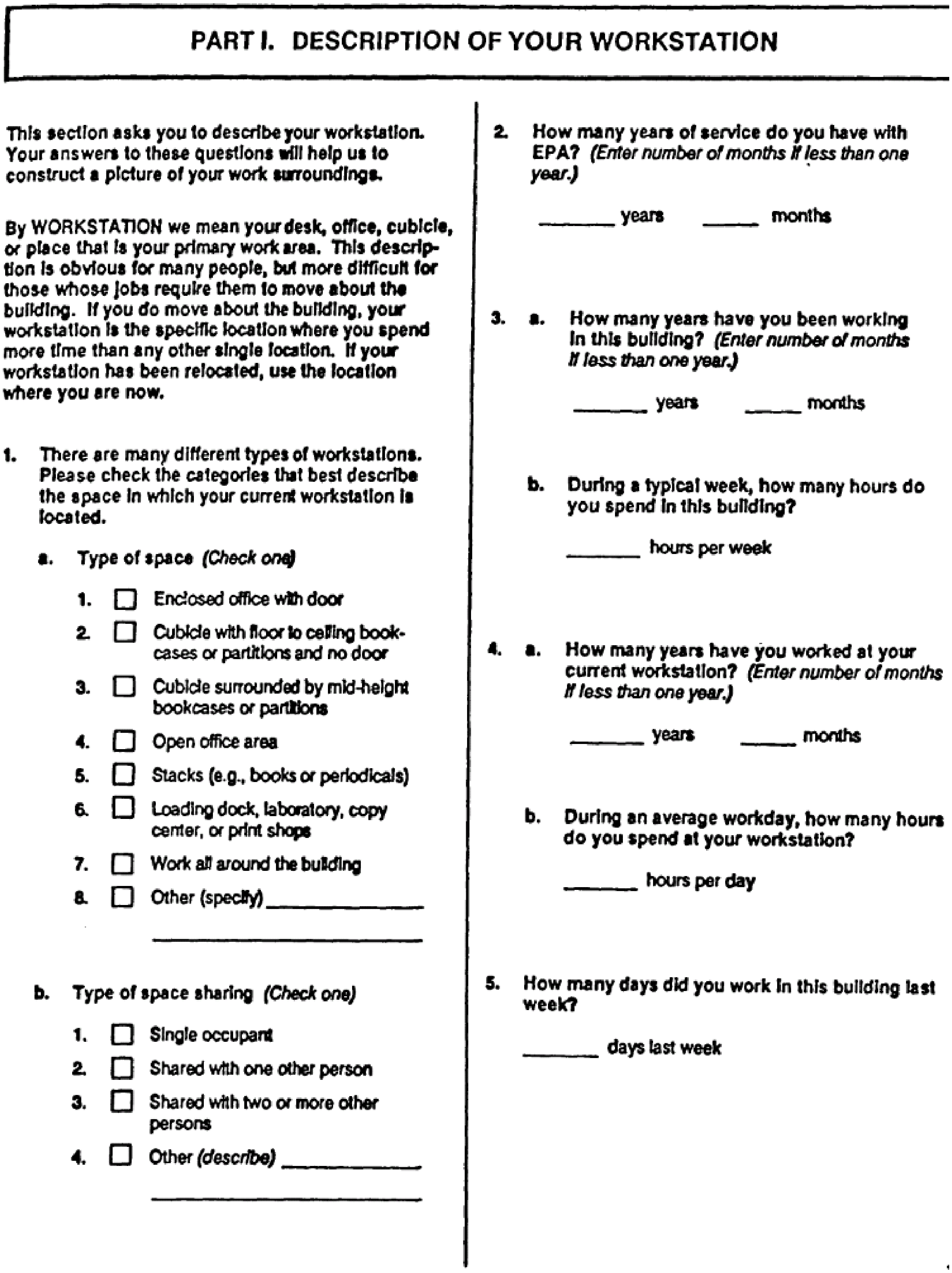
| **RESPONSIBILITY** | **YES (1)** | **NO (2)** |
|---|---|---|
| Major responsibility for child care duties | | |
| Major responsibility for housekeeping duties | | |
| Major responsibility for care of an elderly or disabled person on a regular basis | | |
| Regular commitment of five hours or more per week, paid or unpaid, outside of this job *(include educational courses, volunteer work, second job, etc.)* | | |

PLEASE USE THE REMAINING SPACE TO DISCUSS ANY ASPECTS OF THE BUILDING ENVIRONMENT OR EMPLOYEE HEALTH THAT YOU FEEL APPROPRIATE

_/_/_/_/_/_/_/

# Appendix H : IAQ and work environment questionnaire

EPA Headquarters follow-up survey (EPA 1991b)



## PART I. DESCRIPTION OF YOUR WORKSTATION

This section asks you to describe your workstation. Your answers to these questions will help us to construct a picture of your work surroundings.

By WORKSTATION we mean your desk, office, cubicle, or place that is your primary work area. This description is obvious for many people, but more difficult for those whose jobs require them to move about the building. If you do move about the building, your workstation is the specific location where you spend more time than any other single location. If your workstation has been relocated, use the location where you are now.

1. There are many different types of workstations. Please check the categories that best describe the space in which your current workstation is located.

   a. Type of space *(Check one)*

      1. ☐ Enclosed office with door
      2. ☐ Cubicle with floor to ceiling bookcases or partitions and no door
      3. ☐ Cubicle surrounded by mid-height bookcases or partitions
      4. ☐ Open office area
      5. ☐ Stacks (e.g., books or periodicals)
      6. ☐ Loading dock, laboratory, copy center, or print shops
      7. ☐ Work all around the building
      8. ☐ Other (specify) ______________

         ______________

   b. Type of space sharing *(Check one)*

      1. ☐ Single occupant
      2. ☐ Shared with one other person
      3. ☐ Shared with two or more other persons
      4. ☐ Other *(describe)* ______________

         ______________

2. How many years of service do you have with EPA? *(Enter number of months if less than one year.)*

   _______ years _____ months

3. a. How many years have you been working in this building? *(Enter number of months if less than one year.)*

   _______ years _____ months

   b. During a typical week, how many hours do you spend in this building?

   _______ hours per week

4. a. How many years have you worked at your current workstation? *(Enter number of months if less than one year.)*

   _______ years _____ months

   b. During an average workday, how many hours do you spend at your workstation?

   _______ hours per day

5. How many days did you work in this building last week?

   _______ days last week

6. What time do you usually:

| | | AM | PM |
|---|---|---|---|
| a. | Arrive at work ____:____ | ☐ | ☐ |
| b. | Leave work ____:____ | ☐ | ☐ |

c. Varies *(describe)* ____________________

____________________________________

7. **Which of the following items are presently located within 15 feet of your workstation?** *(Check "no" or "yes" for each item.)*

| | | No<br>1 | Yes<br>2 |
|---|---|---|---|
| a. | Metal desk ............... | ☐ | ☐ |
| b. | Wood or composition desk .. | ☐ | ☐ |
| c. | Metal bookshelves or bookcases ............... | ☐ | ☐ |
| d. | Wood or composition bookshelves or bookcases .. | ☐ | ☐ |
| e. | File cabinet(s) ............. | ☐ | ☐ |
| f. | Other metal furniture ....... | ☐ | ☐ |
| g. | Other wood or composition furniture ................. | ☐ | ☐ |
| h. | Fabric-covered partitions ... | ☐ | ☐ |
| i. | Portable humidifier ......... | ☐ | ☐ |
| j. | Laser printer .............. | ☐ | ☐ |
| k. | Photocopy machine ........ | ☐ | ☐ |
| l. | Live plants ............... | ☐ | ☐ |

8. **Is there carpeting on most or all of the floor at your workstation?**

1. ☐ No
2. ☐ Yes

9. **During a typical day LAST WEEK, how much time did you spend working with each of the following items?** *(If you worked with an item at all, but less than 1 hour, enter 1 hour per day.)*

| | | Hours per day |
|---|---|---|
| a. | Computer or word processor with screen/keyboard ....... | ____ |
| b. | Photocopy machine ........ | ____ |
| c. | Photographic developing and processing ............ | ____ |
| d. | Printing processing (press, binding materials, etc.) ...... | ____ |
| e. | Other chemicals such as glues, adhesives, cleansers, white out, rubber cement, pesticides, etc. ............ | ____ |

**NOTE: If you have worked in this building for less than a year, answer the following questions for the part of the year that you worked in this building.**

10. **Were any of the following items regularly used at your workstation during the LAST YEAR:** *(Check "no" or "yes" for each item.)*

| | | No<br>1 | Yes<br>2 |
|---|---|---|---|
| a. | Portable fan ............... | ☐ | ☐ |
| b. | Portable air filter, or cleaner, or negative-ion generator .... | ☐ | ☐ |
| c. | Portable heater ............ | ☐ | ☐ |
| d. | Desk lamp ................ | ☐ | ☐ |

**11. During the LAST YEAR (and since you've been in your current workstation) have any of the following changes taken place within 15 feet of your current workstation?** ***(Check "no" or "yes" for each item.)***

| | No 1 | Yes 2 |
|---|---|---|
| a. New carpeting ............ | ☐ | ☐ |
| b. New drapes or curtains .... | ☐ | ☐ |
| c. New furniture ............. | ☐ | ☐ |
| d. New equipment, such as a computer ............ | ☐ | ☐ |
| e. Walls painted ............. | ☐ | ☐ |
| f. Rearranged walls .......... | ☐ | ☐ |

**12. At any time during the LAST YEAR, have you noticed evidence of new or continuing water leaks from the ceiling, floors, walls, or pipes near your workstation?**

1. ☐ No
2. ☐ Yes

## PART II. INFORMATION ABOUT YOUR HEALTH AND WELL-BEING

This section asks questions about the status of your health and well-being. Your answers to these questions will help us construct a profile of the health status of the employees in this building. Please answer all the questions even if you don't associate these health conditions with your work.

1. a. Do you wear contact lenses?

   1. ☐ Never → Go to Q.2
   2. ☐ Sometimes
   3. ☐ Often
   4. ☐ Always

   b. Do you wear contact lenses at work?

   1. ☐ Never
   2. ☐ Sometimes → Go to Q.2
   3. ☐ Often → Go to Q.2
   4. ☐ Always → Go to Q.2

   c. If never worn at work, why?

   ______________________________

   ______________________________

   ______________________________

2. During work, how often do you wear eyeglasses (NOT including contacts) for close-up work?

   1. ☐ Never
   2. ☐ Sometimes
   3. ☐ Often
   4. ☐ Always

3. Which of the following best describes your history of smoking tobacco products such as cigarettes, cigars or pipes?

   1. ☐ Never smoked → Go to Q.7
   2. ☐ Former smoker → Go to Q.7
   3. ☐ Current smoker

4. Do you smoke tobacco products at your workstation?

   1. ☐ Never
   2. ☐ Sometimes
   3. ☐ Often

5. Do you smoke tobacco products elsewhere at work?

   1. ☐ Never
   2. ☐ Sometimes
   3. ☐ Often

6. In a typical 24 hour day, how many CIGARETTES do you usually smoke?

   1 ☐ None
   2. ☐ 1 to 5
   3. ☐ 6 to 10
   4. ☐ 11 to 20
   5. ☐ 21 to 30
   6. ☐ 31 or more

**7.** Please answer the three questions to the right about each symptom listed below, even if you believe the symptom is not related to the building.
*(For each symptom, answer the first question. If the response is "never," go down to the next symptom.)*

| | Please indicate how often during the LAST YEAR you have experienced this symptom while working in this building. | | | | | Please indicate how many days LAST WEEK you experienced this symptom while working in this building. | Does the symptom usually change when not at work? | | |
|---|---|---|---|---|---|---|---|---|---|
| | Never | Rarely | Some-times | Often | Always | *(Fill in No. of days)* | Gets Worse | Stays Same | Gets Better |
| a. headache ................ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| b. nausea ................ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| c. runny nose ................ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| d. stuffy nose/sinus congestion ... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| e. sneezing ................ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| f. cough ................ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| g. wheezing or whistling in chest .. | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| h. shortness of breath ........... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| i. chest tightness ............ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| j. dry, itching, or tearing eyes ..... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| k. sore/strained eyes ............ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| l. blurry/double vision ........... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| m. burning eyes ................ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| n. sore throat ................ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| o. hoarseness ................ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| p. dry throat ................ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| q. unusual fatigue or tiredness .... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| r. sleepiness or drowsiness ..... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |

*(continued)*

| *(For each symptom, answer the first question. If the response is "never," go down to the next symptom.)* | Please indicate how often during the LAST YEAR you have experienced this symptom while working in this building. | | | | | Please indicate how many days LAST WEEK you experienced this symptom while working in this building. | Does the symptom usually change when not at work? | | |
|---|---|---|---|---|---|---|---|---|---|
| | Never | Rarely | Sometimes | Often | Always | *(Fill in No. of days)* | Gets Worse | Stays Same | Gets Better |
| s. chills | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| t. fever | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| u. aching muscles or joints | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| v. problems with contact lenses | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| w. difficulty remembering things | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| x. dizziness/lightheadedness | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| y. feeling depressed | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| z. tension or nervousness | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| aa. difficulty concentrating | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| bb. dry or itchy skin | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| cc. pain or stiffness in upper back | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| dd. pain or stiffness in lower back | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| ee. pain or numbness in shoulder/neck | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |
| ff. pain or numbness in hands or wrists | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | ______ | 1 ☐ | 2 ☐ | 3 ☐ |

NOTE: The next four questions (Questions 8-11) refer to your symptoms described in Question 7. *If you reported that you never experienced any of these symptoms, go to Question 12.*

8. How often during the LAST YEAR have any of your symptoms reduced your ability to work in this building?

1. ☐ Never
2. ☐ Rarely
3. ☐ Sometimes
4. ☐ Often
5. ☐ Always

9. a. Have any of your symptoms caused you to stay home from work or leave work early during the LAST YEAR?

1. ☐ Never → *Go to Q.10*
2. ☐ Rarely
3. ☐ Sometimes
4. ☐ Often

b. Which symptoms?

____________________________

____________________________

____________________________

10. In which season(s) are you bothered more by the symptoms you reported in Question 7? *(Check all that apply.)*

1. ☐ Winter
2. ☐ Spring
3. ☐ Summer
4. ☐ Fall
5. ☐ No relation to seasons

11. a. Do you associate any of the symptoms you reported in Question 7 with your work in this building?

1. ☐ No → *Go to Q.12*
2. ☐ Yes

b. Have these symptoms:

1. ☐ improved over the last year
2. ☐ become worse over the last year
3. ☐ stayed the same

12. During the LAST YEAR, have you had an illness in which you had repeated episodes of THREE OR MORE of the following symptoms at the same time: wheezing, cough, shortness of breath, fever, chills, aching joints/muscles?

1. ☐ No
2. ☐ Yes

13. During the LAST YEAR, have you had any chest illnesses, such as bronchitis or pneumonia, that have kept you off work, indoors at home, or in bed?

1. ☐ No
2. ☐ Yes

14. Has a physician ever told you that you have, or had, eczema?

1. ☐ No
2. ☐ Yes

15. During the LAST YEAR, have you had any episodes of wheezing (whistling in the chest) WITHOUT fever, or chills, or sore throat?

1. ☐ No
2. ☐ Yes

16. a. Has a physician ever told you that you have, or had, asthma?

1. ☐ No ⟶ Go to Q.17
2. ☐ Yes

b. In what year was it first diagnosed?

19 ______

c. Have you had an asthma attack during the LAST YEAR?

1. ☐ No
2. ☐ Yes

17. Comparing your health since working in this building with your health before you began to work in this building . . .

a. . . . do you have infections (e.g., colds, flu, bronchitis, etc.) . . .

1. ☐ more frequently?
2. ☐ less frequently?
3. ☐ with the same frequency?

b. . . . do your infections (e.g., colds, flu, bronchitis, etc.) tend to . . .

1. ☐ last longer?
2. ☐ last a shorter amount of time?
3. ☐ last about the same amount of time?

18. Do you believe you are or may be allergic to any of the following? *(Check "no" or "yes" for each item.)*

| | No<br>1 | Yes<br>2 |
|---|---|---|
| a. pollen or plants ........... | ☐ | ☐ |
| b. animals .................. | ☐ | ☐ |
| c. dust ...................... | ☐ | ☐ |
| d. molds .................... | ☐ | ☐ |
| e. Other *(specify)* ............ ______ | ☐ | ☐ |

19. During the LAST YEAR, how often do you believe you have experienced EYE, NOSE, THROAT, OR RESPIRATORY IRRITATION at your workstation from:

| | NEVER | RARELY | SOMETIMES | OFTEN | ALWAYS |
|---|---|---|---|---|---|
| a. Tobacco smoke ... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| b. Fumes from a photocopying machine ......... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| c. Fumes from printing processing (press, binding materials, etc.) .... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| d. Fumes from other chemicals such as adhesives, glues, cleansers, white out, rubber cement, etc. ...... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| e. Fumes from pesticides ........ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| f. Fumes from new carpeting ..... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| g. Fumes from new drapes, curtains, or furniture .......... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| h. Fumes from paint ............ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| i. Fumes from cleaning of carpets, drapes, or other furnishings ....... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| j. Other *(specify)* .... ______ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |

20. Do you consider yourself especially sensitive to any of the items in Question19?

1. ☐ No
2. ☐ Yes

21. How old are you?

_______ years

22. Are you:

1. ☐ Male ⟶ Go to Part III on pg. 11
2. ☐ Female

Women working in office buildings have occasionally reported patterns of gynecological or women's health problems. The following questions have been included to help sort out some of these issues in this building.

As with the rest of the questions in this survey, your responses are entirely voluntary and will be kept confidential.

23. During the LAST YEAR have you menstruated (had a period)?

1 ☐ No ⟶ Go to Q.29
2. ☐ Yes

24. How often during the LAST YEAR has your period been regular? (By regular, we mean your periods come about once a month, you can usually predict when they will come plus or minus 4 days, and each time they last about the same number of days.)

1. ☐ Never
2. ☐ Rarely
3. ☐ About half the time
4. ☐ Often
5. ☐ Always

25. a. How many days does your menstrual flow (period) typically last?

_______ days

b. During the last year, what was the LONGEST period you had?

_______ days

c. During the last year, what was the SHORTEST period you had?

_______ days

26. a. How many days does your cycle typically last? (Count from the first day of one period to the first day of the next.)

_______ days

b. During the last year, what was the LONGEST cycle you had?

_______ days

c. During the last year, what was the SHORTEST cycle you had?

_______ days

27. How often during the LAST YEAR has there been bleeding or spotting between your periods?

1. ☐ Never
2. ☐ 1 - 3 times
3. ☐ 4 - 6 times
4. ☐ 7 - 9 times
5. ☐ 10 or more times

28. a. Some women experience menstrual symptoms, such as headaches, weight gain, irritability, cramping, breast tenderness, or back pain. How often have you experienced any of these menstrual symptoms during the LAST YEAR?

1. ☐ Never ——→ Go to Q.29
2. ☐ 1 - 3 times
3. ☐ 4 - 6 times
4. ☐ 7 - 9 times
5. ☐ 10 or more times

b. When you experience these symptoms, typically how severe are they?

1. ☐ Mild; could be ignored at times
2. ☐ Moderate; pain, bloating, or mood change noticeably present
3. ☐ Severe; difficult to do most tasks
4. ☐ Extreme; incapacitating

29. During the LAST YEAR have you been . . . *(Check "no" or "yes" for each item.)*

| | | No<br>1 | Yes<br>2 |
|---|---|---|---|
| a. | Pregnant or nursing? ....... | ☐ | ☐ |
| b. | Taking birth control pills? ... | ☐ | ☐ |
| c. | Going through menopause (change of life)? ........... | ☐ | ☐ |
| d. | Post-menopausal (completed menopause)? ... | ☐ | ☐ |
| e. | Taking estrogen replacement therapy? ............ | ☐ | ☐ |

30. a. During the LAST YEAR have you been taking hormones prescribed by a physician?

1. ☐ No ——→ *Go to Q.31*
2. ☐ Yes

b. Specify what kind(s) and what they were prescribed for.

__________________________________

__________________________________

__________________________________

31. a. Has a physician ever told you that you had . . . *(Check "no" or "yes" for each item.)*

| | No<br>1 | Yes<br>2 | Year First Diagnosed |
|---|---|---|---|
| Fibroids? ........... | ☐ | ☐ | ____ |
| Cysts? ............. | ☐ | ☐ | ____ |
| Enlarged uterus? ..... | ☐ | ☐ | ____ |

——→ *If all are "no," go to Part III*

b. Have there been noticeable changes during the last year? *(Check one box for each item.)*

| | Decreased In Size<br>1 | Increased In Size<br>2 | No Change<br>3 | Other, Specify Below<br>4 |
|---|---|---|---|---|
| Fibroids ... | ☐ | ☐ | ☐ | ☐ |
| Cysts ..... | ☐ | ☐ | ☐ | ☐ |
| Enlarged uterus ..... | ☐ | ☐ | ☐ | ☐ |

*Specify* ____________________________

__________________________________

__________________________________

## PART III. INFORMATION ABOUT YOUR PRESENT WORK ENVIRONMENT

**This section asks you to report specific responses to the physical environment at your present workstation. You or a co-worker may have altered your work environment with a portable fan, heater, humidifier, etc. If so, please tell us how your work environment would have been without this equipment.**

| **1. At your present workstation, HOW OFTEN . . .** *(Please check one box for last year and one box for last week.)* | **. . . during the LAST YEAR** | | | | | **. . . during the LAST WEEK** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Never | Rarely | Some-times | Often | Always | Never | Rarely | Some-times | Often | Always |
| **a.** was there too much air movement? . . . . . . | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| **b.** was there too little air movement? . . . . . . | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| **c.** did you want to adjust the air movement? . . . . . . . . | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| **d.** was the temperature too hot? . . . . . . . . . . . | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| **e.** was the temperature too cold? . . . . . . . . . . | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| **f.** did you want to adjust the temperature? . . . . . . . . | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| **g.** was it too humid? . . . . | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| **h.** was it too dry? . . . . . . | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| **i.** did you want to adjust the humidity? . . . . . . . . . . | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| **j.** was the air too stuffy? . . . . . . . . . . . . | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| **k.** was it too noisy? . . . . | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| **l.** was it too quiet? . . . . | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| **m.** was the work area too dusty? . . . . . . | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |

**2. During the LAST YEAR, how often, if at all, have you noticed any of these types of ODORS at your present workstation?** *(Check one box for each item.)*

| | NEVER | RARELY | SOMETIMES | OFTEN | ALWAYS |
|---|---|---|---|---|---|
| a. Body odor ....... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| b. Cosmetics, such as perfume or after-shave ....... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| c. Tobacco smoke ... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| d. Fishy smells ...... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| e. Other food smells .. | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| f. Musty or damp basement smells .. | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| g. Odors from new carpet ....... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| h. Odors from new drapes or curtains . | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| i. Odors from diesel or other engine exhaust .......... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| j. Odors from a photocopying machine ......... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| k. Odors from printing processing (press, binding materials, etc.) .... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |

**2.** *(continued)*

| | NEVER | RARELY | SOMETIMES | OFTEN | ALWAYS |
|---|---|---|---|---|---|
| l. Odors from other chemicals such as adhesives, glues, cleansers, white out, rubber cement, pesticides, etc. .... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| m. Odors from pesticides ........ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| n. Odors from cleaning of carpets, drapes, or other furnishings ....... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| o. Odors from paint ............ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| p. Other unpleasant odors *(describe)* ... ________________ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |

**3. In which seasons would you most like to adjust the physical conditions around your workstation?** *(Check all that apply)*

| | None | Winter | Spring | Summer | Fall |
|---|---|---|---|---|---|
| a. Air movement ... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| b. Temperature .... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| c. Humidity ....... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| d. Odors ......... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |

**4. Please rate the lighting at your workstation.**

1. ☐ Much too dim
2. ☐ A little too dim
3. ☐ Just right
4. ☐ A little too bright
5. ☐ Much too bright

**5. a. Do you experience a reflection or "glare" in your field of vision when at your workstation?**

1. ☐ Never ——→ *Go to Q.6*
2. ☐ Sometimes
3. ☐ Often
4. ☐ Always

**b. Where does the reflection or glare come from?** *(Check all that apply)*

1. ☐ Window, sunlight, outside reflection
2. ☐ Overhead fluorescent lights
3. ☐ Video display screen and/or reflections when looking at screen
4. ☐ Desk lamp
5. ☐ Other *(specify)* ______________

**6. Can you see out an outside window from your workstation?**

1. ☐ No
2. ☐ Yes

**7. a. How comfortable is the chair at your workstation?**

1. ☐ Reasonably comfortable
2. ☐ Somewhat uncomfortable
3. ☐ Very uncomfortable
4. ☐ Don't have one specific chair ——→ *Go to Q.8*

**b. Is your chair easily adjustable?**

1. ☐ No
2. ☐ Yes
3. ☐ Not adjustable

**8. How comfortable is the current set-up of your desk or work table (that is, height and general arrangement of the table, chair, and equipment you work with)?**

1. ☐ Reasonably comfortable
2. ☐ Somewhat uncomfortable
3. ☐ Very uncomfortable
4. ☐ Don't have one specific desk or work table

**9. a. During the LAST YEAR, how many times per week did you go outdoors, weather permitting, during work hours (for lunch, break, or other reasons)?**

___ time(s) per week → If zero, go to Q.10

**b. How many of these times did you go outdoors primarily to get some fresh air?**

___ time(s) per week for fresh air

**NOTE: The next four questions concern the overall physical environment at your workstation, that is, the air quality, temperature, light, noise, odor, etc.**

**10. During the LAST WEEK, how satisfied were you with the physical environment at your workstation?**

1. ☐ Very satisfied
2. ☐ Somewhat satisfied
3. ☐ Not too satisfied
4. ☐ Not at all satisfied

**11. During the LAST YEAR, how satisfied were you with the overall physical environment at your workstation?**

1. ☐ Very satisfied
2. ☐ Somewhat satisfied
3. ☐ Not too satisfied
4. ☐ Not at all satisfied

**12. During the LAST YEAR, has the overall physical environment in the vicinity of your workstation:**

1. ☐ improved
2. ☐ become worse
3. ☐ stayed the same

**13. During a typical work day, does the overall physical environment in the vicinity of your workstation:**

1. ☐ improve during the day
2. ☐ become worse during the day
3. ☐ stay the same

# PART IV. CHARACTERISTICS OF YOUR JOB

**This section asks you to describe your job in terms of specific qualities. In order to gain a better understanding of your work environment, we would like to know how you feel about your job situation. As stated before, your responses will be kept confidential.**

**1. We would like you to think about the TYPE OF WORK YOU DO IN YOUR JOB.** ***(Check one box for each statement)***

**a. All in all, how satisfied are you with your job?**

1. ☐ Very satisfied
2. ☐ Somewhat satisfied
3. ☐ Not too satisfied
4. ☐ Not at all satisfied

**b. Knowing what you know now, if you had to decide again whether to take the job you now have, what would you decide? Would you . . .**

1. ☐ Decide without hesitation to take the same job
2. ☐ Have some second thoughts
3. ☐ Decide definitely not to take the same job

**c. If you were free right now to go into any type of job you wanted, what would your choice be? Would you . . .**

1. ☐ Take the same job
2. ☐ Take a different job
3. ☐ Not want to work

**d. If a friend of yours told you he/she was interested in working in a job like yours, what would you tell him/her? Would you . . .**

1. ☐ Strongly recommend it
2. ☐ Have doubts about recommending it
3. ☐ Advise against it

**2. How satisfied are you with your salary?**

1. ☐ Very satisfied
2. ☐ Somewhat satisfied
3. ☐ Not too satisfied
4. ☐ Not at all satisfied

**3. How satisfied are you with your opportunity for advancement at EPA?**

1. ☐ Very satisfied
2. ☐ Somewhat satisfied
3. ☐ Not too satisfied
4. ☐ Not at all satisfied

Conflicts can occur in any job. For example, someone may ask you to do work in a way which is different from what you think is best, or you may find that it is difficult to satisfy everyone. HOW OFTEN do you face problems in your work like the ones listed below? *(Check one box for each statement)*

| | RARELY OR NEVER | SOMETIMES | FAIRLY OFTEN | VERY OFTEN |
|---|---|---|---|---|
| a. Persons equal in rank and authority over you ask you to do things which conflict. ............. | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ |
| b. People in a good position to see if you do what they ask give you things to do which conflict with one another. ...... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ |
| c. People whose requests should be met give you things which conflict with other work you have to do. ........... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ |

5. The next series of questions asks HOW MUCH influence you now have in each of several areas at work. By influence we mean the degree to which you control what is done by others and have freedom to determine what you do yourself. *(Check one box for each question)*

| | VERY LITTLE | LITTLE | A MODERATE AMOUNT | MUCH | VERY MUCH |
|---|---|---|---|---|---|
| a. How much influence do you have over the amount of work you do? ...... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| b. How much influence do you have over the availability of materials you need to do your work? ..... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| c. How much do you influence the policies and procedures in your work group? ........... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| d. How much influence do you have over the arrangement of furniture and other work equipment at your workstation? ...... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |

The next series of questions asks HOW OFTEN certain things happen at your job. *(Check one box for each question)*

| | RARELY | OCCASIONALLY | SOMETIMES | FAIRLY OFTEN | VERY OFTEN |
|---|---|---|---|---|---|
| a. How often does your job require you to work very fast? ......... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| b. How often does your job require you to work very hard? ......... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| c. How often does your job leave you with little time to get things done? ...... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| d. How often is there a great deal to be done? ............ | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| e. How often does your job let you use the skills and knowledge you learned in school? .......... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| f. How often are you given a chance to do the things you do best? .......... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |

6. *(Continued)*

| | RARELY | OCCASIONALLY | SOMETIMES | FAIRLY OFTEN | VERY OFTEN |
|---|---|---|---|---|---|
| g. How often can you use the skills from your previous experience and training? ......... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| h. How often are you clear on what your job responsibilities are? ............. | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| i. How often can you predict what others will expect of you on the job? ............. | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| j. How much of the time are your work objectives well defined? .......... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| k. How often are you clear about what others expect of you on the job? ....... | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |

7. **In order to better understand your responsibilities outside your normal working day, the next series of questions deals with other significant aspects of your life.** ***(Check "no" or "yes" for each question)***

| | No<br>1 | Yes<br>2 |
|---|---|---|
| **a. Do you have children at home? ...............** | ☐ | ☐ |
| **b. Do you have major responsibility for childcare duties? ........** | ☐ | ☐ |
| **c. Do you have major responsibility for housecleaning duties? ....** | ☐ | ☐ |
| **d. Do you have major responsibility for the care of an elderly or disabled person on a regular basis? ...........** | ☐ | ☐ |
| **e. Are you taking courses for credit toward a degree or a diploma? .....** | ☐ | ☐ |
| **f. Do you have a regular commitment of five hours or more per week, paid or unpaid, outside of this job?** ***(include volunteer work, charitable work, second job, etc.)*** **.....** | ☐ | ☐ |

# PART V. CONCLUDING QUESTIONS

This section concludes this survey. Your answers to these questions, like your answers to the previous questions, will be kept confidential. This information is needed for statistical purposes.

1. What day of the week did you complete this survey?

   1. ☐ Monday
   2. ☐ Tuesday
   3. ☐ Wednesday
   4. ☐ Thursday
   5. ☐ Friday

2. Which of the following best describes your current living and financial arrangements?

   1. ☐ Live alone, sole provider of rent/mortgage, utilities, food, and other living expenses.
   2. ☐ Live alone, but receive assistance from one or more others in paying rent/mortgage, utilities, food, and other living expenses.
   3. ☐ Live with one or more other persons, but sole provider of rent/mortgage, utilities, food, and other living expenses.
   4. ☐ Live with one or more other persons who help to pay rent/mortgage, utilities, food, and other living expenses.

3. What is the highest grade you completed in school?

   1. ☐ 8th grade or less
   2. ☐ 9th, 10th, or 11th grade
   3. ☐ High school graduate
   4. ☐ 2 years of college or Associate Degree
   5. ☐ Bachelor's or technical degree
   6. ☐ Some graduate work
   7. ☐ Graduate or professional degree

4. a. What is your pay plan and grade (e.g., GS-5, GM-14, SES-2, WG-2, etc.)?

   ______________________________

   b. Which of the following best describes your job duties and responsibilities? *(If more than one applies, check the ONE box for the job duties on which you spend the most time.)*

   1. ☐ Managerial (such as administrator, manager, etc.)
   2. ☐ Professional (such as engineer, scientist, lawyer, etc.)
   3. ☐ Technical (such as technician, programmer, etc.)
   4. ☐ Administrative Support (such as clerical, computer operator, etc.)
   5. ☐ Service (such as health services, food preparation, janitorial, etc.)
   6. ☐ Craftsman (such as mechanic, repairer, etc.)
   7. ☐ Operator or laborer
   8. ☐ *Other (specify)*______________

      ______________________

The following information is needed so that your workstation can be located within this building. This is necessary so that we can relate your responses to the air measurements that will be taken in a few weeks. As with the rest of the questions in this survey, this information will be kept confidential. Please tell us:

5. a. Your room number

   ______________________________

   b. Your workstation telephone number (your direct or private number.)

   ______________________________

6. Is there anything else you would like to tell us about environmental or health matters in this building? If so, please use this space provided for that purpose.

Please put your completed questionnaire in the return envelope provided. Seal it and take it to one of the return boxes located near the elevators and building exits.

# Appendix I : MM 040 NA questionnaire

| | | |
|---|---|---|
| **INDOOR CLIMATE**<br>**Work environment**<br>**ENGLISH VERSION** | **MM 040 NA**<br>Date<br>year month day<br>\|___\|___\|___\|___\|___\|___\| | Name (voluntary information)<br>Company/Institution (important information) |

1-6

7-11 Occupation|___|___|___|___|___|

Department (important information)

12-21 User |___|___|___|___|___| Group |___|___|___|___|___|

Filled in by investigator

**This questionnaire concerns your indoor climate and possible symptoms you may be experiencing.**

### BACKGROUND FACTORS

22-23 Year of birth 19 |___|___|

24 Sex Male ☐1 Female ☐2

25 Do you smoke? Yes ☐1 No ☐2

Occupation ..........................................................

How long have you been at your present place of work? |___|___| years 26-27

### WORK ENVIRONMENT

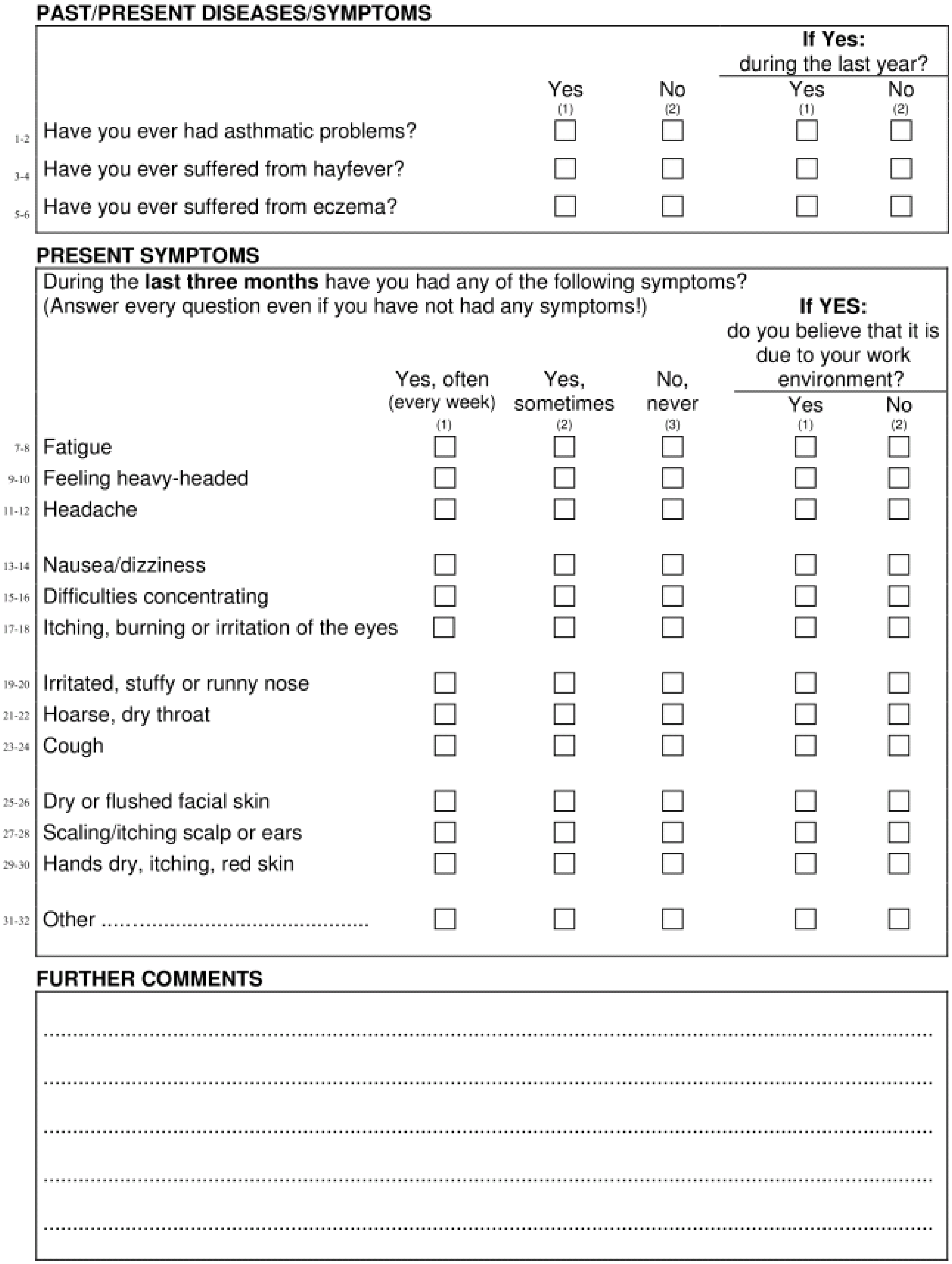
| Have you been **bothered** during **the last three months** by any of the following factors at **your work place**?<br>(Answer every question even if you have not been bothered!) | Yes, often (every week) (1) | Yes, sometimes (2) | No, never (3) |
|---|---|---|---|
| 28 Draught | ☐ | ☐ | ☐ |
| 29 Room temperature too high | ☐ | ☐ | ☐ |
| 30 Varying room temperature | ☐ | ☐ | ☐ |
| 31 Room temperature too low | ☐ | ☐ | ☐ |
| 32 Stuffy "bad" air | ☐ | ☐ | ☐ |
| 33 Dry air | ☐ | ☐ | ☐ |
| 34 Unpleasant odour | ☐ | ☐ | ☐ |
| 35 Static electricity, often causing shocks | ☐ | ☐ | ☐ |
| 36 Passive smoking | ☐ | ☐ | ☐ |
| 37 Noise | ☐ | ☐ | ☐ |
| 38 Light that is dim or causes glare and/or reflections | ☐ | ☐ | ☐ |
| 39 Dust and dirt | ☐ | ☐ | ☐ |

### WORK CONDITIONS

| | Yes, often (1) | Yes, sometimes (2) | No, seldom (3) | No, never (4) |
|---|---|---|---|---|
| 40 Do you regard your work as interesting and stimulating? | ☐ | ☐ | ☐ | ☐ |
| 41 Do you have too much work to do? | ☐ | ☐ | ☐ | ☐ |
| 42 Do you have any opportunity to influence your workin conditions? | ☐ | ☐ | ☐ | ☐ |
| 43 Do your fellow-workers help you with problems you may have in your work? | ☐ | ☐ | ☐ | ☐ |

75-80 |___|___|___|___|___|___|

Andersson K. Epidemiological approach to indoor air problems. Indoor Air 1998;suppl 4:32-9.
Dept of Occup and Environm Med, Örebro University Hospital, Sweden. Fax +46 19 120404.
E-mail kjell.andersson@orebroll.se. Version 8910-2 K.Andersson©/IF.
The questionnaire is free to use in research and non-commercial activities.



**PAST/PRESENT DISEASES/SYMPTOMS**

| | | | | **If Yes:** during the last year? | |
|---|---|---|---|---|---|
| | | Yes (1) | No (2) | Yes (1) | No (2) |
| 1-2 | Have you ever had asthmatic problems? | ☐ | ☐ | ☐ | ☐ |
| 3-4 | Have you ever suffered from hayfever? | ☐ | ☐ | ☐ | ☐ |
| 5-6 | Have you ever suffered from eczema? | ☐ | ☐ | ☐ | ☐ |

**PRESENT SYMPTOMS**

During the **last three months** have you had any of the following symptoms?
(Answer every question even if you have not had any symptoms!)

| | | | | | **If YES:** do you believe that it is due to your work environment? | |
|---|---|---|---|---|---|---|
| | | Yes, often (every week) (1) | Yes, sometimes (2) | No, never (3) | Yes (1) | No (2) |
| 7-8 | Fatigue | ☐ | ☐ | ☐ | ☐ | ☐ |
| 9-10 | Feeling heavy-headed | ☐ | ☐ | ☐ | ☐ | ☐ |
| 11-12 | Headache | ☐ | ☐ | ☐ | ☐ | ☐ |
| 13-14 | Nausea/dizziness | ☐ | ☐ | ☐ | ☐ | ☐ |
| 15-16 | Difficulties concentrating | ☐ | ☐ | ☐ | ☐ | ☐ |
| 17-18 | Itching, burning or irritation of the eyes | ☐ | ☐ | ☐ | ☐ | ☐ |
| 19-20 | Irritated, stuffy or runny nose | ☐ | ☐ | ☐ | ☐ | ☐ |
| 21-22 | Hoarse, dry throat | ☐ | ☐ | ☐ | ☐ | ☐ |
| 23-24 | Cough | ☐ | ☐ | ☐ | ☐ | ☐ |
| 25-26 | Dry or flushed facial skin | ☐ | ☐ | ☐ | ☐ | ☐ |
| 27-28 | Scaling/itching scalp or ears | ☐ | ☐ | ☐ | ☐ | ☐ |
| 29-30 | Hands dry, itching, red skin | ☐ | ☐ | ☐ | ☐ | ☐ |
| 31-32 | Other ............................................ | ☐ | ☐ | ☐ | ☐ | ☐ |

**FURTHER COMMENTS**

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

Source: (Andersson 1998)

# Appendix J : Walk through check list

- Household no: ____________________ Area: ____________________________________________
- Building type: ______________________________________________________________________
- Building age (as per residents and/or building guardian): ______________________________
- Building construction materials: _____________________________________________________

  _____________________________________________________________________________________
- Interior pollution sources: __________________________________________________________
- Exterior pollution sources: __________________________________________________________
- Type of HVAC system: ______________________________________________________________
- Manufacturer of HVAC system: ________________________________________________________
- HVAC maintenance company and procedure (as per residents and/or guardian): ______________________________________

  ______________________________________
- % of outdoor air flow (as per manufacturer or maintenance company): ______________________________________

  ______________________________________
- Number of occupants: _______________________________________________________________
- Other observations:

  _______________________________________________________________

# Appendix K : Participant diary note

Please record the following during the measurement day:

**Occupancy profiles:** (1) From______ to ______:

No. of occupants: ___________________________________

Activities: __________________________________________

(2) From______ to ______:

No. of occupants: ____________________________________

Activities: ___________________________________________

(3) From______ to ______:

No. of occupants: ____________________________________

Activities: ___________________________________________

4) From______ to ______:

No. of occupants: ___________________________________

Activities: ___________________________________________

**HVAC operation:** (1) From______ to ______, the HVAC is Opened

(2) From______ to ______, the HVAC is Opened

(3) From______ to ______, the HVAC is Opened

(4) From______ to ______, the HVAC is Opened

(5) From______ to ______, the HVAC is Opened

**Window opening:** (1) From______ to ______, the window/s are Opened

(2) From______ to ______, the window/s are Opened

(3) From______ to ______, the window/s are Opened

(4) From______ to ______, the window/s are Opened

(5) From______ to ______, the window/s are Opened

# Appendix L: Consent letter – Cross sectional survey

## Survey about the influential factors on SBS and IAQ in UAE housing

**Researcher's Name, Phone Number, and E-mail address:** Muna Ali, 0554373330, 2014139131@student.buid.ac.ae

Dear: ________________________________________,

You are invited to participate in a research study. This research purpose is to explore and prioritize the influential factors on SBS and IAQ in UAE housing. SBS symptoms includes all health disorders that occur indoors and seems to disappear or do not develop outdoors whereas IAQ stands for indoor air quality. The results of this study will help in identifying the major factors influencing the recent deterioration of IAQ in UAE housing and subsequently assist in determining appropriate and efficient control measures.

The British University in Dubai Institutional Review Board approved the study and its procedures. The study involves no foreseeable risks or harm to you. The procedure includes a questionnaire in which you will be asked some information such as: (1) personal data i.e. age, health status, etc.; (2) house characteristics i.e. type, applied AC system, etc.; and (3) SBS symptoms i.e. headache, cough, skin irritations, etc.

You are free to ask any questions about the study or about being a participant by calling me at 0554373330 or e-mail: 2014139131@student.buid.ac.ae. Your participation in this study is voluntary; you are under no obligation to participate. You may withdraw at any time. By returning the completed surveys implies consent for participating in the study. To maintain anonymity, please do not write your name on any of the materials.

The completed study will be reported in the aggregate. Confidentiality will be maintained. All data will be collected by Researcher's Name, stored in a secure place and will be destroyed in three years.

I have read this informed letter and voluntarily consent to participate in this study.

If your participation in our survey has caused you to feel uncomfortable in any way, or if our survey prompted you to consider personal matters about which you are concerned, we encourage you to take advantage of the confidential counseling services offered at BUiD University. You can contact a counselor at ---------------------

You may keep this letter for your records.

# Appendix M : Consent letter – Field study

## Research about the influential factors on SBS and IAQ in UAE housing

**Researcher's Name, Phone Number, and E-mail address:** Muna Ali, 0554373330, 2014139131@student.buid.ac.ae

Dear: ________________________________________,

You are invited to participate in a research study. This research purpose is to explore and prioritize the influential factors on SBS and IAQ in UAE housing. SBS symptoms includes all health disorders that occur indoors and seems to disappear or do not develop outdoors whereas IAQ stands for indoor air quality. The results of this study will help in identifying the major factors influencing the recent deterioration of IAQ in UAE housing and subsequently assist in determining appropriate and efficient control measures.

The British University in Dubai Institutional Review Board approved the study and its procedures. The study involves no foreseeable risks or harm to you. The procedure includes: (A) field measurements of specific indoor air contaminants that involves the installation of some sampling devices inside the house for 24 hours duration; (B) a walk through the house to [i] characterize its features; and [ii] identify the proposed areas for installing the sampling devices; (C) a questionnaire in which you will be asked some information such as: [i] personal data i.e. age, health status, etc.; [ii] house characteristics i.e. type, applied AC system, etc.; and [iii] SBS symptoms i.e. headache, cough, skin irritations, etc.

You are free to ask any questions about the study or about being a participant by calling me at 0554373330 or e-mail: 2014139131@student.buid.ac.ae. Your participation in this study is voluntary; you are under no obligation to participate. You may withdraw at any time. By returning the completed surveys implies consent for participating in the study. To maintain anonymity, please do not write your name on any of the materials.

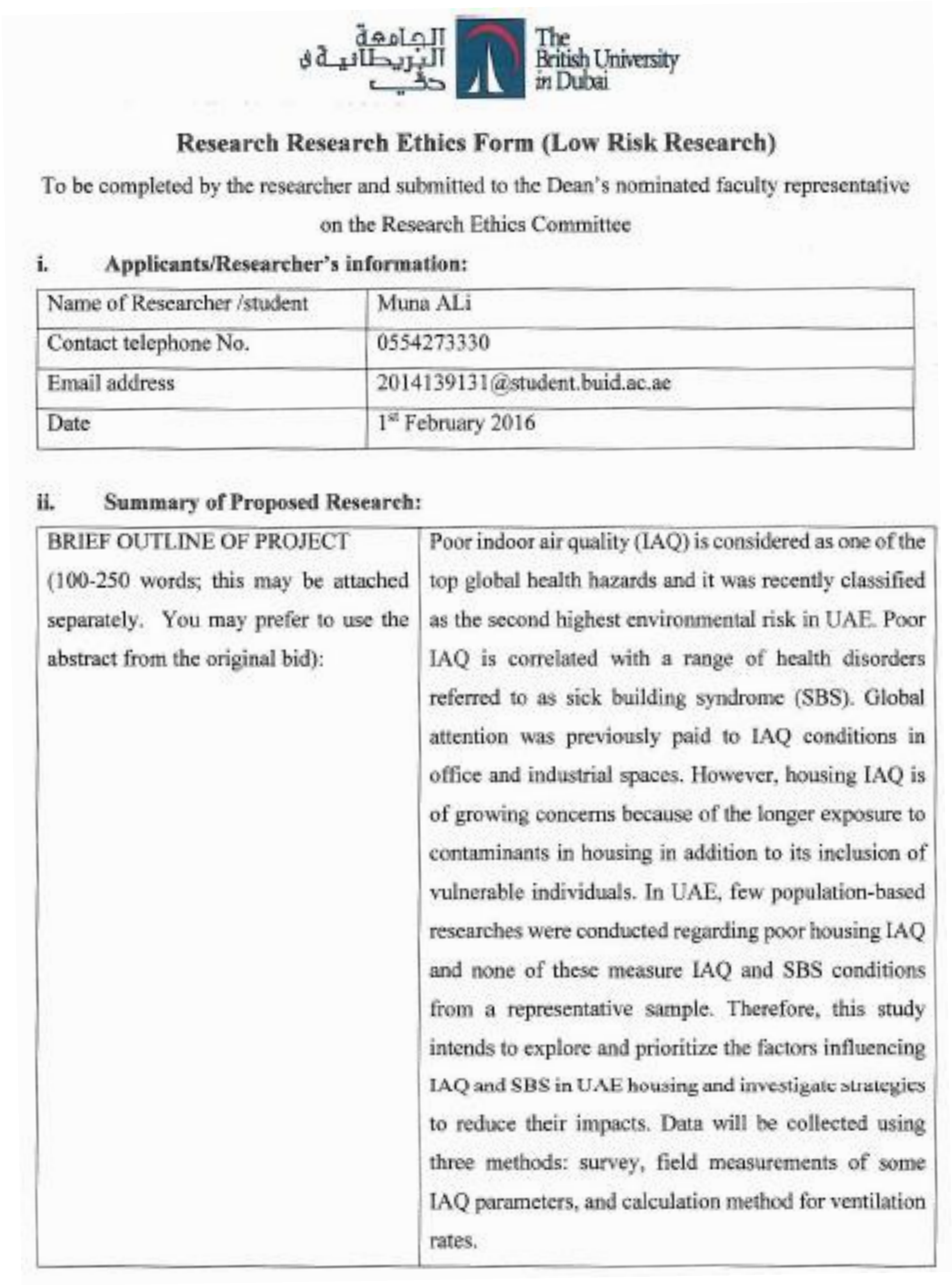
The completed study will be reported in the aggregate. Confidentiality will be maintained. All data will be collected by Researcher's Name, stored in a secure place and will be destroyed in three years.

I have read this informed letter and voluntarily consent to participate in this study.

If your participation in our survey has caused you to feel uncomfortable in any way, or if our survey prompted you to consider personal matters about which you are concerned, we encourage you to take advantage of the confidential counseling services offered at the British University in Dubai. You can contact a counselor at ---------------------.

You may keep this letter for your records.

# Appendix N: Research ethics form



الجامعة البريطانية في دبي

The British University in Dubai

## Research Research Ethics Form (Low Risk Research)

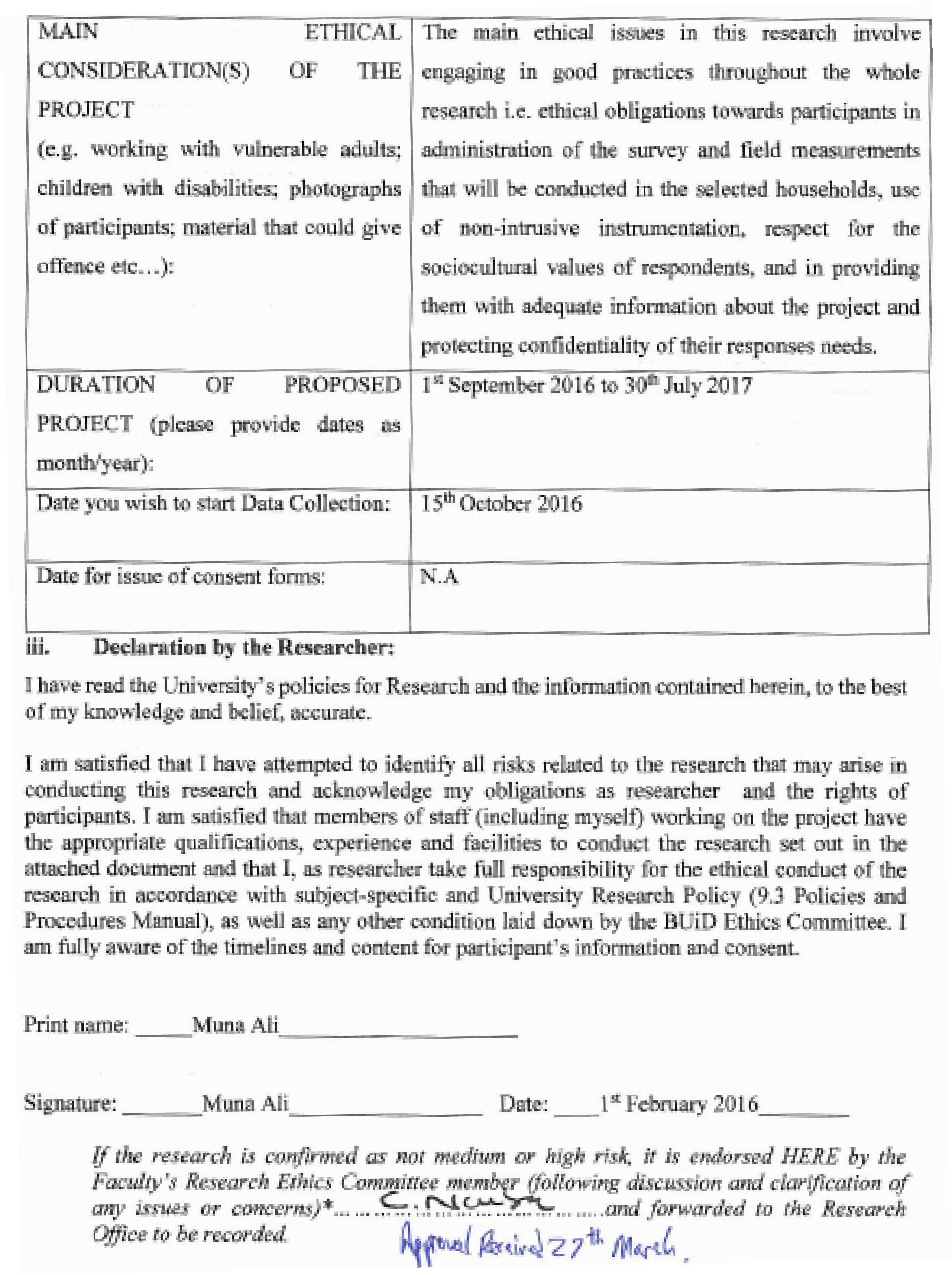
To be completed by the researcher and submitted to the Dean's nominated faculty representative on the Research Ethics Committee

**i. Applicants/Researcher's information:**

| | |
|---|---|
| Name of Researcher /student | Muna ALi |
| Contact telephone No. | 0554273330 |
| Email address | 2014139131@student.buid.ac.ae |
| Date | 1st February 2016 |

**ii. Summary of Proposed Research:**

| | |
|---|---|
| BRIEF OUTLINE OF PROJECT (100-250 words; this may be attached separately. You may prefer to use the abstract from the original bid): | Poor indoor air quality (IAQ) is considered as one of the top global health hazards and it was recently classified as the second highest environmental risk in UAE. Poor IAQ is correlated with a range of health disorders referred to as sick building syndrome (SBS). Global attention was previously paid to IAQ conditions in office and industrial spaces. However, housing IAQ is of growing concerns because of the longer exposure to contaminants in housing in addition to its inclusion of vulnerable individuals. In UAE, few population-based researches were conducted regarding poor housing IAQ and none of these measure IAQ and SBS conditions from a representative sample. Therefore, this study intends to explore and prioritize the factors influencing IAQ and SBS in UAE housing and investigate strategies to reduce their impacts. Data will be collected using three methods: survey, field measurements of some IAQ parameters, and calculation method for ventilation rates. |



| | |
|---|---|
| MAIN ETHICAL CONSIDERATION(S) OF THE PROJECT (e.g. working with vulnerable adults; children with disabilities; photographs of participants; material that could give offence etc…): | The main ethical issues in this research involve engaging in good practices throughout the whole research i.e. ethical obligations towards participants in administration of the survey and field measurements that will be conducted in the selected households, use of non-intrusive instrumentation, respect for the sociocultural values of respondents, and in providing them with adequate information about the project and protecting confidentiality of their responses needs. |
| DURATION OF PROPOSED PROJECT (please provide dates as month/year): | 1st September 2016 to 30th July 2017 |
| Date you wish to start Data Collection: | 15th October 2016 |
| Date for issue of consent forms: | N.A |

**iii. Declaration by the Researcher:**

I have read the University's policies for Research and the information contained herein, to the best of my knowledge and belief, accurate.

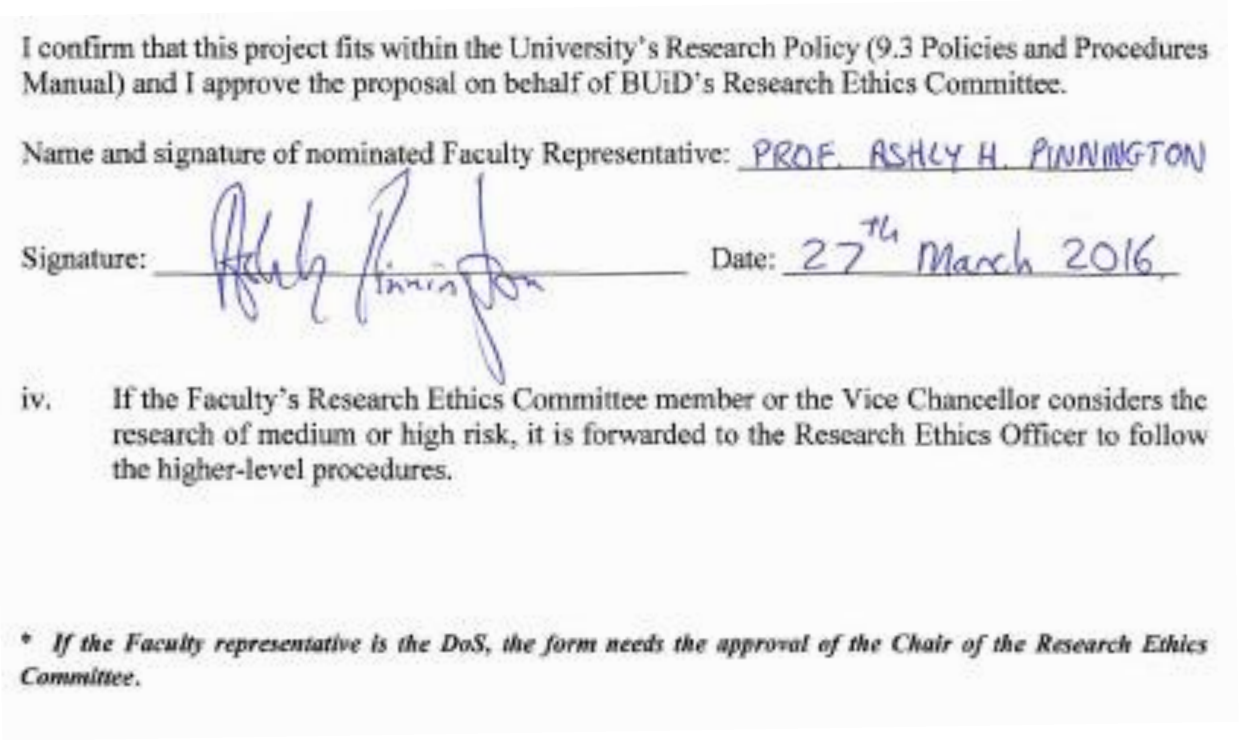
I am satisfied that I have attempted to identify all risks related to the research that may arise in conducting this research and acknowledge my obligations as researcher and the rights of participants. I am satisfied that members of staff (including myself) working on the project have the appropriate qualifications, experience and facilities to conduct the research set out in the attached document and that I, as researcher take full responsibility for the ethical conduct of the research in accordance with subject-specific and University Research Policy (9.3 Policies and Procedures Manual), as well as any other condition laid down by the BUiD Ethics Committee. I am fully aware of the timelines and content for participant's information and consent.

Print name: _____Muna Ali_____________________

Signature: _______Muna Ali_________________ Date: ____1st February 2016________

*If the research is confirmed as not medium or high risk, it is endorsed HERE by the Faculty's Research Ethics Committee member (following discussion and clarification of any issues or concerns)*……………………………and forwarded to the Research Office to be recorded.*

Approval Received 27th March.



I confirm that this project fits within the University's Research Policy (9.3 Policies and Procedures Manual) and I approve the proposal on behalf of BUiD's Research Ethics Committee.

Name and signature of nominated Faculty Representative: PROF. ASHLY H. PINNINGTON

Signature: __________ Date: 27th March 2016

iv. If the Faculty's Research Ethics Committee member or the Vice Chancellor considers the research of medium or high risk, it is forwarded to the Research Ethics Officer to follow the higher-level procedures.

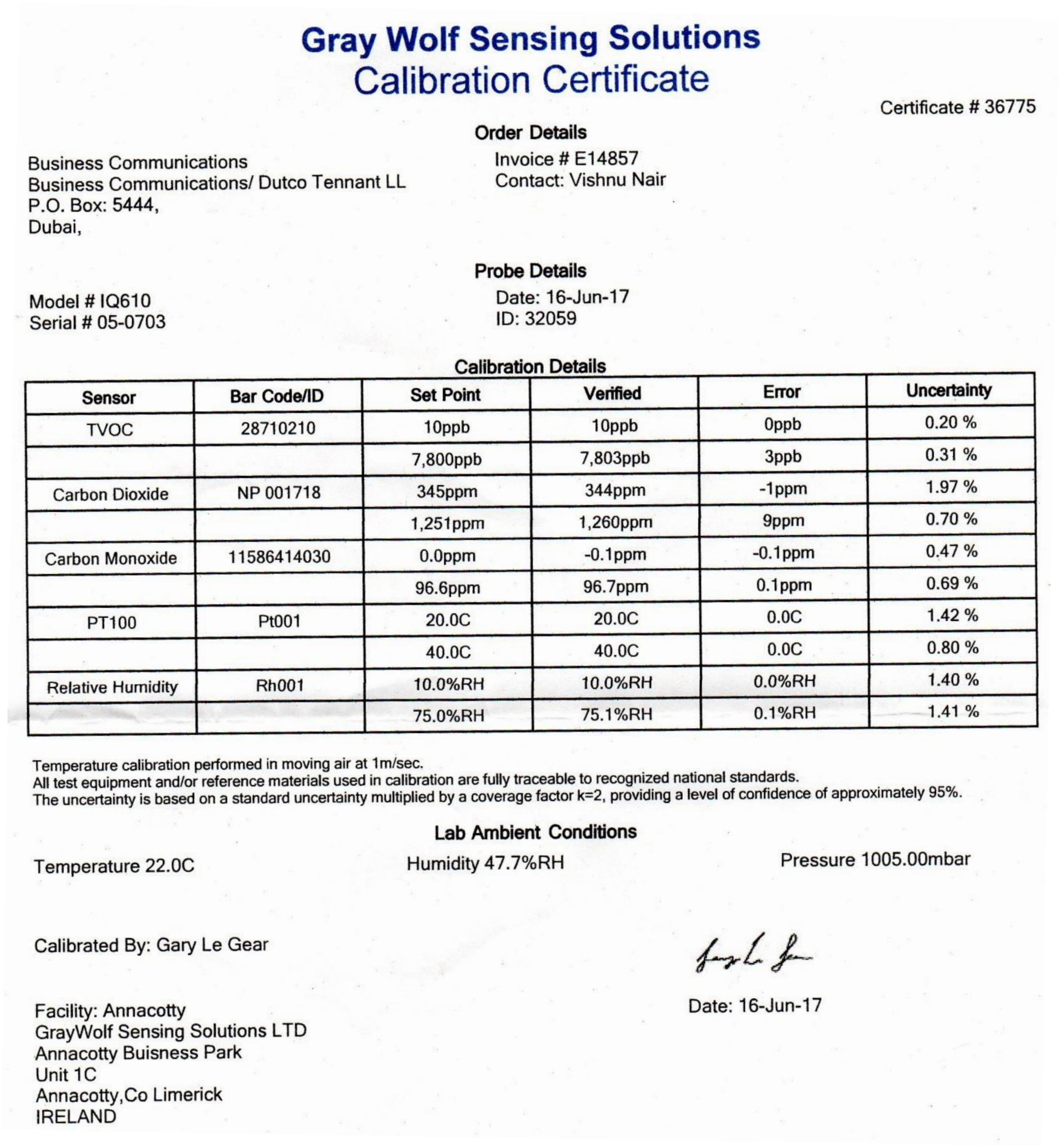
**** If the Faculty representative is the DoS, the form needs the approval of the Chair of the Research Ethics Committee.***

# Appendix O : Compliance declarations of monitoring devices

Table O-1: Compliance declarations of monitoring devices

| Device | Manufacturer | Declaration of conformance |
|---|---|---|
| **DirectSense IQ – 610** | GrayWolf Sensing Solutions | Compliance with EEC Directive on Electromagnetic Compatibility (EMC) 89/336/EEC, applied Harmonized Standards: EN50081-1, Radiated Emissions and EN50082-01, Radiated and ESD immunities and EMC directive 2004/108/EC demonstrating conformity to EN61326-1: 2006, EN61000-3-2: 2006 and EN6100-3-3: 2008 (Davenport 2016) |
| **HCHO detector FP 30** | RKI instruments Inc. | IS0 14001,<br>ISO 9001 (RKI Instruments Inc. 2016) |
| **OPS 3330** | TSI Inc. | ISO 9001<br>CE Immunity/Emissions<br>CAN/CSA<br>EN61236-1:2006<br>C22.2 No. 61010-1 (TSI Inc. 2012) |

# Appendix P : Calibration certificates



## Gray Wolf Sensing Solutions
## Calibration Certificate

Certificate # 36775

**Order Details**

Business Communications
Business Communications/ Dutco Tennant LL
P.O. Box: 5444,
Dubai,

Invoice # E14857
Contact: Vishnu Nair

**Probe Details**

Model # IQ610
Serial # 05-0703

Date: 16-Jun-17
ID: 32059

**Calibration Details**

| Sensor | Bar Code/ID | Set Point | Verified | Error | Uncertainty |
|---|---|---|---|---|---|
| TVOC | 28710210 | 10ppb | 10ppb | 0ppb | 0.20 % |
| | | 7,800ppb | 7,803ppb | 3ppb | 0.31 % |
| Carbon Dioxide | NP 001718 | 345ppm | 344ppm | -1ppm | 1.97 % |
| | | 1,251ppm | 1,260ppm | 9ppm | 0.70 % |
| Carbon Monoxide | 11586414030 | 0.0ppm | -0.1ppm | -0.1ppm | 0.47 % |
| | | 96.6ppm | 96.7ppm | 0.1ppm | 0.69 % |
| PT100 | Pt001 | 20.0C | 20.0C | 0.0C | 1.42 % |
| | | 40.0C | 40.0C | 0.0C | 0.80 % |
| Relative Humidity | Rh001 | 10.0%RH | 10.0%RH | 0.0%RH | 1.40 % |
| | | 75.0%RH | 75.1%RH | 0.1%RH | 1.41 % |

Temperature calibration performed in moving air at 1m/sec.
All test equipment and/or reference materials used in calibration are fully traceable to recognized national standards.
The uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%.

**Lab Ambient Conditions**

Temperature 22.0C

Humidity 47.7%RH

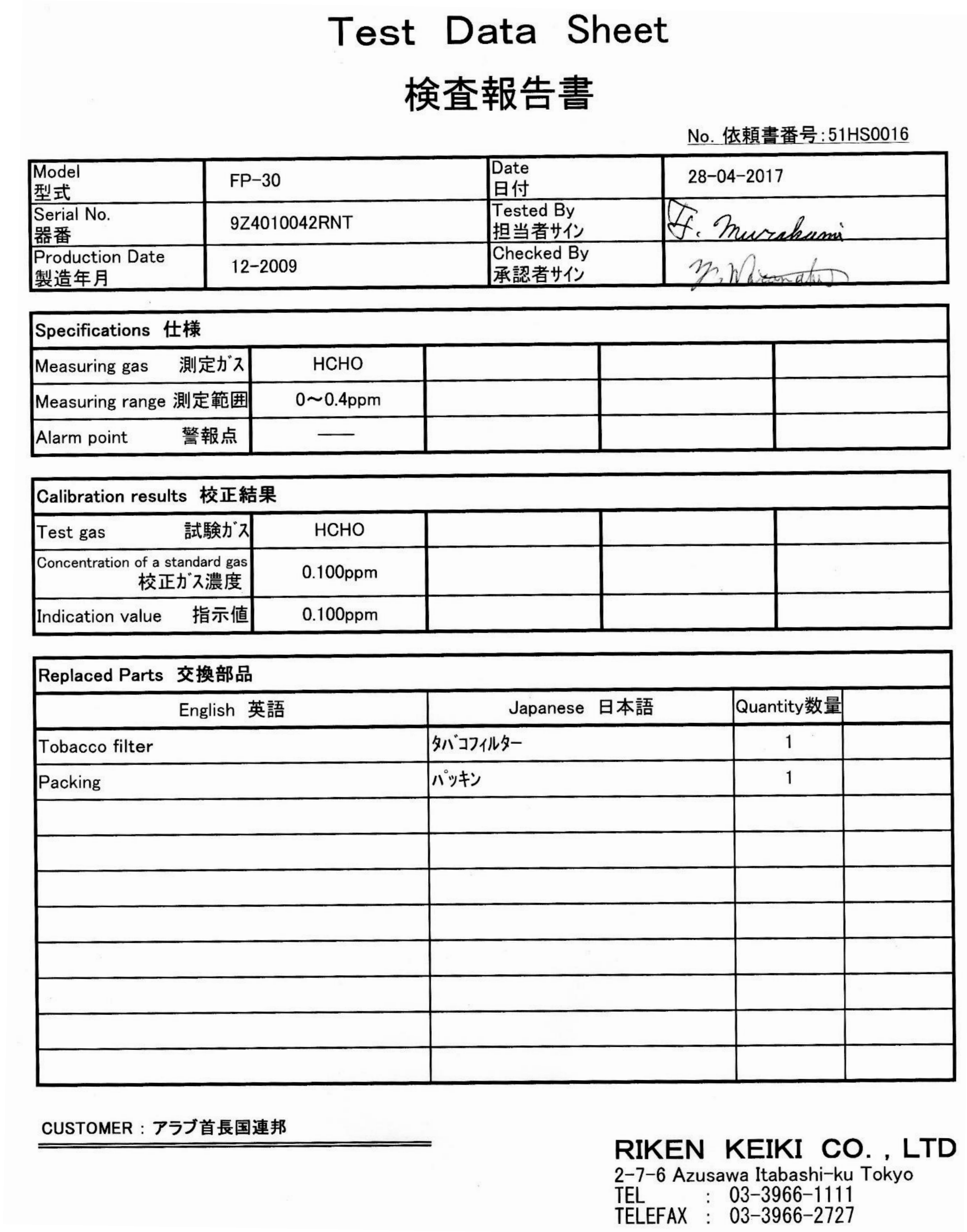
Pressure 1005.00mbar

Calibrated By: Gary Le Gear

Date: 16-Jun-17

Facility: Annacotty
GrayWolf Sensing Solutions LTD
Annacotty Buisness Park
Unit 1C
Annacotty,Co Limerick
IRELAND

Figure P-1: Calibration certificate for DirectSense Probe



# Test Data Sheet

# 検査報告書

No. 依頼書番号:51HS0016

| | | | |
|---|---|---|---|
| Model<br>型式 | FP-30 | Date<br>日付 | 28-04-2017 |
| Serial No.<br>器番 | 9Z4010042RNT | Tested By<br>担当者ｻｲﾝ | F. Murakami |
| Production Date<br>製造年月 | 12-2009 | Checked By<br>承認者ｻｲﾝ | |

**Specifications 仕様**

| | | | | |
|---|---|---|---|---|
| Measuring gas 測定ｶﾞｽ | HCHO | | | |
| Measuring range 測定範囲 | 0～0.4ppm | | | |
| Alarm point 警報点 | —— | | | |

**Calibration results 校正結果**

| | | | | |
|---|---|---|---|---|
| Test gas 試験ｶﾞｽ | HCHO | | | |
| Concentration of a standard gas 校正ｶﾞｽ濃度 | 0.100ppm | | | |
| Indication value 指示値 | 0.100ppm | | | |

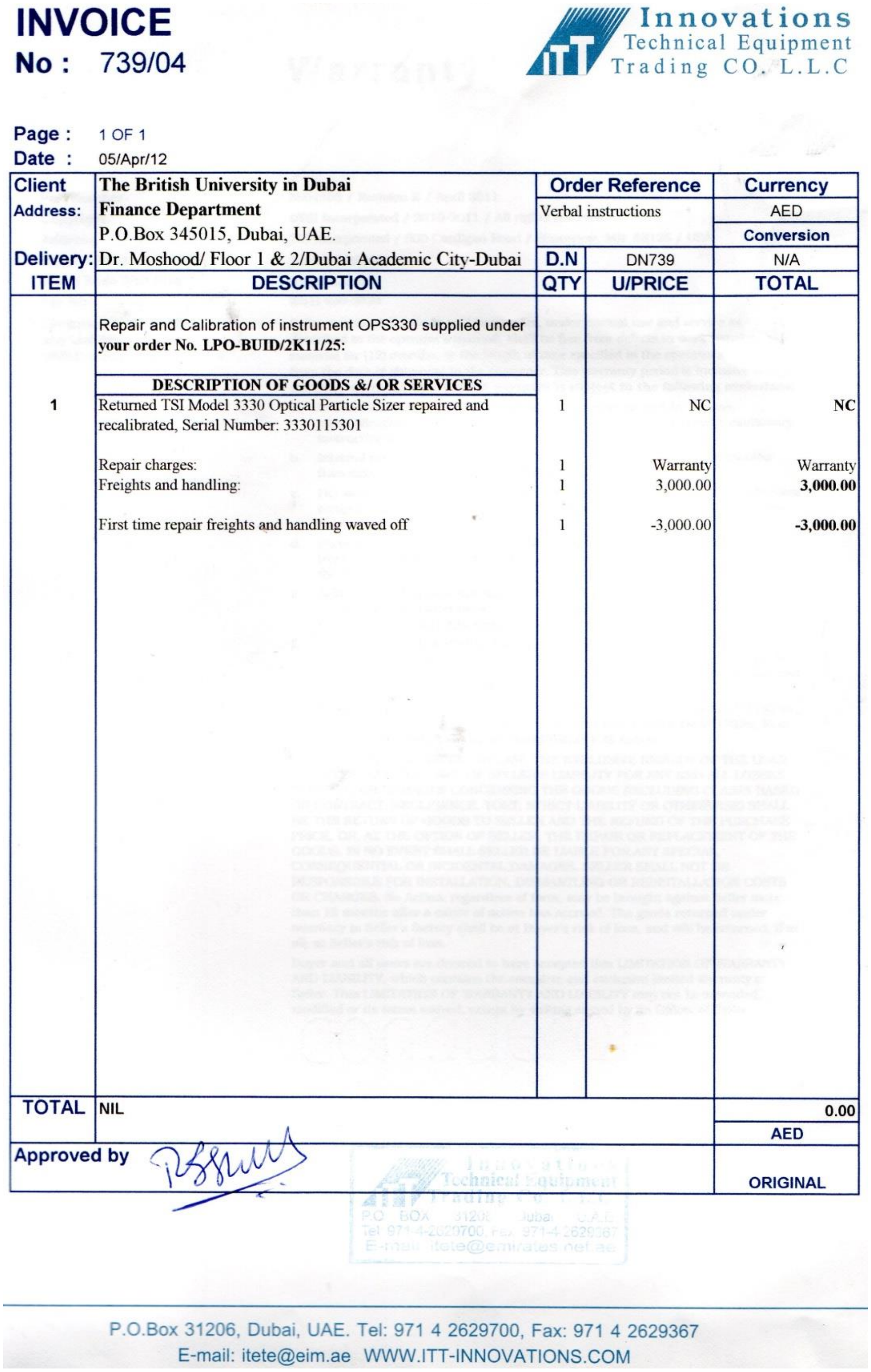
**Replaced Parts 交換部品**

| English 英語 | Japanese 日本語 | Quantity数量 | |
|---|---|---|---|
| Tobacco filter | ﾀﾊﾞｺﾌｨﾙﾀｰ | 1 | |
| Packing | ﾊﾟｯｷﾝ | 1 | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

CUSTOMER：アラブ首長国連邦

**RIKEN KEIKI CO. , LTD**
2-7-6 Azusawa Itabashi-ku Tokyo
TEL : 03-3966-1111
TELEFAX : 03-3966-2727

Figure  P-2: Calibration certificate of FP - 30



# INVOICE

**No :** 739/04

Innovations
Technical Equipment
Trading CO. L.L.C

**Page :** 1 OF 1
**Date :** 05/Apr/12

| | | | | |
|---|---|---|---|---|
| **Client** | **The British University in Dubai** | **Order Reference** | | **Currency** |
| **Address:** | **Finance Department**<br>P.O.Box 345015, Dubai, UAE. | Verbal instructions | | AED<br>**Conversion** |
| **Delivery:** | Dr. Moshood/ Floor 1 & 2/Dubai Academic City-Dubai | **D.N** | DN739 | N/A |
| **ITEM** | **DESCRIPTION** | **QTY** | **U/PRICE** | **TOTAL** |
| | Repair and Calibration of instrument OPS330 supplied under **your order No. LPO-BUID/2K11/25:** | | | |
| | **DESCRIPTION OF GOODS &/ OR SERVICES** | | | |
| 1 | Returned TSI Model 3330 Optical Particle Sizer repaired and recalibrated, Serial Number: 3330115301 | 1 | NC | **NC** |
| | Repair charges: | 1 | Warranty | Warranty |
| | Freights and handling: | 1 | 3,000.00 | **3,000.00** |
| | First time repair freights and handling waved off | 1 | -3,000.00 | **-3,000.00** |
| **TOTAL** | NIL | | | **0.00**<br>**AED** |
| **Approved by** | | | | **ORIGINAL** |

Innovations Technical Equipment Trading Co. L.L.C
P.O. BOX 31206 Dubai U.A.E.
Tel 971-4-2629700 Fax 971-4-2629367
E-mail itete@emirates.net.ae

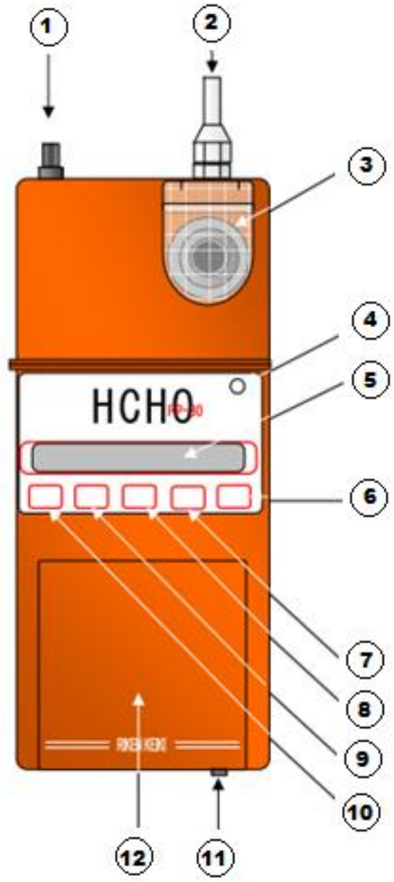
P.O.Box 31206, Dubai, UAE. Tel: 971 4 2629700, Fax: 971 4 2629367
E-mail: itete@eim.ae WWW.ITT-INNOVATIONS.COM

Figure P-3: Calibration invoice for OPS 3330

# Appendix Q : HCHO gas detector Model FP 30

Figure Q-1: View of HCHO gas detector Model FP 30 (RKI Instruments Inc. 2017)

---



1. Gas outlet
2. Gas inlet
3. Detection TAB cover
4. Back lit window
5. LCD display unit
6. ON/OFF switch
7. DATA Switch
8. ▼ Switch
9. ▲ Switch
10. START Switch
11. RS – 232C output connector
12. Battery cover
13. Carrying case

Figure Q-2: Parts of the HCHO gas detector Model FP 30 (RKI Instruments Inc. 2012)

# Appendix R: Optical Particle Sizer (OPS) Model 3330

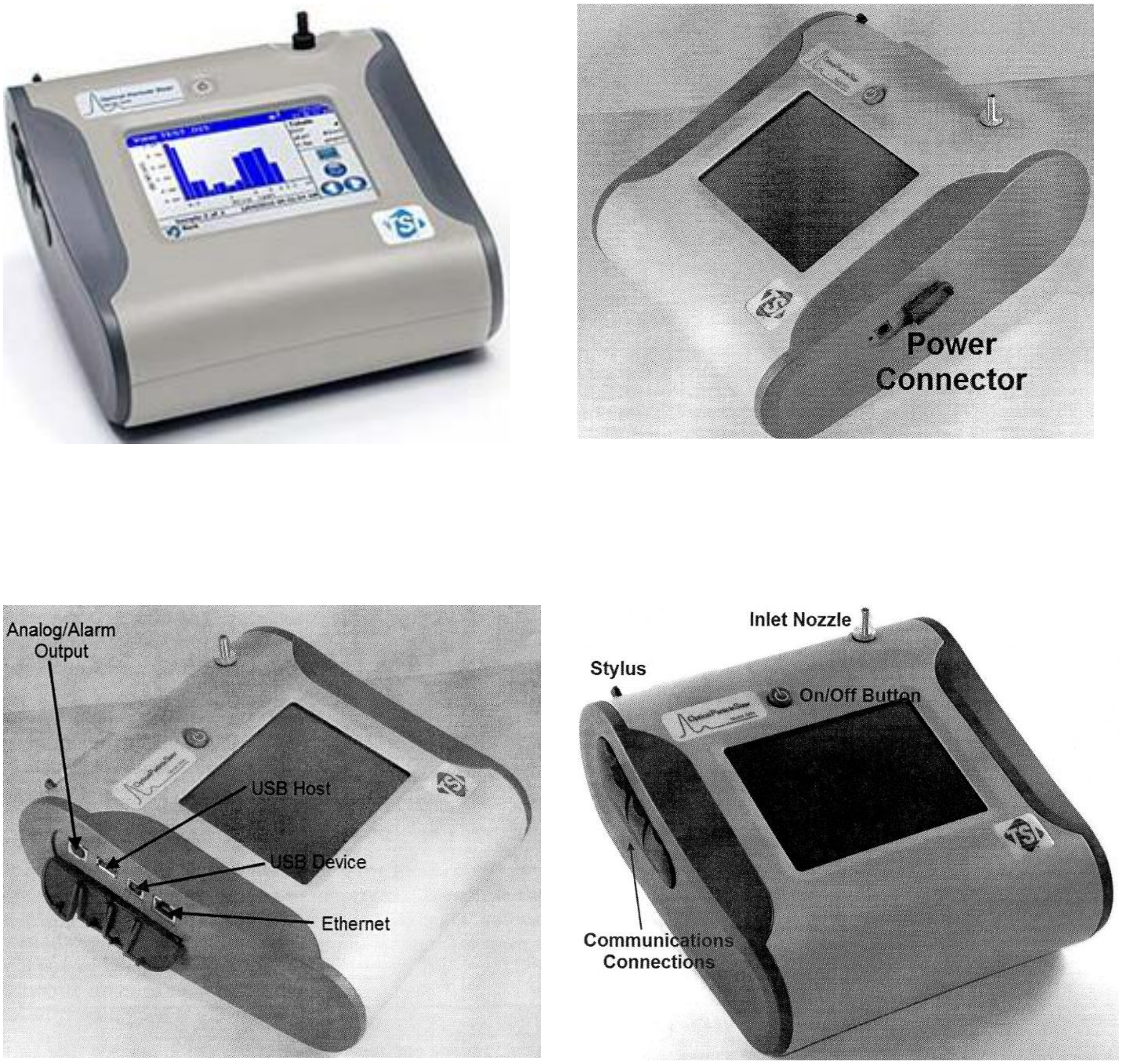


Figure R-1: Different views demonstrating OPS Model 3330 parts (TSI Inc. 2012)

# Appendix S :   DirectSense probe & GrayWolf Pocket PC

Figure  S-1: View of GrayWolf Pocket PC (LH) and DirectSense IQ – 610 probe (RH) (GrayWolf Sensing Solutions Inc. 2014)

Figure  S-2: Parts of GrayWolf Pocket PC (GrayWolf Sensing Solutions Inc. 2016)

# Appendix T: SOP of HCHO gas detector Model FP 30

The following SOP of measuring HCHO by using the gas detector Model FP 30 was built on the device manual instructions (RKI Instruments Inc. 2003 & 2012).

1. Daily checking of the instrument for any physical damage prior each visit.
2. Install a new detection TAB following below instructions:
    i. Open the detection TAB cover and place the TAB into the slot under the cover (Figure T-1).

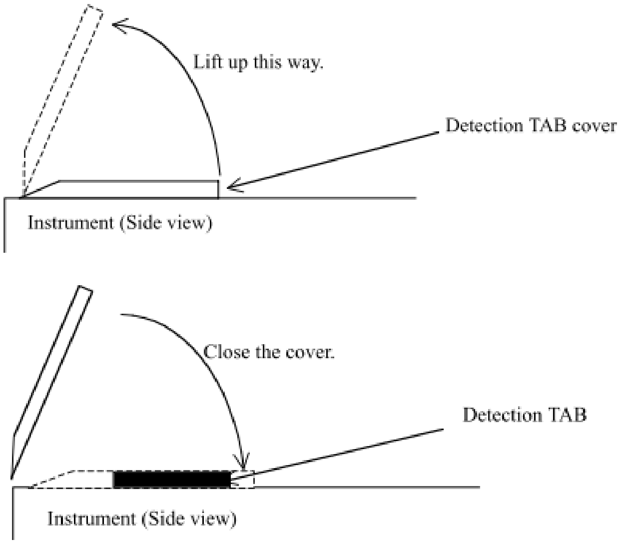


Figure T-1: Installing Model FP 30 detection tab

    ii. Press the center of the detection cover to assure proper TAB seating.
3. When doing the above steps, it is important to ensure the following:
    - Not to touch the white test paper of the detection TAB (Figure T-2).

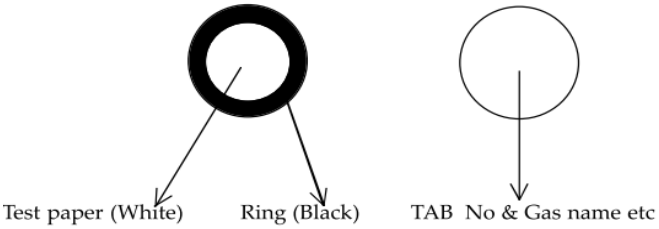


Figure T-2: Installing Model FP 30 detection tab (3)

    - Slowly close the detection TAB door to avoid pinching finger.
    - Use TAB immediately after removing from package.
    - Use each TAB for once.

4. Turning the instrument on by pressing ON/OFF switch for 2 seconds to turn the instrument on and start warm-up and self-diagnosis.
5. A report regarding the battery capacity will be displayed (Figure T-3).

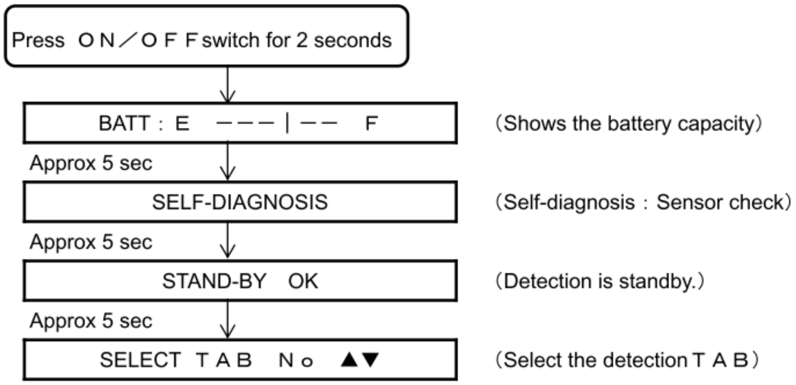


Figure T-3: Model FP 30 Self-diagnosis

6. If batteries are charged, go to step (6). Otherwise, replace batteries as follows:
   - Ensure that it is non-hazardous zone free from explosives.
   - Use the designated battery.
   - Checking that the power is off.
   - Removing the carrying case.
   - Pressing slightly on the battery cover to open.
   - Removing the 4 pcs batteries and mount the new ones.
7. Turning the instrument on by pressing ON/OFF switch for 2 seconds to turn instrument on and start warm-up and self-diagnosis.
8. During self-diagnosis, it is essential to:
   - Make sure the sensor check is at its suitable time.
   - Not to remove the detection TAB during sensor check.
9. Select the detection range by pressing UP ▲ /DOWN ▼ keys. Then select TAB no. (008) to enable measuring (0~0.4 ppm) and the selected measurement time will be set as 30 minutes.
10. Delete all previously stored data in the device as follows:
    i. Press the START + DATA Switches simultaneously.
    ii. Press START switch to delete all the stored detection results (Figure T-4).

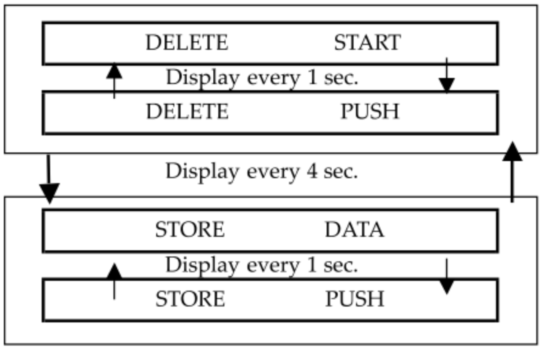


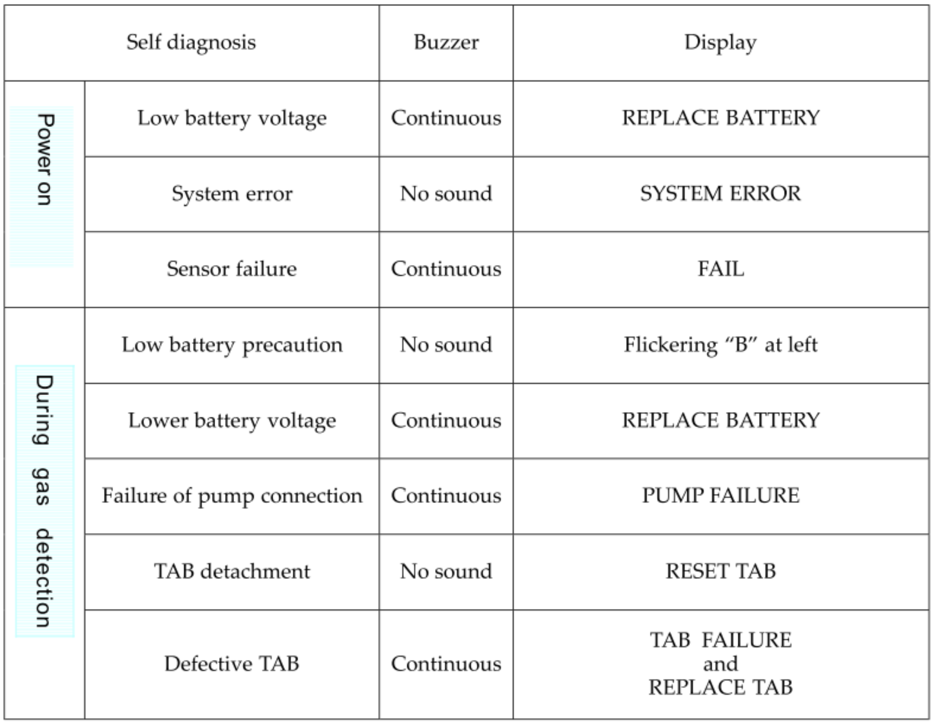
Figure T-4: Model FP 30 data retrieving

11. Turning the instrument off by pressing ON/OFF switch for 2 seconds.
12. Placing the device in an appropriate location as described in (Section 3.6).
13. Turning the instrument on by pressing ON/OFF switch for 2 seconds.
14. Start the detection cycle by pressing START Switch.
15. Daily Pump suction check and confirm that the pump is working by listening to the roaring sound or pump sucking.
16. When detection is completed, the average gas reading is shown in the LCD display screen. The reading will be displayed, accompanied with buzzer sound, until the tab is removed. During detection, it is important not to:
    - remove tab during detection.
    - block the gas outlet.
17. Check stored data when the detection finished condition as follows:
    - Pressing DATA Switch.
    - Use the UP ▲ /DOWN ▼ keys to check the stored results.
    - Press DATA Switch again to return to the detection finished condition.
18. Transferring the result to an excel file and save 2 copies of it in different discs.
19. Turning the instrument off by pressing ON/OFF switch for 2 seconds.
20. Repeat above steps when conducting HCHO measurement in each household.

    In performing the above operational steps, it is important to ensure the following:
    - Not to suck water or oil into the instrument.
    - Not to mix up substances inside the instrument during TAB replacement.
    - Not to throw the instrument.
    - Not to splash the instrument with water.

- Not to use the walkie-talkie nearby.
- To be used within the allowed temperature and relative humidity range.
- To be attentive towards the signs provided by the self-diagnosis (Table T-1).

Table T-1: Types of self-diagnosis notifications (RKI Instruments Inc. 2012)



| Self diagnosis | | Buzzer | Display |
|---|---|---|---|
| Power on | Low battery voltage | Continuous | REPLACE BATTERY |
| | System error | No sound | SYSTEM ERROR |
| | Sensor failure | Continuous | FAIL |
| During gas detection | Low battery precaution | No sound | Flickering "B" at left |
| | Lower battery voltage | Continuous | REPLACE BATTERY |
| | Failure of pump connection | Continuous | PUMP FAILURE |
| | TAB detachment | No sound | RESET TAB |
| | Defective TAB | Continuous | TAB FAILURE<br>and<br>REPLACE TAB |

# Appendix U: SOP of OPS Model 3330

The following SOP of measuring $PM_{2.5}$ and $PM_{10}$ by using the OPS Model 3330 was built on the device manual instructions (TSI Inc. 2011).

1. Running instrument using an external AC adapter as follows:
   - Plug the AC adapter into an ACoutlet then press On/Off button (
   - Figure  U-1 & Figure  U-2). The main window appears (Figure  U-3).

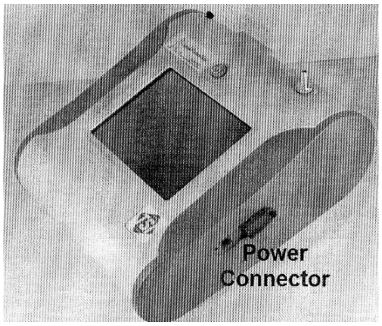


Figure  U-1:  AC adaptor charging

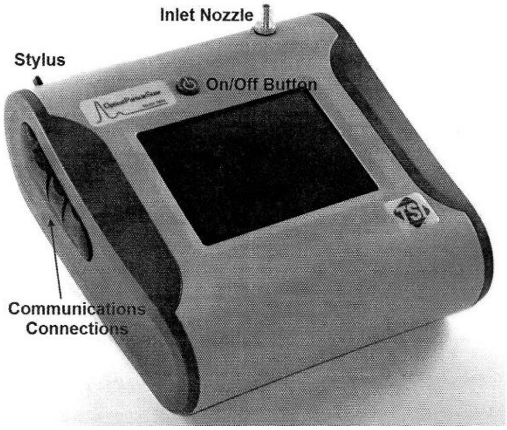
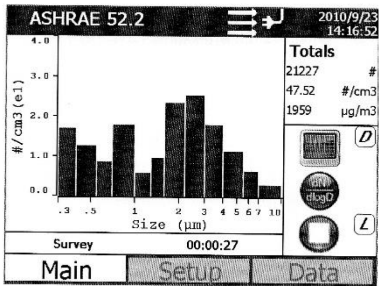


Figure  U-2: External sockets



ASHRAE 52.2

2010/9/23
14:16:52

Totals
21227 #
47.52 #/cm3
1959 µg/m3

Survey 00:00:27

Figure  U-3: Main window

2. Setting sampling methods following the below steps:
   - Select Setup Tab then select the Sampling icon. The following window will be displayed (Figure U-4).

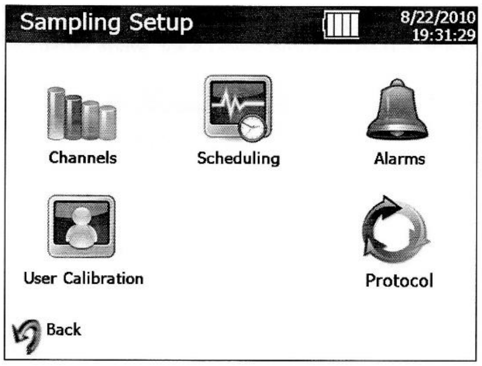
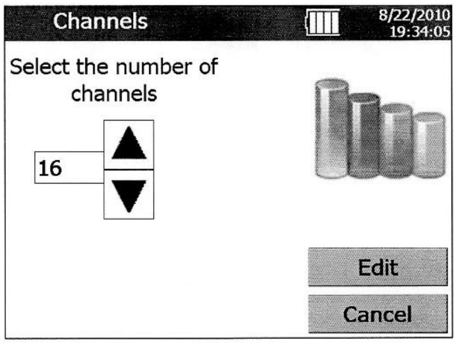


Figure U-4: Sampling Setup Window

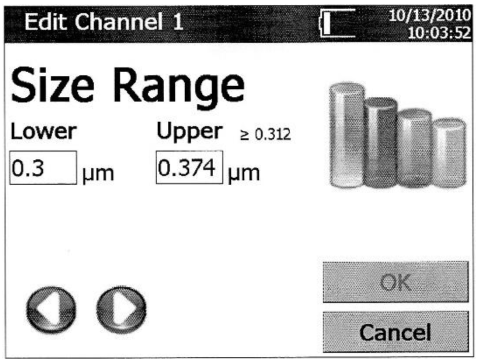
3. Select Channels icon to set the number of channels and the parameter for each channel. The following window will be displayed (Figure U-5).



Select the number of channels
16

Figure U-5: OPS Model 3330 Channels Window

   - Enter 2 and then press Edit button. For Channel 1, enter the lower and upper size ranges as (0.3 – 2.5) µm consecutively to represent $PM_{2.5}$ when the below window is displayed (Figure U-6).

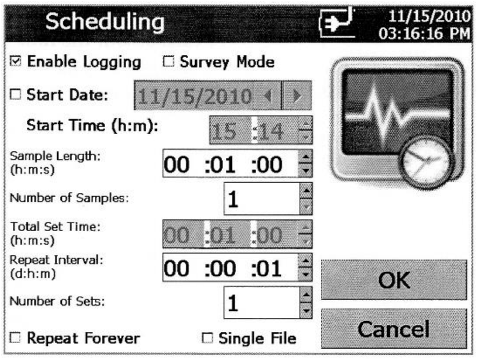


Size Range
Lower 0.3 µm
Upper ≥ 0.312 0.374 µm

Figure U-6: Edit Channel 1 Window

- Press the arrow to display Channel 2 size range, press
- For Channel 2, enter the lower and upper size ranges as (0.3 – 10) µm consecutively to represent $PM_{10}$.
- Press OK.

4. Setting the sampling scheduling parameters following the below instructions:
   - From the Setup Window, select Scheduling icon. The following screen will be displayed (Figure U-7).



Scheduling 11/15/2010 03:16:16 PM

☑ Enable Logging ☐ Survey Mode

☐ Start Date: 11/15/2010

Start Time (h:m): 15 :14

Sample Length: (h:m:s) 00 :01 :00

Number of Samples: 1

Total Set Time: (h:m:s) 00 :01 :00

Repeat Interval: (d:h:m) 00 :00 :01

Number of Sets: 1

☐ Repeat Forever ☐ Single File

Figure U-7: OPS Model 3330 Scheduling Window

   - The following settings should be applied in order to sample every minute for 24 hours (1440 minutes) (Table U-1).

Table U-1: Applied scheduling settings

| Enable Logging | Activated |
|---|---|
| Sample length (h:m:s) | 00:01:00 |
| Number of samples | 1440 |
| Total Set Time (h:m:s) | 00:01:00 |
| Repeat Interval (d:h:m) | 00:00:01 |
| Number of Sets | 1 |

   - Select the Protocol icon.The following screen will be displayed (Figure U-8).

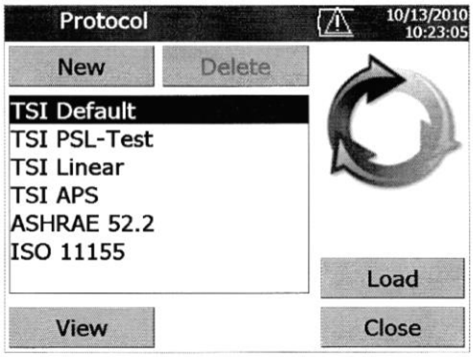
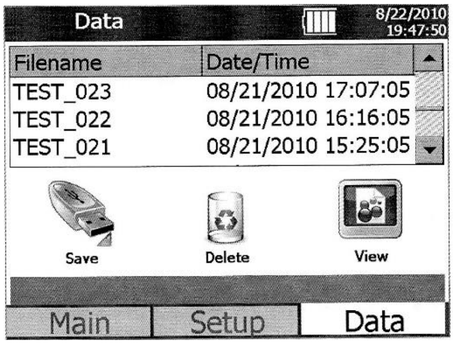


Figure U-8: Protocol Window

   - Select the New button to save the current settings. Enter “PhD Research” when the window requiring entering a new name for the protocol appears. Click OK button after doing that.
   - Highlight the “PhD Research” protocol and press Load button. The settings of that protocol will then be loaded for the instrument to use.

5. Turn off the device and unplug the AC adapter from the AC wall outlet.
6. Place the device in an appropriate location as described in Section 3.6.
7. Place the spectrometer cabinet in a clean; hard surface where there at least 100 mm clearance between the back panel and any other surface. The sides should also have at least 75 mm clearance between the cabinet and any other surface to allow for cable connections.
8. Plug the AC adapter into an AC wall outlet then press the On/Off button.
9. Save the stored data after measurements’ completion in a USB as follows:
   - Insert a USB cable to the USB Host of the device.
   - From the Setup Window, select the Data tab (Figure  U-9).



| Filename | Date/Time |
|---|---|
| TEST_023 | 08/21/2010 17:07:05 |
| TEST_022 | 08/21/2010 16:16:05 |
| TEST_021 | 08/21/2010 15:25:05 |

Figure  U-9: Data Window

   - Click on the Save icon then click the Yes button to save the file.

10. Repeat Steps (6 – 10) when launching measurement in each of the remaining households.

# Appendix V: SOP of DirectSense probes and GrayWolf Pocket PC

The following SOP of measuring $CO_2$, CO, TVOCs, RH, and T by using the DirectSense IQ – 610 and GrayWolf probe socket was built on the device manual instructions (GrayWolf Sensing Solutions Inc. 2016).

1. Attach DirectSense IQ - 610 probe to the GrayWolf probe socket found at the bottom of the GrayWolf Pocket PC shown in (Figure V-1 and Figure V-2). The bottom connectors utilize a self-latching system. Align the red dot on the probe connector with the red dot /square notch on the socket and simply push the probe connection axially into the socket.

Figure V-1: DirectSense IQ - 610 probe IQ – 610

Figure V-2: GrayWolf Pocket PC

2. Connect the device to a 100/240V AC charger on the 9V DC input found in the left side of the GrayWolf Pocket PC (Figure V-2).When connected, the AC charge indicator on the front top left side will illuminate Red while charging and will turn Green when fully charged.
3. Press the Power button on the front top right side of GrayWolf Pocket PC (Figure V-2) to turn the device on.
4. Click on the Start Menu at top left corner and select WolfSense from the dropdown menu. The unit will automatically start the WolfSense data logger software. The software will always start on the Live Screen that displays current readings from the attached probe(s).
5. Create a location for each household following instruction shown below.
    - Access the the Log Menu shown at the bottom of WolfSense window.
    - Select Locations to access Locations Menu. Write names of two locations for each house. The indoor measurements will measured in “House Number indoors” while the outdoor measurements will be stored in “House Number outdoors”.
6. Place the device in an appropriate location as described in Section 3.6.
7. To launch indoor measurements, following steps should be performed:
    - Select the indoor location specified for the house.
    - On WolfSense Window , click on the Log tab to at the bottom o to open its menu.
    - Select Trend Log. Specify the interval as 00:01:00 H:M:S. Accordingly, the device is set to measure at 1 minute intervals.
    - Perform continuous measurement of indoor $CO_2$, CO, TVOCs, T, and RH for 24 hours.
8. Perform a snap shot measurement for outdoor $CO_2$ and store it in the specified outdoor location file following steps demonstrated below:
    - Select the outdoor location specified for the house.
    - Placing the device in an appropriate location as described in this study protocol discussed in Section 3.6.
    - To initiate SnapShot log, select the Log Menu then Snap Shot Log.

9. Transfer data via a USB cable by connecting the GrayWolf Pocket PC with a PC and then transfer the required data.
10. When completing measurements in each house:
    - Press the Power button to turn the device off.
    - Unplug the AC charger and disconnect attached probe by pulling the outer sleeve of the connector to disengage the latch and then withdraw the probe connector from the socket.
11. Repeat above steps when performing measurements in each household.

# Appendix W : Initially proposed sampling method

The initially proposed sampling strategy involved the conduct of two probability sampling methods which were a multistage cluster and stratified random sampling focusing on Dubai Emirate as a feasible alternative that solves the wide dispersion of UAE population (Cresswell 2012 & 2014). Following were the proposed survey stages designed to decrease coverage and sampling error (Dillman et al. 2009):

1. Identifying Dubai regions in which Emirati residents are not less than 11% to ensure representing their portion within UAE population (Government .ae 2019; Snoj 2015). That enables the questionnaires conduct for both Emirati and expatriates within similar neighbourhood and ascertains the exposure of all residents to similar outdoor environmental characteristics.
2. Classifying these neighbourhoods into 12 categories according to their utilized air-conditioning (AC) systems and age following the criteria shown in Table 3-28.
3. Randomly selecting a neighbourhood from each category using computerized method which is a convenient probabilistic one (Cresswell 2014).
4. Listing households of the selected areas and then stratifying the households into expatriates and nationals within each area. Stratified sampling represents the real proportions of individuals of specific characteristics within the population (Dillman 2009). Unlike simple random sampling, stratified random sampling ensures attaining a sample of 11% nationals and 89% expatriates that represents UAE residents (Government .ae 2019).
5. Randomly selecting a sample of 6 Emirati households and 44 expatriate households leading to a sample of 50 cases from each of the 12 areas resulting 600 cases as whole.

# Appendix X: Dubai communities of participants per sector

Table X-1: Communities in Sector 1

| | Community | Frequency | % of Total |
|---|---|---|---|
| 1 | Al Mamzar | 11 | 2.0% |
| 2 | Abu Hail | 5 | 0.9% |
| 3 | Port Saeed | 1 | 0.2% |
| 4 | Al Riqa | 2 | 0.4% |
| 5 | Hor Al Anz | 2 | 0.4% |
| 6 | Deira | 20 | 3.7% |
| 7 | Al Muraqabat | 1 | 0.2% |
| 8 | AL Buteen | 1 | 0.2% |
| 9 | Al Hamryia | 1 | 0.2% |
| 10 | Al Baraha | 1 | 0.2% |
| | Total | 45 | 8.3% |

Table X-2: Communities in Sector 2

| | Community | Frequency | % of Total |
|---|---|---|---|
| 1 | Mirdif | 18 | 3.3% |
| 2 | Al Garhood | 4 | 0.7% |
| 3 | Al Nahda | 37 | 6.8% |
| 4 | Al Qusais | 36 | 6.6% |
| 5 | Al Mizher | 6 | 1.1% |
| 6 | Al Tawar | 9 | 1.7% |
| 7 | Al Rashidyia | 6 | 1.1% |
| 8 | Al khawaneej | 3 | 0.6% |
| 9 | Muhaisnah | 6 | 1.1% |
| | Total | 125 | 23.0% |

Table X-3: Communities in Sector 3

| | Community | Frequency | % of Total |
|---|---|---|---|
| 1 | Bur Dubai | 26 | 4.8% |
| 2 | Al Rafaa | 1 | 0.2% |
| 3 | Al Karama | 17 | 3.1% |
| 4 | Al Barsha | 16 | 2.9% |
| 5 | Al Jaflyia | 5 | 0.9% |
| 6 | Downtown | 6 | 1.1% |
| 7 | Jumeira | 13 | 2.4% |
| 8 | Al Barsha Heights | 2 | 0.4% |
| 9 | Al Sofouh | 3 | 0.6% |
| 10 | Al Khail Gates | 4 | 0.7% |
| 11 | Business Bay | 3 | 0.6% |
| 12 | Mankhoul | 5 | 0.9% |
| 13 | Discovery Gardens | 14 | 2.6% |
| 14 | The Greens | 4 | 0.7% |
| 15 | Al Satwa | 2 | 0.4% |
| 16 | DIFC | 2 | 0.4% |
| 17 | Marina | 6 | 1.1% |
| 18 | The Gardens | 2 | 0.4% |
| 19 | Al Hudaiba | 1 | 0.2% |
| 20 | Al Qoz | 4 | 0.7% |
| 21 | Oud Metha | 4 | 0.7% |
| 22 | Al Musallah | 1 | 0.2% |
| 23 | The Springs | 1 | 0.2% |
| 24 | Al Badia | 1 | 0.2% |
| 25 | The Meadows | 1 | 0.2% |
| 26 | Um Suqeim | 2 | 0.4% |
| 27 | Al Fahidi | 2 | 0.4% |
| 28 | JBR | 1 | 0.2% |
| 29 | Al Wasl | 1 | 0.2% |
| | | 150 | 27.6% |

Table X-4: Communities in Sector 4

| | Community | Frequency | % of Total |
|---|---|---|---|
| 1 | Al Warqaa | 14 | 2.5% |
| 2 | Ras Al Khor | 1 | 0.2% |
| 3 | Nad Al Hamar | 1 | 0.2% |
| 4 | Al Khor | 1 | 0.2% |
| | Total | 17 | 3.1% |

Table X-5: Communities in Sector 5

| | Community | Frequency | % of Total |
|---|---|---|---|
| 1 | Jabal Ali | 2 | 0.4% |
| 2 | Al Firjan | 1 | 0.2% |
| | Total | 3 | 0.6% |

Table X-6: Communities in Sector 6

| | Community | Frequency | % of Total |
|---|---|---|---|
| 1 | Dubai Land | 19 | 3.5% |
| 2 | International City | 47 | 8.7% |
| 3 | The Villa | 1 | 0.2% |
| 4 | Motor City | 5 | 0.9% |
| 5 | Dubai Sports City | 4 | 0.7% |
| 6 | Nad Al Shaba | 4 | 0.7% |
| 7 | Wadi Al Safa | 1 | 0.2% |
| 8 | Silicon Oasis | 32 | 5.9% |
| 9 | Falcon City | 1 | 0.2% |
| 10 | IMPZ | 3 | 0.6% |
| 11 | JVC | 3 | 0.6% |
| 12 | DIAC | 12 | 2.2% |
| 13 | Arabian Ranches | 2 | 0.4% |
| 14 | Al Barari | 1 | 0.2% |
| 15 | Al Warsan | 1 | 0.2% |
| 16 | Damac Hills | 1 | 0.2% |
| 17 | Al Ramtha | 1 | 0.2% |
| 18 | Nad Al Shiba | 1 | 0.2% |
| | Total | 139 | 25.6% |

Table X-7: Communities in Sector 7

| | Community | Frequency | % of Total |
|---|---|---|---|
| 1 | Al Aweer | 1 | 0.2% |
| | Total | 1 | 0.2% |

Table X-8: Communities in Sector 8

| | Community | Frequency | % of Total |
|---|---|---|---|
| 1 | Hata | 2 | 0.4% |
| | Total | 2 | 0.4% |

# Appendix Y: Frequency of odors experiences

Table Y-1:Frequency of odors experiences

| | | Never | 1 - 3 days/Yr | 1 - 3 days/Month | 1 - 3 days/Wk | Daily/ Almost daily | Total |
|---|---|---|---|---|---|---|---|
| Incense smoke | N | 328 | 67 | 45 | 35 | 68 | 543 |
| | % | 60.4 | 12.3 | 8.3 | 6.4 | 12.5 | 100 |
| New carpets odors | N | 382 | 111 | 26 | 17 | 7 | 543 |
| | % | 70.3 | 20.4 | 4.8 | 3.1 | 1.3 | 100 |
| Dampness odors | N | 351 | 102 | 57 | 22 | 11 | 543 |
| | % | 64.6 | 18.8 | 10.5 | 4.1 | 2.0 | 100 |
| Fishy & food odors | N | 221 | 106 | 103 | 64 | 49 | 543 |
| | % | 40.7 | 19.5 | 19.0 | 11.8 | 9.0 | 100 |
| Body odors | N | 285 | 91 | 60 | 49 | 58 | 543 |
| | % | 52.5 | 16.8 | 11.0 | 9.0 | 10.7 | 100 |
| Paint odors | N | 290 | 187 | 43 | 13 | 10 | 543 |
| | % | 53.4 | 34.4 | 7.9 | 2.4 | 1.8 | 100 |
| Chemical odors | N | 317 | 128 | 63 | 21 | 14 | 543 |
| | % | 58.4 | 23.6 | 11.6 | 3.9 | 2.6 | 100 |
| Tobacco smoke | N | 335 | 64 | 38 | 39 | 67 | 543 |
| | % | 61.7 | 11.8 | 7.0 | 7.2 | 12.3 | 100 |
| Diesel odors | N | 399 | 69 | 46 | 14 | 15 | 543 |
| | % | 73.5 | 12.7 | 8.5 | 2.6 | 2.8 | 100 |

# Appendix Z: Frequency of IEQ comfort experiences

Table Z-1: Frequency of IEQ comfort experiences

| | | Never | 1 - 3 days/Yr | 1 - 3 days/Month | 1 - 3 days/Wk | Daily Almost daily | Total |
|---|---|---|---|---|---|---|---|
| Dust | N | 139 | 113 | 134 | 73 | 84 | 543 |
| & dirt | % | 25.6 | 20.8 | 24.7 | 13.4 | 15.5 | 100 |
| Stuffy | N | 253 | 116 | 97 | 42 | 35 | 543 |
| bad air | % | 46.6 | 21.4 | 17.9 | 7.7 | 6.4 | 100 |
| Little | N | 271 | 102 | 92 | 47 | 31 | 543 |
| Air | % | 49.9 | 18.8 | 16.9 | 8.7 | 5.7 | 100 |
| Too | N | 190 | 114 | 120 | 64 | 55 | 543 |
| hot | % | 35.0 | 21.0 | 22.1 | 11.8 | 10.1 | 100 |
| Too | N | 206 | 136 | 109 | 60 | 32 | 543 |
| cold | % | 37.9 | 25.0 | 20.1 | 11.0 | 5.9 | 100 |
| Too | N | 207 | 117 | 117 | 58 | 44 | 543 |
| humid | % | 38.1 | 21.5 | 21.5 | 10.7 | 8.1 | 100 |
| Too | N | 242 | 113 | 99 | 51 | 38 | 543 |
| dry | % | 44.6 | 20.8 | 18.2 | 9.4 | 7.0 | 100 |
| Too | N | 289 | 111 | 75 | 41 | 27 | 543 |
| glary | % | 53.2 | 20.4 | 13.8 | 7.6 | 5.0 | 100 |
| Too | N | 318 | 102 | 66 | 37 | 20 | 543 |
| dim | % | 58.6 | 18.8 | 12.2 | 6.8 | 3.7 | 100 |
| Too | N | 246 | 109 | 87 | 47 | 54 | 543 |
| noisy | % | 45.3 | 20.1 | 16.0 | 8.7 | 9.9 | 100 |
| Too | N | 272 | 93 | 57 | 41 | 80 | 543 |
| quiet | % | 50.1 | 17.1 | 10.5 | 7.6 | 14.7 | 100 |

# Appendix AA : Frequency of health symptoms

Table AA-1: Frequency of health symptoms

| | | Never | 1 – 3 days/Yr | 1 - 3 days/Month | 1 - 3 days/Wk | Daily/ Almost daily | Total |
|---|---|---|---|---|---|---|---|
| Headache Nausea | N | 135 | 141 | 174 | 61 | 32 | 543 |
| | % | 24.9 | 26.0 | 32.0 | 11.2 | 5.9 | 100 |
| Nose symptoms | N | 110 | 179 | 164 | 57 | 33 | 543 |
| | % | 20.3 | 33.0 | 30.2 | 10.5 | 6.1 | 100 |
| Chest symptoms | N | 262 | 159 | 79 | 32 | 11 | 543 |
| | % | 48.3 | 29.3 | 14.5 | 5.9 | 2.0 | 100 |
| Cough | N | 105 | 234 | 138 | 54 | 12 | 543 |
| | % | 19.3 | 43.1 | 25.4 | 9.9 | 2.2 | 100 |
| Eye symptoms | N | 208 | 190 | 91 | 37 | 17 | 543 |
| | % | 38.3 | 35.0 | 16.8 | 6.8 | 3.1 | 100 |
| Throat symptoms | N | 153 | 220 | 119 | 43 | 8 | 543 |
| | % | 28.2 | 40.5 | 21.9 | 7.9 | 1.5 | 100 |
| Fatigue sleepiness | N | 173 | 161 | 118 | 52 | 39 | 543 |
| | % | 31.9 | 29.7 | 21.7 | 9.6 | 7.2 | 100 |
| Fever | N | 139 | 282 | 93 | 23 | 6 | 543 |
| | % | 25.6 | 51.9 | 17.1 | 4.2 | 1.1 | 100 |
| Pain in muscles, back | N | 136 | 157 | 154 | 52 | 44 | 543 |
| | % | 25.0 | 28.9 | 28.4 | 9.6 | 8.1 | 100 |
| Nervous symptoms | N | 247 | 130 | 83 | 53 | 30 | 543 |
| | % | 45.5 | 23.9 | 15.3 | 9.8 | 5.5 | 100 |
| Dry skin | N | 189 | 163 | 99 | 56 | 36 | 543 |
| | % | 34.8 | 30.0 | 18.2 | 10.3 | 6.6 | 100 |

# Appendix BB : Checking bias in the MLR model of population variables (IV) on Eye, Nose, Throat, and Chest symptoms (DV)

- Linearity, homoscedasticity, and error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure BB-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of vertical straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

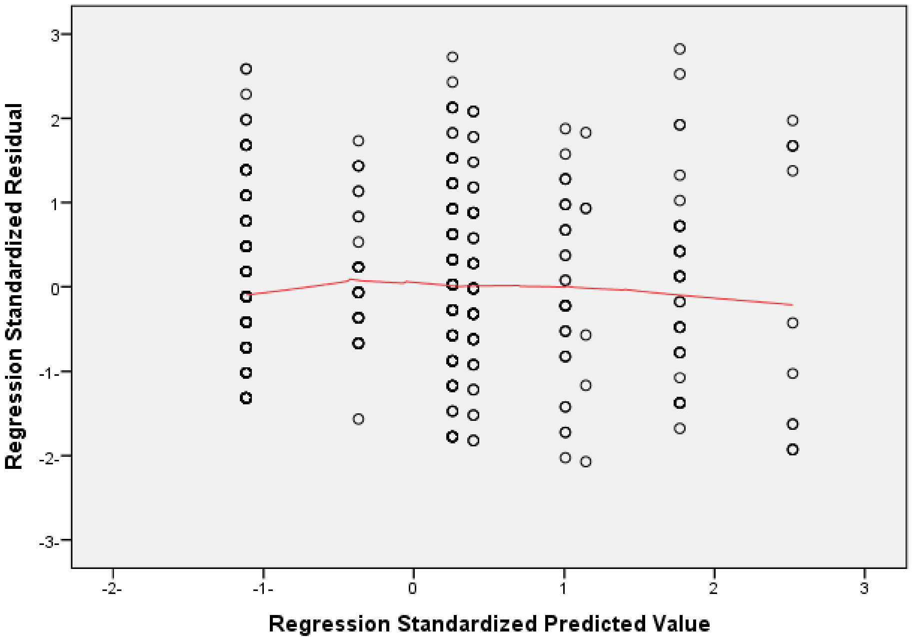


Figure BB-1: Scatter plot of the regression standardized residuals and predicted values of population variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

- As shown in Figure BB-2, normal distribution of the residuals can be assumed for the final regression model since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013; Eberly College of Science 2018c). Also, as illustrated in Figure BB-3 and Figure BB-4, the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the highest VIF was 1.054 (Field 2016; Ballance 2015; Ghani & Ahmad 2010).

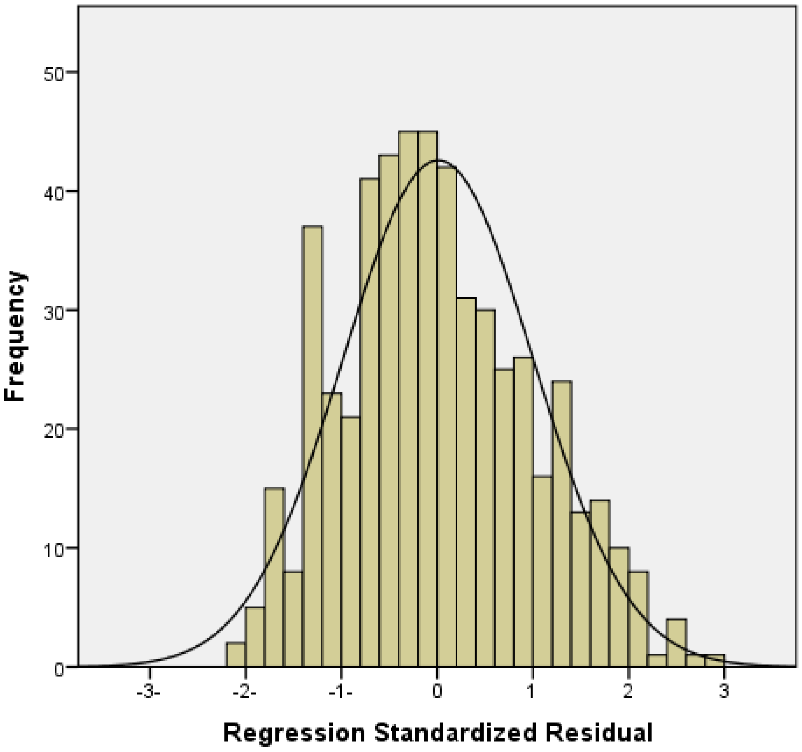


Figure BB-2: Histogram of the regression standardized residuals of population variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

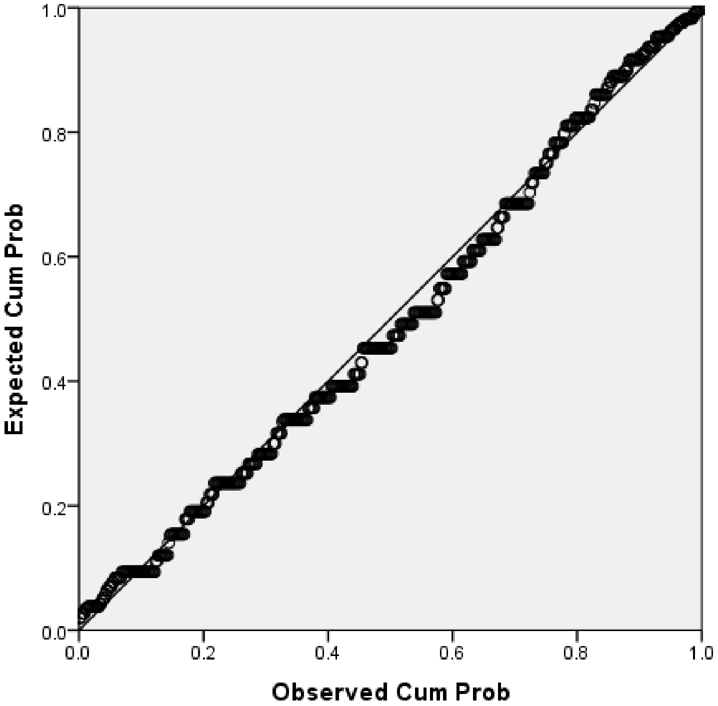


Figure BB-3: P-P plot of regression standardized residuals of population variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

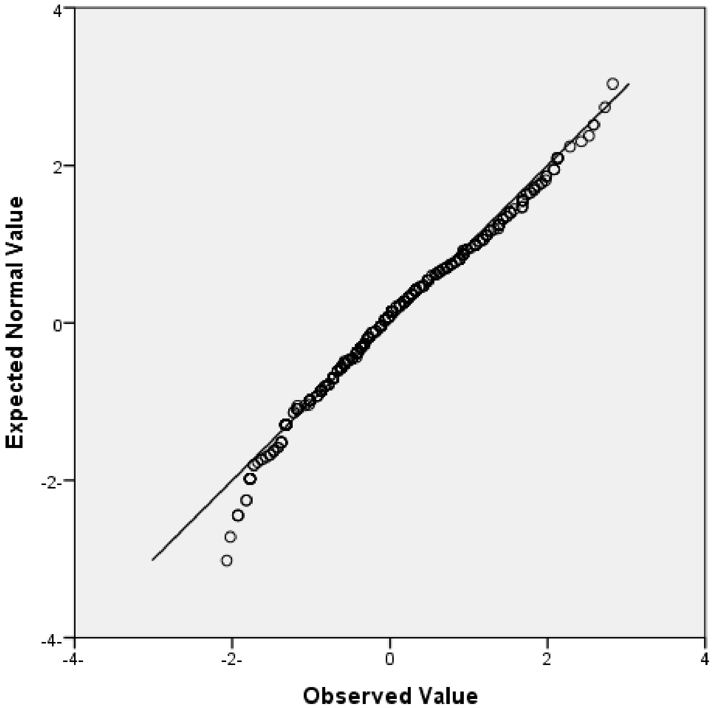
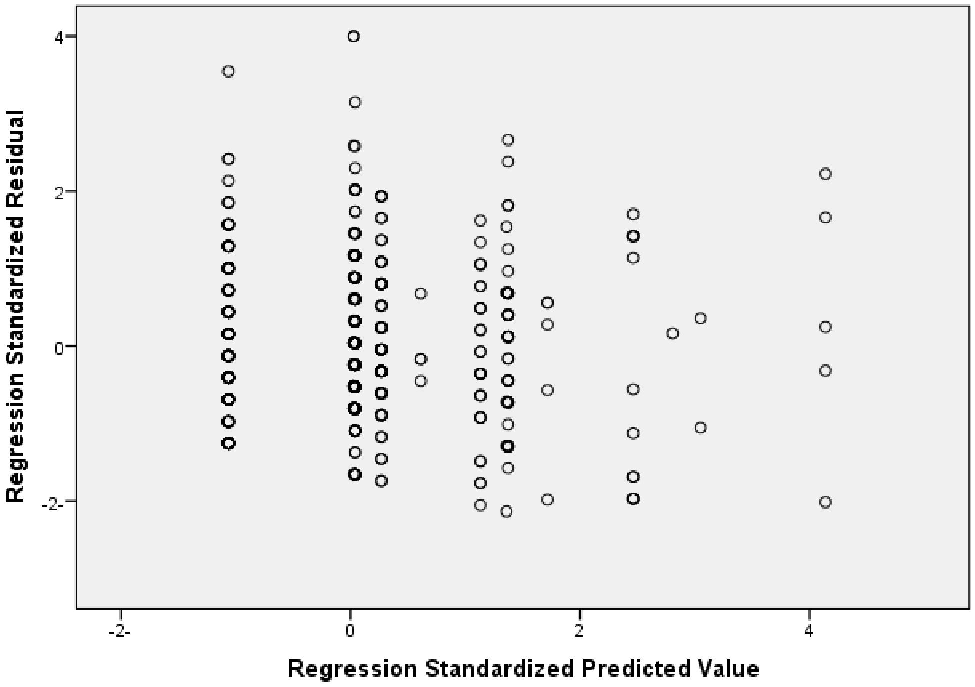


Figure BB-4: Q-Q plot of standardized residual of population variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. Five data points of standardized residual values, shown on the top left corner of Figure BB-5 (A), were not following those criteria. According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the five data points were deleted.
- Examining data points of high leverage in the initial regression model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=17 parameters and n=542 in the initial model, the cutoff value 2p/n and 3p/n were 0.06 and 0.09; respectively. As shown in Figure BB-6 (A), a number of 17 data points above 0.06 were obviously isolated from the majority of the observations. After deleting 7 of them, all other data points were close to each other with leverage value ≤ 0.017 (Figure BB-6 (B)). Figure BB-5 (B) shows scatter plots of regression standardized residuals and standardized predicted values after deleting the described outliers and high leverage data points.
- Examining data points of high influence in the initial regression model followed the general cutoff value Cook's distance of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Plus 2004) as discussed in Section 3.4.3. No influential points were detected since the highest Cook's distance and DFBETAS were 0.0211 and 0.212; respectively. Figure BB-7 (A) and (B) illustrates the Cook's distances for regression models before and after deleting above described unusual data points. Notably that the difference between Cook's distances are closer in (B) compared than (A) and no data point appears to be isolated from others.

(A)



(B)

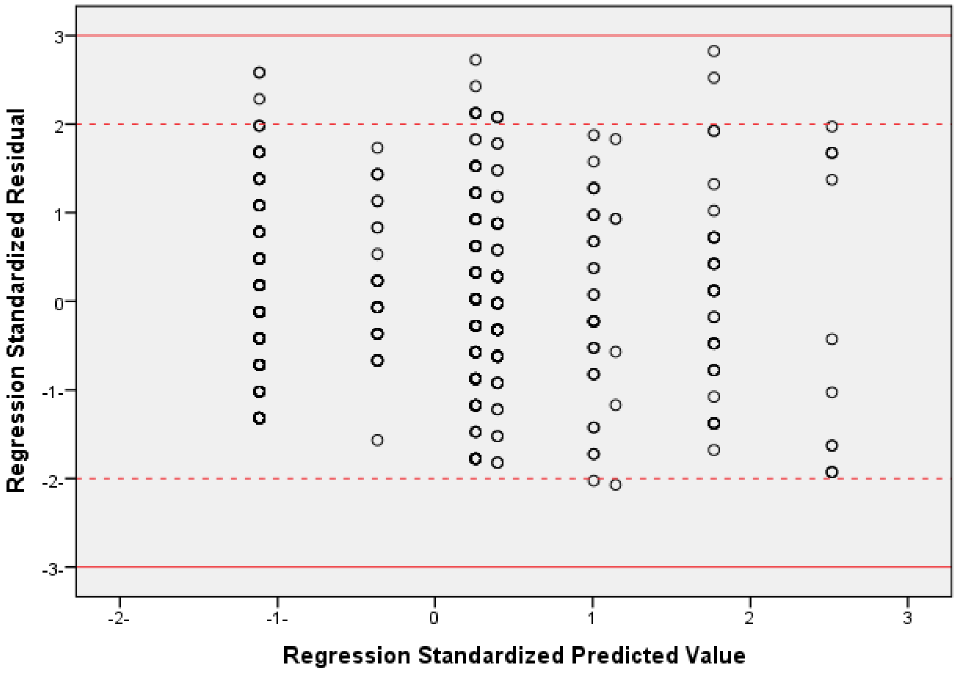
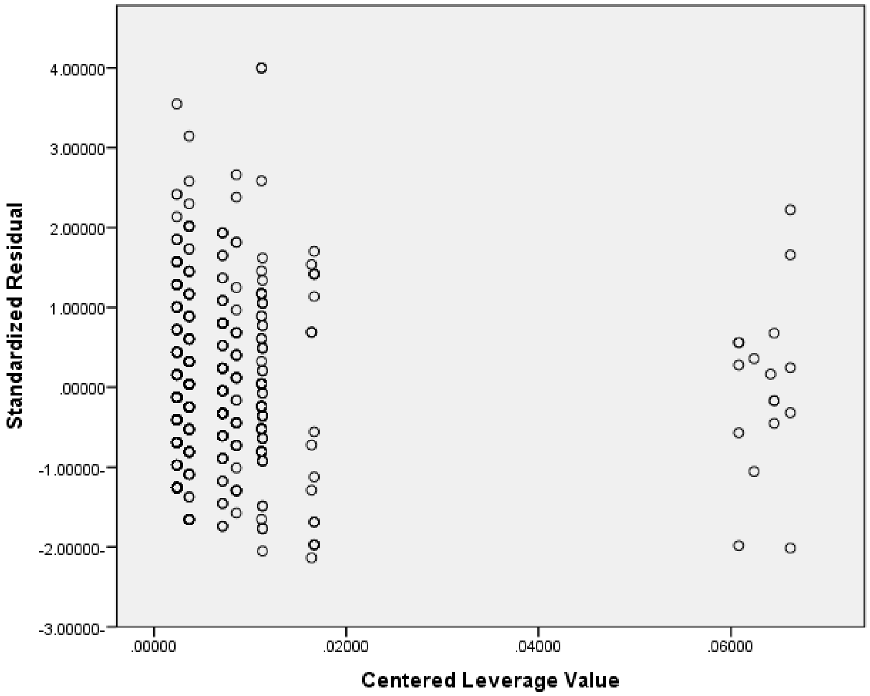


Figure  BB-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values of population variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual data points

(A)



(B)

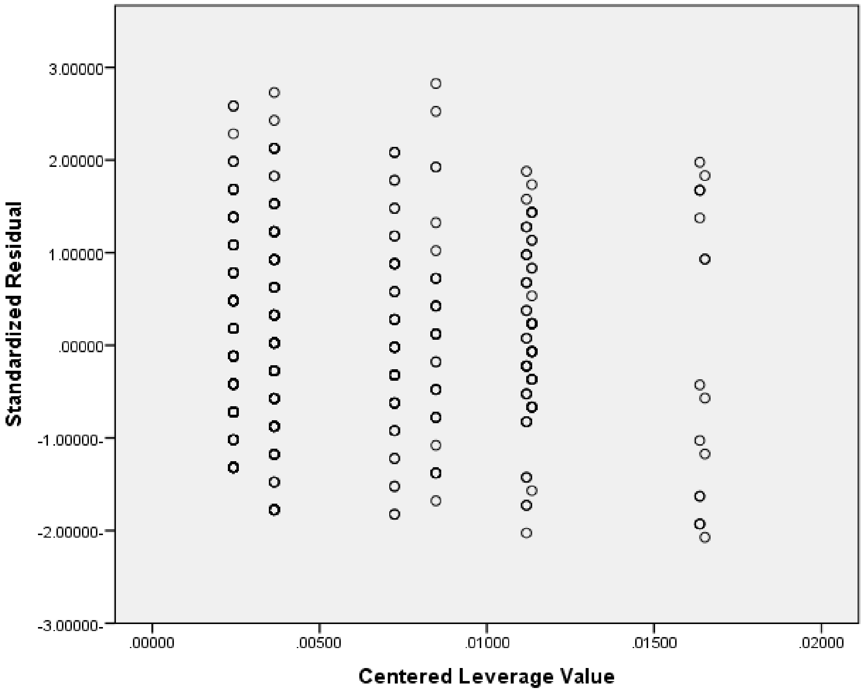


Figure BB-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values of population variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual data points

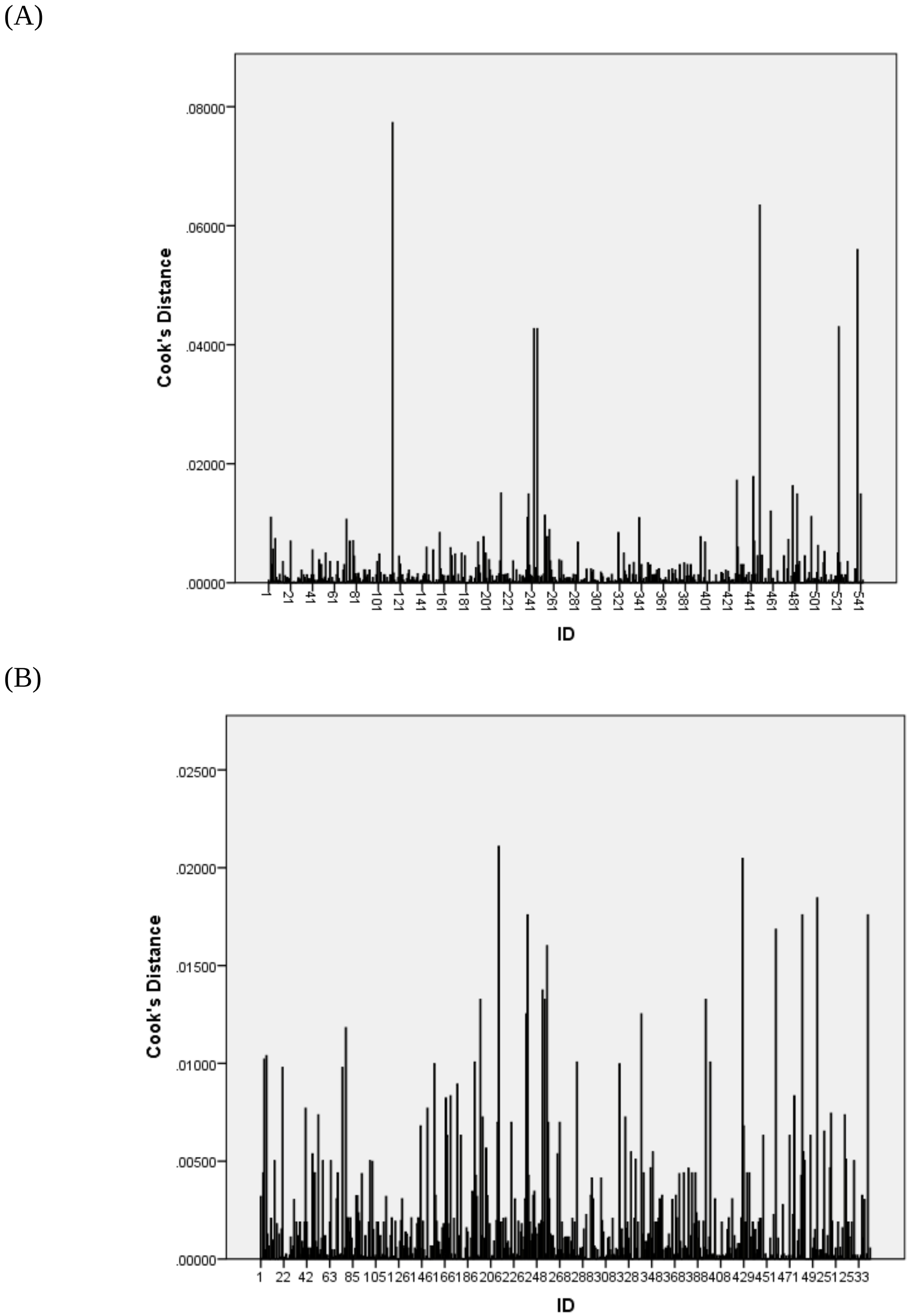


Figure BB-7: Bar charts (A) & (B) of Cook's distances for the regression model of population variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual data points

## Appendix CC : Checking bias in the MLR model of population variables (IV) on general, ergonomic, nervous, and skin symptoms (DV)

- Linearity, homoscedasticity, and error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure CC-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of vertical straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

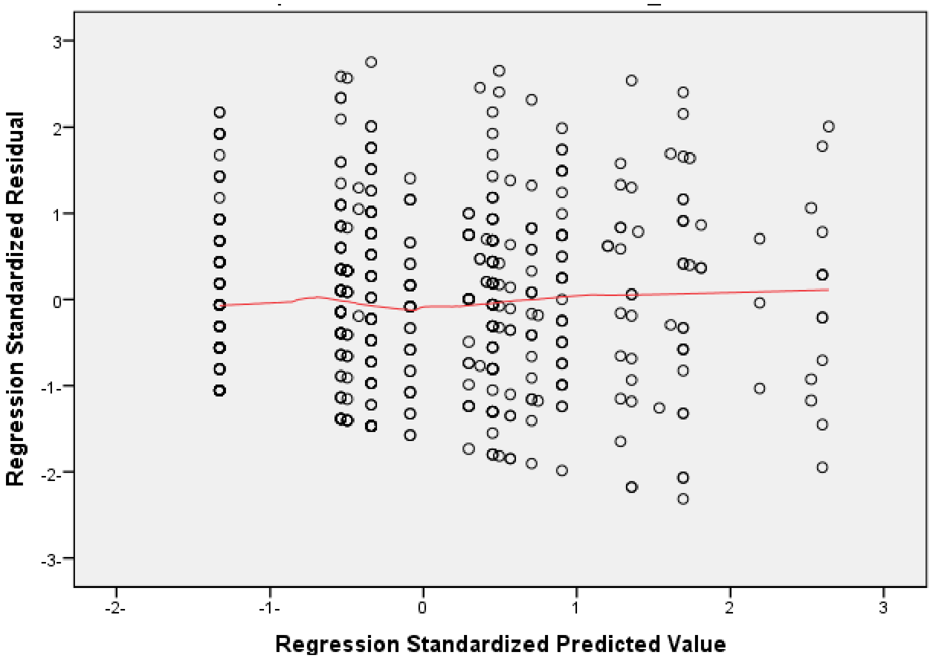


Figure CC-1: Scatter plot of regression standardized residuals and predicted values of population (IV) and General, Ergonomic, Nervous, and Skin symptoms (DV)

- As shown in Figure CC-2, normal distribution of the residuals can be assumed for the final regression model since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013; Eberly College of Science 2018c). Also, as illustrated in Figure CC-3 and Figure CC-4; the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 1.29 (Field 2016; Ballance 2015; Ghani & Ahmad 2010).

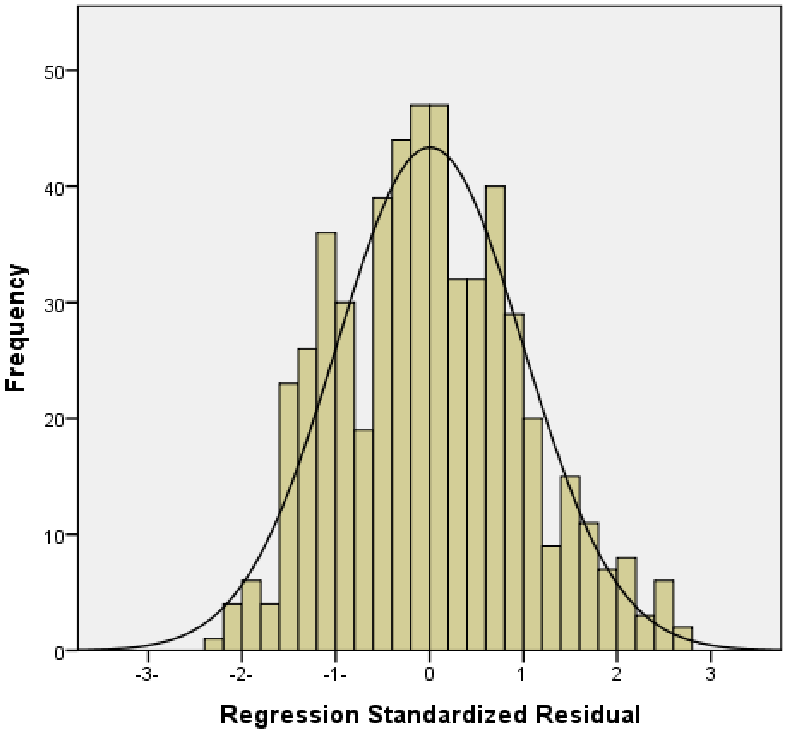


Figure CC-2: Histogram of the regression standardized residuals of population variables (IV) and General, Ergonomic, Nervous, and Skin symptoms (DV)

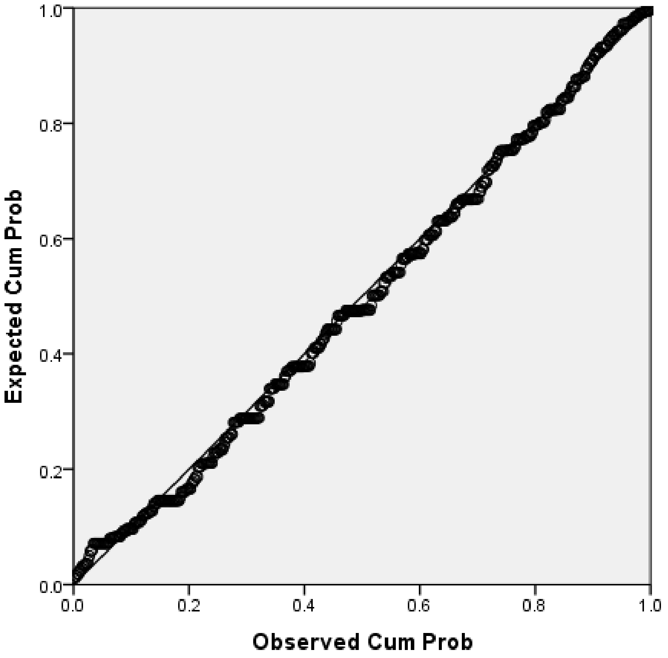


Figure CC-3: P-P plot of regression standardized residuals of population variables (IV) and General, Ergonomic, Nervous, and Skin symptoms (DV)

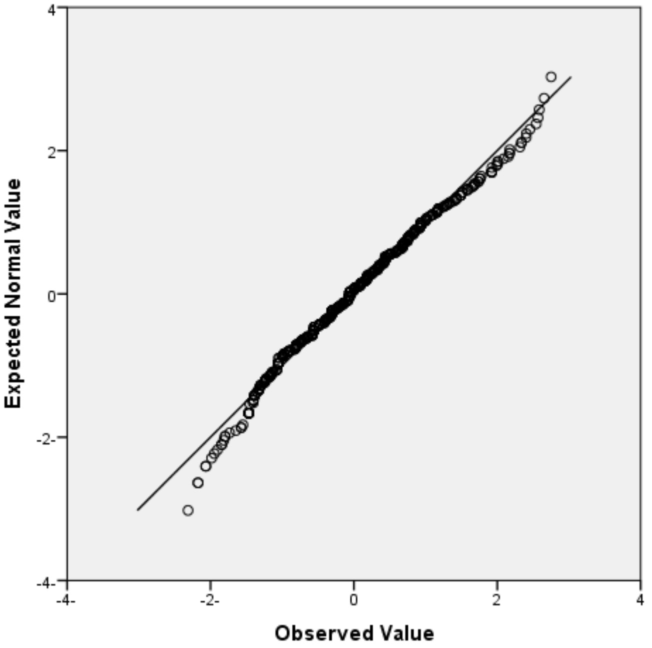
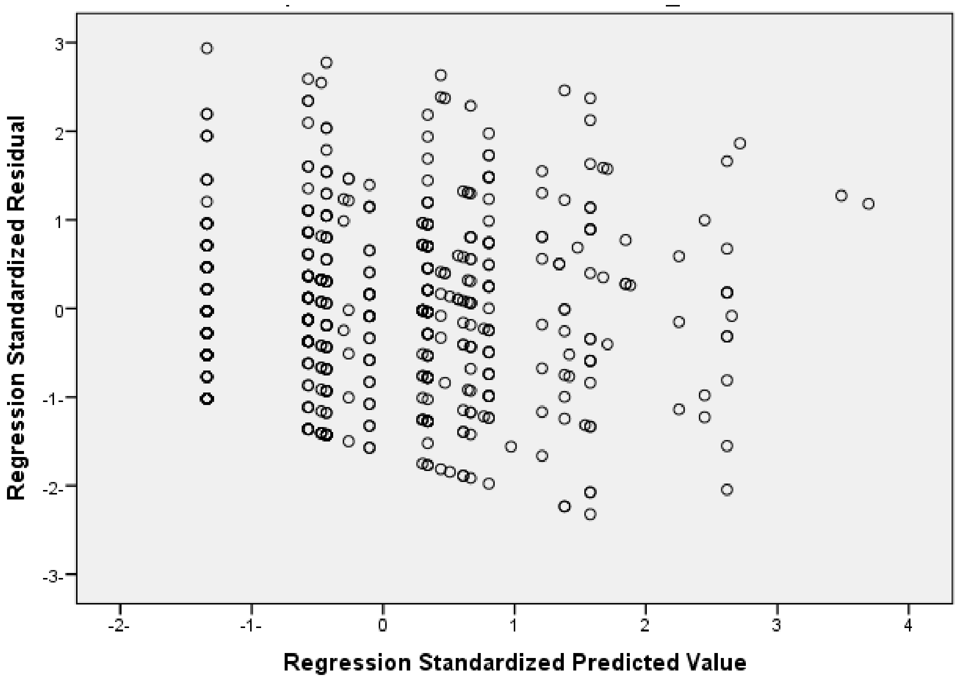


Figure CC-4: Q-Q plot of standardized residual of population variables (IV) and General, Ergonomic, Nervous, and Skin symptoms (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29 (Simonof 2017; Field 2016; Oyeyemi et al. 2015). Only one data point of standardized residual values, shown on the top left corner of Figure CC-5 (A), was not following those criteria. According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, that data point was deleted.
- Examining data points of high leverage in the initial regression model followed the size adjusted cutoff value of 2p/n or 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=17 parameters and n=542 in the initial regression model, the cutoff value of 2p/n and 3p/n were 0.06 and 0.09; respectively. As shown in Figure CC-6 (A), a number of 20 data points were obviously isolated from the majority of the observations of leverage value between 0.05 – 0.07 with two of them above the specified cutoff of 0.06. After deleting these two, all other data points were not isolated from each other and falls below the cutoff value of 0.06 with leverage ≤ 0.036 (Figure CC-6 (B)). Figure CC-5 (B) shows the scatter plots of regression standardized residuals and standardized predicted values before and after deleting the described outliers and high leverage points.
- Examining data points of high influence in the initial model followed the general cutoff value Cook’s distance of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Plus 2004) as discussed in Section 3.4.3. No influential points were detected since the highest Cook’s distance and DFBETAS were 0.0278 and 0.247; respectively. Figure CC-7 (A) and (B) illustrates the Cook’s distances for models before and after deleting unusual data points. Notably that the difference between Cook’s distances are closer in (B) compared than (A) and no data point appears to be isolated from others.

(A)



(B)

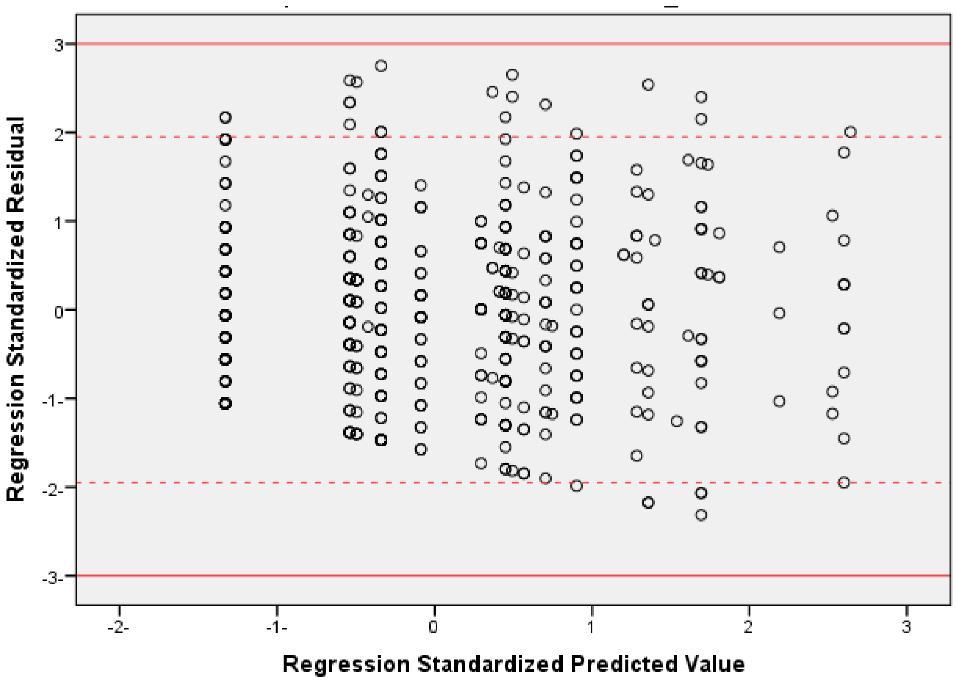


Figure CC-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values of population variables (IV) and General, Ergonomic, Nervous, and Skin symptoms (DV) before and after deleting unusual data points

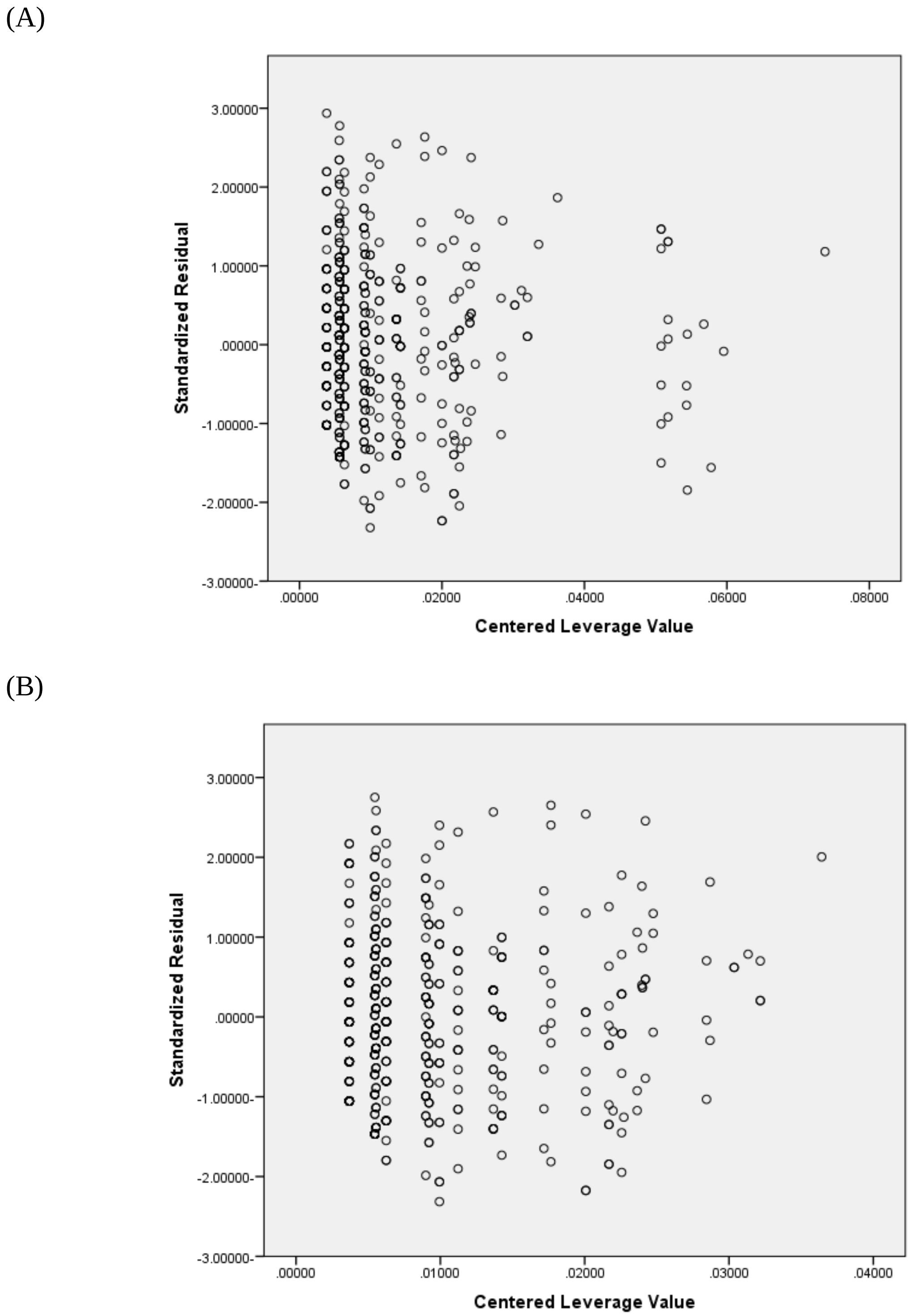


Figure CC-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values of population variables (IV) and General, Ergonomic, Nervous, and Skin symptoms (DV) before and after deleting unusual data points

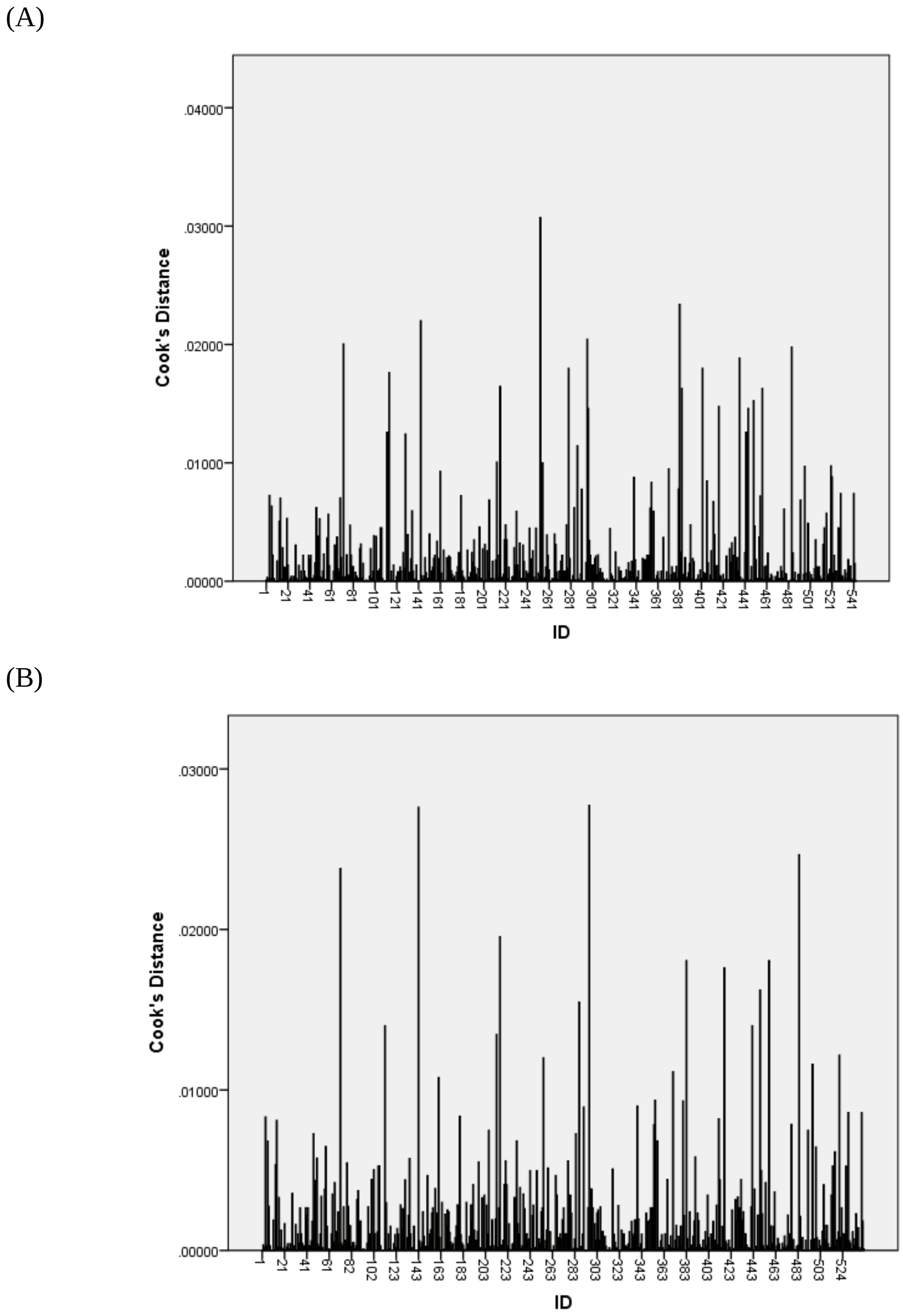


Figure CC-7: Bar charts (A) & (B) of Cook's distances for the regression model of population variables (IV) and General, Ergonomic, Nervous, and Skin symptoms (DV) before and after deleting unusual data points

# Appendix DD : Checking bias in the MLR model of population variables (IV) on Thermal, Lighting, and Noise discomfort (DV)

- Linearity, homoscedasticity, and error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure DD-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of vertical straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

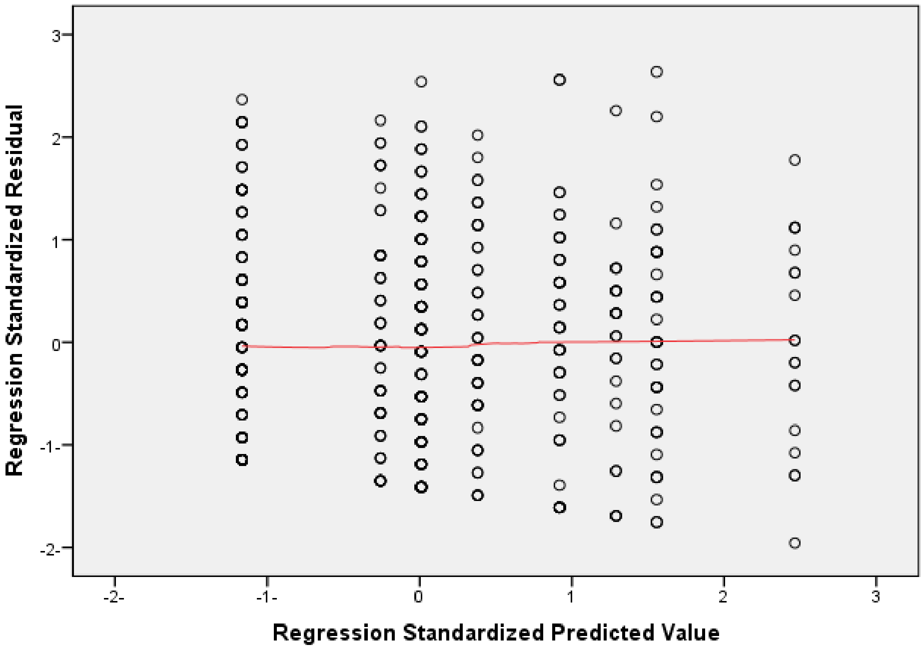


Figure DD-1: Scatter plot of the regression standardized residuals and predicted values of population (IV) and Thermal, Lighting, and Noise discomfort (DV)

- As shown in Figure DD-2, the histogram of the standard residuals of the final regression model suggests that the distribution is a little skewed to the left (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013; Eberly College of Science 2018c). However, as illustrated in Figure DD-3 and Figure DD-4; the residuals in the P-P plots and the Q-Q plots were not significantly deviating from line. Reference to Schmidt & Finan (2018), Mangiafico (2016) & UCLA (2018), regression models with normality violations often still yield valid results particularly when having a large sample size of at least 10 observations for each parameter. That applies to this final regression model of 535 observations and included 17 parameters meaning that each parameter has about 31 observations. Reference to Schmidt & Finan (2018), this model estimators can be qualified as "Best linear unbiased estimators" or "BLUE" since the error can be assumed as independent, homoscedastic, and it had zero mean.
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 1.26 (Field 2016; Ballance 2015; Ghani & Ahmad 2010).

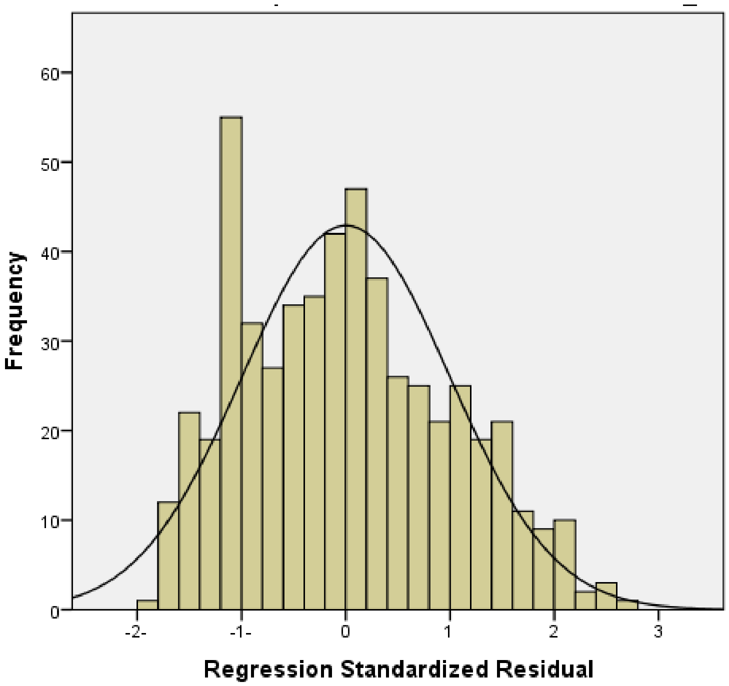


Figure DD-2: Histogram of the regression standardized residuals of population variables (IV) and Thermal, Lighting, and Noise discomfort (DV)

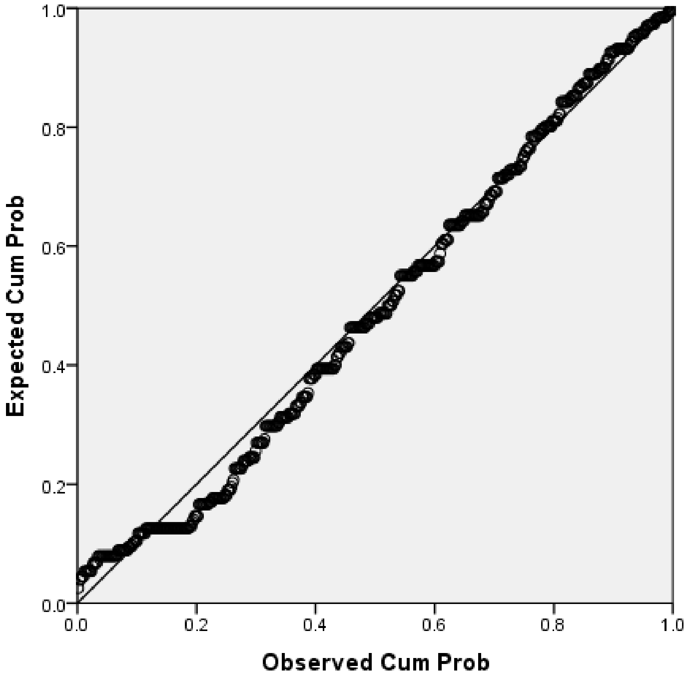


Figure DD-3: P-P plot of regression standardized residuals of population variables (IV) and Thermal, Lighting, and Noise discomfort (DV)

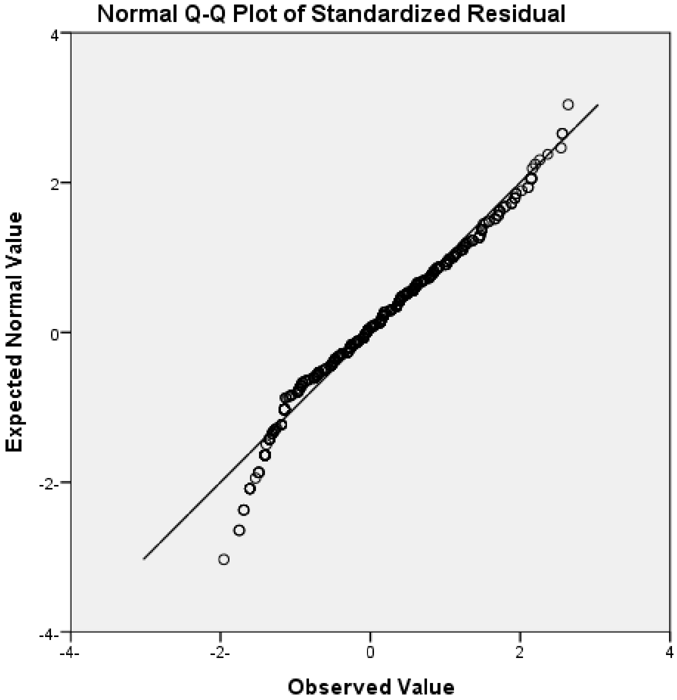


Figure DD-4: Q-Q plot of standardized residual of population variables (IV) and Thermal, Lighting, and Noise discomfort (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29 (Simonof 2017, Field 2016, Oyeyemi et al. 2015). A number of 3 data point of standardized residual values, shown on the left side of Figure DD-5 (A), were not following those criteria. According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 3 data points were deleted.
- Examining data points of high leverage in the initial regression model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=17 parameters and n=542 in the initial regression model, the cutoff value for 2p/n and 3p/n was 0.06 and 0.09; respectively. As shown in Figure DD-6 (A), a number of 4 data points were obviously isolated from the majority of the observations of leverage value above 0.25. After deleting these 4 data points, all other data points were close together and falls below the cutoff value of 0.06 with leverage value ≤ 0.012 (Figure CC-6 (B)). Figure CC-5 (B) shows the scatter plots of regression standardized residuals and standardized predicted values before and after deleting outliers and high leverage data points.
- Examining data points of high influence in the initial regression model followed the general cutoff value Cook's distance of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Plus 2004) as discussed in Section 3.4.3. No influential points were detected since the highest Cook's distance and DFBETAS were 0.019 and 0.204; respectively. Figure DD-7 (A) and (B) illustrates the Cook's distances for regression models before and after deleting unusual data points. Notably that the difference between Cook's distances are closer in (B) compared than (A) and no data point appears to be isolated from others.

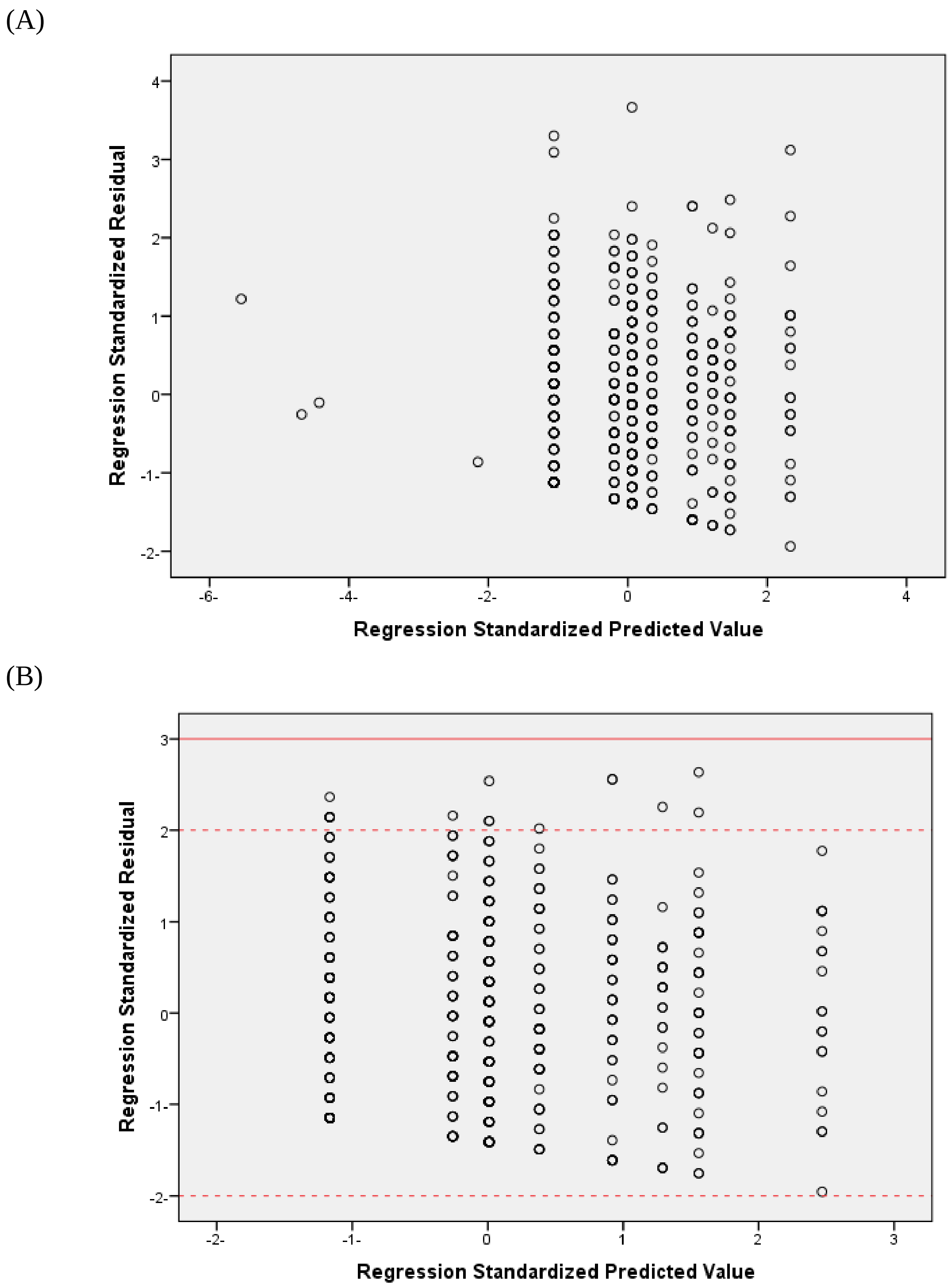
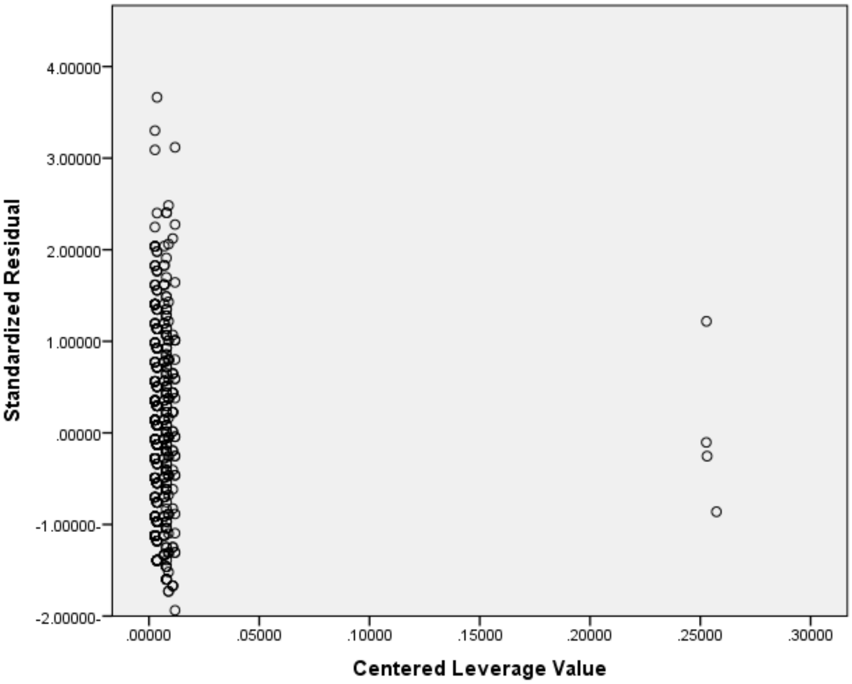


Figure DD-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values of population variables (IV) Thermal, Lighting, and Noise discomfort (DV) before and after deleting unusual data points

(A)



(B)

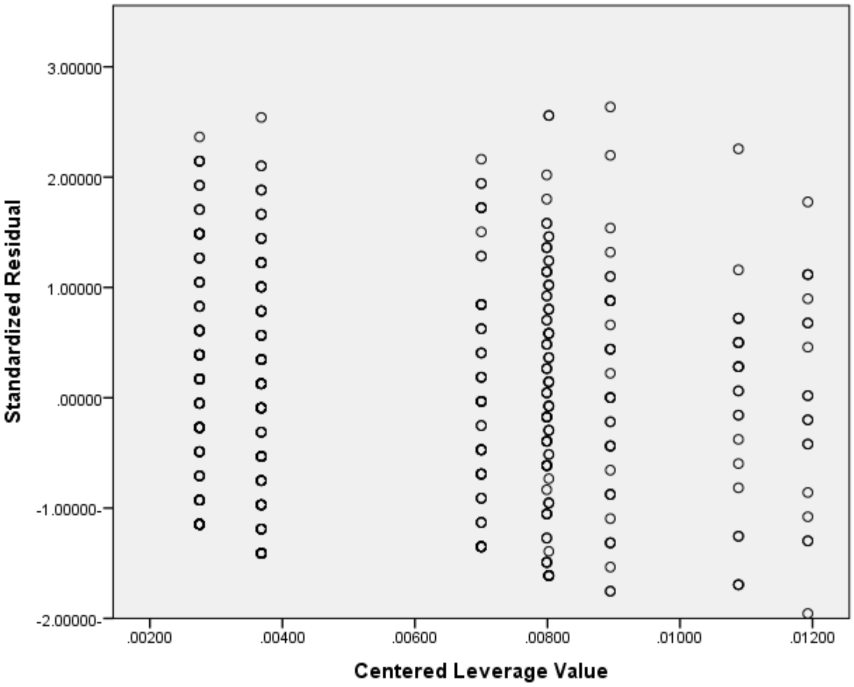


Figure DD-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values of population variables (IV) and Thermal, Lighting, and Noise discomfort (DV) before and after deleting unusual data points

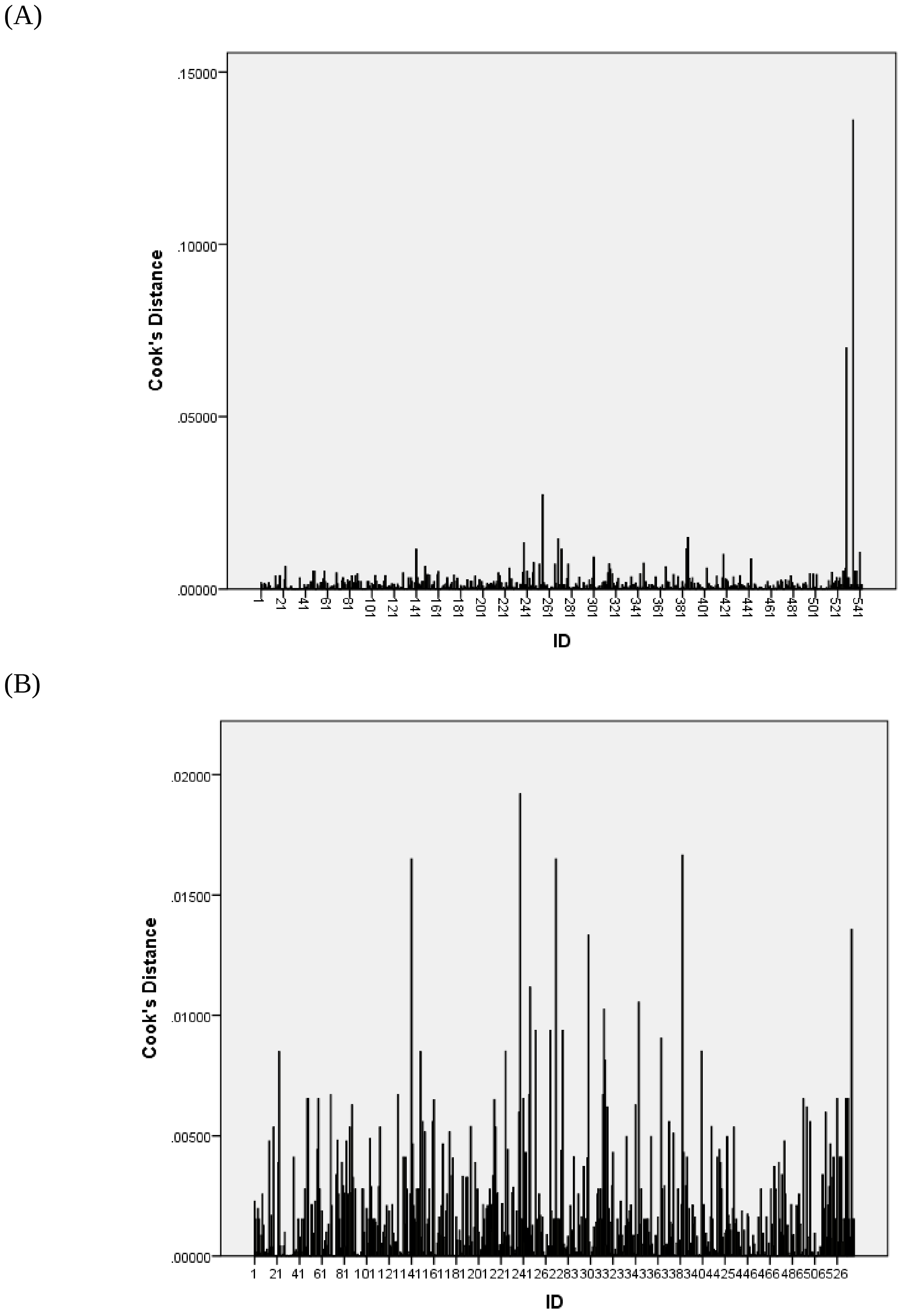


Figure DD-7: Bar charts (A) & (B) of Cook's distances for the regression model of population variables (IV) and Thermal, Lighting, and Noise discomfort (DV) before and after deleting unusual data points

# Appendix EE : Checking bias in the MLR model of population variables (IV) on IAQ discomfort (DV)

- Linearity, homoscedasticity, and error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure EE-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

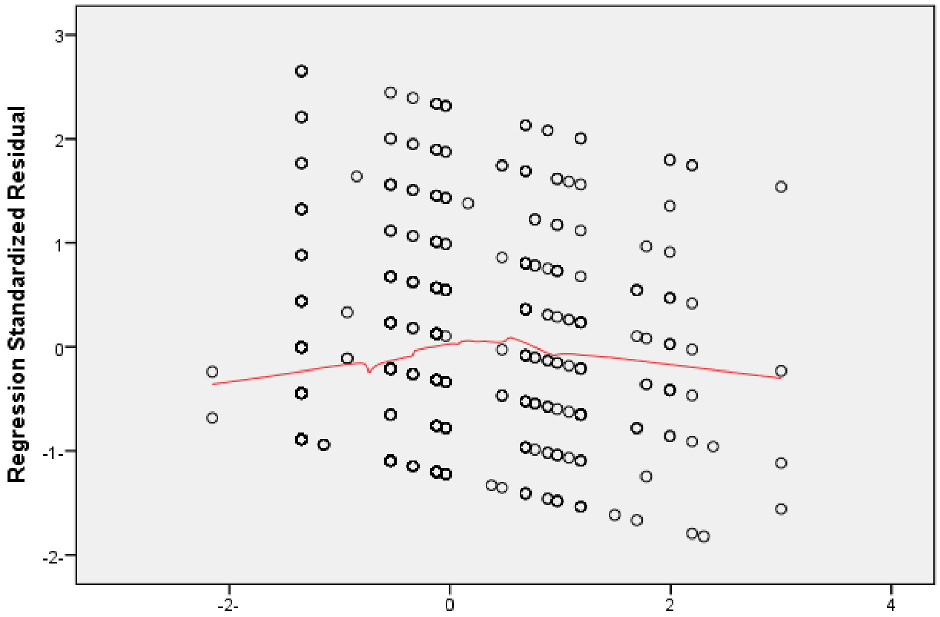


Figure EE-1: Scatter plot of the regression standardized residuals and predicted values of population (IV) and IAQ discomfort (DV)

- As shown in Figure  EE-2 , the histogram of the standard residuals for the final regression model suggests that the  distribution is a little skewed to the left (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013;  Eberly College of Science 2018c). However, as illustrated, as illustrated in Figure  FF-3 and Figure EE-4; the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. Reference to Schmidt & Finan (2018), Mangiafico (2016) & UCLA (2018), regression models with normality violations often still yield valid results particularly when having a large sample size of at least 10 observations per parameter. That applies to this regression model of 542 observations and included 17 variables meaning that each parameter has about 31 observations. Reference to Schmidt & Finan (2018), this model estimators can be qualified as "Best linear unbiased estimators" or "BLUE" since the error can be assumed as independent, homoscedastic, and it had zero mean.
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 1.334 (Field 2016;  Ballance 2015; Ghani & Ahmad 2010).

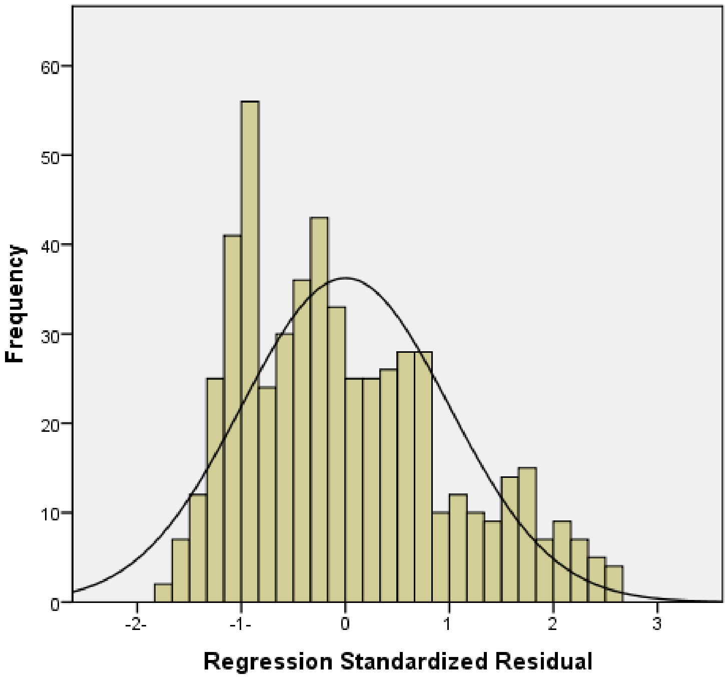


Figure  EE-2: Histogram of the regression standardized residuals of population variables (IV) and IAQ discomfort (DV)

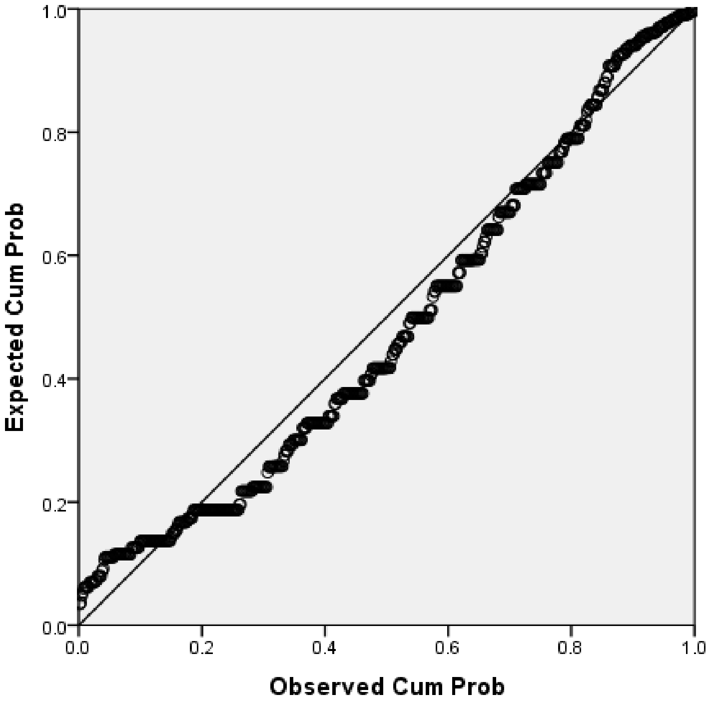


Figure EE-3: P-P plot of regression standardized residuals of population variables (IV) and IAQ discomfort (DV)

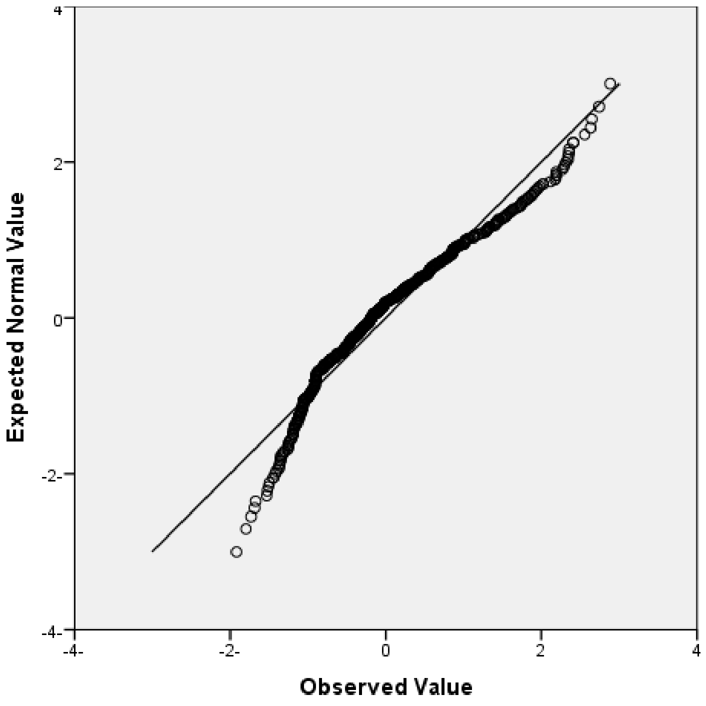


Figure EE-4: Q-Q plot of standardized residual of population variables (IV) and IAQ discomfort (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29 (Simonof 2017; Field 2016; Oyeyemi et al. 2015). All standardized residual values were following those criteria as shown in Figure EE-5. According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); following those criteria is an evidence of having an acceptable error, accurate variable estimation, unbiased results, and that the model is a good fit for the sample data.

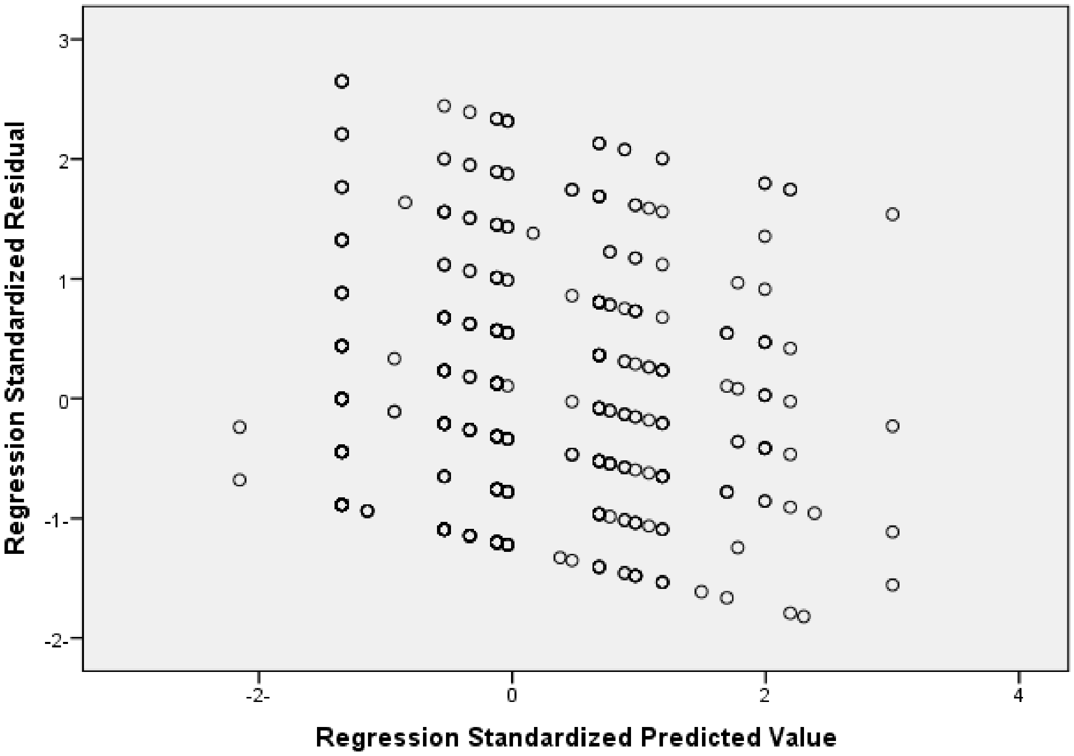


Figure EE-5: Scatter plots of regression standardized residuals and standardized predicted values of population variables (IV) and IAQ discomfort (DV)

- Examining data points of high leverage in the initial regression model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute

Inc. 2015; Hamilton 2013). Having p=17 parameters and n=542 in the initial regression model, the cutoff value for 2p/n and 3p/n was 0.06 and 0.09; respectively. As shown in Figure EE-6, all data points have leverage value below the specified cutoff value of 0.06 and the highest leverage value in the model was 0.044.

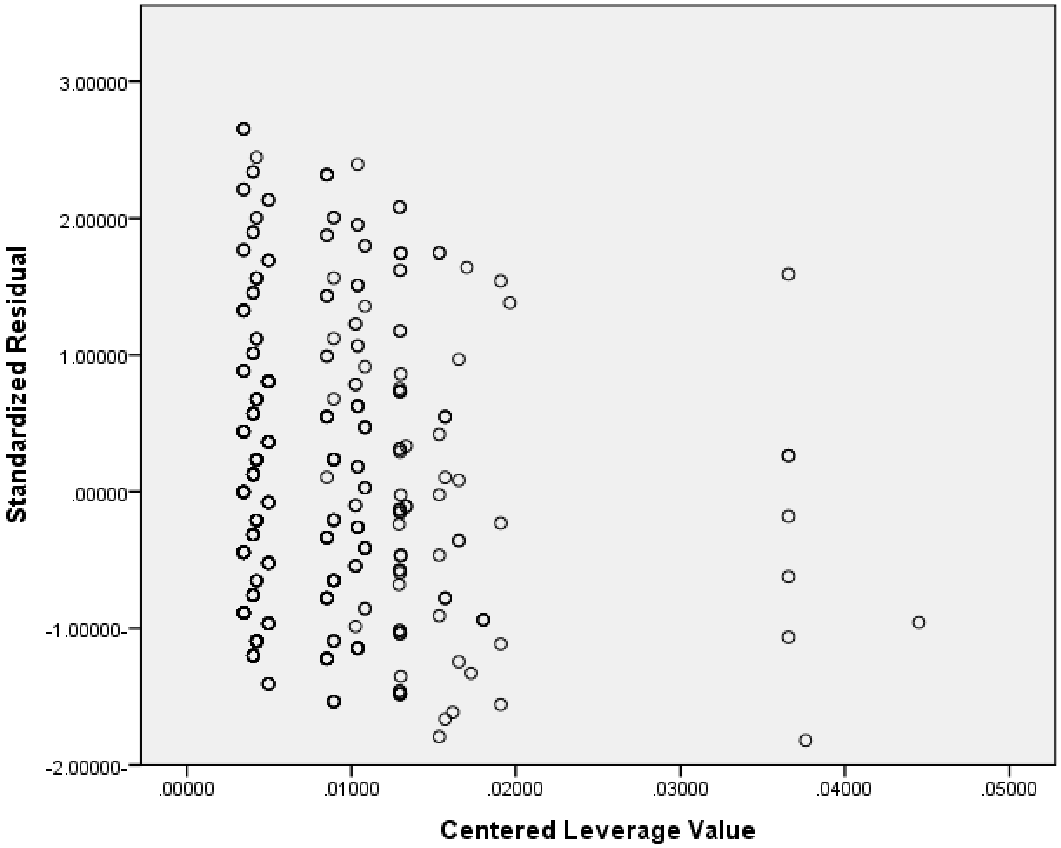


Figure EE-6: Scatter plots of regression standardized residuals and centered leverage values having population variables (IV) and IAQ discomfort (DV)

- Examining data points of high influence in the initial regression model followed the general cutoff value Cook's distance of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Plus 2004) as discussed in Section 3.4.3. No influential points were detected since the highest

Cook’s distance and DFBETAS were 0.028 and 0.868; respectively. Figure EE-7 illustrates the Cook’s distances for the regression model.

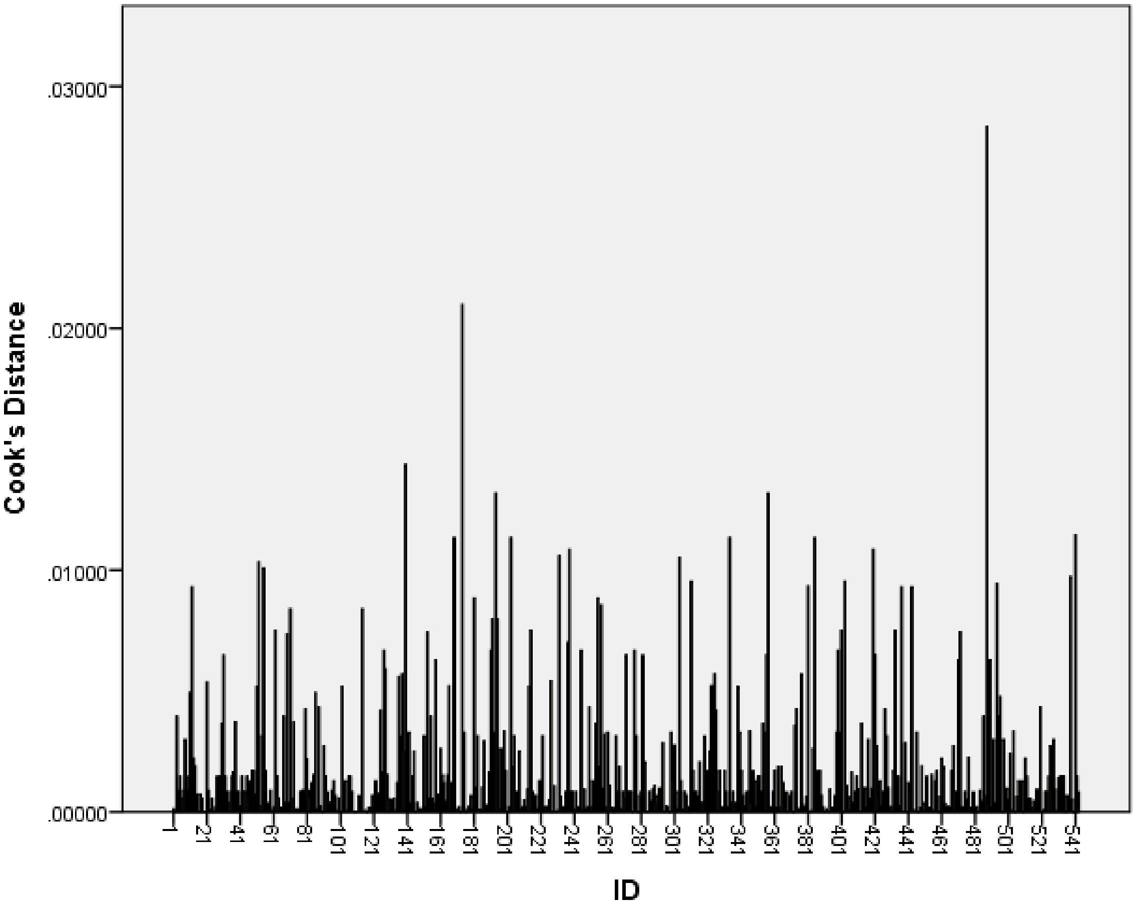


Figure EE-7: Bar charts of Cook’s distances for the regression model having population variables (IV) and IAQ discomfort (DV)

## Appendix FF : Checking bias in the MLR model of population variables as (IV) on odors as (DV)

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure FF-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

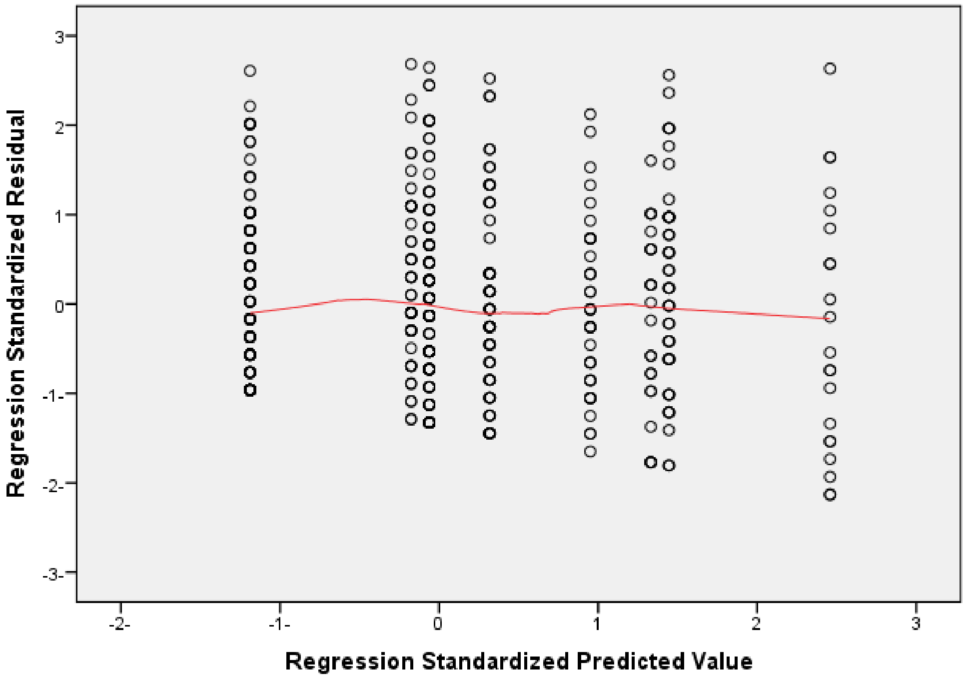


Figure FF-1: Scatter plot of regression standardized residuals and predicted values having population (IV) and odors (DV)

- As shown in Figure FF-2, normal distribution of the residuals can be assumed for the final regression model since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013; Eberly College of Science 2018c). Also, as illustrated in Figure FF-3 and Figure FF-4; the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 1.251 (Field 2016; Ballance 2015; Ghani & Ahmad 2010).

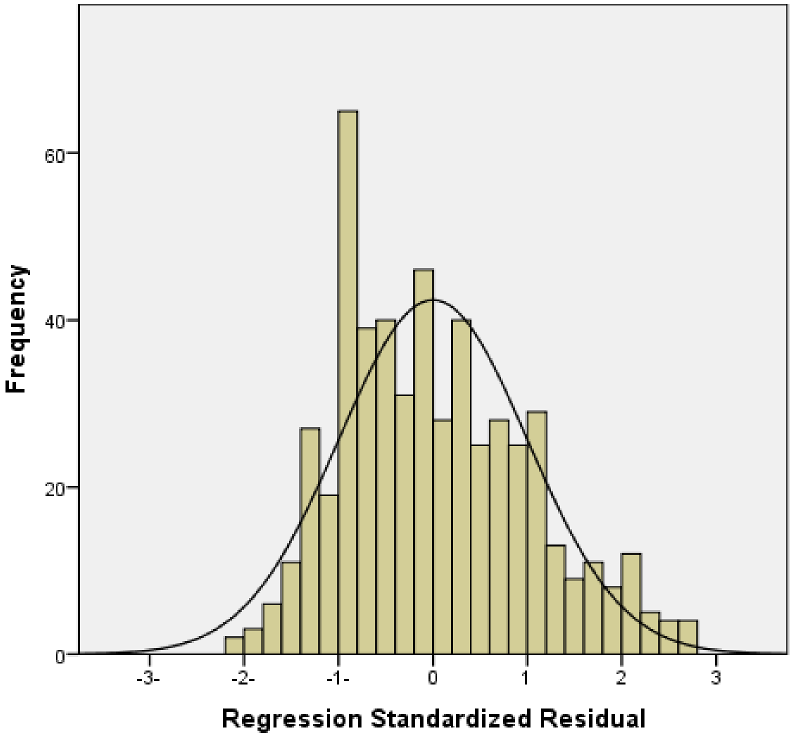


Figure FF-2: Histogram of the regression standardized residuals of population variables (IV) and odors (DV)

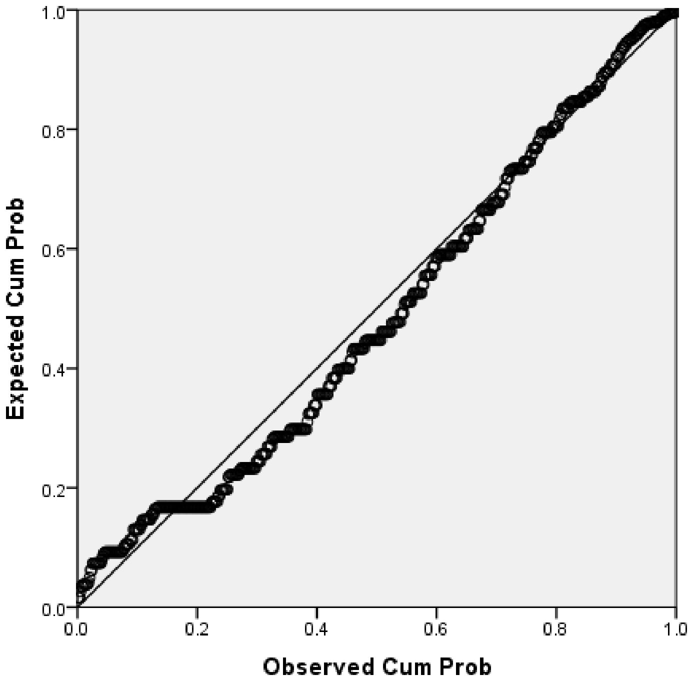


Figure FF-3: P-P plot of regression standardized residuals having population variables (IV) and odors (DV)

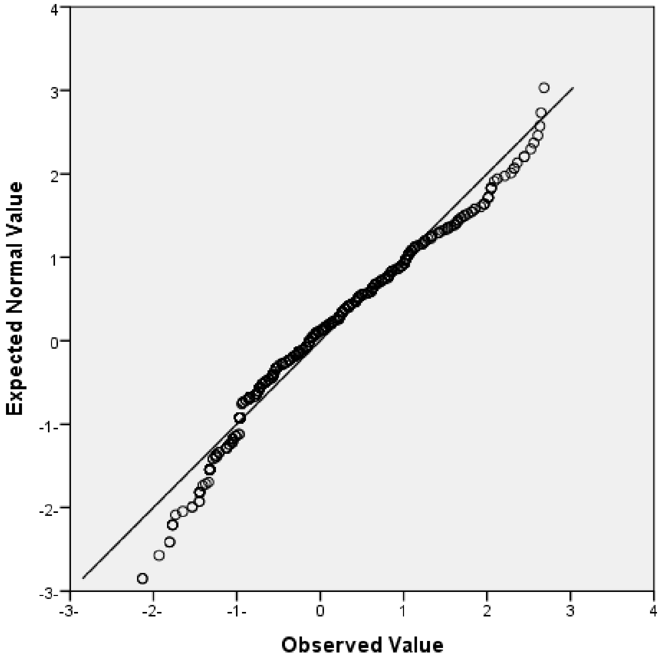
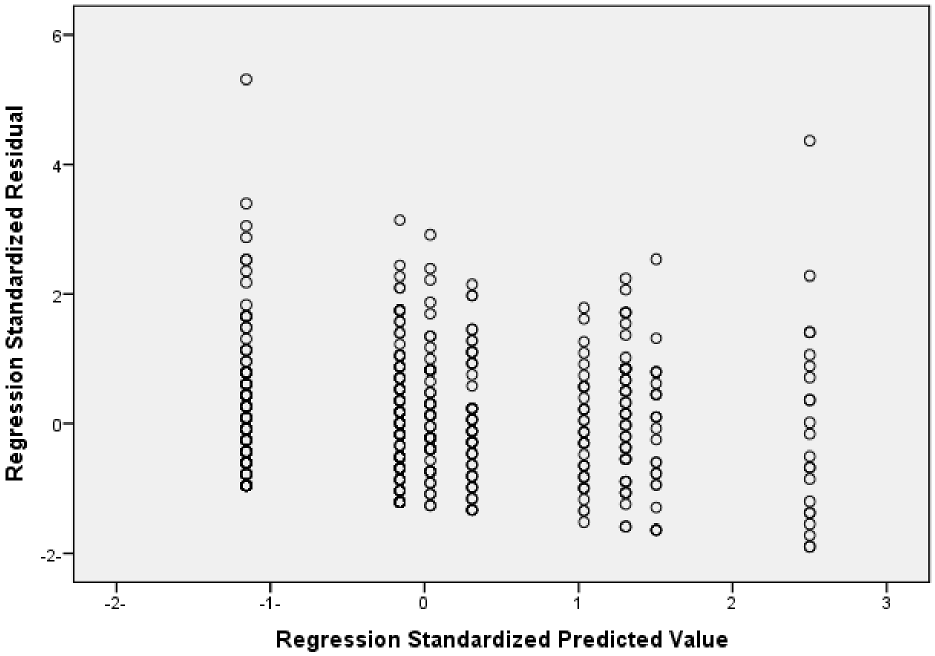


Figure FF-4: Q-Q plot of standardized residual having population variables (IV) and odors (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29 (Simonof 2017; Field 2016; Oyeyemi et al. 2015). A number of 13 data points of standardized residual values (Figure FF-5 (A)), were not following those criteria. According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 13 data points were deleted. Figure FF-5 (B) shows the scatter plots of regression standardized residuals and standardized predicted values before and after deleting outliers.
- Examining data points of high leverage in the initial regression model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=17 parameters and n=542 in the initial regression model, the cutoff value for 2p/n and 3p/n was 0.06 and 0.09; respectively. As shown in Figure FF-6 (A) and (B), all data points were following the below the cutoff value of 0.06. The highest leverage value in the final model was 0.012.
- Examining data points of high influence in the initial regression model followed the general cutoff value Cook's distance of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Plus 2004) as discussed in Section 3.4.3. No influential points were detected since the highest Cook's distance and DFBETAS were 0.025 and 0.208; respectively. Figure FF-7 (A) and (B) illustrates the Cook's distances for regression models before and after deleting unusual data points. Notably that the difference between Cook's distances are closer in (B) compared than (A) and no data point appears to be isolated from others.

(A)



(B)

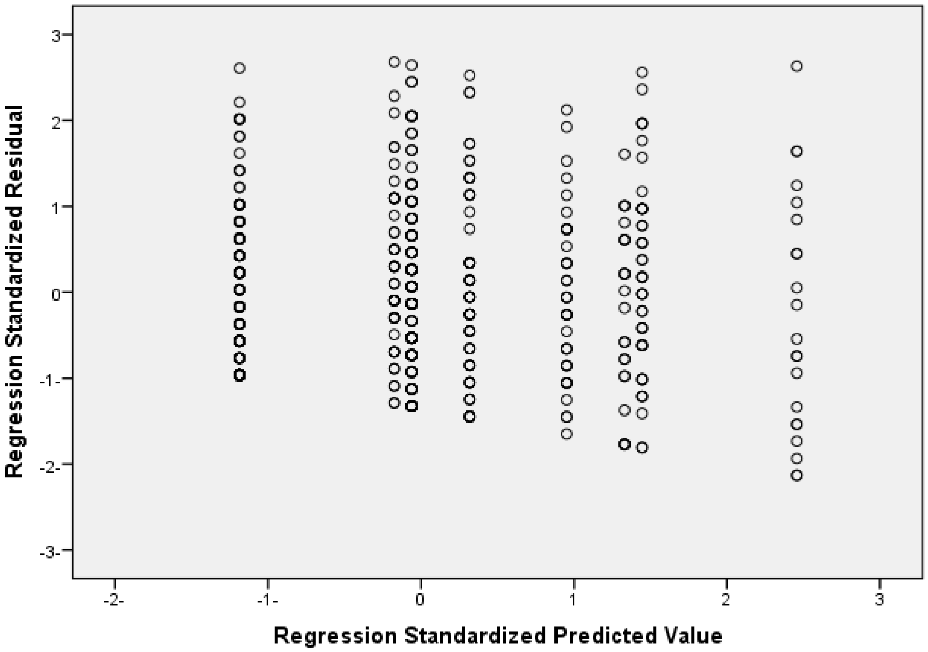
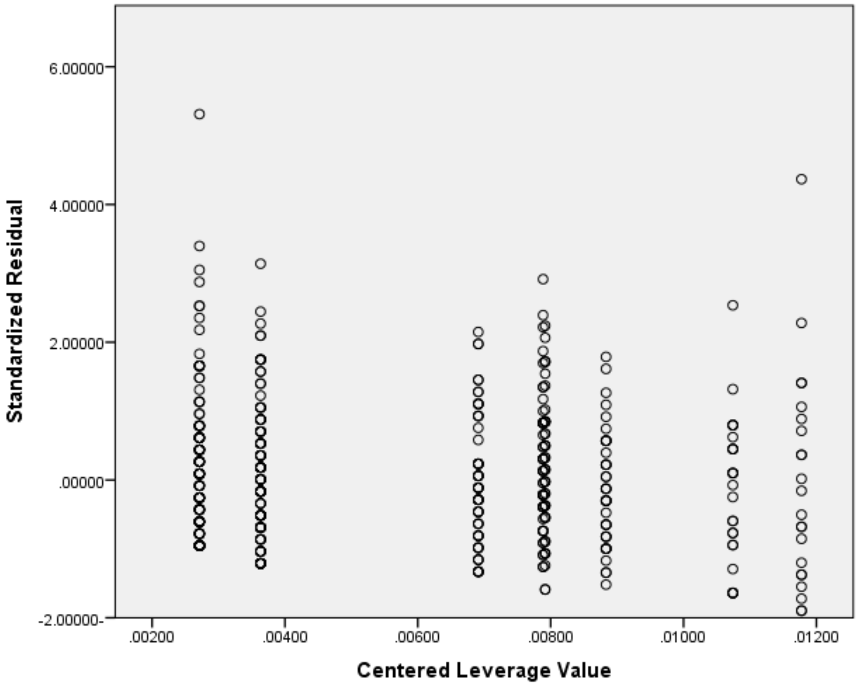


Figure FF-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values having population variables (IV) and odors (DV) before and after deleting unusual data points

(A)



(B)

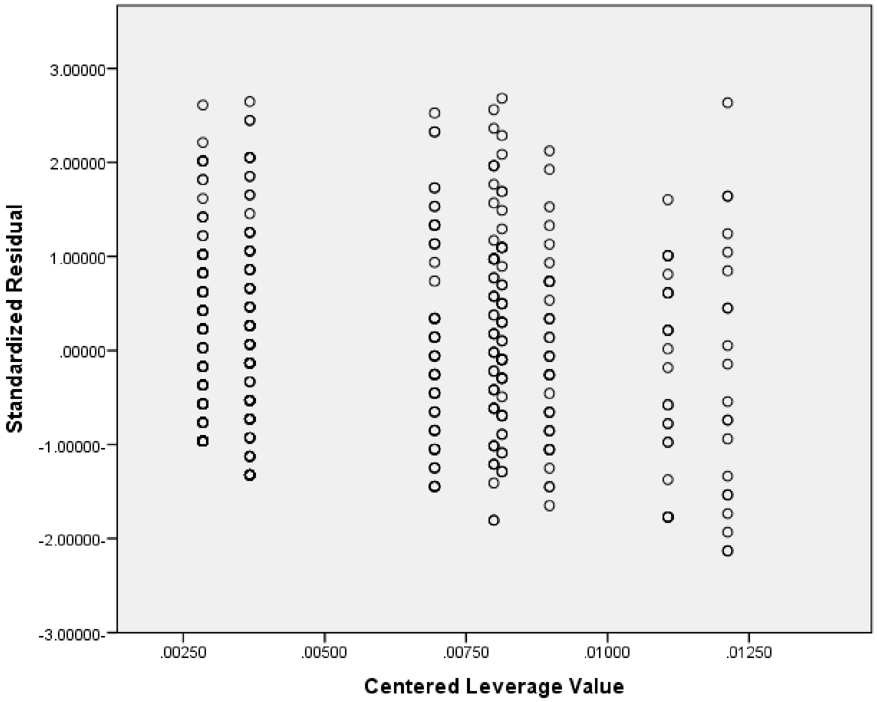
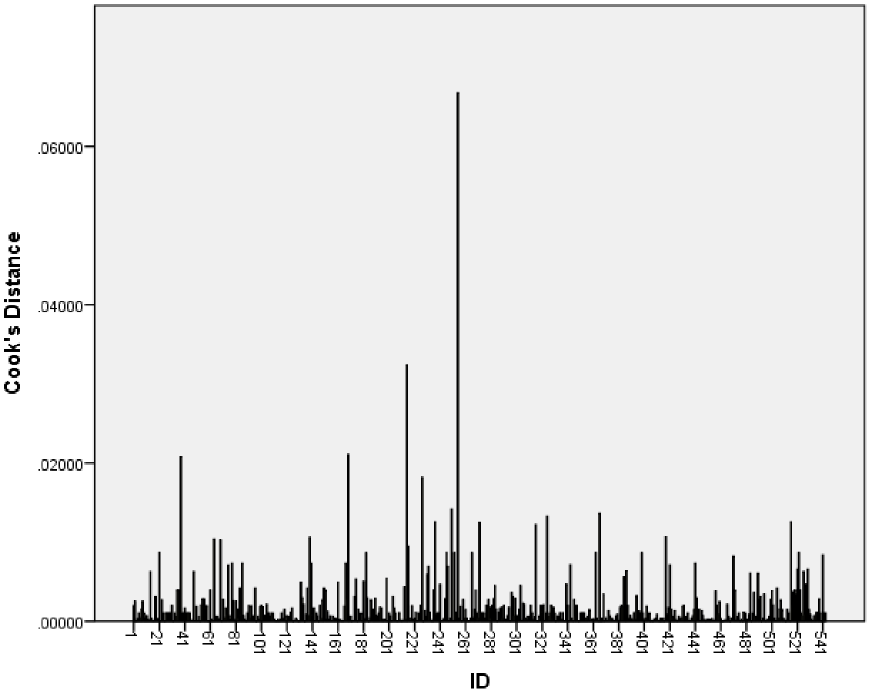


Figure FF-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values having population variables (IV) and odors (DV) before and after deleting unusual data points

(A)



(B)

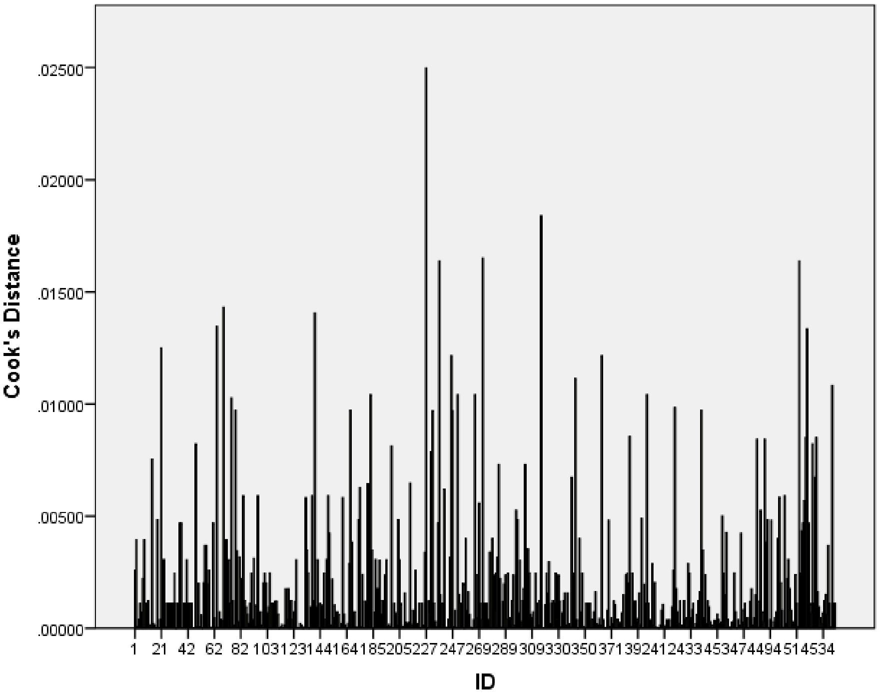


Figure FF-7: Bar charts (A) & (B) of Cook's distances for the regression model having population variables (IV) and odors (DV) before and after deleting unusual data points

# Appendix GG : Checking bias in the MLR model of building variables as (IV) on Eye, Nose, Throat, and Chest symptoms as (DV)

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure GG-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of vertical straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

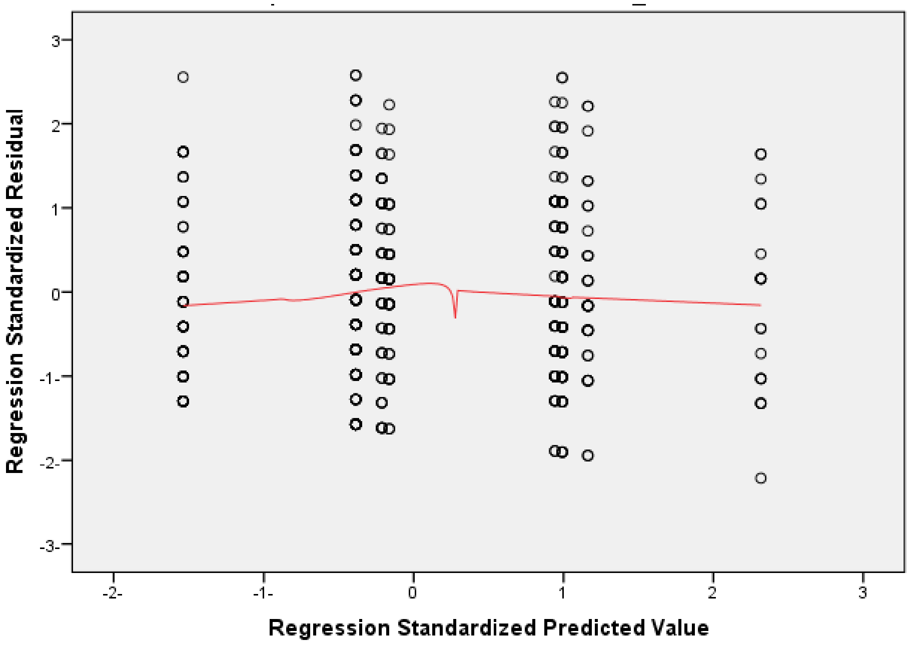


Figure GG-1: Scatter plot of regression standardized residuals and predicted values with building variables (IV) and the Eye, Nose, Throat, and Chest symptoms (DV)

- As shown in Figure GG-2, normal distribution of the residuals for the final regression model can be assumed since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013; Eberly College of Science 2018c). Also, as illustrated in Figure GG-3 and Figure GG-4; the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).
- No multicollinearity was detected for the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 2.18 (Field 2016; Ballance 2015; Ghani & Ahmad 2010).

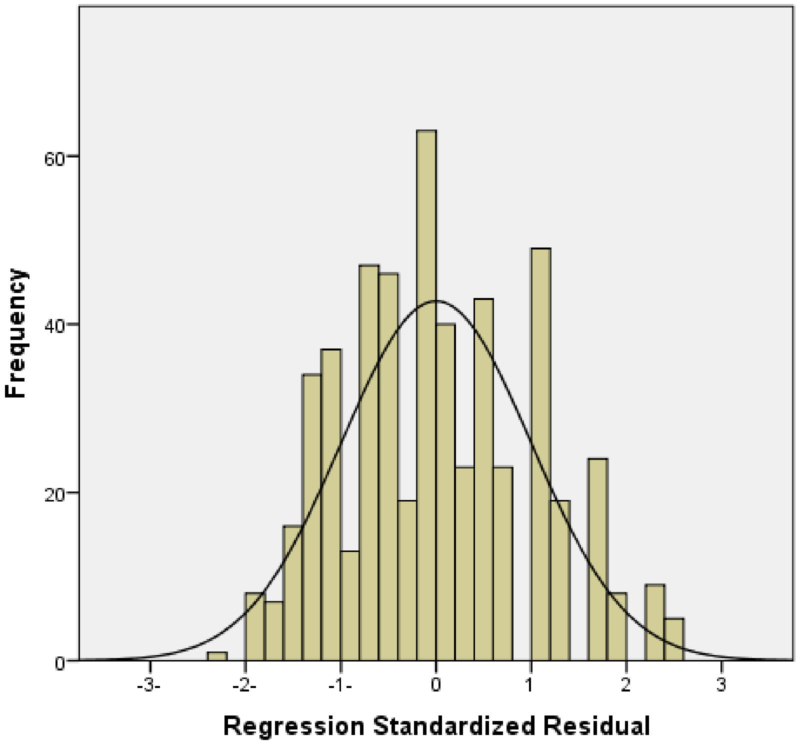


Figure GG-2: Histogram of the regression standardized residuals having building variables (IV) and the Eye, Nose, Throat, and Chest related symptoms (DV)

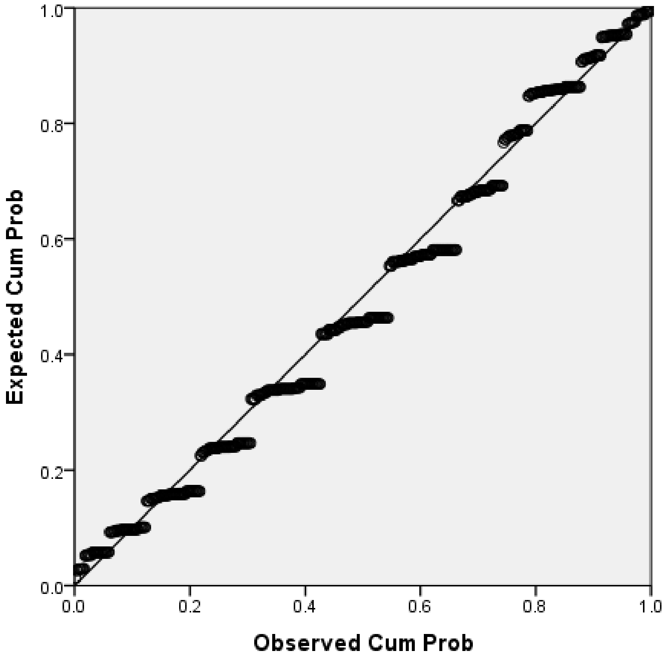


Figure GG-3: P-P plot of regression standardized residuals having building variables (IV) and the Eye, Nose, Throat, and Chest symptoms (DV)

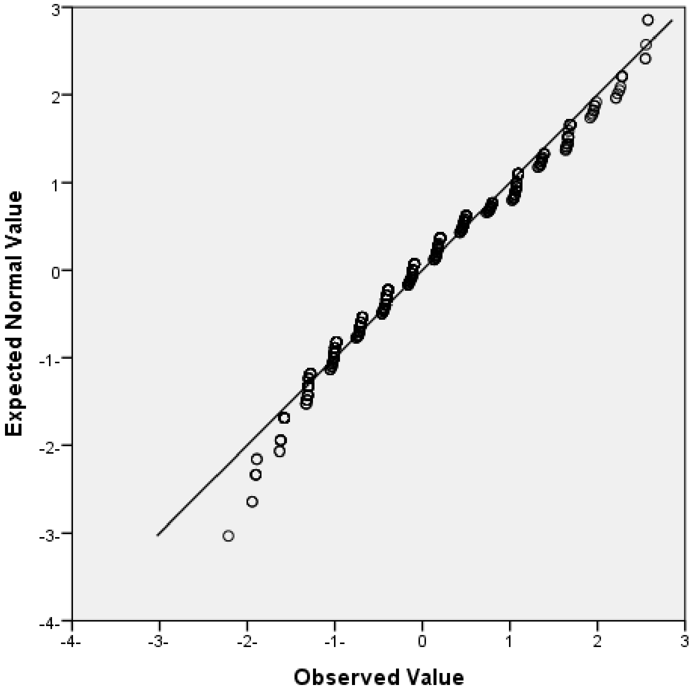
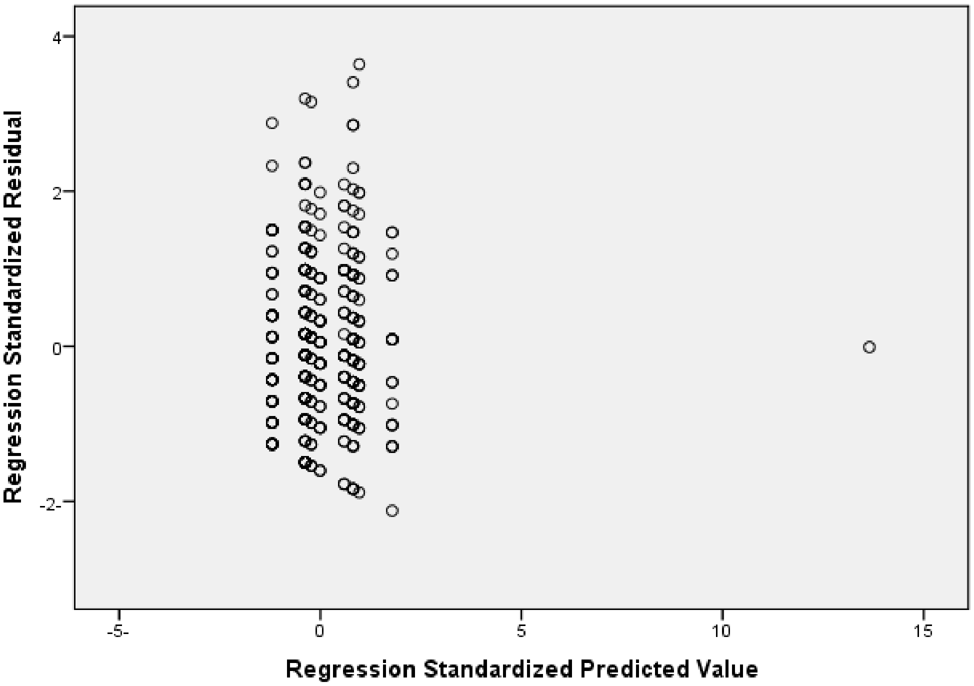


Figure GG-4: Q-Q plot of standardized residual having building variables (IV) and the Eye, Nose, Throat, and Chest related symptoms (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. A number of 7 data points of standardized residual values, shown on the top left corner of Figure GG-5 (A), were not following those criteria. According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 8 data points were deleted.
- Examining data points of high leverage in the initial regression model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=24 parameters and n=481 in the initial regression model, the cutoff value of 2p/n and 3p/n was 0.1 and 0.15; respectively. As shown in Figure GG-6 (A), one data point was obviously isolated from the majority of the observations with leverage value of 1. After deleting it, all other data points were close to each other and falls below the cutoff value with leverage value ≤ 0.012 (Figure GG-6 (B)). Figure GG-5 (B) shows scatter plots of regression standardized residuals and standardized predicted values after deleting the above described unusual data points.
- Examining data points of high influence in the initial regression model followed the general cutoff value Cook's distance of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Plus 2004) as discussed in Section 3.4.3. No influential points were detected since the highest Cook's distance and DFBETAS were 0.017 and 0.230; respectively. Figure GG-7 (A) and (B) illustrates the Cook's distances for regression models before and after deleting above described unusual data points. Notably that the difference between Cook's distances are closer in (B) compared than (A) and no data point appears to be isolated from others.

(A)



(B)

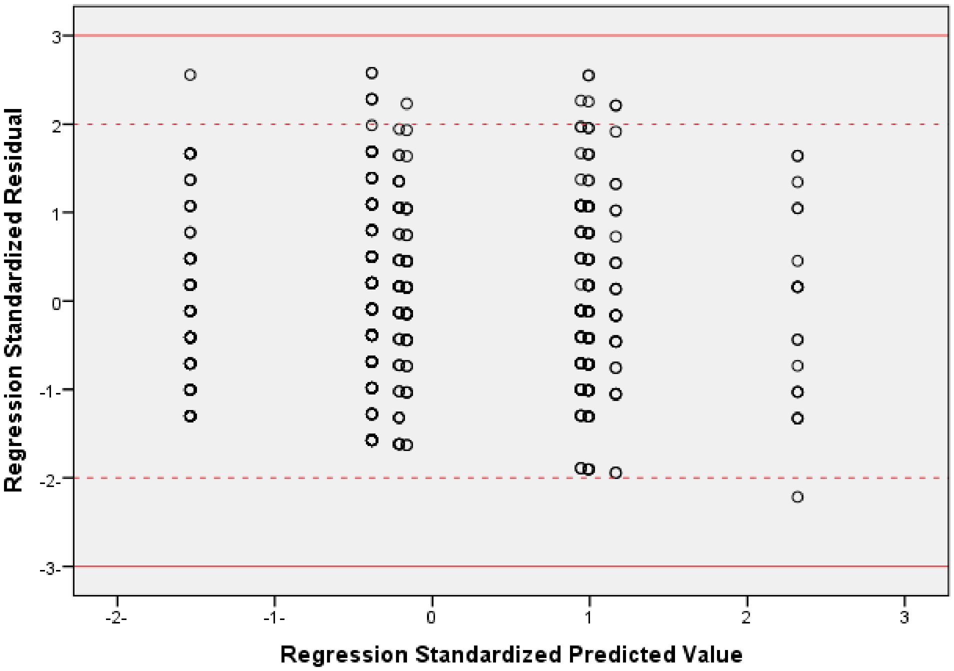
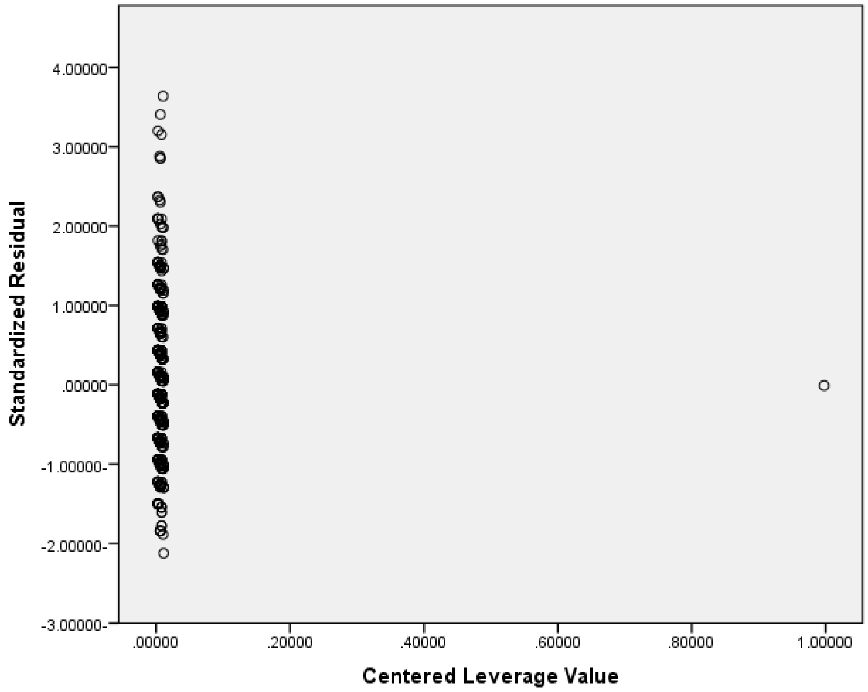


Figure GG-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values having building variables (IV) and the Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual data points

(A)



(B)

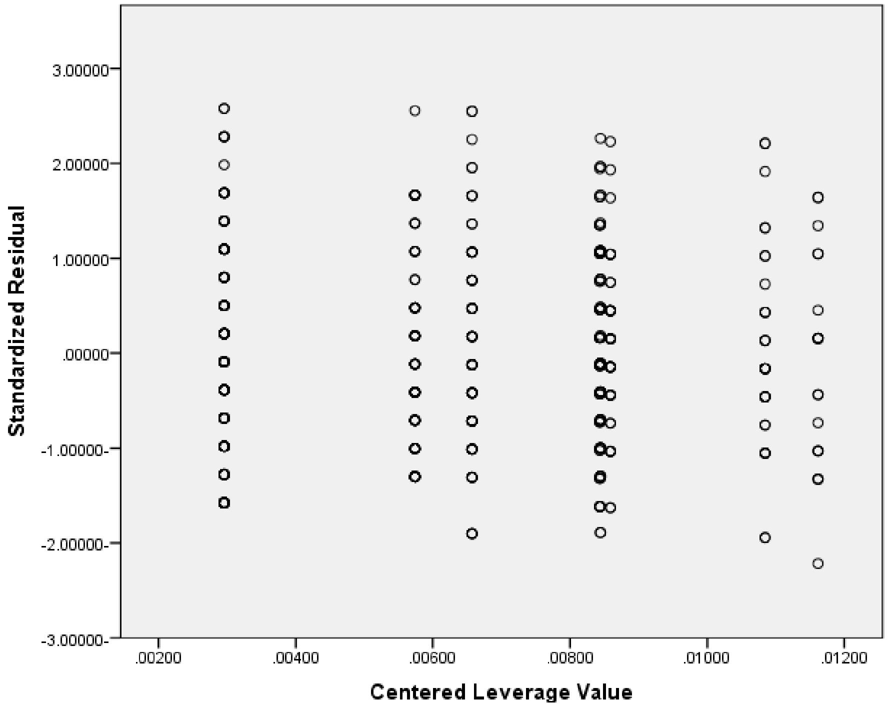


Figure GG-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values having building variables (IV) and the Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual data points

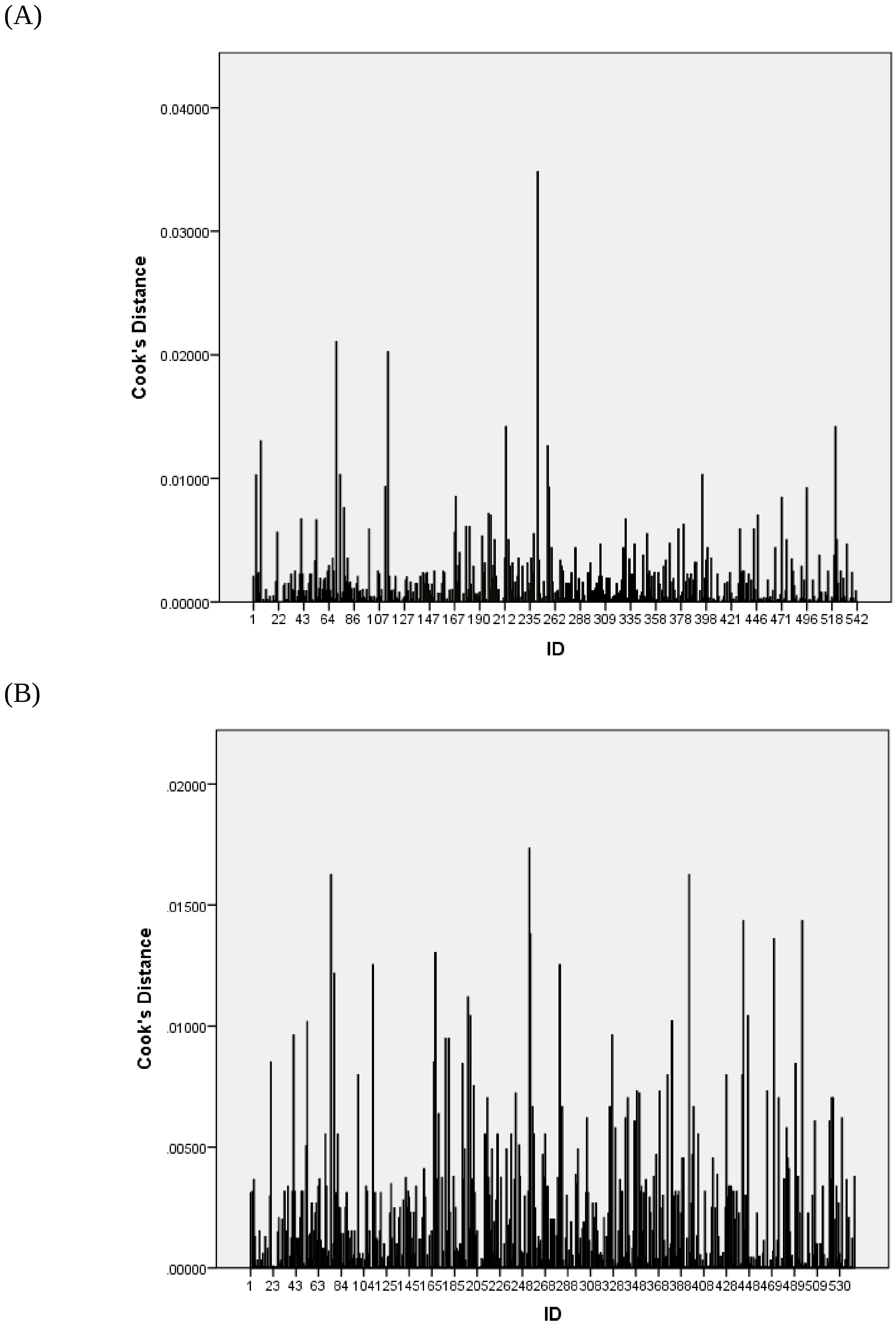


Figure GG-7: Bar charts (A) & (B) of Cook's distances for the regression model of building variables (IV) and the Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual data points

# Appendix HH : Checking bias in the MLR model of building variables (IV) on general, ergonomic, nervous & skin symptoms (DV)

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure HH-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of vertical straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

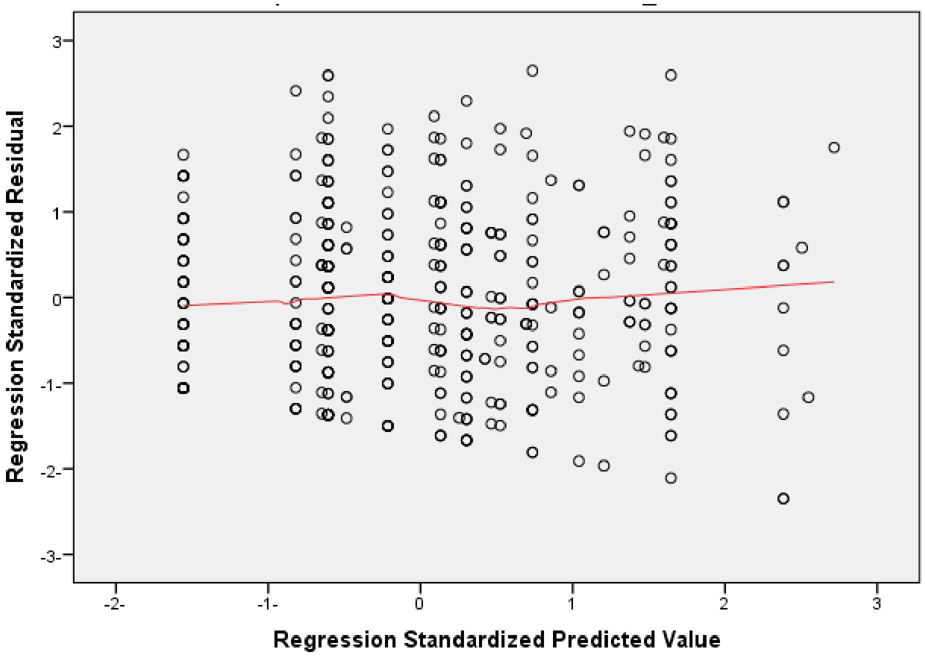


Figure HH-1: Scatter plot of regression standardized residuals and predicted values with building (IV) and the general, ergonomic, nervous & skin symptoms (DV)

- As shown in Figure HH-2, normal distribution of the residuals for the final regression model can be assumed since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013; Eberly College of Science 2018c). Also, as illustrated in Figure HH-3 and Figure HH-4; the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 2.40 (Field 2016; Ballance 2015; Ghani & Ahmad 2010).

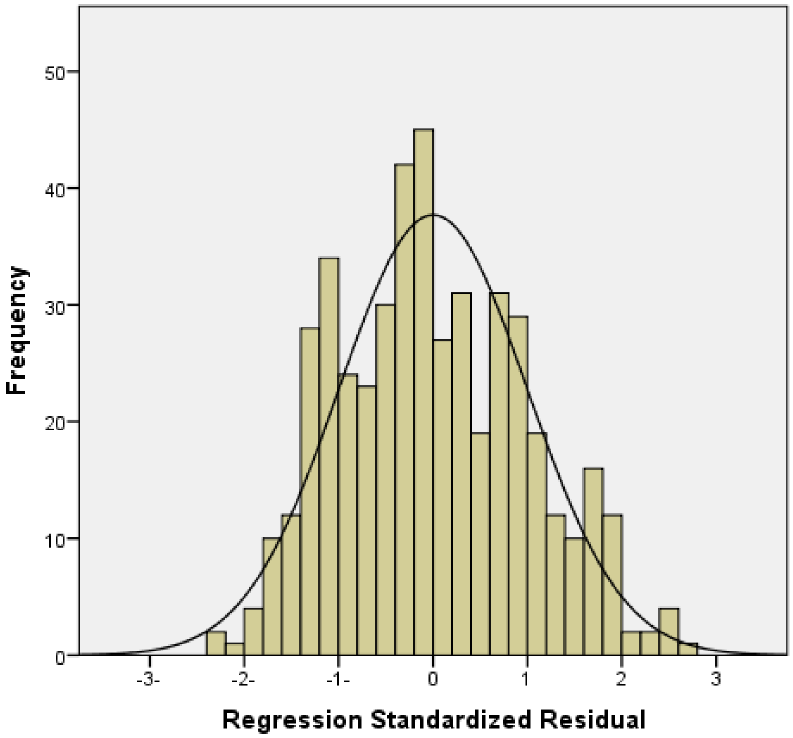


Figure HH-2: Histogram of the regression standardized residuals having building variables (IV) and general, ergonomic, nervous & skin symptoms (DV)

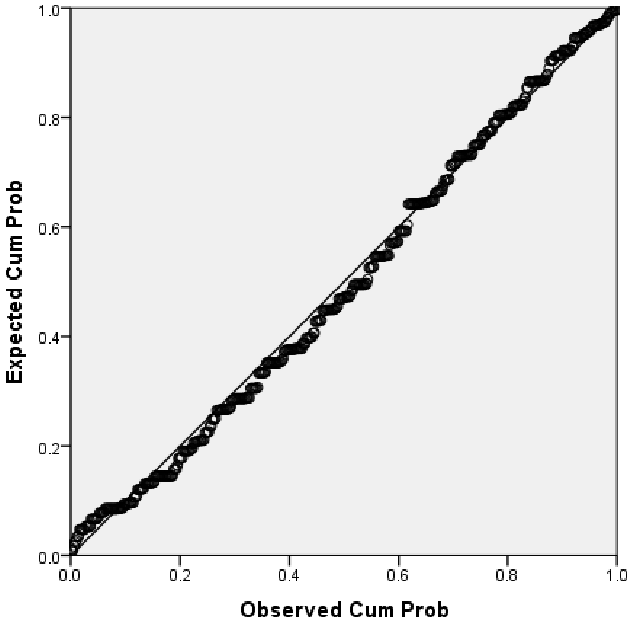


Figure HH-3: P-P plot of regression standardized residuals having building variables (IV) and the general, ergonomic, nervous & skin symptoms (DV)

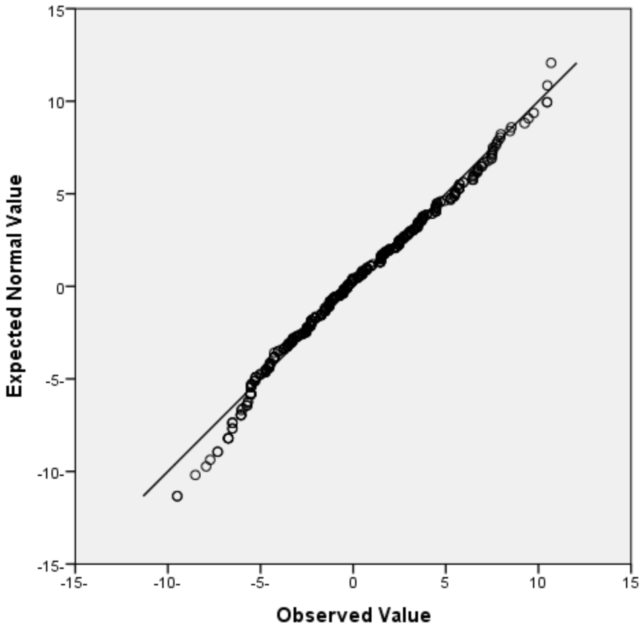
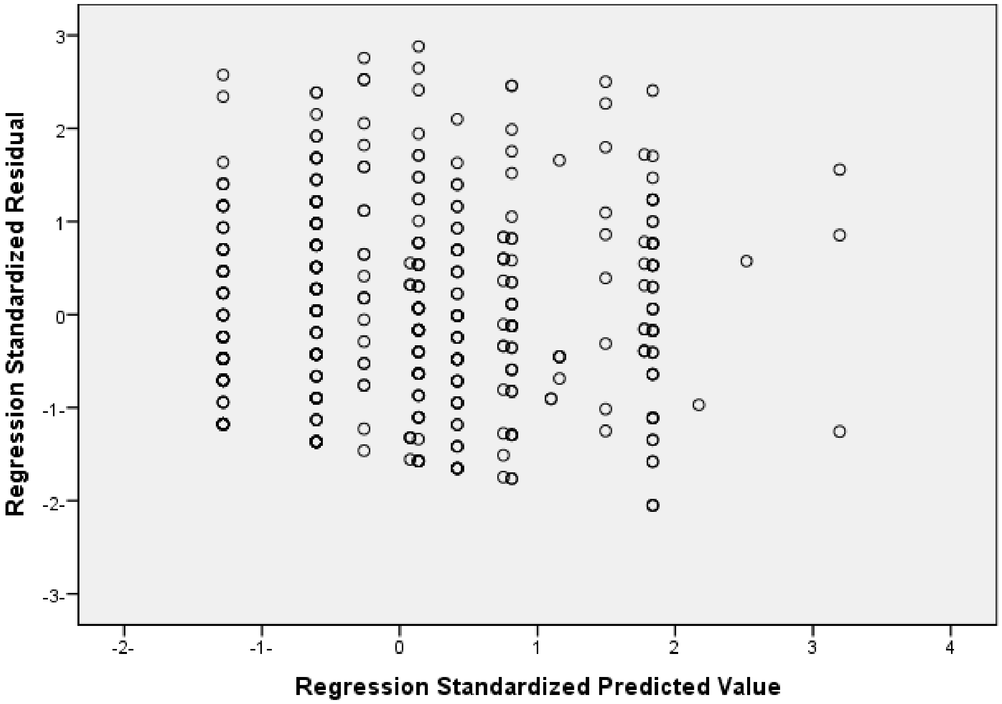


Figure HH-4: Q-Q plot of standardized residual having building variables (IV) and the Eye, nose, throat, and general, ergonomic, nervous & skin symptoms (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. A number of 12 data points of standardized residual values were not following those criteria (Figure HH-5 (A)). According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 12 data points were deleted. Figure HH-5 (B) shows scatter plots of regression standardized residuals and standardized predicted values after deleting the above described unusual data points.
- Examining data points of high leverage in the initial regression model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=24 parameters and n=481 in the initial regression model, the cutoff value of 2p/n and 3p/n was 0.1 and 0.15; respectively. As shown in Figure HH-6 (A), all data points were below the cutoff value of 0.1 in the initial model. The highest leverage value in the final model was ≤ 0.043 (Figure HH-6 (B)).
- Examining data points of high influence in the initial regression model followed the general cutoff value Cook's distance of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Plus 2004) as discussed in Section 3.4.3. No influential points were detected since the highest Cook's distance and DFBETAS were 0.024 and 0.301; respectively. Figure HH-7 (A) and (B) illustrates the Cook's distances for regression models before and after deleting above described unusual data points. Notably that the difference between Cook's distances are closer in (B) compared than (A) and no data point appears to be isolated from others.

(A)



(B)

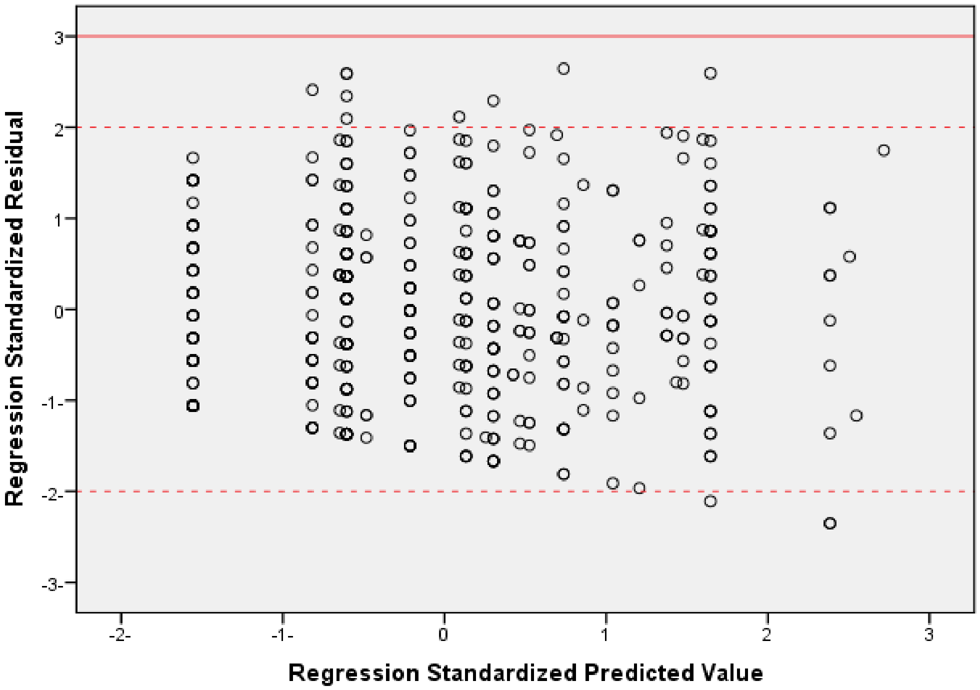
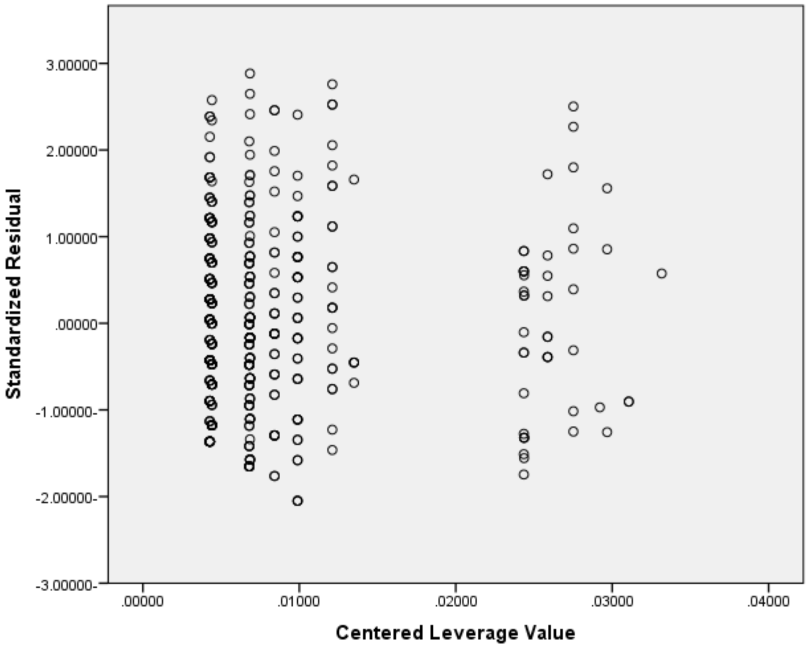


Figure HH-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values having building variables (IV) and the general, ergonomic, nervous & skin symptoms (DV) before and after deleting unusual data points

(A)



(B)

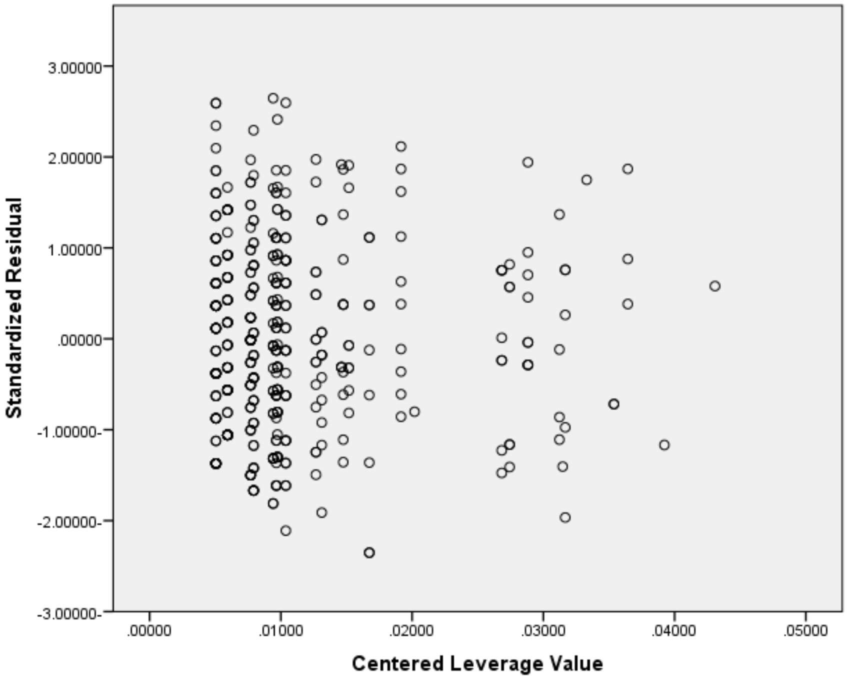
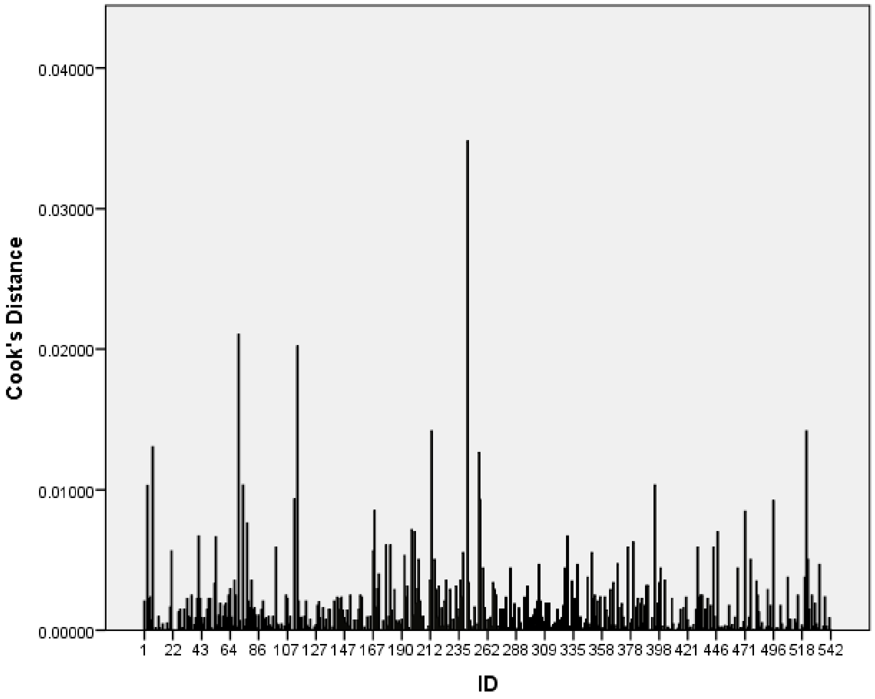


Figure HH-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values having building variables (IV) and the general, ergonomic, nervous & skin symptoms (DV) before and after deleting unusual data points

(A)



(B)

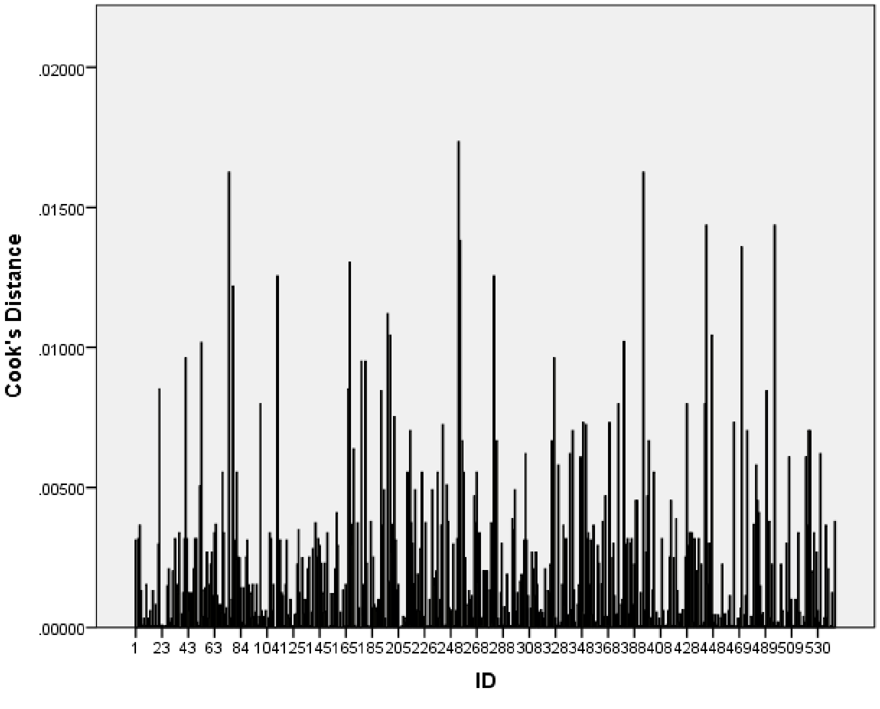


Figure HH-7: Bar charts (A) & (B) of Cook’s distances for the regression model of building variables (IV) and the general, ergonomic, nervous & skin symptoms (DV) before and after deleting unusual data points

# Appendix II : Checking bias in the MLR model of building variables (IV) on Thermal, Lighting, and Noise discomfort (DV)

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure II-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of vertical straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

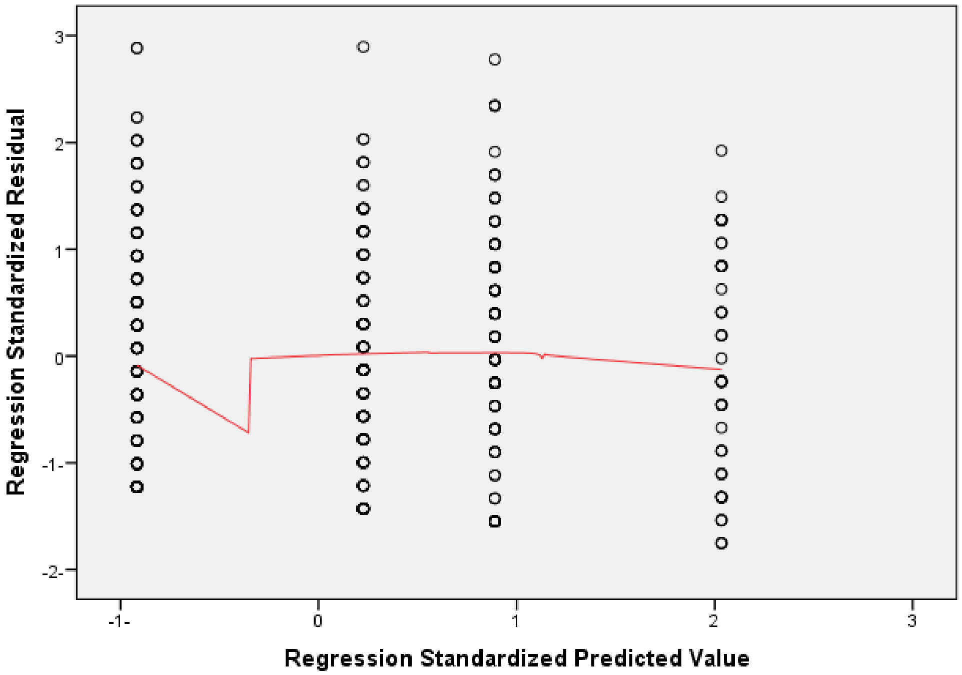


Figure II-1: Scatter plot of regression standardized residuals and predicted values with building (IV) and Thermal, Lighting, and Noise discomfort (DV)

- As shown in Figure II-2, the histogram of the standard residuals of the final regression model suggests that the distribution is a little skewed to the left (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013; Eberly College of Science 2018c). However, as illustrated in Figure II-3 and Figure II-4; the residuals in the P-P plots and the Q-Q plots were not significantly deviating from line. Reference to (Schmidt & Finan 2018; Mangiafico 2016; UCLA 2018) regression models with normality violations often still yield valid results particularly when having a large sample size of at least 10 observations for each predictor. That applies to this regression final model of 478 observations and included 24 variables meaning that each predictor has 19 observations. Reference to Schmidt & Finan (2018), this model estimators can be qualified as “Best linear unbiased estimators” or “BLUE” since the error can be assumed as independent, homoscedastic, and it had zero mean.
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 1.084 (Field 2016; Ballance 2015; Ghani & Ahmad 2010).

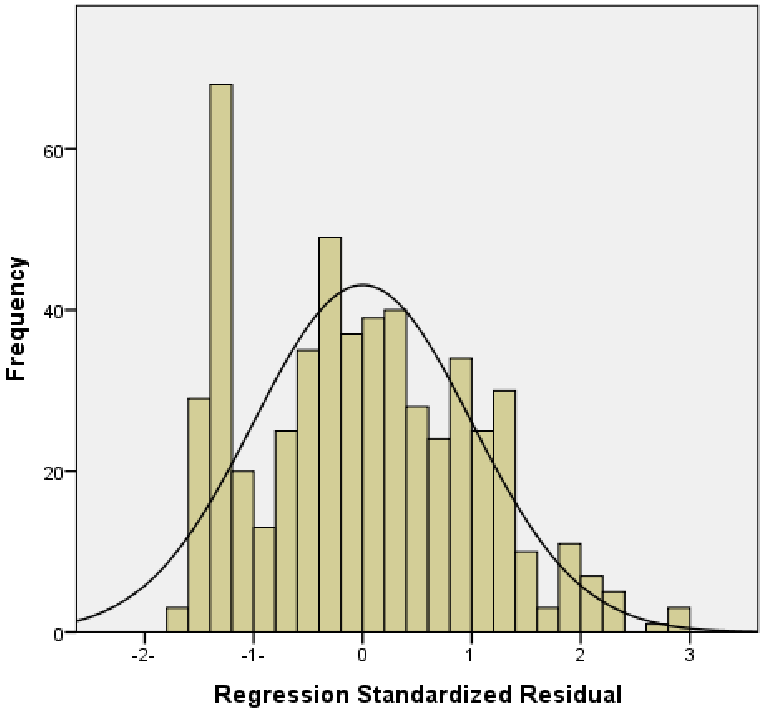


Figure II-2: Histogram of the regression standardized residuals having building variables (IV) and Thermal, Lighting, and Noise discomfort (DV)

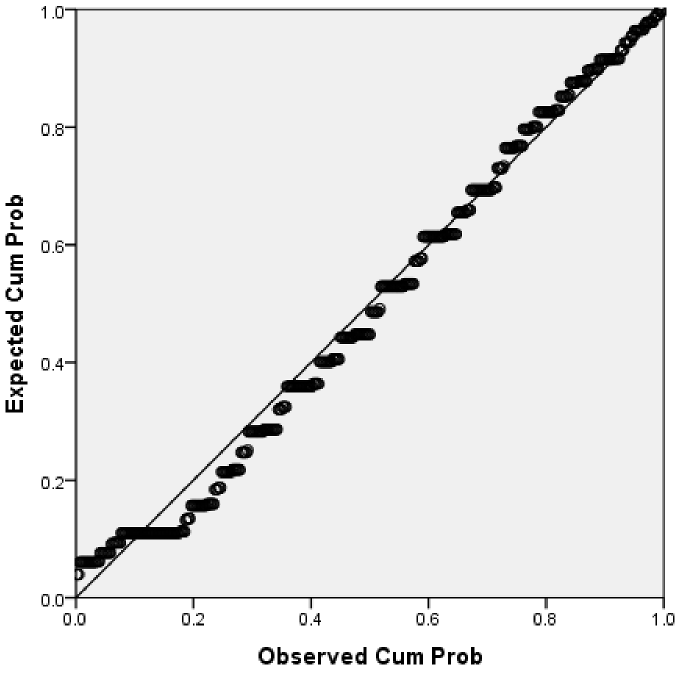


Figure II-3: P-P plot of regression standardized residuals having building variables (IV) and Thermal, Lighting, and Noise discomfort (DV)

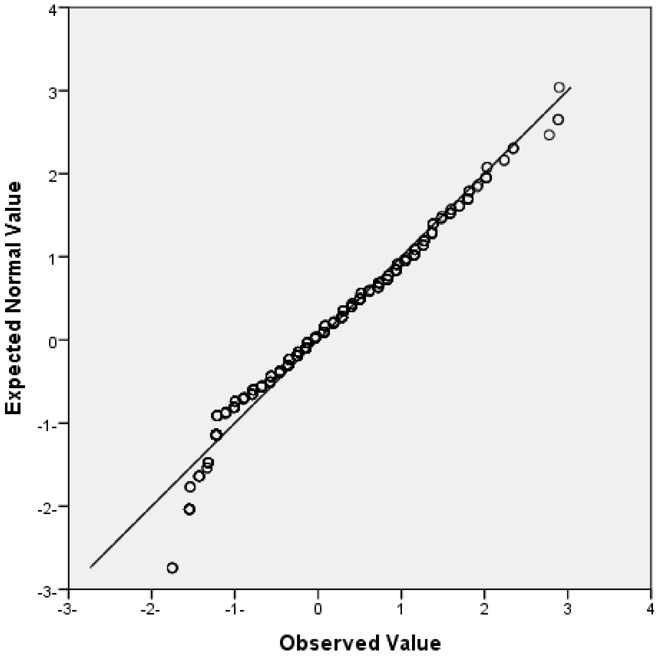
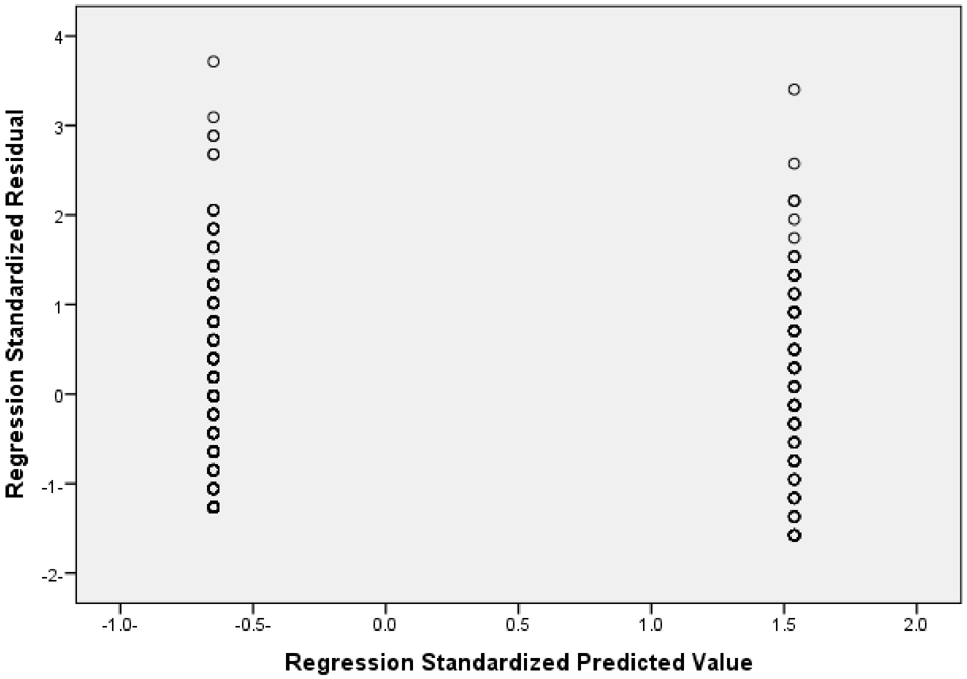


Figure II-4: Q-Q plot of standardized residual having building variables (IV) and the Eye, nose, throat, and Thermal, Lighting, and Noise discomfort (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. A number of 3 data points of standardized residual values were not following those criteria (Figure II-5 (A)). According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 3 data points were deleted. Figure II-5 (B) shows scatter plots of regression standardized residuals and standardized predicted values after deleting the above described unusual data points.
- Examining data points of high leverage in the initial regression model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=24 parameters and n=481 in the initial regression model, the cutoff value of 2p/n and 3p/n was 0.1 and 0.15; respectively. As shown in Figure II-6 (A), all data points were below the cutoff value of 0.1. The highest leverage value in the final model was ≤ 0.009 (Figure II-6 (B)).
- Examining data points of high influence in the initial regression model followed the general cutoff value Cook’s distance of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Plus 2004) as discussed in Section 3.4.3. No influential points were detected since the highest Cook’s distance and DFBETAS were 0.021 and 0.201; respectively. Figure II-7 (A) and (B) illustrates the Cook’s distances for regression models before and after deleting above described unusual data points. Notably that the difference between Cook’s distances are closer in (B) compared than (A) and no data point appears to be isolated from others.

(A)



(B)

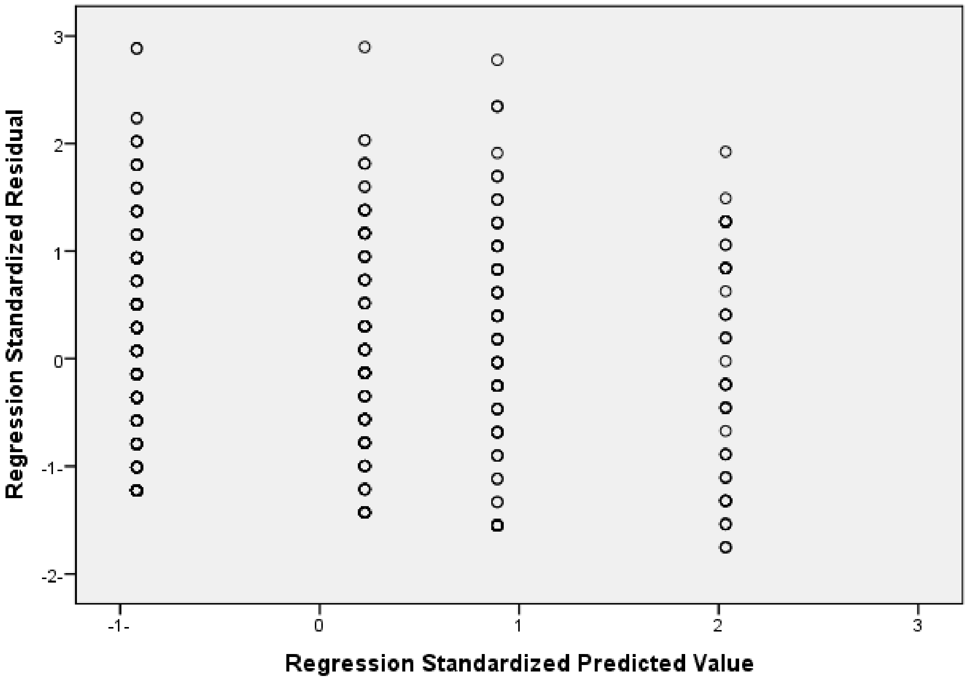
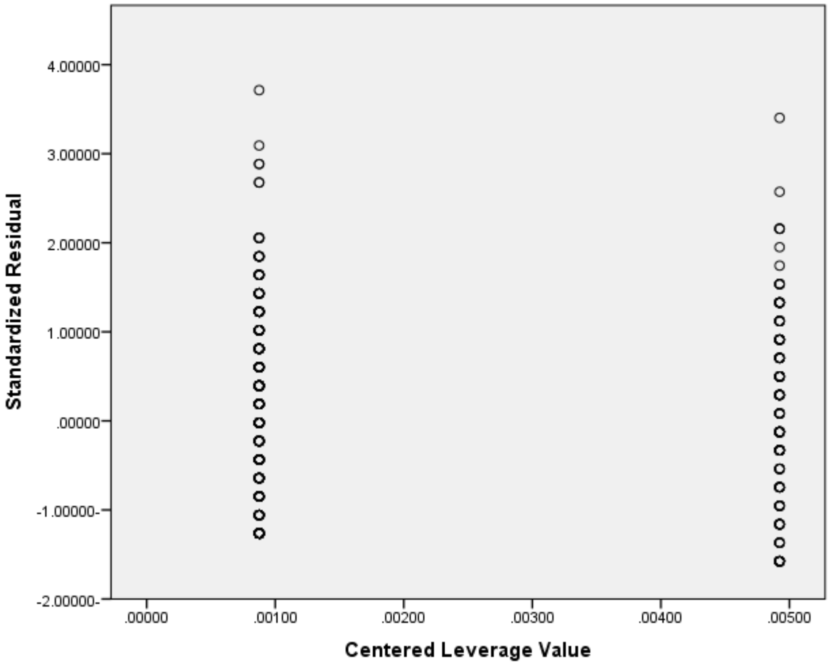


Figure II-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values having building variables (IV) and Thermal, Lighting, and Noise discomfort (DV) before and after deleting unusual data points

(A)



(B)

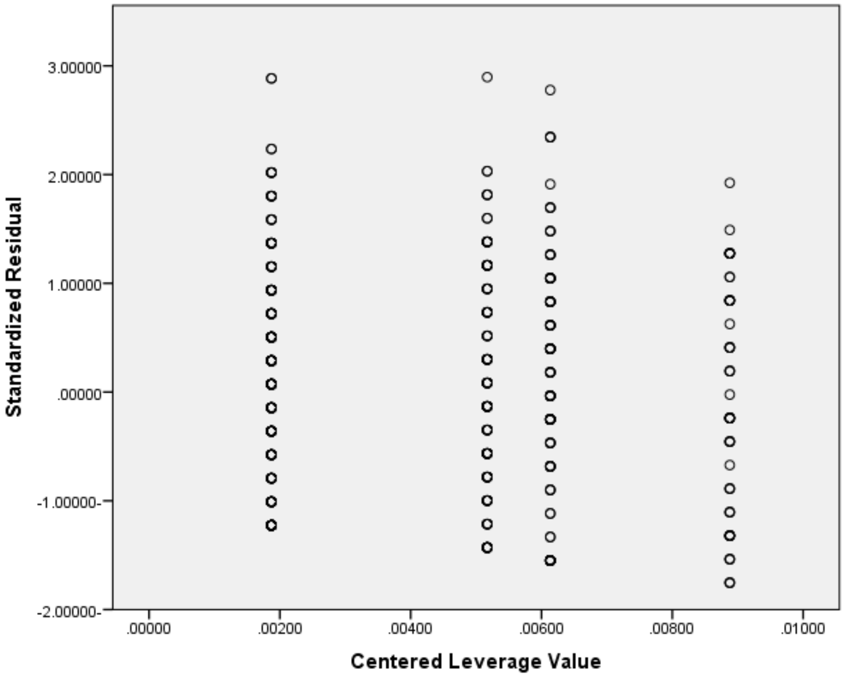


Figure II-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values having building variables (IV) and Thermal, Lighting, and Noise discomfort (DV) before and after deleting unusual data points

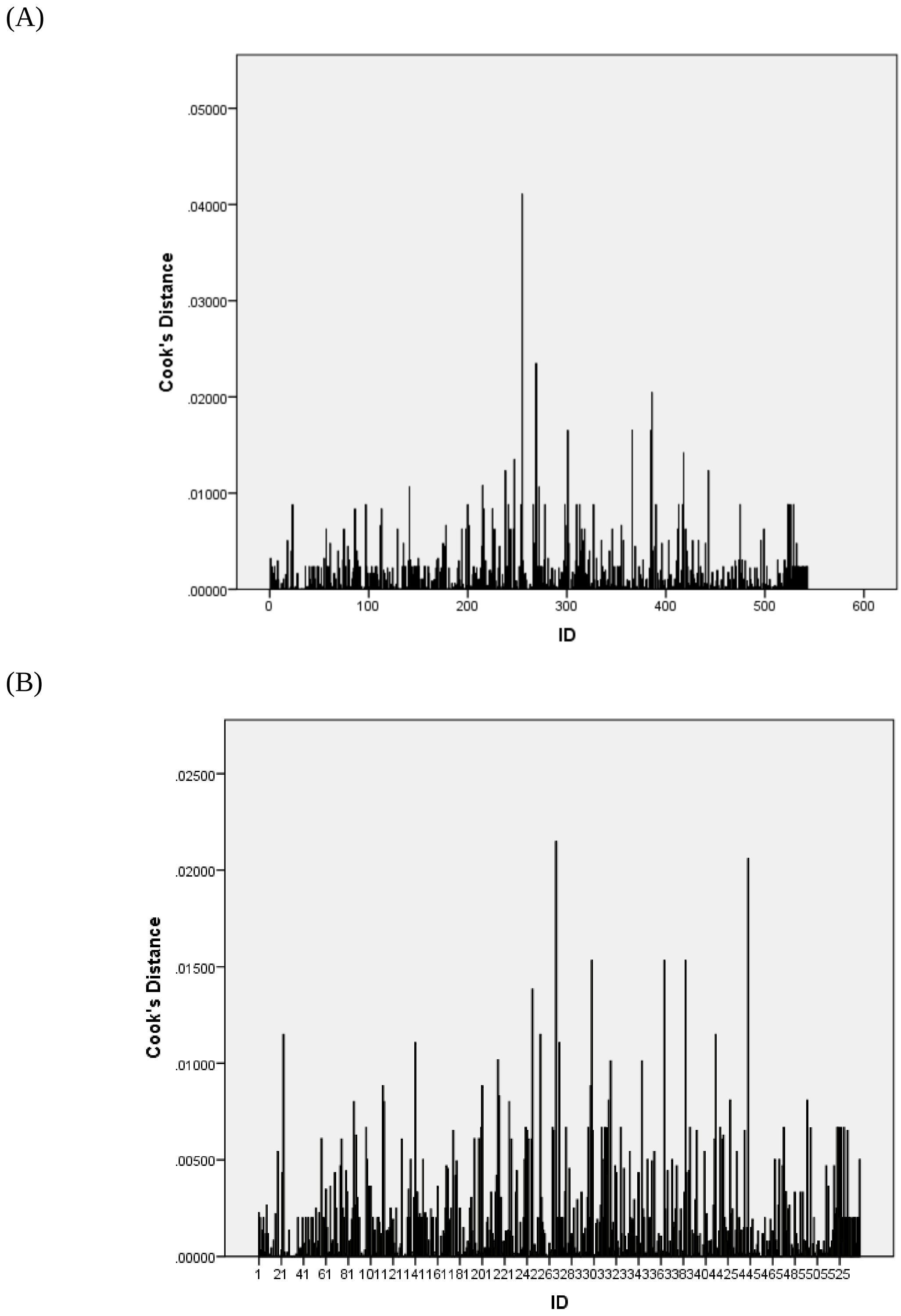


Figure II-7: Bar charts (A) & (B) of Cook's distances for the regression model of building variables (IV) and Thermal, Lighting, and Noise discomfort (DV) before and after deleting unusual data points

# Appendix JJ : Checking bias in the MLR model of building variables (IV) on IAQ discomfort (DV)

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure JJ-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of vertical straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

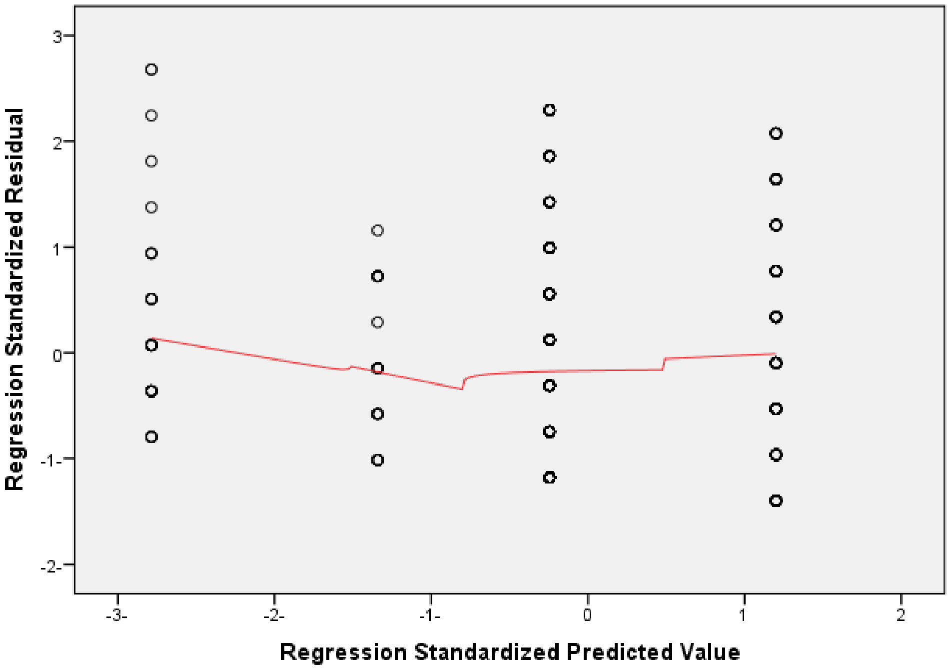


Figure JJ-1: Scatter plot of regression standardized residuals and predicted values with building (IV) and IAQ discomfort (DV)

- As shown in Figure JJ-2, the histogram of the standard residuals of the final regression model suggests that the distribution is a little bit skewed to the left (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013; Eberly College of Science 2018c). However, as illustrated in Figure JJ-3 and Figure JJ-4; the residuals in the P-P plots and the Q-Q plots were not significantly deviating from line. Reference to (Schmidt & Finan 2018; Mangiafico 2016; UCLA 2018); regression models with normality violations often still yield valid results particularly when having a large sample size of at least 10 observations for each predictor. That applies to this regression final model of 481 observations and included 24 variables meaning that each predictor has 20 observations. Reference to Schmidt & Finan (2018), this model estimators can be qualified as "Best linear unbiased estimators" or "BLUE" since the error can be assumed as independent, homoscedastic, and it had zero mean.
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 1.219 (Field 2016; Ballance 2015; Ghani & Ahmad 2010).

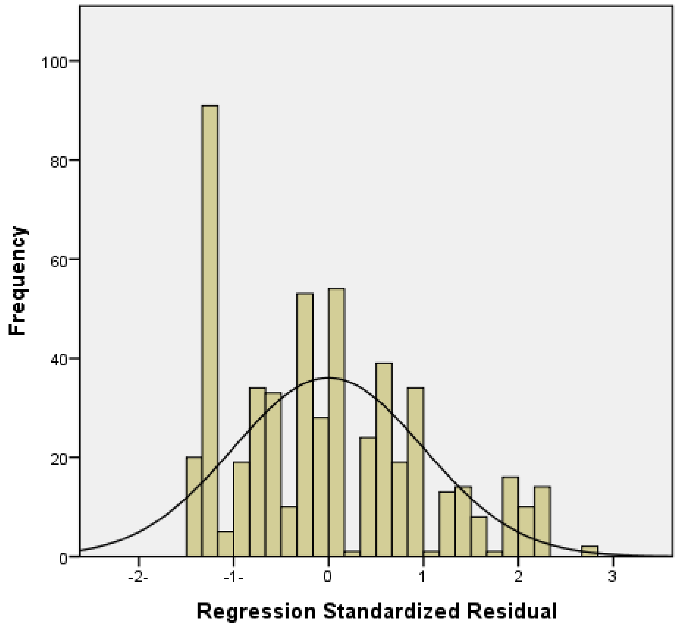


Figure JJ-2: Histogram of the regression standardized residuals having building variables (IV) and IAQ discomfort (DV)

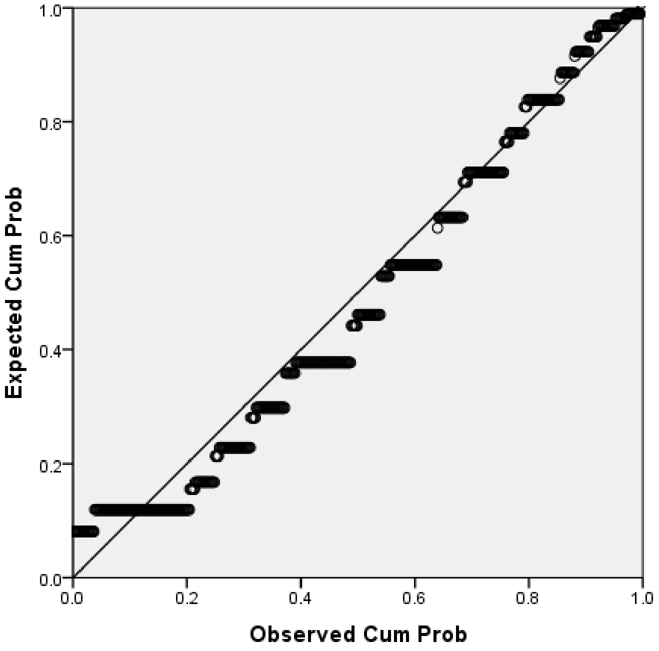


Figure JJ-3: P-P plot of regression standardized residuals having building variables (IV) and IAQ discomfort (DV)

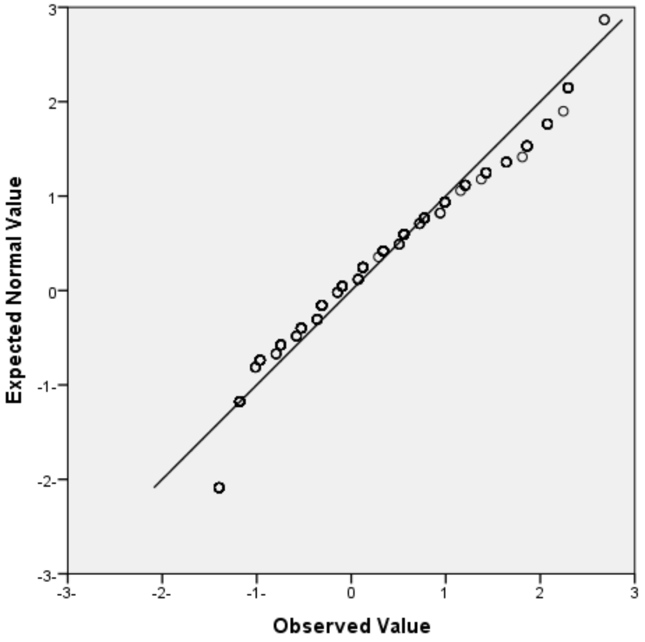


Figure JJ-4: Q-Q plot of standardized residual having building variables (IV) and IAQ discomfort (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. The standardized residual values of all data points were following those criteria (Figure JJ-5). According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); following those criteria is an evidence of having an acceptable error, correct variable estimation, unbiased results, and that the model is a good fit of the sample data.

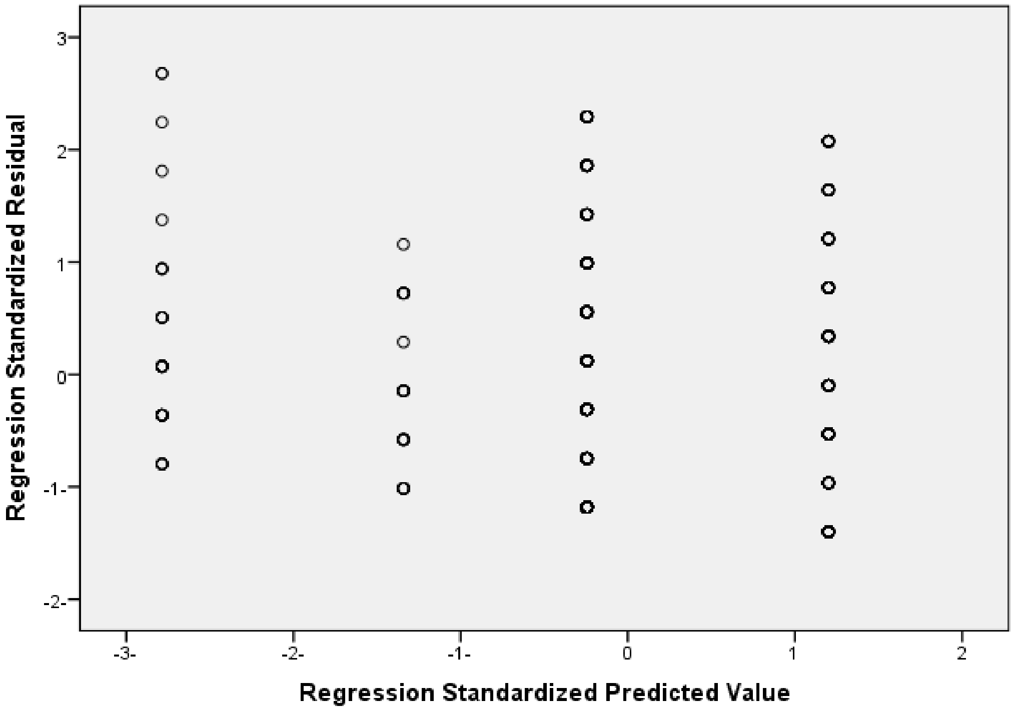


Figure JJ-5: Scatter plots of regression standardized residuals and standardized predicted values having building variables (IV) and IAQ discomfort (DV)

- Examining data points of high leverage in the initial regression model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=24 parameters and n=481 in the initial regression model, the cutoff value of 2p/n and 3p/n was 0.1 and 0.15; respectively. As shown in Figure JJ-6, all data points were below 2p/n cutoff values with leverage ≤ 0.022.

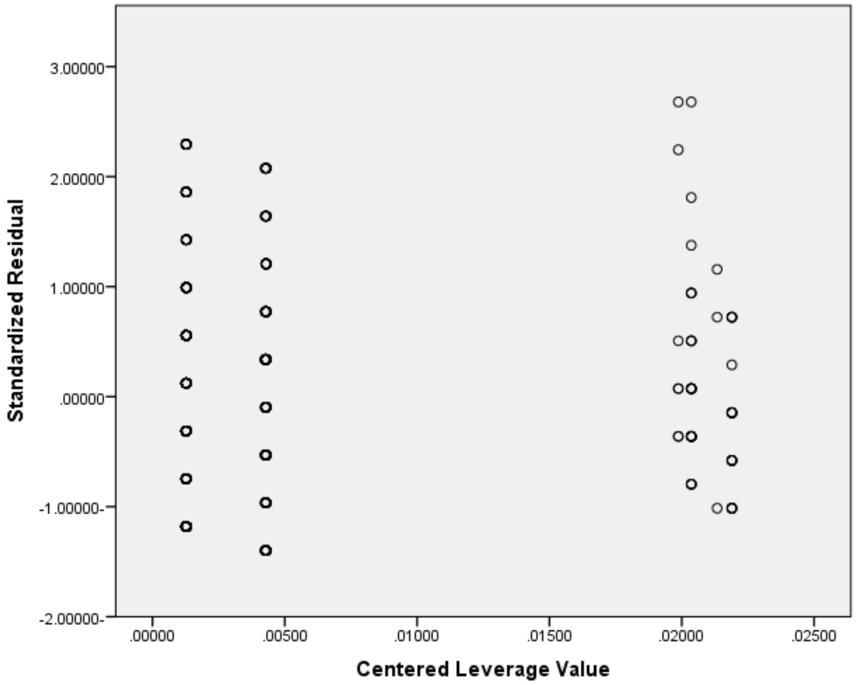


Figure JJ-6: Scatter plots of regression standardized residuals and centered leverage values having building variables (IV) and IAQ discomfort (DV)

- Examining data points of high influence in the initial regression model followed the general cutoff value Cook's distance of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Plus 2004) as discussed in Section 3.4.3. No influential points were detected in the final regression model since the highest Cook's distance and DFBETAS were 0.056 and 0.382; respectively. Figure JJ-7 illustrates the Cook's distances for regression model. Notably that the values of the highest Cook's distances in the figure were 0.05 and 0.04. Although they are below the cutoff value of 1, a trial was performed to assess their influence on the results. No change in the two predictors and their significance. A very slight change occurred in $R^2$, adjusted $R^2$, and the *SE* of estimates of about .005, .005, and .016; respectively. Hence, although the two points seems dominant in Figure  JJ-7, their deletion might slightly change the results.

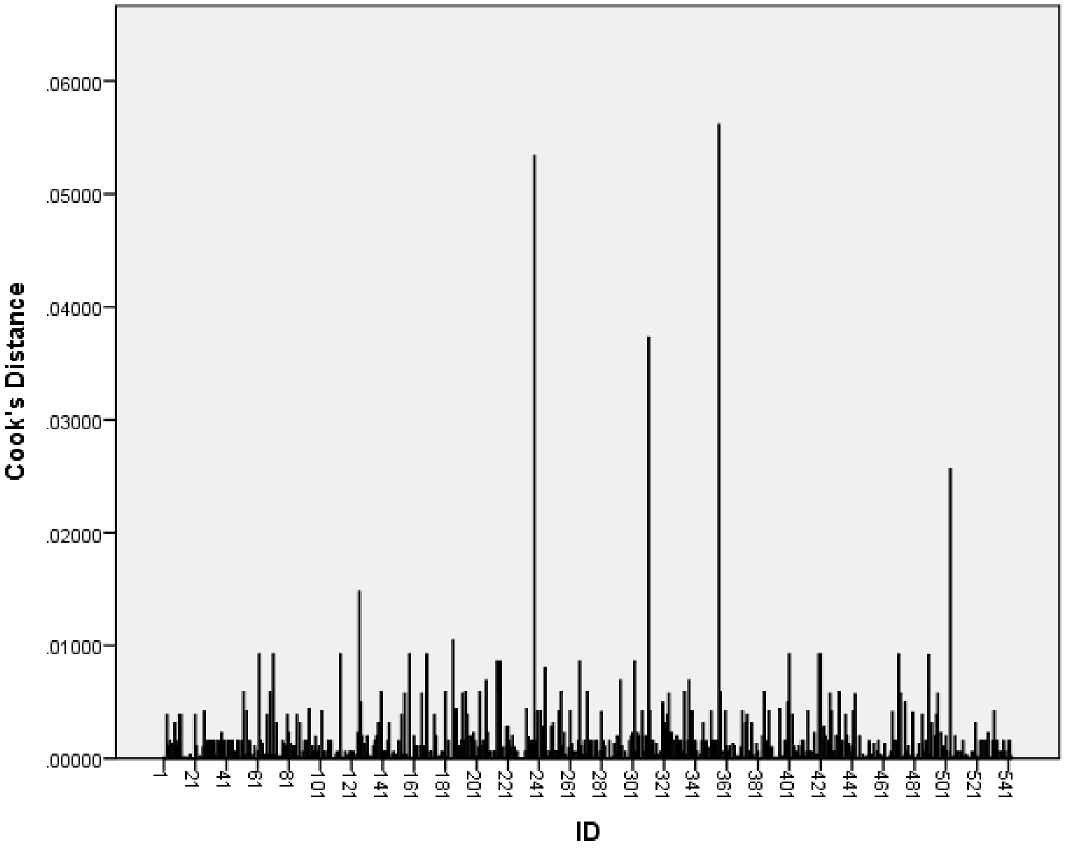


Figure  JJ-7: Bar charts of Cook's distances for the regression model of building variables (IV) and IAQ discomfort (DV)

# Appendix KK : Checking bias in the MLR model of building variables (IV) on odors (DV)

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure KK-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of vertical straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

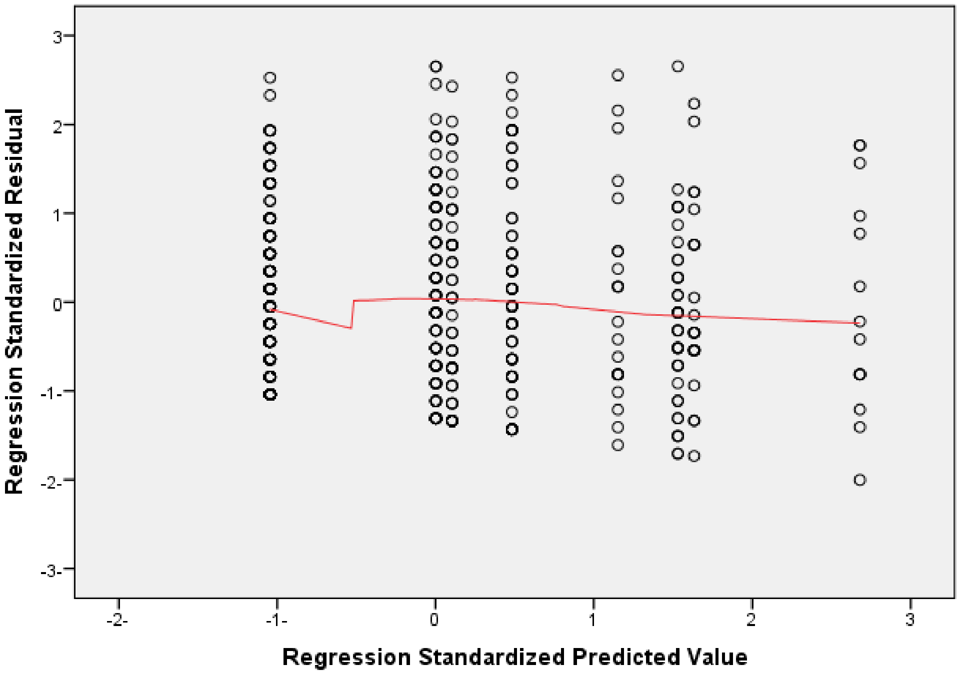


Figure KK-1: Scatter plot of regression standardized residuals and predicted values with building variables (IV) and odors (DV)

- As shown in Figure KK-2, normal distribution of the residuals can be assumed for the final regression model since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013; Eberly College of Science 2018c). Also, as illustrated in Figure KK-3 and Figure KK-4; the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 2.402 (Field 2016;, Ballance 2015; Ghani & Ahmad 2010).

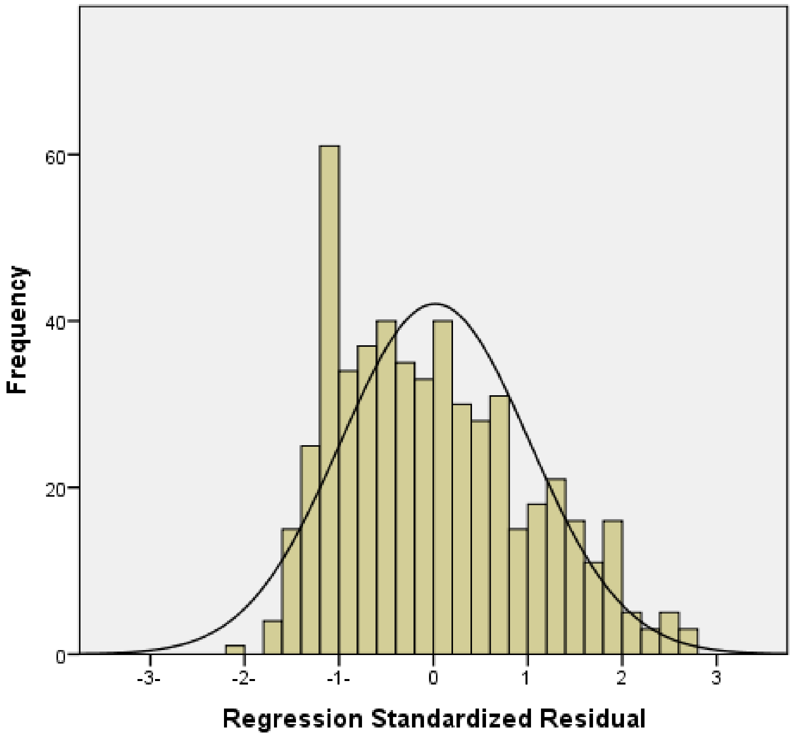


Figure KK-2: Histogram of the regression standardized residuals having building variables (IV) and odors (DV)

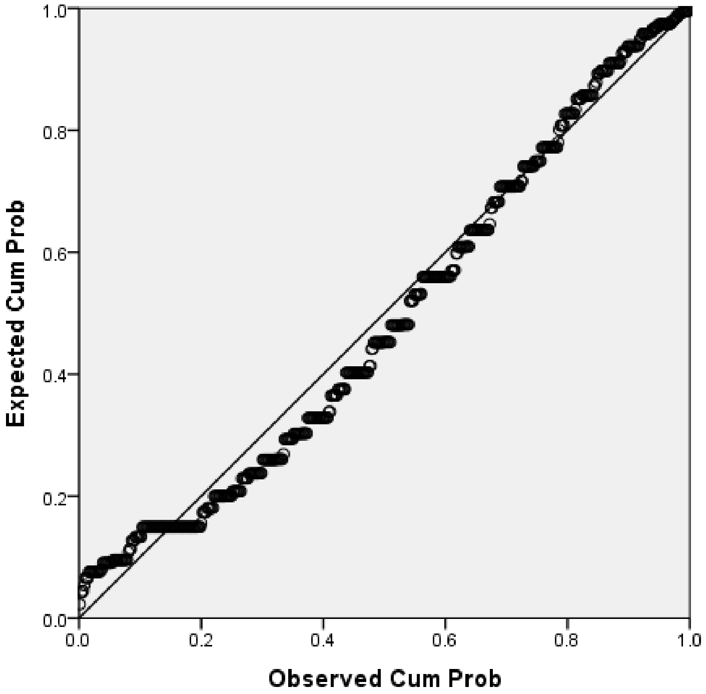


Figure KK-3: P-P plot of regression standardized residuals having building variables (IV) and odors (DV)

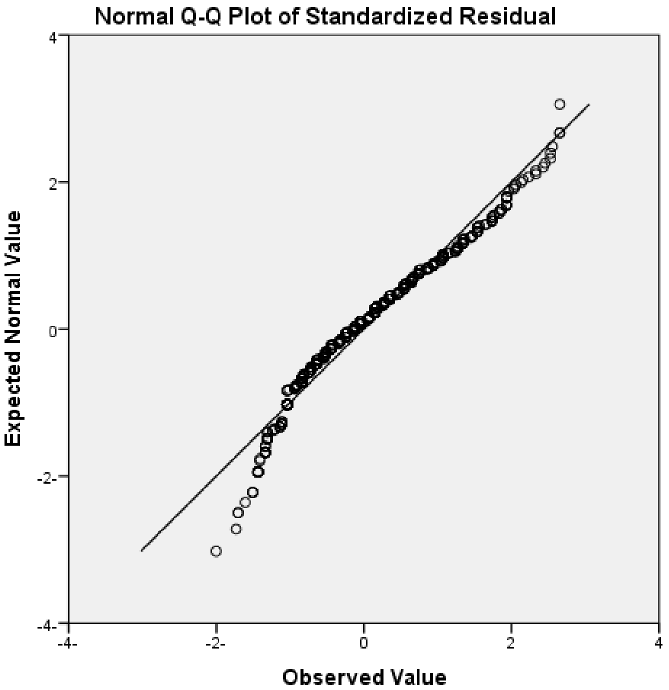
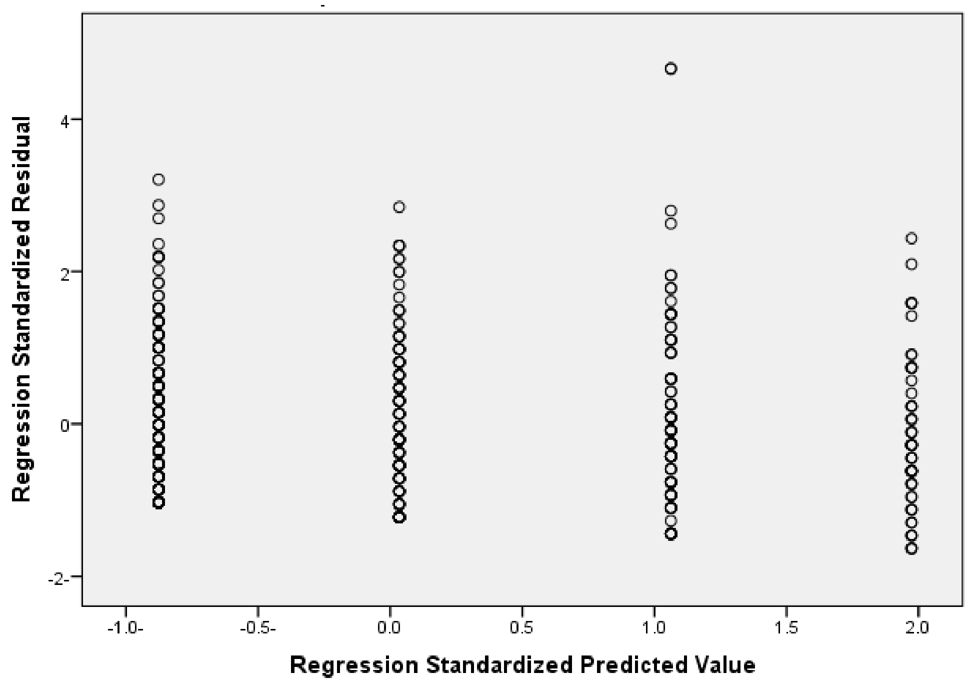


Figure KK-4: Q-Q plot of standardized residual having building variables (IV) and odors (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. A number of 16 data points of standardized residual values were not following those criteria (Figure KK-5 (A)). According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 16 data points were deleted. Figure KK-5 (B) shows scatter plots of regression standardized residuals and standardized predicted values after deleting the above described data points.
- Examining data points of high leverage in the initial regression model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=24 parameters and n=481 in the initial regression model, the cutoff value of 2p/n and 3p/n was 0.1 and 0.15; respectively. As shown in Figure KK-6 (A) and (B), all data points were below the 2p/n cutoff value of 0.1 in both the initial and final regression model. The highest leverage value in the final model was ≤ 0.017.
- Examining data points of high influence in the initial regression model followed the general cutoff value Cook’s distance of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Plus 2004) as discussed in Section 3.4.3. No influential points were detected in the final regression model since the highest Cook’s distance and DFBETAS were 0.026 and 0.235; respectively. Figure KK-7 (A) and (B) illustrates the Cook’s distances for regression models before and after deleting above described unusual data points. Notably that the difference between Cook’s distances are closer in (B) compared than (A) and no data point appears to be isolated from others.

(A)



(B)

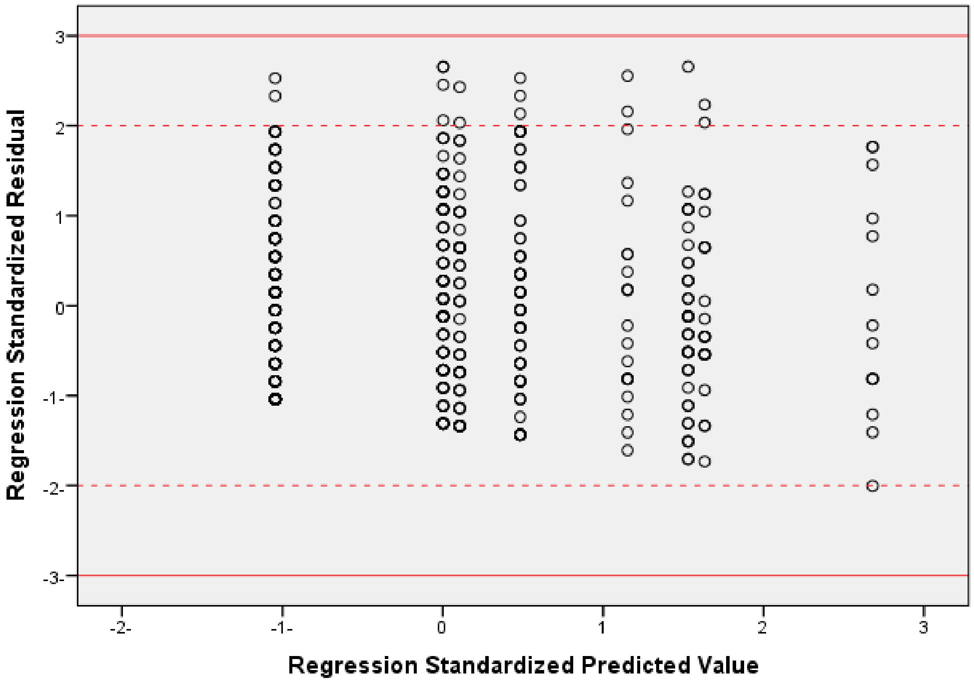


Figure KK-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values having building variables (IV) and odors (DV) before and after deleting unusual points

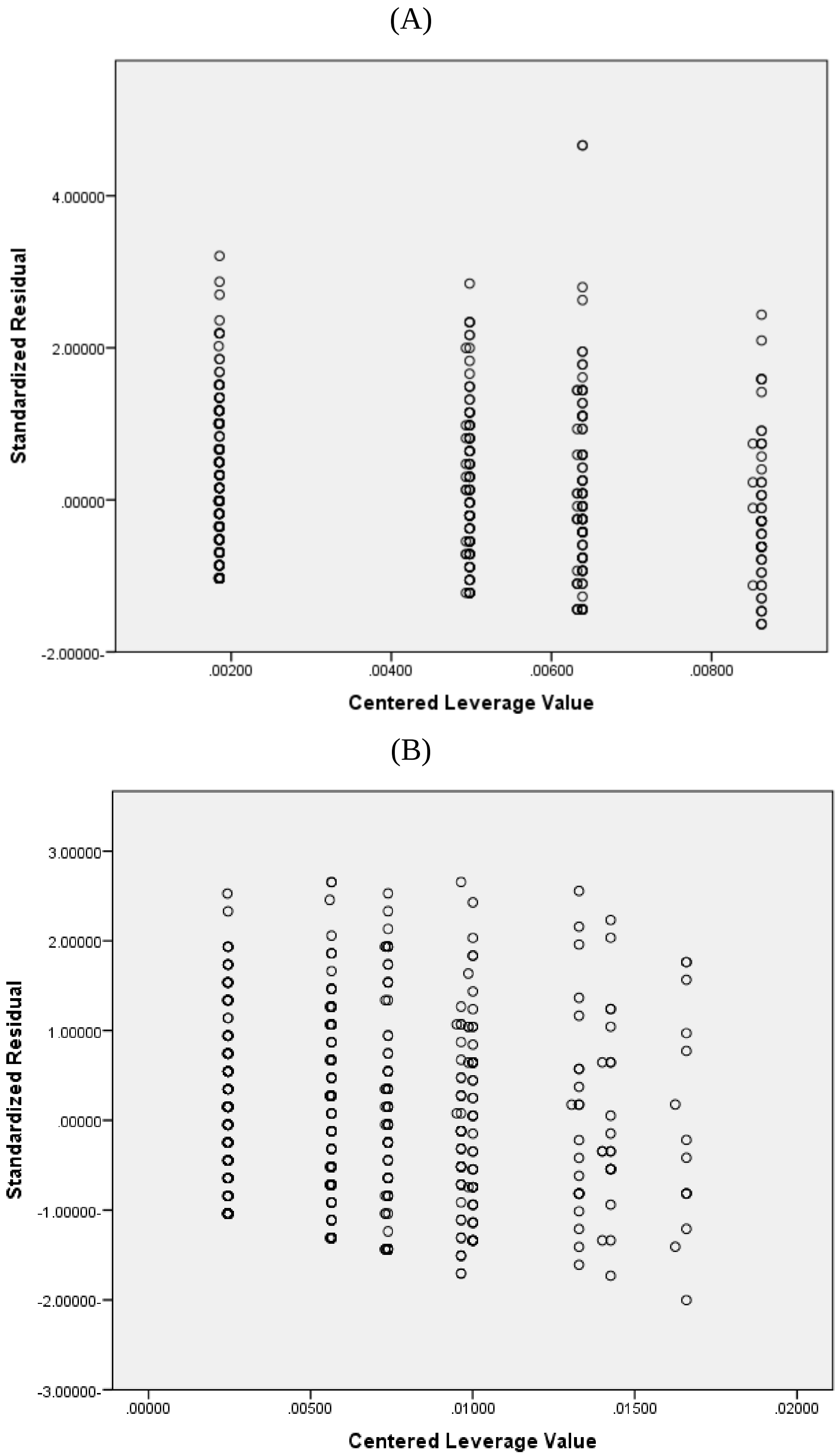


Figure KK-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values having building variables (IV) and odors (DV) before and after deleting unusual data points

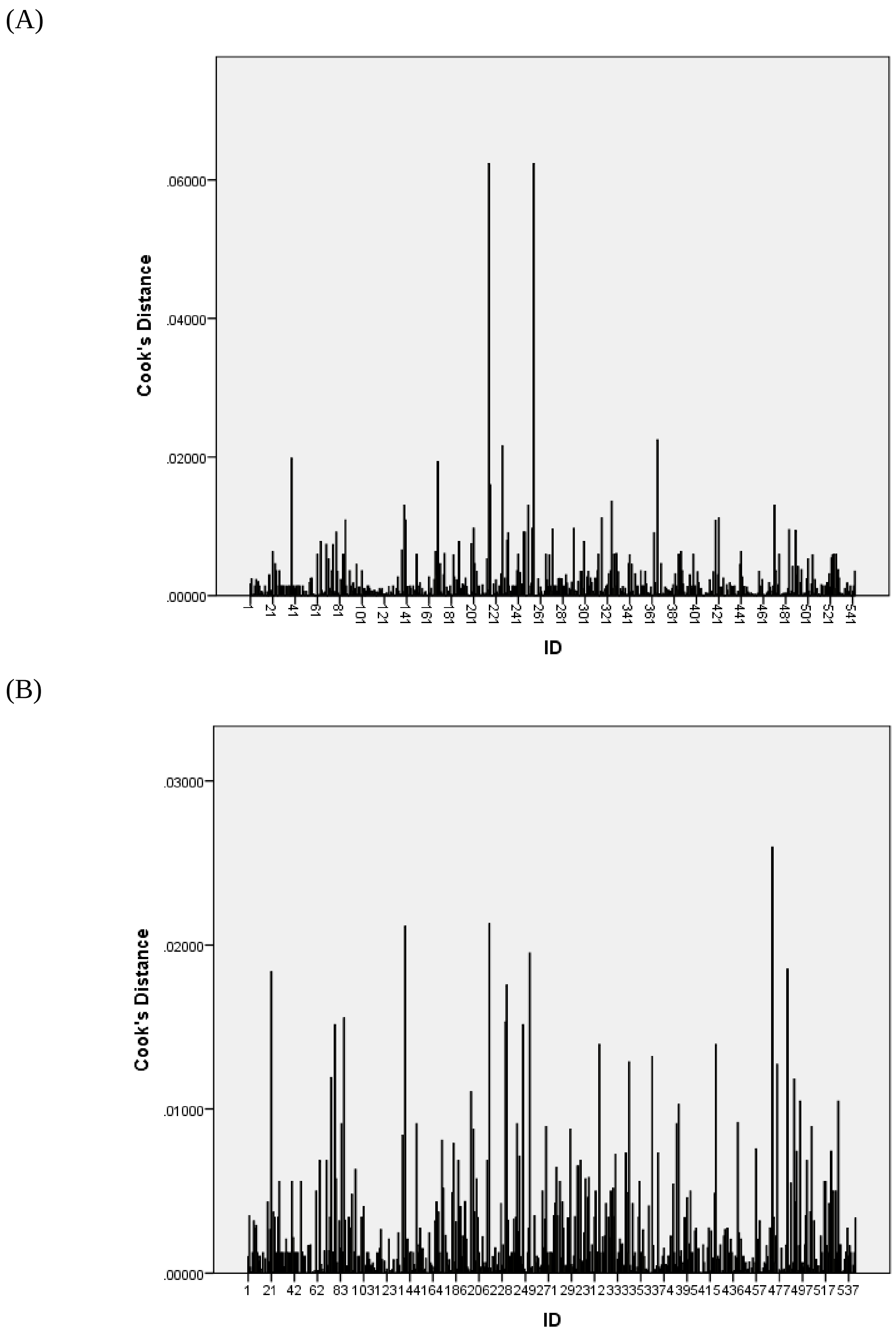


Figure KK-7: Bar charts (A) & (B) of Cook's distances for the regression model of building variables (IV) and odors (DV) before and after deleting unusual points

# Appendix LL : Checking bias in the MLR model of IEQ factors (IV) on Eye, Nose, Throat, and Chest related symptoms (DV)

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure LL-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

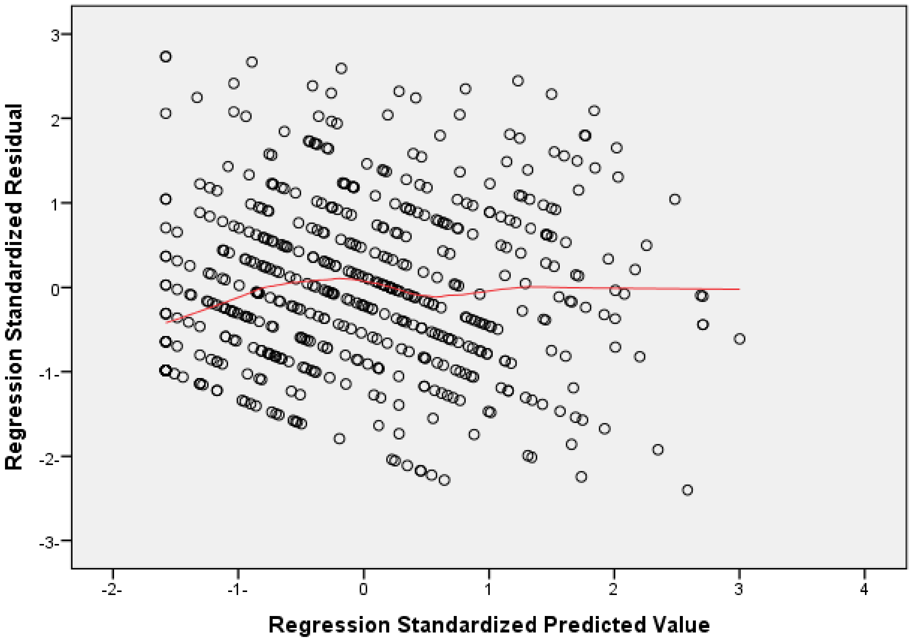


Figure LL-1: Scatter plot of regression standardized residuals and predicted values having comfort and odor components (IV) and ENT & chest symptoms (DV)

- As shown in Figure LL-2, normal distribution of the residuals can be assumed for the final regression model since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013; Eberly College of Science 2018c). Also, as illustrated in Figure LL-3 and Figure LL-4, the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).

- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 1.455 (Field 2016; Ballance 2015; Ghani & Ahmad 2010).

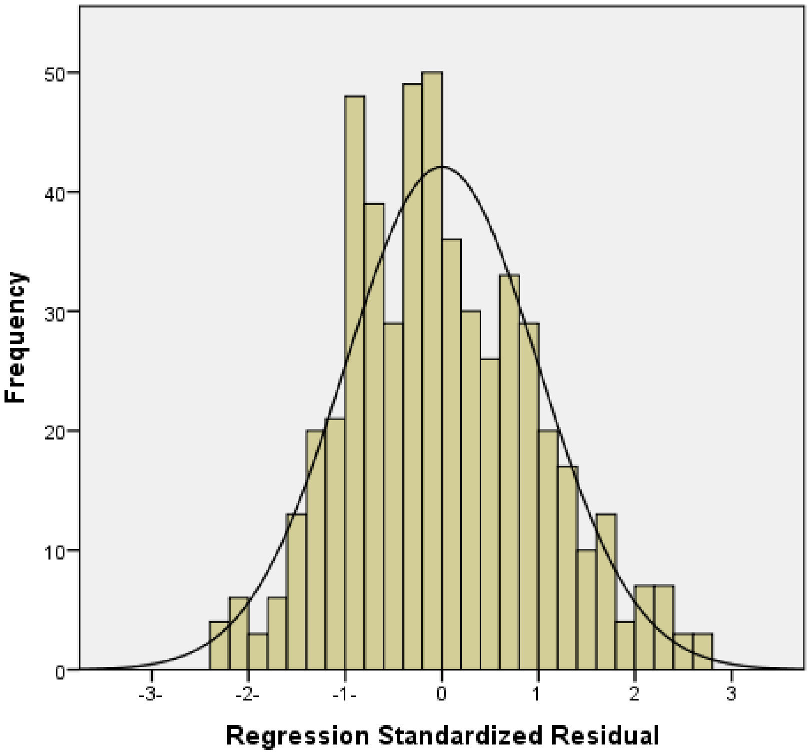


Figure LL-2: Histogram of the regression standardized residuals having comfort and odor factors (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

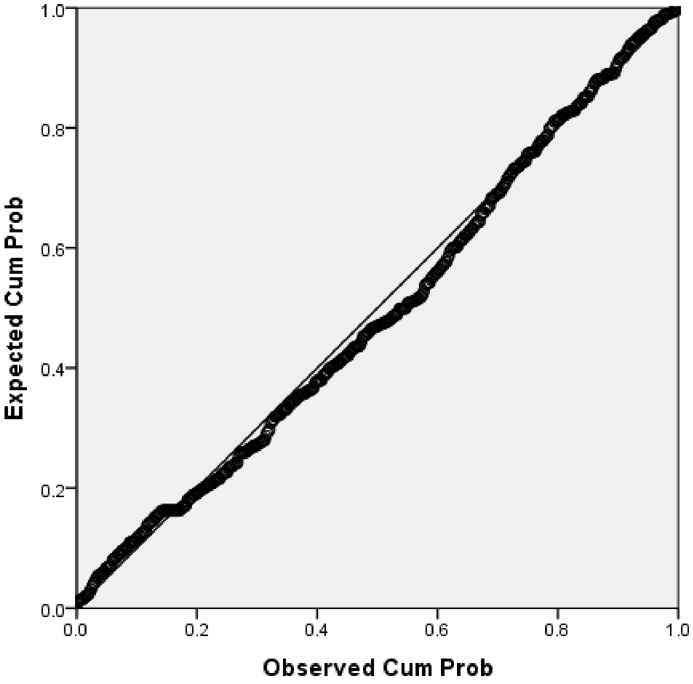


Figure  LL-3: P-P plot of regression standardized residuals having comfort and odor factors (IV) and Eye, Nose, Throat, and Chest symptoms (DV) (Adjusted model)

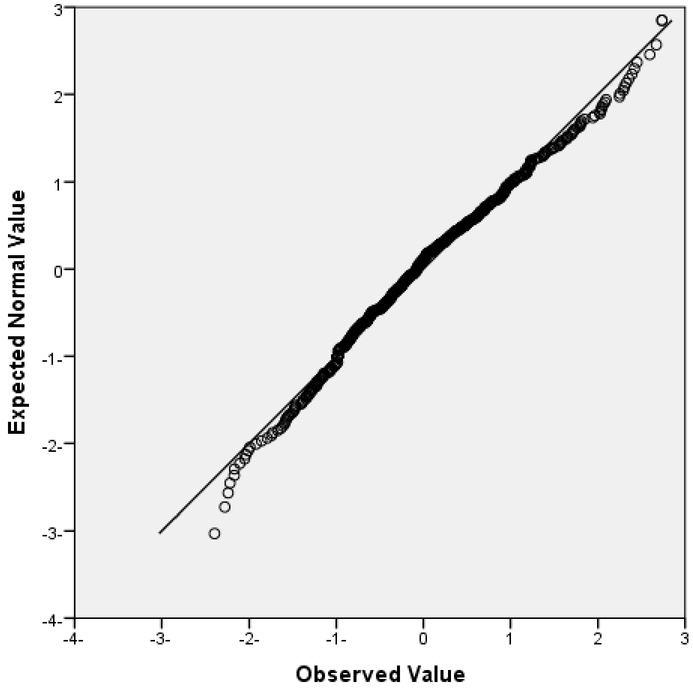
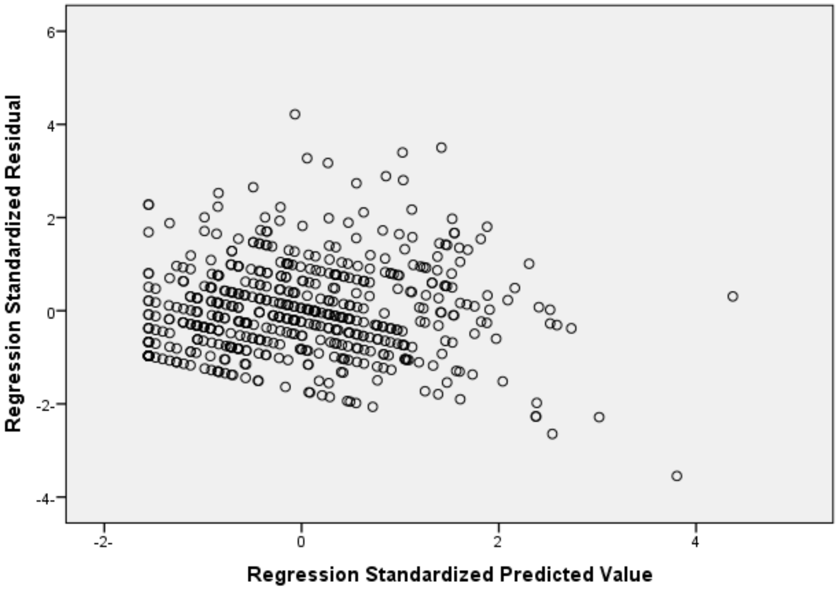


Figure  LL-4: Q-Q plot of standardized residual having comfort and odor factors (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. A number of 14 data points of standardized residual values were not following those criteria (Figure LL-5 (A)). According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 14 data points were deleted. Figure LL-5 (B) shows scatter plots of regression standardized residuals and standardized predicted values after deleting the above described data points.
- Examining data points of high leverage in the initial regression model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=4 parameters and n=542 in the initial regression model, the cutoff value of 2p/n and 3p/n was about 0.015 and 0.022; respectively. A number of 33 data points had leverage value above the cutoff value 2p/n and 9 points above the cutoff value of 3p/n in the initial model. As shown in Figure LL-6 (A), a number of 3 data points of leverage value ≤ 0.039 were far away and obviously isolated from others. When deleting them, all other points were close and no data point appears to be isolated (Figure LL-6 (B)). A number of 7 points above the 3p/n cutoff were retained in the final model because their deletion did not alter the in the variables identified as statistically significant and resulted in an insignificant change in $R^2$, adjusted $R^2$, and *SE* of estimation which was 0.006, 0.005, and 0.01; respectively. The highest leverage value in the final model was 0.034.
- Examining data points of high influence in the initial regression model followed the general cutoff value Cook's distance of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Plus 2004) as discussed in Section 3.4.3. No influential points were detected in the final regression model since the highest Cook's distance and DFBETAS were

0.029 and 0.265; respectively. Figure LL-7 (A) and (B) illustrates the Cook's distances for regression models before and after deleting unusual data points. Notably that the difference between Cook's distances are closer in (B) compared than (A) and no data point appears to be isolated from others.

(A)



(B)

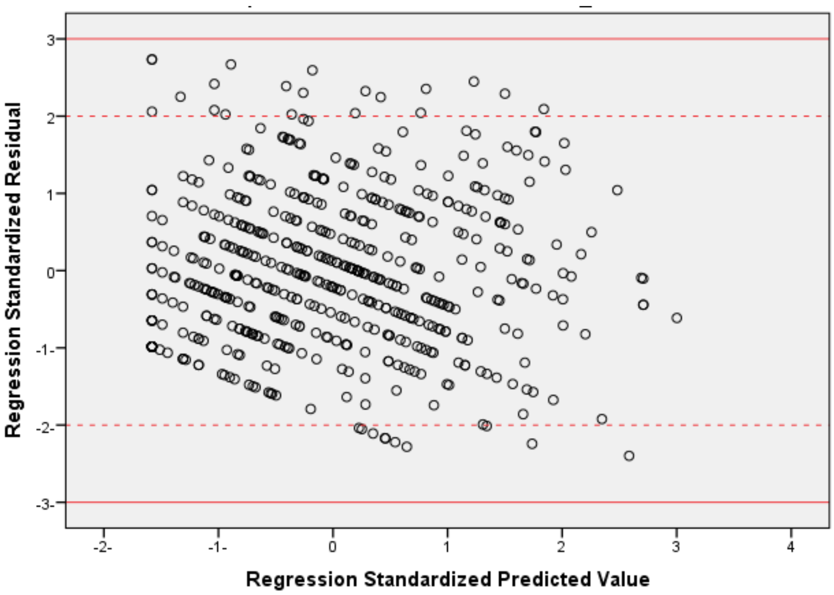
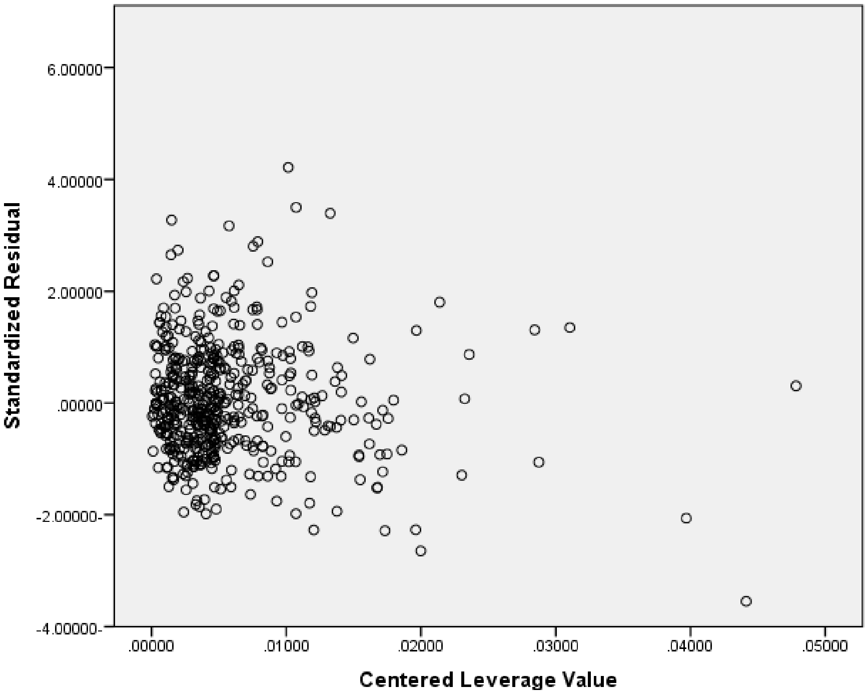


Figure LL-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values having comfort and odor factors (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual points

(A)



(B)

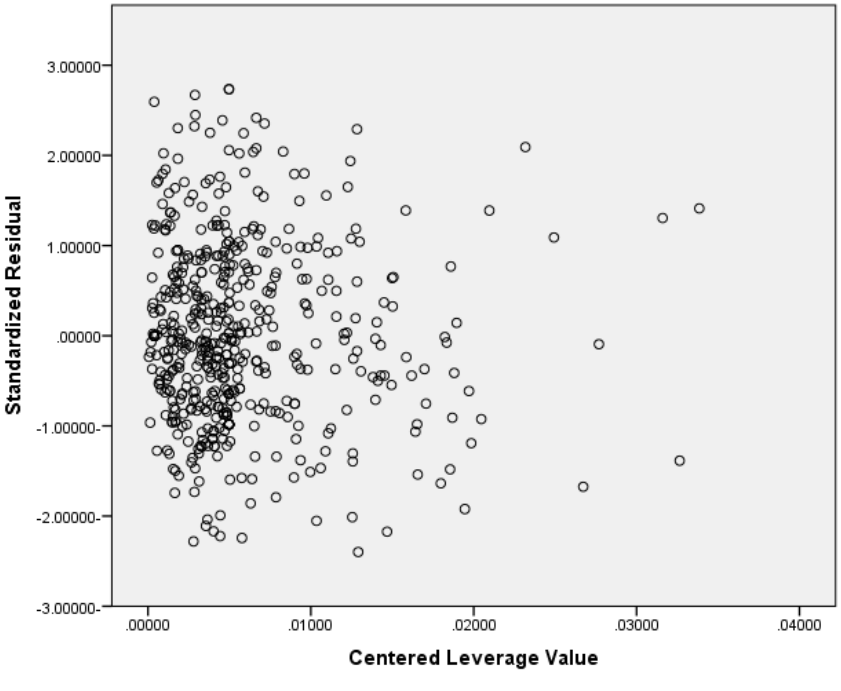


Figure LL-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values having comfort and odor factors (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual points

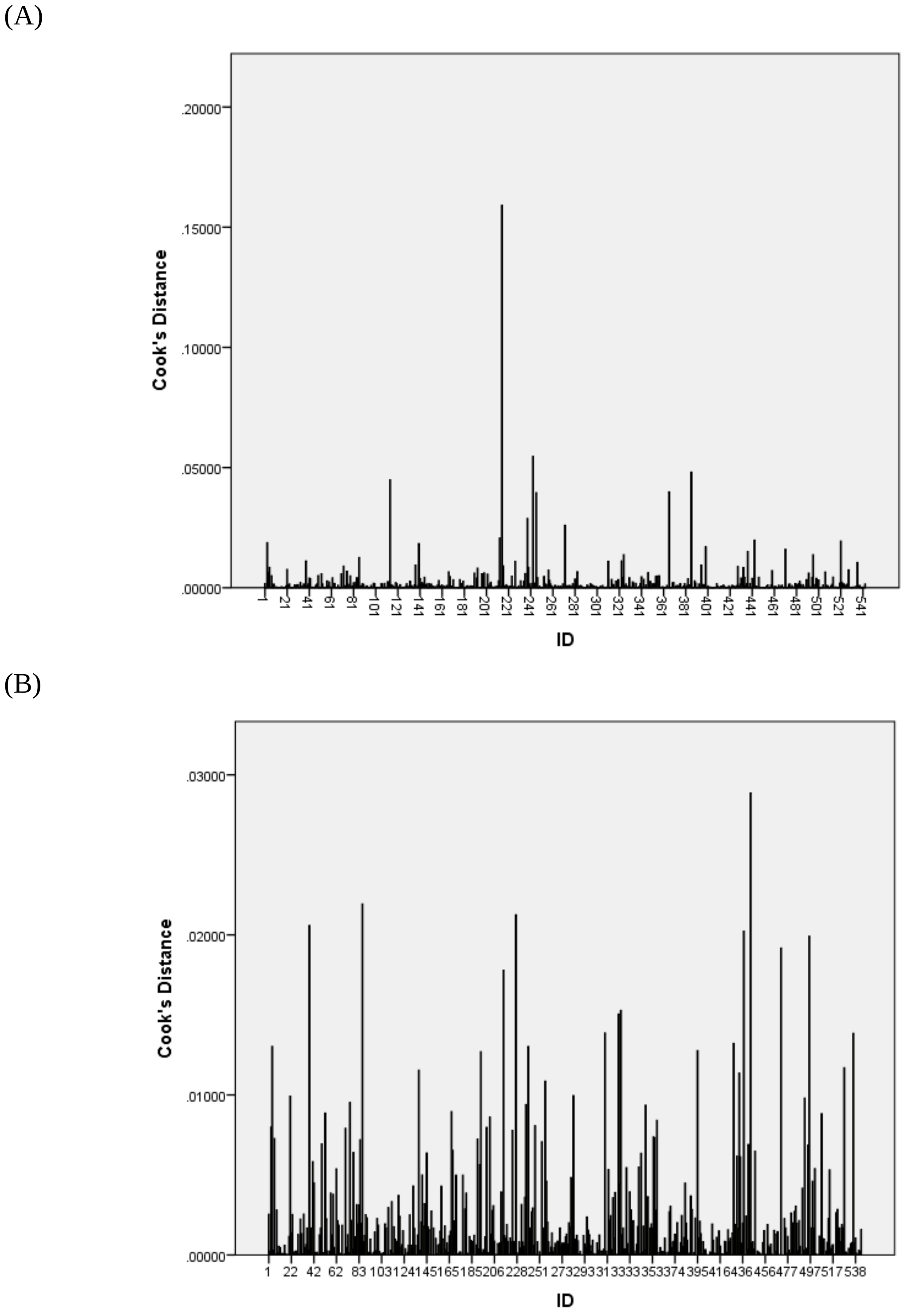


Figure LL-7: Bar charts (A) & (B) of Cook's distances for the regression model having comfort and odor factors (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual data points

# Appendix MM : Checking bias in the MLR model of IEQ factors (IV) on Eye, Nose, Throat, and Chest related symptoms (DV) adjusted for significant population and building variables

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure MM-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots.

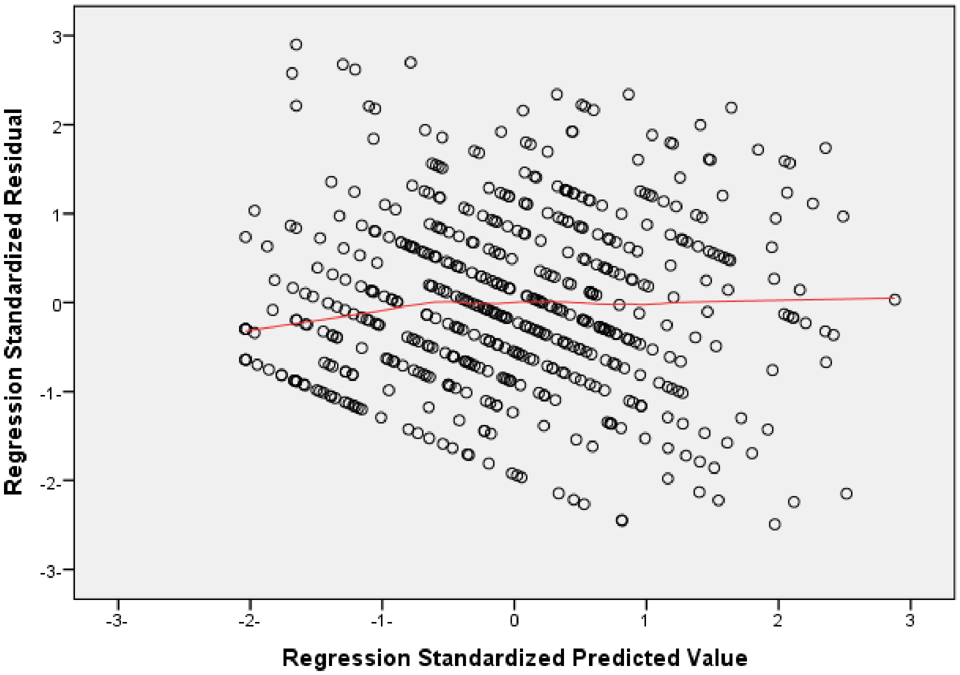


Figure MM-1: Scatter plot of regression standardized residuals and predicted values having comfort and odors factors (IV) and ENT & chest symptoms (DV) (Adjusted model)

- As shown in Figure MM-2, normal distribution of the residuals can be assumed for the final regression model since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013; Eberly College of Science 2018c). Also, as illustrated in Figure MM-3 and Figure MM-4, the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 1.523 (Field 2016; Ballance 2015; Ghani & Ahmad 2010).

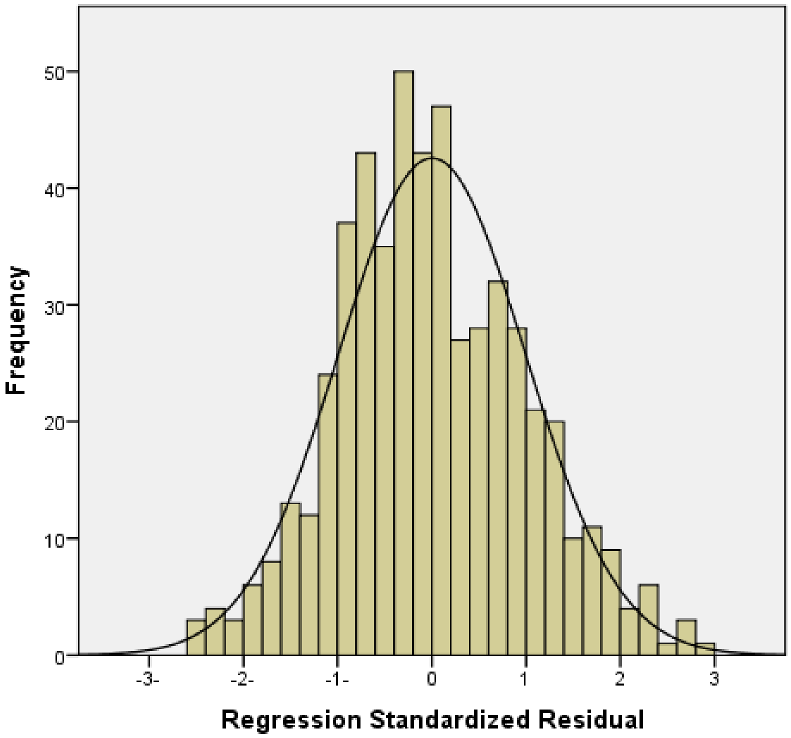


Figure MM-2: Histogram of the regression standardized residuals having comfort and odors factors (IV) and Eye, Nose, Throat, and Chest symptoms (DV) (Adjusted model)

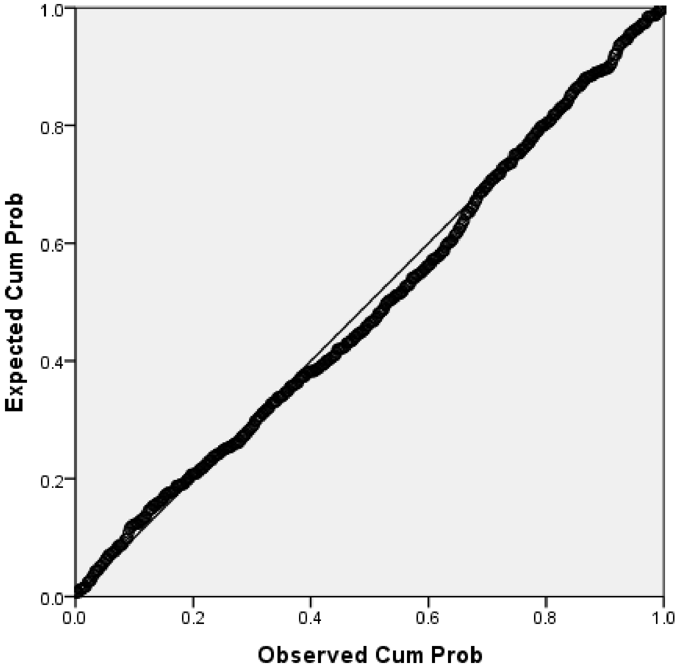


Figure MM-3: P-P plot of regression standardized residuals having comfort and odors factors (IV) and Eye, Nose, Throat, and Chest symptoms (DV) (Adjusted model)

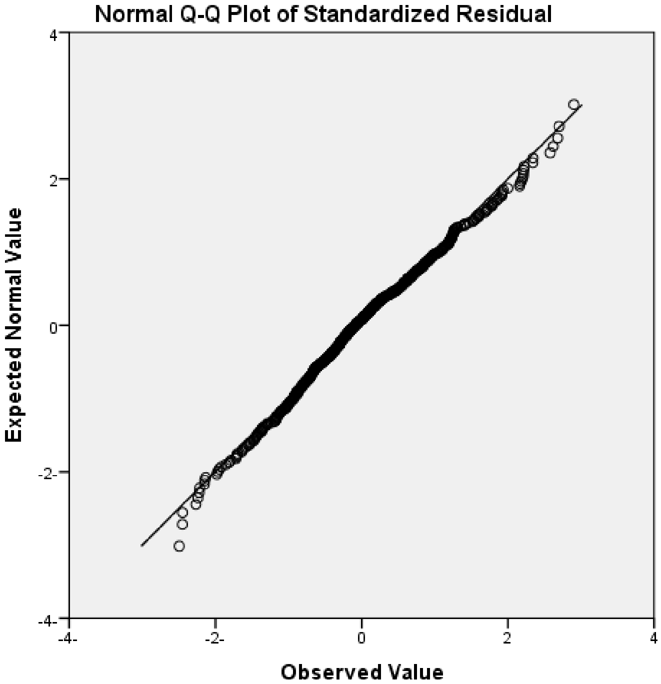
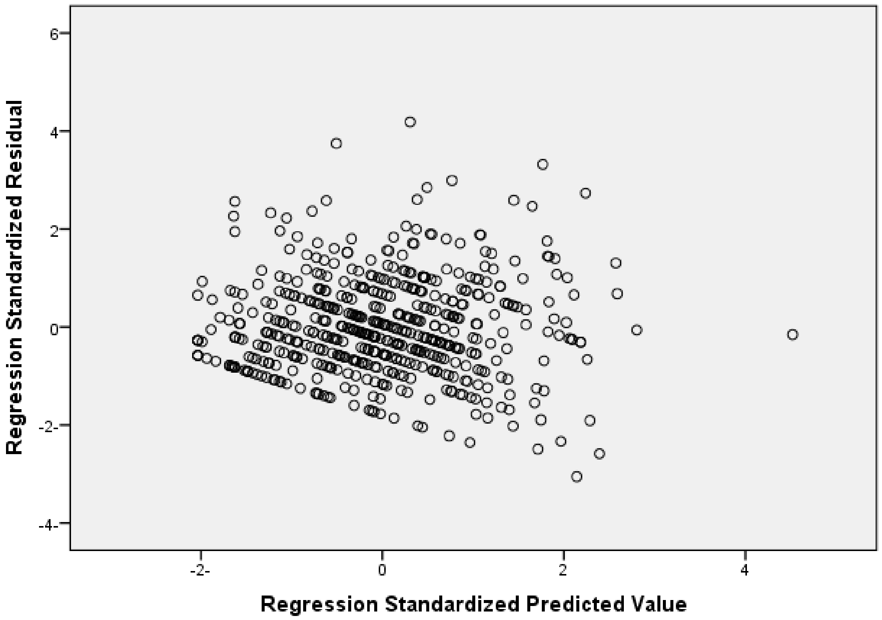


Figure  MM-4: Q-Q plot of standardized residual having comfort and odors factors (IV) and Eye, Nose, Throat, and Chest symptoms (DV) (Adjusted model)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. A number of 13 data points of standardized residual values were not following those criteria (Figure MM-5 (A)). According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 13 data points were deleted. Figure  MM-5 (B) shows scatter plots of regression standardized residuals and standardized predicted values after deleting the above described data points.
- Examining data points of high leverage in the initial regression model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=10 parameters and n=542 in the initial regression model, the cutoff value of 2p/n and 3p/n was about 0.04 and 0.06; respectively. As shown in Figure  MM-6 (A) and Figure  MM-5 (B), one point was obviously isolated from others above the 3p/n cutoff value. After deleting it, all data points falls below the 3p/n cutoff value Figure  MM-6 (B). However, a number of 6 points above the 2p/n cutoff were retained in the final model because their deletion did not alter the in the variables identified as statistically significant and resulted in an insignificant change in $R^2$, adjusted $R^2$, and *SE* of estimation which was 0.004, 0.004, and 0.046; respectively. The highest leverage value in the final model was 0.050.
- Examining data points of high influence in the initial regression model followed the general cutoff value Cook's distance of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Nelson 2007) as discussed in Section 3.4.3. No influential points were detected in the final regression model since the highest Cook's distance and DFBETAS were

0.061 and 0.415; respectively. Figure MM-7 (A) and (B) illustrates the Cook's distances for regression models before and after deleting above described unusual data points. Notably that the difference between Cook's distances are closer in (B) compared than (A) and no data point appears to be isolated from others.

(A)



(B)

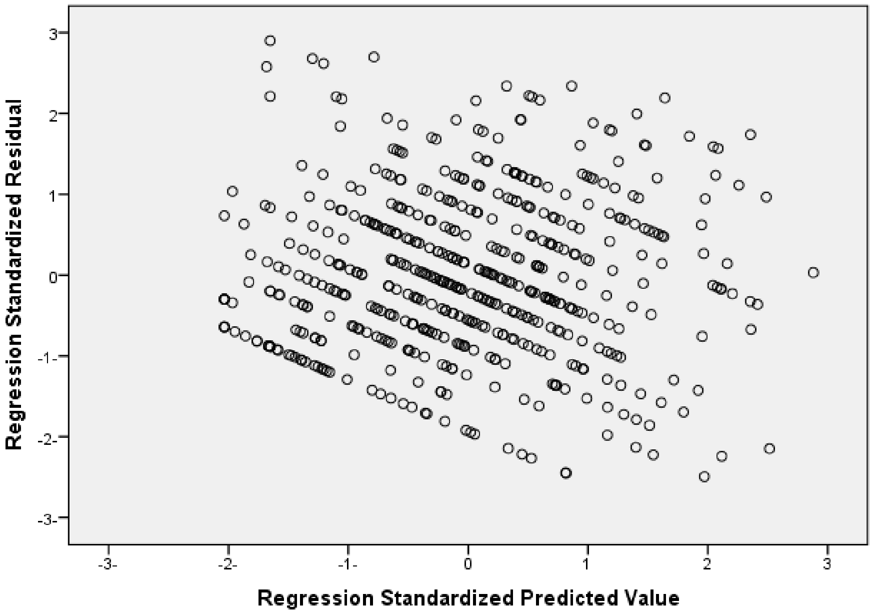
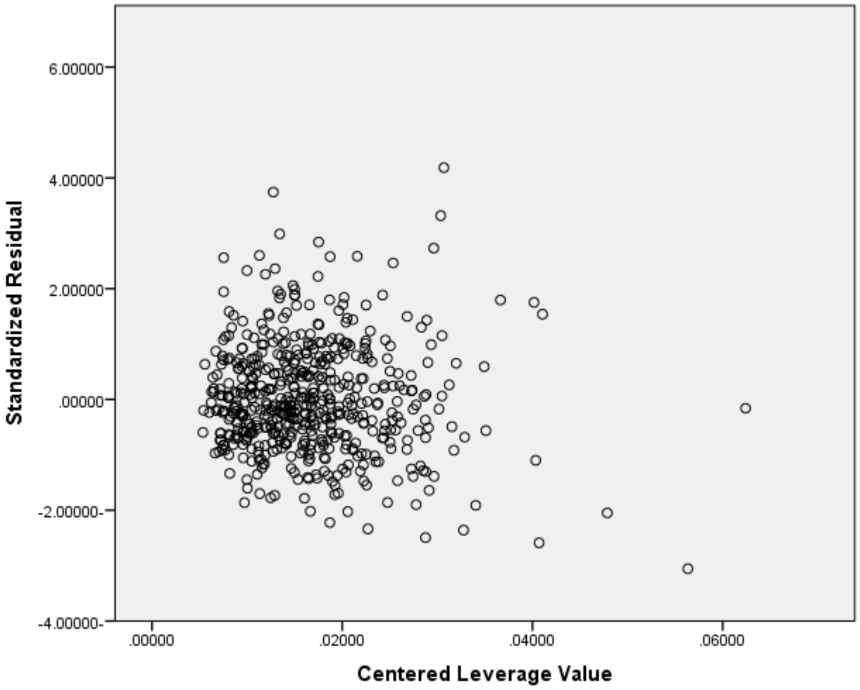


Figure MM-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values comfort and odors factors (IV) and Eye, Nose, Throat, and

Chest symptoms (DV) before and after deleting unusual points (Adjusted model)

(A)



(B)

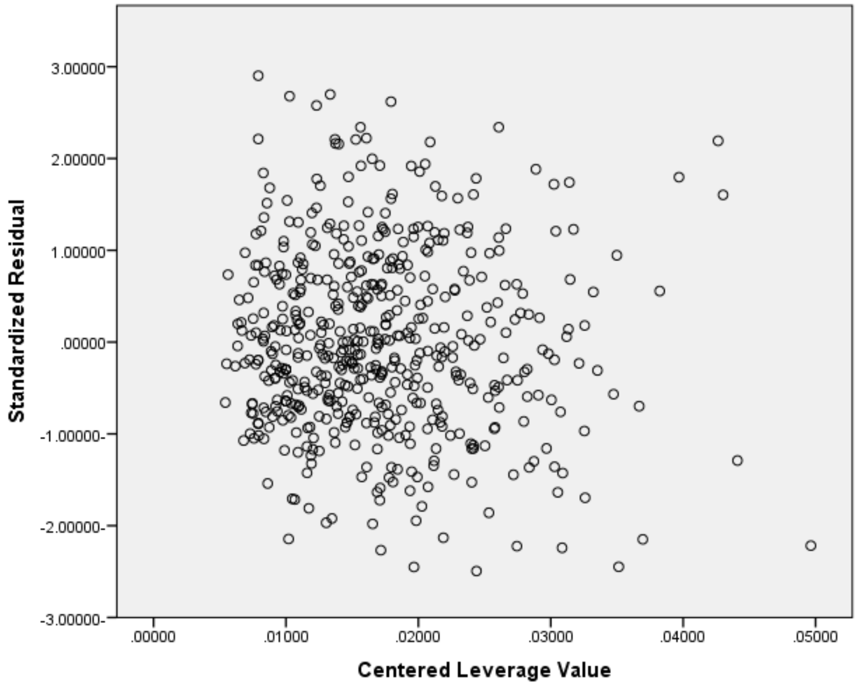


Figure MM-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values comfort and odors factors (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual points (Adjusted model)

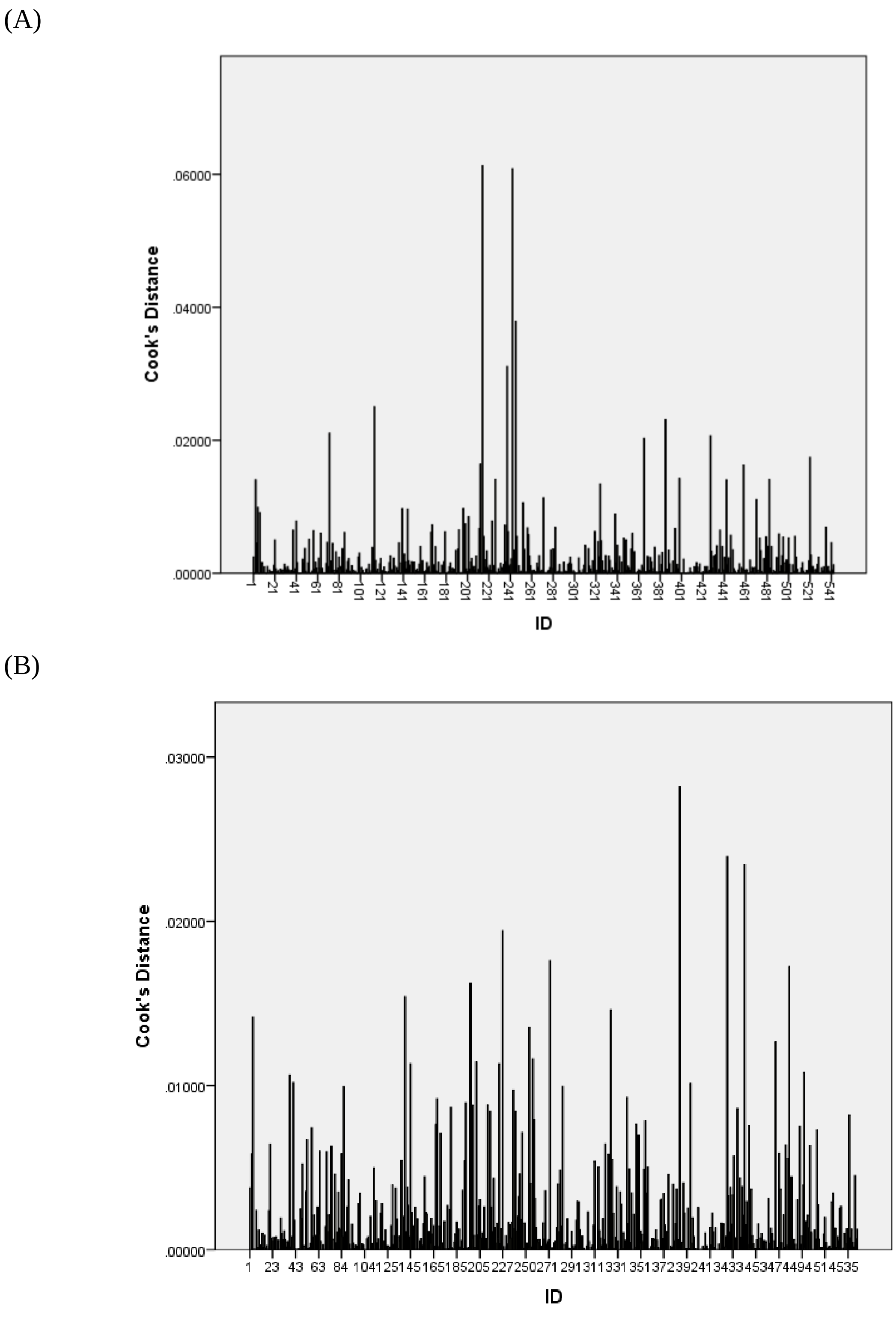


Figure MM-7: Bar charts (A) & (B) of Cook's distances for the regression model comfort and odors factors (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual data points (Adjusted model)

## Appendix NN : Checking bias in the MLR model of IEQ factors (IV) on general, ergonomic, nervous & skin symptoms (DV)

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure NN-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots.

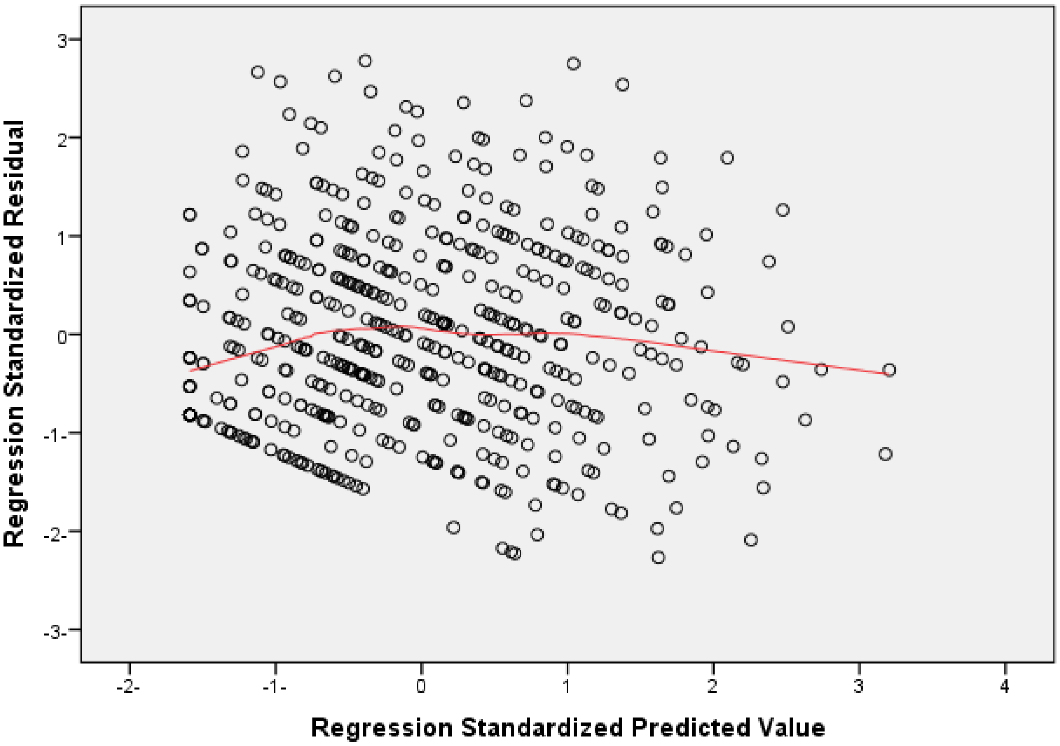


Figure NN-1: Scatter plot of regression standardized residuals and predicted values having comfort and odors factors (IV) and General, Ergonomic, Nervous, and Skin symptoms (DV)

- As shown in Figure  NN-2, normal distribution of the residuals can be assumed for the final regression model since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013;  Eberly College of Science 2018c). Also, as illustrated in Figure  NN-3 and Figure  NN-4, the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 1.468 (Field 2016;  Ballance 2015; Ghani & Ahmad 2010).

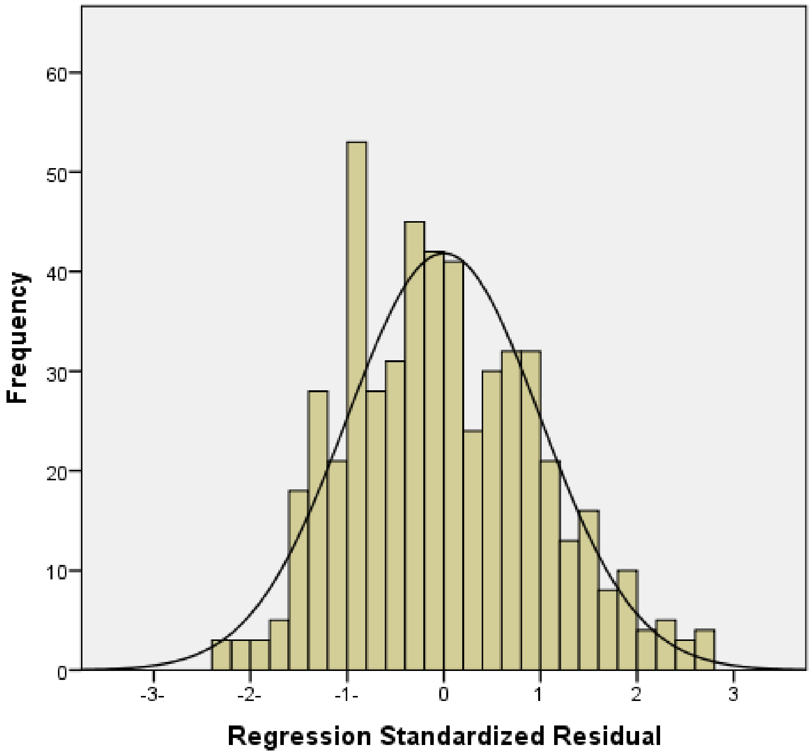


Figure  NN-2: Histogram of the regression standardized residuals having comfort and odors factors (IV) and General, Ergonomic, Nervous, and Skin symptoms (DV)

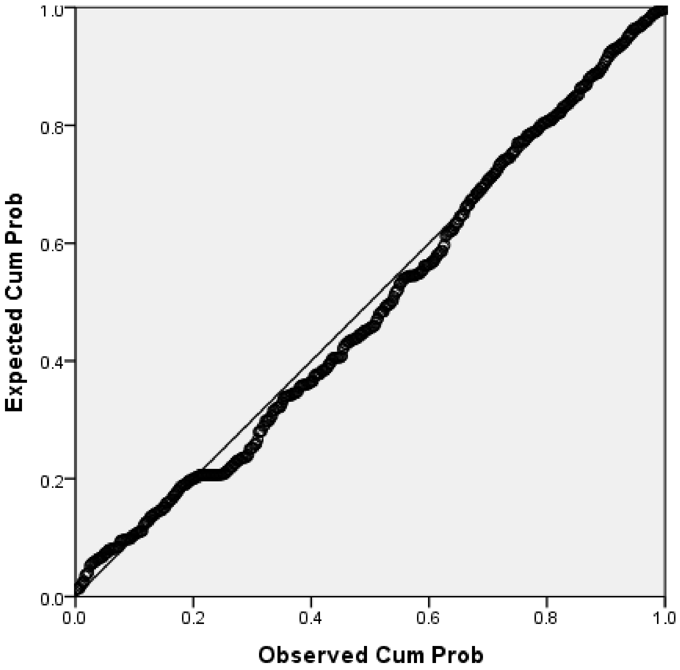


Figure NN-3: P-P plot of regression standardized residuals having comfort and odors factors (IV) and General, Ergonomic, Nervous, and Skin symptoms (DV)

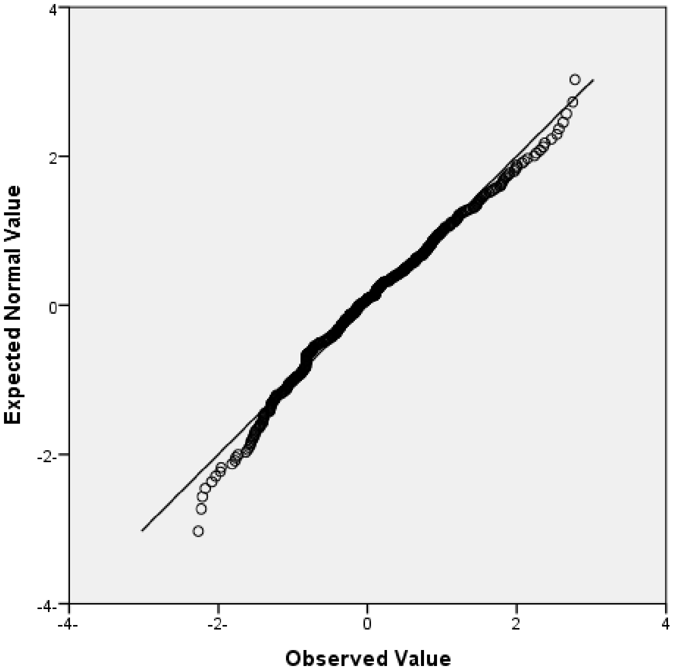
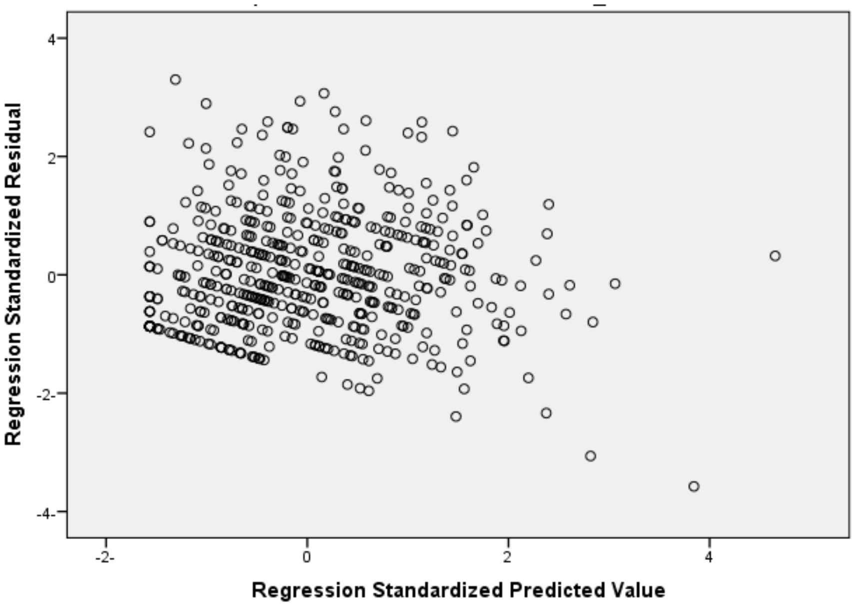


Figure NN-4: Q-Q plot of standardized residual having comfort and odors factors (IV) and General, Ergonomic, Nervous, and Skin symptoms (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. A number of 17 data points of standardized residual values were not following those criteria (Figure NN-5 (A)). According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 17 data points were deleted. Figure NN-5 (B) shows scatter plots of regression standardized residuals and standardized predicted values after deleting the above described data points.
- Examining data points of high leverage in the initial model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=4 parameters and n=542 in the initial model, the cutoff value of 2p/n and 3p/n was about 0.015 and 0.022; respectively. About 33 points had leverage values above the 2p/n cutoff value of and 9 points above 3p/n in the initial model. As shown in Figure NN-6 (A), a number of 3 points of leverage value ≤ 0.04 were far away and obviously isolated from others. When deleting them, all other points were close to each other with leverage value ≤ 0.03 (Figure NN-6 (B)). A number of 7 points above the 3p/n cutoff were retained in the final model because their deletion did not alter the in the variables identified as statistically significant and resulted in an insignificant change in $R^2$, adjusted $R^2$, and *SE* of estimation which was 0.004, 0.004, and 0.017; respectively. The highest leverage in the final model was 0.034.
- Examining data points of high influence in the initial regression model followed the general cutoff value Cook's distance of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Nelson 2004) as discussed in Section 3.4.3. No influential points were detected in the final regression model since the highest Cook's distance and DFBETAS were 0.029 and 0.247; respectively. Figure NN-7 (A) and (B) illustrates the Cook's

distances for regression models before and after deleting unusual points. Notably that the difference between Cook's distances are closer in (B) compared with (A) and no data point appears to be isolated from others.

(A)



(B)

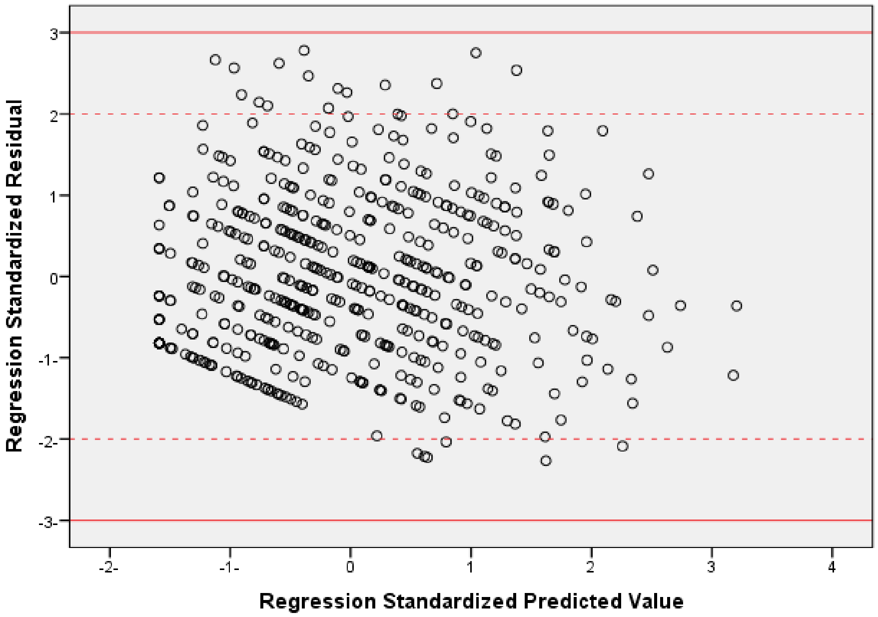
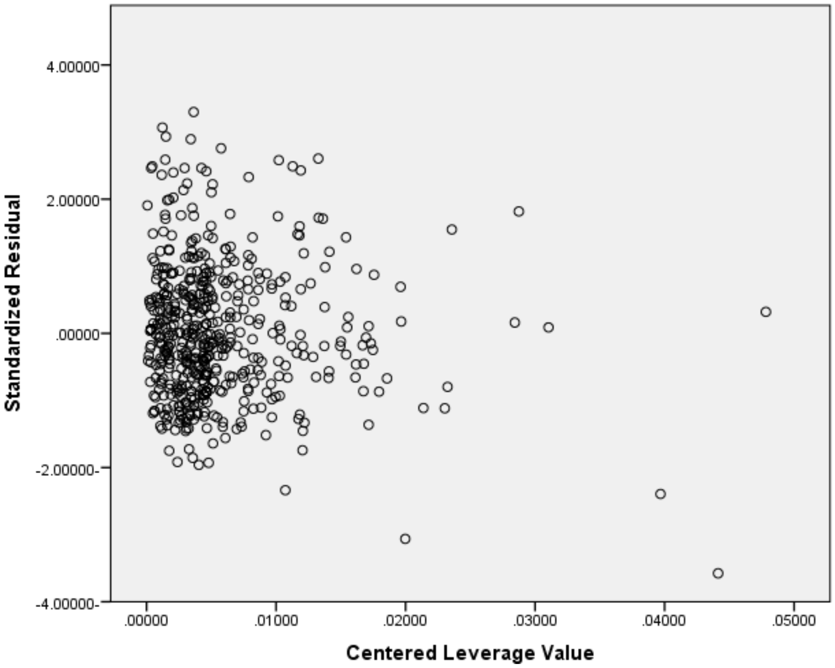


Figure NN-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values having comfort and odor factors (IV) and General, Ergonomic, Nervous, and Skin symptoms (DV) before and after deleting unusual points

(A)



(B)

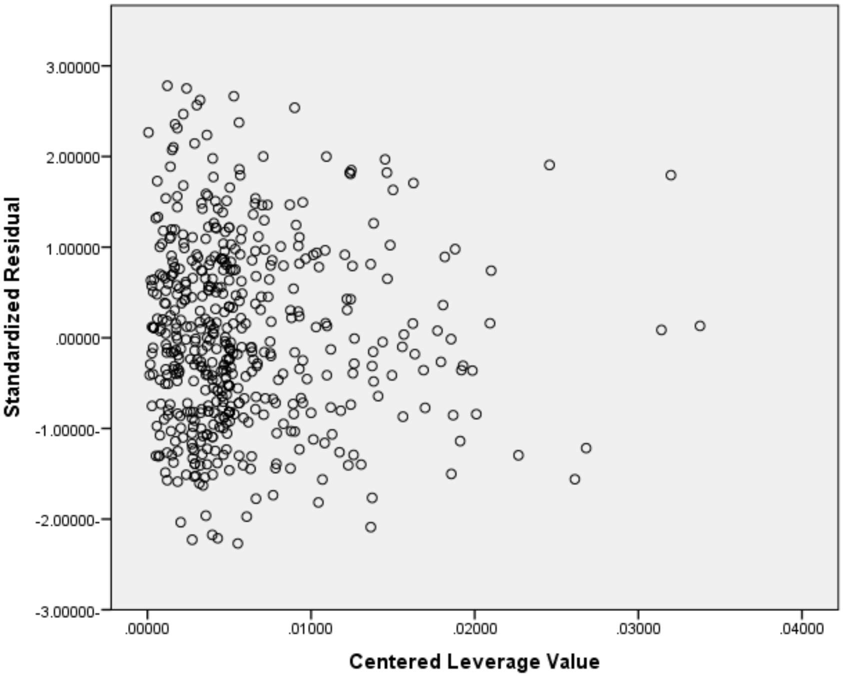
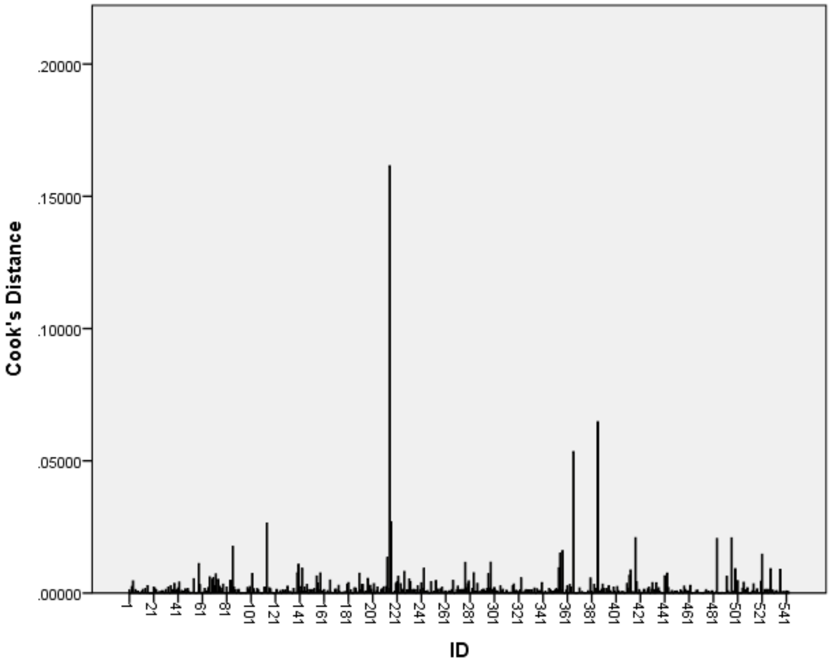


Figure NN-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values having comfort and odors factors (IV) and general, ergonomic, nervous & skin symptoms (DV) before and after deleting unusual points

(A)



(B)

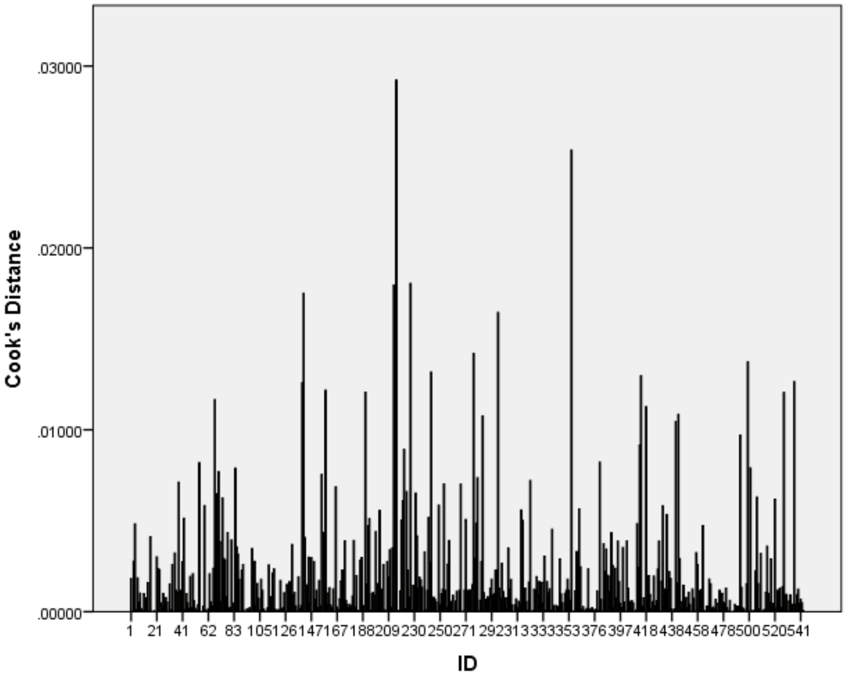


Figure NN-7: Bar charts (A) & (B) of Cook's distances for the regression model having comfort and odors factors (IV) and General, Ergonomic, Nervous, and Skin symptoms (DV) before and after deleting unusual data points

# Appendix OO : Checking bias in the MLR model of IEQ factors (IV) on general, ergonomic, nervous & skin symptoms (DV) adjusted for significant population and building variables

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure OO-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots.

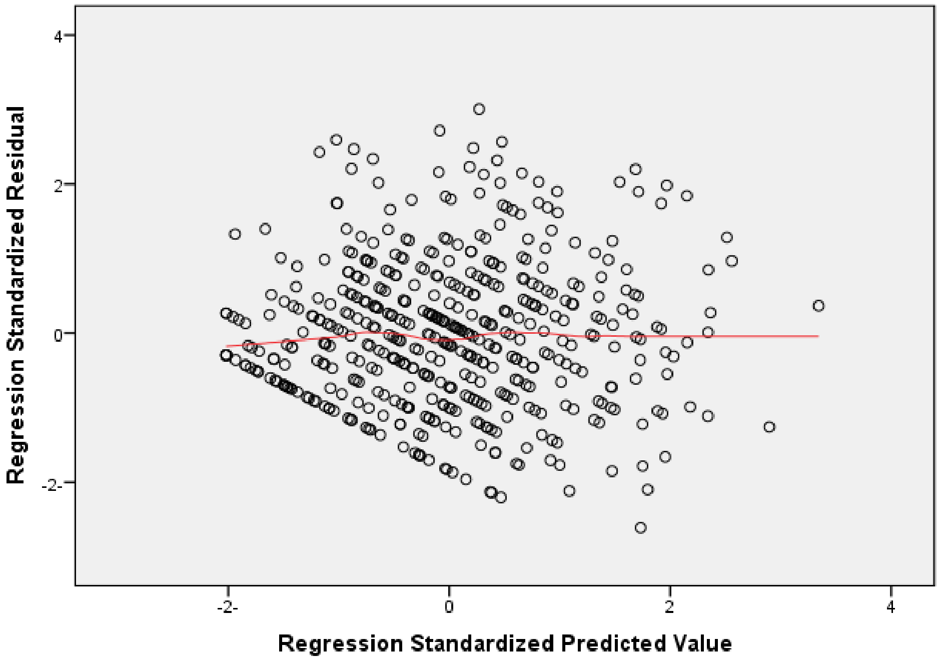


Figure OO-1: Scatter plot of regression standardized residuals and predicted values having comfort and odors factors (IV) and General, Ergonomic, Nervous, and Skin symptoms (DV) (Adjusted model)

- As shown in Figure  OO-2, normal distribution of the residuals can be assumed for the final regression model since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013;  Eberly College of Science 2018c). Also, as illustrated in Figure  OO-3 and Figure  OO-4, the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 1.561 (Field 2016;  Ballance 2015; Ghani & Ahmad 2010).

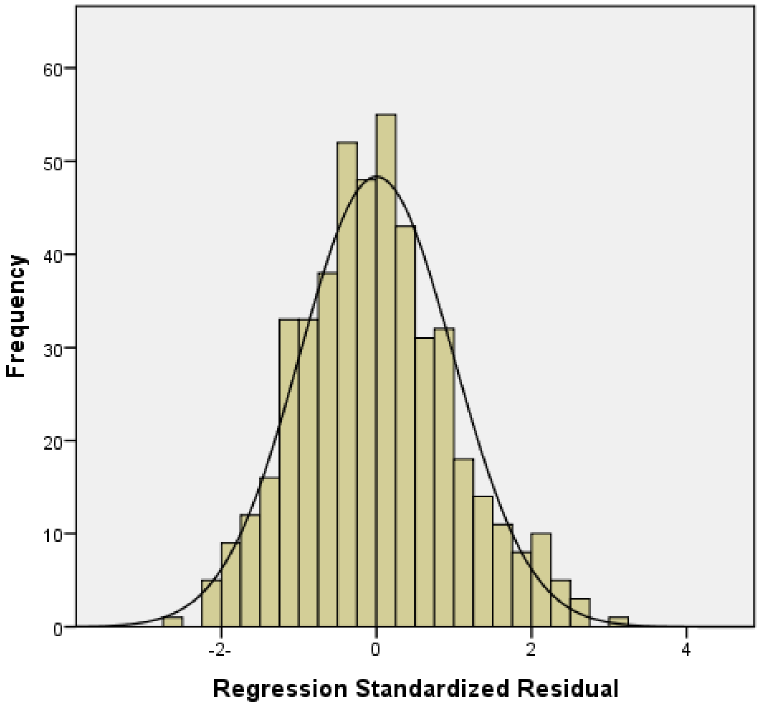


Figure  OO-2: Histogram of the regression standardized residuals having comfort and odors factors (IV) and general, ergonomic, nervous & skin symptoms (DV) (Adjusted model)

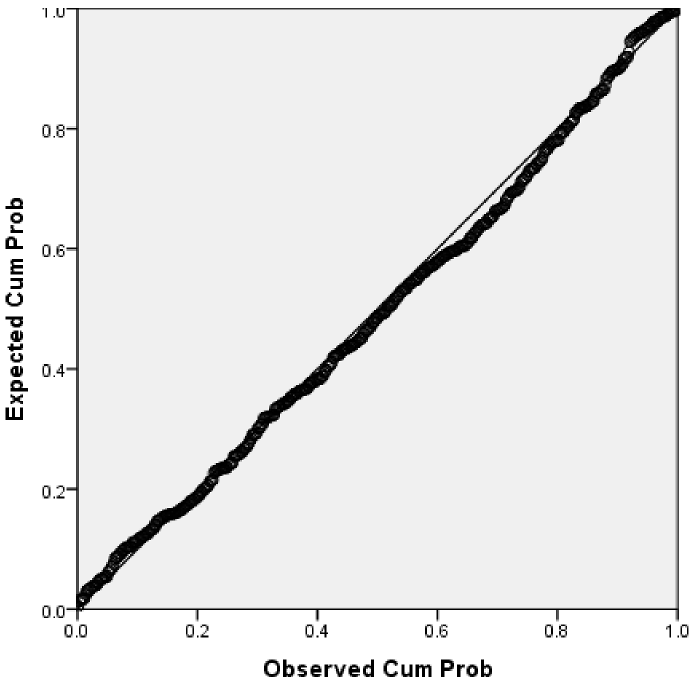


Figure OO-3: P-P plot of regression standardized residuals having comfort and odors factors (IV) and General, Ergonomic, Nervous, and Skin symptoms (DV)

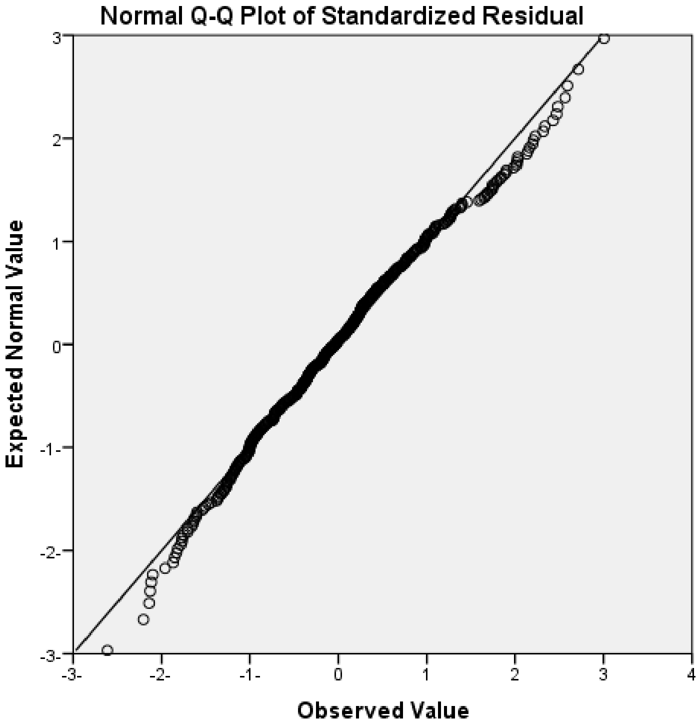
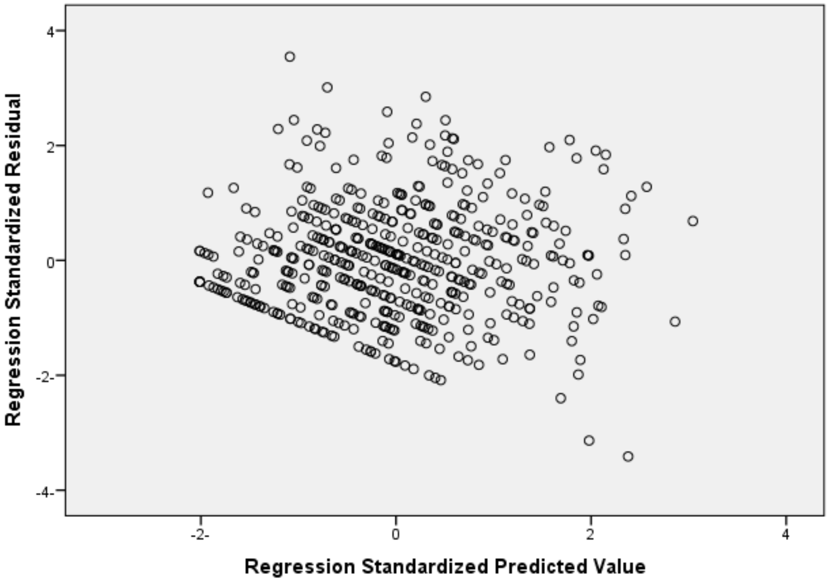


Figure OO-4: Q-Q plot of standardized residual having comfort and odors factors (IV) and General, Ergonomic, Nervous, and Skin symptoms (DV) (Adjusted model)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. A number of 4 data points of standardized residual values were not following those criteria (Figure OO-5(A)). According to (Simonof 2017, Field 2016, Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 4 data points were deleted. Figure OO-5 (B) shows scatter plots of regression standardized residuals and standardized predicted values after deleting the above described data points.
- Examining data points of high leverage in the initial regression model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=14 parameters and n=481 in the initial regression model, the cutoff value of 2p/n and 3p/n was about 0.06 and 0.09; respectively. As shown in Figure OO-6 (A) and (B), all data points were below the cutoff value of 3p/n in both the initial and final regression model. Although a number of 8 points were above cutoff value of 2p/n; they were retained in the final regression model. That was because their deletion did not alter the in the variables identified as statistically significant and resulted in an insignificant change in $R^2$, adjusted $R^2$, and *SE* of estimation which was 0.013, 0.001, and 0.061; respectively. Data points in the final model were below the 3p/n cutoff and their leverage value was ≤ 0.079.
- Examining data points of high influence in the initial regression model followed the general cutoff value Cook’s distance of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Nelson 2004) as discussed in Section 3.4.3. No influential points were detected in the final regression model since the highest Cook’s distance and DFBETAS were 0.030 and 0.376; respectively. Figure OO-7 (A) and (B) illustrates the Cook’s distances for regression models before and after deleting above described unusual

data points. Notably that the difference between Cook's distances are closer in (B) compared than (A) and no data point appears to be isolated from others.

(A)



(B)

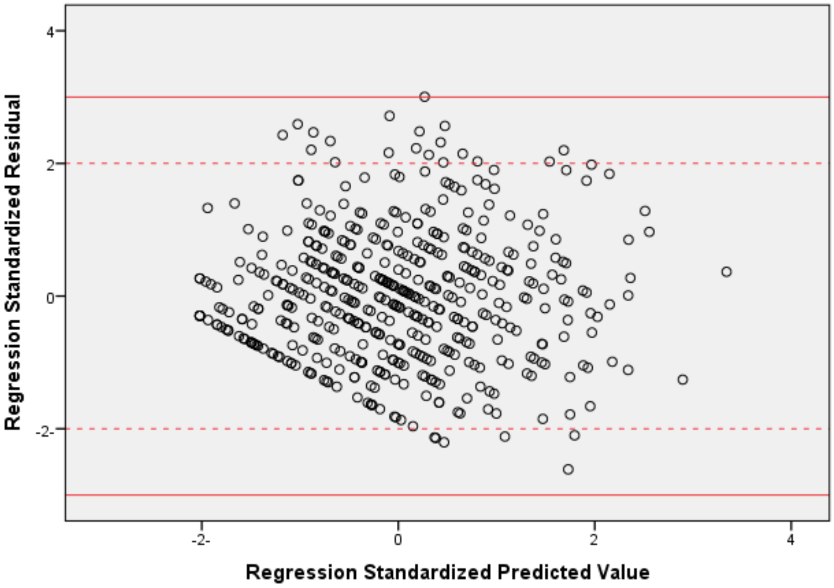
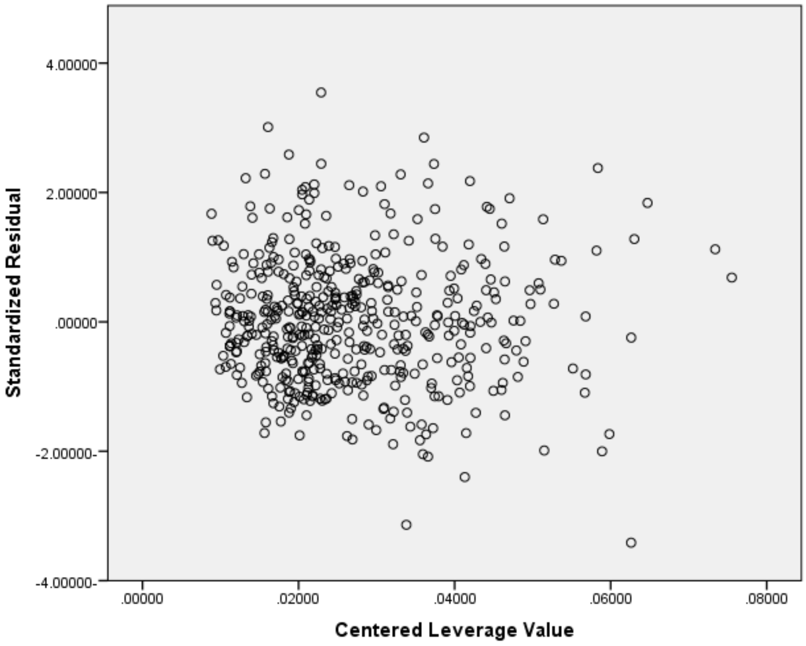


Figure OO-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values having comfort and odors factors (IV) and general, ergonomic, nervous & skin symptoms (DV) before and after deleting unusual (Adjusted model)

(A)



(B)

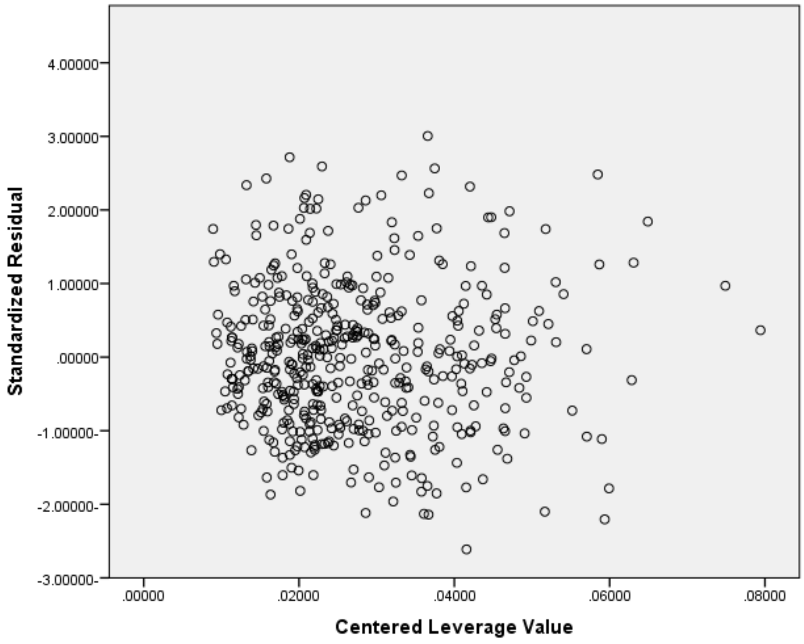
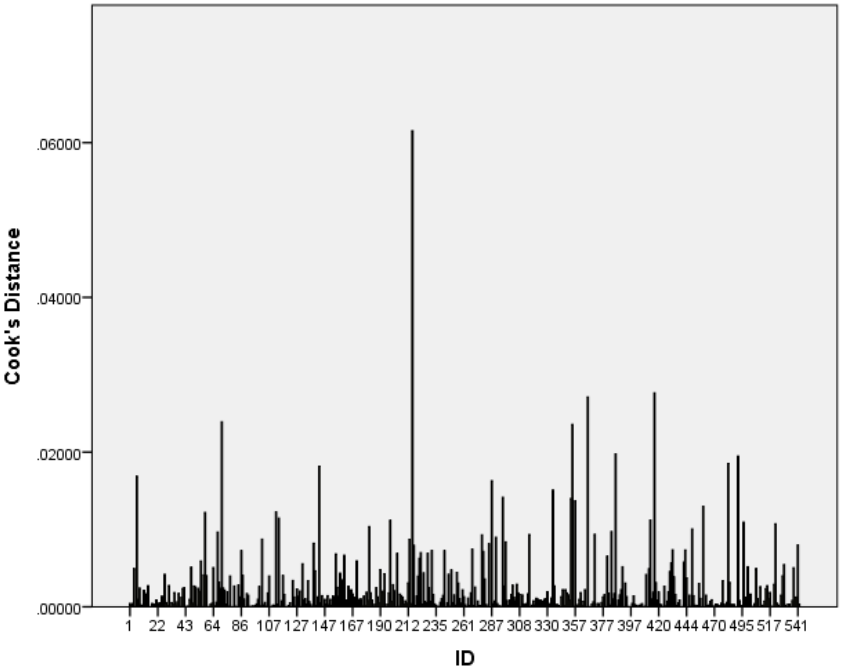


Figure OO-6: Scatter plots (A) & (B) of regression standardized residuals and leverage values having comfort and odors factors (IV) and general, ergonomic, nervous & skin symptoms (DV) before and after deleting unusual data points (Adjusted model)

(A)



(B)

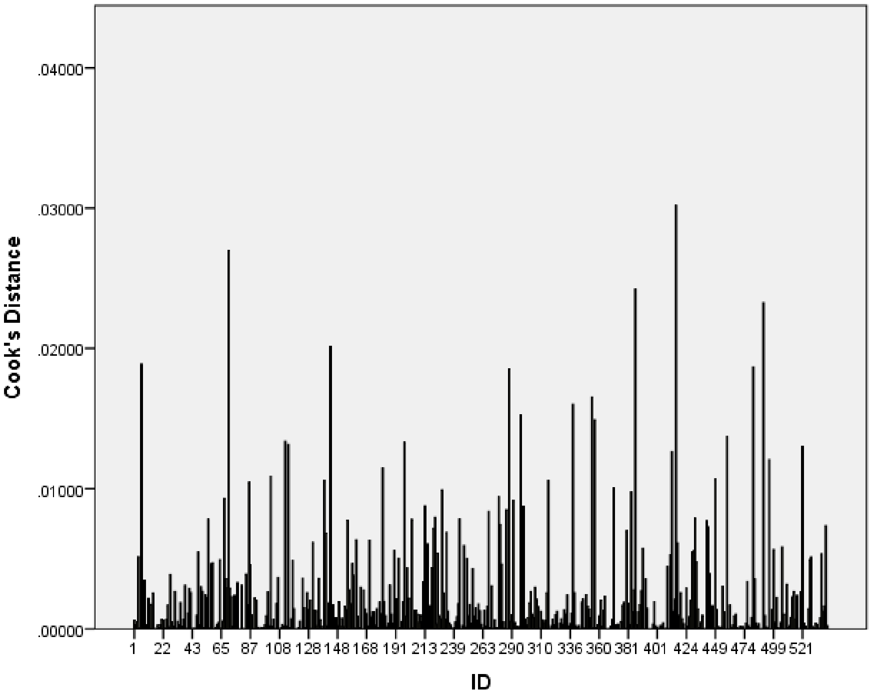


Figure OO-7: Bar charts (A) & (B) of Cook's distances for the regression model having comfort and odors factors (IV) and General, Ergonomic, Nervous, and Skin symptoms (DV) before and after deleting unusual data points (Adjusted model)

# Appendix PP : Checking bias in the MLR model of thermal, light, & noise comfort and odors factors (IV) on IAQ discomfort (DV)

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure PP-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

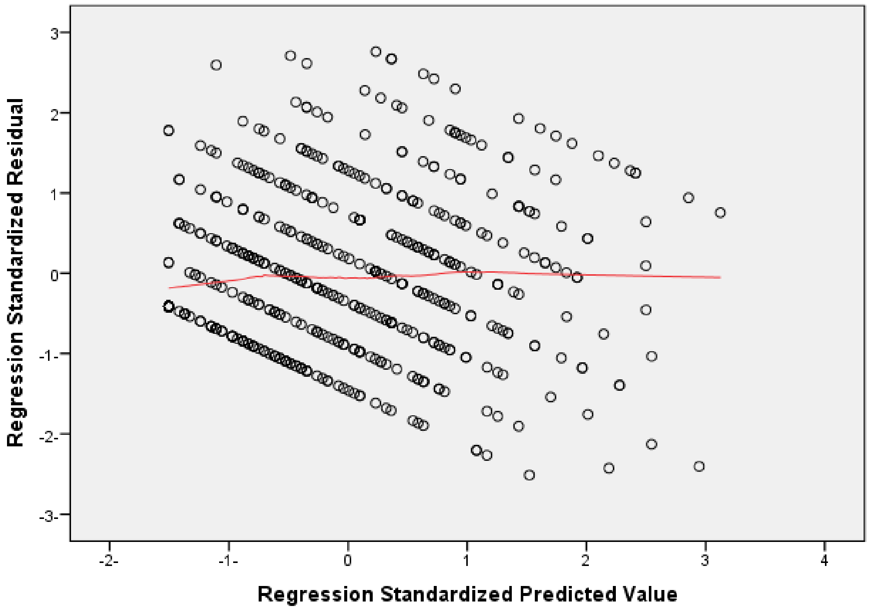


Figure PP-1: Scatter plot of regression standardized residuals and predicted values having thermal, lighting, noise discomfort and odors factors (IV) and IAQ discomfort (DV)

- As shown in Figure  PP-2, normal distribution of the residuals can be assumed for the final regression model since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013;  Eberly College of Science 2018c). Also, as illustrated in Figure  PP-3 and Figure  PP-4, the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 1.279 (Field 2016;  Ballance 2015; Ghani & Ahmad 2010).

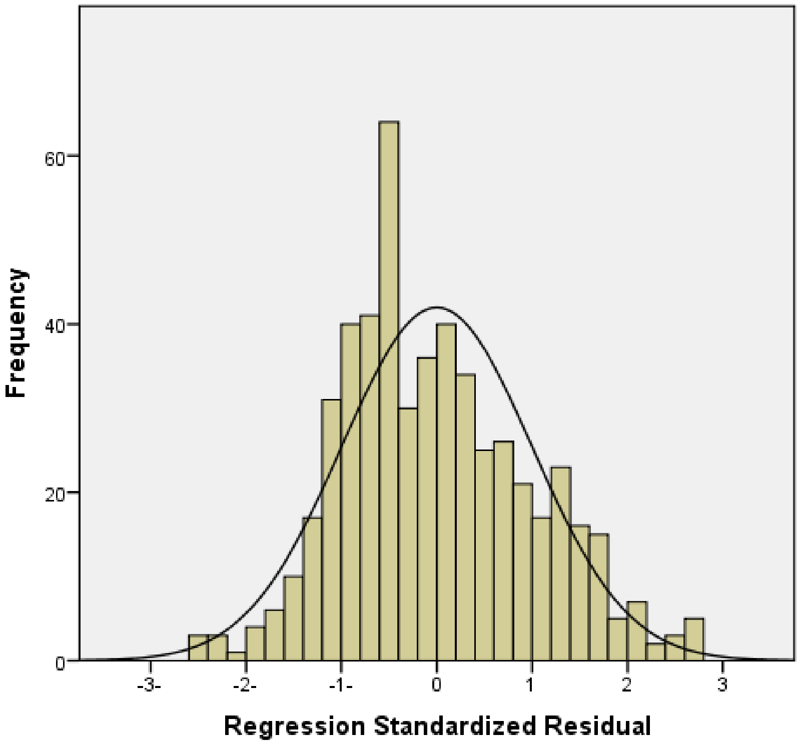


Figure  PP-2: Histogram of the regression standardized residuals having thermal, lighting, noise discomfort and odors factors (IV) and IAQ discomfort (DV)

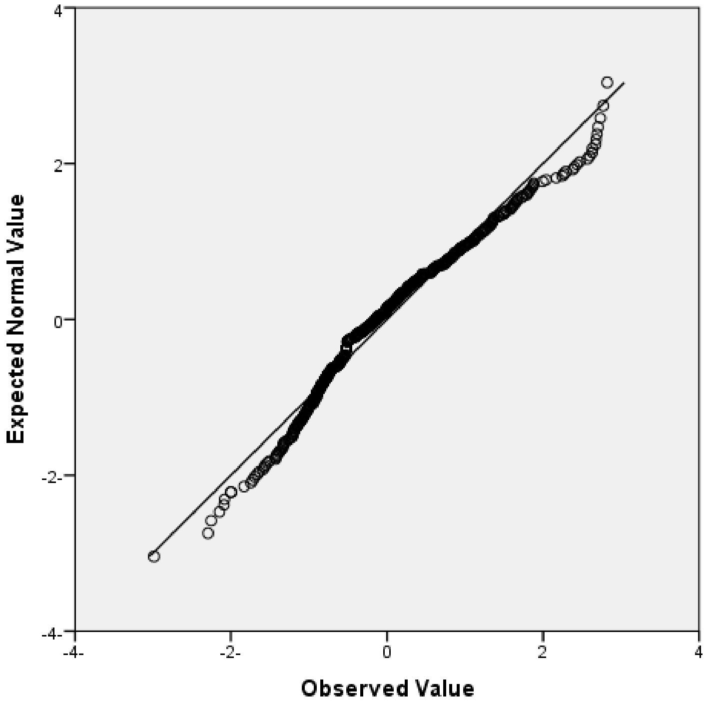


Figure PP-3: P-P plot of regression standardized residuals having thermal, lighting, noise discomfort and odors factors (IV) and IAQ discomfort (DV)

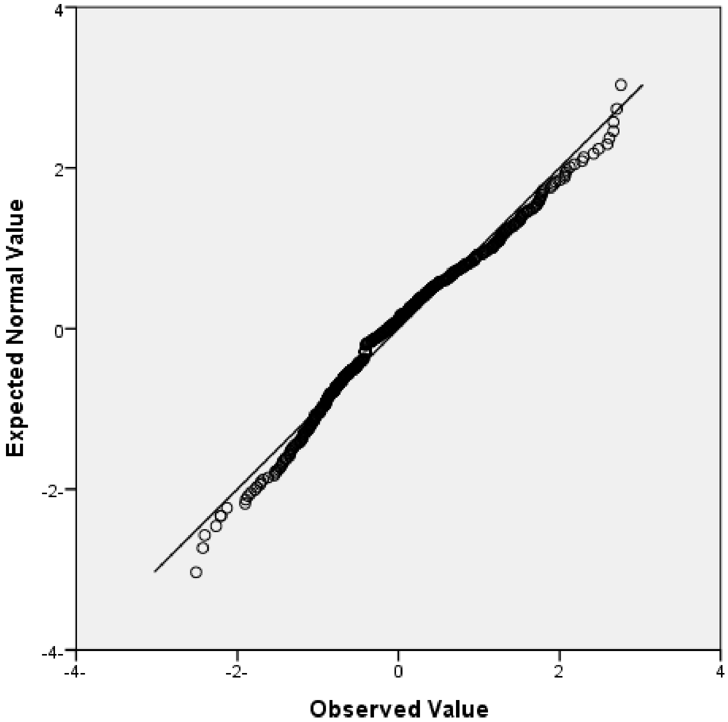
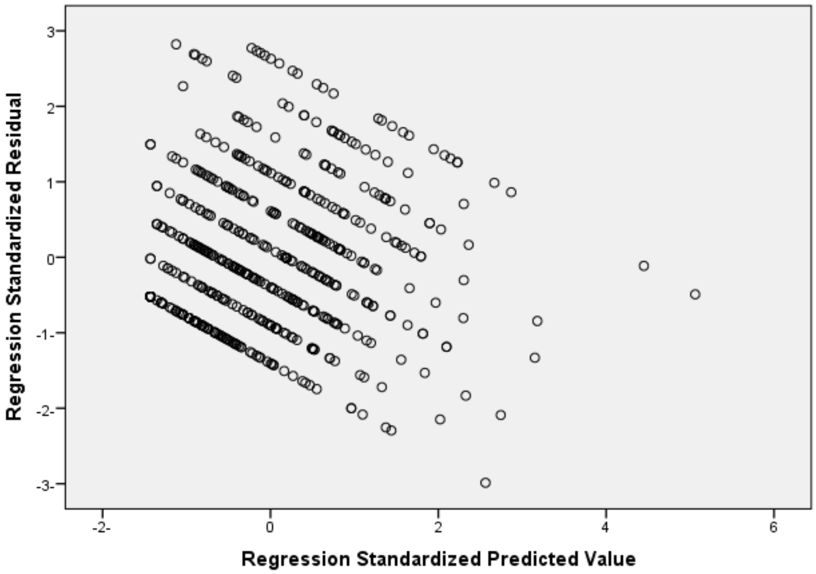


Figure PP-4: Q-Q plot of standardized residual having thermal, lighting, noise discomfort and odors factors (IV) and IAQ discomfort (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. A number of 12 data points of standardized residual values were not following those criteria (Figure PP-5(A)). According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 12 data points were deleted. Figure PP-5 (B) shows scatter plots of regression standardized residuals and standardized predicted values after deleting the above described data points.
- Examining data points of high leverage in the initial model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=3 parameters and n=542 in the initial model, the cutoff value of 2p/n and 3p/n was about 0.01 and 0.02; respectively. About 9 data points had leverage value above the 3p/n cutoff value and 28 points above 2p/n in the initial model. As shown in the right side of Figure PP-6 (A), a number of 6 data points of leverage value ≤ 0.02 were far away and obviously isolated from others. When deleting those points, all others were close and no point appeared to be isolated (Figure PP-6 (B)). A number of 12 points above the 2p/n cutoff values were retained in the final model since they did not seem to be unusual compared with others. Also, deleting them did not alter the in the variables identified as statistically significant and resulted in an insignificant change of about 0.01, 0.01, and 0.02 in $R^2$, adjusted $R^2$, and *SE* of estimate respectively. The highest leverage value in the final model was 0.02.
- Examining data points of high influence in the initial model followed the general Cook's distance cutoff value of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Plus 2007) as discussed in Section 3.4.3. No influential points were detected in the final model since the highest Cook's distance and DFBETAS were 0.041 and 0.302;

respectively. Figure  PP-7 (A) and (B) illustrates the Cook's distances for models before and after deleting above described unusual data points. Notably that the difference between Cook's distances are closer in (B) compared than (A) and no data point appears to be isolated from others.

(A)



(B)

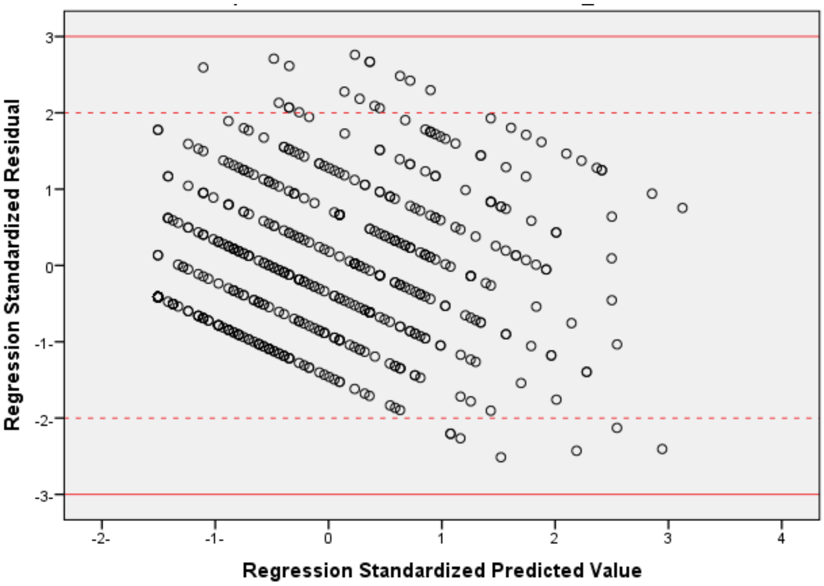
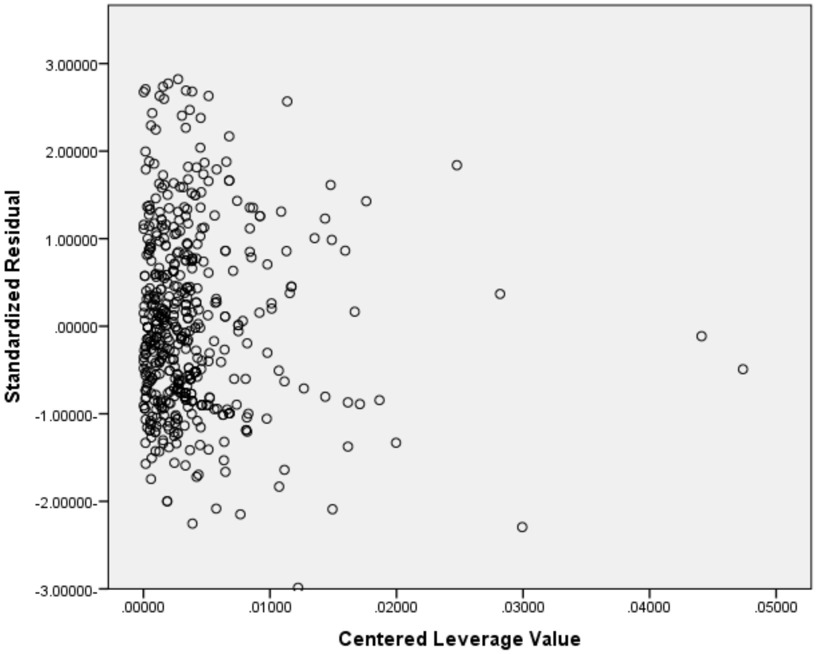


Figure  PP-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values having thermal, lighting, noise discomfort and odors factors (IV) and IAQ discomfort (DV) before and after deleting unusual points

(A)



(B)

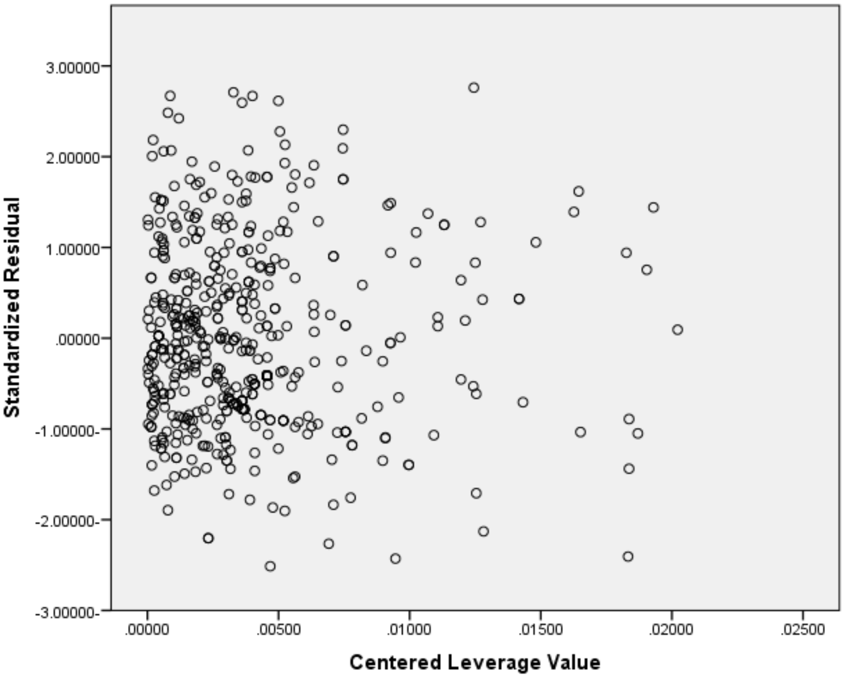
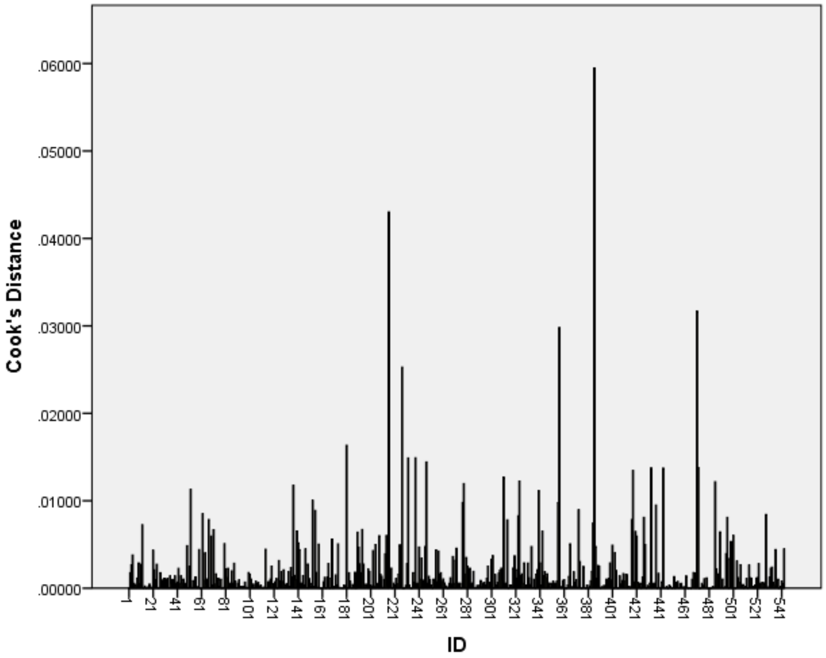


Figure PP-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values having thermal, lighting, noise discomfort and odors factors (IV) and IAQ discomfort (DV) before and after deleting unusual data points

(A)



(B)

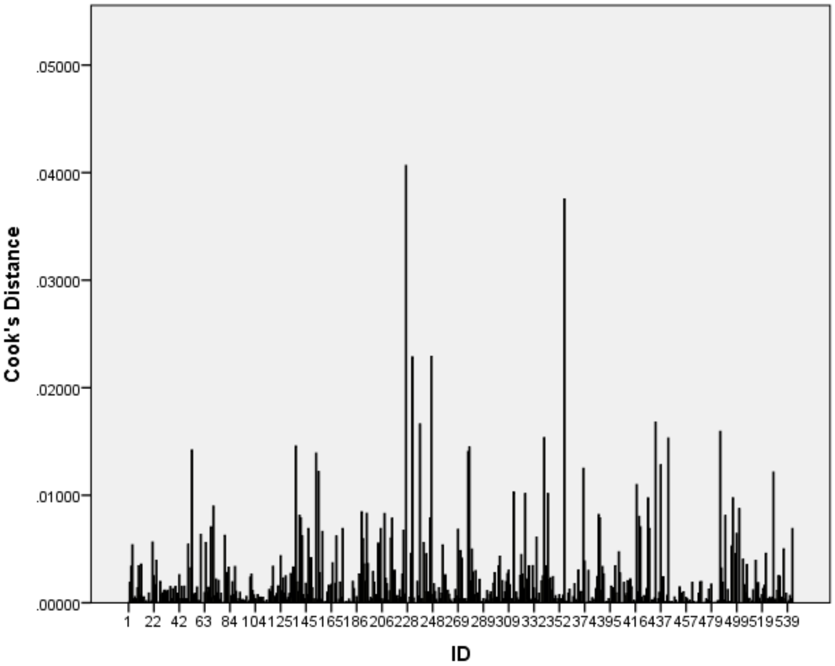


Figure PP-7: Bar charts (A) & (B) of Cook's distances for the regression model having thermal, lighting, noise discomfort and odors factors (IV) and IAQ discomfort (DV) before and after deleting unusual data points

# Appendix QQ : Checking bias in the MLR model of thermal, light, & noise comfort and odors factors (IV) on IAQ discomfort (DV) adjusted for significant population and building variables

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure QQ-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

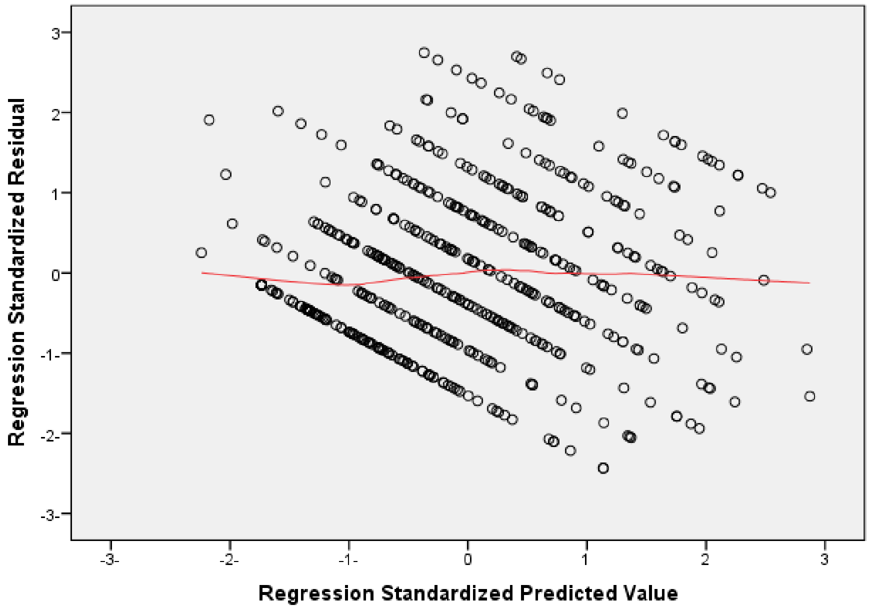


Figure QQ-1: Scatter plot of regression standardized residuals and predicted values having thermal, lighting, noise comfort and odors factors (IV) and IAQ discomfort (DV) (Adjusted model)

- As shown in Figure QQ-2, normal distribution of the residuals can be assumed for the final regression model since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013; Eberly College of Science 2018c). Also, as illustrated in Figure QQ-3 and Figure QQ-4, the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 1.287 (Field 2016; Ballance 2015; Ghani & Ahmad 2010).

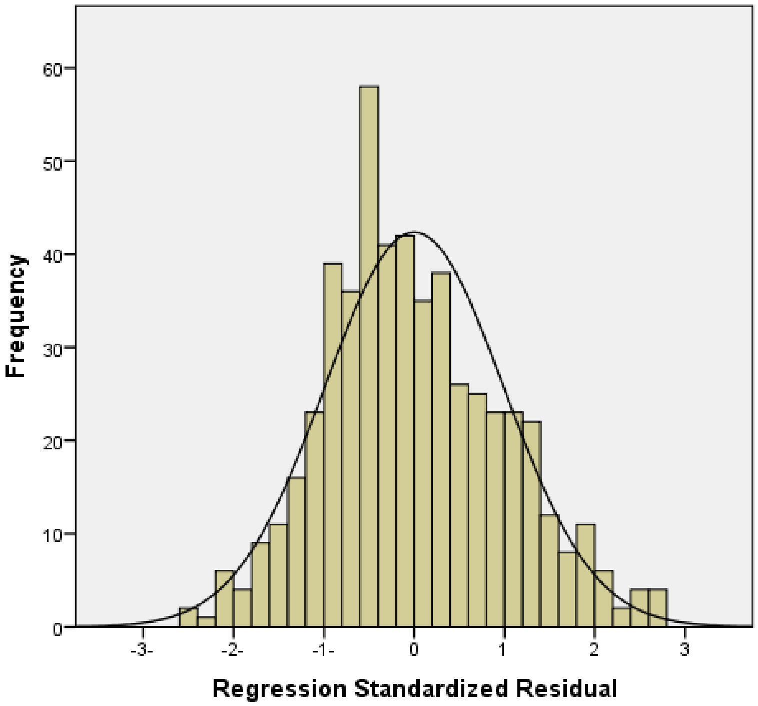


Figure QQ-2: Histogram of the regression standardized residuals having thermal, lighting, noise comfort and odors factors (IV) and IAQ discomfort (DV) (Adjusted model)

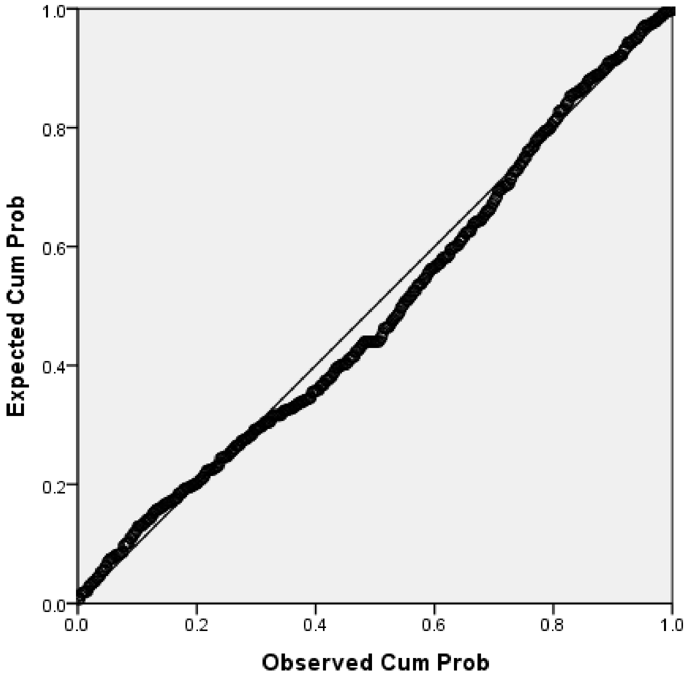


Figure QQ-3: P-P plot of standardized residuals having thermal, lighting, noise comfort and odors factors (IV) and IAQ discomfort (DV) (Adjusted model)

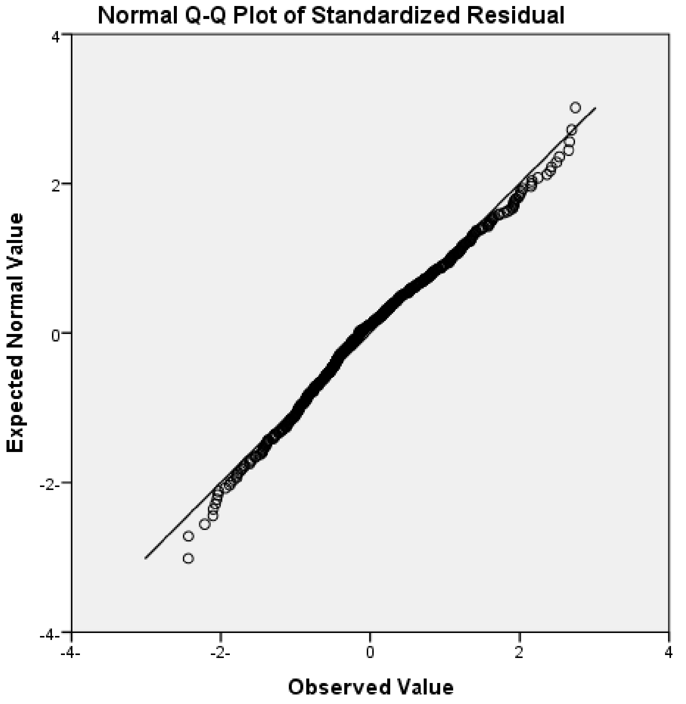
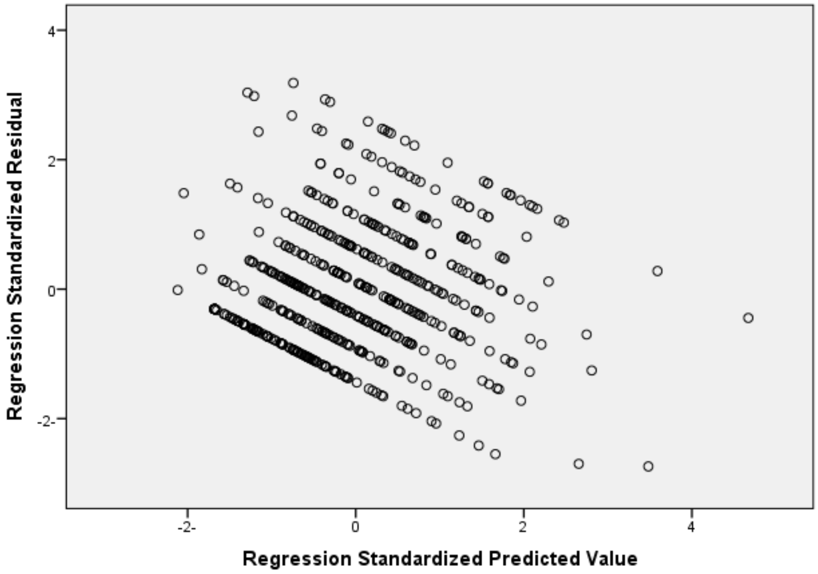


Figure QQ-4: Q-Q plot of standardized residual having thermal, lighting, noise comfort and odors factors (IV) and IAQ discomfort (DV) (Adjusted model)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. A number of 14 data points of standardized residual values were not following those criteria (Figure QQ-5 (A)). According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 14 data points were deleted. Figure QQ-5 (B) shows scatter plots of regression standardized residuals and standardized predicted values after deleting the above described data points.
- Examining data points of high leverage in the initial model followed the size adjusted cutoff value of 2p/n and 3p/n discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=9 parameters and n=542 in the initial regression model, the cutoff value of 2p/n and 3p/n was about 0.03 and 0.05; respectively. About 19 data points had leverage value above the 2p/n cutoff value and 2 points were above the 3p/n in the initial model as shown in the right side of Figure QQ-6 (A). The 2 data points were far away and obviously isolated from other observations. When deleting those data points, all others were close and no data point appeared to be isolated (Figure QQ-6 (B)). A number of 18 points were above the 2p/n cutoff value retained in the final model because deleting them did not alter the in the variables identified as statistically significant and resulted in an insignificant change of about 0.01, 0.01, and 0.03 in $R^2$, adjusted $R^2$, and *SE* of estimate respectively. The highest leverage value in the final model was 0.05.
- Examining data points of high influence in the initial model followed the general cutoff value Cook's distance of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Nelson 2004) as discussed in Section 3.4.3. No influential points were detected in the final model since the highest Cook's distance and DFBETAS were 0.027 and 0.288; respectively. Figure QQ-7 (A) and (B) illustrates the Cook's distances for models

before and after deleting above described unusual points. Notably that the difference between Cook's distances are closer in (B) compared with (A) and no point appears to be isolated from others.

(A)



(B)

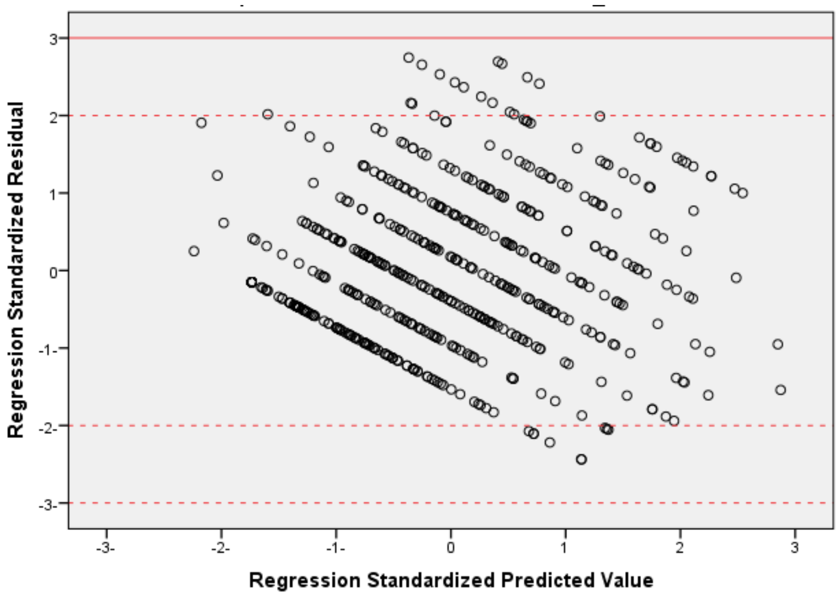
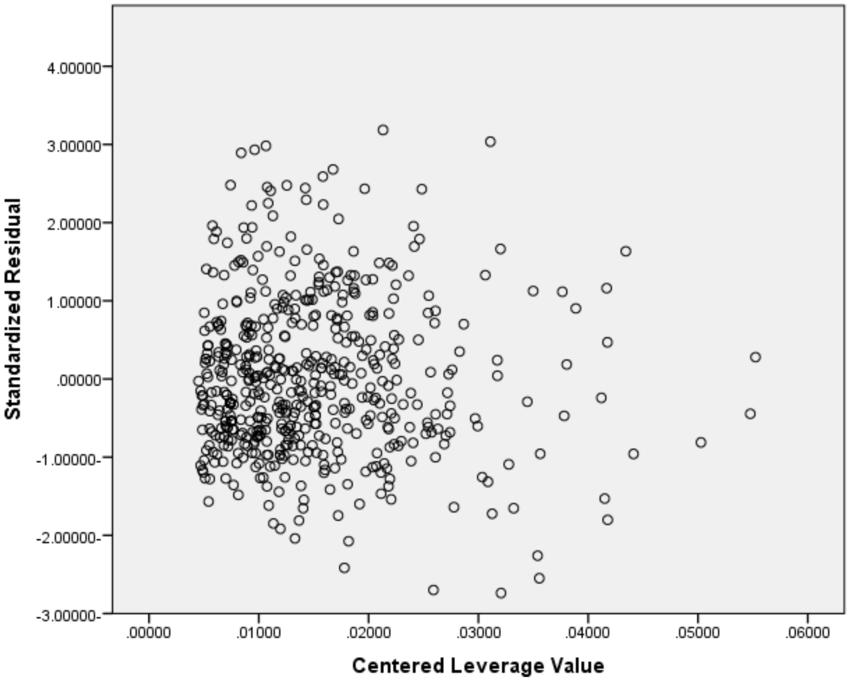


Figure QQ-5: Scatter plots (A) & (B) of standardized residuals and standardized predicted values having thermal, lighting, noise comfort and odors factors (IV) and IAQ discomfort (DV) before and after deleting unusual points (Adjusted model)

(A)



(B)

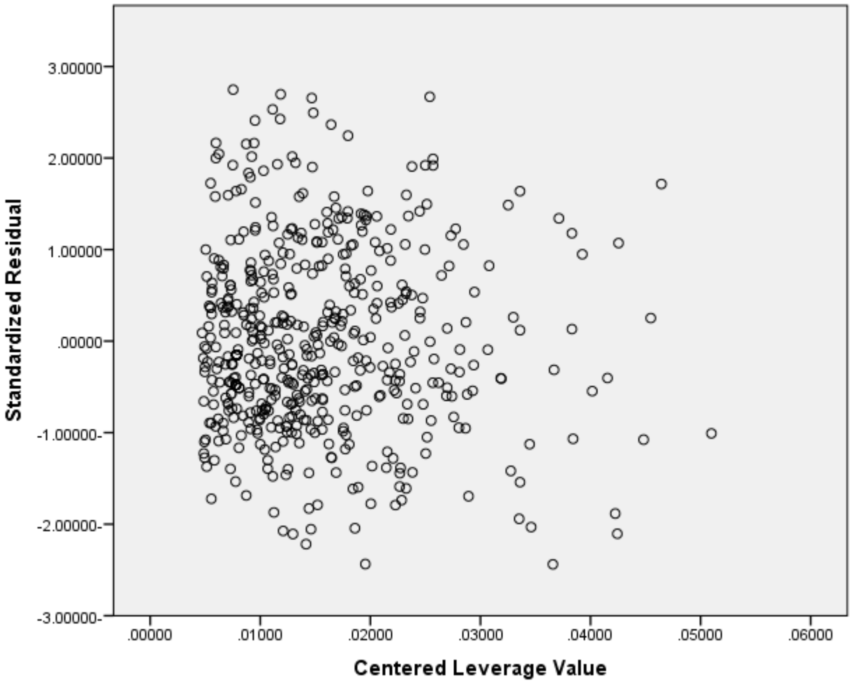


Figure QQ-6: Scatter plots (A) & (B) of standardized residuals and leverage values having thermal, lighting, noise comfort and odors factors (IV) and IAQ discomfort (DV) before and after deleting unusual data points (Adjusted model)

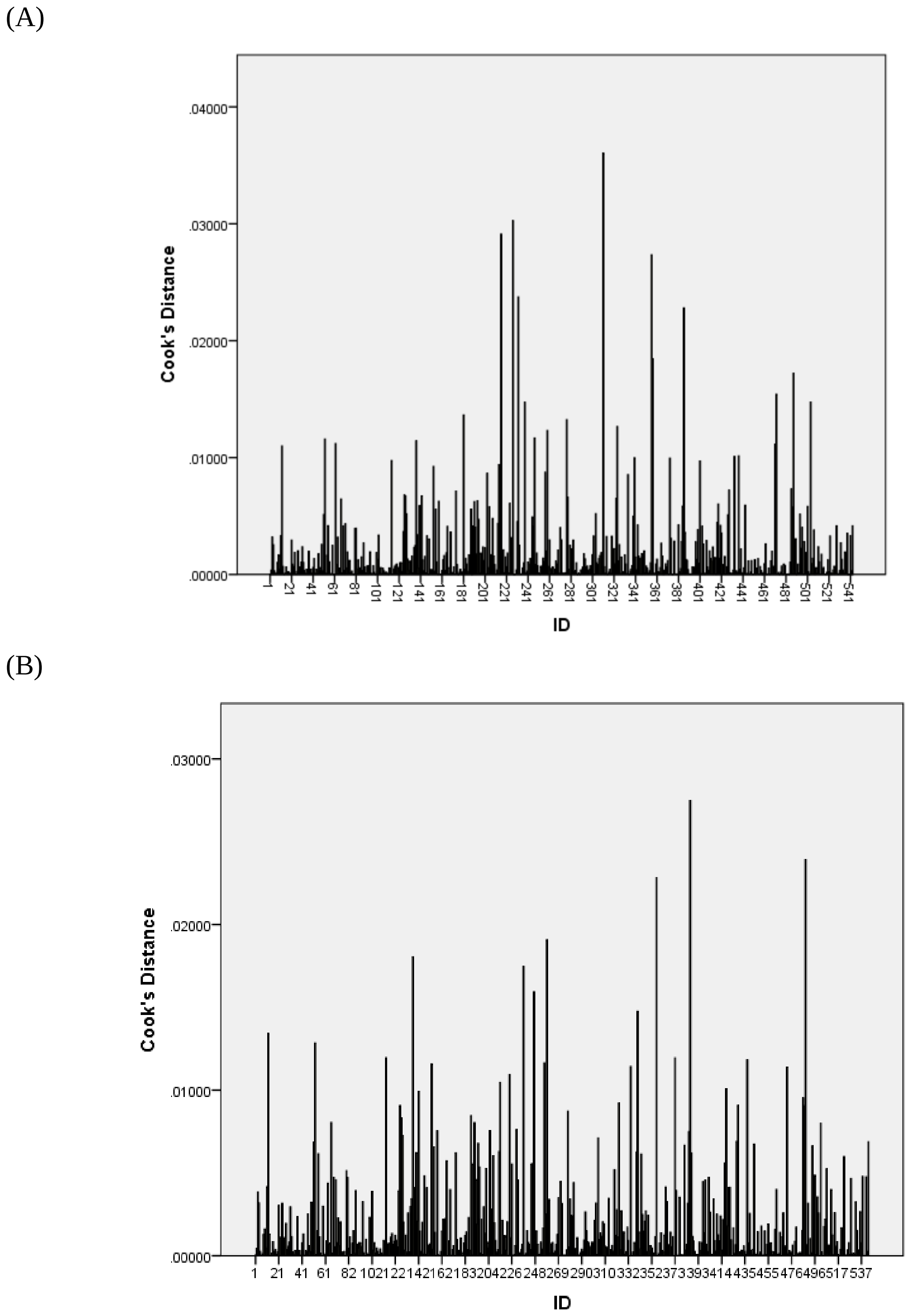


Figure QQ-7: Bar charts (A) & (B) of Cook's distances for the regression model having thermal, lighting, noise comfort and odors factors (IV) and IAQ discomfort (DV) before and after deleting unusual points (Adjusted model)

# Appendix RR : Checking bias in the MLR model of thermal, light, & noise discomfort variables (IV) on Eye, Nose, Throat, and Chest symptoms (DV)

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure RR-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

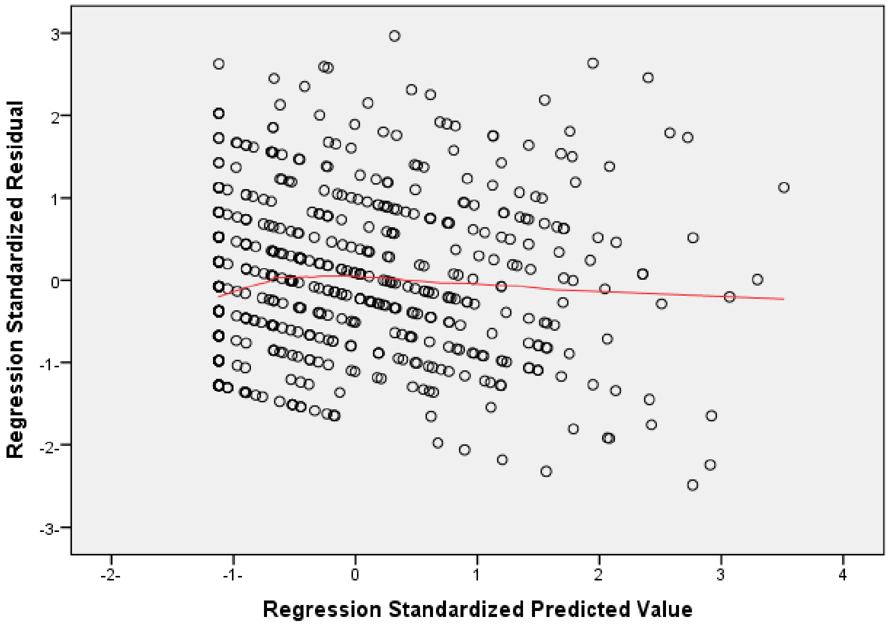


Figure RR-1: Scatter plot of regression standardized residuals and predicted values having thermal, lighting, noise discomfort variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

- As shown in Figure RR-2, normal distribution of the residuals can be assumed for the final regression model since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013; Eberly College of Science 2018c). Also, as illustrated in Figure RR-3 and Figure RR-4, the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 1.556 (Field 2016; Ballance 2015; Ghani & Ahmad 2010).

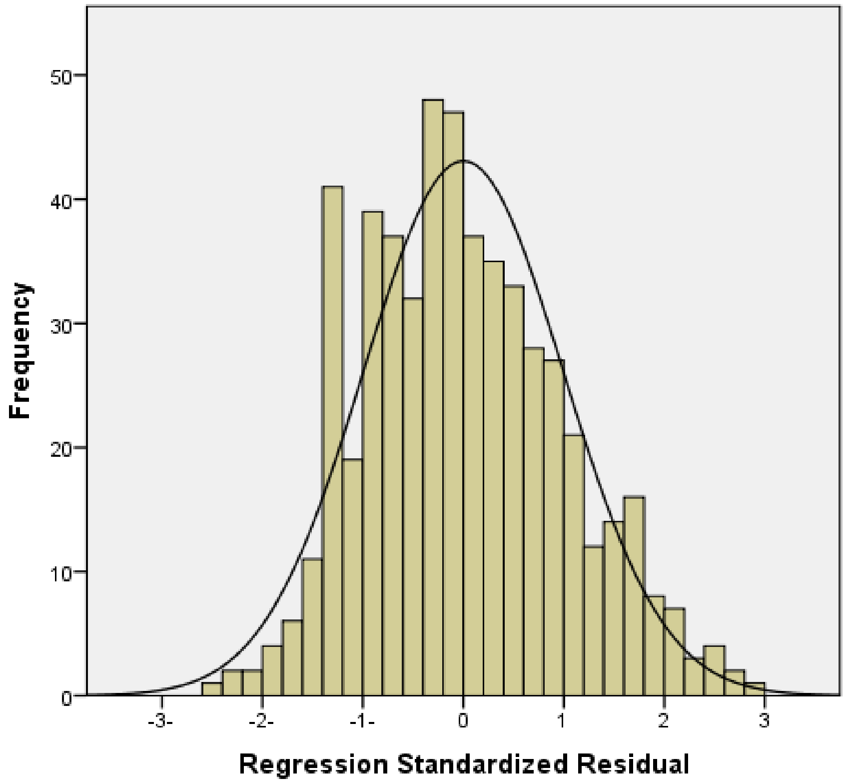


Figure RR-2: Histogram of the regression standardized residuals of thermal, lighting, noise discomfort variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

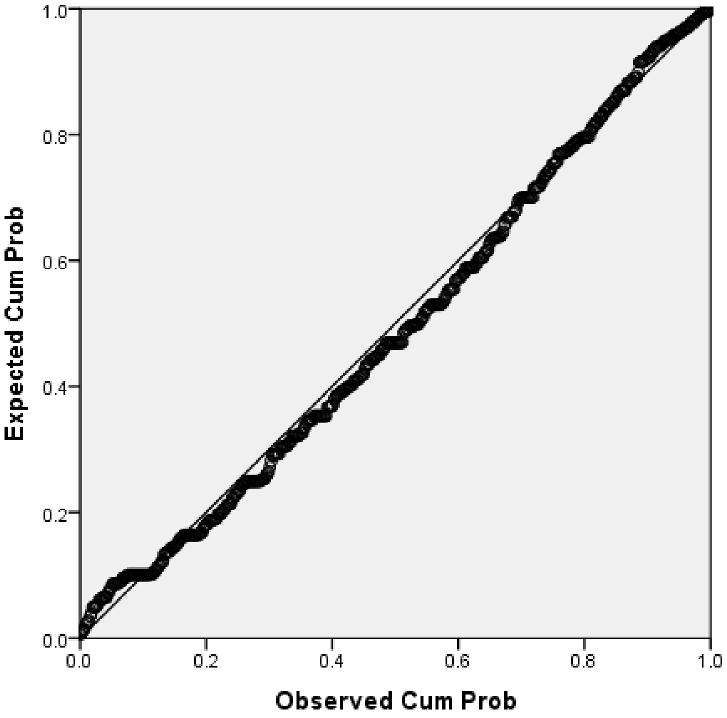


Figure RR-3: P-P plot of regression standardized residuals having thermal, lighting, noise discomfort variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

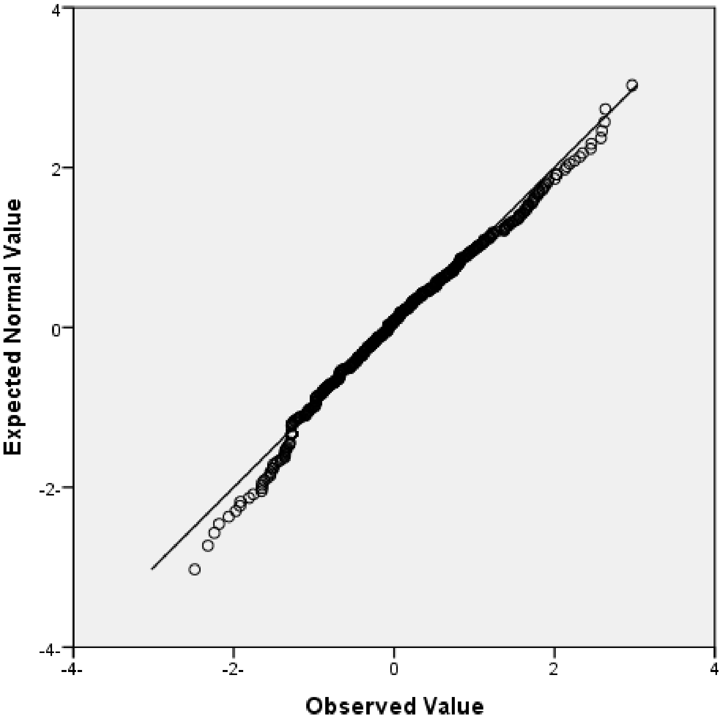


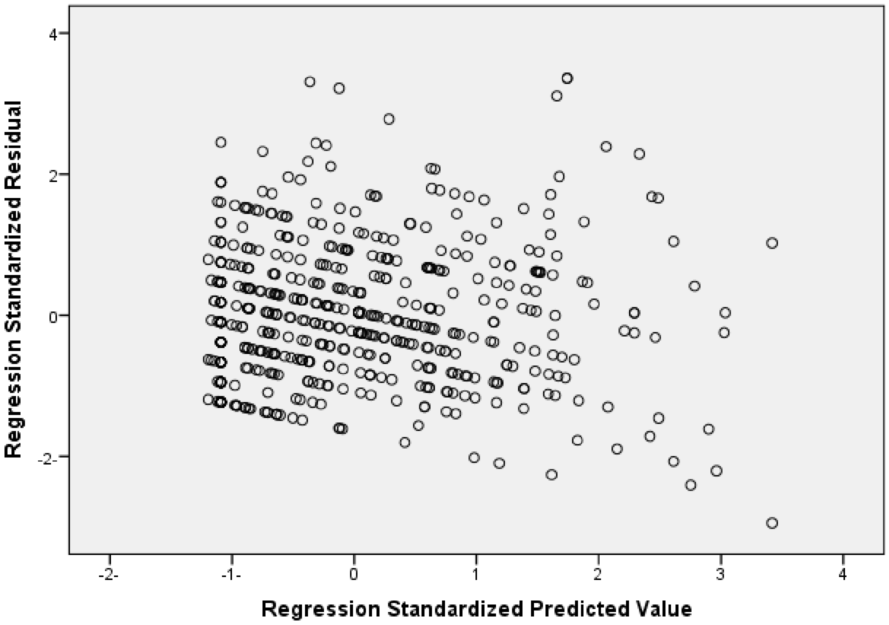
Figure RR-4: Q-Q plot of standardized residual having thermal, lighting, noise discomfort variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. A number of 6 data points of standardized residual values were not following those criteria (Figure RR-5 (A)). According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 6 data points were deleted. Figure RR-5 (B) shows scatter plots of regression standardized residuals and standardized predicted values after deleting the above described data points.
- Examining data points of high leverage in the initial model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=7 parameters and n=542 in the initial model,

the cutoff value of 2p/n and 3p/n was about 0.03 and 0.04; respectively. About 6 data points had leverage value above the 3p/n cutoff value and 48 points above 2p/n in the initial model. As shown in the right side of Figure RR-6 (A), a number of 2 data points of leverage value 0.0573 were far away and obviously isolated from others. Deleting those points did not alter the in the variables identified as statistically significant; didn't affect $R^2$, and adjusted $R^2$, and caused insignificant change of 0.012 in the *SE* of estimate. Deleting the 6 points caused insignificant change of about 0.005, 0.005, and 0.015 in $R^2$, adjusted $R^2$, and *SE* of estimate respectively. Therefore, those 6 points above the 3p/n cutoff with leverage values ≤ 0.06 (Figure RR-6 (B) were retained in the final model since deleting them caused insignificant change.

- Examining data points of high influence in the initial model followed the general Cook's distance cutoff value of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Nelson 2004) as discussed in Section 3.4.3. No influential points were detected in the final model since the highest Cook's distance and DFBETAS were 0.042 and 0.422; respectively. Figure RR-7 (A) and (B) illustrates the Cook's distances for models before and after deleting above described unusual data points.

(A)



(B)

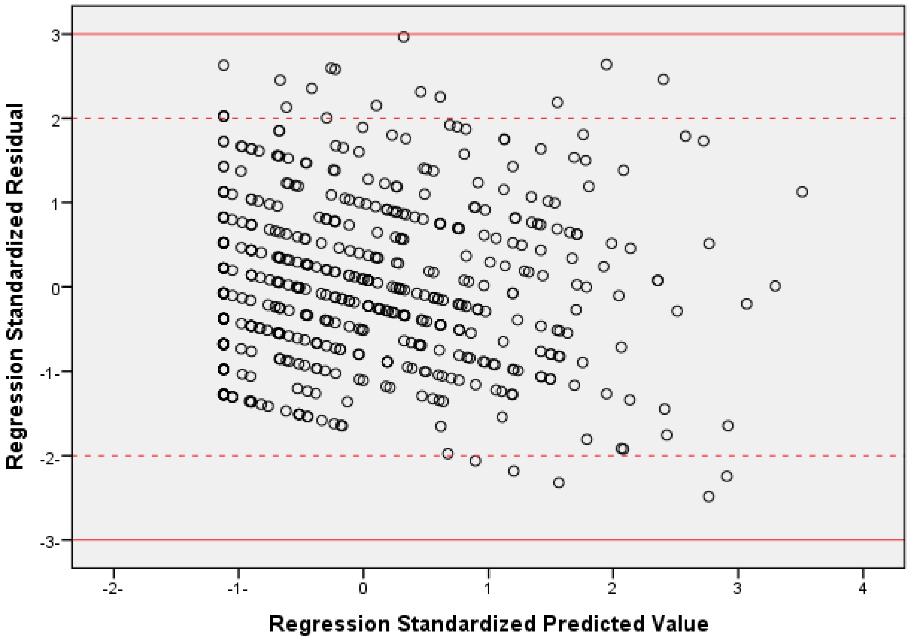
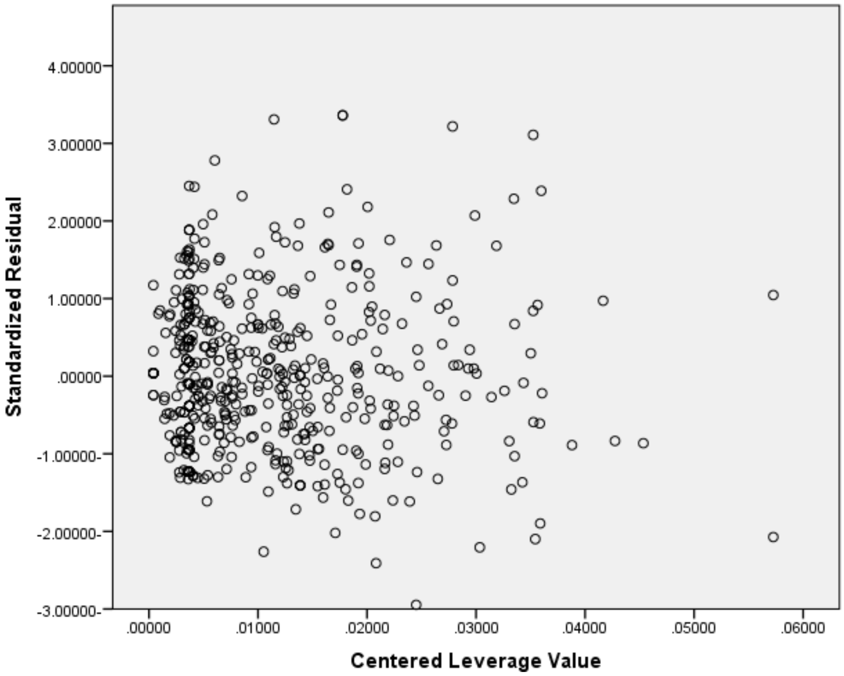


Figure RR-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values having thermal, lighting, noise discomfort variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual points

(A)



(B)

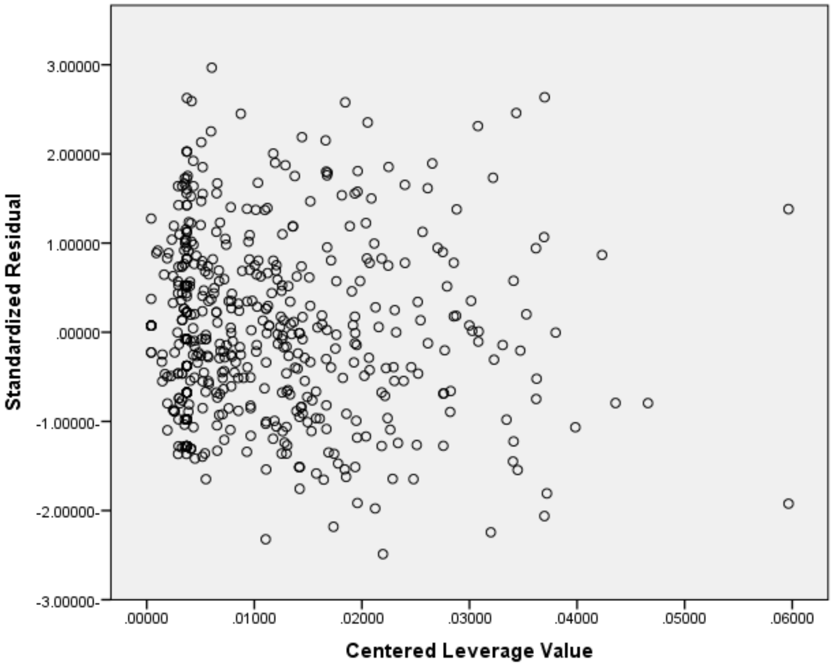
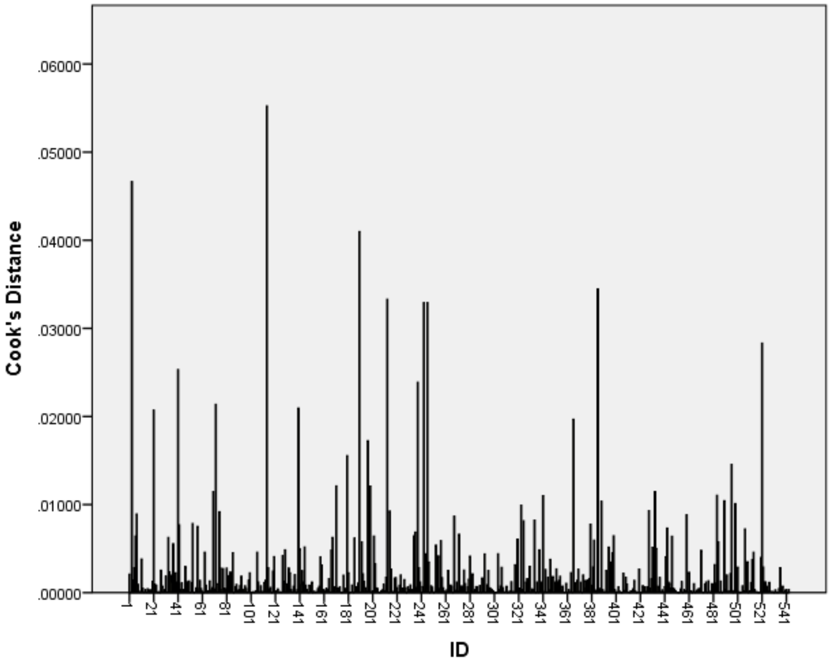


Figure RR-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values thermal, lighting, noise discomfort variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual data points

(A)



(B)

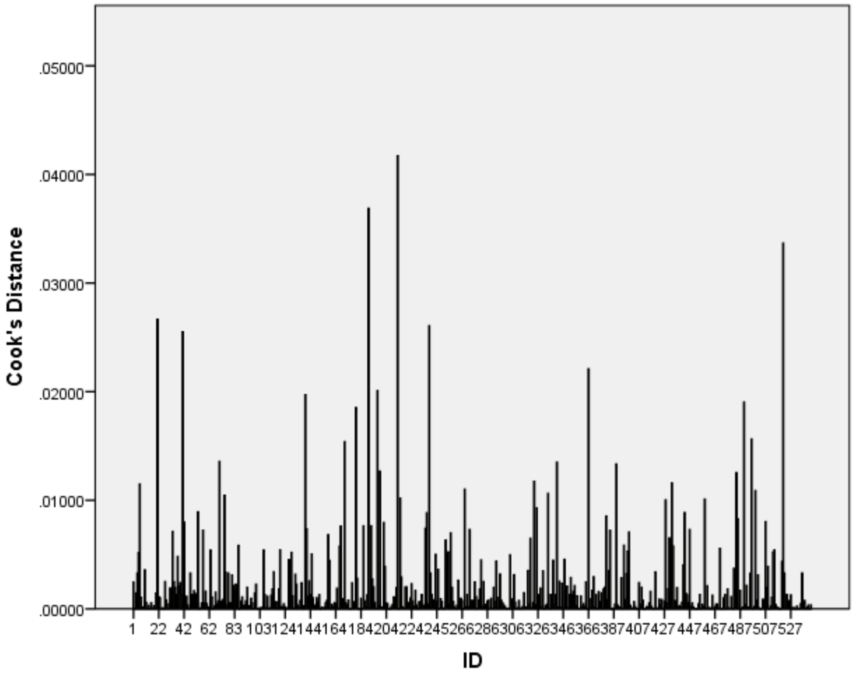


Figure  RR-7: Bar charts (A) & (B) of Cook's distances for the regression model having thermal, lighting, noise discomfort variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual data points

## Appendix SS : Checking bias in the MLR model of IAQ discomfort variables (IV) on Eye, Nose, Throat, and Chest symptoms (DV)

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure  SS-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of vertical straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

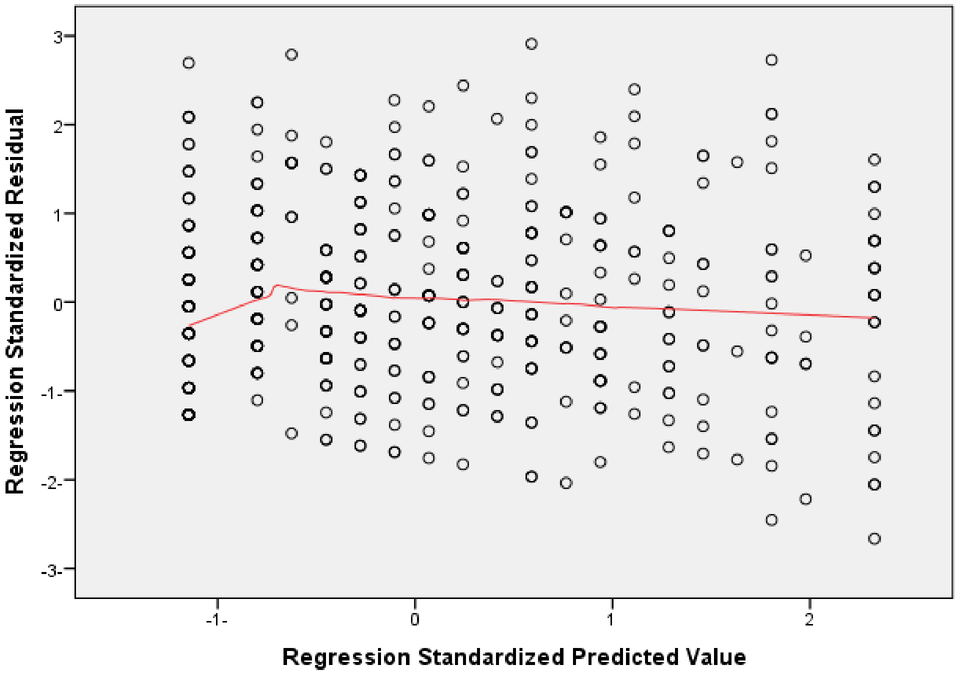


Figure SS-1: Scatter plot of regression standardized residuals and predicted values having IAQ discomfort variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

- As shown in Figure SS-2, normal distribution of the residuals can be assumed for the final regression model since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013; Eberly College of Science 2018c). Also, as illustrated in Figure SS-3 and Figure SS-4, the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 1.481 (Field 2016; Ballance 2015; Ghani & Ahmad 2010).

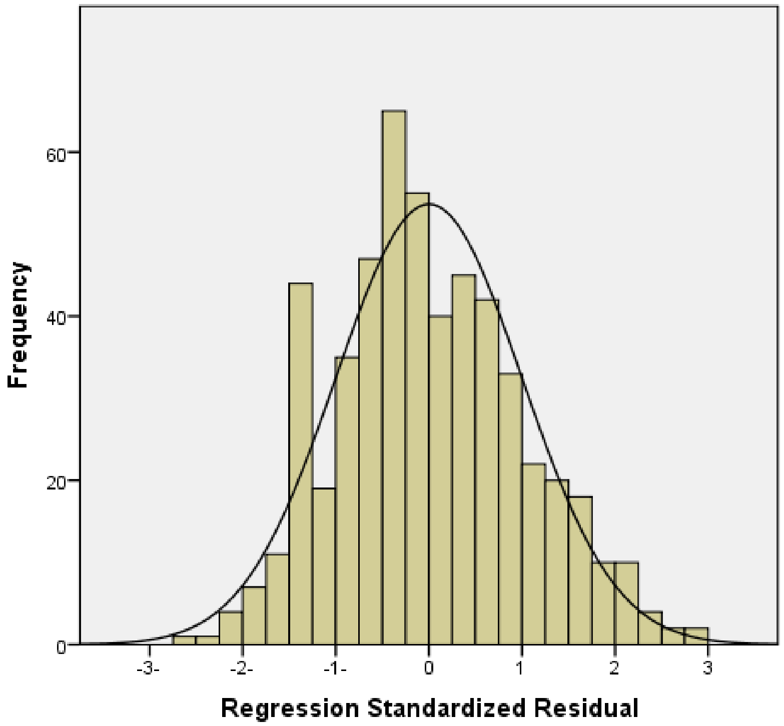


Figure SS-2: Histogram of the regression standardized residuals of IAQ discomfort variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

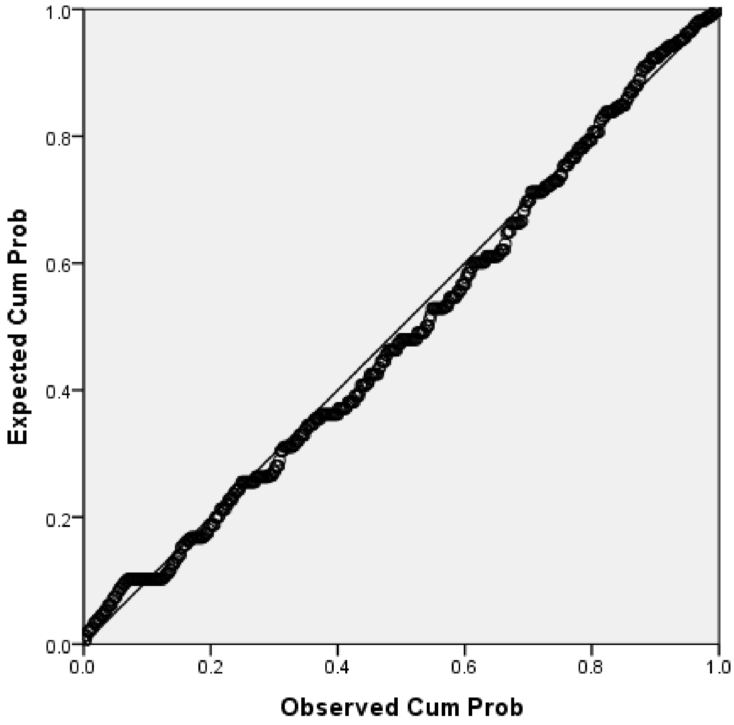


Figure SS-3: P-P plot of regression standardized residuals of IAQ discomfort variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

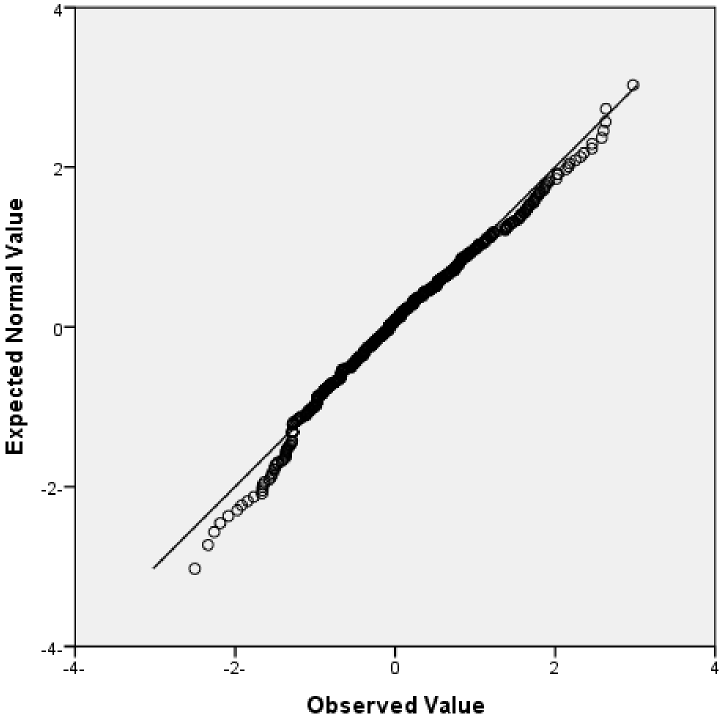


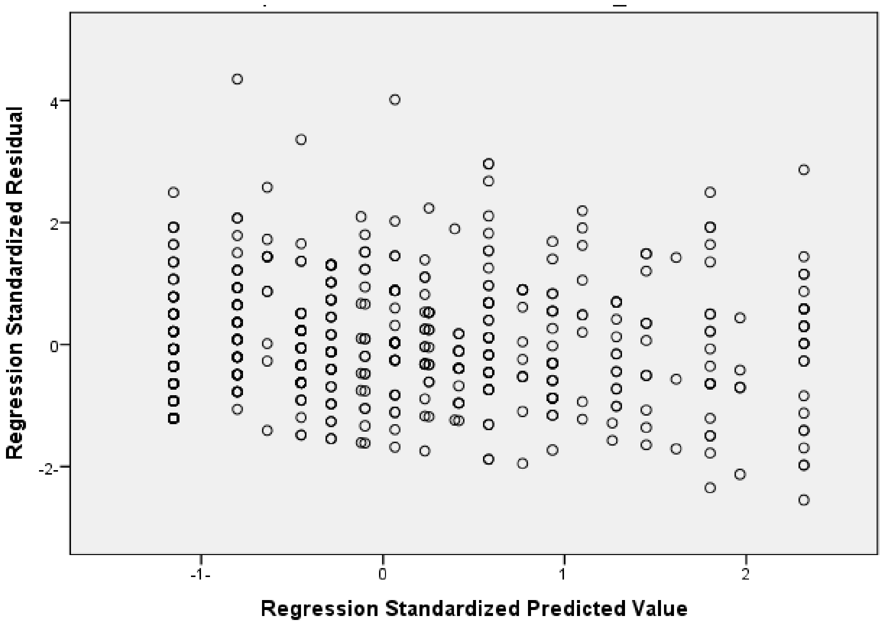
Figure SS-4: Q-Q plot of standardized residual of IAQ discomfort variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. A number of 6 data points of standardized residual values were not following those criteria (Figure SS-5(A)). According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 6 data points were deleted. Figure SS-5(B) shows scatter plots of regression standardized residuals and standardized predicted values after deleting the above described data points.
- Examining data points of high leverage in the initial model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu

2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=3 parameters and n=542 in the initial model, the cutoff value of 2p/n and 3p/n was about 0.011 and 0.017; respectively. About 4 data points had leverage value above the 3p/n cutoff value and 21 points above 2p/n in the initial model. As shown in the right side of Figure SS-6 (A), a number of 4 data points of leverage value ≥ 0.017 were far away and obviously isolated from others. Deleting those points did not alter the in the variables identified as statistically significant and resulted in an insignificant change of about 0.006, 0.006, and 0.02 in $R^2$, adjusted $R^2$, and *SE* of estimate respectively. Therefore, those 4 points above the 3p/n cutoff (Figure SS-6 (B)) were retained in the final model since deleting them caused insignificant change. The highest leverage value in the final model was 0.02.

- Examining data points of high influence in the initial model followed the general Cook's distance cutoff value of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Nelson 2004) as discussed in Section 3.4.3. No influential points were detected in the final model since the highest Cook's distance and DFBETAS were 0.043 and 0.431; respectively. Figure SS-7 (A) and (B) illustrates the Cook's distances for models before and after deleting above described unusual data points.

(A)



(B)

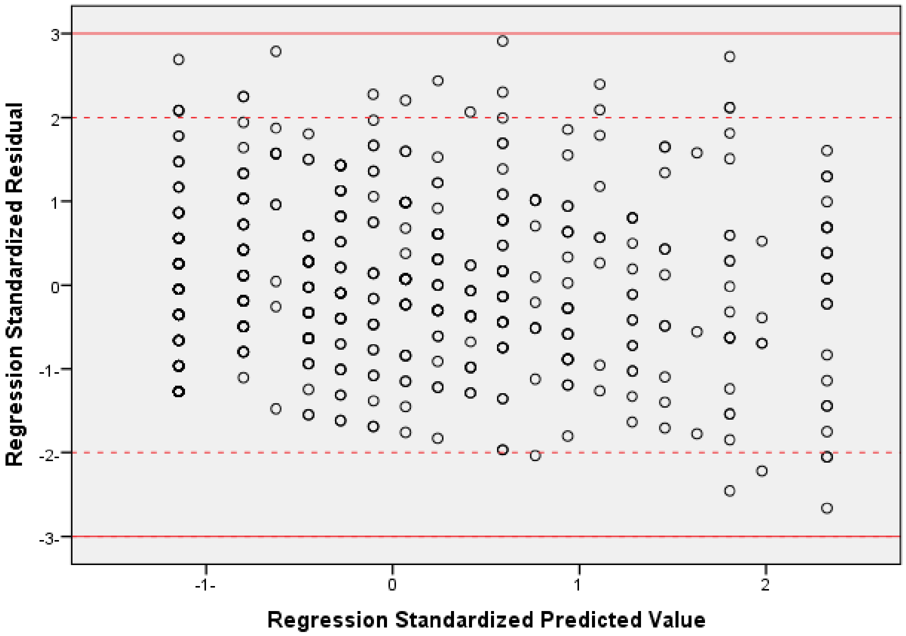
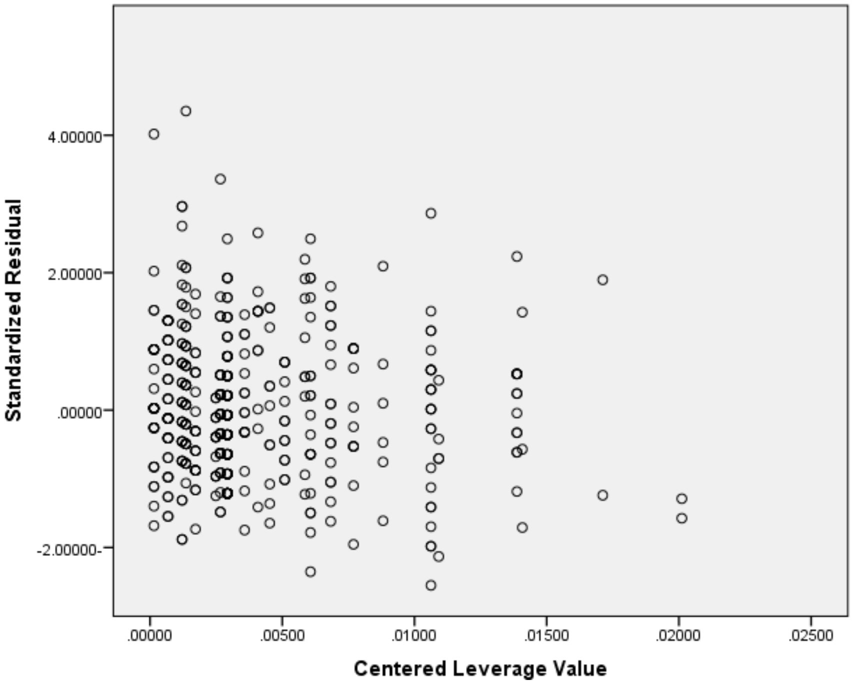


Figure  SS-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values having IAQ discomfort variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual points

(A)



(B)

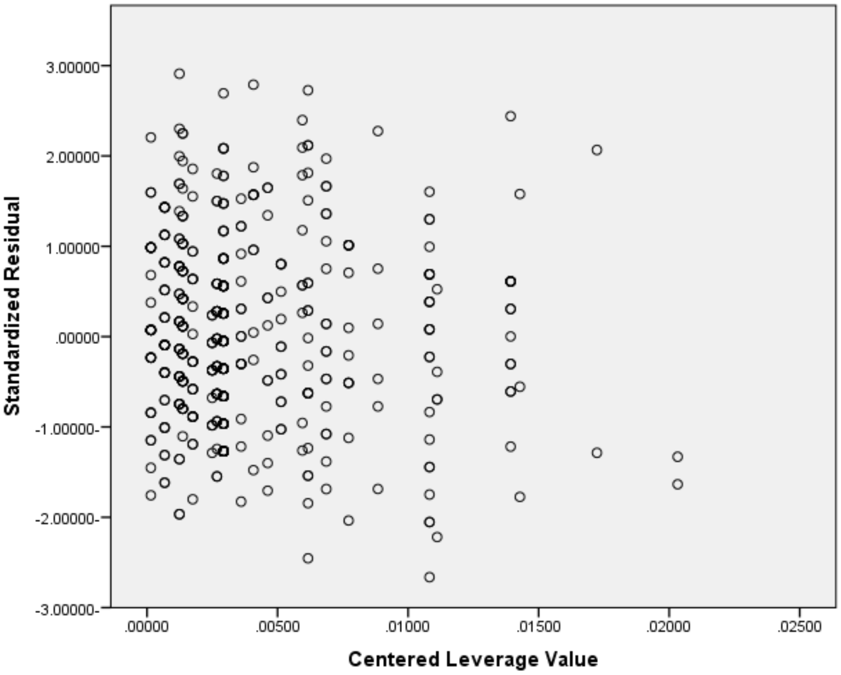


Figure SS-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values of IAQ discomfort variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual data points

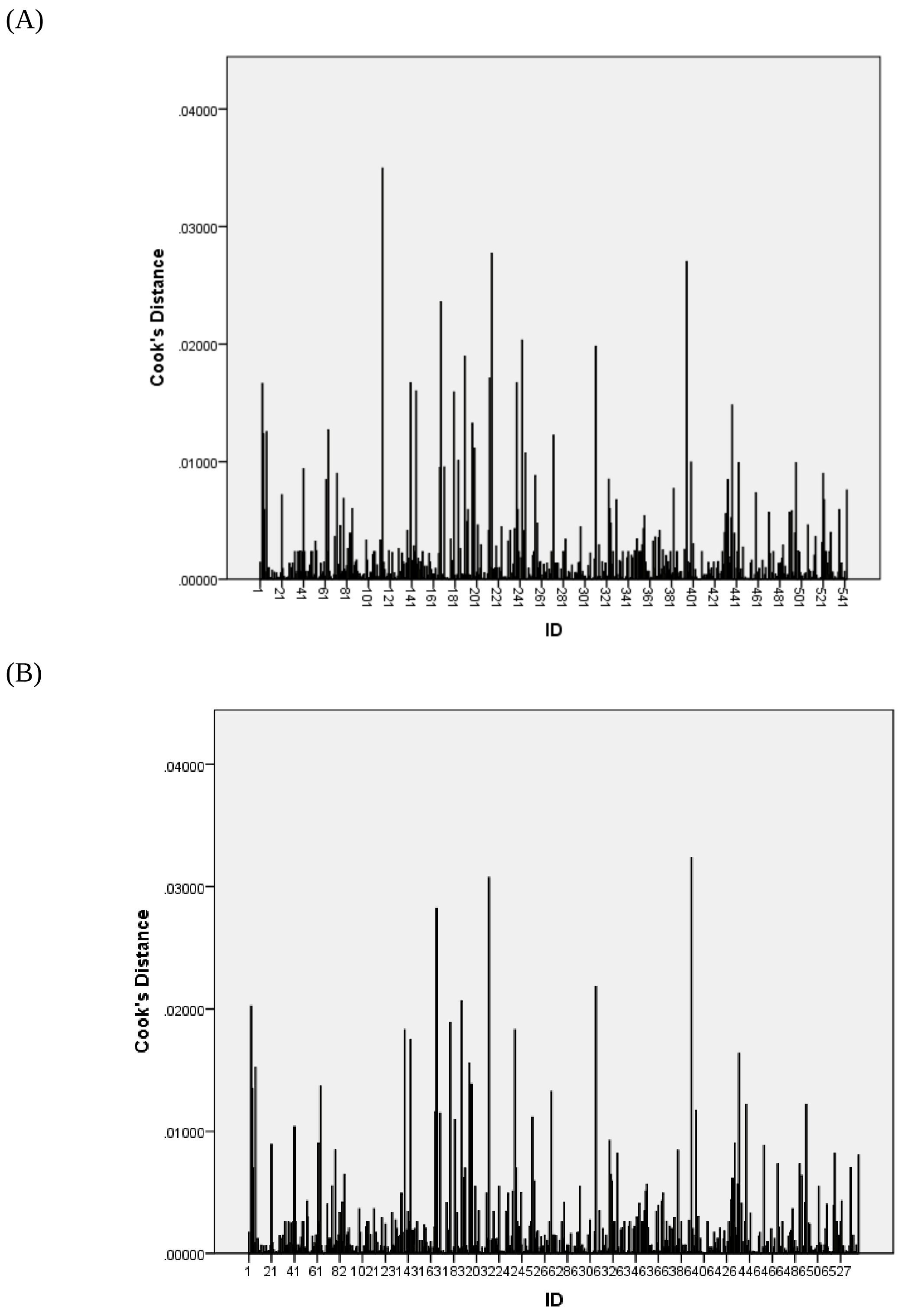


Figure SS-7: Bar charts (A) & (B) of Cook's distances for the regression model of IAQ discomfort variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual data points

# Appendix TT : Checking bias in the MLR model of odors variables (IV) on Eye, Nose, Throat, and Chest symptoms (DV)

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure TT-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

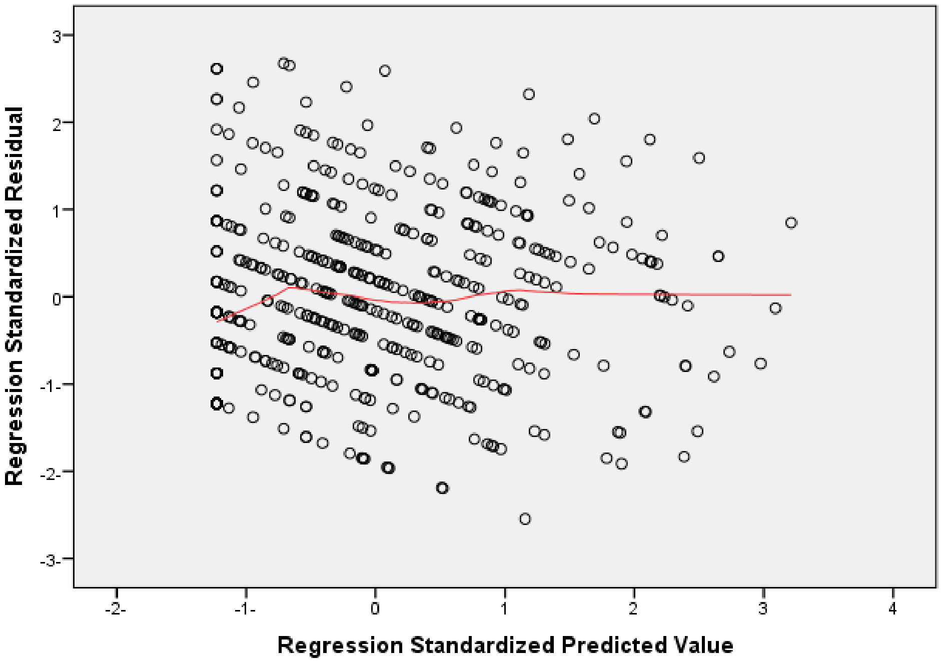


Figure TT-1: Scatter plot of regression standardized residuals and predicted values having odors variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

- As shown in Figure  TT-2, normal distribution of the residuals can be assumed for the final regression model since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013;  Eberly College of Science 2018c). Also, as illustrated in Figure  TT-3 and Figure  TT-4, the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 1.419 (Field 2016;  Ballance 2015; Ghani & Ahmad 2010).

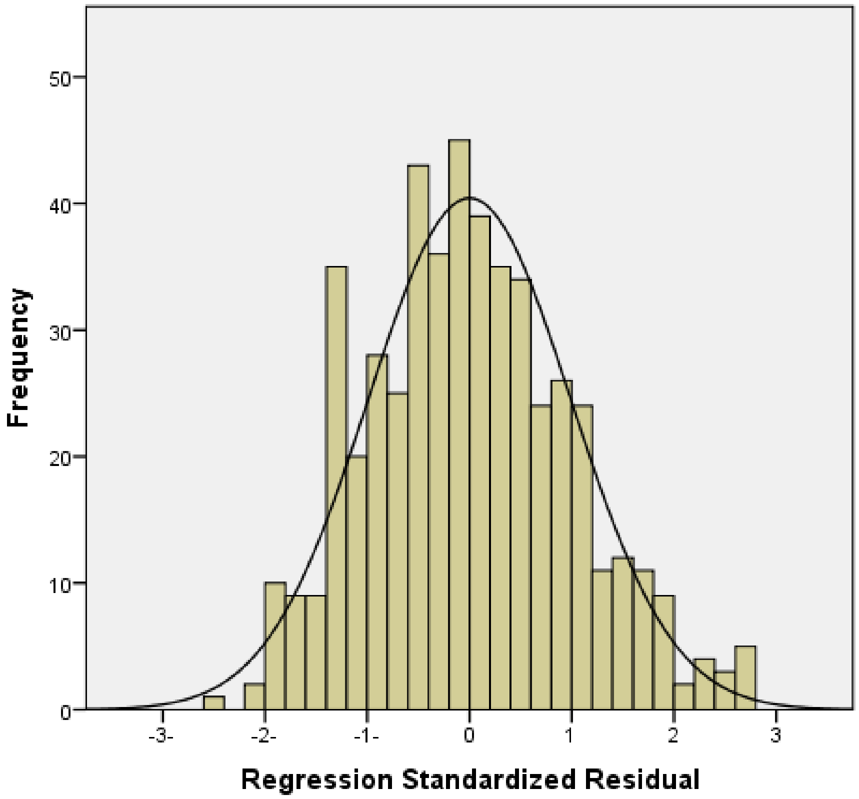


Figure  TT-2: Histogram of the regression standardized residuals of odors variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

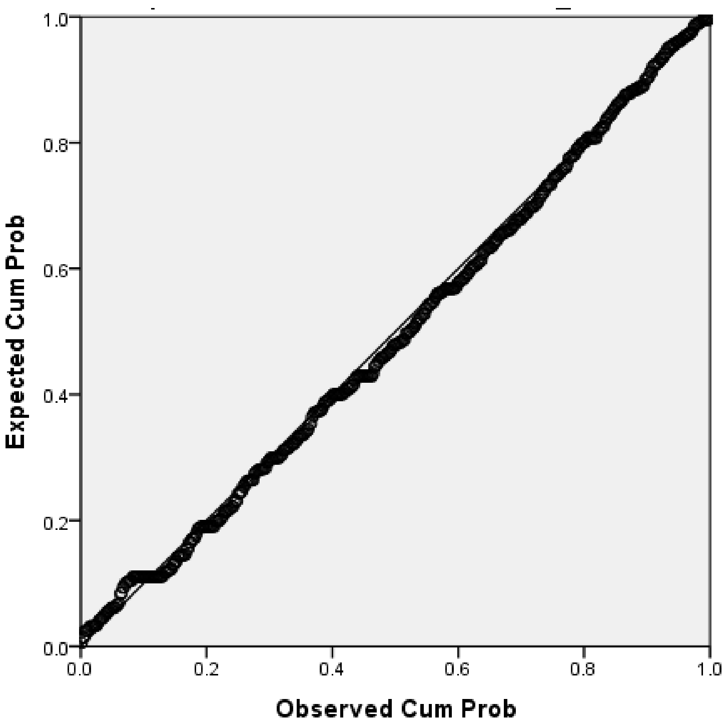


Figure TT-3: P-P plot of regression standardized residuals of odors variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

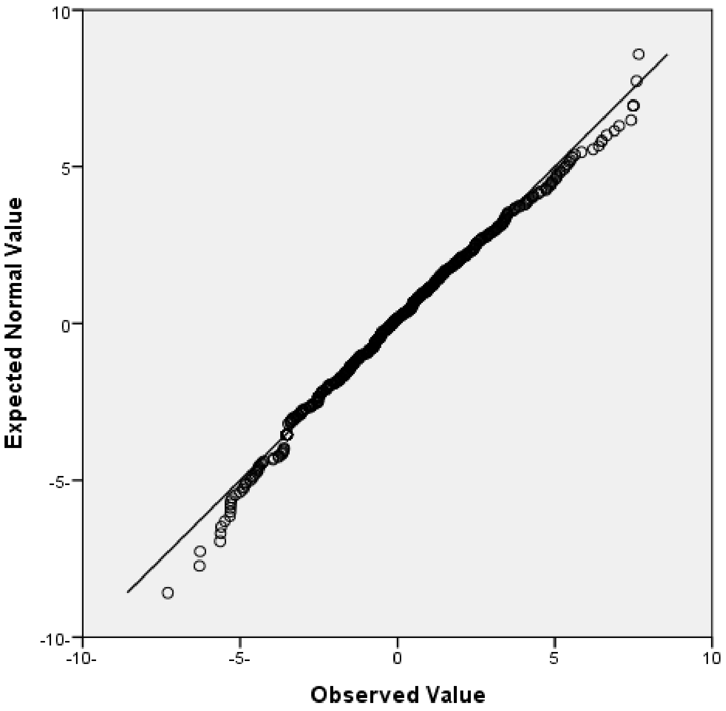
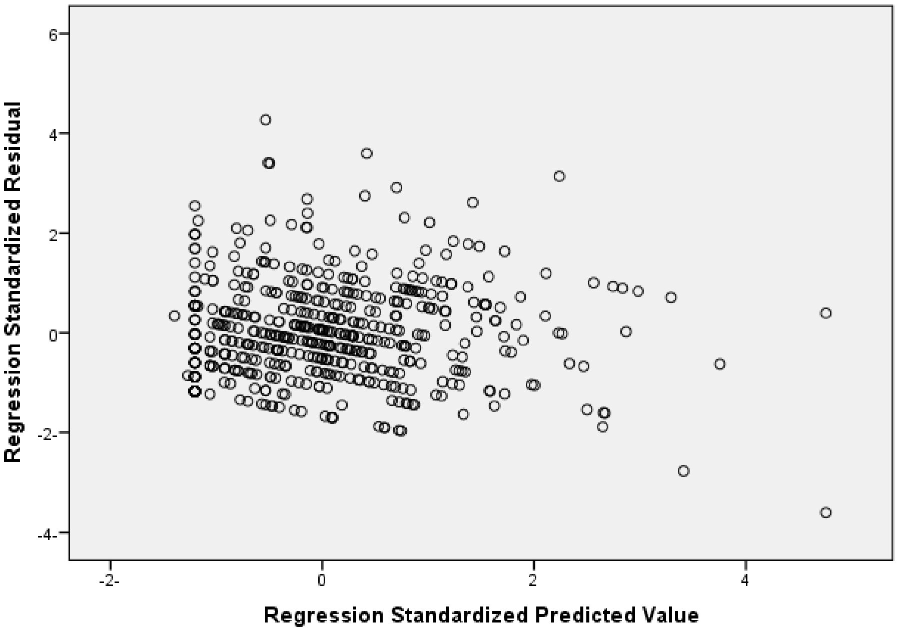


Figure TT-4: Q-Q plot of standardized residual of odors variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. A number of 26 data points of standardized residual values were not following those criteria (Figure TT-5 (A)). According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 26 data points were deleted. Figure TT-5 (B) shows scatter plots of regression standardized residuals and standardized predicted values after deleting the above described data points.
- Examining data points of high leverage in the initial model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=10 parameters and n=542 in the initial model, the cutoff value of 2p/n and 3p/n was about 0.04 and 0.06; respectively. About 17 data points had leverage value above the 3p/n cutoff value and 57 points above 2p/n in the initial model (Figure TT-6 (A)). A number of 15 data points above 3p/n cutoff were deleted but another 11 points above 3p/n cutoff were retained in the final model. As shown in Figure TT-6 (B), the retained data points were close and were not isolated from others. Deleting those points did not alter the in the variables identified as statistically significant and resulted in an insignificant change of about 0.009, 0.009, and 0.003 in $R^2$, adjusted $R^2$, and *SE* of estimate respectively. Therefore, those 11 points above the 3p/n cutoff were retained in the final model since deleting them caused insignificant change. The highest leverage value in the final model was 0.073.
- Examining data points of high influence in the initial model followed the general Cook's distance cutoff value of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Nelson 2004) as discussed in Section 3.4.3. No influential points were detected in the final model since the highest Cook's distance and DFBETAS were 0.032 and 0.257;

respectively. Figure TT-7 (A) and (B) illustrates the Cook's distances for models before and after deleting above described unusual data points.

(A)



(B)

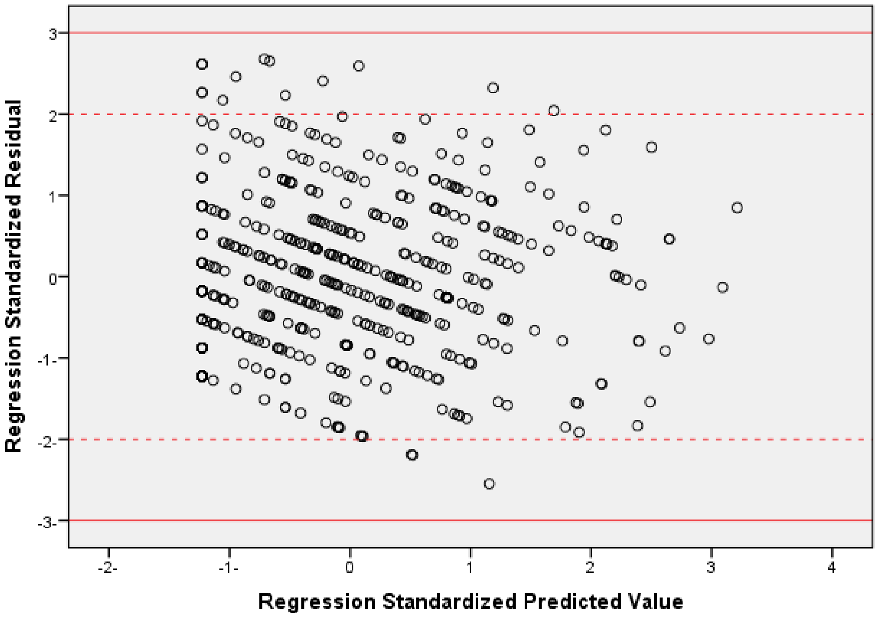
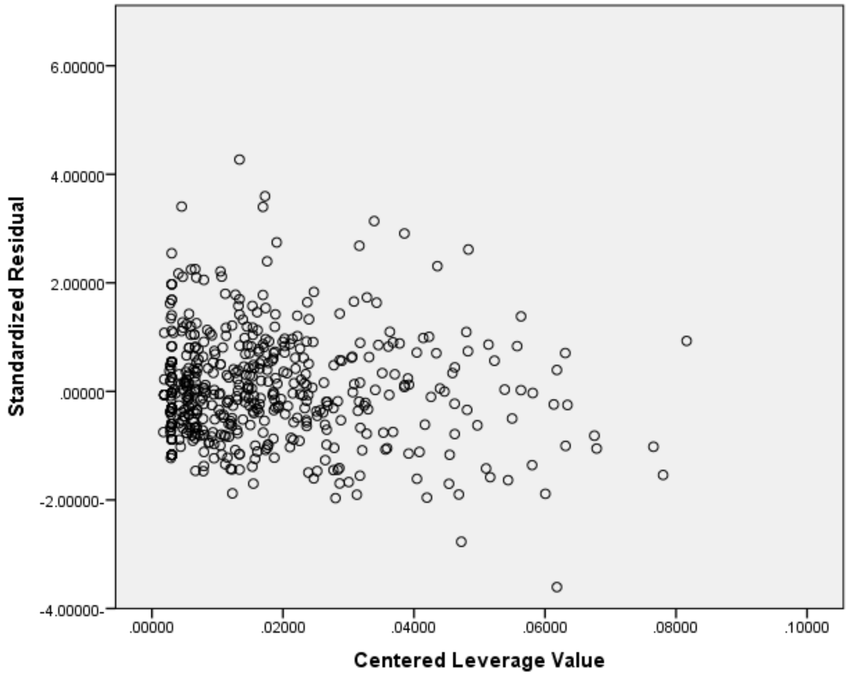


Figure TT-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values having odors variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual points

(A)



(B)

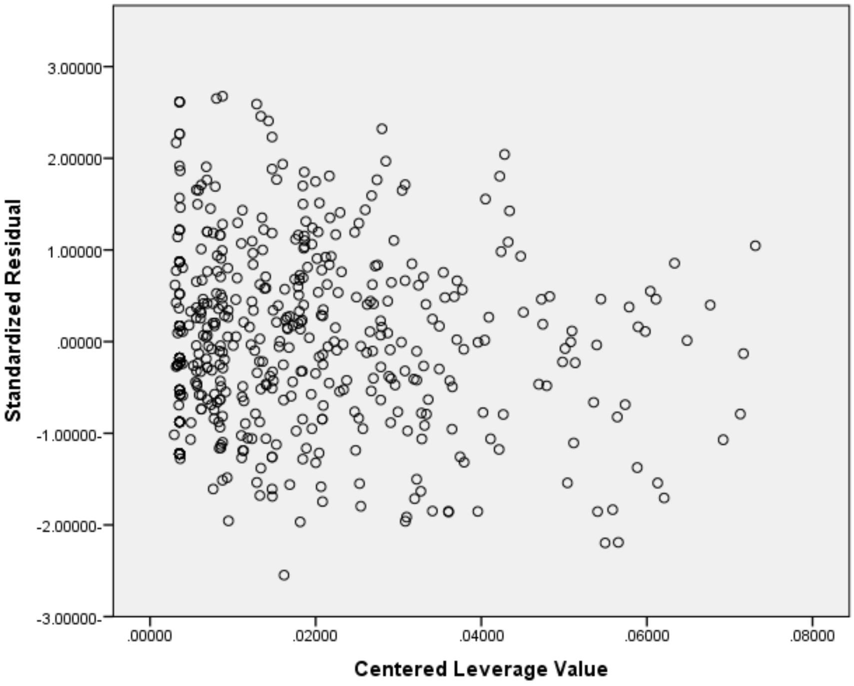


Figure TT-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values of odors variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual data points

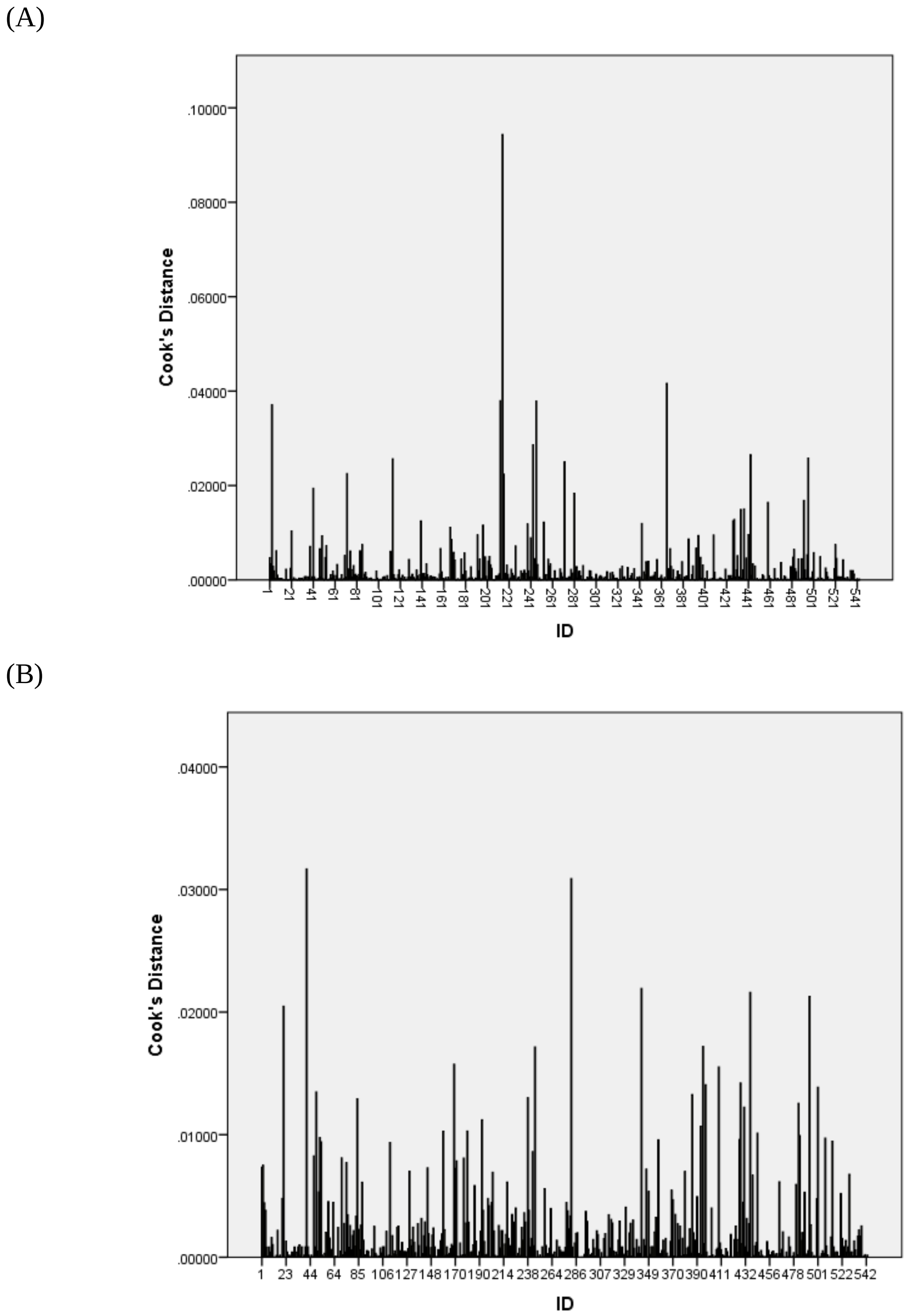


Figure TT-7: Bar charts (A) & (B) of Cook's distances for the regression model of odors variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual data points

# Appendix UU : Checking bias in the MLR model of thermal, light, & noise discomfort variables (IV) on General, Ergonomic, Nervous, and Skin symptoms (DV)

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure UU-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

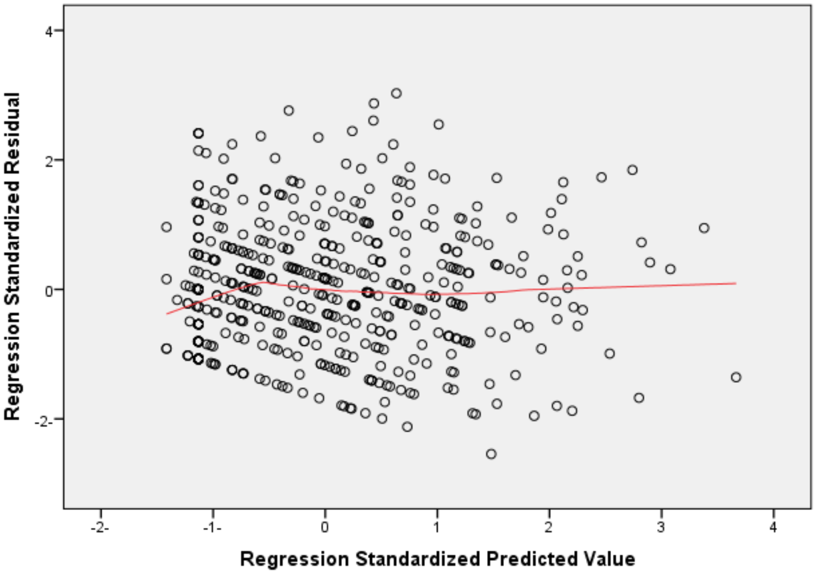


Figure UU-1: Scatter plot of regression standardized residuals and predicted values having thermal, lighting, noise discomfort variables (IV) general, ergonomic, nervous, and skin symptoms (DV)

- As shown in Figure UU-2, normal distribution of the residuals can be assumed for the final regression model since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013; Eberly College of Science 2018c). Also, as illustrated in Figure UU-3 and Figure UU-4, the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 1.868 (Field 2016; Ballance 2015; Ghani & Ahmad 2010).

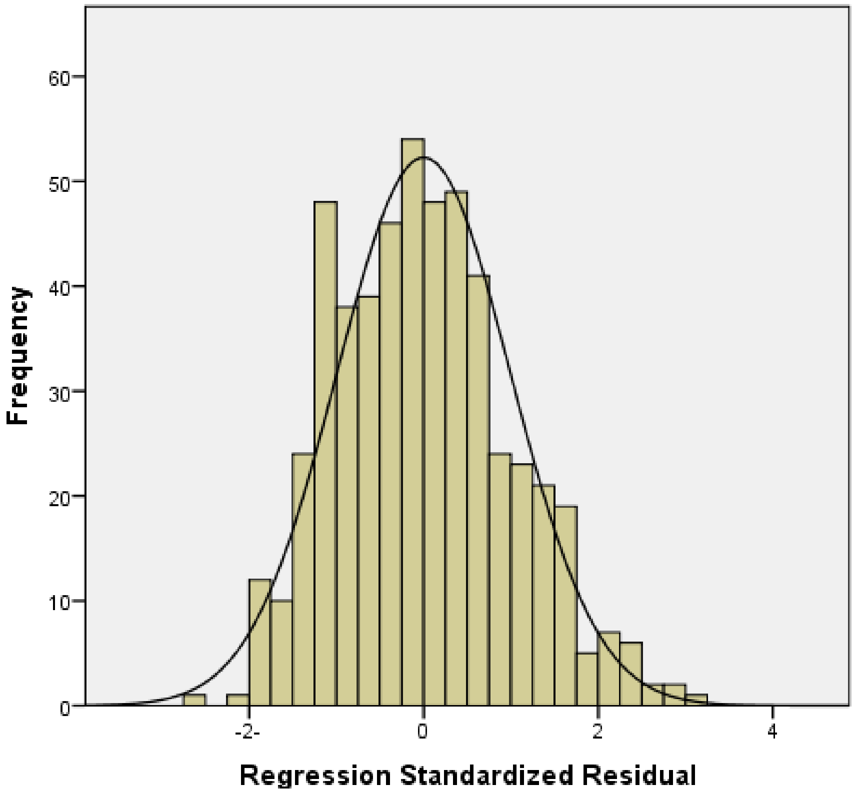


Figure UU-2: Histogram of the regression standardized residuals of thermal, lighting, noise discomfort variables (IV) and general, ergonomic, nervous, and skin symptoms (DV)

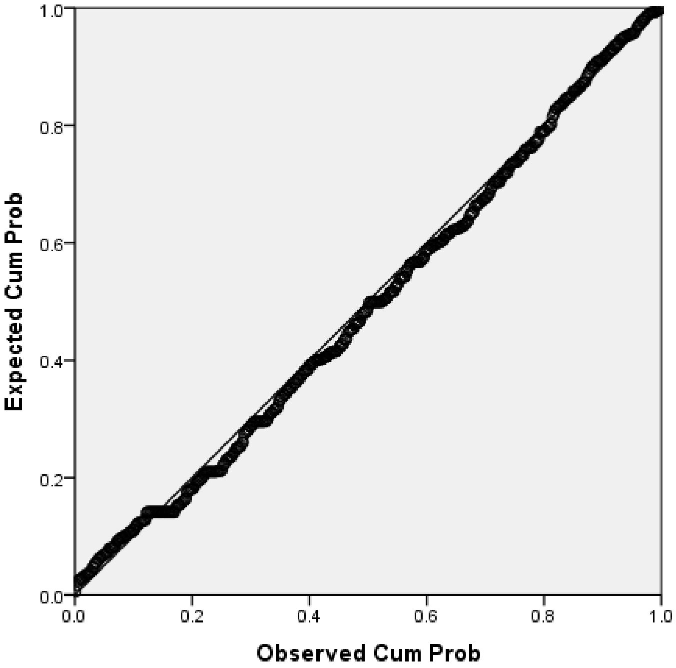


Figure UU-3: P-P plot of regression standardized residuals of thermal, lighting, noise discomfort variables (IV) and general, ergonomic, nervous, and skin symptoms (DV)

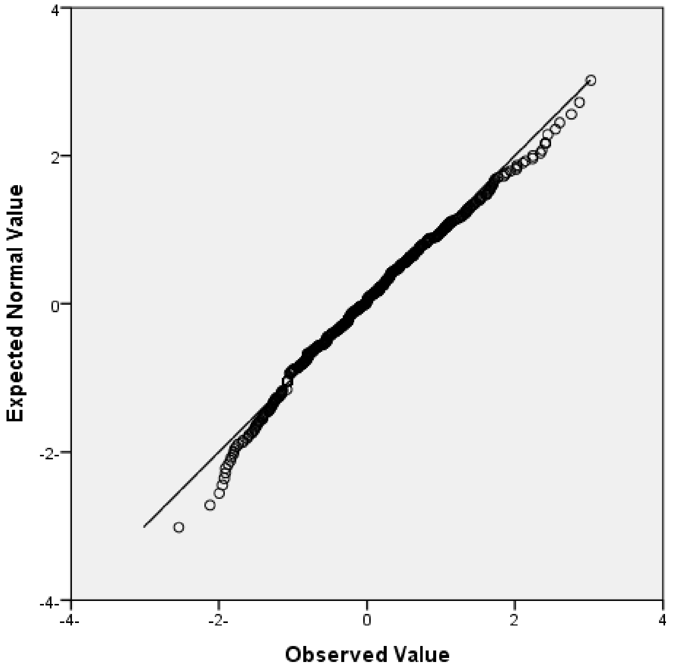
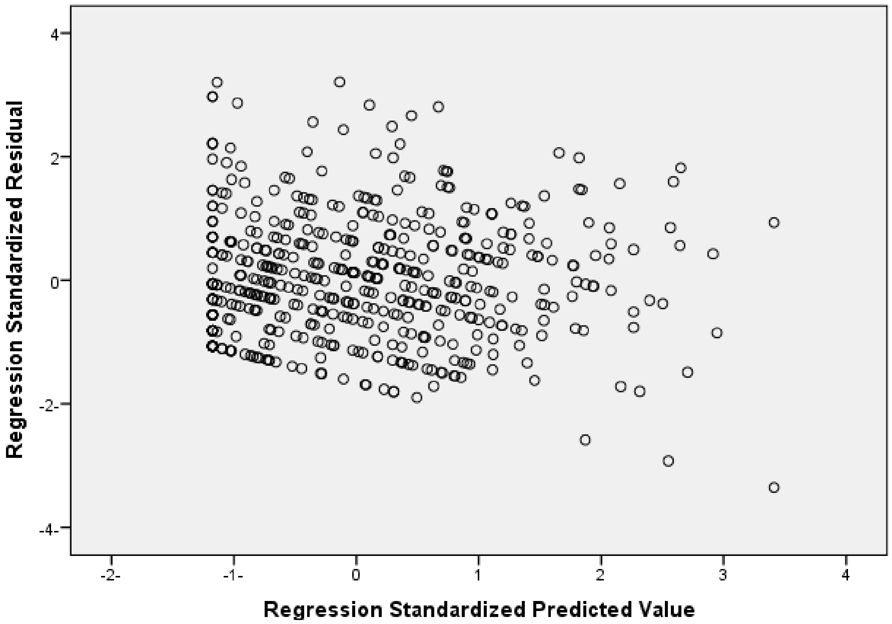


Figure UU-4: Q-Q plot of standardized residual of thermal, lighting, noise discomfort variables (IV) and general, ergonomic, nervous, and skin symptoms (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. A number of 7 data points of standardized residual values were not following those criteria (Figure UU-5 (A)). According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 7 data points were deleted. Figure UU-5 (B) shows scatter plots of regression standardized residuals and standardized predicted values after deleting the above described data points.
- Examining data points of high leverage in the initial model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=7 parameters and n=542 in the initial model, the cutoff value of 2p/n and 3p/n was about 0.026 and 0.039; respectively. About 5 data points had leverage value above the 3p/n cutoff value and 48 points above 2p/n in the initial model (Figure UU-6 (A)). A number of 13 data points of high leverage were deleted but another 5 points above 3p/n cutoff and 41 points above 2p/n cutoff were retained in the final model. As shown in Figure UU-6 (B), the retained data points were close and were not isolated from others. Deleting a number of 16 points of those did not alter the in the variables identified as statistically significant and resulted in an insignificant change of about 0.004, 0.004, and 0.002 in $R^2$, adjusted $R^2$, and *SE* of estimate respectively. Therefore, the above points above the cutoff values were retained in the final model since deleting them caused insignificant change. The highest leverage value in the final model was 0.044.
- Examining data points of high influence in the initial model followed the general Cook’s distance cutoff value of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Nelson 2004) as discussed in Section 3.4.3. No influential points were detected in the final model since the highest Cook’s distance and DFBETAS were 0.026 and 0.406;

respectively. Figure UU-7 (A) and (B) illustrates the Cook's distances for models before and after deleting above described unusual data points.

(A)



(B)

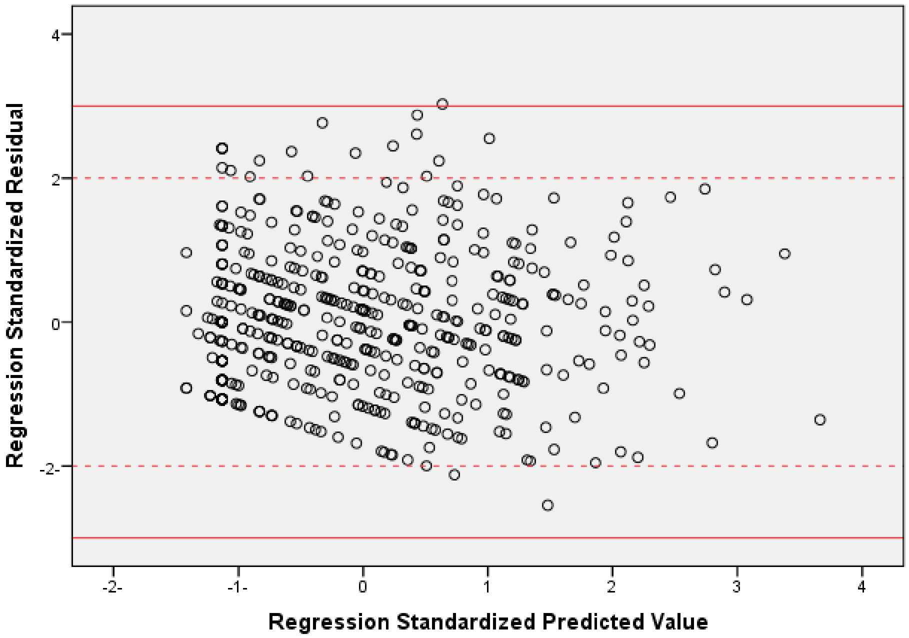
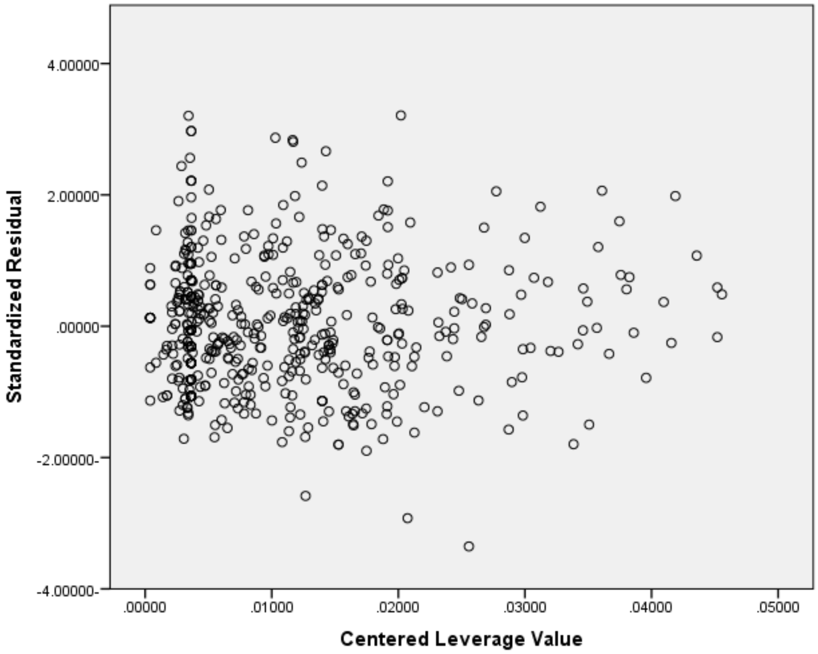


Figure UU-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values having thermal, lighting, noise discomfort variables (IV) and general, ergonomic, nervous, and skin symptoms (DV) before and after deleting unusual points

(A)



(B)

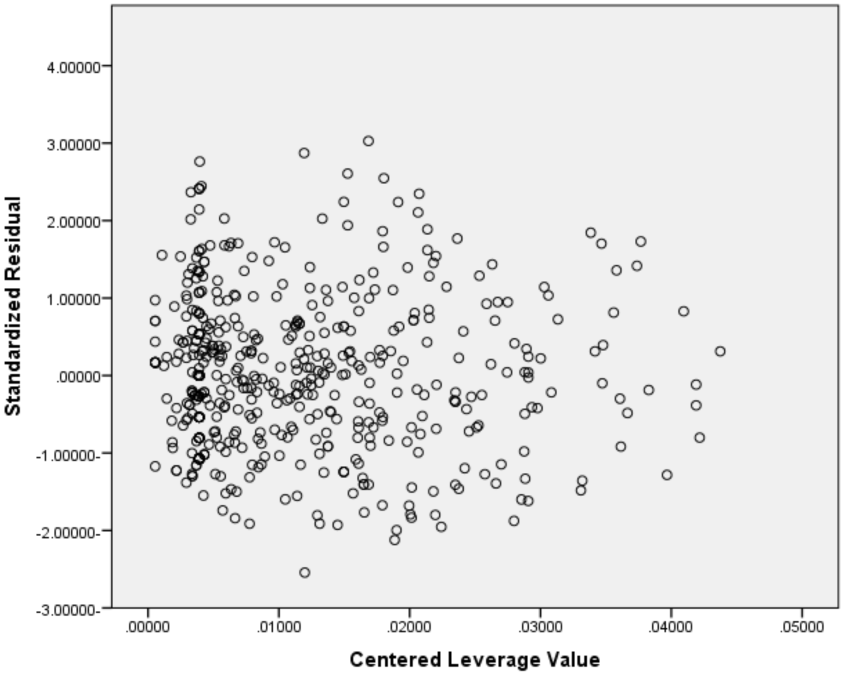


Figure UU-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values of thermal, lighting, noise discomfort variables (IV) and general, ergonomic, nervous, and skin symptoms (DV) before and after deleting unusual data points

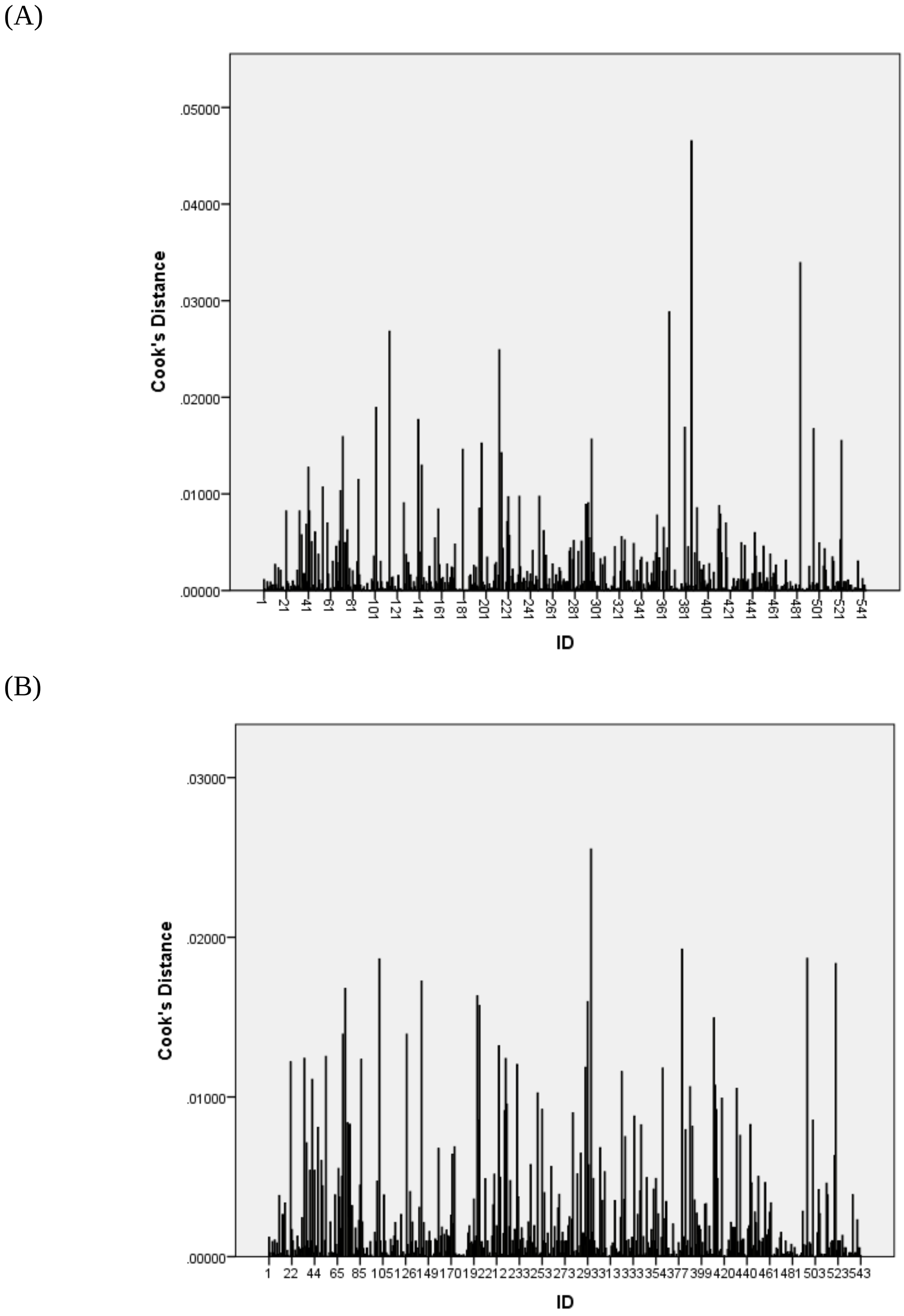


Figure UU-7: Bar charts (A) & (B) of Cook's distances for the regression model of thermal, lighting, noise discomfort variables (IV) and general, ergonomic, nervous, and skin symptoms (DV) before and after deleting unusual data points

## Appendix VV : Checking bias in the MLR model of IAQ discomfort variables (IV) on General, Ergonomic, Nervous, and Skin symptoms (DV)

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure VV-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

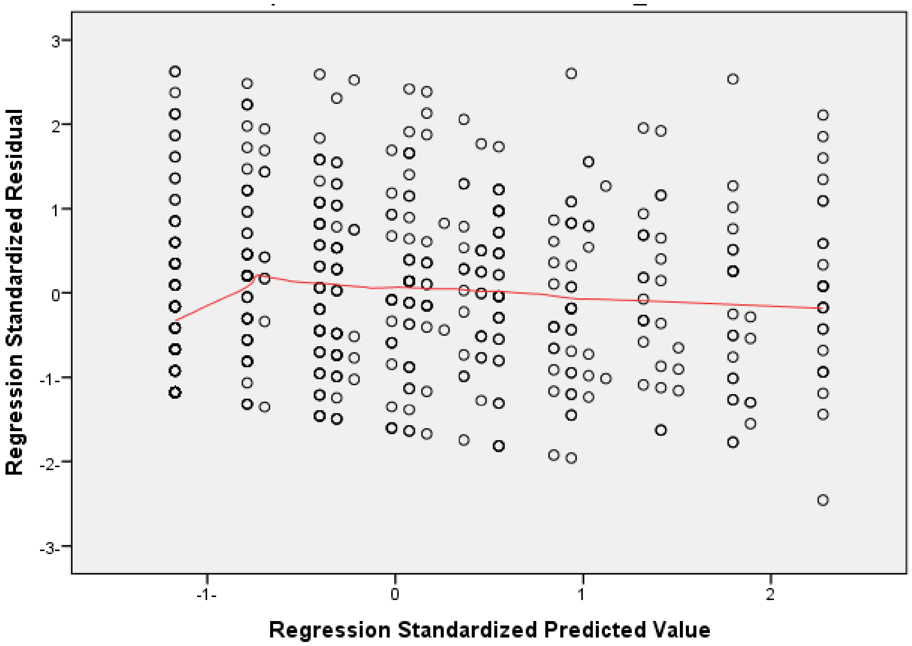


Figure VV-1: Scatter plot of regression standardized residuals and predicted values having IAQ discomfort variables (IV) general, ergonomic, nervous, and skin symptoms (DV)

- As shown in Figure VV-2, normal distribution of the residuals can be assumed for the final regression model since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013; Eberly College of Science 2018c). Also, as illustrated in Figure VV-3 and Figure VV-4, the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 1.491 (Field 2016; Ballance 2015; Ghani & Ahmad 2010).

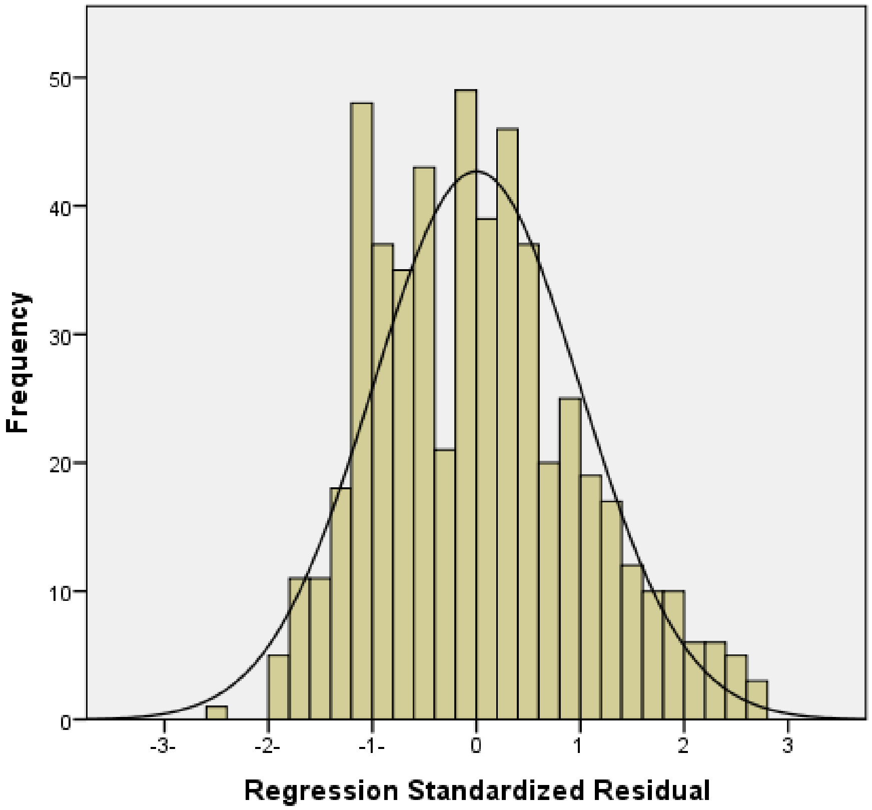


Figure VV-2: Histogram of the regression standardized residuals of IAQ discomfort variables (IV) and general, ergonomic, nervous, and skin symptoms (DV)

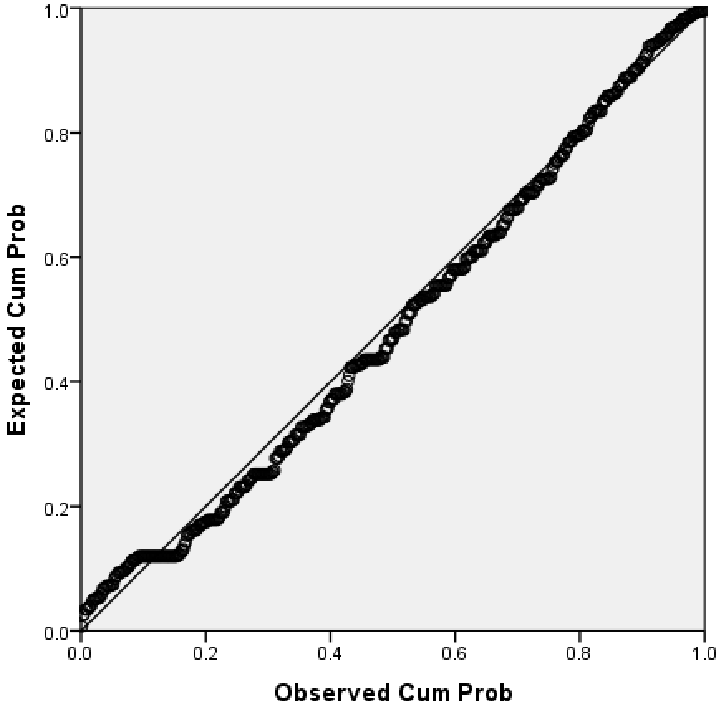


Figure VV-3: P-P plot of regression standardized residuals of IAQ discomfort variables (IV) and general, ergonomic, nervous, and skin symptoms (DV)

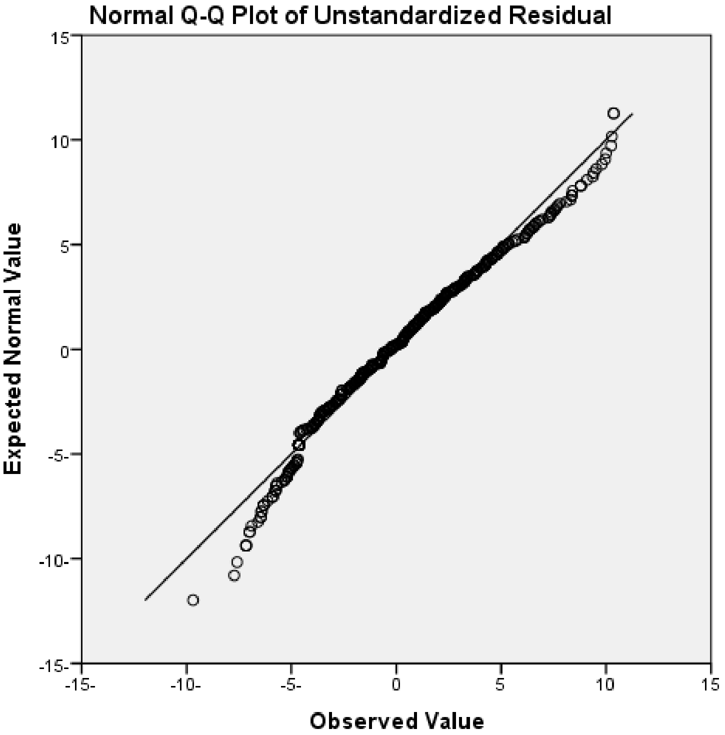
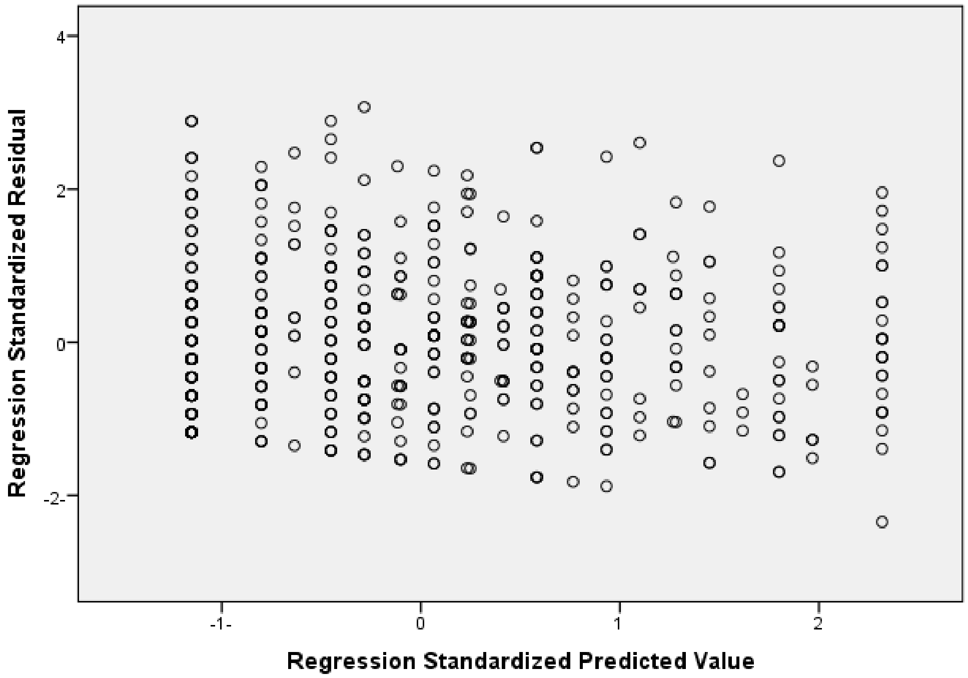


Figure VV-4: Q-Q plot of standardized residual of IAQ discomfort variables (IV) and general, ergonomic, nervous, and skin symptoms (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. A number of 9 data points of standardized residual values were not following those criteria (Figure VV-5 (A)). According to (Simonof 2017, Field 2016, Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 9 data points were deleted. Figure VV-5 (B) shows scatter plots of regression standardized residuals and standardized predicted values after deleting the above described data points.
- Examining data points of high leverage in the initial model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=3 parameters and n=542 in the initial model, the cutoff value of 2p/n and 3p/n was about 0.011 and 0.017; respectively. About 4 data points had leverage value above the 3p/n cutoff value and 21 points above 2p/n in the initial model. As shown in Figure VV-6 (A), a number of 4 data points above the 3p/n cutoff value appeared far from others and isolated. Deleting those points did not alter the in the variables identified as statistically significant but only resulted in an insignificant change of about 0.001and 0.002 in $R^2$ and *SE* of estimate respectively. Therefore, those 4 points above the cutoff values were retained in the final model since deleting them caused insignificant change. The highest leverage value in the final model was 0.02 (Figure VV-6 (B)).
- Examining data points of high influence in the initial model followed the general Cook's distance cutoff value of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Nelson 2004) as discussed in Section 3.4.3. No influential points were detected in the final model since the highest Cook's distance and DFBETAS were 0.023 and 0.235; respectively. Figure VV-7 (A) and (B) illustrates the Cook's distances for models before and after deleting above described unusual data points.

(A)



(B)

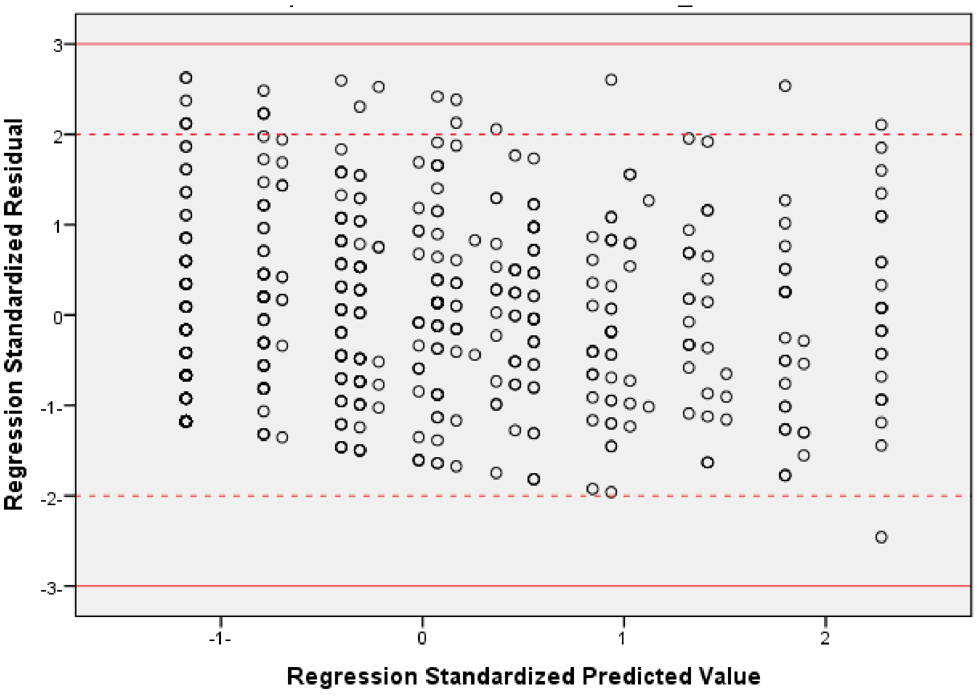
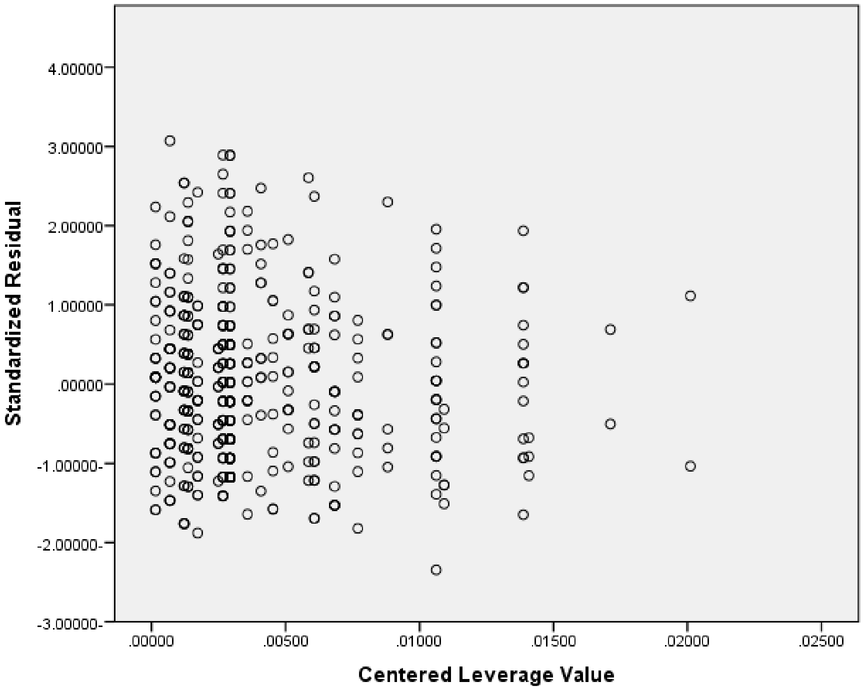


Figure VV-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values having IAQ discomfort variables (IV) and general, ergonomic, nervous, and skin symptoms (DV) before and after deleting unusual points

(A)



(B)

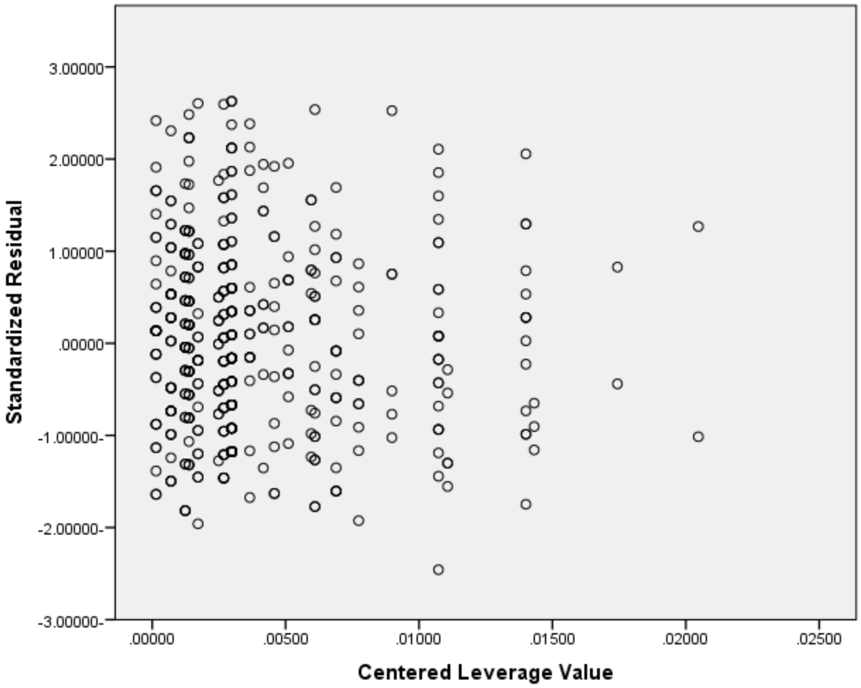
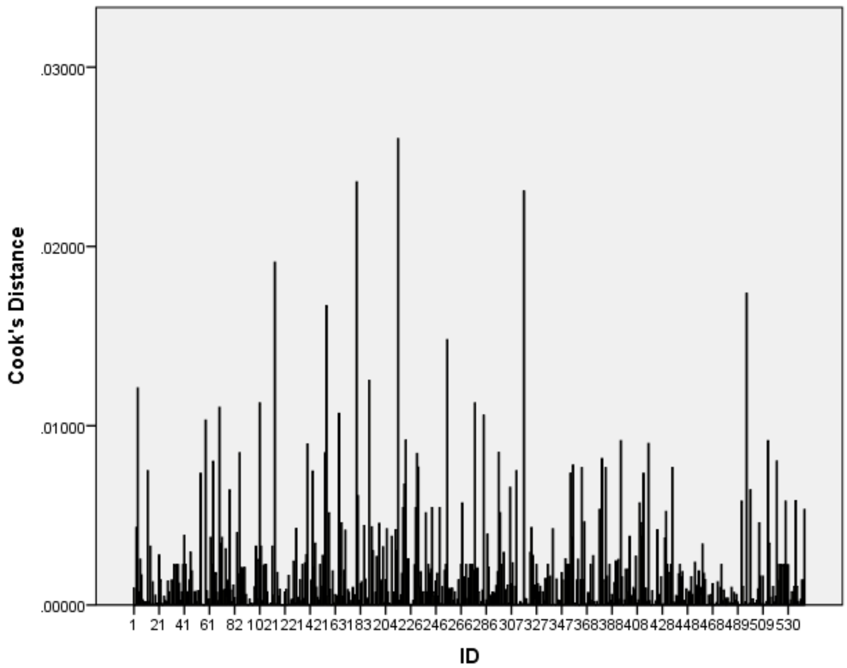


Figure VV-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values of IAQ discomfort variables (IV) and general, ergonomic, nervous, and skin symptoms (DV) before and after deleting unusual data points

(A)



(B)

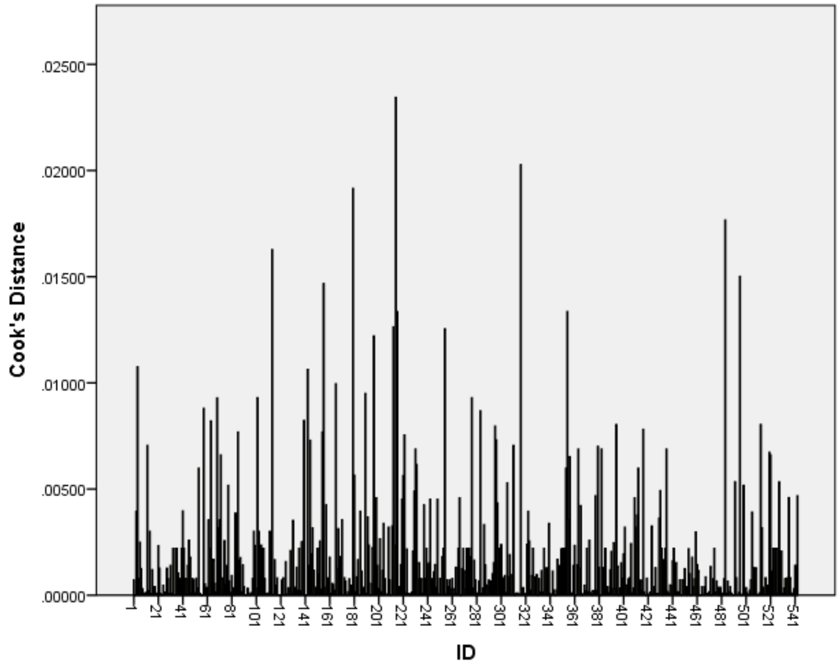


Figure VV-7: Bar charts (A) & (B) of Cook’s distances for the regression model of IAQ discomfort variables (IV) and general, ergonomic, nervous, and skin symptoms (DV) before and after deleting unusual data points

## Appendix WW : Checking bias in the MLR model of odors variables (IV) on General, Ergonomic, Nervous, and Skin symptoms (DV)

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure WW-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

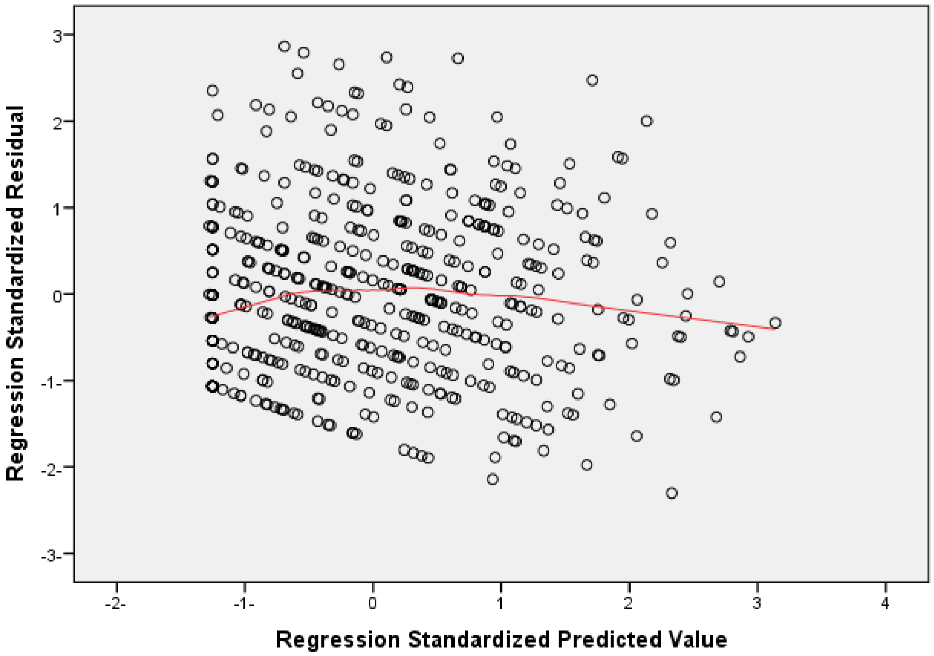


Figure WW-1: Scatter plot of regression standardized residuals & predicted values having odors variables (IV) general, ergonomic, nervous, & skin symptoms (DV)

- As shown in Figure  WW-2, normal distribution of the residuals can be assumed for the final regression model since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013;  Eberly College of Science 2018c). Also, as illustrated in Figure  WW-3 and Figure  WW-4, the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 1.455 (Field 2016;  Ballance 2015; Ghani & Ahmad 2010).

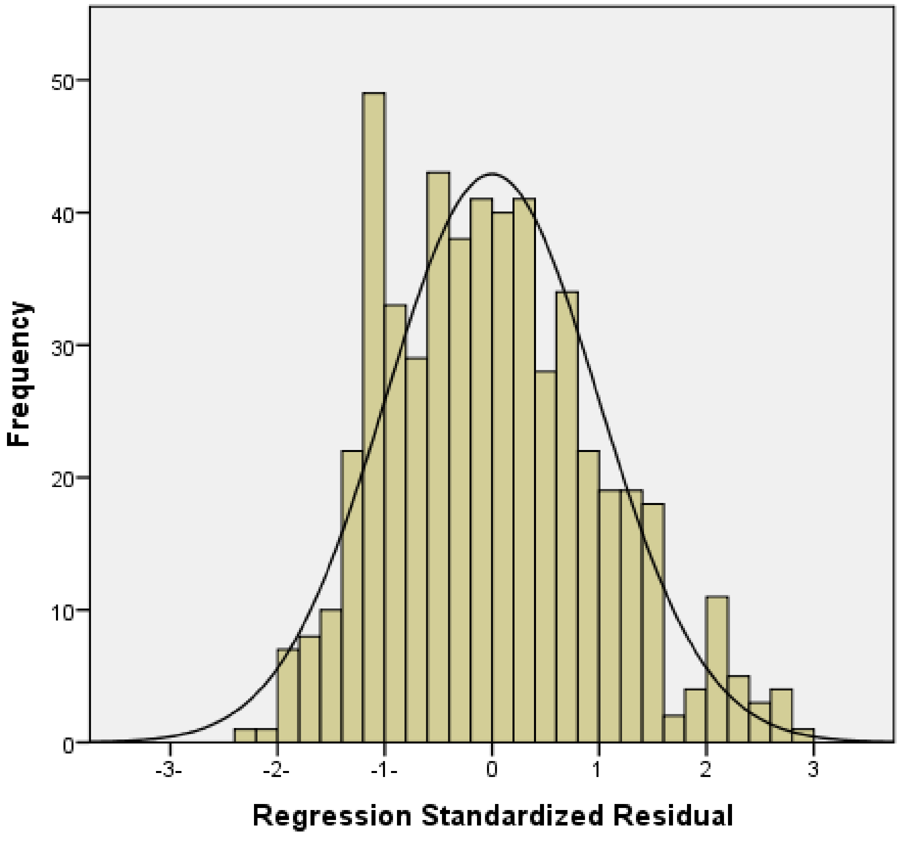


Figure  WW-2: Histogram of the regression standardized residuals of odors variables (IV) and general, ergonomic, nervous, and skin symptoms (DV)

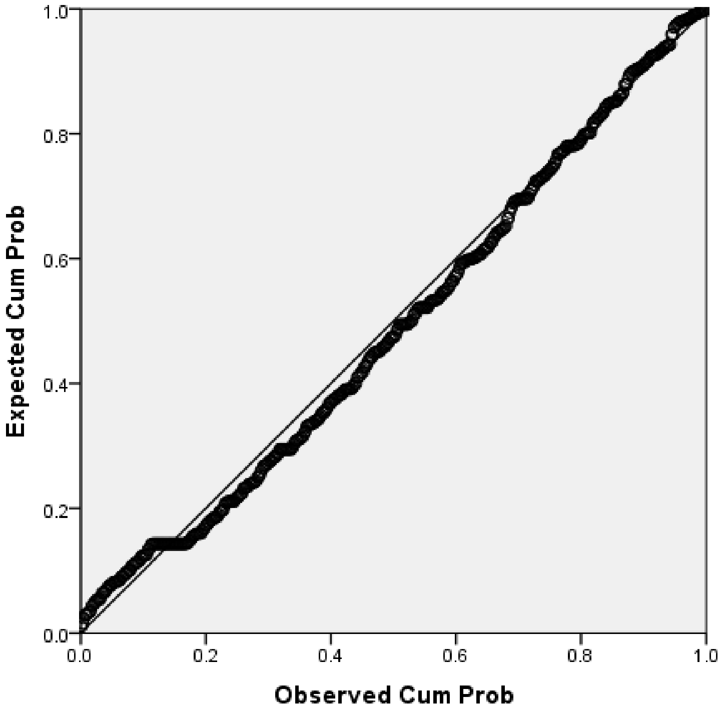


Figure  WW-3: P-P plot of regression standardized residuals of odors variables (IV) and general, ergonomic, nervous, and skin symptoms (DV)

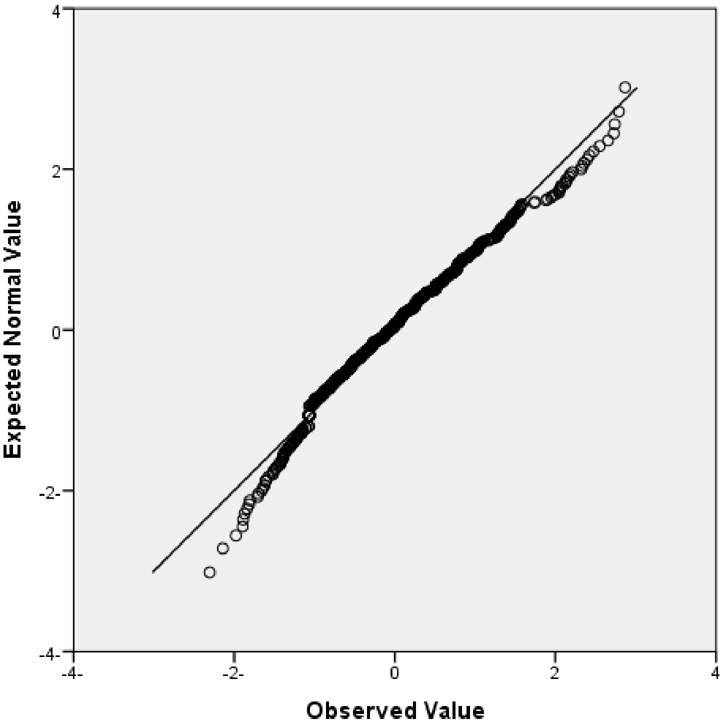
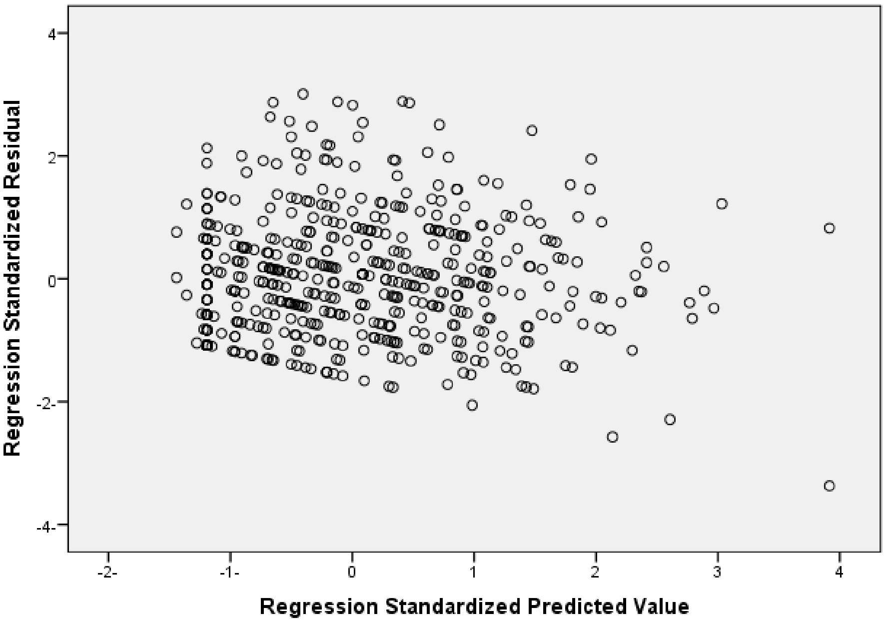


Figure  WW-4: Q-Q plot of standardized residual of odors variables (IV) and general, ergonomic, nervous, and skin symptoms (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. A number of 8 data points of standardized residual values were not following those criteria (Figure WW-5 (A)). According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 8 data points were deleted. Figure WW-5 (B) shows scatter plots of regression standardized residuals and standardized predicted values after deleting the above described data points.
- Examining data points of high leverage in the initial model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=10 parameters and n=542 in the initial model, the cutoff value of 2p/n and 3p/n was about 0.04 and 0.06; respectively. About 17 data points had leverage value above the 3p/n cutoff value and 57 points above 2p/n in the initial model (Figure WW-6(A)). A number of 2 data points above the 3p/n cutoff value were deleted but another 15 points above the 3p/n cutoff were retained in the final model. The deletion of those points did not alter the in the variables identified as statistically significant but only resulted in an insignificant change of about 0.002, 0.002, and 0.01 in $R^2$, adjusted $R^2$, and *SE* of estimate respectively. Therefore, those 15 points above the cutoff values were retained in the final model since deleting them caused insignificant change. The highest leverage value in the final model was 0.09 (Figure WW-6 (B)).
- Examining data points of high influence in the initial model followed the general Cook’s distance cutoff value of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Nelson 2004) as discussed in Section 3.4.3. No influential points were detected in the final model since the highest Cook’s distance and DFBETAS were 0.034 and 0.416;

respectively. Figure WW-7 (A) and (B) illustrates the Cook's distances for models before and after deleting above described unusual data points.

(A)



(B)

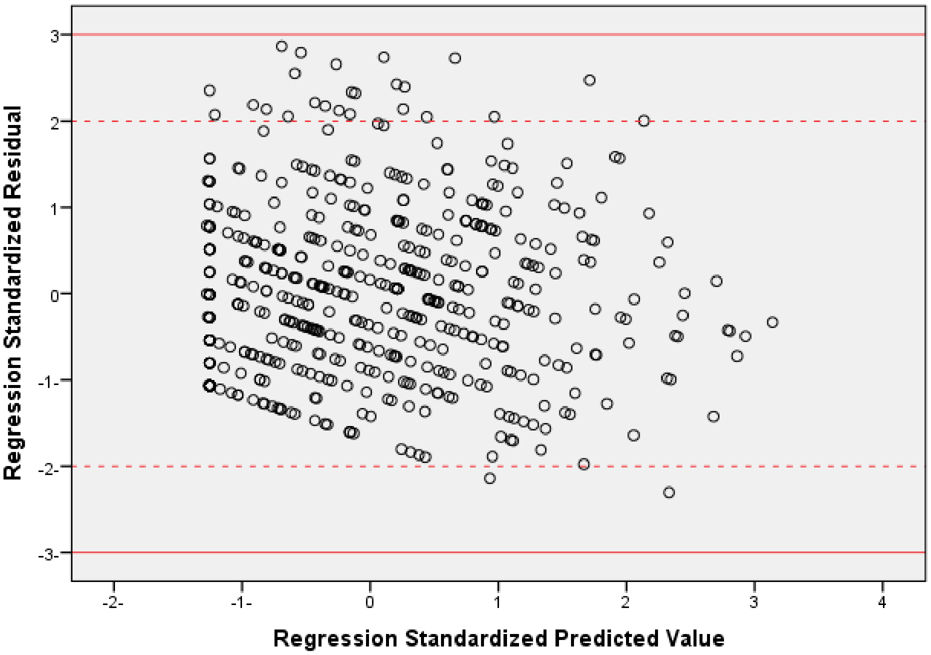
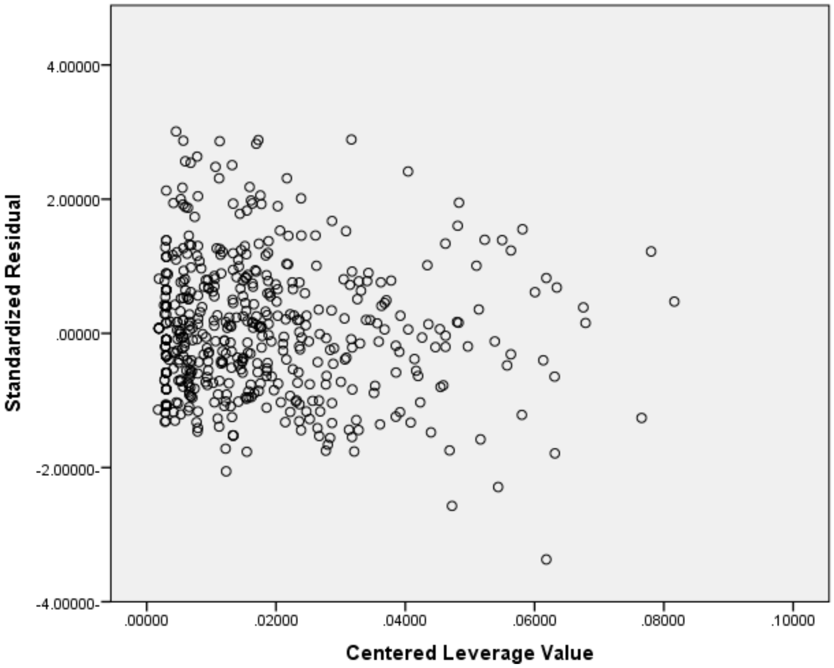


Figure WW-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values having odors variables (IV) and general, ergonomic, nervous, and skin symptoms (DV) before and after deleting unusual points

(A)



(B)

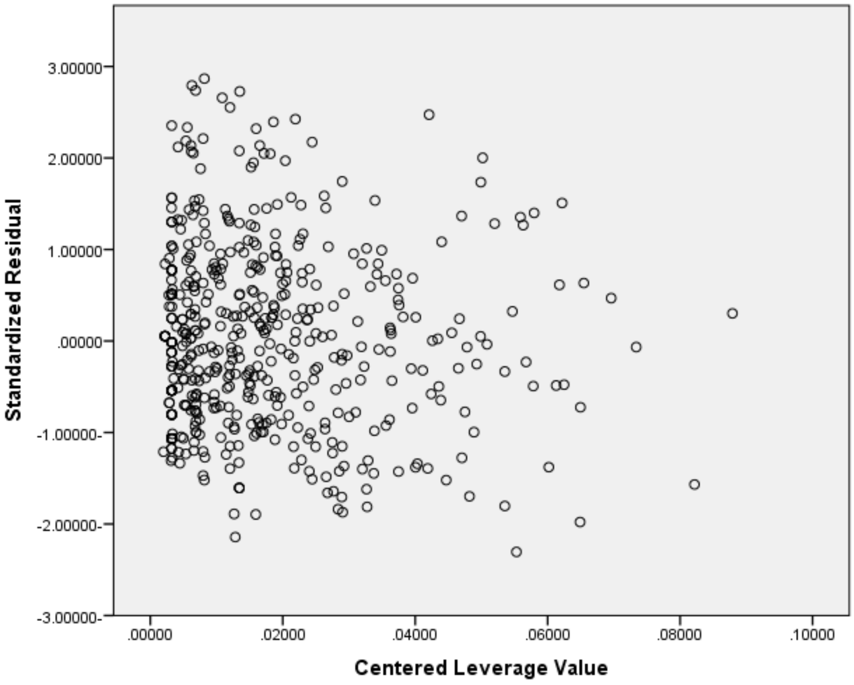
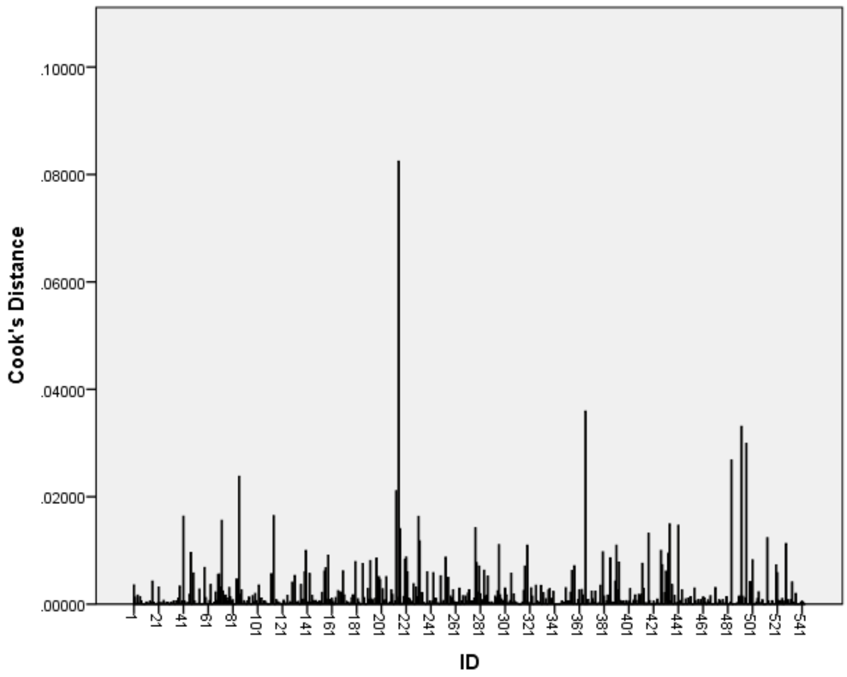


Figure WW-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values of odors variables (IV) and general, ergonomic, nervous, and skin symptoms (DV) before and after deleting unusual data points

(A)



(B)

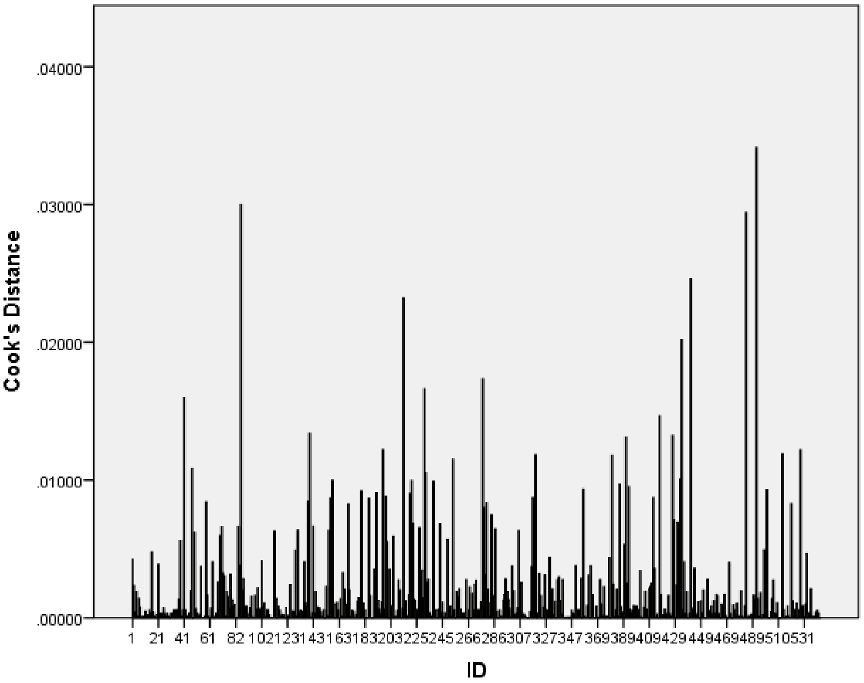


Figure WW-7: Bar charts (A) & (B) of Cook's distances for the regression model of odors variables (IV) and general, ergonomic, nervous, and skin symptoms (DV) before and after deleting unusual data points

# Appendix XX : Checking bias in the MLR model of IEQ variables (IV) on Eye, Nose, Throat, and Chest related symptoms (DV)

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure XX-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

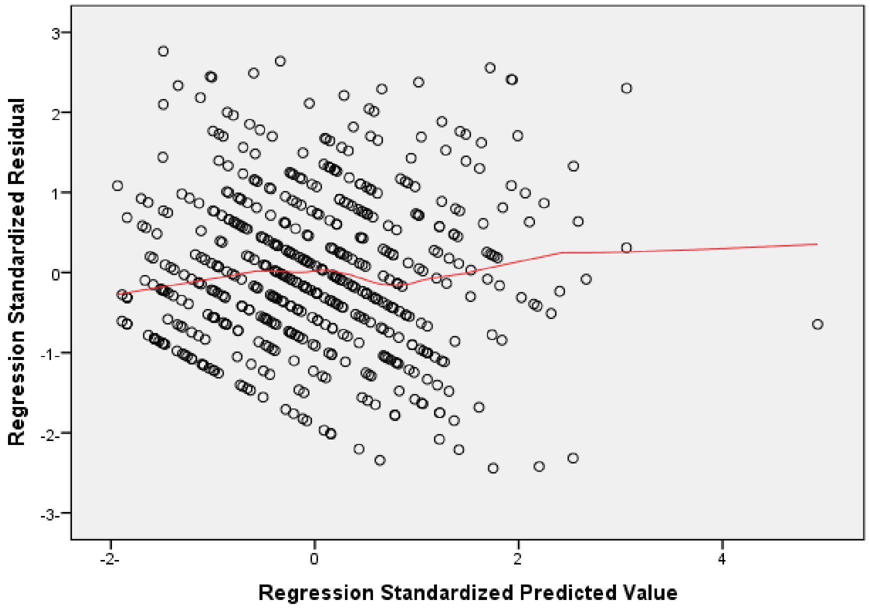


Figure XX-1: Scatter plot of regression standardized residuals and predicted values having IEQ variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

- As shown in Figure XX-2, normal distribution of the residuals can be assumed for the final regression model since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013; Eberly College of Science 2018c). Also, as illustrated in Figure XX-3 and Figure XX-4, the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 1.900 (Field 2016; Ballance 2015; Ghani & Ahmad 2010).

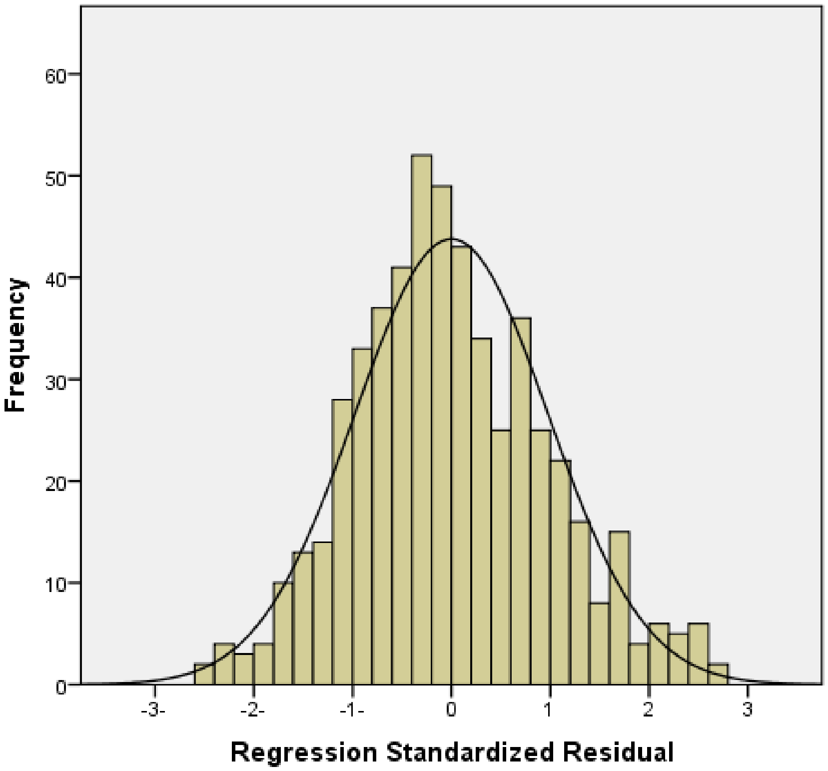


Figure XX-2: Histogram of the regression standardized residuals of IEQ variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

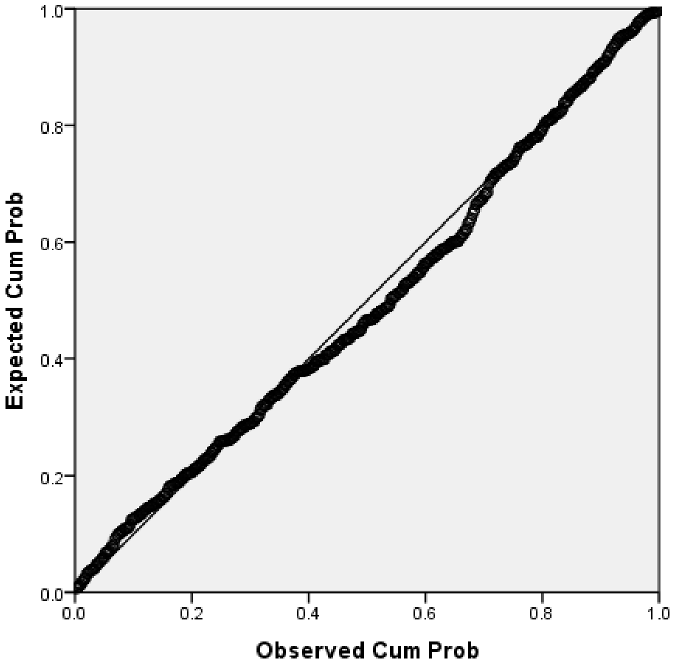


Figure XX-3: P-P plot of regression standardized residuals of IEQ variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

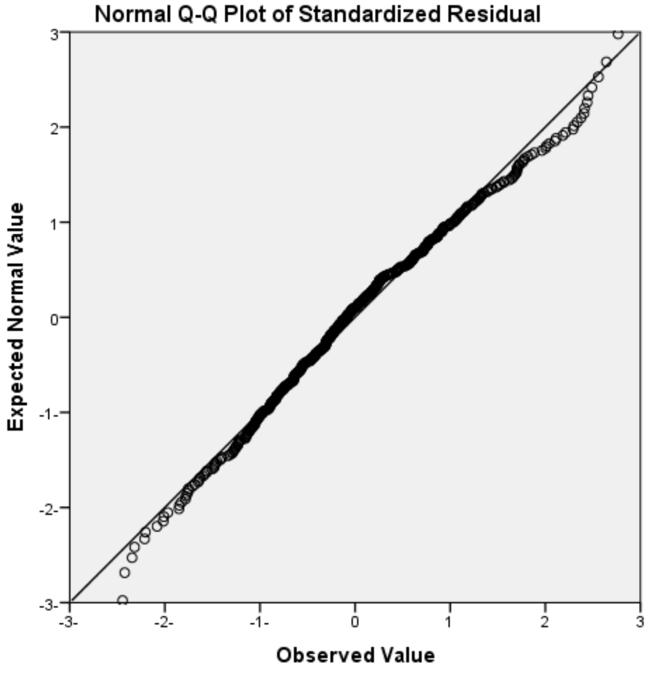
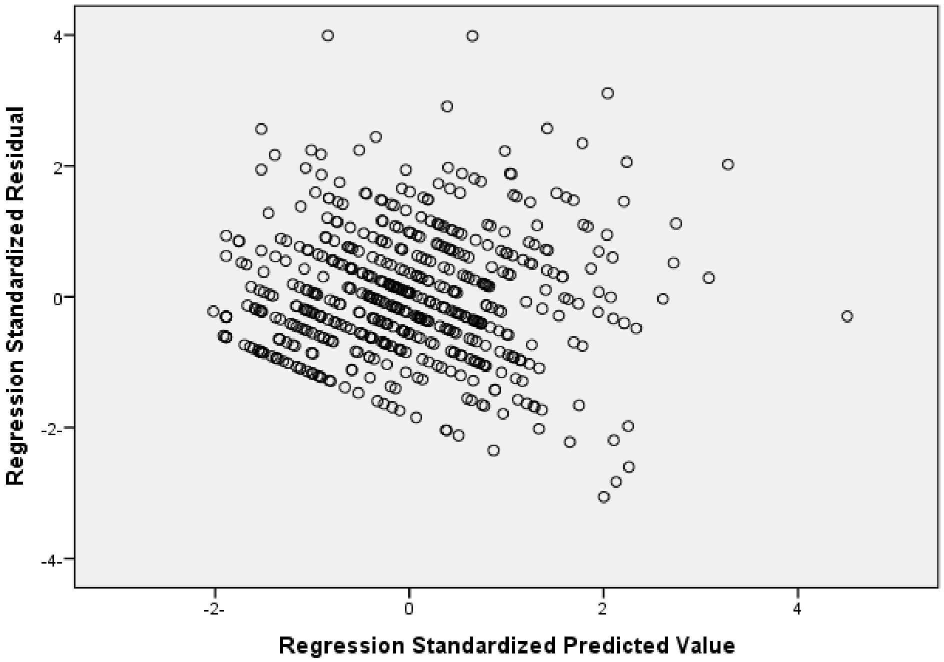


Figure XX-4: Q-Q plot of standardized residual of IEQ variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. A number of 6 data points of standardized residual values were not following those criteria (Figure XX-5 (A)). According to (Simonof 2017, Field 2016, Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 6 data points were deleted. Figure XX-5 (B) shows scatter plots of regression standardized residuals and standardized predicted values after deleting the above described data points.
- Examining data points of high leverage in the initial model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=24 variables and n=542 in the initial model, the cutoff value of 2p/n and 3p/n was about 0.09 and 0.13; respectively. No data points had leverage value above the 3p/n cutoff value while 23 points above 2p/n in the initial model (Figure XX-6 (A)). A number of 26 data points above 2p/n cutoff were retained in the final model. As shown in Figure XX-6 (B), the retained data points were close and were not isolated from others. Deleting points above the 2p/n cutoff had resulted in an insignificant change of about 0.007, 0.006, and 0.04 in $R^2$, adjusted $R^2$, and *SE* of estimate respectively. Therefore, those points above the 2p/n cutoff were retained in the final model since deleting them caused insignificant change. The highest leverage value in the final model was 0.119.
- Examining data points of high influence in the initial model followed the general Cook's distance cutoff value of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Nelson 2004) as discussed in Section 3.4.3. No influential points were detected in the final model since the highest Cook's distance and DFBETAS were 0.033 and 0.253; respectively. Figure XX-7 (A) and (B) illustrates the Cook's distances for models before and after deleting above described unusual data points.

(A)



(B)

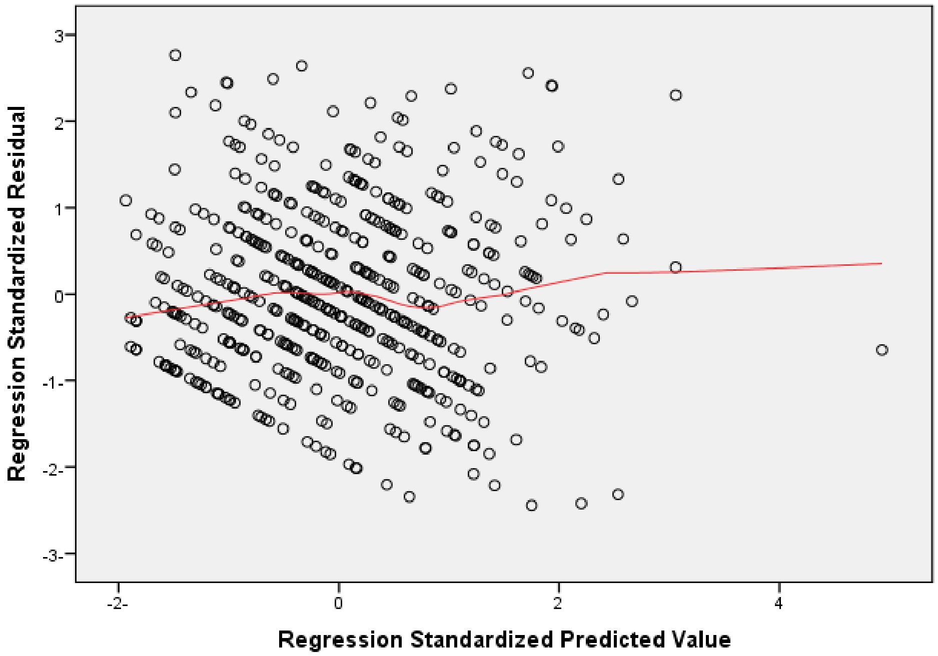
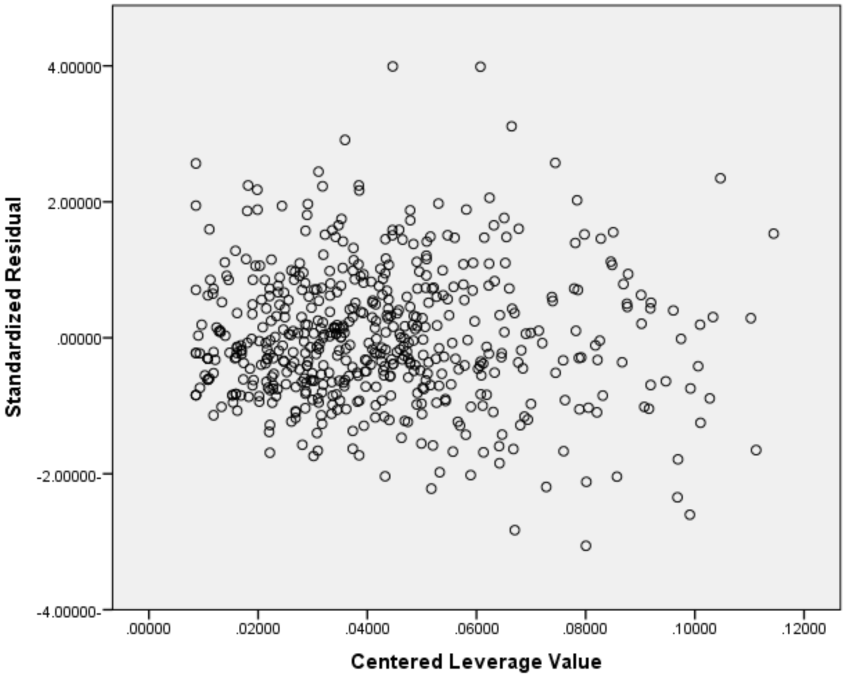


Figure XX-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values having IEQ variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual points

(A)



(B)

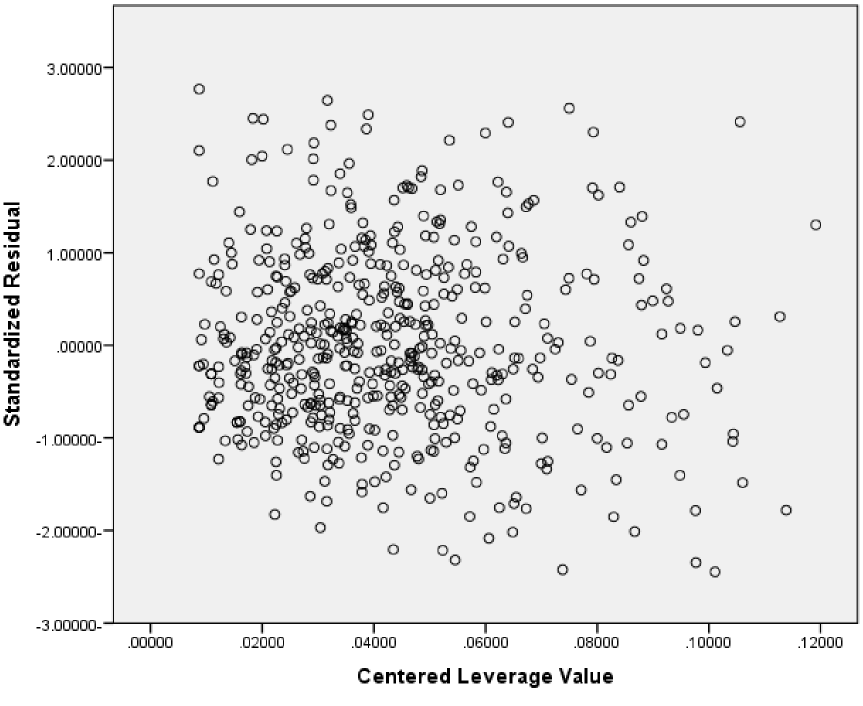


Figure XX-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values of IEQ variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual data points

(A)

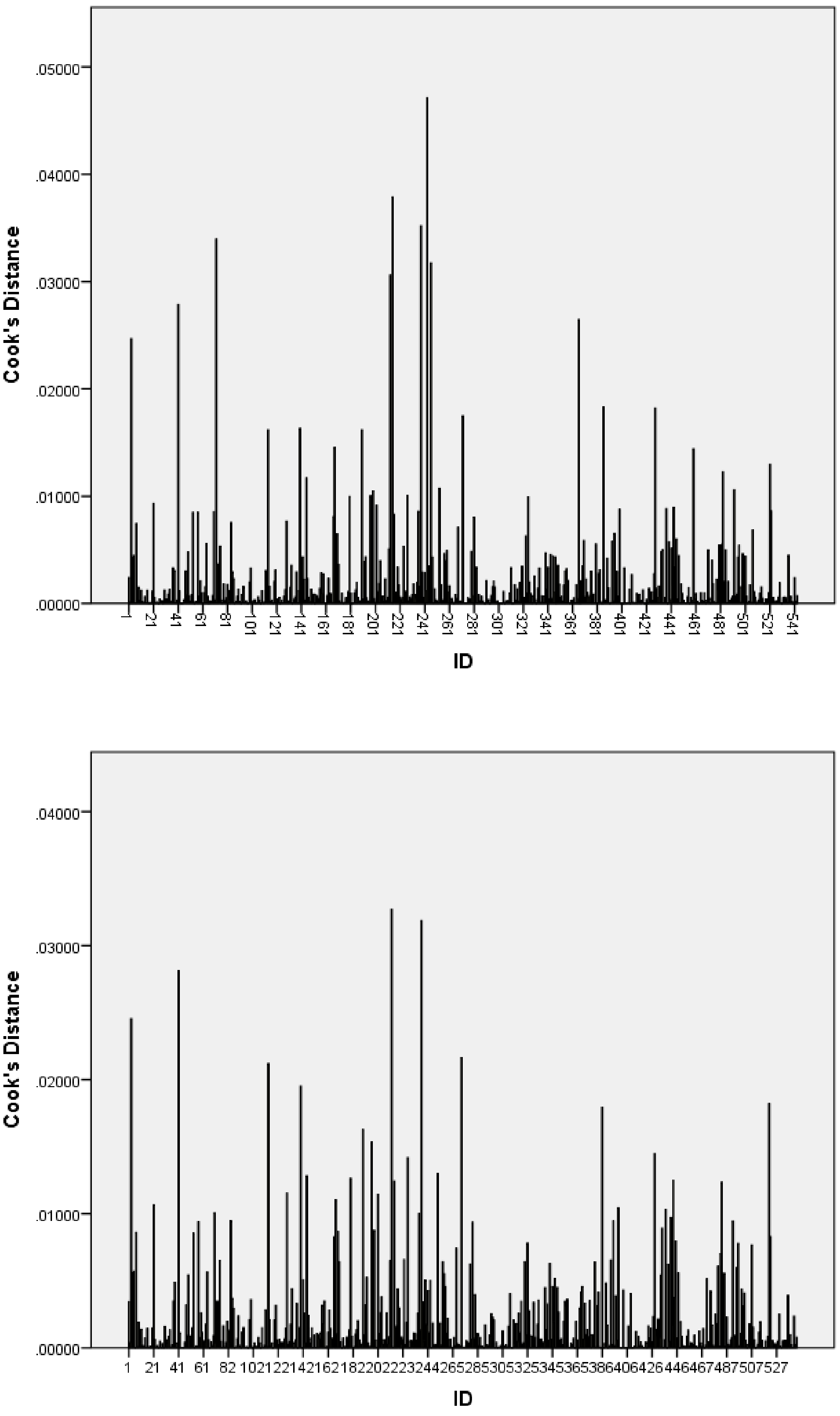


Figure XX-7: Bar charts (A) & (B) of Cook's distances for the regression model of IEQ variables (IV) and Eye, Nose, Throat, and Chest symptoms (DV) before and after deleting unusual data points

# Appendix YY : Checking bias in the MLR model of IEQ variables (IV) on General, Ergonomic, Nervous, and Skin symptoms (DV)

- Linearity, homoscedasticity, error independence and were graphically assessed for the final regression model using scatter plots of standardized residuals against standardized predicted values. For linearity testing, a Loess Curve was fitted through the scatter plot as shown in Figure YY-1. Linearity between the outcome and the predictor can be assumed since the fitted Loess Curve was roughly linear around zero (UCLA 2018). Homoscedasticity can also be assumed as the variance of residuals is randomly and uniformly distributed and the dots were not forming a particular pattern i.e. a funnel, v shape, pie wedge or fan shape (Field 2016; UCLA 2018; Barker & Shaw 2015; Ballance 2015). According to (Field 2016), independence of errors can also be assumed when having a random distribution of dots. Notably that, as explained by (SPSS Tutorials 2018), the striking pattern of straight lines is due to the initial measurement of the DVs in a 5 point likert scale that hold limited values from 0 – 5.

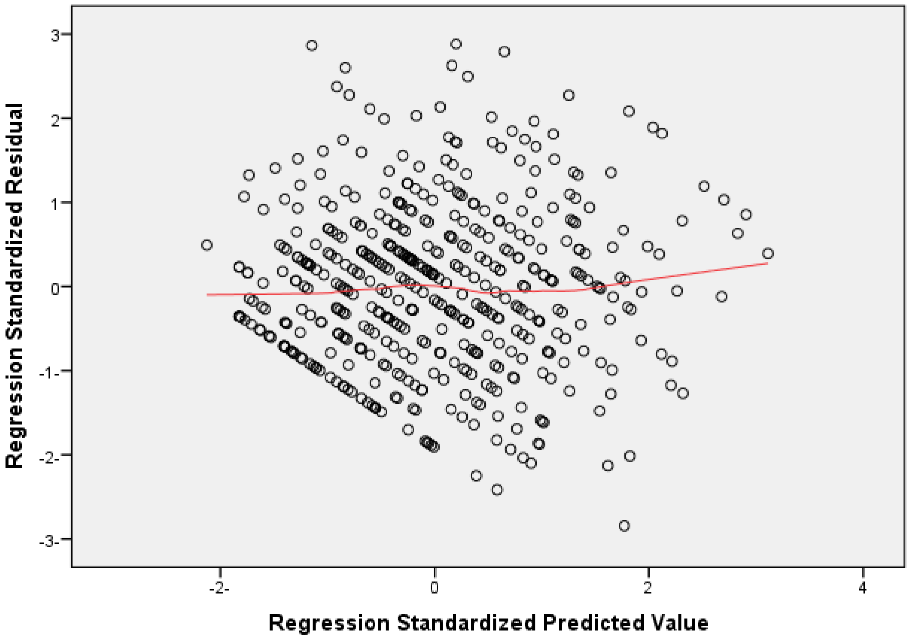


Figure YY-1: Scatter plot of regression standardized residuals and predicted values having IEQ variables (IV) and general, ergonomic, nervous & skin symptoms (DV)

- As shown in Figure YY-2, normal distribution of the residuals can be assumed for the final regression model since the histogram of the standardized residuals forms a bell shaped curve (SPSS Tutorials 2018; CDC 2012; Australian Bureau of Statistics 2013; Eberly College of Science 2018c). Also, as illustrated in Figure YY-3 and Figure YY-4, the residuals in the P-P plots or the Q-Q plots were not significantly deviating from line. That also supports the normality assumption (Barker & Shaw 2015; UCLA 2018; Field 2012).
- No multicollinearity was detected in the final regression model since the highest VIF for all entered predictors are highly below 5 and the maximum VIF was 2.013 (Field 2016; Ballance 2015; Ghani & Ahmad 2010).

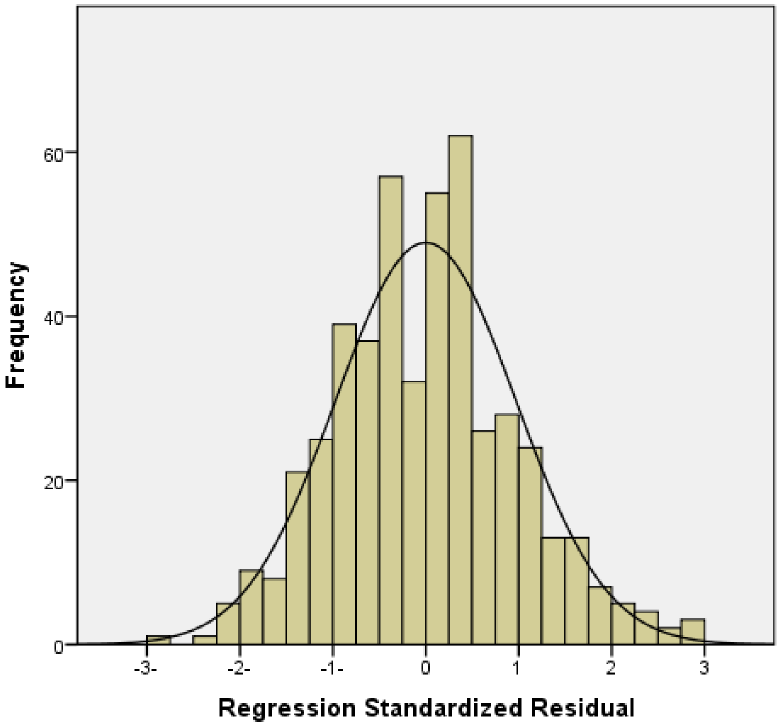


Figure YY-2: Histogram of the regression standardized residuals of IEQ variables (IV) and general, ergonomic, nervous & skin symptoms (DV)

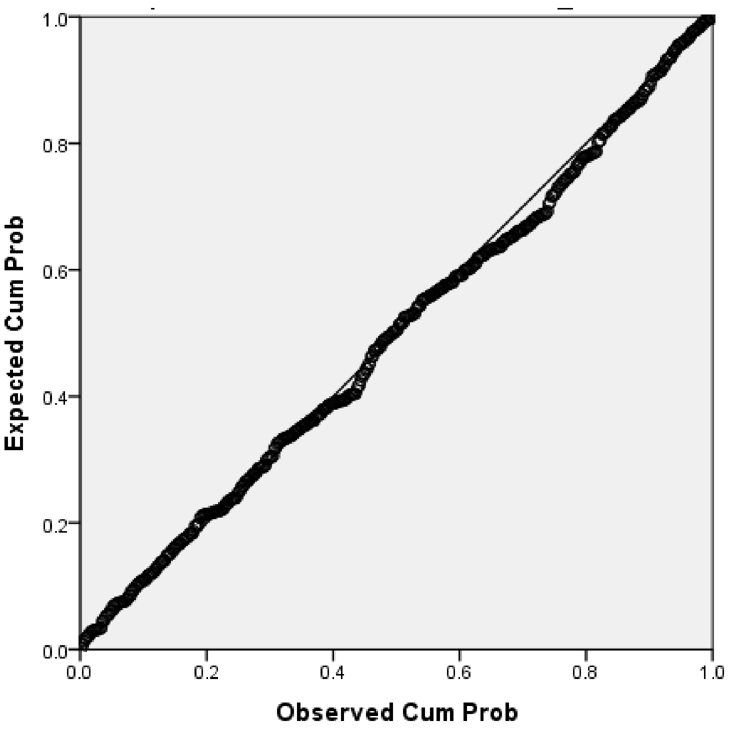


Figure YY-3: P-P plot of regression standardized residuals of IEQ variables (IV) and general, ergonomic, nervous & skin symptoms (DV) (DV)

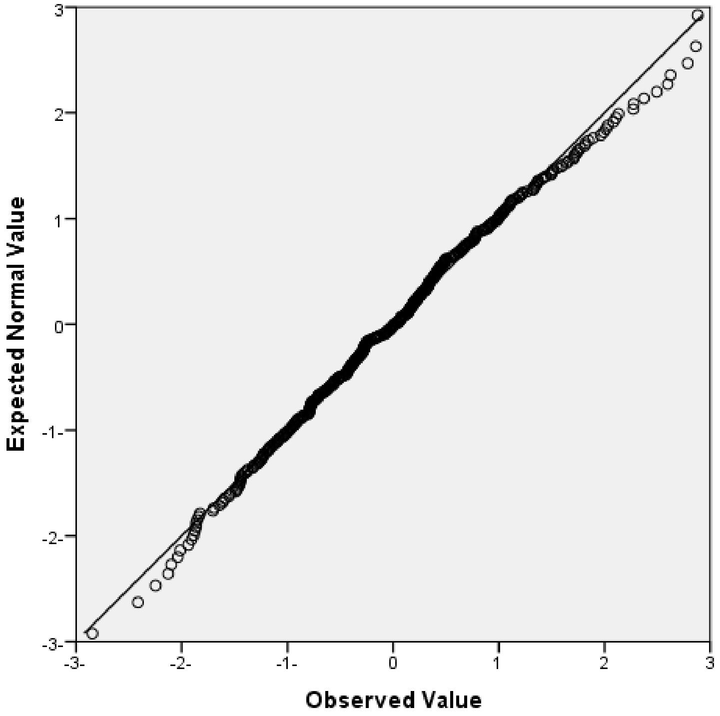


Figure YY-4: Q-Q plot of standardized residual of IEQ variables (IV) and general, ergonomic, nervous & skin symptoms (DV)

- Outliers were examined in the initial regression model following the criteria discussed in Section 3.4.3 of having: (i) 95% of the standardized residuals within ±1.96; (ii) 99% of them to be within ±2.58; and (iii) 99.9% of the standardized residuals or almost all of them should be between ±3.29. A number of 5 data points of standardized residual values were not following those criteria (Figure YY-5 (A)). According to (Simonof 2017; Field 2016; Oyeyemi et al. 2015); not following those criteria is an evidence of having an unacceptable error, incorrect variable estimation, biased results, and that the model is a poor fit of the sample data. To avoid that, the 5 data points were deleted. Figure YY-5 (B) shows scatter plots of regression standardized residuals and standardized predicted values after deleting the above described data points.
- Examining data points of high leverage in the initial model followed the size adjusted cutoff value of 2p/n and 3p/n as discussed in Section 3.4.3 (Imon & Apu 2016; Eberly College of Science 2018b; Montero Ledezma 2017; SAS Institute Inc. 2015; Hamilton 2013). Having p=27 variables and n=542 in the initial model, the cutoff value of 2p/n and 3p/n was about 0.11 and 0.16; respectively. No data points had leverage value above the 3p/n cutoff value while 18 points above 2p/n in the initial model (Figure YY-6 (A)). A number of 36 data points above 2p/n cutoff were retained in the final model. As shown in Figure YY-6 (B), the retained data points were close and were not isolated from others. Deleting a number of 20 points above the 2p/n cutoff had resulted in an insignificant change of about 0.01, 0.01, and 0.1 in $R^2$, adjusted $R^2$, and *SE* of estimate respectively. Therefore, those points above the 2p/n cutoff were retained in the final model since deleting them caused insignificant change. The highest leverage value in the final model was 0.148.
- Examining data points of high influence in the initial model followed the general Cook's distance cutoff value of 1 (Simonof 2017; Mehamet & Jacobsen 2017; Field 2016; Strand et al. 2011) and DFBETAS of 1 (Field 2016; Nelson 2004) as discussed in Section 3.4.3. No influential points were detected in the final model since the highest Cook's distance and DFBETAS were 0.041 and 0.440; respectively. Figure YY-7(A) and (B) illustrates the Cook's distances for models before and after deleting above described unusual data points.

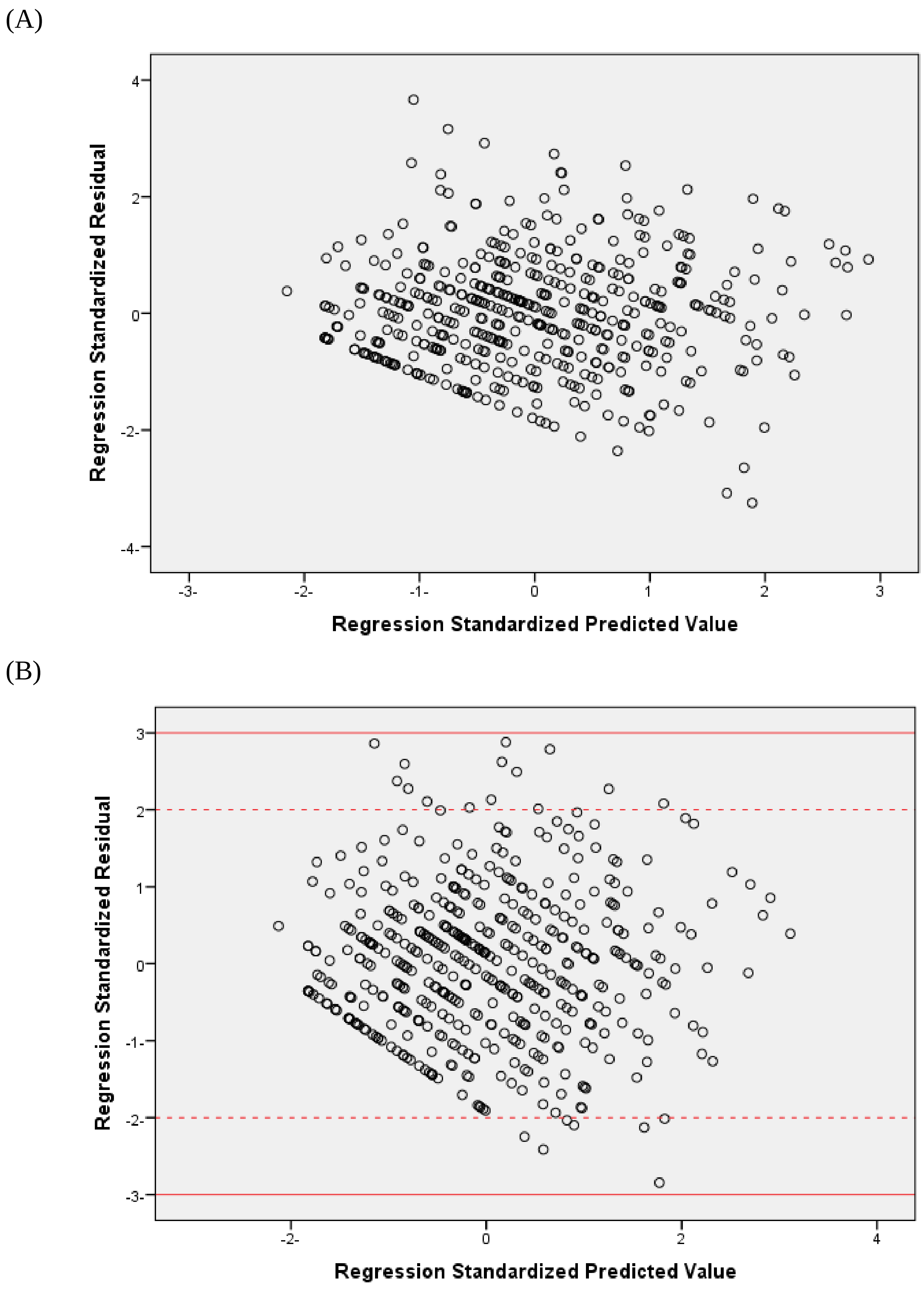
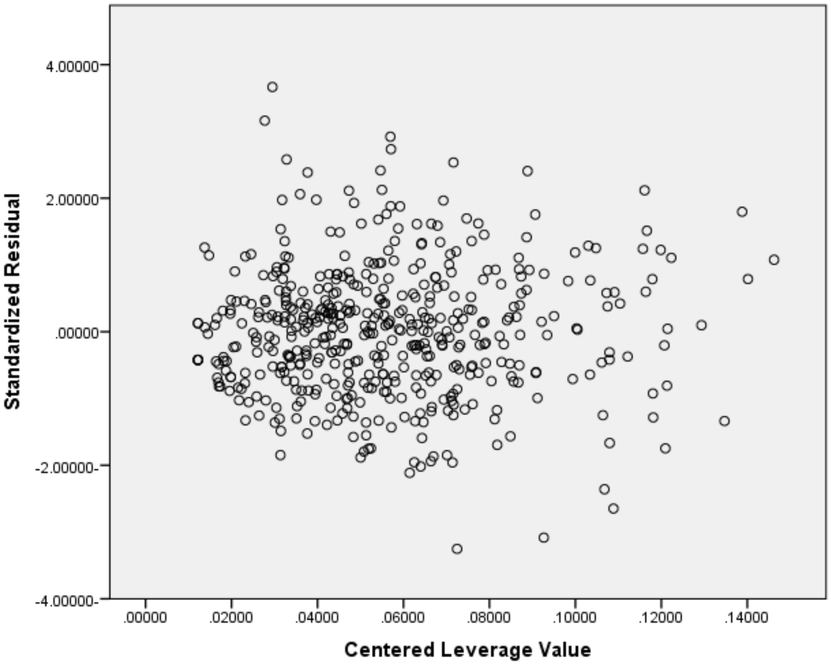


Figure YY-5: Scatter plots (A) & (B) of regression standardized residuals and standardized predicted values having IEQ variables (IV) and general, ergonomic, nervous & skin symptoms (DV) before and after deleting unusual points

(A)



(B)

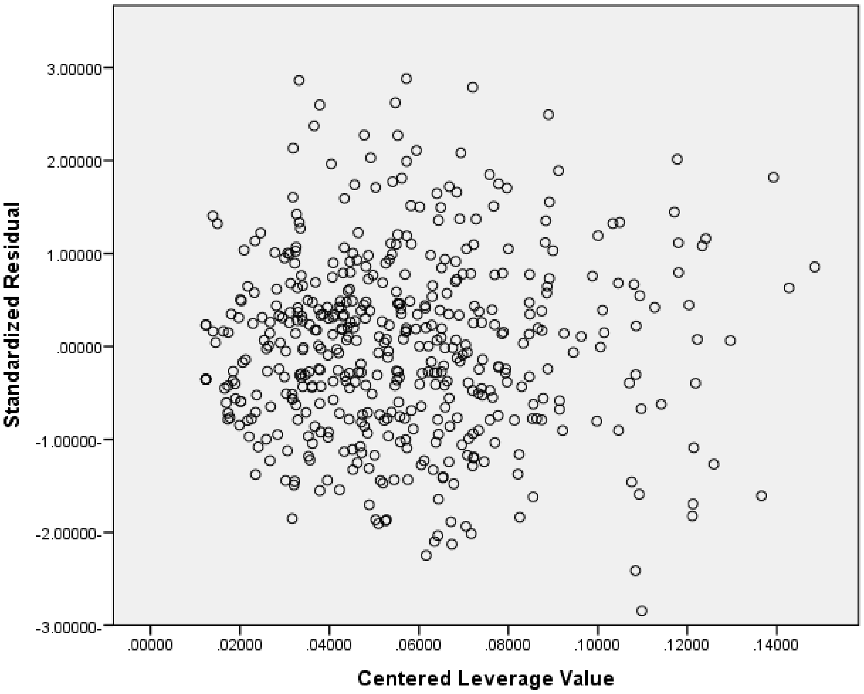
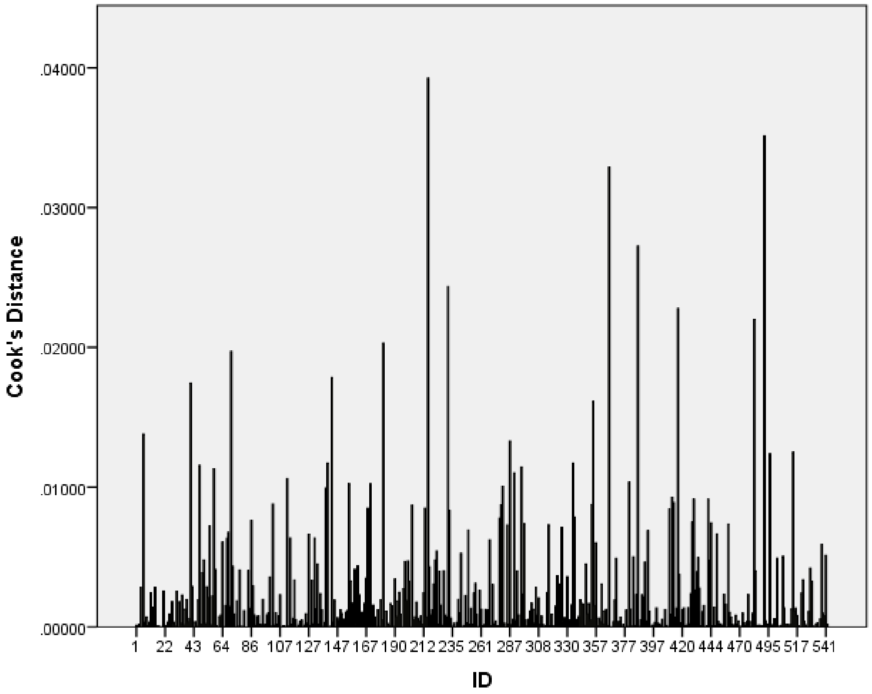


Figure YY-6: Scatter plots (A) & (B) of regression standardized residuals and centered leverage values of IEQ variables (IV) and general, ergonomic, nervous & skin symptoms (DV) before and after deleting unusual data points

(A)



(B)

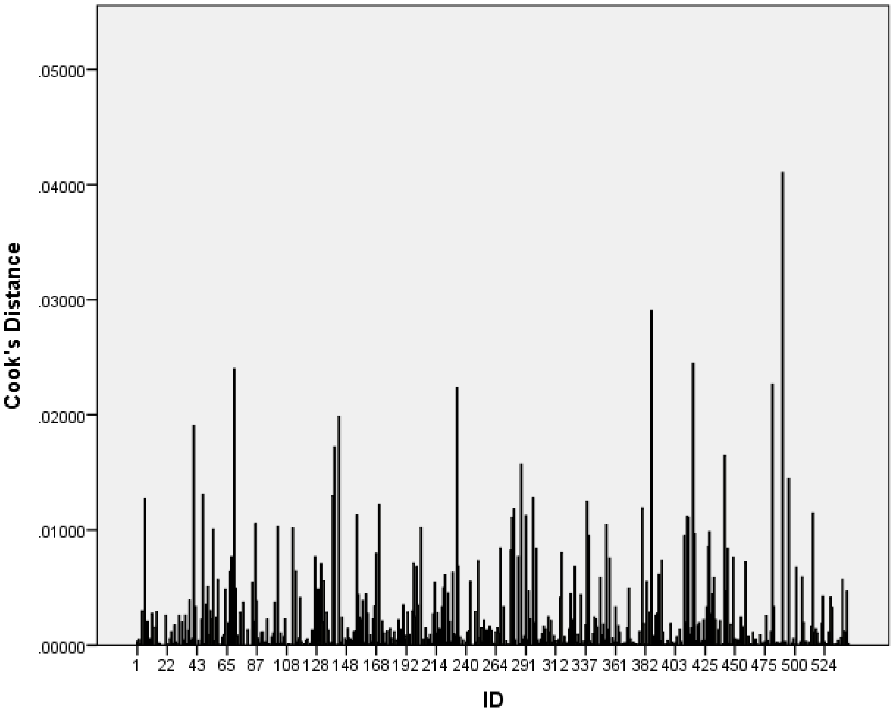


Figure YY-7: Bar charts (A) & (B) of Cook's distances for the regression model of IEQ variables (IV) and general, ergonomic, nervous & skin symptoms (DV) before and after deleting unusual data points

# Appendix ZZ : Results of field measurements for individual houses

## *House (1)*

Table ZZ-1: Levels of continuously measured variables indoor House (1)

| | **TVOC (μg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (μg/m³)** | **$PM_{10}$ (μg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 148 | 327.0 | 0.05 | 214.1 | 234.9 | 22.2 | 31.9 |
| **Mean** | 345 | 552.2 | 0.70 | 263.3 | 309.4 | 24.7 | 46.0 |
| **Max** | 825 | 736.0 | 1.90 | 315.9 | 538.5 | 27.2 | 60.9 |

Table ZZ-2: Levels of spot measured variables in outdoor air of House (1)

| | **TVOC (μg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 292 | 487 | 0.6 | 30.1 | 71.4 |

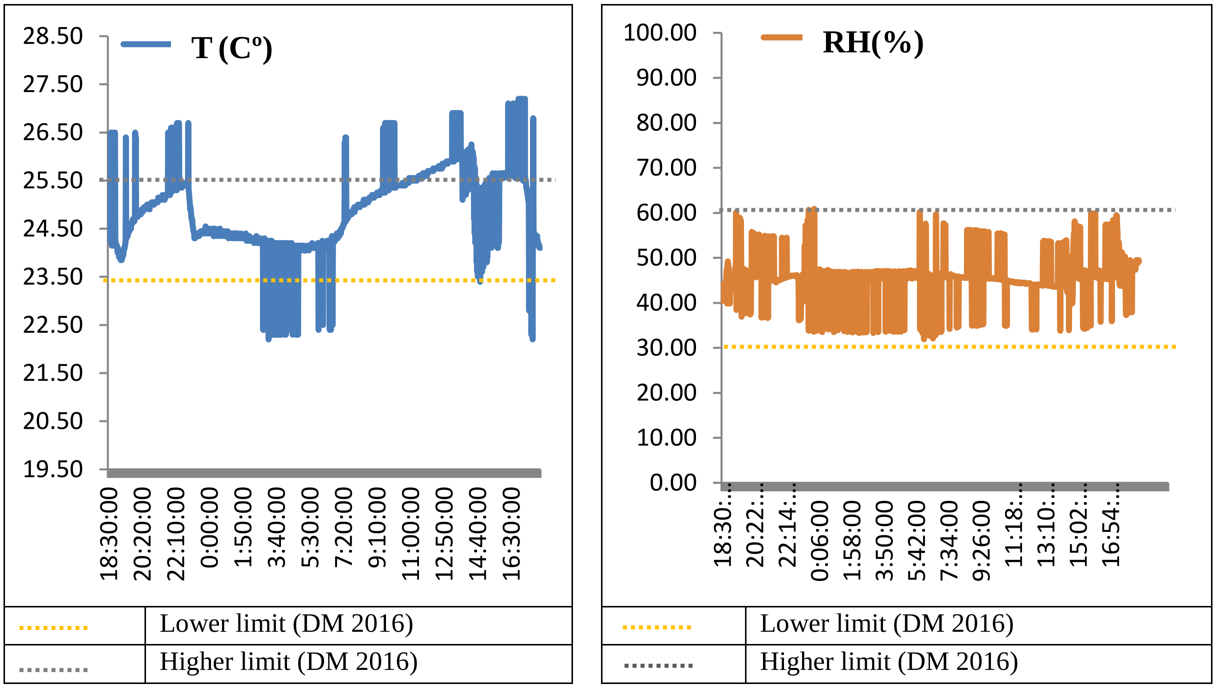


Figure ZZ-1: Compliance of indoor T and RH with established standards (House 1)

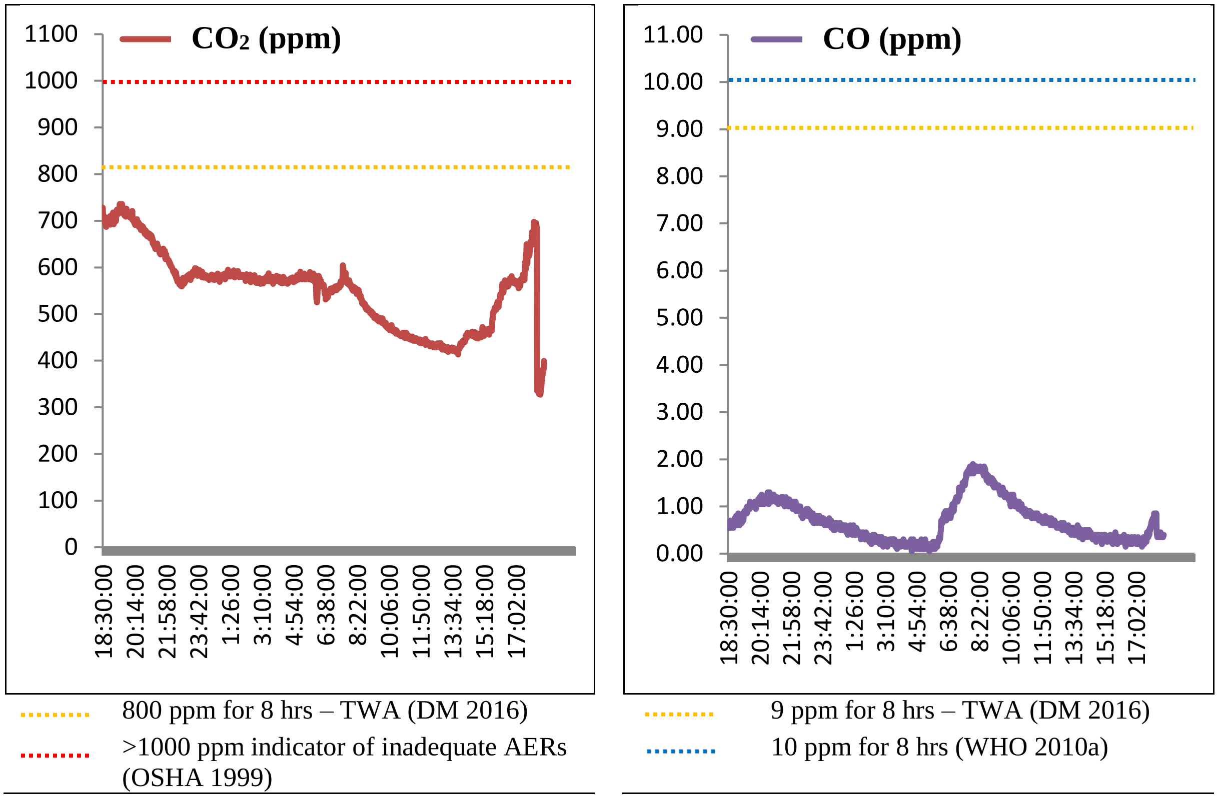


Figure ZZ-2: Compliance of $CO_2$ and CO levels in House (1) with established standards

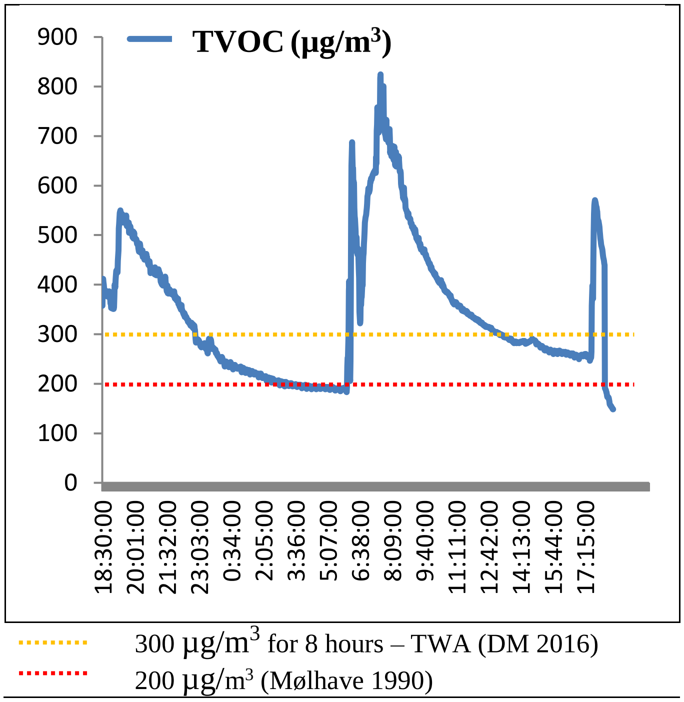


Figure ZZ-3: Compliance of indoor TVOC levels in House (1) with established standards

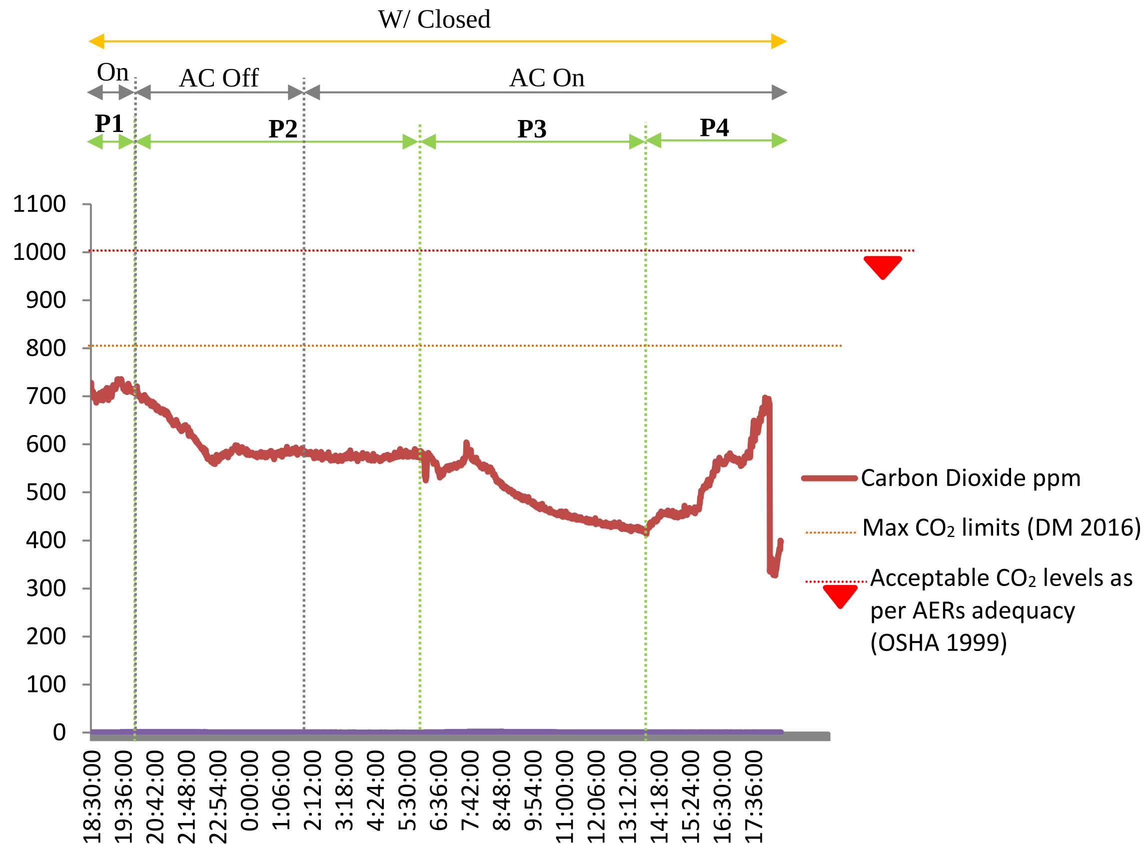


Figure ZZ-4: Occupancy profiles of the living hall projected on $CO_2$ levels (House 1)

Table ZZ-3: Occupancy profiles of the living hall during measurement period (House 1)

| **Profile** | **Time** | **Occupants** | **System** | **Activities** |
|---|---|---|---|---|
| **P1** | 18:30 – 20:00 | 1 | Mechanical | Sitting, smoking |
| **P2** | 20:00 – 06:00 | 0 | Natural (Infiltration) | Went outside |
| **P3** | 06:00 – 13:45 | 0 | Mechanical | 1 person sleeping in other rooms |
| **P4** | 13:45 – 18:30 | 1 | Natural (Infiltration) | Sitting, smoking |

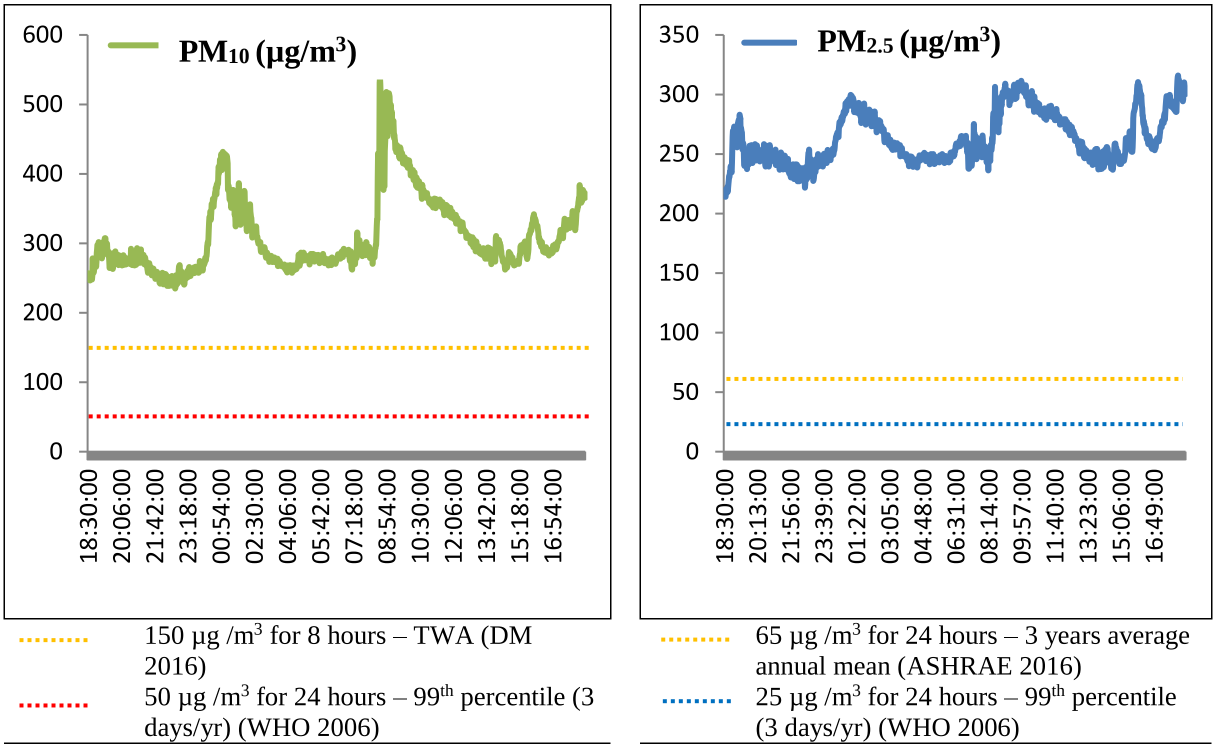


Figure ZZ-5: Compliance of $PM_{10}$ and $PM_{2.5}$ levels with established standards (House 1)

### *House (2)*

Table ZZ-4: Levels of continuously measured variables indoor House (2)

| | **TVOC (μg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (μg/m³)** | **$PM_{10}$ (μg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 372.6 | 836.0 | 0.4 | 568.2 | 633.3 | 26.3 | 43.3 |
| **Mean** | 571.3 | 1209.4 | 1.6 | 1446.7 | 1504.3 | 28.8 | 50.5 |
| **Max** | 1161.5 | 2948.0 | 4.1 | 6667.2 | 6724.5 | 30.3 | 61.6 |

Table ZZ-5: Levels of spot measured variables in outdoor air of House (2)

| | **TVOC (μg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 669.3 | 459 | 1.2 | 30.8 | 83.9 |

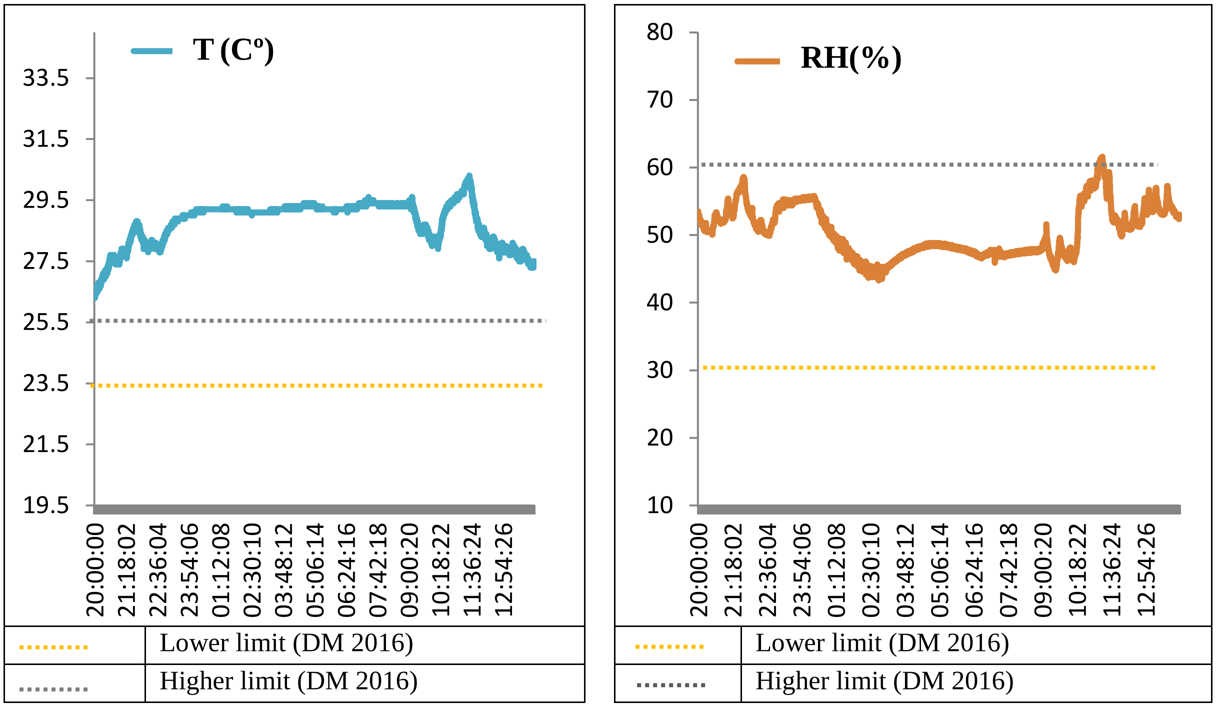


Figure ZZ-6: Compliance of indoor T and RH with established standards (House 2)

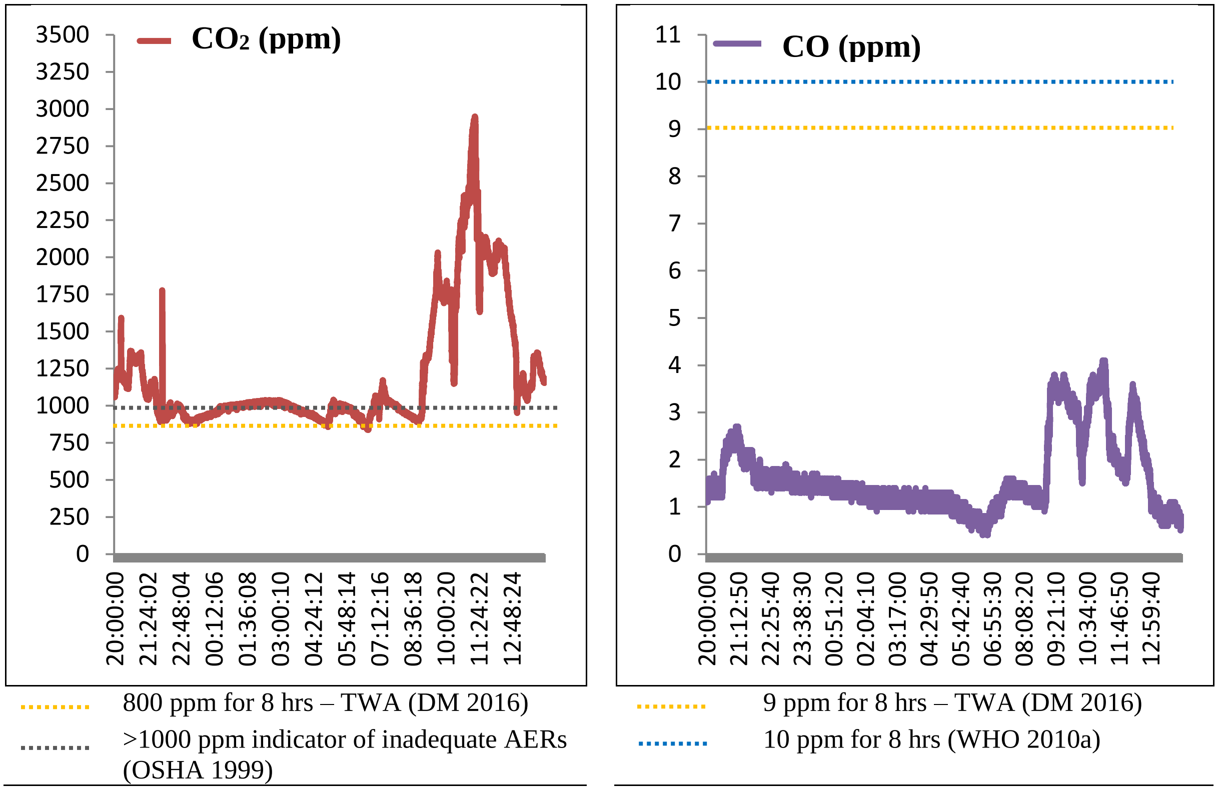


Figure ZZ-7: Compliance of $CO_2$ and CO levels in House (2) with established standards

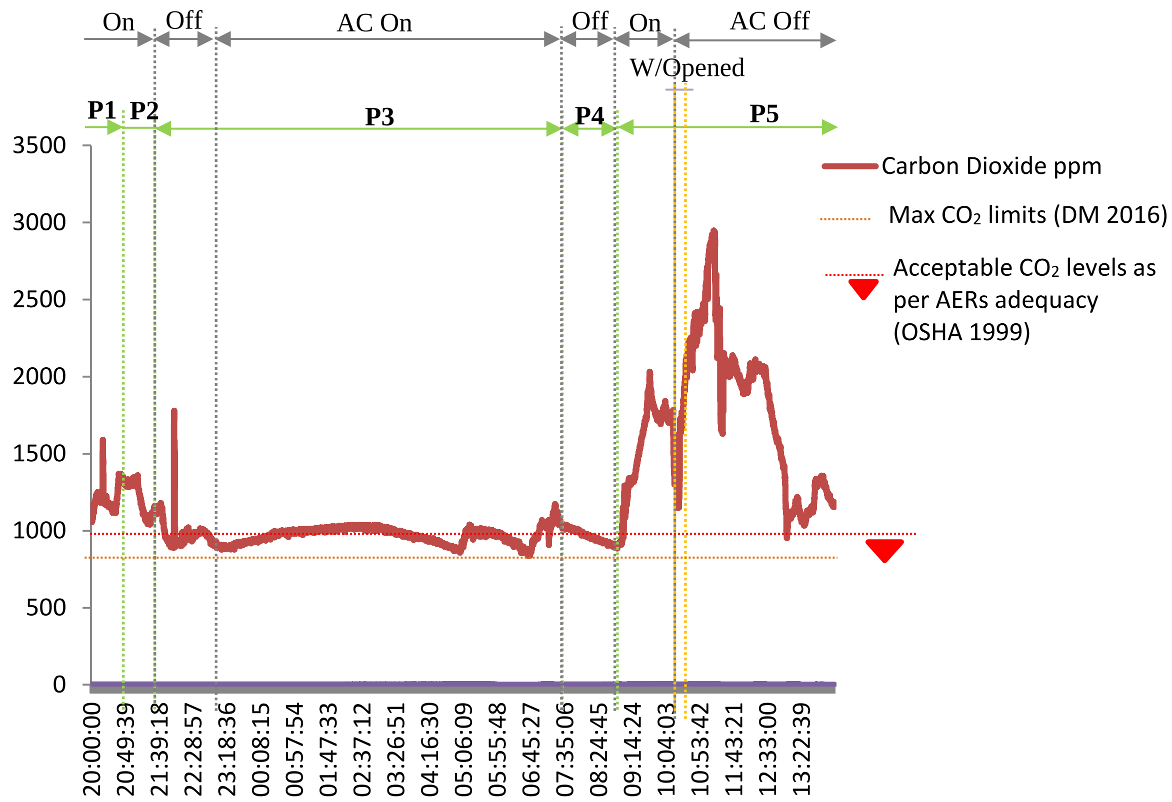


Figure ZZ-8: Occupancy profiles of the living hall projected on $CO_2$ levels (House 2)

Table ZZ-6: Occupancy profiles of the living hall during measurement period (House 2)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 20:00 – 20:40 | 11 | Mechanical | Cooking, sitting |
| **P2** | 20:40 – 21:20 | 5 | Mechanical | Cooking, sitting |
| **P3** | 21:20 – 07:30 | 0 | Mixed:<br>21:20 – 23:00 Mechanical<br>23:00 – 07:30 Natural (Infiltration) | In other rooms |
| **P4** | 7:30 – 09:00 | 0 | Mechanical | In other rooms |
| **P5** | 09:00 – 15:20 | 5 | Mixed:<br>09:00 – 10:14 Mechanical<br>10:15 – 10:30 Natural (Windows)<br>10:30 – 15:20 Natural (Infiltration) | Cooking, sitting |

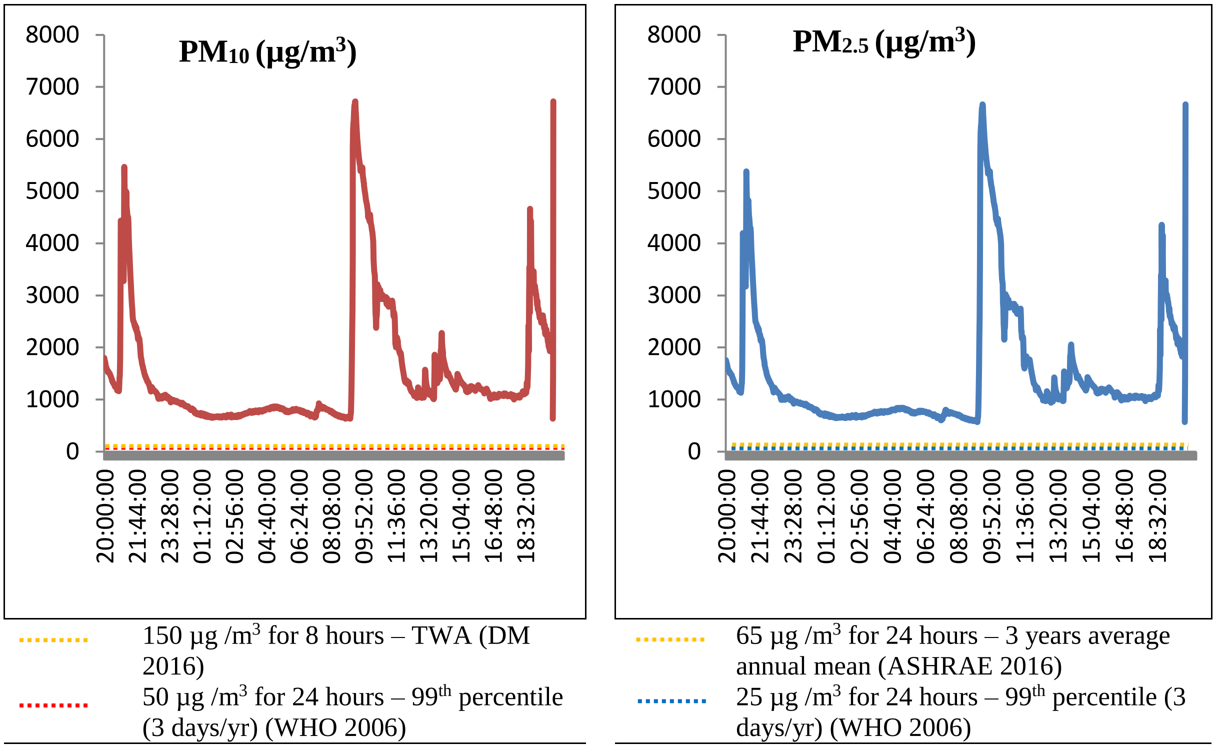


Figure ZZ-9: Compliance of $PM_{10}$ and $PM_{2.5}$ levels with established standards (House 2)

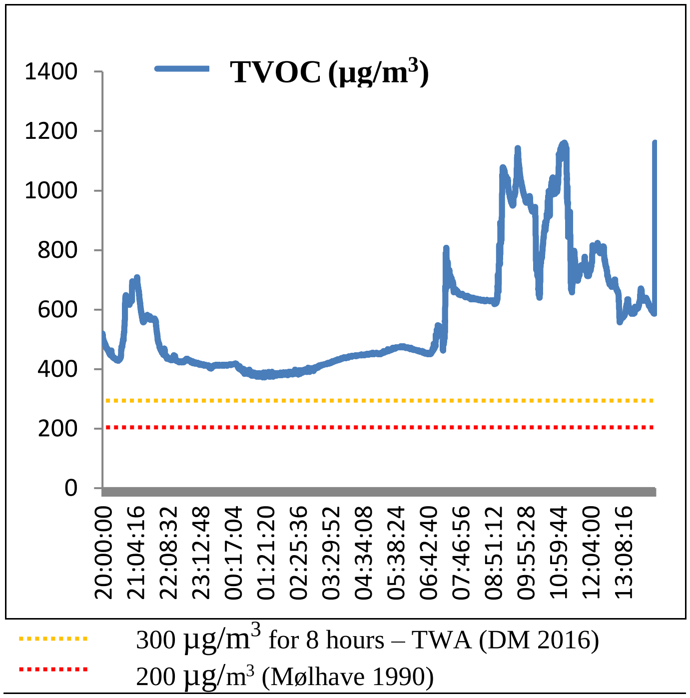


Figure ZZ-10: Compliance of indoor TVOC levels in House (2) with established standards

### *House (3)*

Table ZZ-7: Levels of continuously measured variables indoor House (3)

| | **TVOC (µg/m³)** | **CO₂ (ppm)** | **CO (ppm)** | **PM2.5 (µg/m³)** | **PM10 (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 604.9 | 509.0 | 0.1 | 9.3 | 9.3 | 28.5 | 45.8 |
| **Mean** | 1141.3 | 1842.7 | 2.3 | 1623.6 | 1669.2 | 31.2 | 59.9 |
| **Max** | 1561.7 | 2748.0 | 3.8 | 4562.0 | 5198.3 | 33.3 | 67.2 |

Table ZZ-8: Levels of spot measured variables in outdoor air of House (3)

| | **TVOC (µg/m³)** | **CO₂ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 316 | 491 | 0.5 | 32.7 | 64.9 |

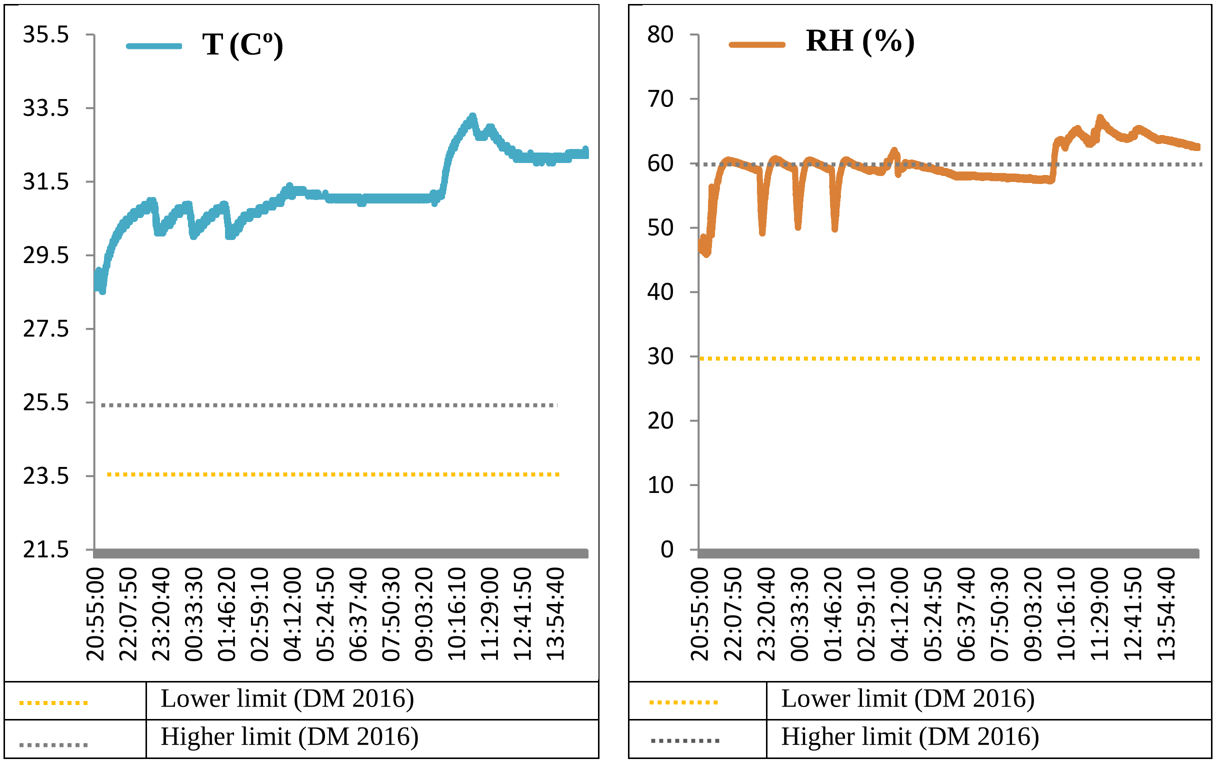


Figure ZZ-11: Compliance of indoor T and RH with established standards (House 3)

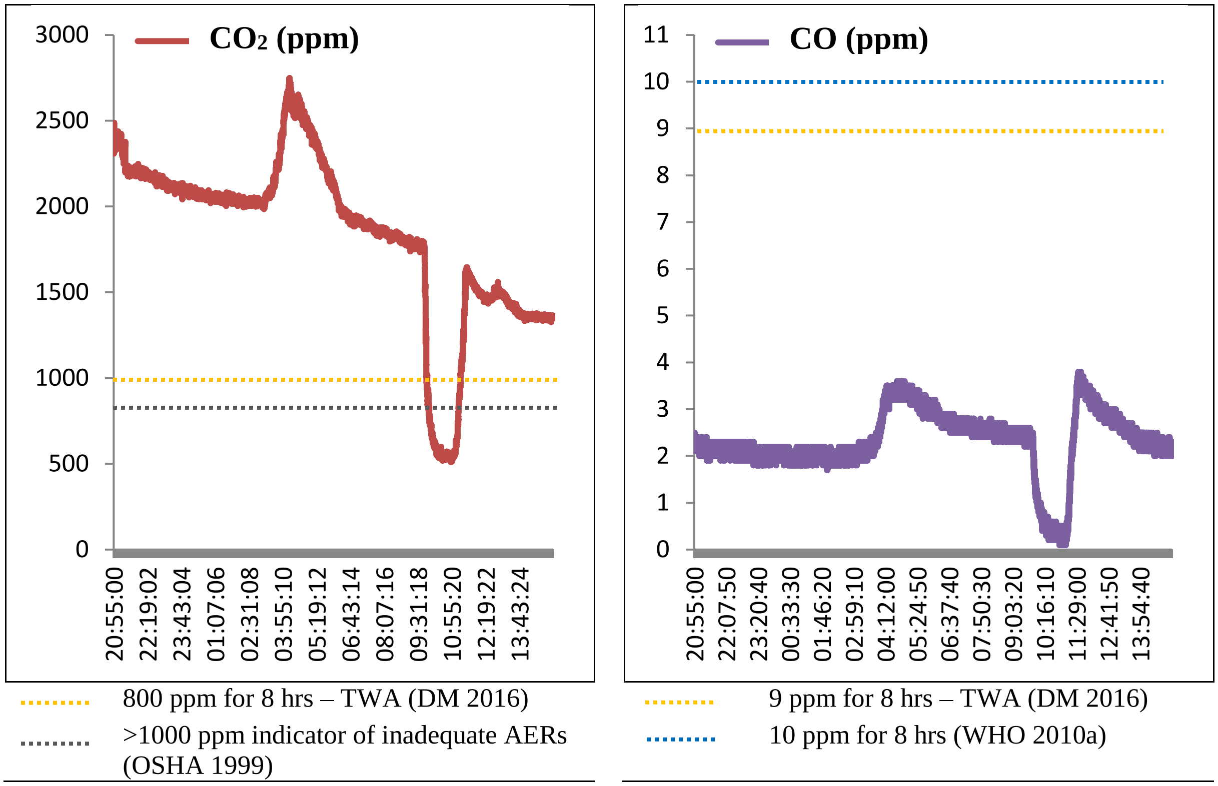


Figure ZZ-12: Compliance of $CO_2$ and CO levels in House (3) with established standards

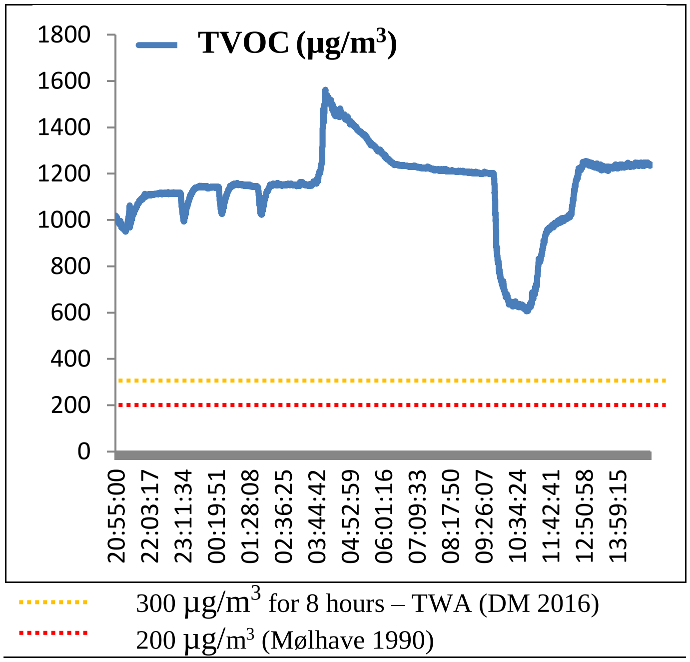


Figure ZZ-13: Compliance of indoor TVOC levels in House (3) with established standards

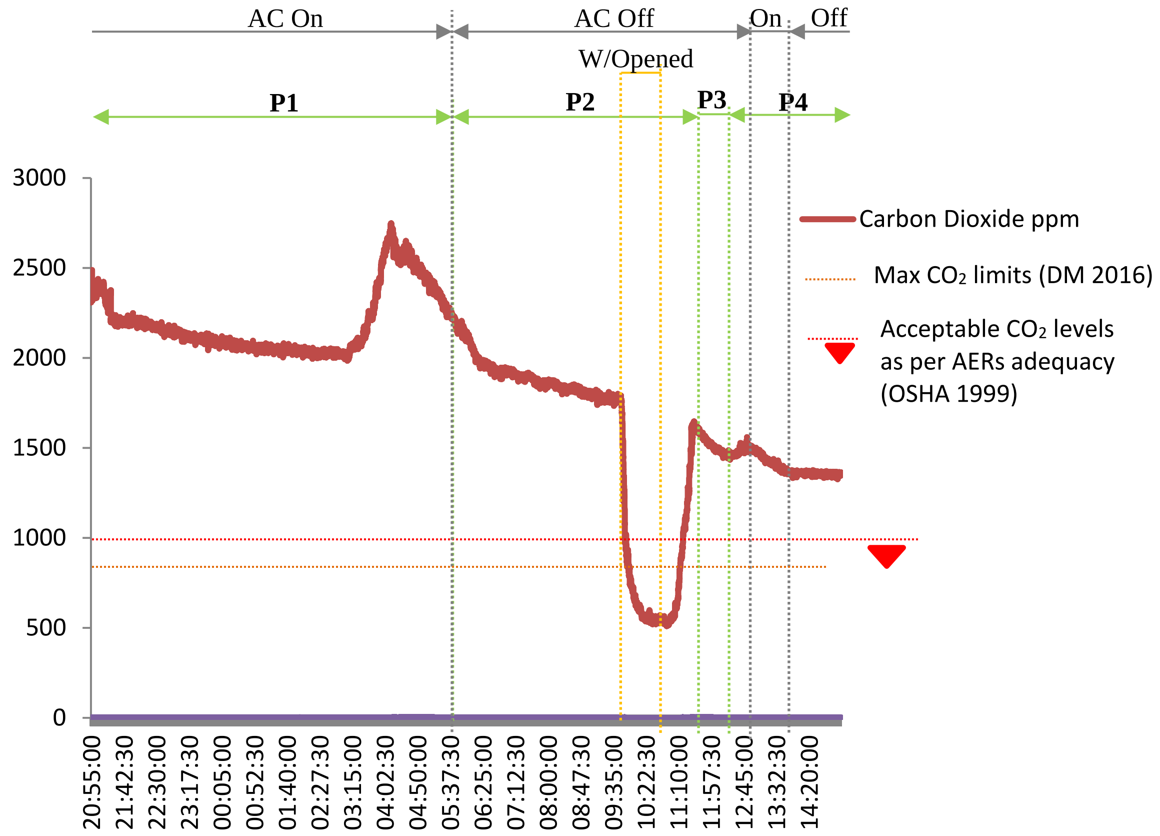
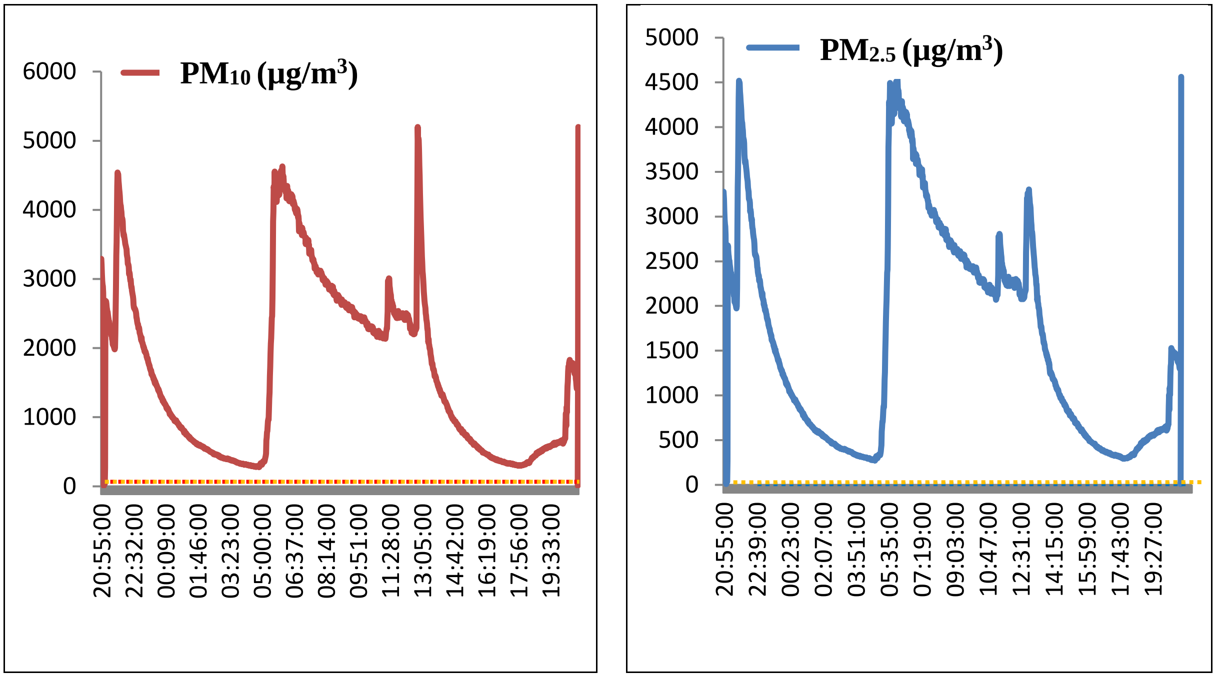


Figure ZZ-14: Occupancy profiles of the living hall projected on $CO_2$ levels (House 3)

Table ZZ-9: Occupancy profiles of the living hall during measurement period (House 3)

| | **Time** | **Occupants** | **System** | **Activities** |
|---|---|---|---|---|
| **P1** | 20:00 – 05:35 | 2 | Mechanical | Sleeping, cooking, breakfast |
| **P2** | 05:35 – 11:30 | 1 | Mixed:<br>05:35 – 09:45 Mechanical<br>09:45 – 10:45 Natural (Window & infiltration)<br>10:45 – 11:30 Mechanical | Cooking, cleaning |
| **P3** | 11:30 – 12:20 | 2 | Natural (Infiltration) | Cooking, cleaning |
| **P4** | 12:20 – 09:15 | 1 | Mixed:<br>12:20 –12:55 Natural (Infiltration)<br>12:55 – 13:50 Mechanical<br>13:50 – 09:15 Natural (Infiltration) | Sitting |



| | | | |
|---|---|---|---|
| ⋯⋯ | 150 µg /m³ for 8 hours – TWA (DM 2016) | ⋯⋯ | 65 µg /m³ for 24 hours – 3 years average annual mean (ASHRAE 2016) |
| ⋯⋯ | 50 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) | ⋯⋯ | 25 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure ZZ-15: Compliance of $PM_{10}$ and $PM_{2.5}$ levels with established standards (House 3)

### *House (4)*

Table ZZ-10: Levels of continuously measured variables indoor House (4)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 257.6 | 427.0 | 0.0 | 132.5 | 135.6 | 25.5 | 36.7 |
| **Mean** | 512.6 | 774.4 | 1.1 | 330.7 | 428.5 | 27.1 | 50.1 |
| **Max** | 1113.2 | 3521.0 | 2.6 | 1169.3 | 1176.8 | 29.5 | 61.4 |

Table ZZ-11: Levels of spot measured variables in outdoor air of House (4)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 331 | 497 | 0.3 | 31.3 | 61.9 |

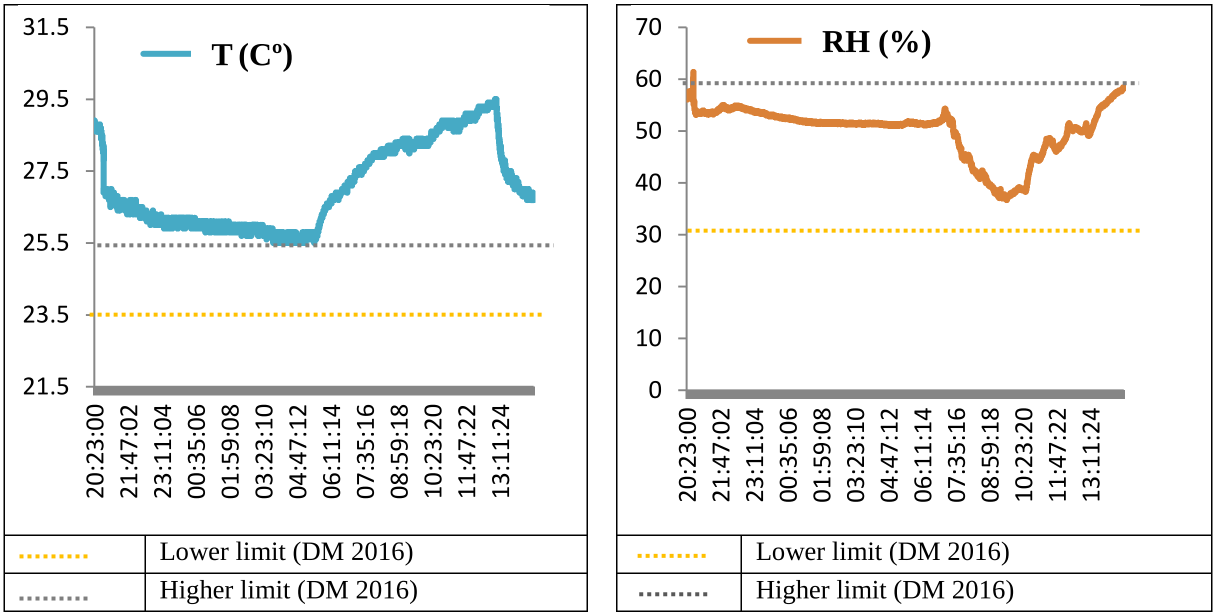


Figure ZZ-16: Compliance of indoor T and RH with established standards (House 4)

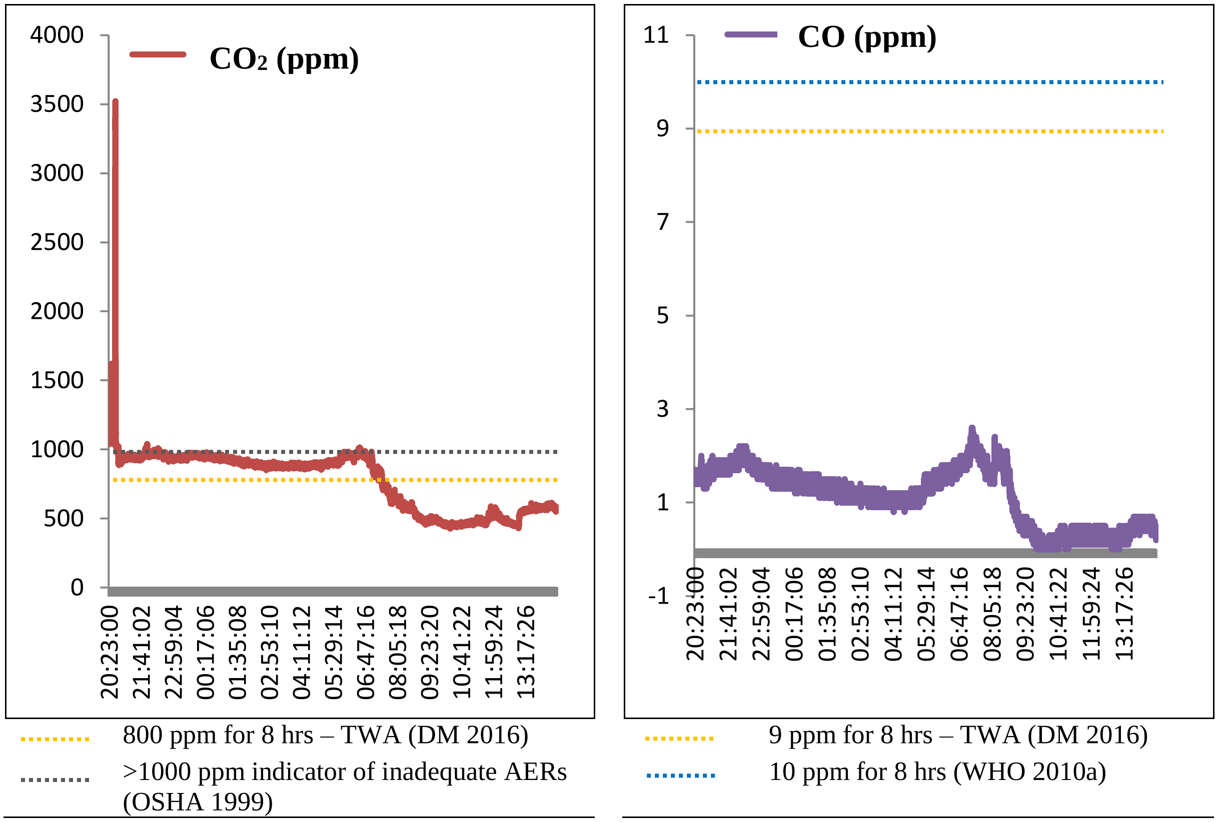


Figure ZZ-17: Compliance of $CO_2$ and CO levels in House (4) with established standards

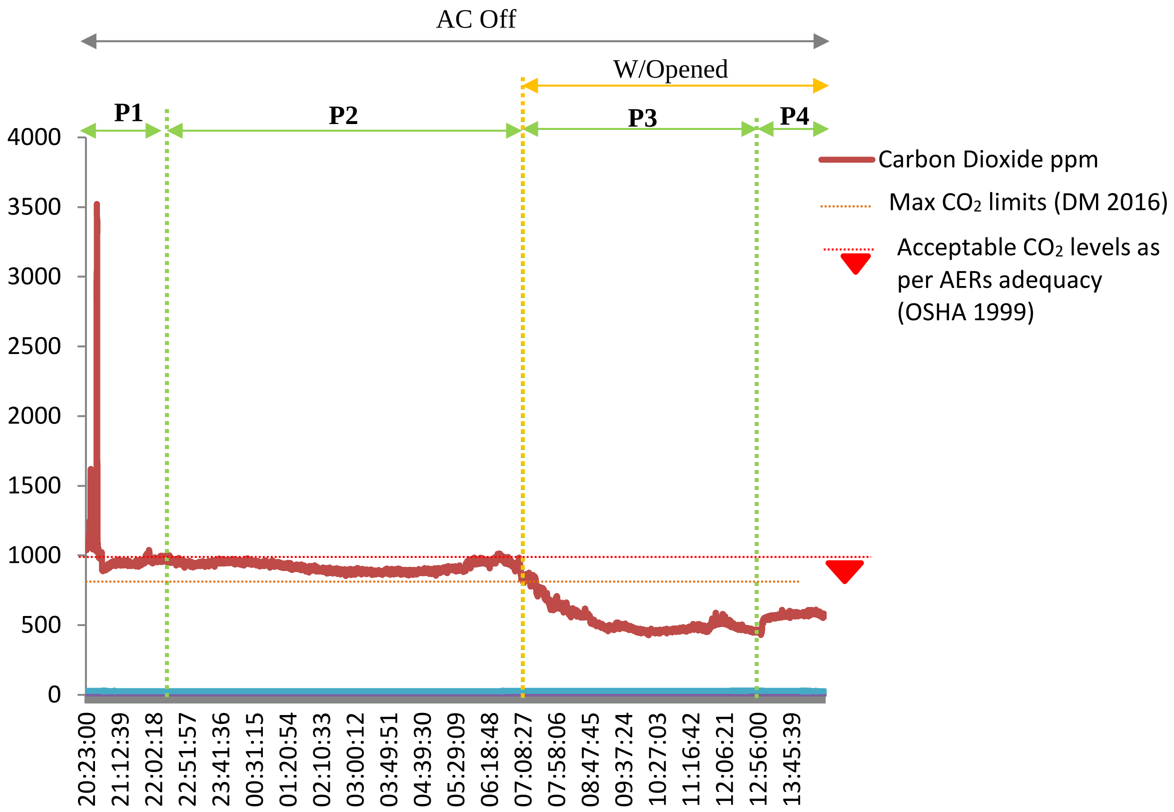


Figure ZZ-18: Occupancy profiles of the living hall projected on $CO_2$ levels (House 4)

Table ZZ-12: Occupancy profiles of the living hall during measurement period (House 4)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 20:23 – 22:20 | 3 | Natural (Infiltration) | Sitting, cooking, washing, dinner |
| **P2** | 22:20 – 07:15 | 0 | Natural (Infiltration) | 4 persons in other rooms |
| **P3** | 07:15 – 01:00 | 5 | Natural (Window & Infiltration) | Cooking/ cleaning |
| **P4** | 01:00 – 02:35 | 3 | Natural (Window & Infiltration) | 3 persons in other rooms |

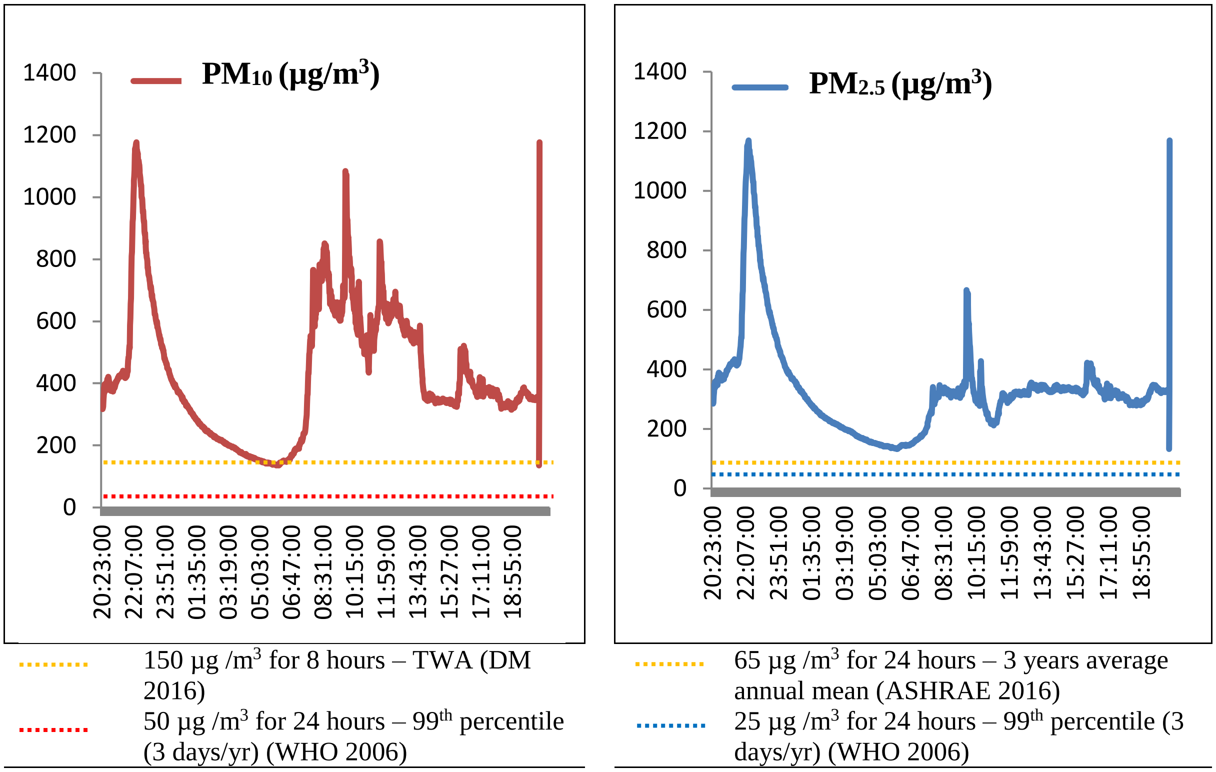


Figure ZZ-19: Compliance of $PM_{10}$ and $PM_{2.5}$ levels with established standards (House 4)

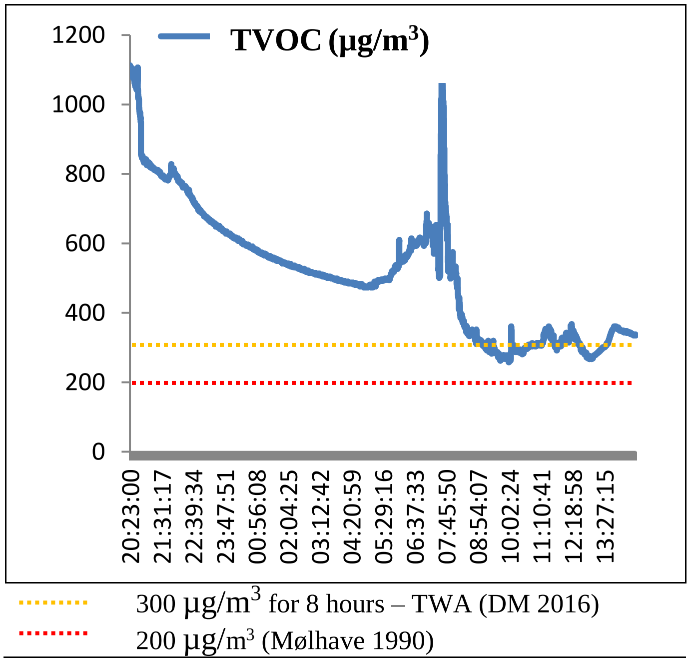


Figure ZZ-20: Compliance of indoor TVOC levels in House (4) with established standards

***House (5)***

Table ZZ-13: Levels of continuously measured variables indoor House (5)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m$^3$)** | **$PM_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 1596.2 | 1183.0 | 2.4 | 132.5 | 153.2 | 25.3 | 34.0 |
| **Mean** | 2073.5 | 1936.1 | 6.7 | 964.6 | 991.9 | 28.5 | 41.3 |
| **Max** | 2743.9 | 2993.0 | 13.4 | 7287.1 | 7356.2 | 30.2 | 45.1 |

Table ZZ-14: Levels of spot measured variables in outdoor air of House (5)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 949.9 | 558 | 2.0 | 29.9 | 66.8 |

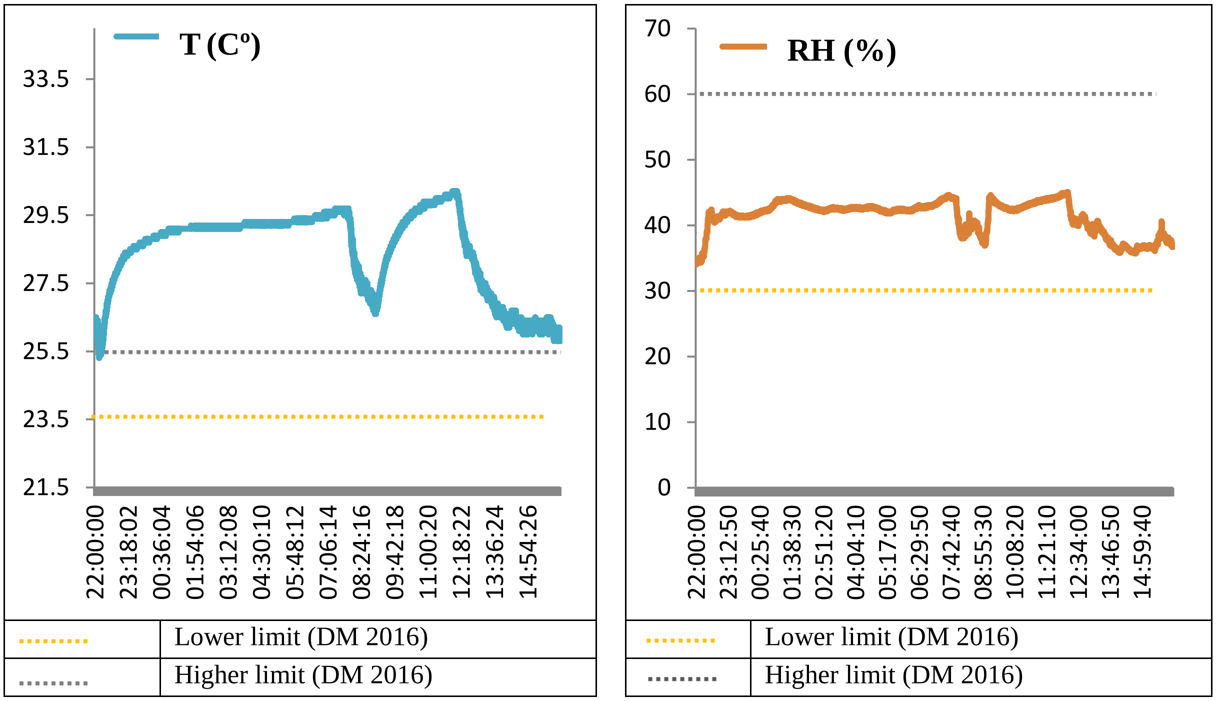


Figure ZZ-21: Compliance of indoor T and RH with established standards (House 5)

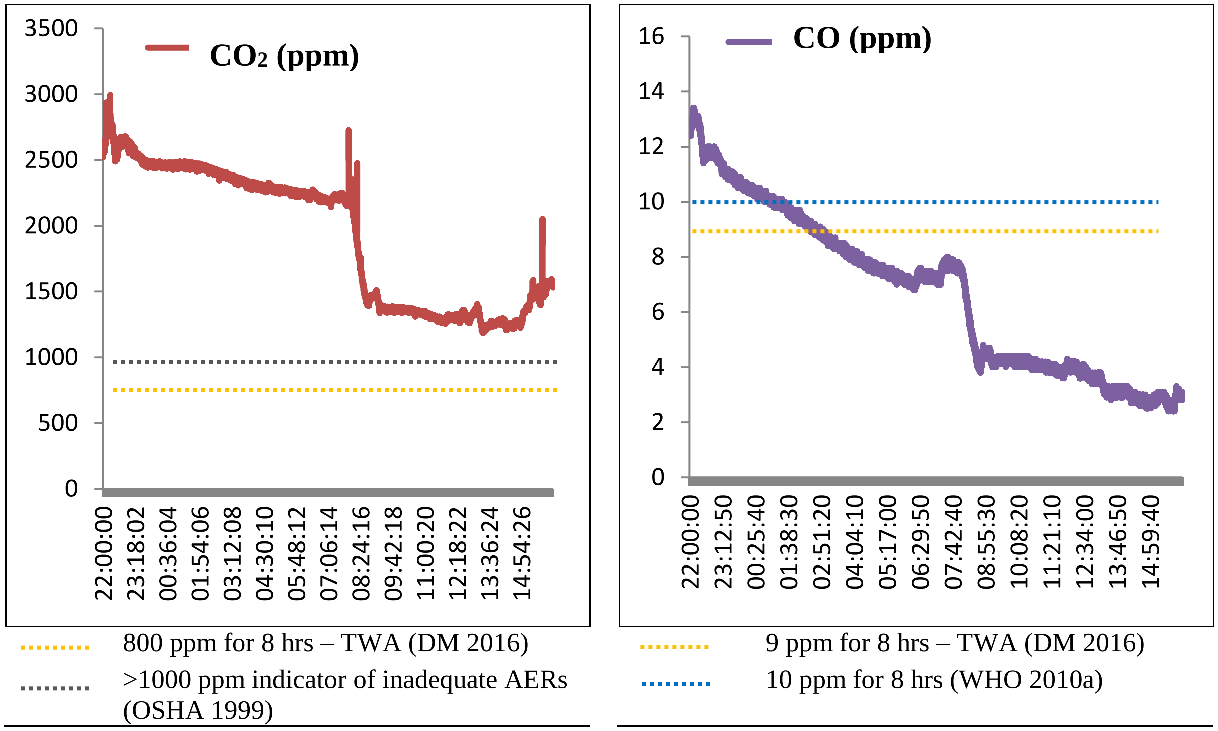


Figure ZZ-22: Compliance of $CO_2$ and CO levels in House (5) with established standards

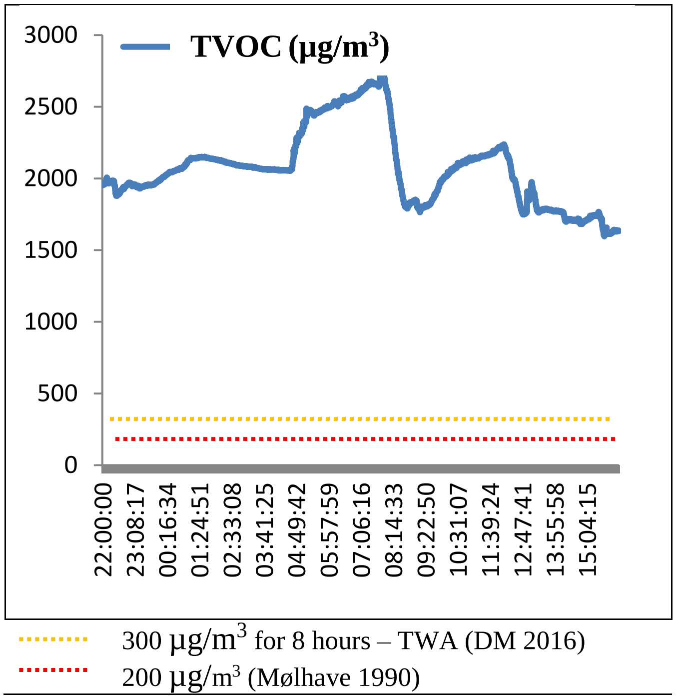


Figure ZZ-23: Compliance of indoor TVOC levels in House (5) with established standards

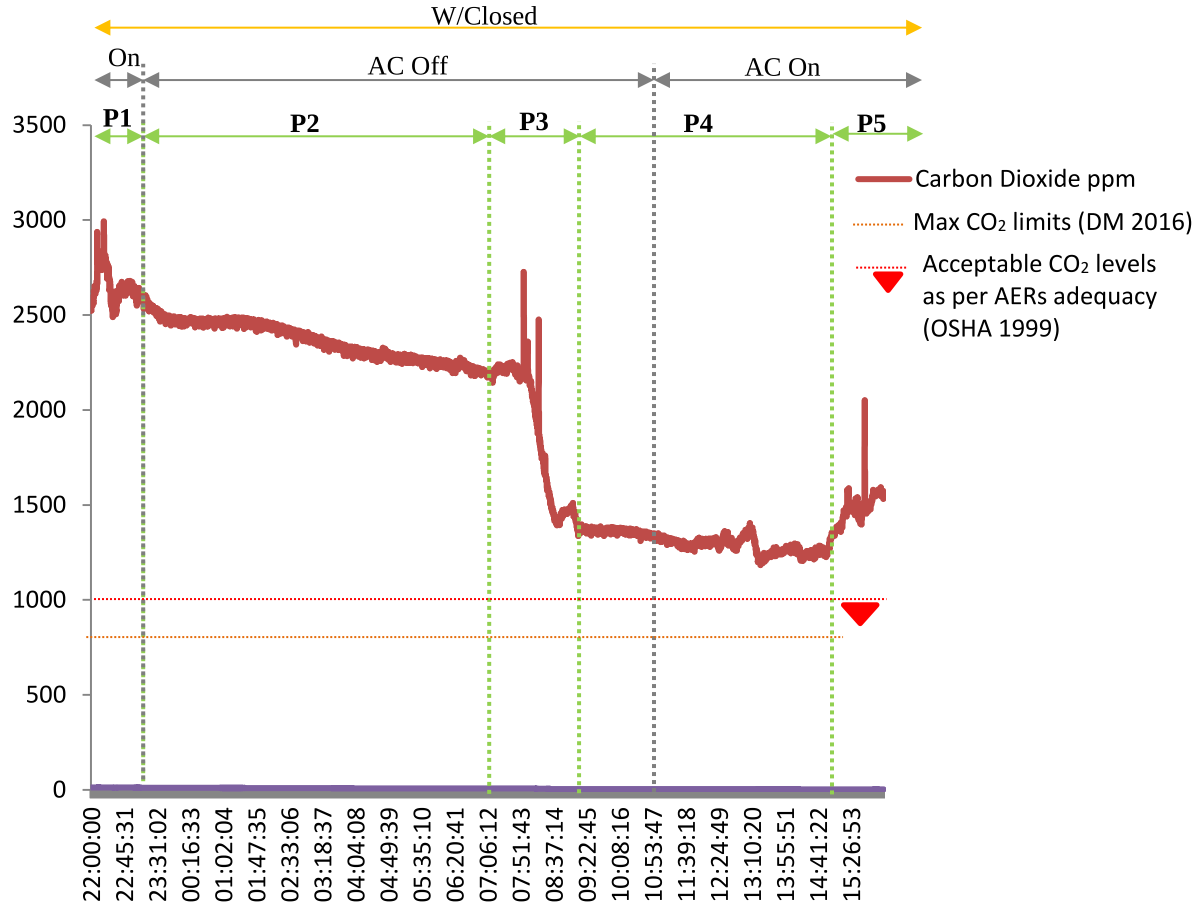


Figure ZZ-24: Occupancy profiles of the living hall projected on $CO_2$ levels (House 5)

Table ZZ-15: Occupancy profiles of the living hall during measurement period (House 5)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 22:00 – 23:00 | 13 | Mechanical | Sitting, dinner |
| **P2** | 23:00 – 07:00 | 0 | Natural (Infiltration) | 13 persons sleeping in other rooms, |
| **P3** | 07:00 – 09:00 | 7 | Natural (Infiltration) | Cooking, breakfast |
| **P4** | 09:00 – 15:00 | 0 | Mixed:<br>09:00 – 10:00 Natural Infiltration<br>10:00 – 15:00 Mechanical | 6 persons in other rooms, Cooking, Cleaning, Washing |
| **P5** | 15:00 – 16:12 | 11 | Mechanical | Cooking, lunch |

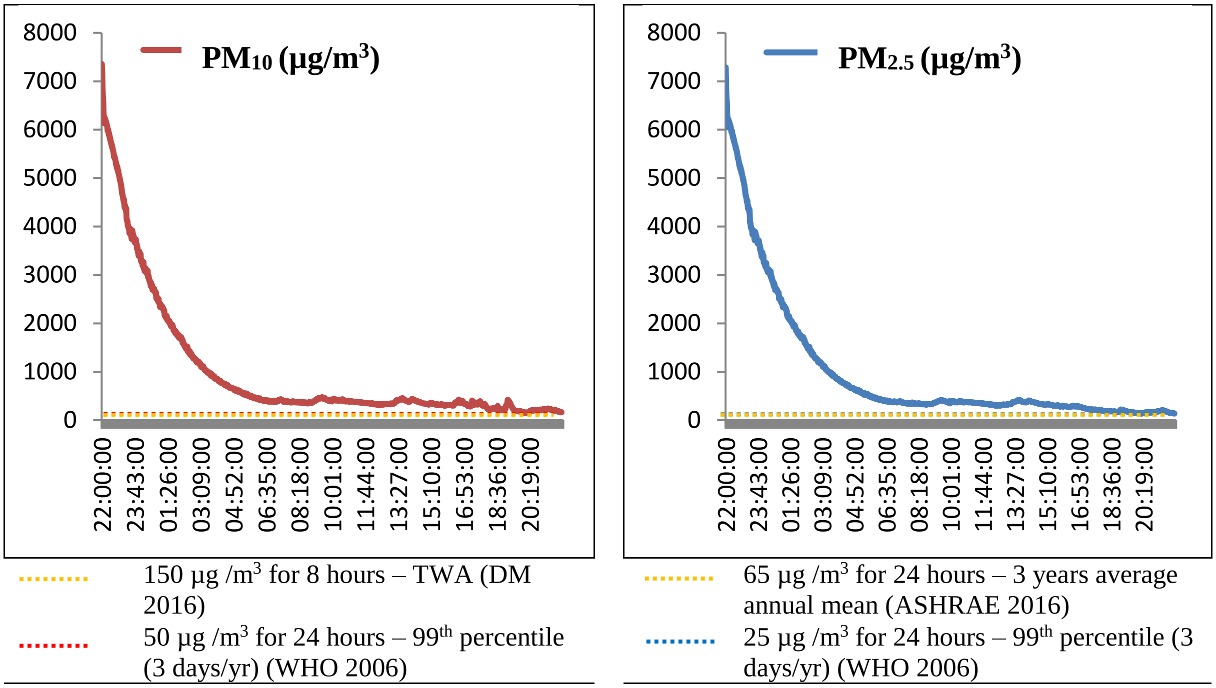


Figure ZZ-25: Compliance of $PM_{10}$ and $PM_{2.5}$ levels with established standards (House 5)

### *House (6)*

Table ZZ-16: Levels of continuously measured variables indoor House (6)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 391.0 | 411.0 | 0.0 | 41.5 | 56.3 | 22.3 | 24.2 |
| **Mean** | 557.9 | 605.0 | 0.6 | 71.9 | 120.8 | 28.9 | 31.1 |
| **Max** | 729.1 | 747.0 | 1.8 | 170.8 | 647.0 | 32.2 | 41.9 |

Table ZZ-17: Levels of spot measured variables in outdoor air of House (6)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 159 | 477 | 2.1 | 42.2 | 12.4 |

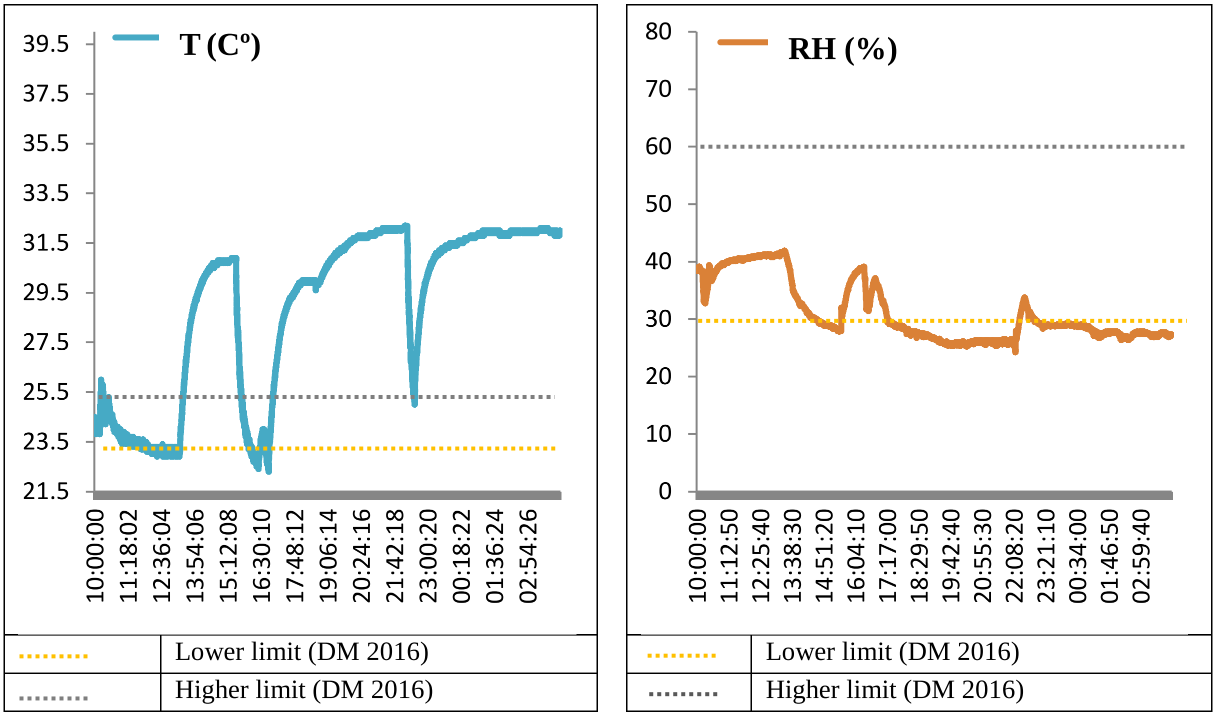


Figure ZZ-26: Compliance of indoor T and RH with established standards (House 6)

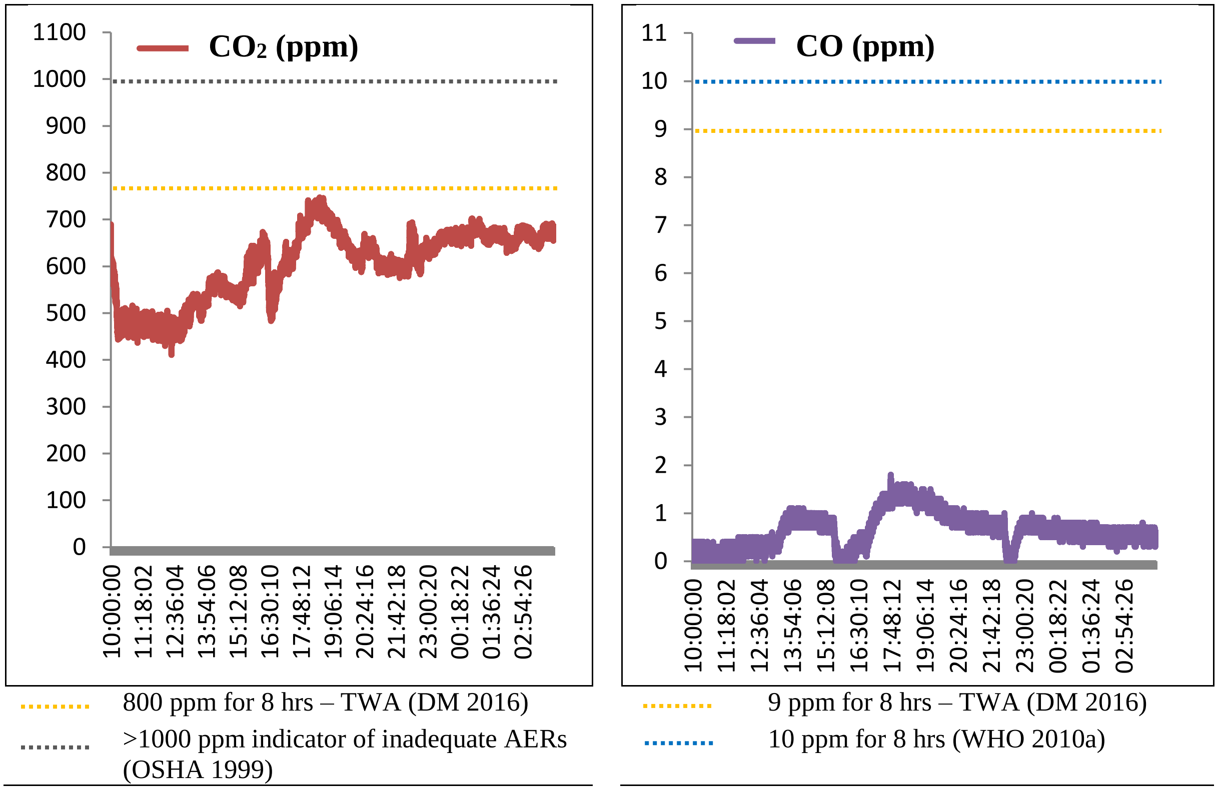


Figure ZZ-27: Compliance of $CO_2$ and CO levels in House (6) with established standards

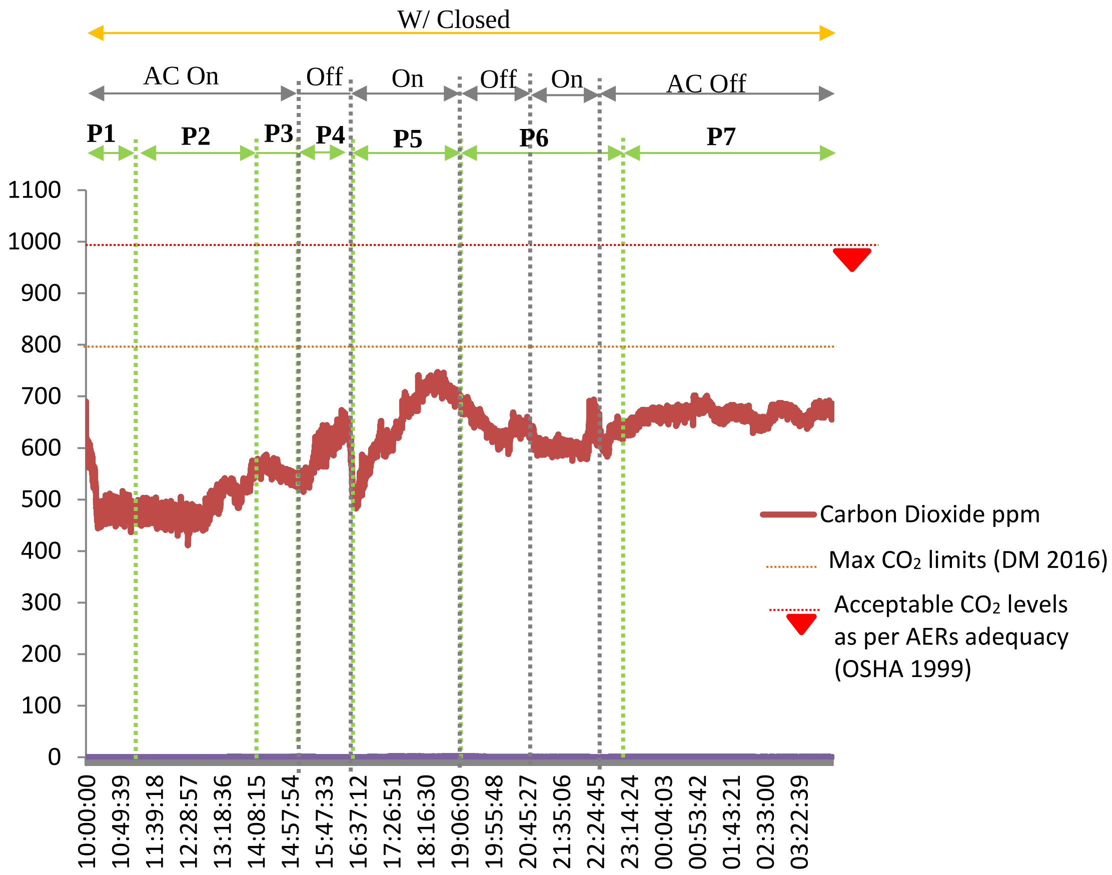


Figure ZZ-28: Occupancy profiles of the living hall projected on $CO_2$ levels (House 6)

Table ZZ-18: Occupancy profiles of the living hall during measurement period (House 6)

| **Profile** | **Time** | **Occupants** | **System** | **Activities** |
|---|---|---|---|---|
| **P1** | 10:00 – 11:00 | 3 | Mechanical | Sitting, cooking |
| **P2** | 11:00 – 14:05 | 0 | Mechanical | 3 persons in other rooms |
| **P3** | 14:05 – 15:15 | 2 | Mechanical | Sitting |
| **P4** | 15:15 – 16:30 | 0 | Natural (Infiltration) | 2 persons in other rooms, cooking |
| **P5** | 16:30 – 19:00 | 5 | Mechanical | Sitting, having visitors |
| **P6** | 19:00 – 23:00 | 3 | Mixed:<br>19:00 – 21:00 Mechanical<br>21:00 – 23:00 Natural (Infiltration) | Sitting, cooking |
| **P7** | 23:00 – 04:12 | 0 | Natural (Infiltration) | 3 Sleeping in other room |

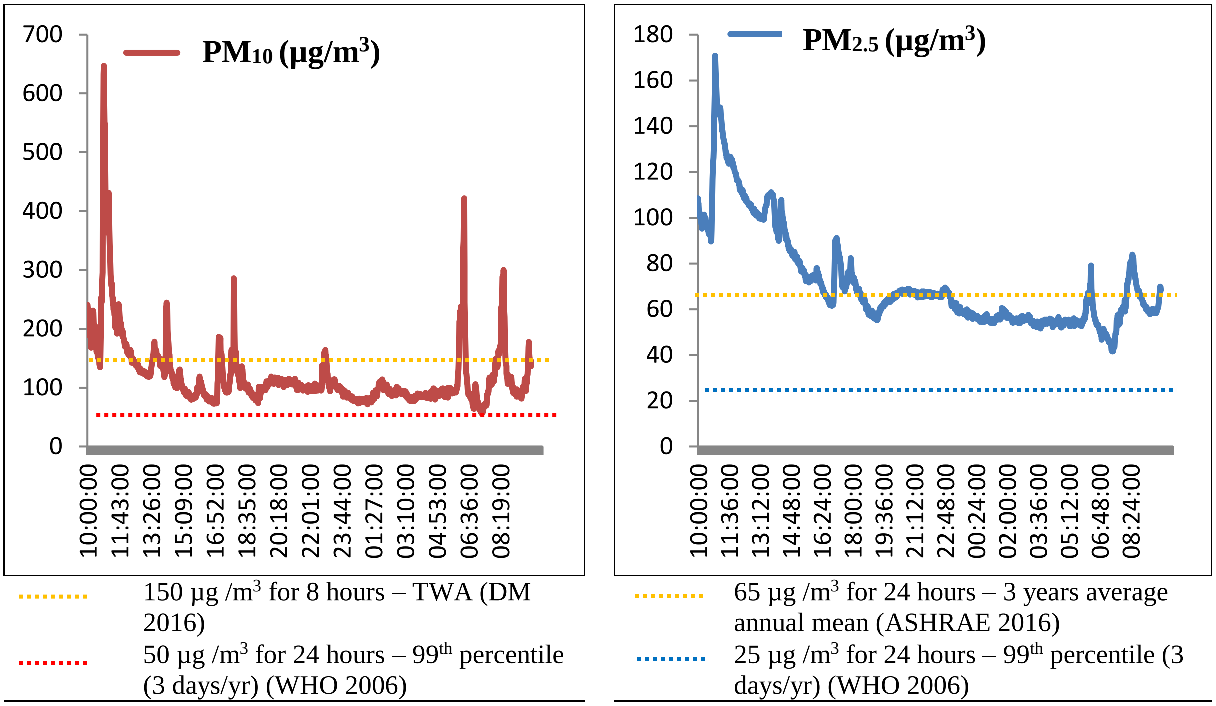


Figure ZZ-29: Compliance of $PM_{10}$ and $PM_{2.5}$ levels with established standards (House 6)

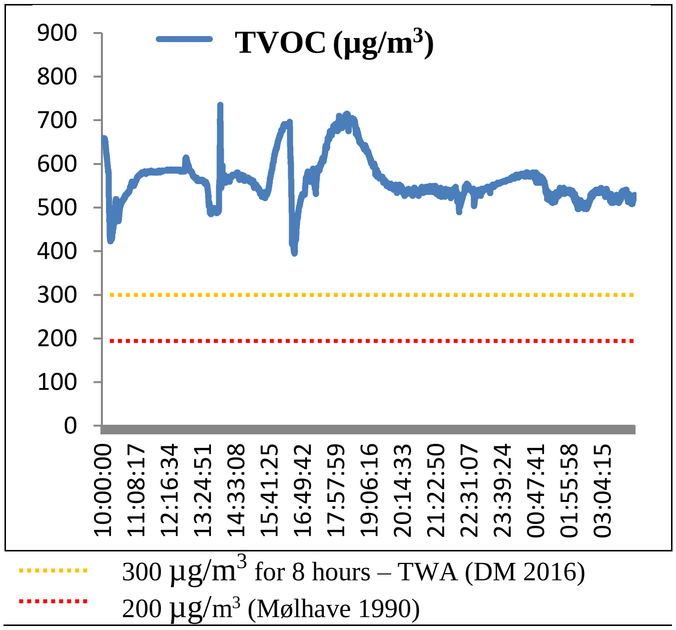


Figure ZZ-30: Compliance of indoor TVOC levels in House (6) with established standards

***House (7)***

Table ZZ-19: Levels of continuously measured variables indoor House (7)

| | **TVOC (µg/m³)** | **CO₂ (ppm)** | **CO (ppm)** | **PM2.5 (µg/m³)** | **PM10 (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 223.1 | 442.0 | 0.0 | 59.0 | 86.8 | 24.1 | 24.8 |
| **Mean** | 705.0 | 655.4 | 1.6 | 102.5 | 174.6 | 27.2 | 32.4 |
| **Max** | 11249.3 | 1306.0 | 14.6 | 242.6 | 921.2 | 29.1 | 42.3 |

Table ZZ-20: Levels of spot measured variables in outdoor air of House (7)

| | **TVOC (µg/m³)** | **CO₂ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 172.5 | 408 | 1.2 | 36.0 | 33.3 |

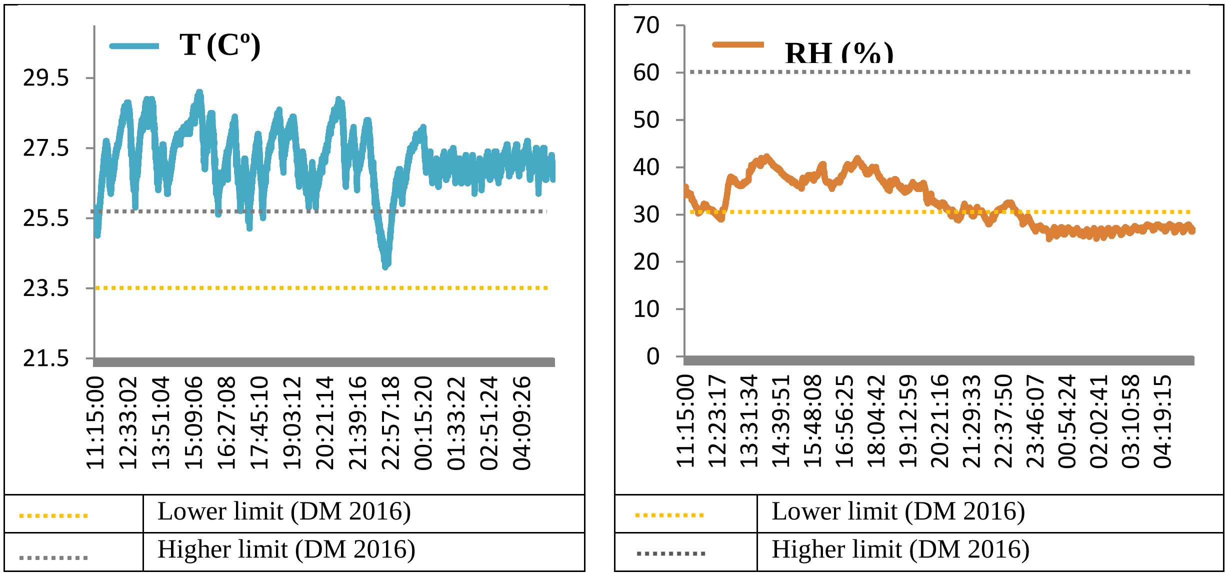


Figure ZZ-31: Continuously measured indoor levels of T and RH in House (7)

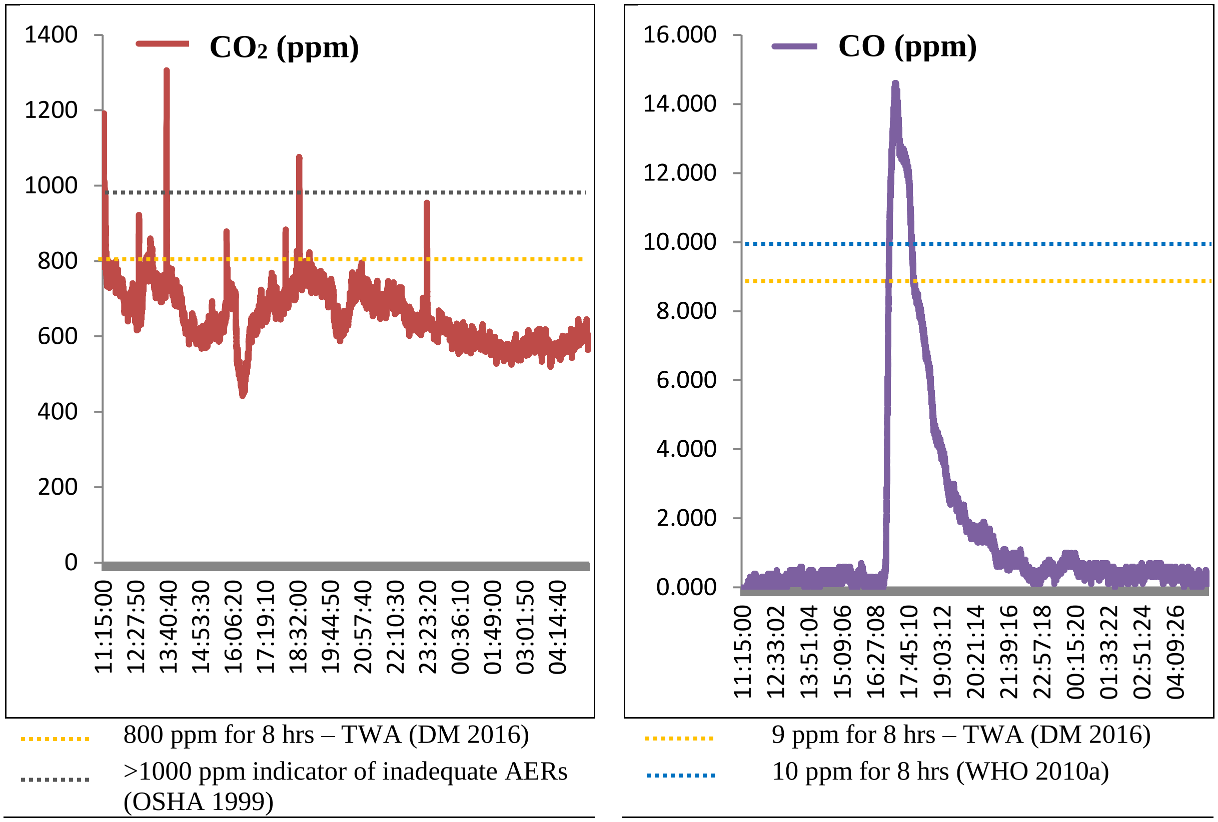


Figure ZZ-32: Compliance of $CO_2$ and CO levels in House (7) with established standards

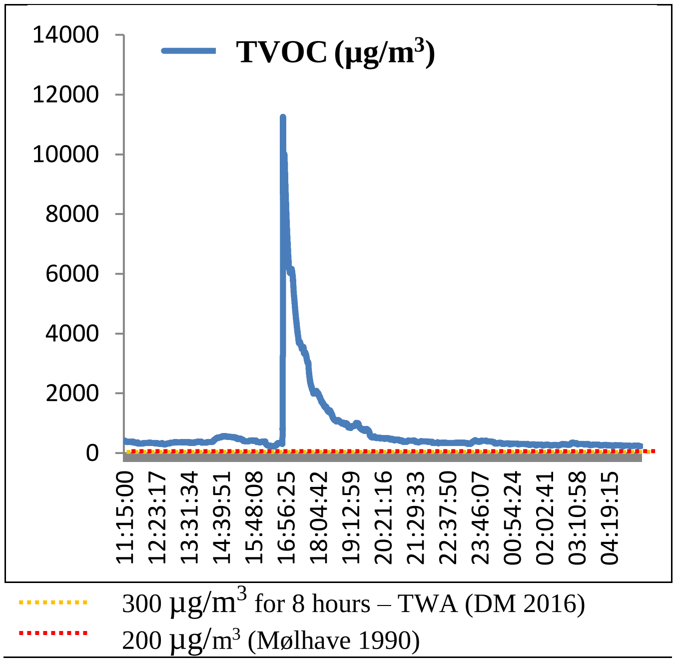


Figure ZZ-33: Compliance of indoor TVOC levels in House (7) with established standards

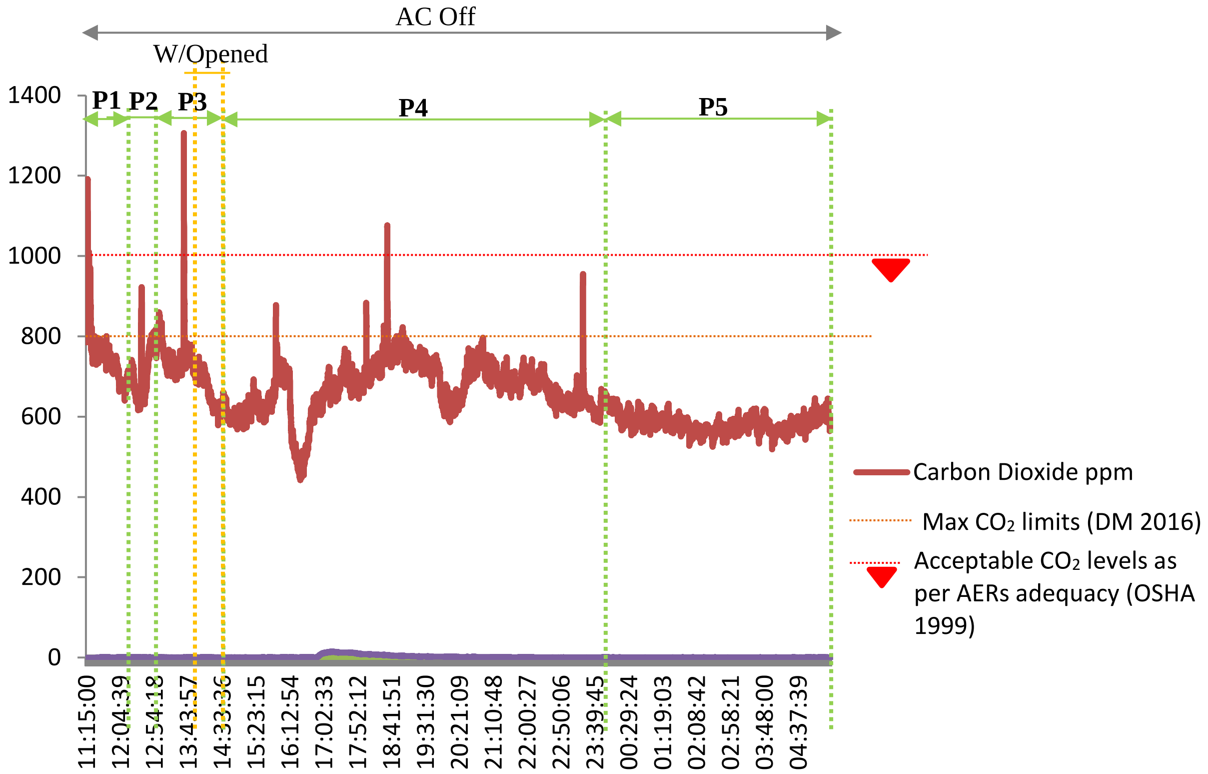


Figure ZZ-34: Occupancy profiles of the living hall projected on $CO_2$ levels (House 7)

Table ZZ-21: Occupancy profiles of the living hall during measurement period (House 7)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 11:15 – 12:15 | 6 | Natural (Infiltration) | Cleaning, cooking, sitting, breakfast |
| **P2** | 12:15 – 13:00 | 4 | Natural (Infiltration) | Cleaning, cooking, sitting |
| **P3** | 13:00 – 14:30 | 5 | Mixed:<br>13:00 – 14:00 Natural (Infiltration)<br>14:00 – 14:30 Natural (Window & Infiltration) | Cleaning, cooking, sitting |
| **P4** | 14:30 – 00:00 | 6 | Natural (Infiltration) | Cleaning, cooking, sitting, lunch, dinner |
| **P4** | 00:00 – 05:27 | 0 | Natural (Infiltration) | 6 persons sleeping in other rooms |

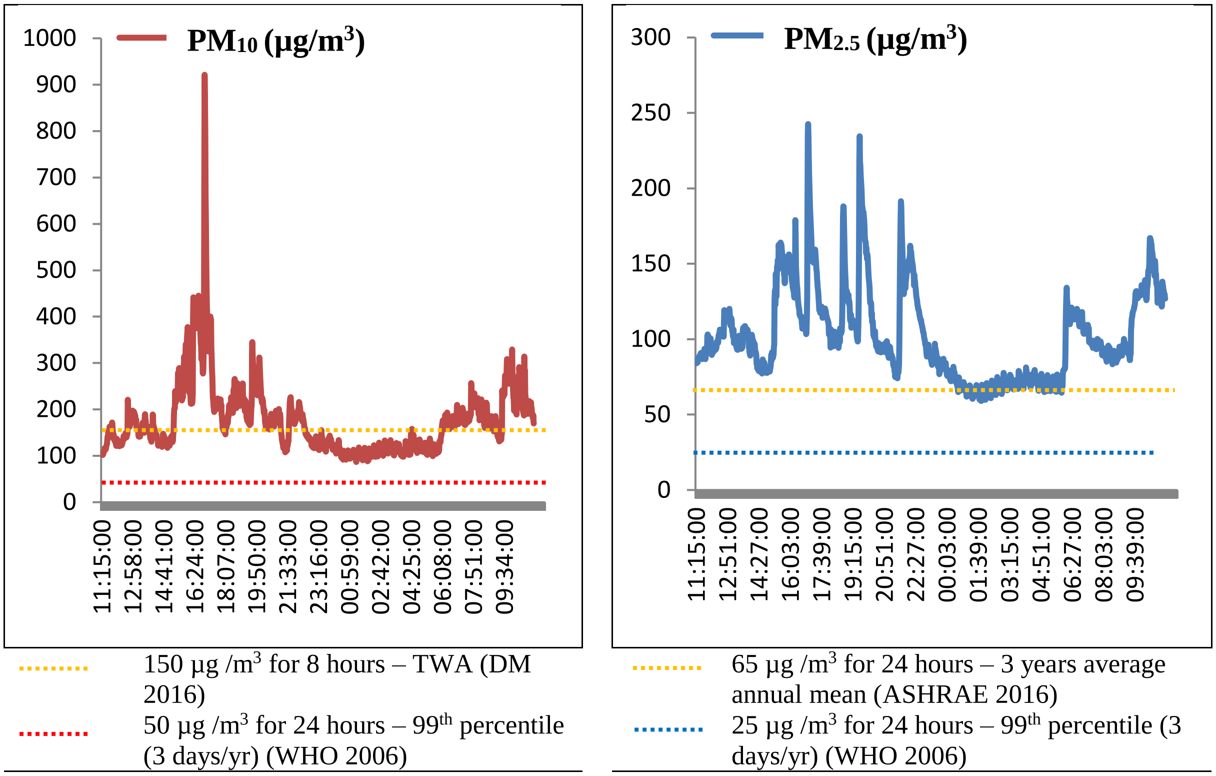


Figure ZZ-35: Compliance of PM$_{10}$ and PM$_{2.5}$ levels with established standards (House 7)

### *House (8)*

Table ZZ-22: Levels of continuously measured variables indoor House (8)

| | **TVOC (µg/m$^3$)** | **CO$_2$ (ppm)** | **CO (ppm)** | **PM$_{2.5}$ (µg/m$^3$)** | **PM$_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 779.7 | 904.0 | 1.5 | 107.0 | 114.1 | 24.6 | 34.8 |
| **Mean** | 1149.3 | 1390.3 | 3.6 | 1307.2 | 1369.3 | 27.8 | 40.0 |
| **Max** | 2001.0 | 1984.0 | 12.3 | 7610.6 | 9456.6 | 29.4 | 55.6 |

Table ZZ-23: Spot measured variables in outdoor air of House (8)

| | **TVOC (µg/m$^3$)** | **CO$_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 354.2 | 555.0 | 2.2 | 30.7 | 58.3 |

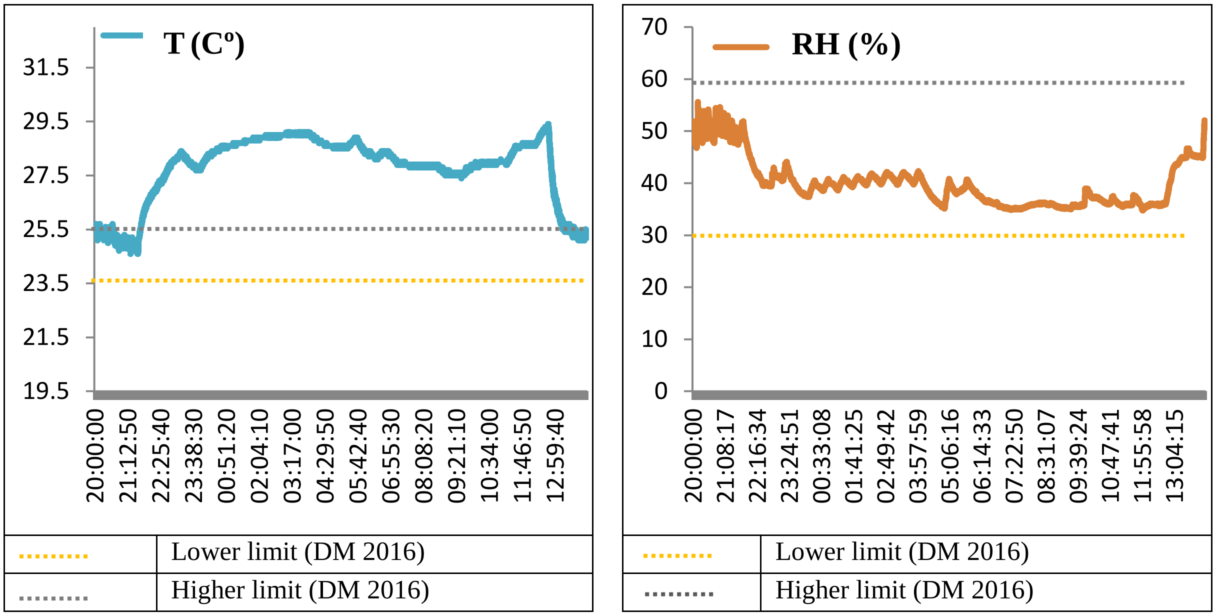


Figure ZZ-36: Continuously measured indoor levels of T and RH in House (8)

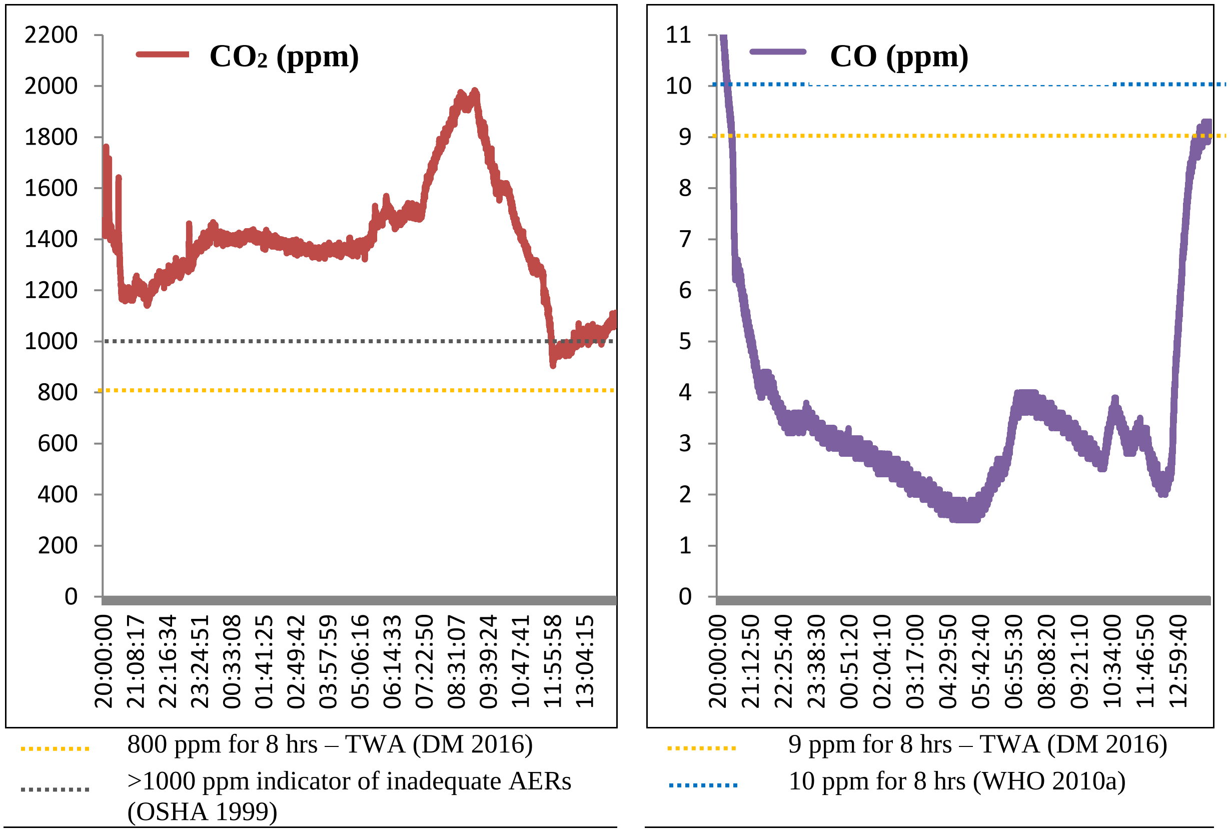


Figure ZZ-37: Compliance of $CO_2$ and CO levels in House (8) with established standards

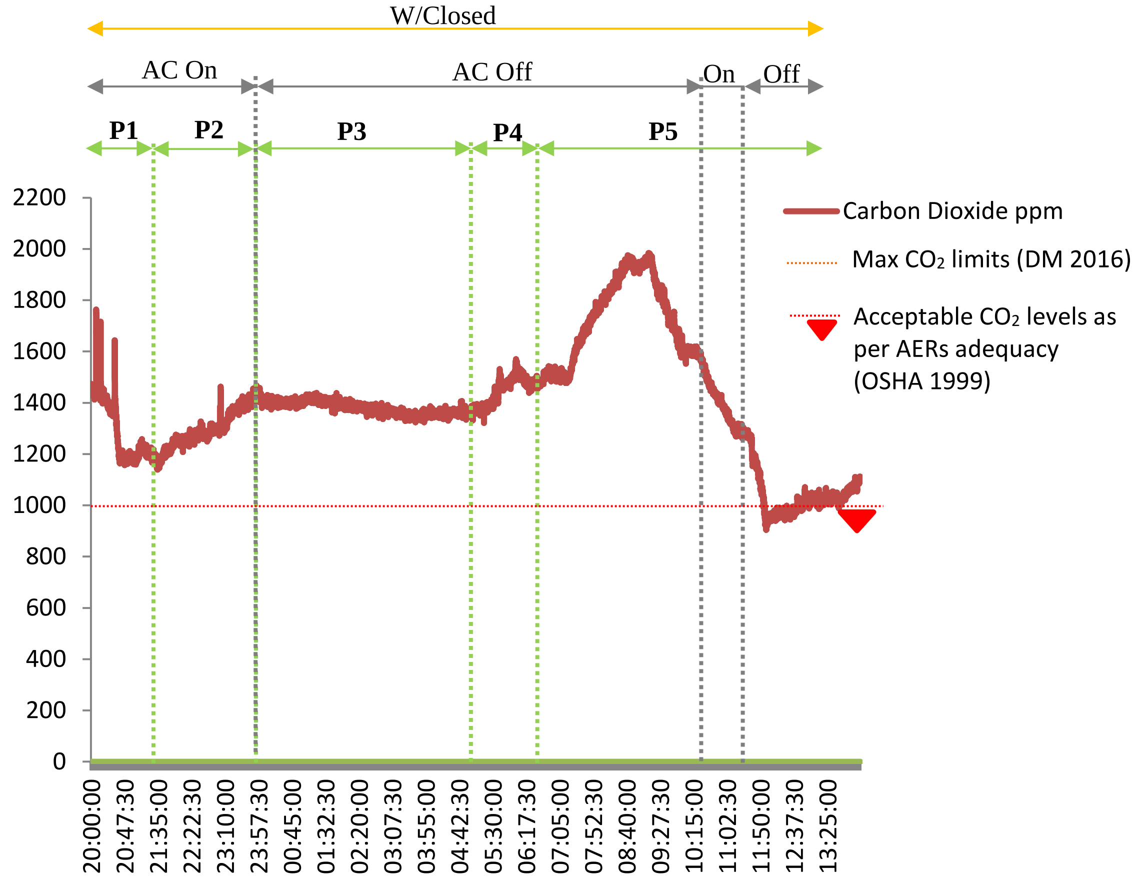
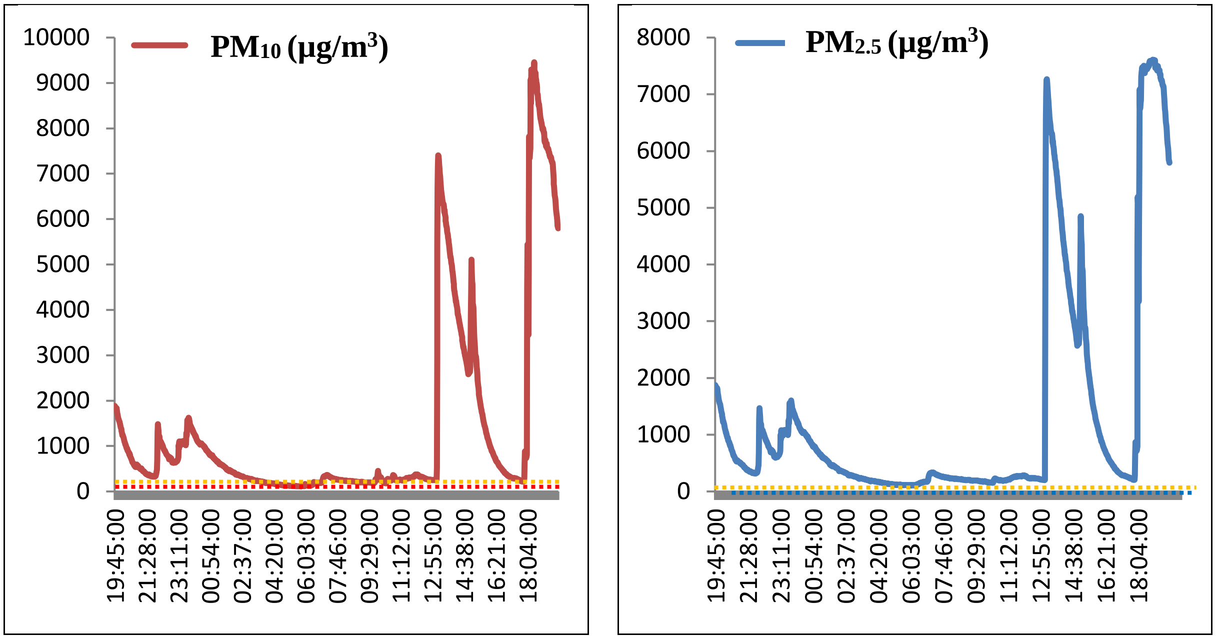


Figure ZZ-38: Occupancy profiles of the living hall projected on $CO_2$ levels (House 8)

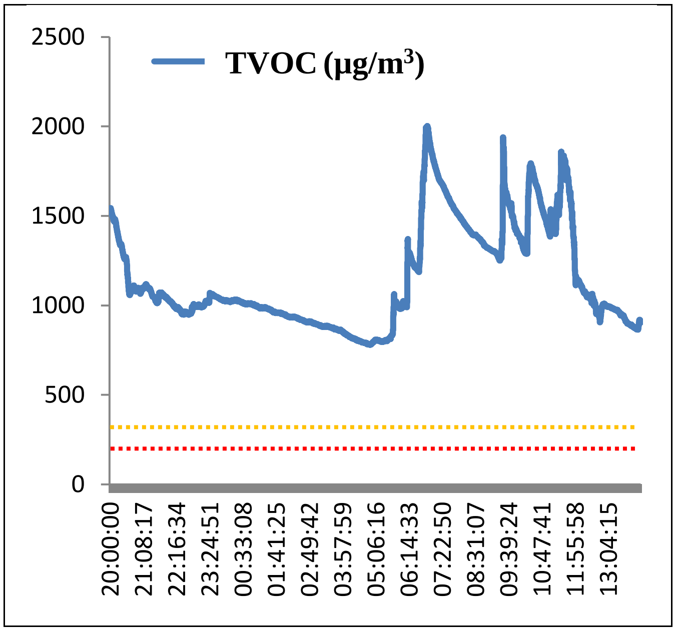
Table ZZ-24: Occupancy profiles of the living hall during measurement period (House 8)

| **Profile** | **Time** | **Occupants** | **System** | **Activities** |
|---|---|---|---|---|
| **P1** | 20:00 – 21:30 | 9 | Mechanical | Having visitors, cooking |
| **P2** | 21:30 – 00:00 | 3 | Mechanical | |
| **P3** | 00:00 – 05:15 | 0 | Natural (Infiltration) | Sleeping |
| **P4** | 05:15 – 07:05 | 7 | Natural (Infiltration) | Cooking |
| **P5** | 07:05 – 14:12 | 3 | Mixed:<br>07:05 – 11:00 Natural (Infiltration)<br>11:00 – 12:00 Mechanical<br>12:00 – 14:12 Natural (Infiltration) | Washing, cleaning, cooking |



| | | | |
|---|---|---|---|
| ⋯⋯ | 150 µg /m$^3$ for 8 hours – TWA (DM 2016) | ⋯⋯ | 65 µg /m$^3$ for 24 hours – 3 years average annual mean (ASHRAE 2016) |
| ⋯⋯ | 50 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) | ⋯⋯ | 25 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure ZZ-39: Compliance of $PM_{10}$ and $PM_{2.5}$ levels with established standards (House 8)



| | |
|---|---|
| ⋯⋯ | 300 µg/m$^3$ for 8 hours – TWA (DM 2016) |
| ⋯⋯ | 200 µg/m$^3$ (Mølhave 1990) |

Figure ZZ-40: Compliance of indoor TVOC levels in House (8) with established standards

***House (9)***

Table ZZ-25: Levels of continuously measured variables indoor House (9)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m$^3$)** | **$PM_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 294.4 | 554.0 | 0.2 | 46.7 | 49.9 | 26.1 | 22.3 |
| **Mean** | 484.3 | 812.6 | 1.3 | 906.9 | 933.4 | 30.5 | 26.9 |
| **Max** | 1777.9 | 1334.0 | 3.5 | 6121.0 | 6181.2 | 32.9 | 40.5 |

Table ZZ-26: Spot measured variables in outdoor air of House (9)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 255.3 | 459 | 1.3 | 31.2 | 75.1 |

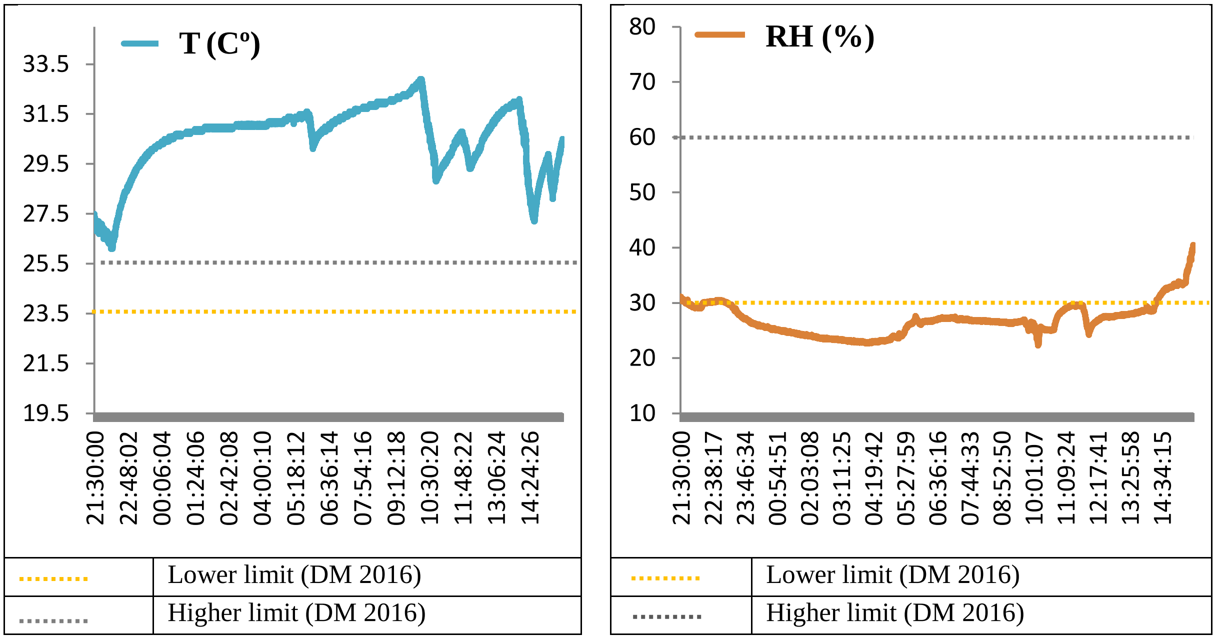


Figure ZZ-41: Continuously measured indoor levels of T and RH in House (9)

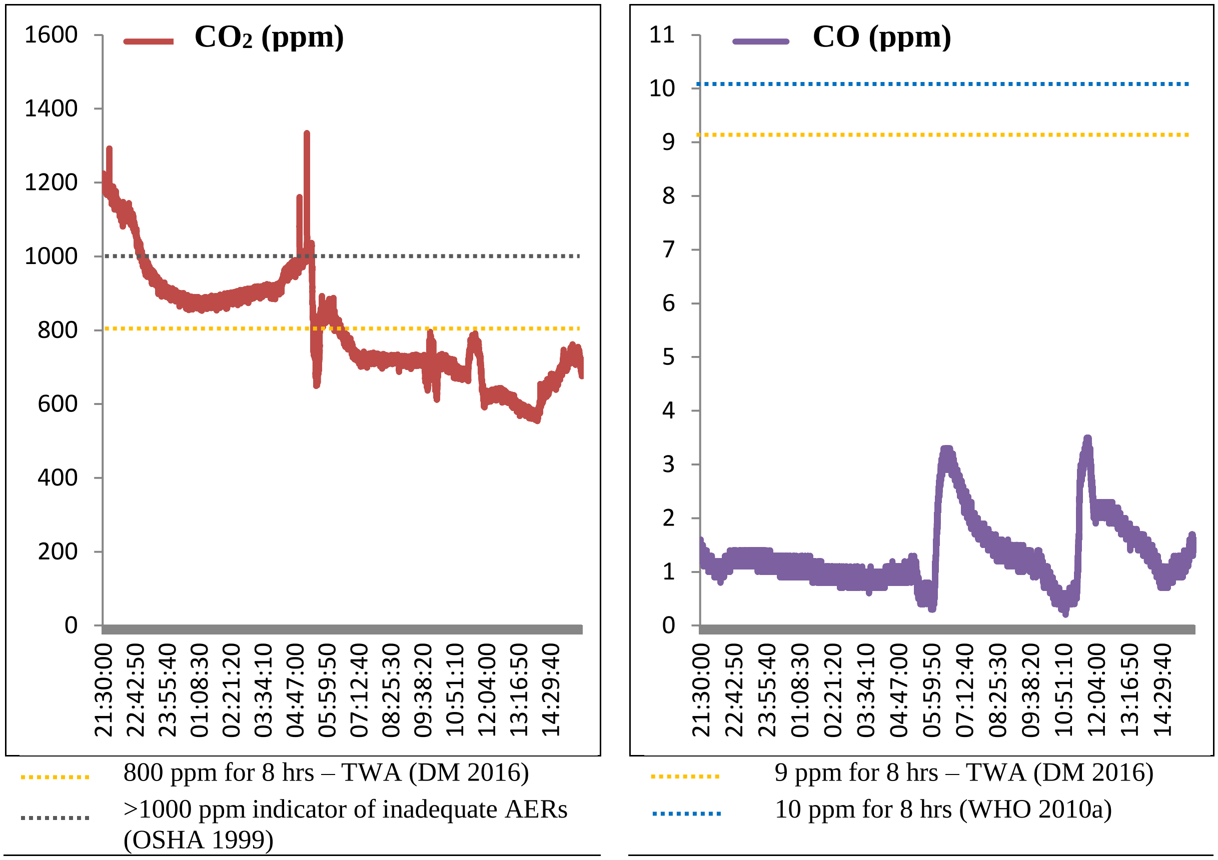


Figure ZZ-42: Compliance of $CO_2$ and CO levels in House (9) with established standards

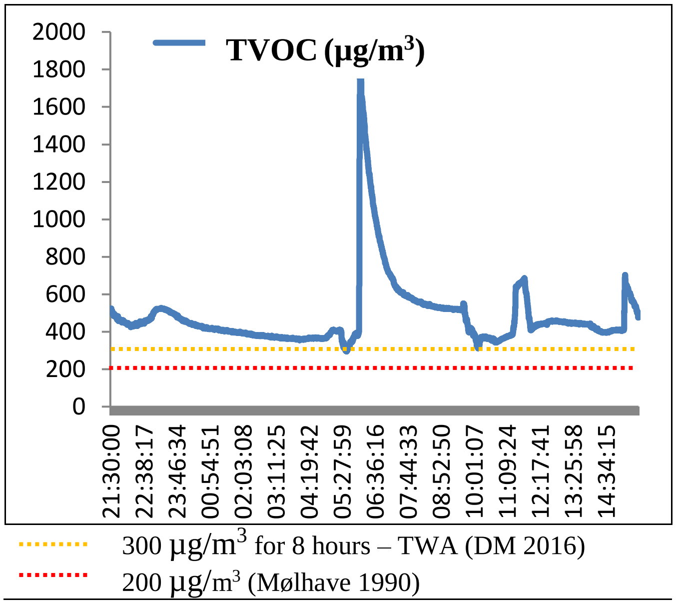


Figure ZZ-43: Compliance of indoor TVOC levels in House (9) with established standards

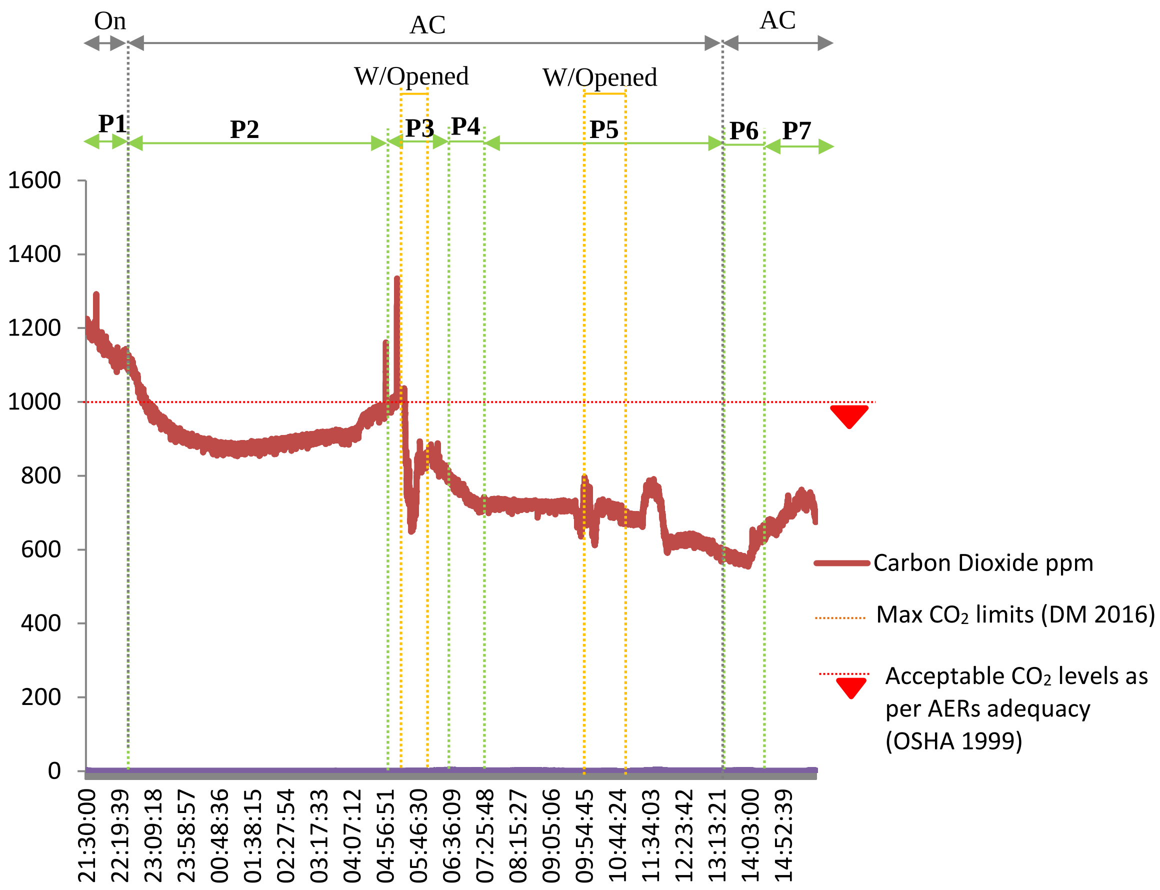
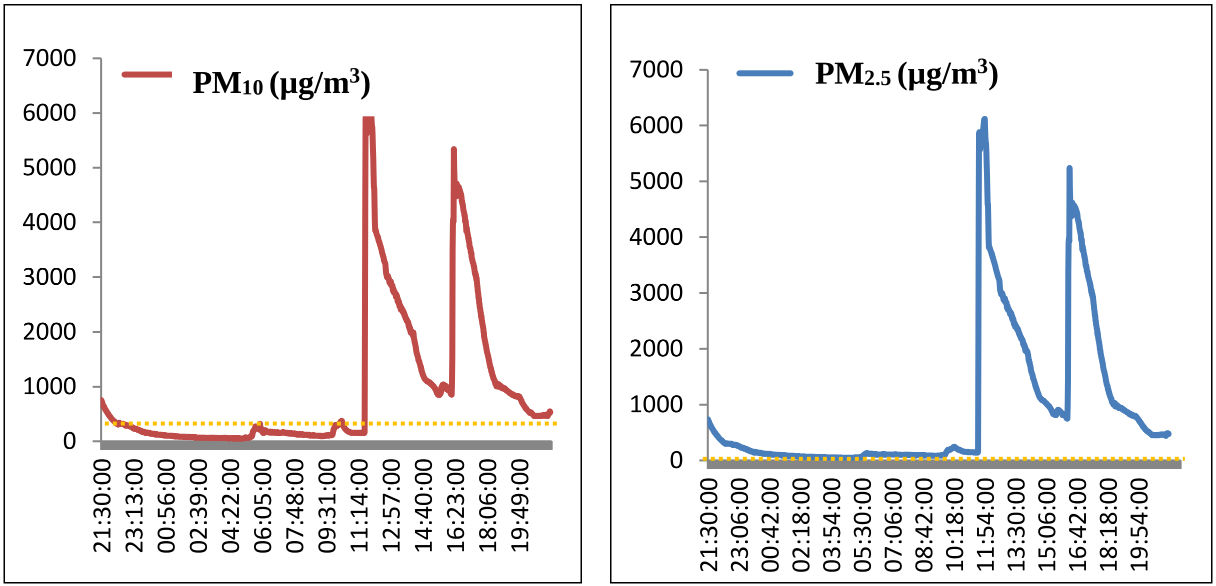


Figure ZZ-44: Occupancy profiles of the living hall projected on $CO_2$ levels (House 9)

Table ZZ-27: Occupancy profiles of the living hall during measurement period (House 9)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 21:30 – 22:30 | 5 | Mechanical | Sitting |
| **P2** | 22:30 – 05:15 | 0 | Natural (Infiltration) | Sleeping |
| **P3** | 05:15 – 06:30 | 4 | Natural:<br>05:15 – 04:45 Natural (Infiltration)<br>04:45 – 06:00 Natural (Window)<br>06:00 – 06:30 Natural (Infiltration) | Cooking |
| **P4** | 06:30 – 07:30 | 0 | Natural (Infiltration) | Went outside |
| **P5** | 07:30 – 13:30 | 1 | Natural:<br>07:30 – 10:00 Natural (Infiltration)<br>10:00 – 11:00 Natural (Window)<br>11:00 – 13:30 Natural (Infiltration) | Cleaning, cooking, sitting |
| **P6** | 13:30 – 14:30 | 0 | Natural (Infiltration) | Went outside |
| **P7** | 14:30 – 16:00 | 5 | Mechanical | Sitting, lunch |



| | | | |
|---|---|---|---|
| ……… | 150 µg /m$^3$ for 8 hours – TWA (DM 2016) | ……… | 65 µg /m$^3$ for 24 hours – 3 years average annual mean (ASHRAE 2016) |
| ……… | 50 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) | ……… | 25 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure ZZ-45: Compliance of PM$_{10}$ and PM$_{2.5}$ levels with established standards (House 9)

### *House (10)*

Table ZZ-28: Levels of continuously measured variables indoor House (10)

| | **TVOC (µg/m$^3$)** | **CO$_2$ (ppm)** | **CO (ppm)** | **PM$_{2.5}$ (µg/m$^3$)** | **PM$_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 61.0 | 466.5 | 0.1 | 490.6 | 549.3 | 21.3 | 42.5 |
| **Mean** | 174.3 | 551.2 | 0.6 | 938.2 | 1027.9 | 25.0 | 53.9 |
| **Max** | 475.0 | 1029.0 | 2.0 | 1463.8 | 1687.3 | 27.7 | 61.4 |

Table ZZ-29: Spot measured variables in outdoor air of House (10)

| | **TVOC (µg/m$^3$)** | **CO$_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 120.75 | 444.5 | 1.65 | 24.3 | 52.35 |

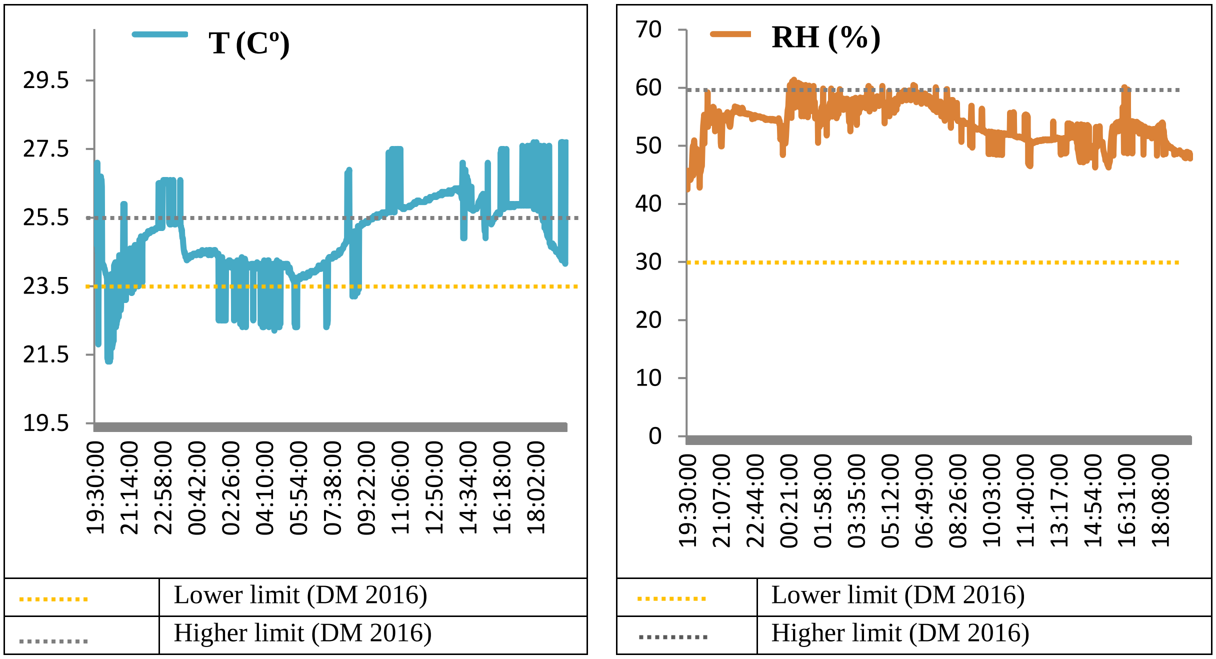


Figure ZZ-46: Continuously measured indoor levels of T and RH in House (10)

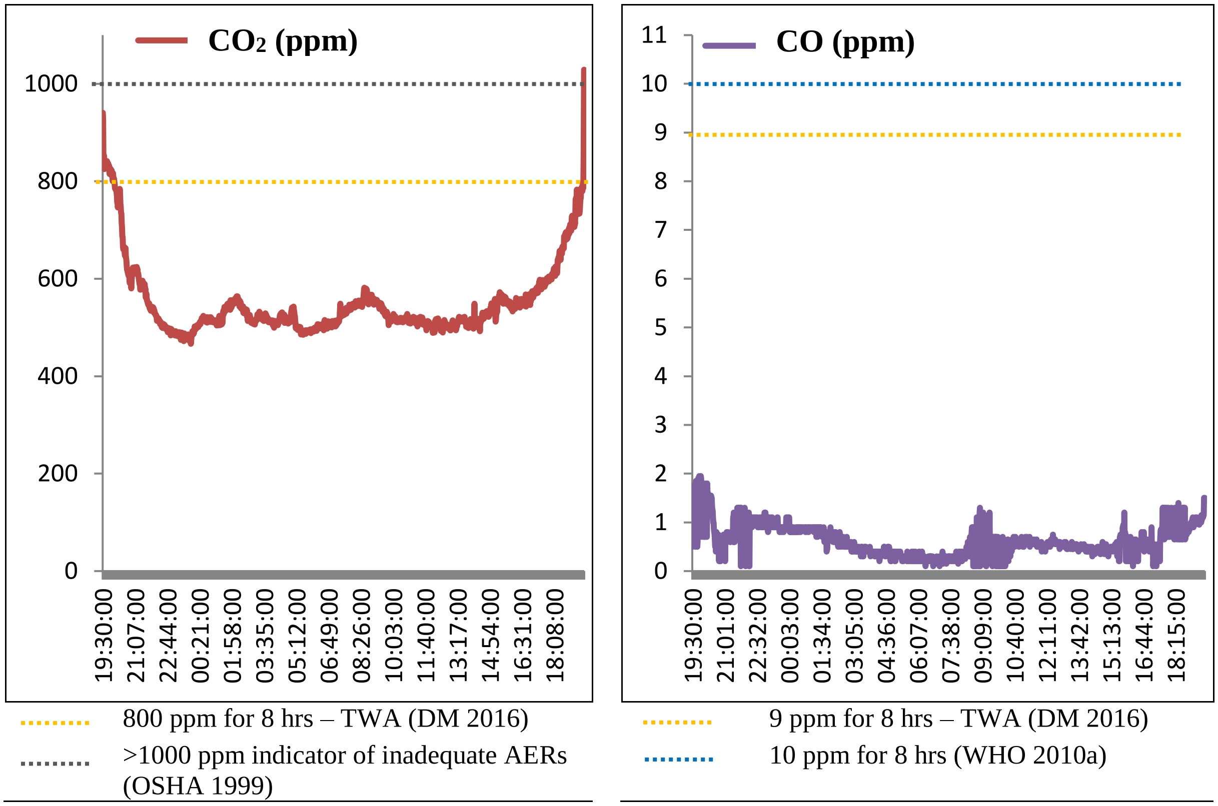


Figure ZZ-47: Compliance of $CO_2$ and CO levels in House (10) with established standards

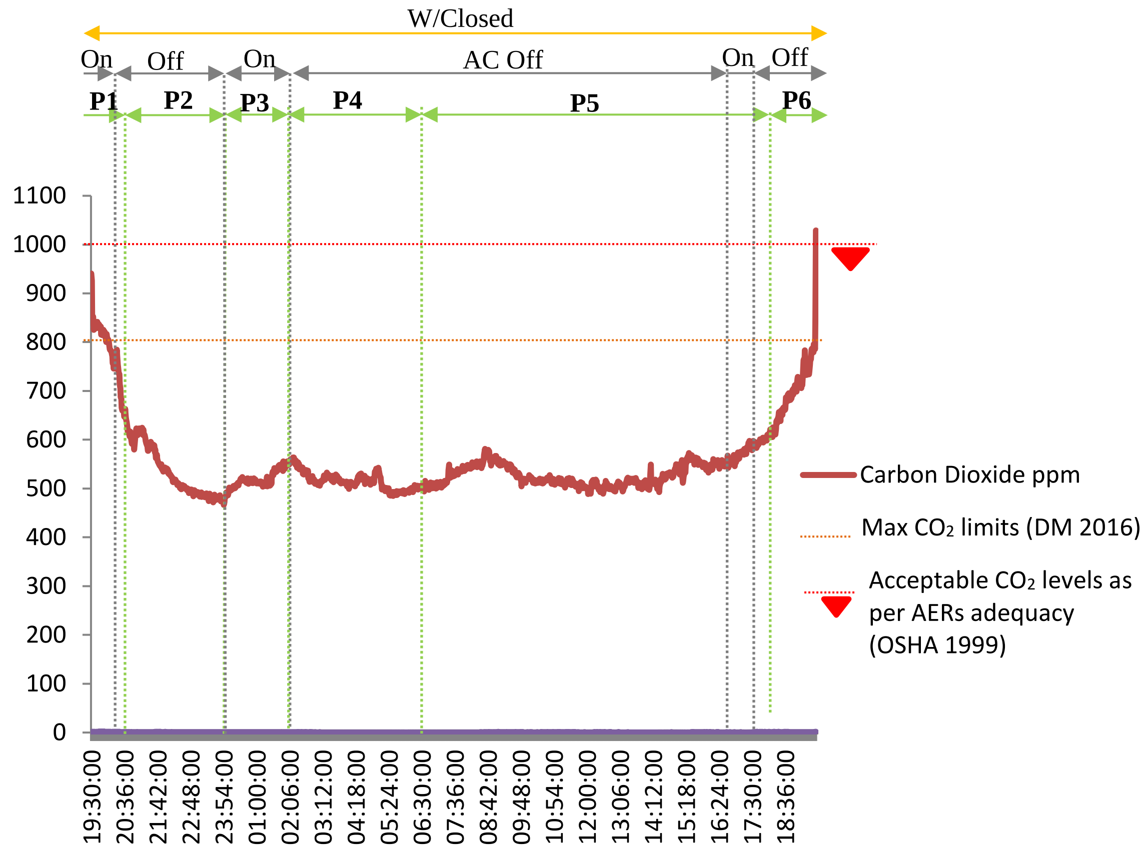


Figure ZZ-48: Occupancy profiles of the living hall projected on $CO_2$ levels (House 10)

Table ZZ-30: Occupancy profiles of the living hall during measurement period (House 10)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 19:30 – 20:40 | 3 | Mixed:<br>19:30 – 20:15 Mechanical<br>20:15 – 20:40 Natural (Infiltration) | Having a visitor |
| **P2** | 20:40 – 12:00 | 0 | Natural (Infiltration) | Went outside |
| **P3** | 12:00 – 02:00 | 2 | Mechanical | Sitting |
| **P4** | 02:00 – 06:30 | 0 | Natural (Infiltration) | 2 persons in other rooms |
| **P5** | 06:30 – 18:00 | 1 | Mixed:<br>06:30 – 16:45 Natural (Infiltration)<br>16:45 – 17:30 Mechanical<br>17:30 – 18:00 Natural (Infiltration) | Sitting/ cooking |
| **P6** | 18:00 – 19:40 | 2 | Natural (Infiltration) | Sitting/ dinner |

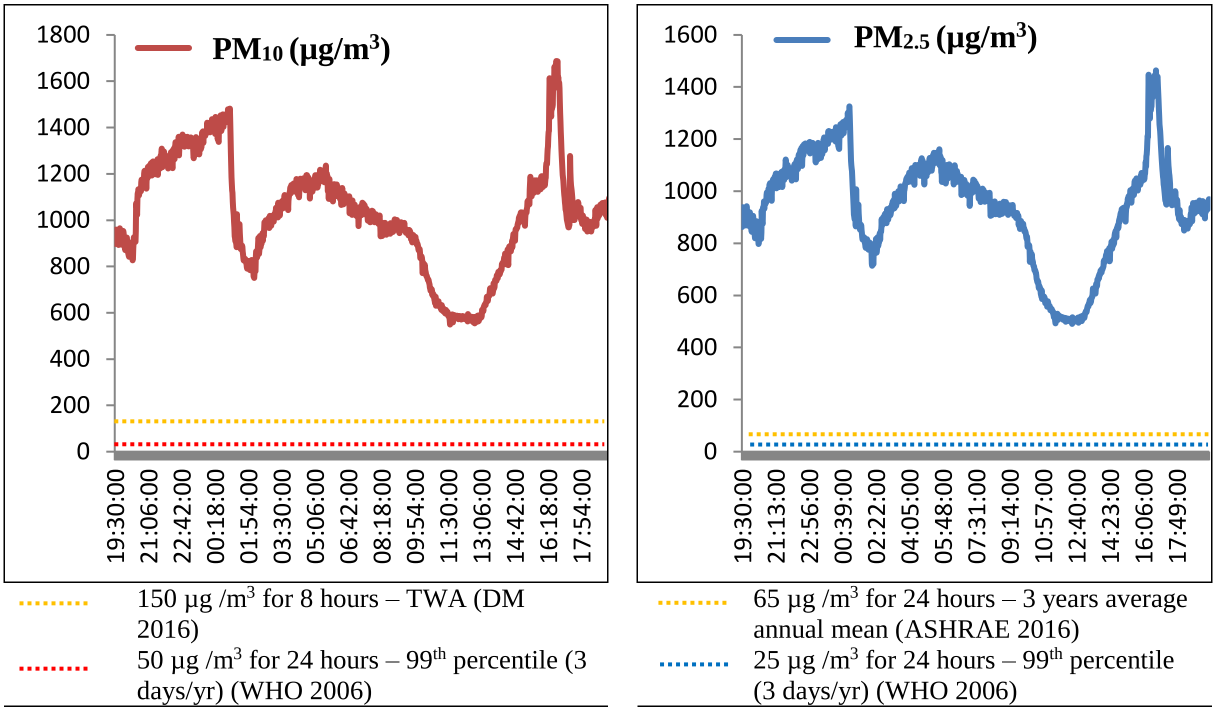


Figure ZZ-49: Compliance of $PM_{10}$ and $PM_{2.5}$ levels with established standards (House 10)

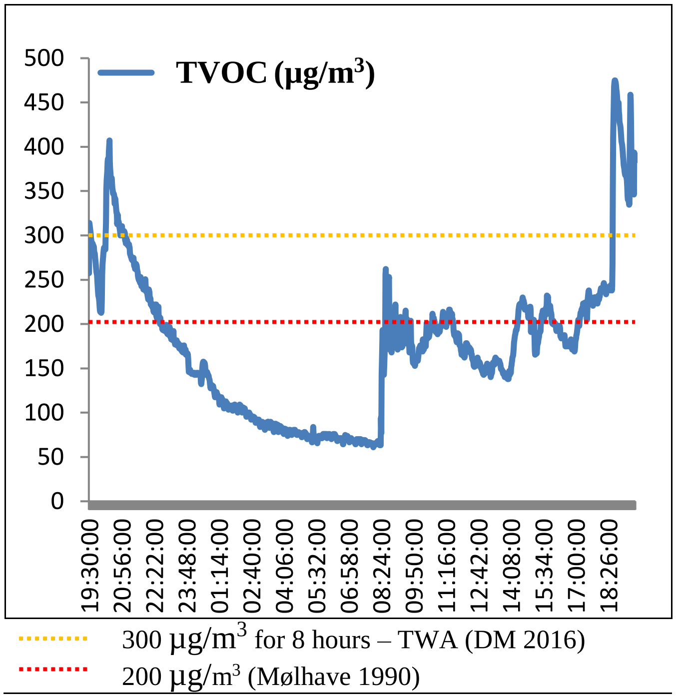


Figure ZZ-50: Compliance of indoor TVOC levels with established standards (House 10)

## ***House (11)***

Table ZZ-31: Levels of continuously measured variables indoor House (11)

| | **TVOC ($\mu g/m^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ ($\mu g/m^3$)** | **$PM_{10}$ ($\mu g/m^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 193.2 | 457.0 | 0.2 | 504.2 | 564.4 | 22.1 | 37.8 |
| **Mean** | 271.1 | 812.8 | 0.9 | 863.7 | 940.4 | 23.3 | 45.7 |
| **Max** | 680.8 | 1883.0 | 1.8 | 1127.0 | 1211.0 | 25.1 | 55.3 |

Table ZZ-32: Spot measured variables in outdoor air of House (11)

| | **TVOC ($\mu g/m^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 106 | 459 | 8.6 | 29.8 | 93.1 |

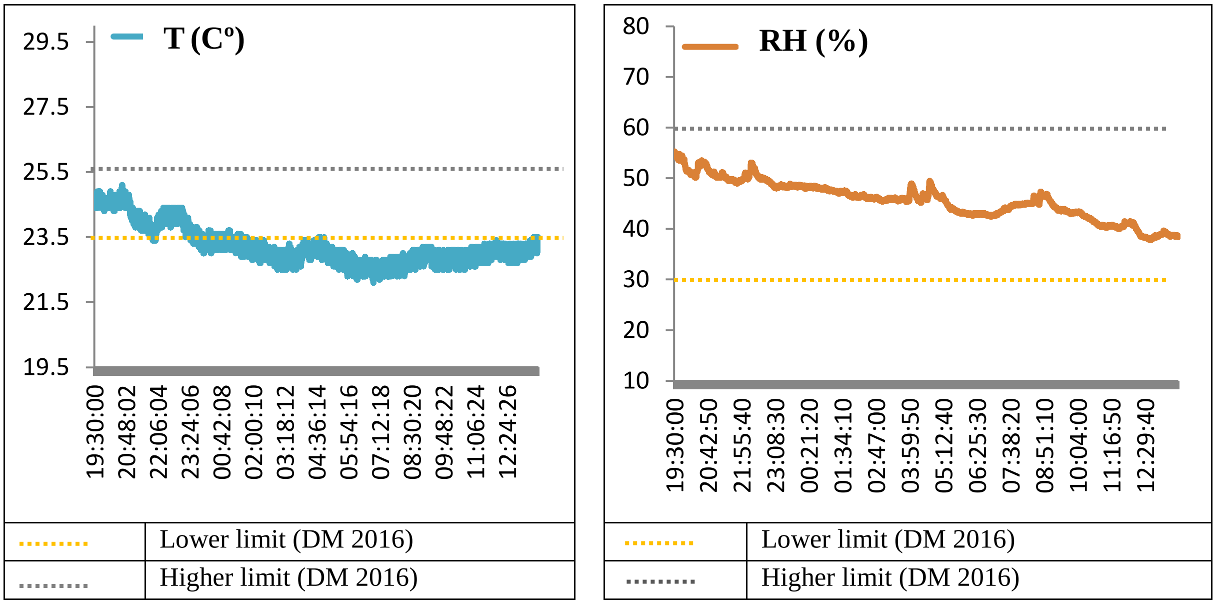


Figure ZZ-51: Continuously measured indoor levels of T and RH in House (11)

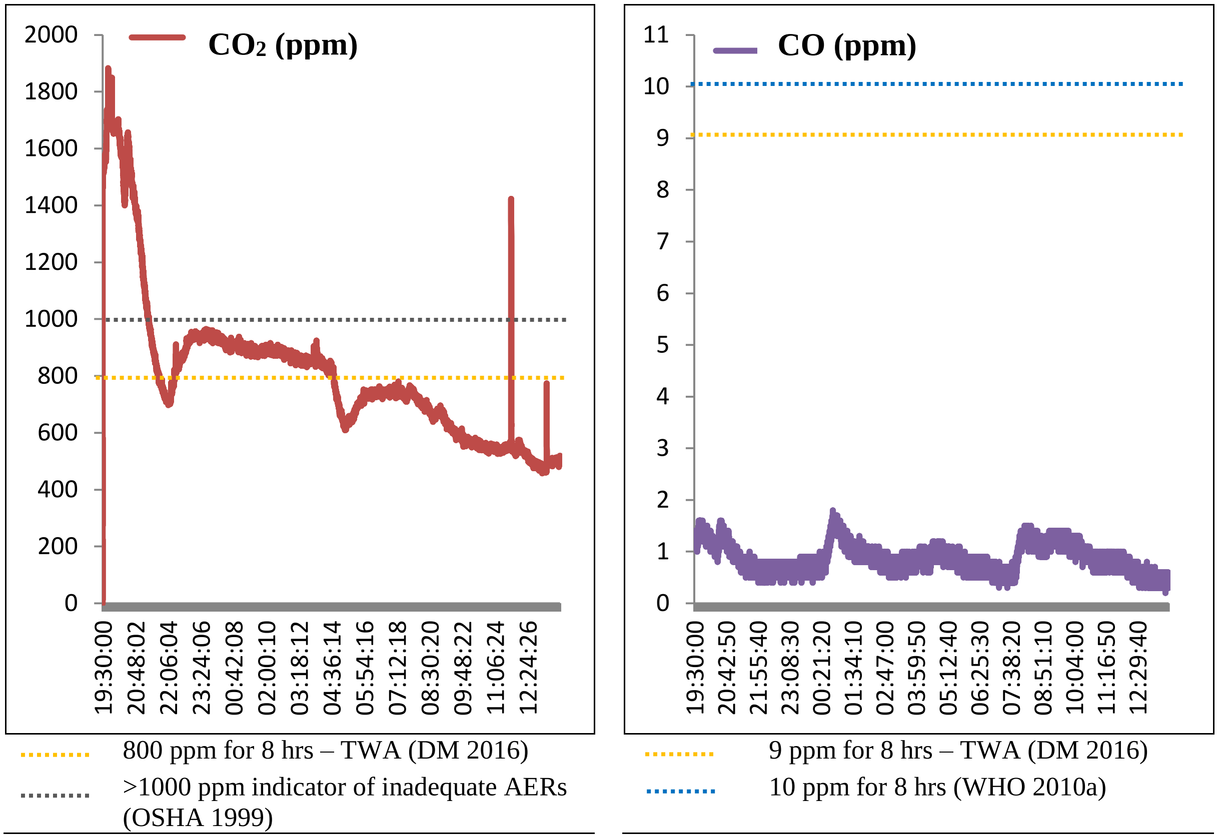


Figure ZZ-52: Compliance of $CO_2$ and CO levels in House (11) with established standards

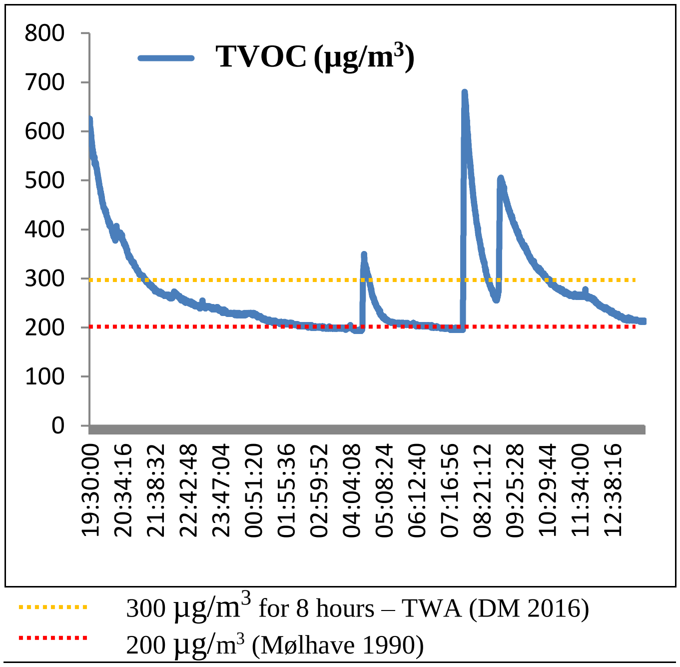


Figure ZZ-53: Compliance of indoor TVOC levels with established standards (House 11)

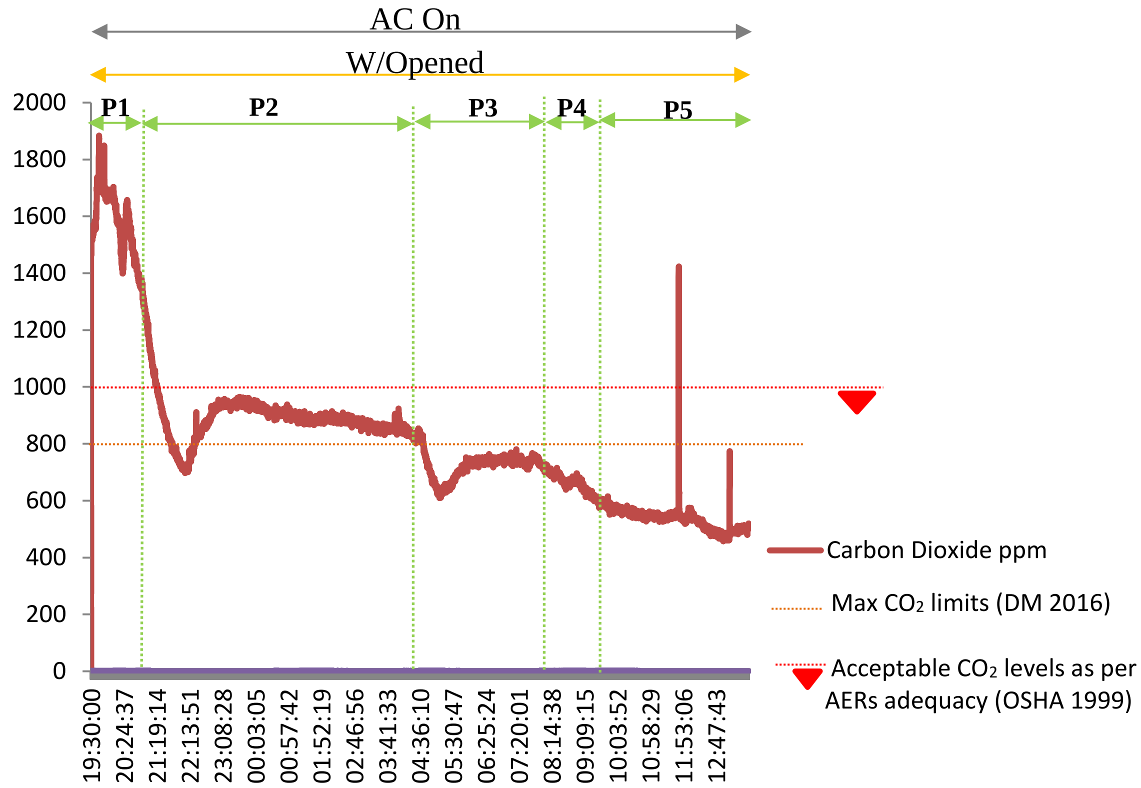


Figure ZZ-54: Occupancy profiles of the living hall projected on $CO_2$ levels (House 11)

Table ZZ-33: Occupancy profiles of the living hall during measurement period (House 11)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 19:30 – 20:50 | 5 | Mixed: Mechanical & natural | Having visitors |
| **P2** | 20:50 – 04:29 | 4 | Mixed: Mechanical & natural | Sleeping |
| **P3** | 04:29 – 08:00 | 3 | Mixed: Mechanical & natural | |
| **P4** | 08:00 – 09:30 | 2 | Mixed: Mechanical & natural | |
| **P5** | 09:30 – 15:30 | 1 | Mixed: Mechanical & natural | |

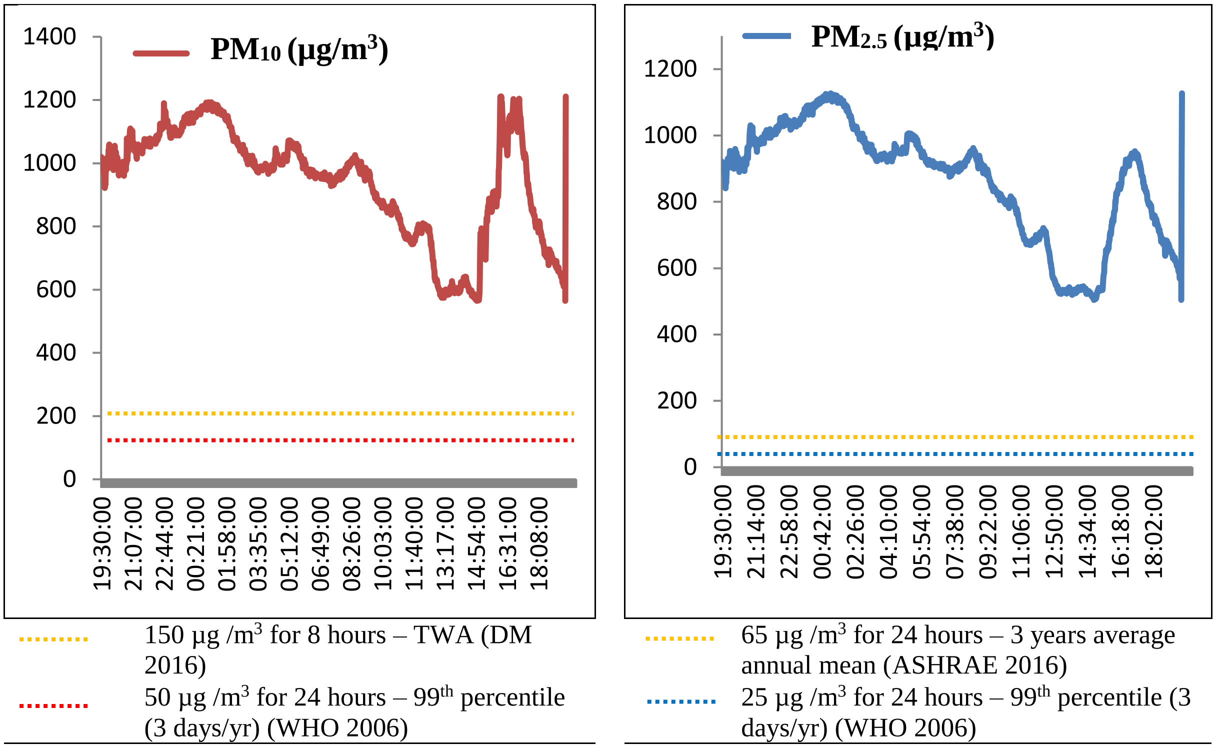


Figure ZZ-55: Compliance of $PM_{10}$ and $PM_{2.5}$ levels with established standards (House 11)

## *House 12*

Table ZZ-34: Levels of continuously measured variables indoor House (12)

|  | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 423.2 | 662.0 | 1.1 | 268.8 | 277.3 | 28.7 | 27.0 |
| **Mean** | 737.2 | 884.4 | 2.4 | 390.5 | 425.5 | 33.4 | 37.7 |
| **Max** | 1460.5 | 1198.0 | 3.7 | 870.9 | 988.1 | 34.3 | 47.1 |

Table ZZ-35: Spot measured variables in outdoor air of House (12)

|  | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 237 | 496 | 1.9 | 33.8 | 69.3 |

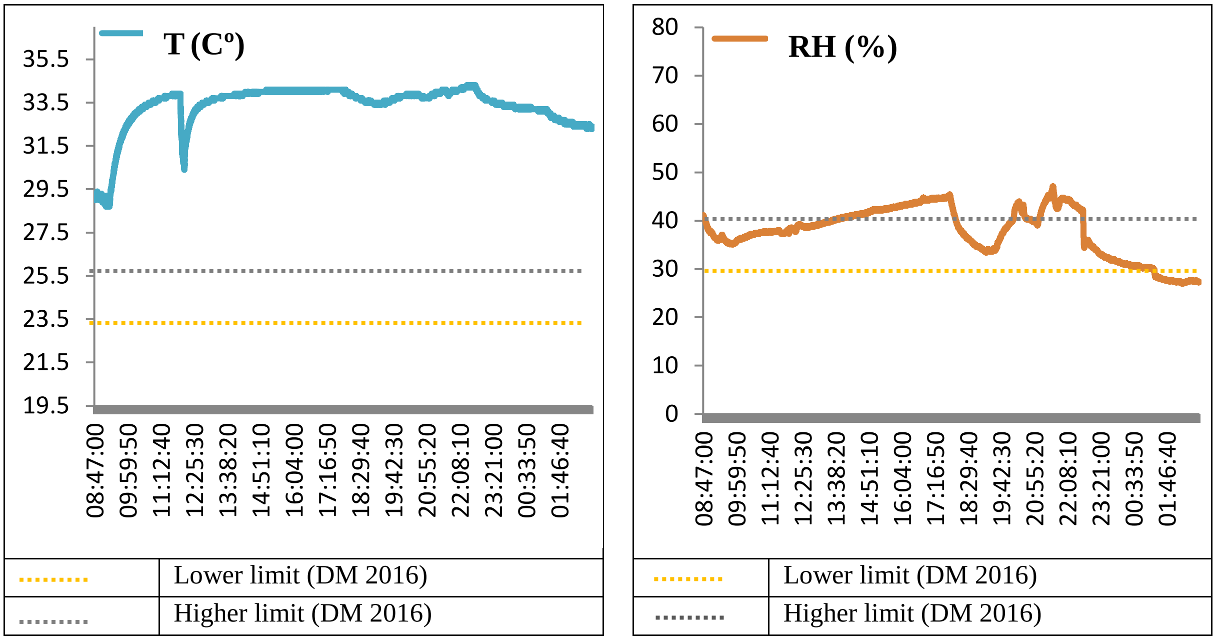


Figure ZZ-56: Continuously measured indoor levels of T and RH in House (12)

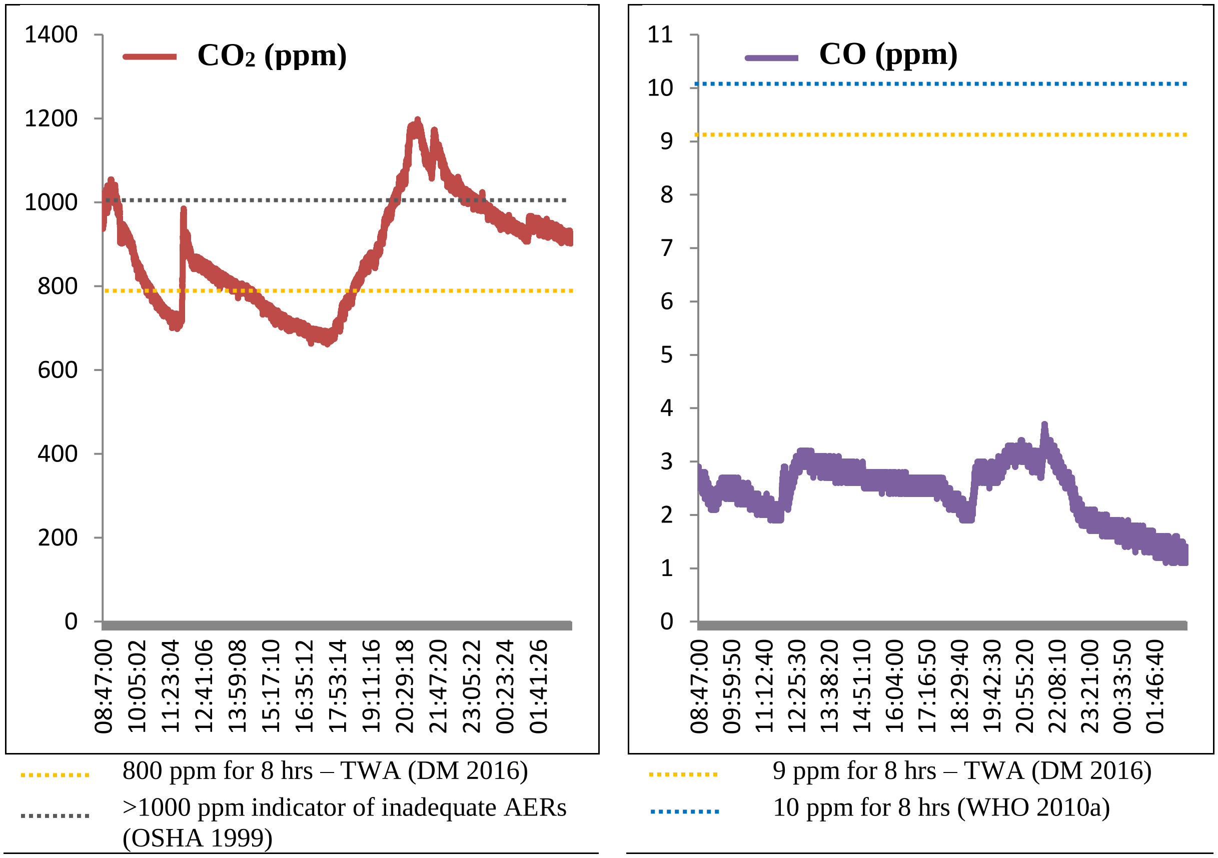


Figure ZZ-57: Compliance of $CO_2$ and CO levels in House (12) with established standards

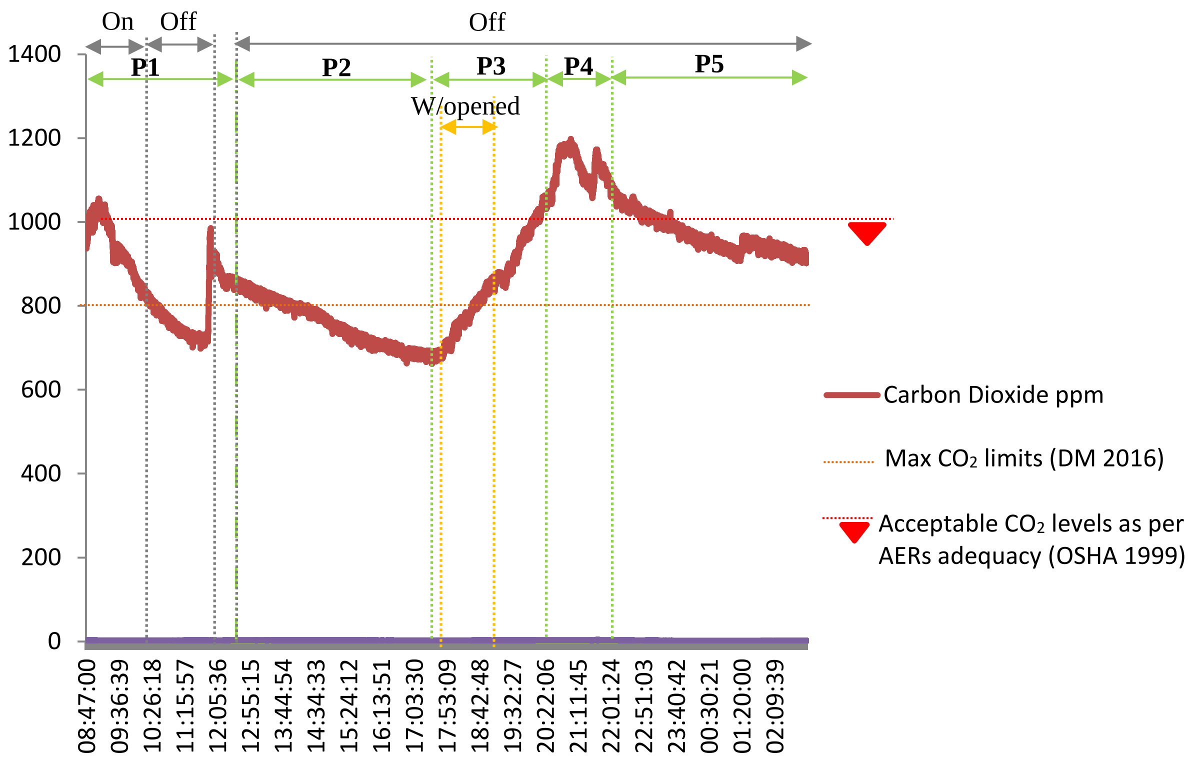
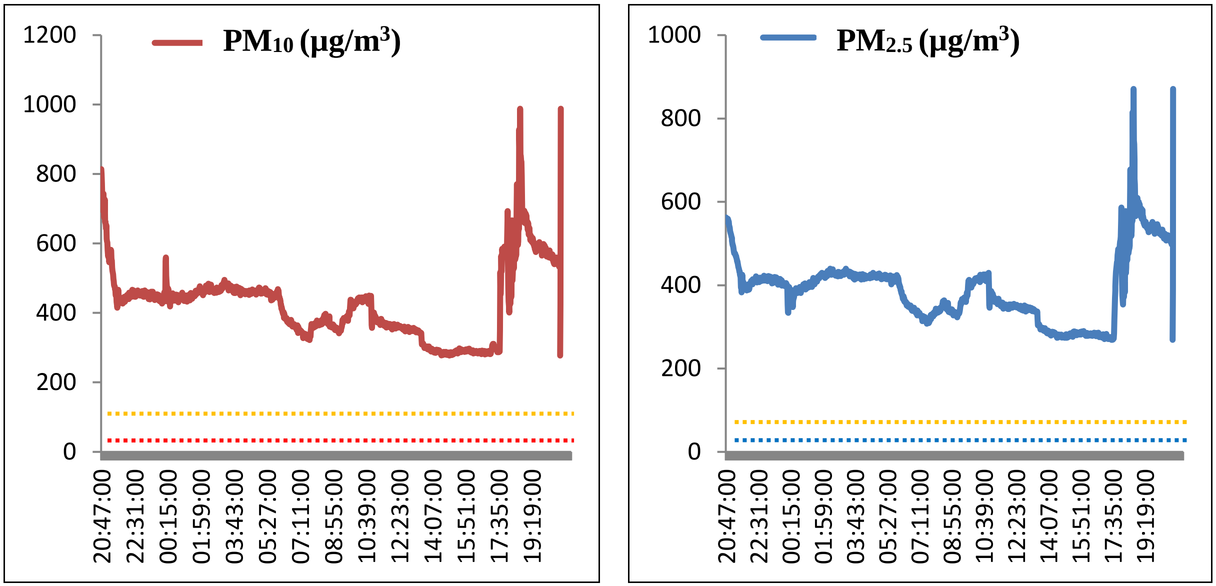


Figure ZZ-58: Occupancy profiles of the living hall projected on $CO_2$ levels (House 12)

Table ZZ-36: Occupancy profiles of the living hall during measurement period (House 12)

| **Profile** | **Time** | **Occupants** | **System** | **Activities** |
|---|---|---|---|---|
| **P1** | 08:47 – 12:30 | 1 | Mixed:<br>08:47 – 10:15 Mechanical<br>10:15 – 12:00 Natural (Infiltration)<br>12:00 – 12:30 Mechanical | Cooking, cleaning |
| **P2** | 12:30 – 17:30 | 0 | Natural (Infiltration) | 1 occupant in other room |
| **P3** | 17:30 – 20:20 | 3 | Natural:<br>17:30 – 17:45 Natural (Infiltration)<br>17:45 – 19:00 Natural (Window)<br>19:00 – 20:20 Natural (Infiltration) | Cooking<br>Sitting |
| **P4** | 20:20 – 22:15 | 4 | Natural (Infiltration) | Cooking |
| **P5** | 22:15 – 02:59 | 0 | Mixed: Mechanical & natural | Sleeping in another room |



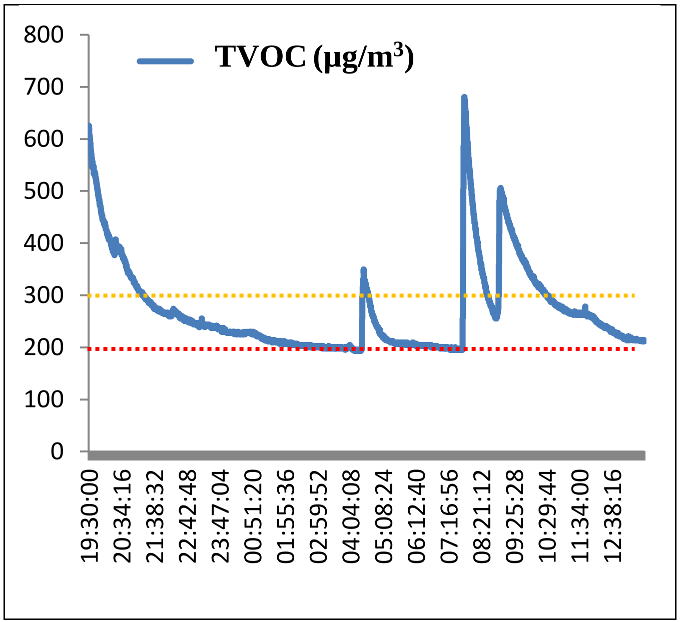
┈┈ 150 µg /m³ for 8 hours – TWA (DM 2016)

┈┈ 50 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006)

┈┈ 65 µg /m³ for 24 hours – 3 years average annual mean (ASHRAE 2016)

┈┈ 25 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006)

Figure ZZ-59: Compliance of $PM_{10}$ and $PM_{2.5}$ levels with established standards (House 12)



┈┈ 300 µg/m³ for 8 hours – TWA (DM 2016)

┈┈ 200 µg/m³ (Mølhave 1990)

Figure ZZ-60: Compliance of indoor TVOC levels with established standards (House 12)

### *House (13)*

Table ZZ-37: Levels of continuously measured variables indoor House (13)

| | **TVOC (μg/$m^3$)** | **CO$_2$ (ppm)** | **CO (ppm)** | **PM$_{2.5}$ (μg/$m^3$)** | **PM$_{10}$ (μg/$m^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 439.3 | 604.0 | 1.0 | 104.5 | 114.1 | 24.8 | 47.6 |
| **Mean** | 580.7 | 754.5 | 1.7 | 206.4 | 284.1 | 25.3 | 51.3 |
| **Max** | 1159.2 | 1861.0 | 3.1 | 480.1 | 746.8 | 26.2 | 56.6 |

Table ZZ-38: Spot measured variables in outdoor air of House (13)

| | **TVOC (μg/$m^3$)** | **CO$_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 369.2 | 524.0 | 1.2 | 24.1 | 50.2 |

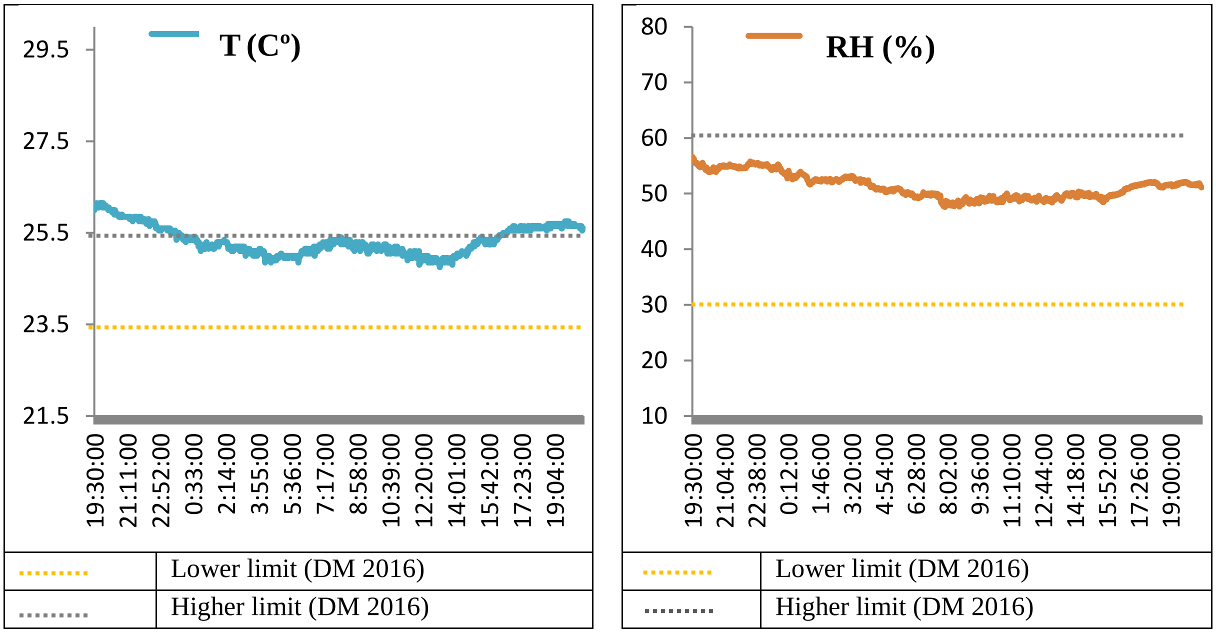


Figure ZZ-61: Continuously measured indoor levels of T and RH in House (13)

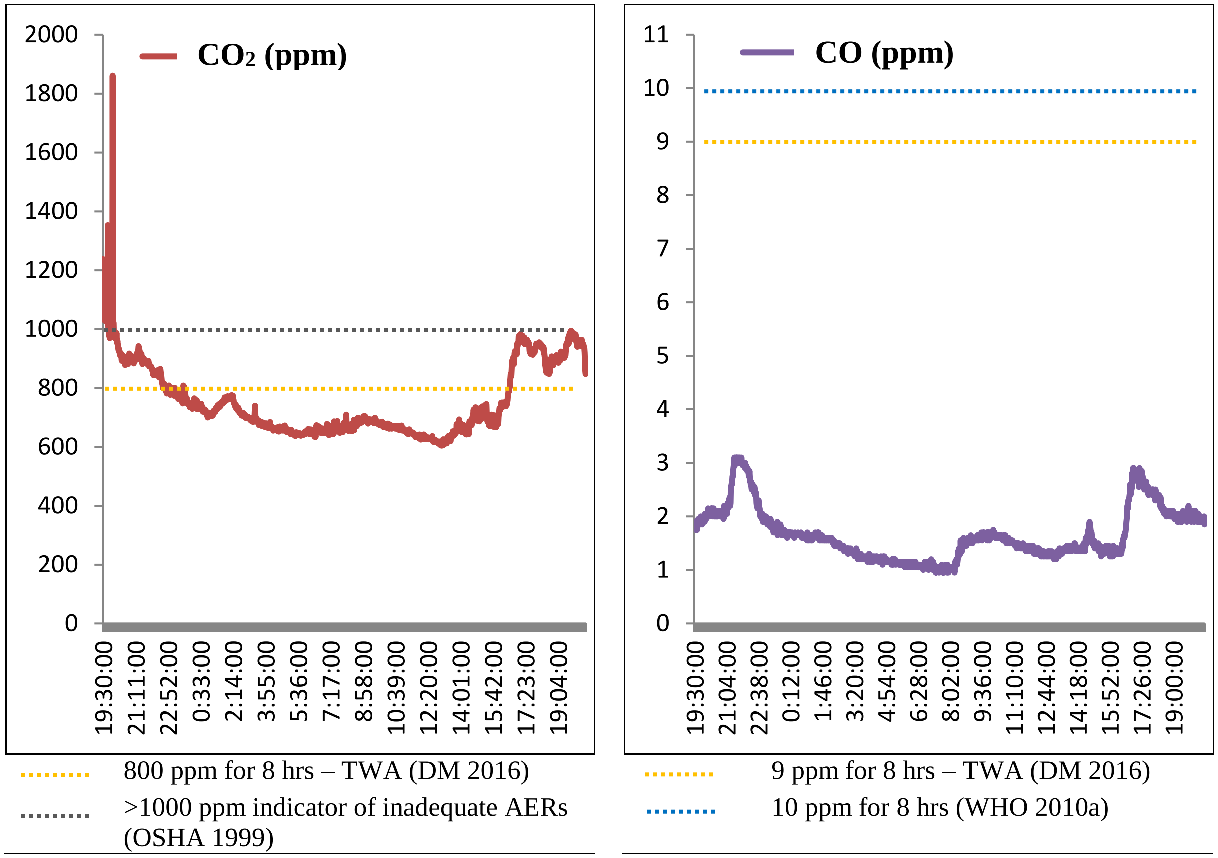


Figure ZZ-62: Compliance of $CO_2$ and CO levels in House (13) with established standards

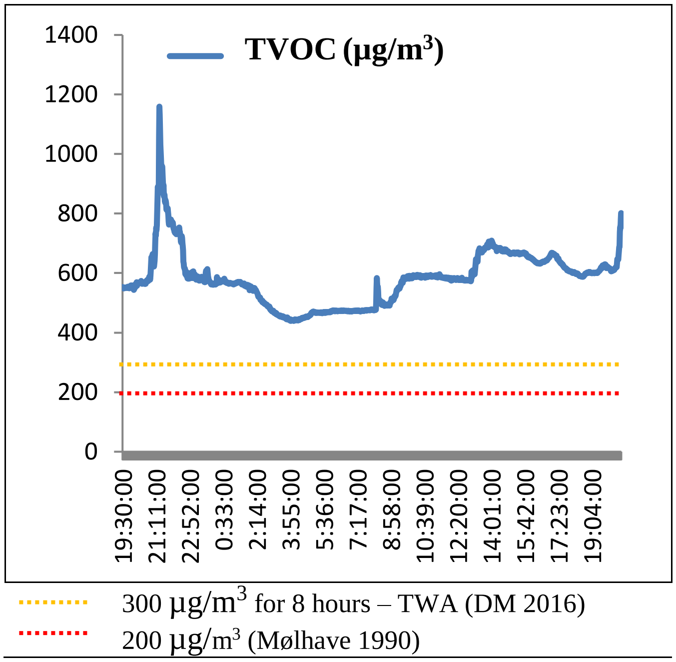


Figure ZZ-63: Compliance of indoor TVOC levels with established standards (House 13)

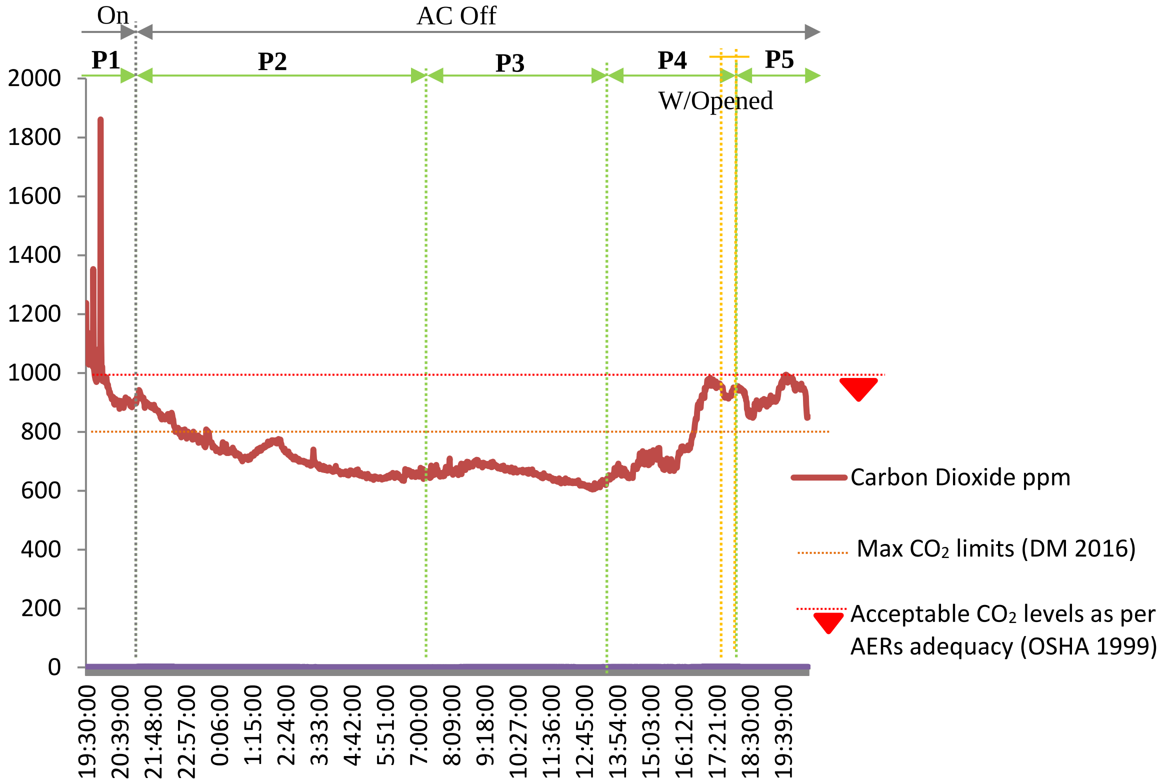


Figure ZZ-64: Occupancy profiles of the living hall projected on $CO_2$ levels (House 13)

Table ZZ-39: Occupancy profiles of the living hall during measurement period (House 13)

| **Profile** | **Time** | **Occupants** | **System** | **Activities** |
|---|---|---|---|---|
| **P1** | 19:35 – 21:00 | 3 | Mechanical | Sitting, dinner |
| **P2** | 21:00 – 07:20 | 0 | Natural (Infiltration) | 3 persons in other rooms |
| **P3** | 07:20 – 13:30 | 0 | Natural (Infiltration) | 2 persons in other rooms |
| **P4** | 13:30 – 18:00 | 4 | Natural (Window & Infiltration) | Having a visitor, cooking, sitting |
| **P5** | 18:00 – 21:00 | 2 | Natural (Infiltration) | Sitting, dinner |

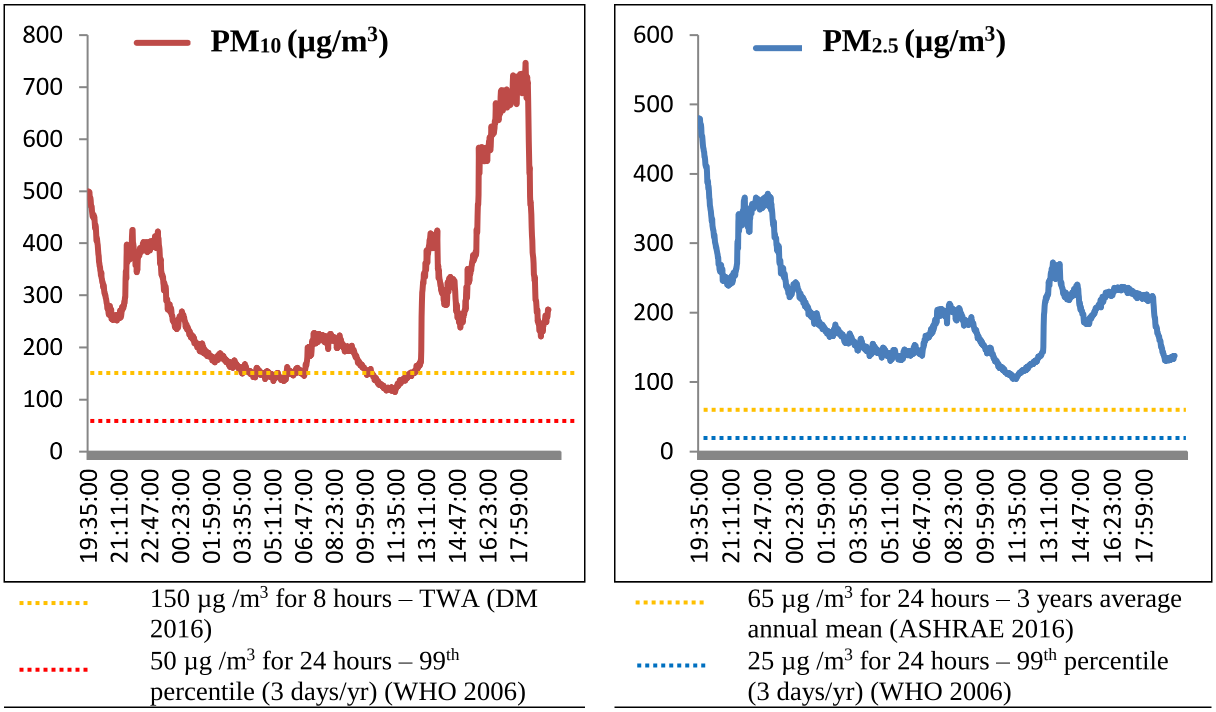


Figure ZZ-65: Compliance of $PM_{10}$ and $PM_{2.5}$ levels with established standards (House 13)

***House (14)***

Table ZZ-40: Levels of continuously measured variables indoor House (14)

| | **TVOC (µg/m³)** | **CO₂ (ppm)** | **CO (ppm)** | **PM2.5 (µg/m³)** | **PM10 (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 464.6 | 616.0 | 1.0 | 52.5 | 57.8 | 29.0 | 45.0 |
| **Mean** | 243.8 | 508.0 | 0.0 | 216.2 | 255.0 | 24.0 | 40.0 |
| **Max** | 685.4 | 1250.0 | 3.0 | 2044.5 | 2782.6 | 30.0 | 55.0 |

Table ZZ-41: Spot measured variables in outdoor air of House (14)

| | **TVOC (µg/m³)** | **CO₂ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 152 | 391 | 0.3 | 33.2 | 32.1 |

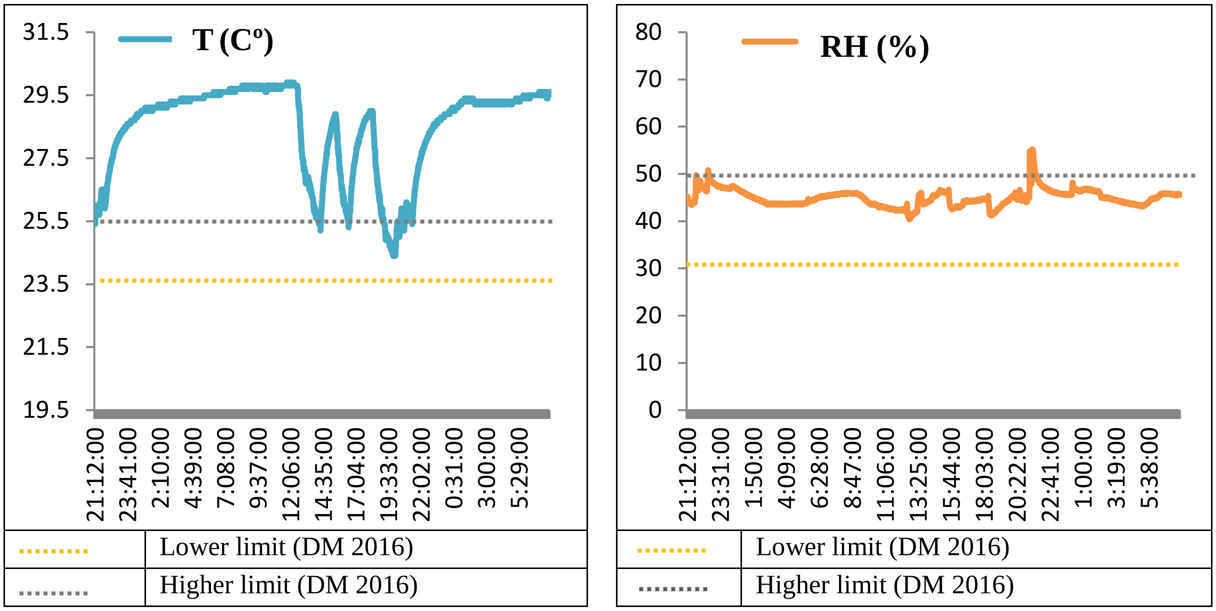


Figure ZZ-66: Continuously measured indoor levels of T and RH in House (14)

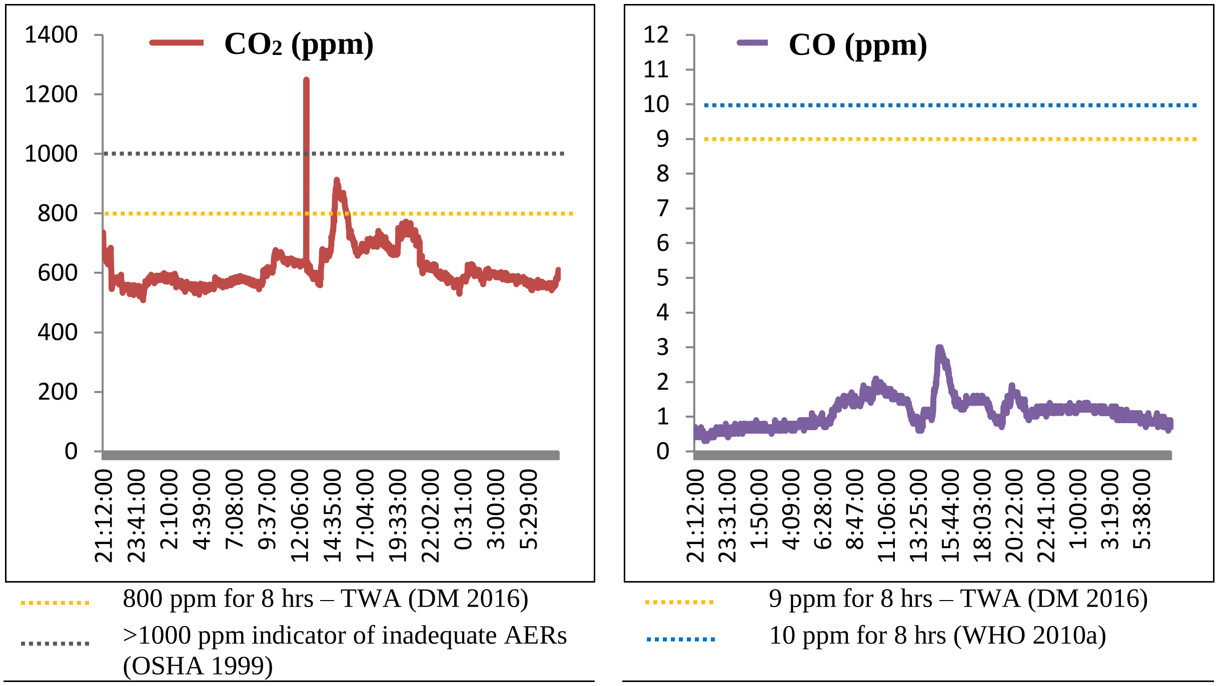


Figure ZZ-67: Compliance of $CO_2$ and CO levels in House (14) with established standards

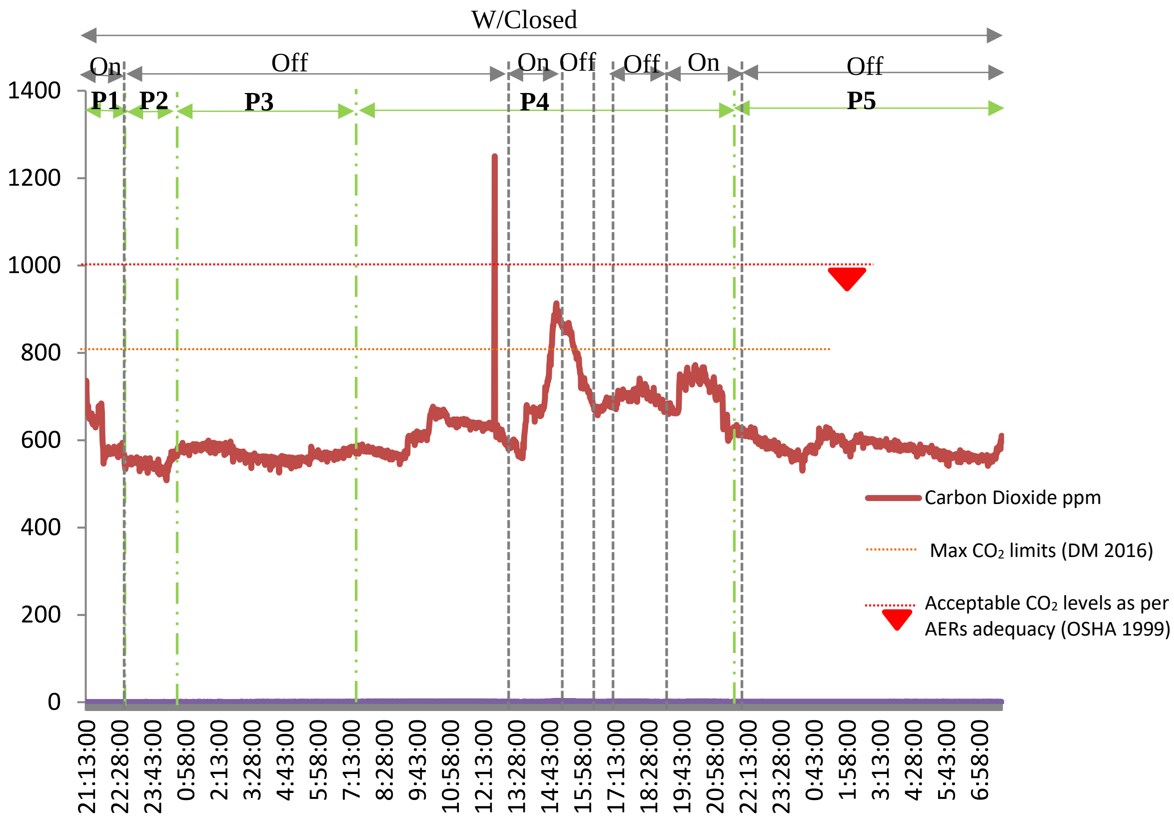


Figure ZZ-68: Occupancy profiles of the living hall projected on $CO_2$ levels (House 14)

Table ZZ-42: Occupancy profiles of the living hall during measurement period (House 14)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 21:12 – 22:35 | 4 | Mechanical | Having visitor<br>Dinner |
| **P2** | 22:35 – 00:45 | 0 | Natural (Infiltration) | 2 persons in other room |
| **P3** | 00:45 – 07:30 | 0 | Natural (Infiltration) | 4 persons in other room |
| **P4** | 07:30 – 21:42 | 3 | Mixed:<br>07:30 – 13:10 Natural (Infiltration)<br>13:10 – 14:54 Mechanical<br>14:54 – 16:07 Natural (Infiltration)<br>16:07 – 17:08 Mechanical<br>17:08 – 19:10 Natural (Infiltration)<br>19:10 – 21:42 Mechanical | Normal day-time activities:<br>Breakfast<br>Child play<br>Lunch<br>Daily cleaning |
| **P5** | 21:42 – 07:30 | 0 | Natural (Infiltration) | 4 persons in another room |

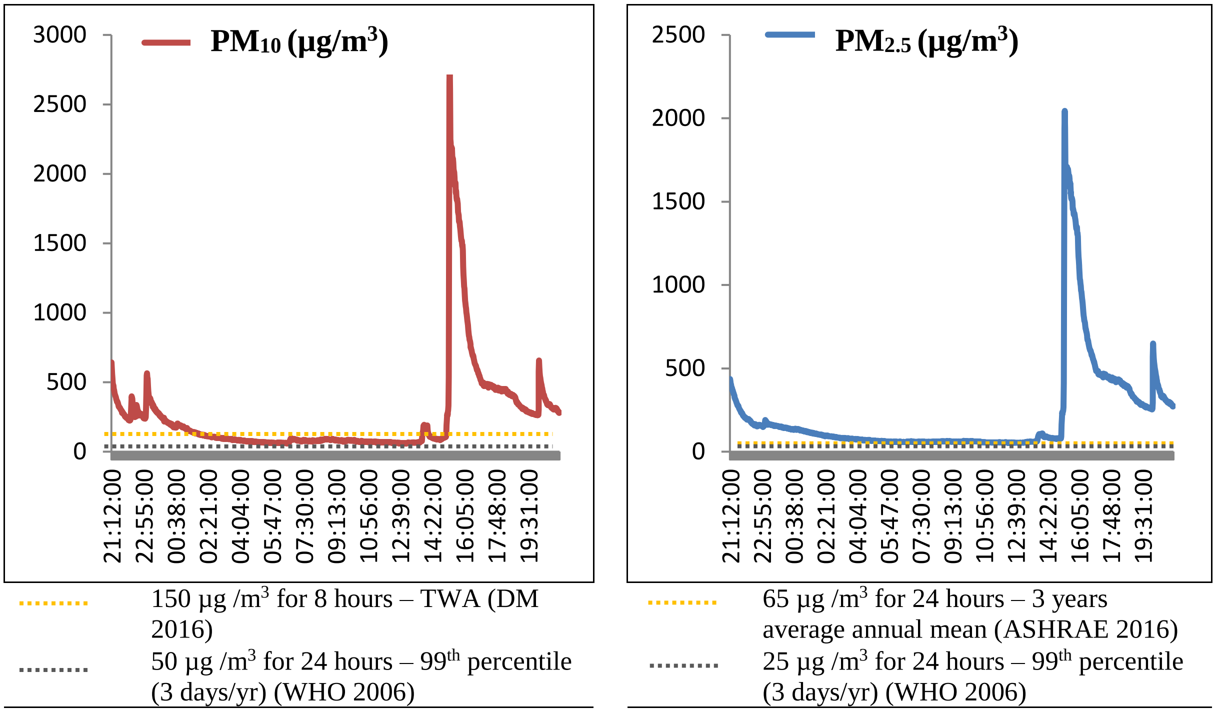


Figure ZZ-69: Compliance of $PM_{10}$ and $PM_{2.5}$ levels with established standards (House 14)

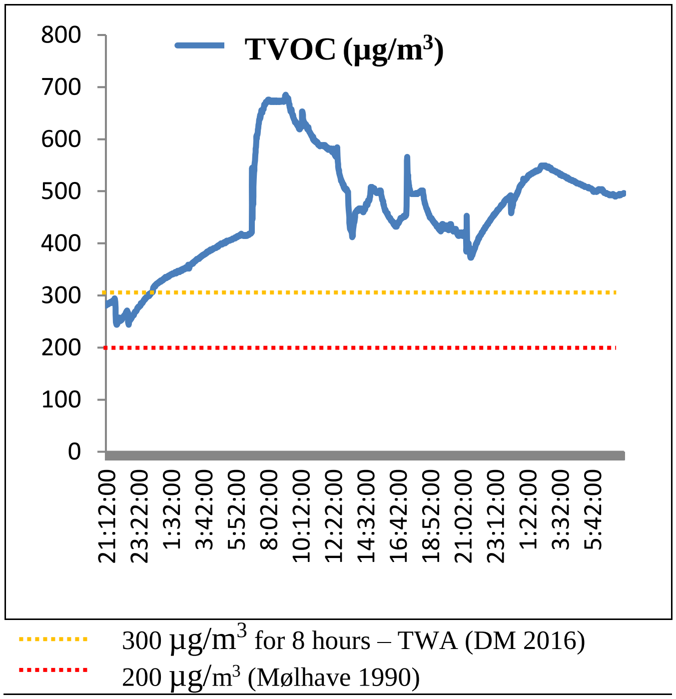


Figure ZZ-70: Compliance of indoor TVOC levels with established standards (House 14)

***House (15)***

Table ZZ-43: Levels of continuously measured variables indoor House (15)

| | **TVOC ($\mu g/m^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ ($\mu g/m^3$)** | **$PM_{10}$ ($\mu g/m^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 432.4 | 664 | 0.9 | 85.9 | 88.5 | 25 | 32 |
| **Mean** | 715.3 | 1082 | 1.804 | 328.6 | 356.4 | 27 | 39 |
| **Max** | 8305.3 | 2116 | 3.6 | 628.8 | 927.0 | 29 | 45 |

Table ZZ-44: Spot measured variables in outdoor air of House (15)

| | **TVOC ($\mu g/m^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 216 | 590 | 1.0 | 28.5 | 66.2 |

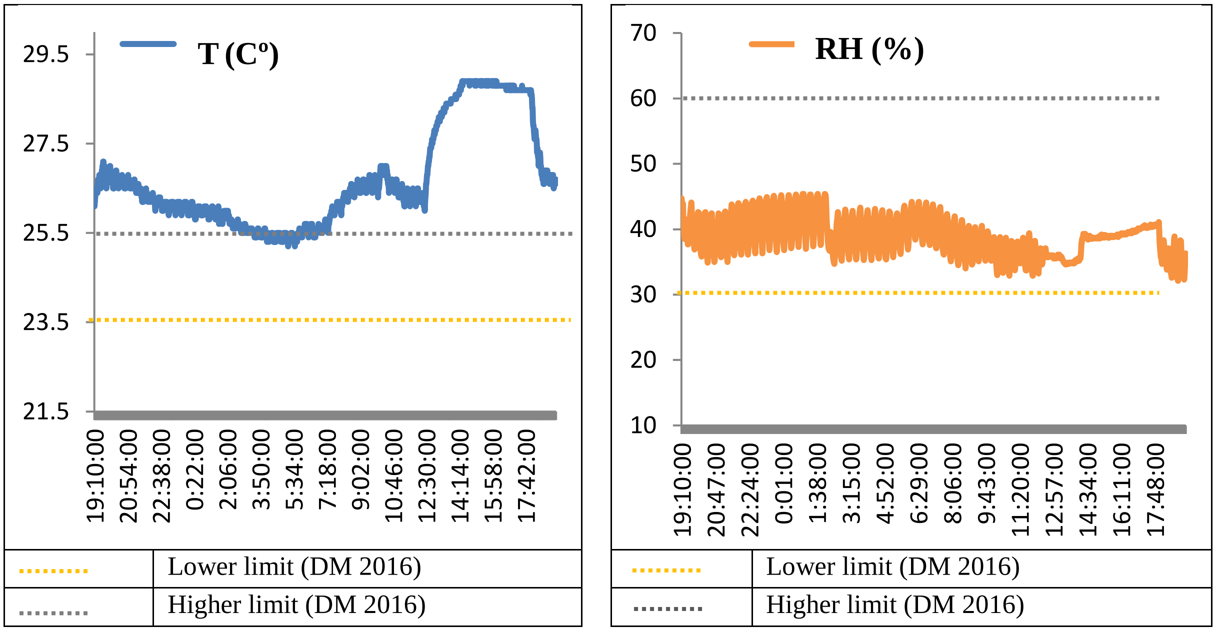


Figure ZZ-71: Continuously measured indoor levels of T and RH in House (15)

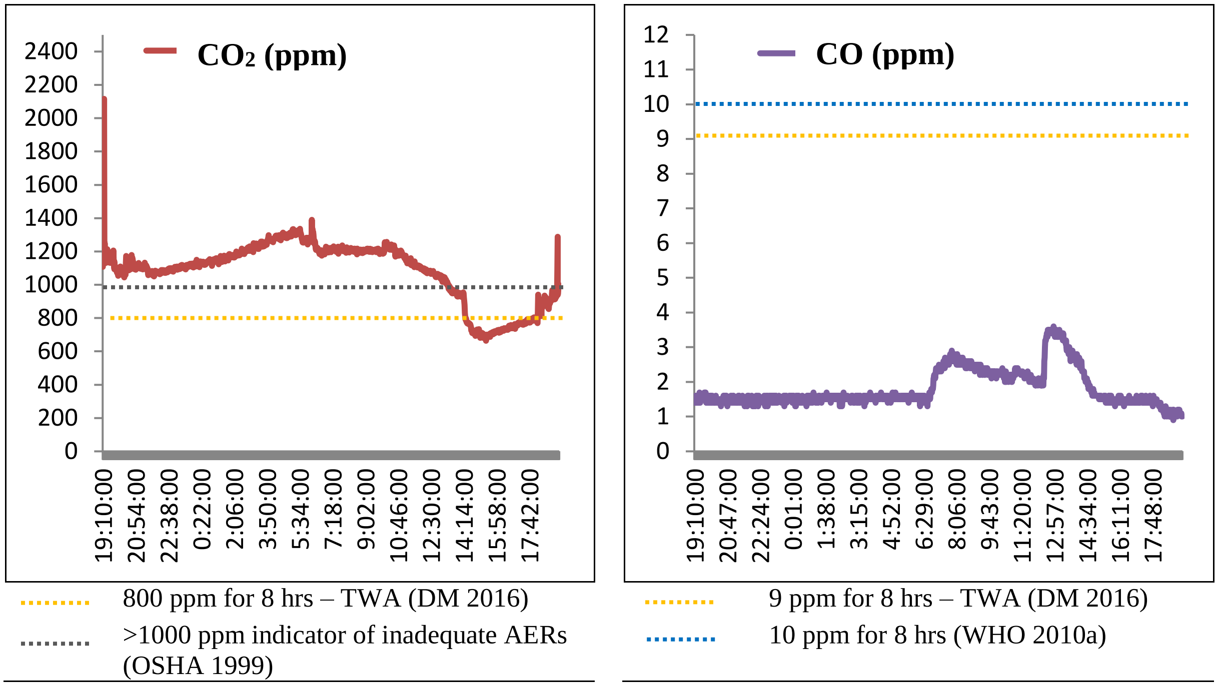


Figure ZZ-72: Compliance of $CO_2$ and CO levels in House (15) with established standards

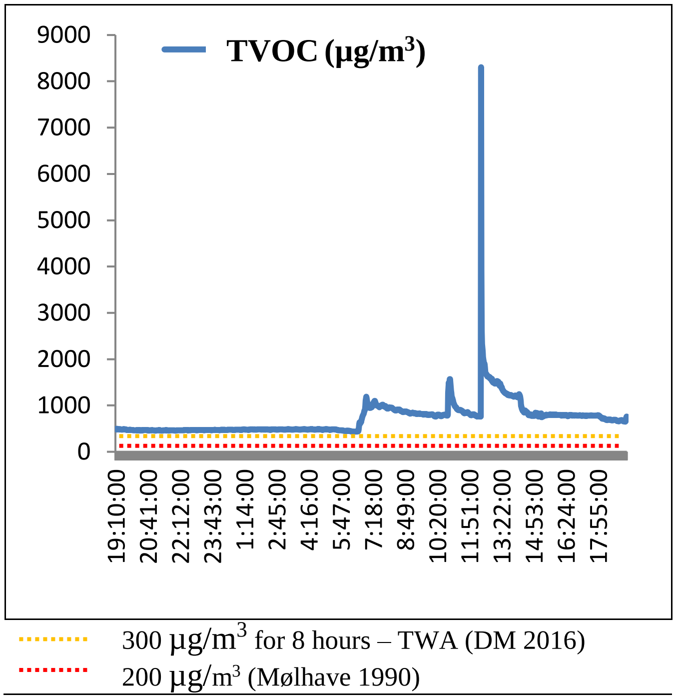


Figure ZZ-73: Compliance of indoor TVOC levels with established standards (House 15)

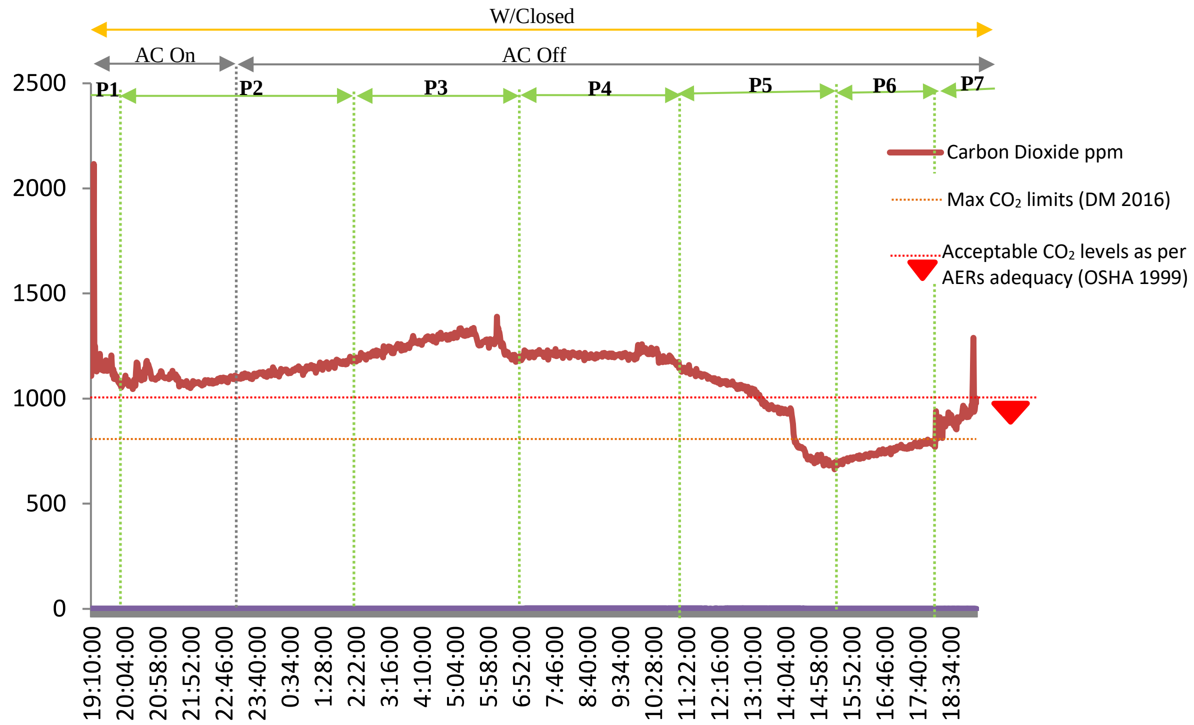
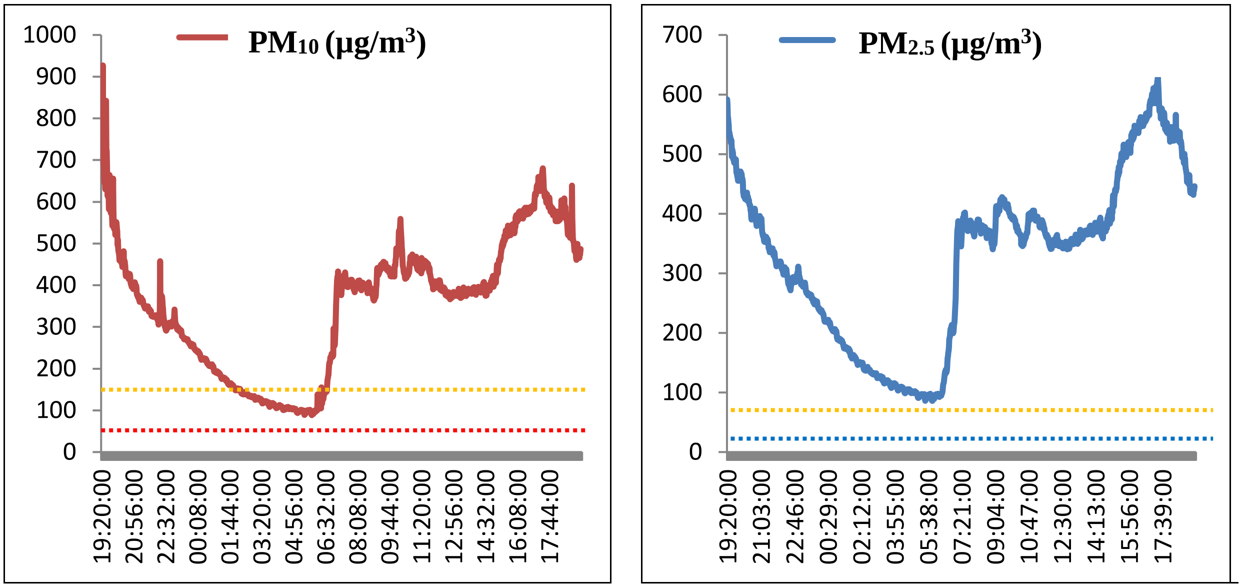


Figure ZZ-74: Occupancy profiles of the living hall projected on $CO_2$ levels (House 15)

Table ZZ-45: Occupancy profiles of the living hall during measurement period (House 15)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 19:10 – 19:45 | 7 | Mechanical | Having visitor<br>Sitting |
| **P2** | 19:45 – 02:15 | 4 | Mixed:<br>19:45 – 10:55 Mechanical<br>10:55 – 02:15 Natural (Infiltration) | Sitting |
| **P3** | 02:15 – 06:45 | 0 | Natural (Infiltration) | 5 persons in other room |
| **P4** | 06:45 – 10:50 | 2 | Natural (Infiltration) | Sitting, daily cleaning |
| **P5** | 10:50 – 15:30 | 1 | Natural (Infiltration) | Sitting |
| **P6** | 15:30 – 18:10 | 2 | Natural (Infiltration) | Sitting |
| **P7** | 18:10 – 17:17 | 3 | Natural (Infiltration) | Sitting |



| | | | |
|---|---|---|---|
| ⋯ | 150 µg /m$^3$ for 8 hours – TWA (DM 2016) | ⋯ | 65 µg /m$^3$ for 24 hours – 3 years average annual mean (ASHRAE 2016) |
| ⋯ | 50 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) | ⋯ | 25 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure ZZ-75: Compliance of PM$_{10}$ and PM$_{2.5}$ levels with established standards (House 15)

### *House (16)*

Table ZZ-46: Levels of continuously measured variables indoor House (16)

| | **TVOC (µg/m$^3$)** | **CO$_2$ (ppm)** | **CO (ppm)** | **PM$_{2.5}$ (µg/m$^3$)** | **PM$_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 98.9 | 432.0 | 0.1 | 46.9 | 47.6 | 24.0 | 21.0 |
| **Mean** | 262.2 | 581.0 | 0.4 | 91.8 | 132.2 | 27.0 | 54.0 |
| **Max** | 2157.4 | 1310.0 | 1.7 | 316.9 | 524.6 | 32.0 | 61.0 |

Table ZZ-47: Spot measured variables in outdoor air of House (16)

| | **TVOC (µg/m$^3$)** | **CO$_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 121.9 | 434 | 1.0 | 32.3 | 49.1 |

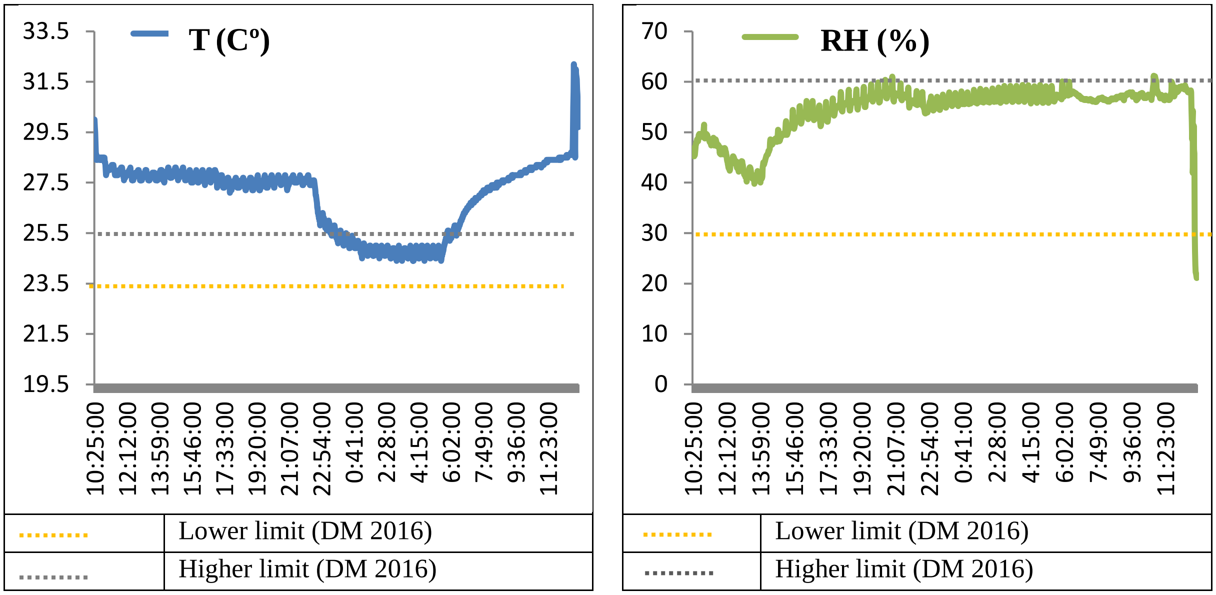


Figure ZZ-76: Continuously measured indoor levels of T and RH in House (16)

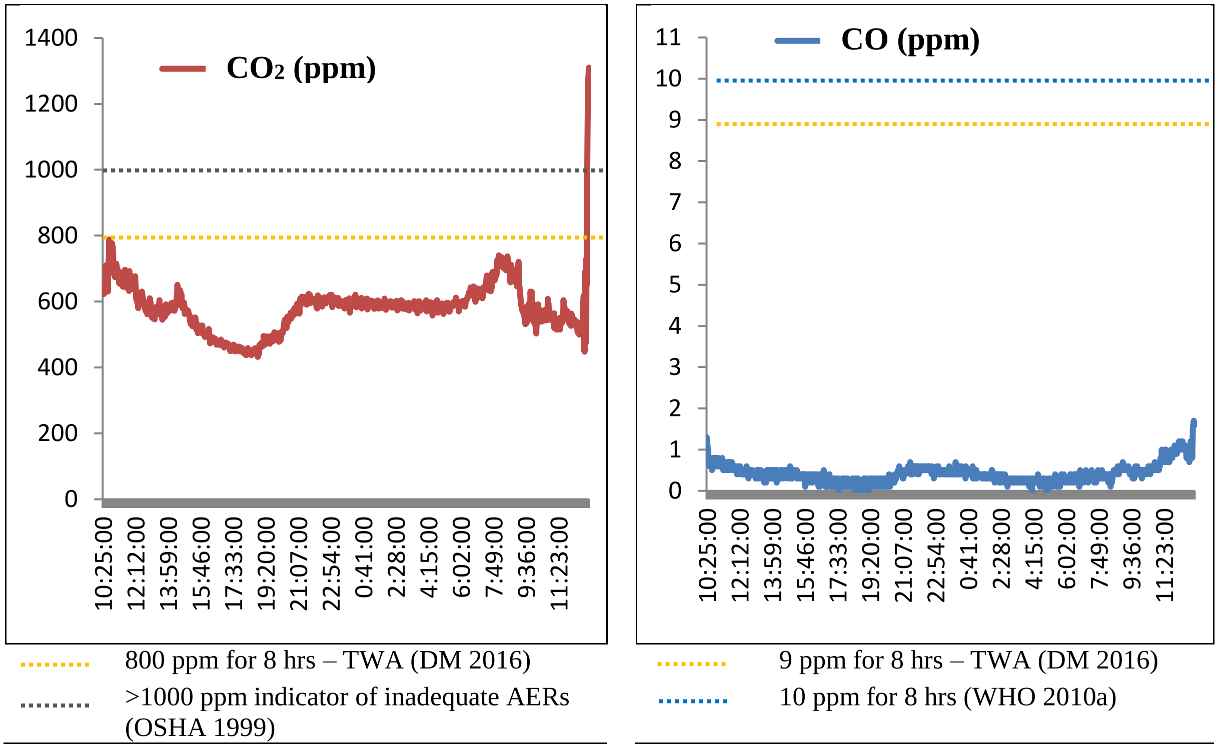


Figure ZZ-77: Compliance of $CO_2$ and CO levels in House (16) with established standards

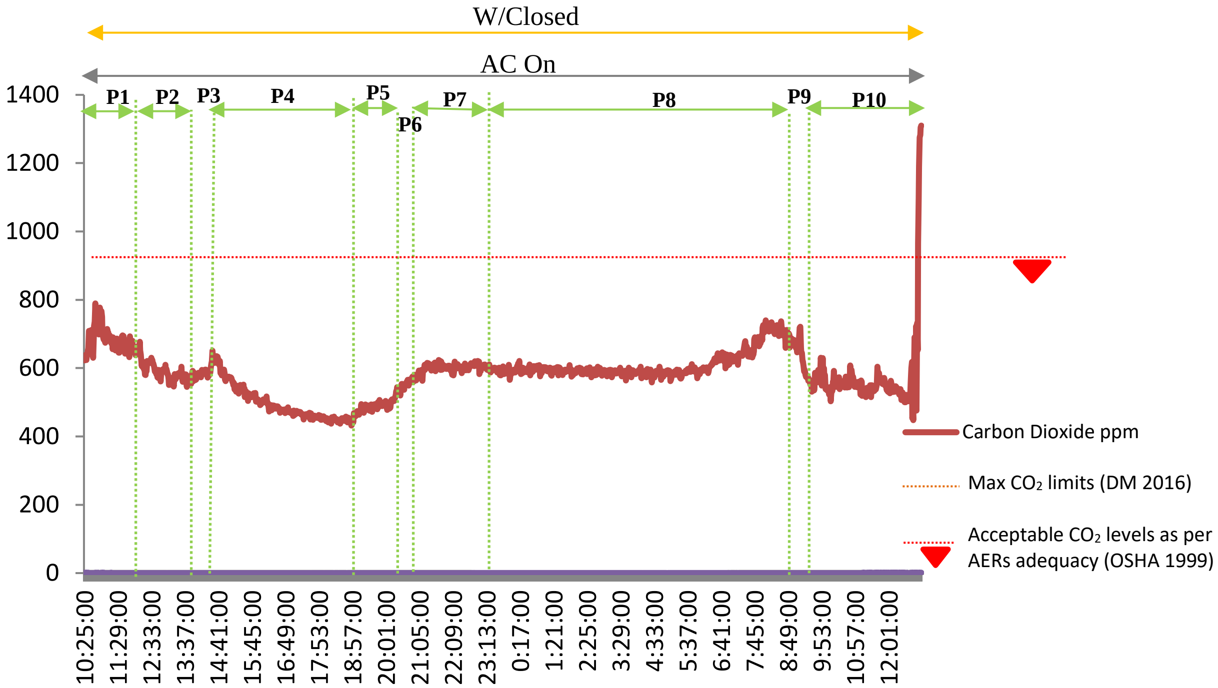


Figure ZZ-78: Occupancy profiles of the living hall projected on $CO_2$ levels (House 16)

Table ZZ-48: Occupancy profiles of the living hall during measurement period (House 16)

| **Profile** | **Time** | **Occupants** | **System** | **Activities** |
|---|---|---|---|---|
| **P1** | 10:25 – 12:00 | 3 | Mechanical | |
| **P2** | 12:00 – 13:45 | 1 | ,, ,, ,, ,, | |
| **P3** | 13:45 – 14:30 | 3 | ,, ,, ,, ,, | |
| **P4** | 14:30 – 19:00 | 0 | ,, ,, ,, ,, | |
| **P5** | 19:00 – 20:20 | 1 | ,, ,, ,, ,, | |
| **P6** | 20:20 – 20:45 | 4 | ,, ,, ,, ,, | |
| **P7** | 20:45 – 23:30 | 3 | ,, ,, ,, ,, | |
| **P8** | 23:30 – 09:00 | 4 | ,, ,, ,, ,, | Sleeping in other room |
| **P9** | 09:00 – 09:30 | 3 | ,, ,, ,, ,, | |
| **P10** | 09:30 – 13:04 | 1 | ,, ,, ,, ,, | Cooking (Separate kitchen) |

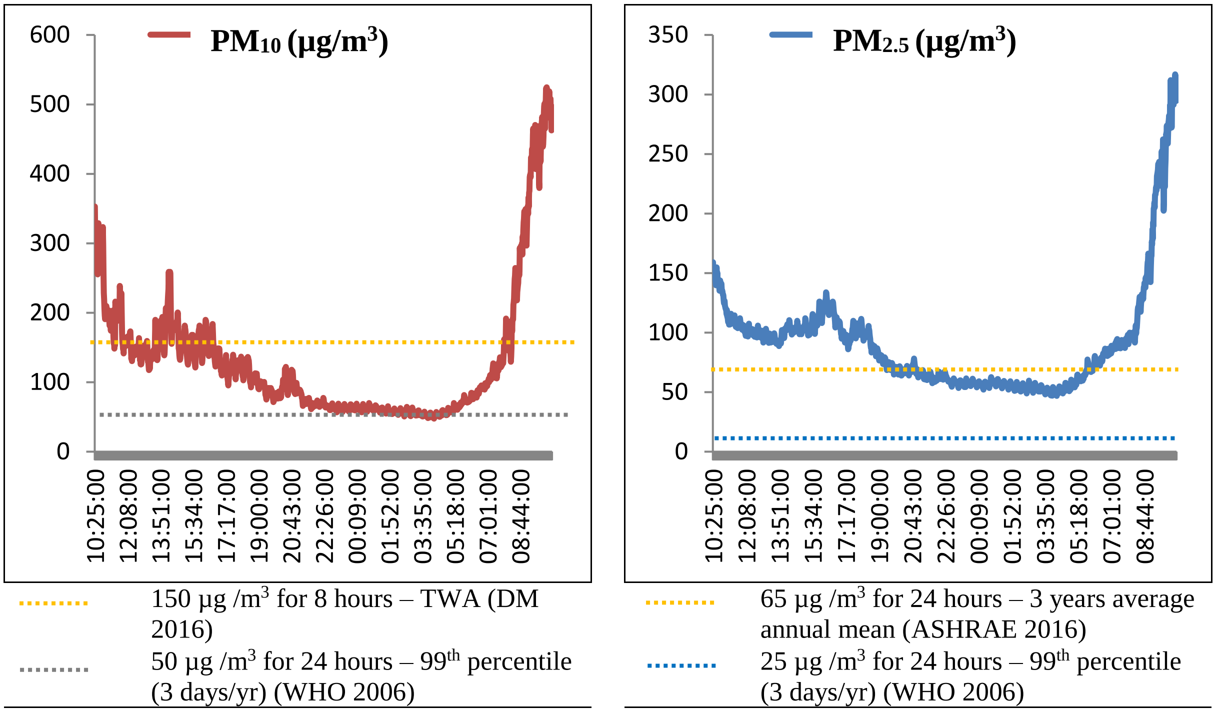


Figure ZZ-79: Compliance of $PM_{10}$ and $PM_{2.5}$ levels with established standards (House 16)

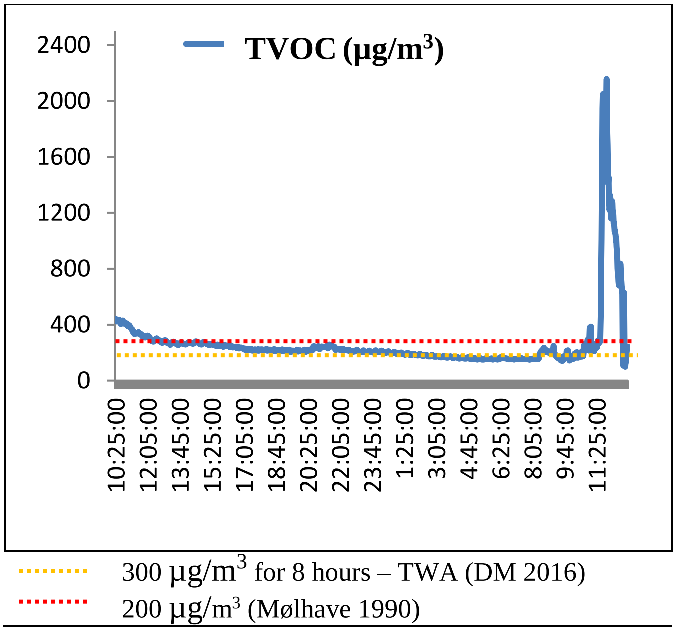


Figure ZZ-80: Compliance of indoor TVOC levels in House (16) with established standards

## *House (17)*

Table ZZ-49: Levels of continuously measured variables indoor House (17)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m$^3$)** | **$PM_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 437.0 | 593.0 | 0.6 | 2.5 | 10.0 | 23.0 | 20.0 |
| **Mean** | 825.7 | 1144.0 | 3.0 | 321.2 | 358.2 | 27.0 | 27.0 |
| **Max** | 2090.7 | 1885.0 | 7.4 | 2073.1 | 2141.0 | 31.0 | 45.0 |

Table ZZ-50: Spot measured variables in outdoor air of House (17)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 85 | 404 | 1.4 | 33.3 | 55.7 |

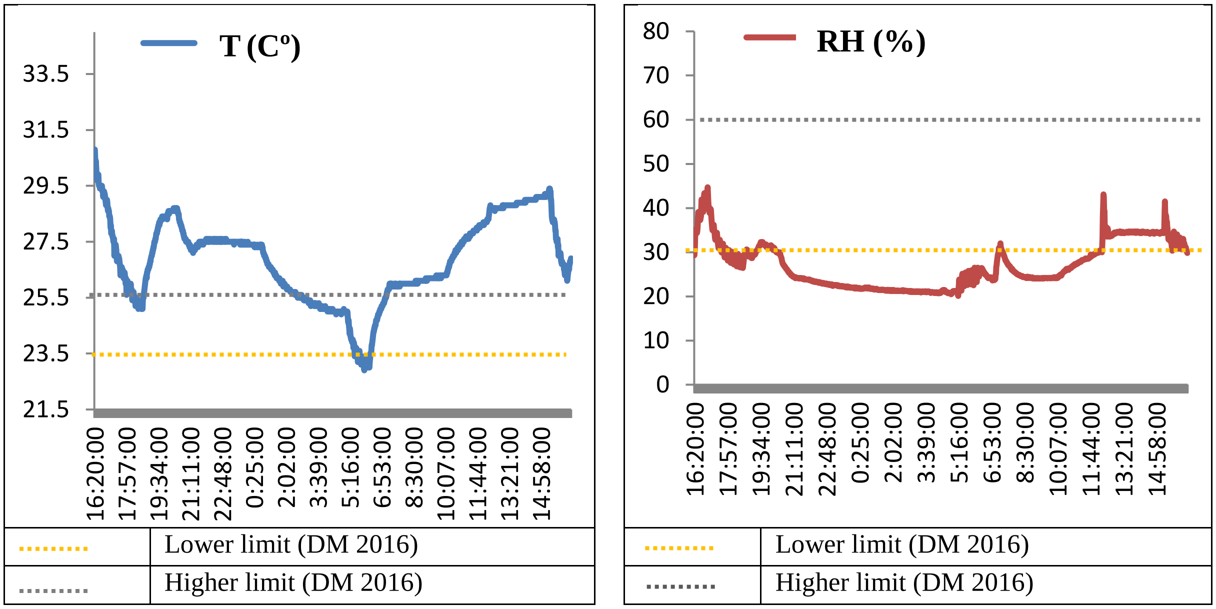


Figure ZZ-81: Continuously measured indoor levels of T and RH in House (17)

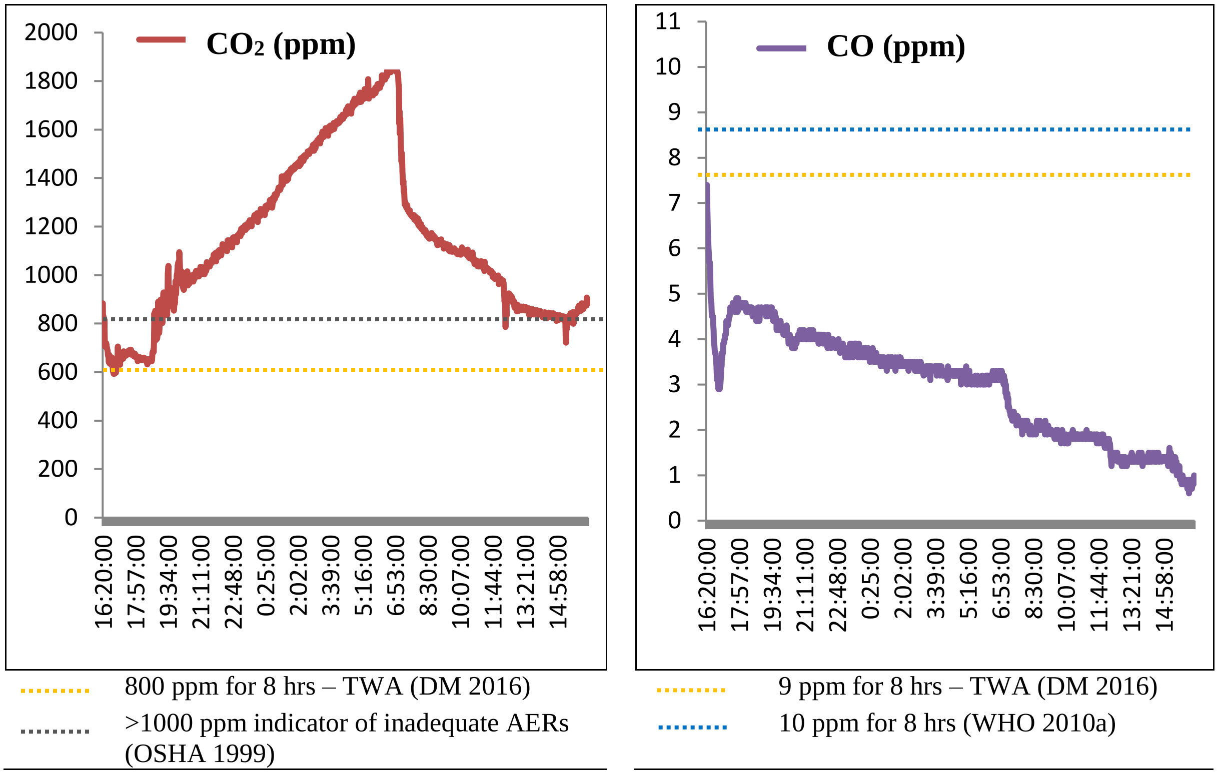


Figure ZZ-82: Compliance of $CO_2$ and CO levels in House (17) with established standards

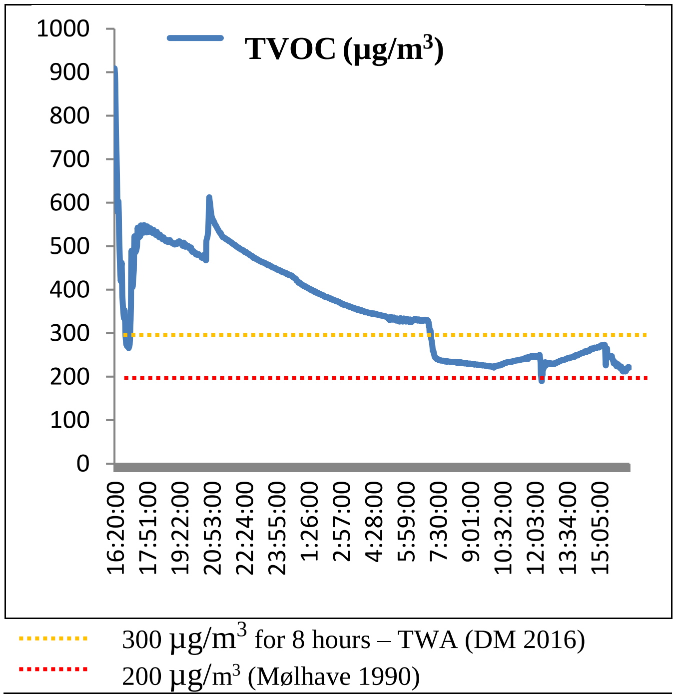


Figure ZZ-83: Compliance of indoor TVOC levels with established standards (House 17)

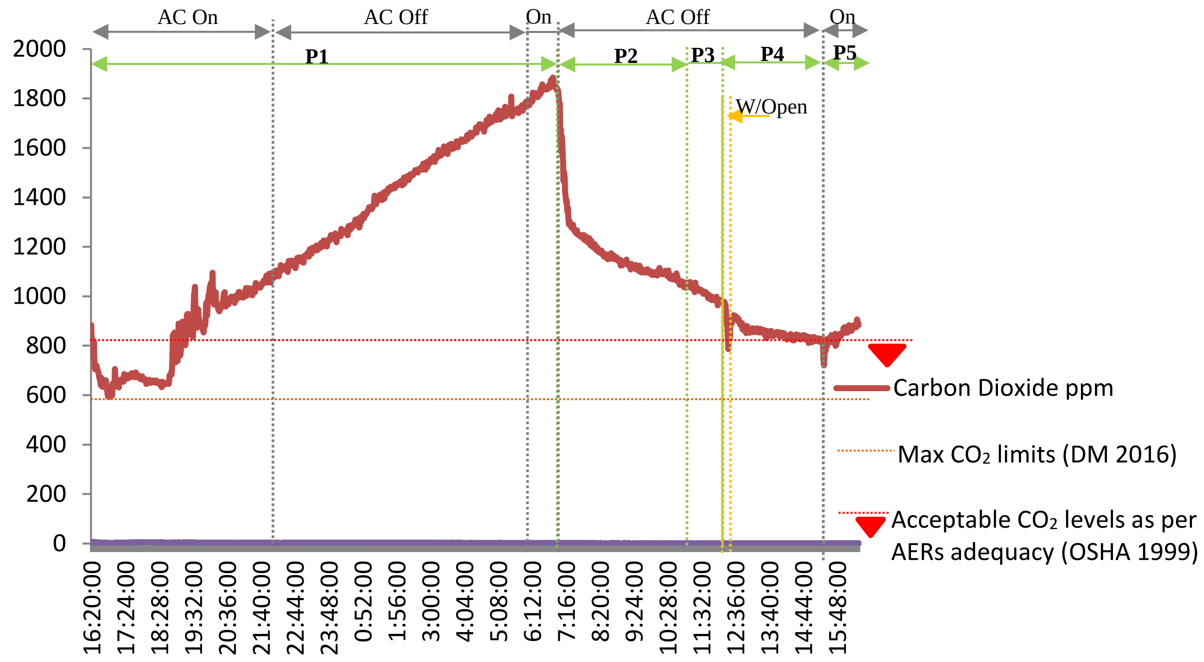
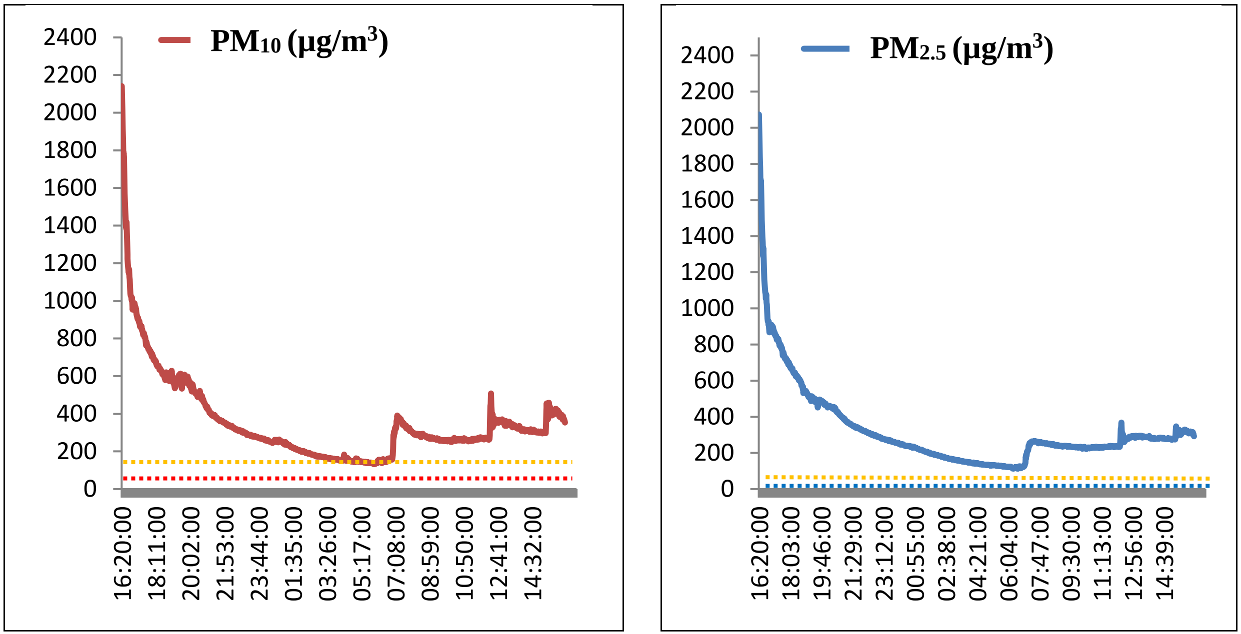


Figure ZZ-84: Occupancy profiles of the living hall projected on $CO_2$ levels (House 17)

Table ZZ-51: Occupancy profiles of the living hall during measurement period (House 17)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 16:20 – 07:00 | 5 | Mixed:<br>16:20 – 22:00 Mechanical<br>22:00 – 06:00 Natural (Infiltration)<br>06:00 – 07:00 Mechanical | Sitting<br>Lunch & dinner<br>No cooking<br>Sleeping |
| **P2** | 07:00 – 10:00 | 1 | Mechanical | Sitting |
| **P3** | 10:00 – 12:00 | 0 | Natural (Infiltration) | |
| **P4** | 12:00 – 15:30 | 1 | Natural:<br>12:00 – 12:15 Window<br>12:15 – 15:30 Infiltration | Daily cleaning |
| **P5** | 15:30 – 16:30 | 5 | Mechanical | Sitting, lunch |



| | | | |
|---|---|---|---|
| ········ | 150 µg /m³ for 8 hours – TWA (DM 2016) | ········ | 65 µg /m³ for 24 hours – 3 years annual mean (ASHRAE 2016) |
| ········ | 50 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) | ········ | 25 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure ZZ-85: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 17)

### *House (18)*

Table ZZ-52: Levels of continuously measured variables indoor House (18)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 446.2 | 787.0 | 0.8 | 27.0 | 28.6 | 26.7 | 41.1 |
| **Mean** | 661.1 | 916.1 | 1.3 | 93.8 | 99.3 | 28.8 | 50.1 |
| **Max** | 1035.0 | 1198.0 | 3.0 | 199.7 | 249.9 | 29.7 | 53.9 |

Table ZZ-53: Spot measured variables in outdoor air of House (18)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 66.7 | 432.0 | 0.6 | 30.7 | 61.9 |

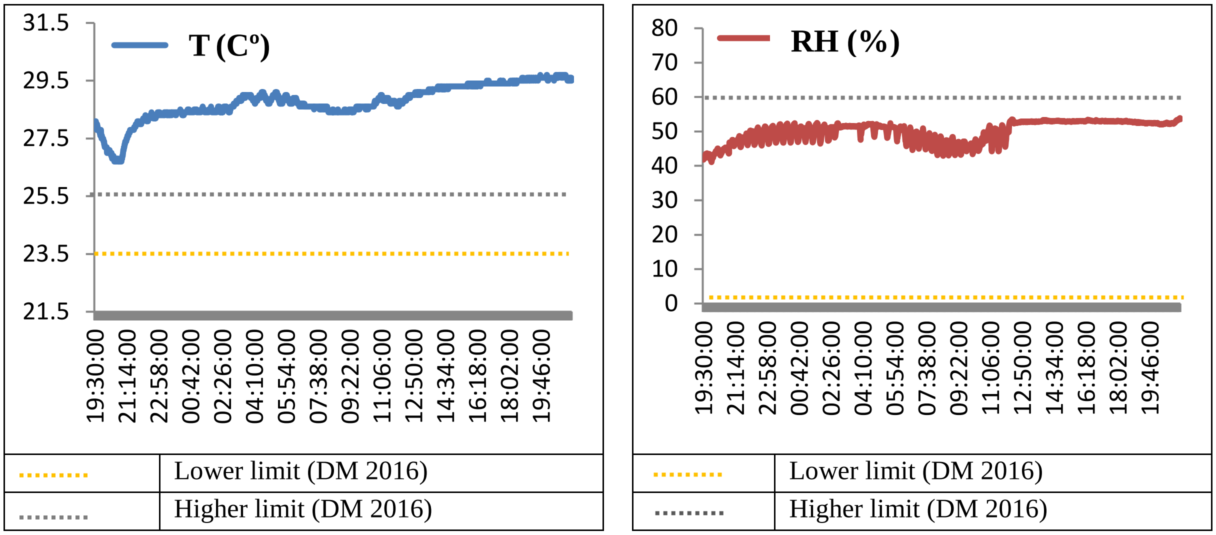


Figure ZZ-86: Continuously measured indoor levels of T and RH in House (18)

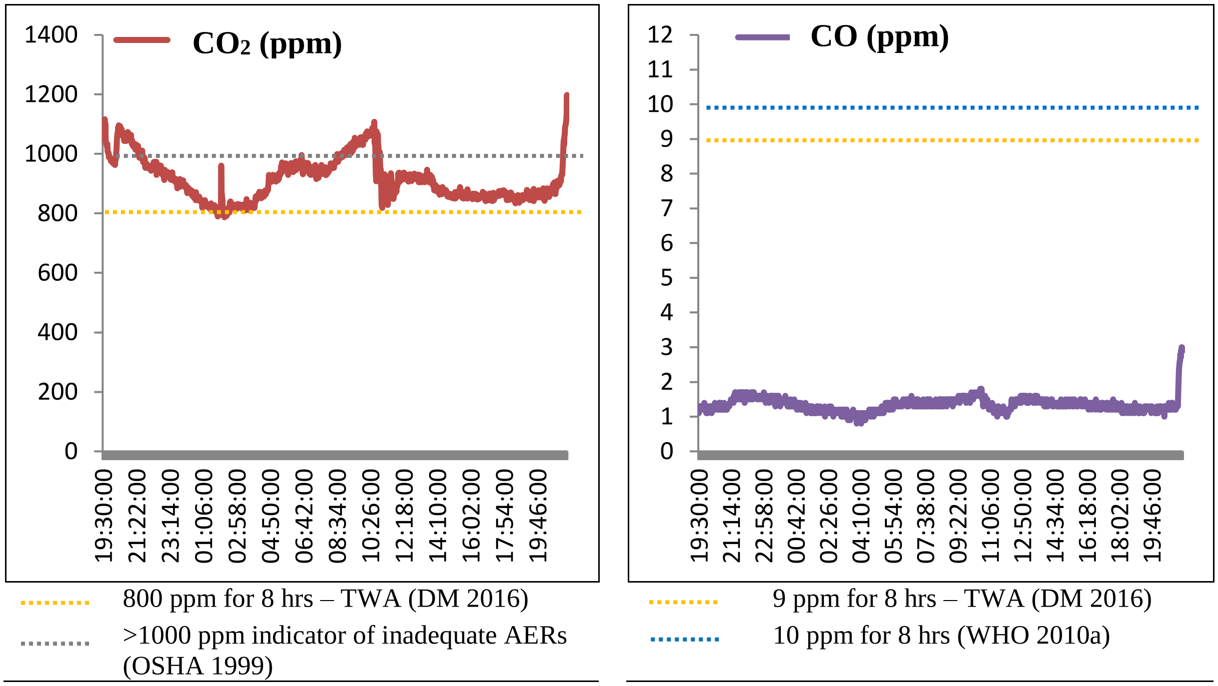


Figure ZZ-87: Compliance of $CO_2$ and CO levels in House (18) with established standards

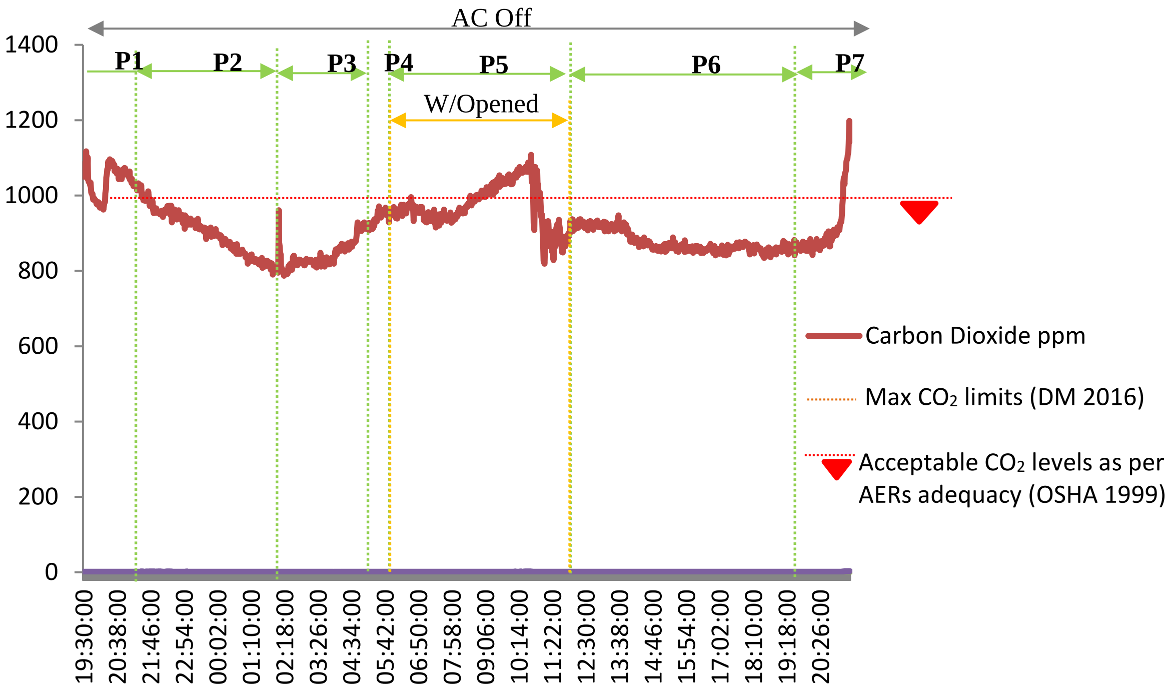


Figure ZZ-88: Occupancy profiles of the living hall projected on CO2 levels (House 18)

Table ZZ-54: Occupancy profiles of the living hall during measurement period (House 18)

| **Profile** | **Time** | **Occupants** | **System** | **Activities** |
|---|---|---|---|---|
| **P1** | 19:30 – 21:00 | 1 | Natural (Infiltration) | |
| **P2** | 21:00 – 02:00 | 0 | Natural (Infiltration) | |
| **P3** | 02:00 – 05:00 | 1 | Natural (Infiltration) | |
| **P4** | 05:00 – 06:00 | 0 | Natural (Infiltration) | |
| **P5** | 06:00 – 12:00 | 1 | Natural (Window & Infiltration) | |
| **P6** | 12:00 – 19:30 | 0 | Natural (Infiltration) | |
| **P7** | 19:30 – 21:00 | 1 | Natural (Infiltration) | Having visitors |

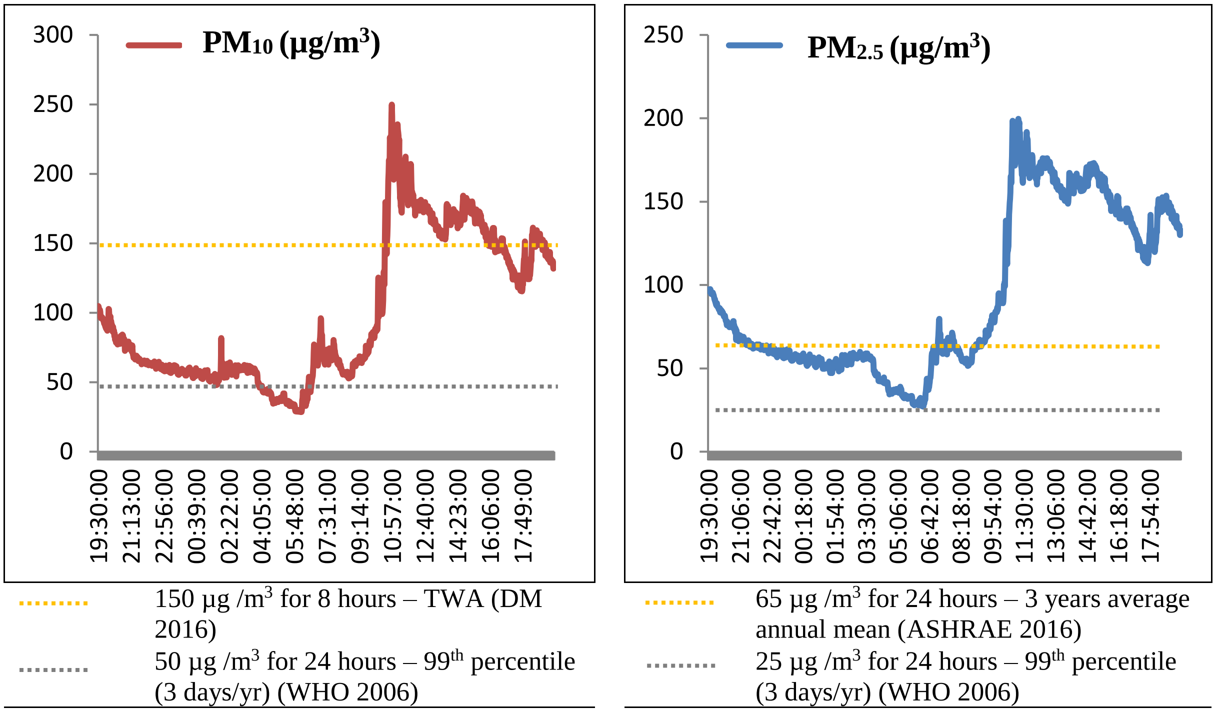


Figure ZZ-89: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 18)

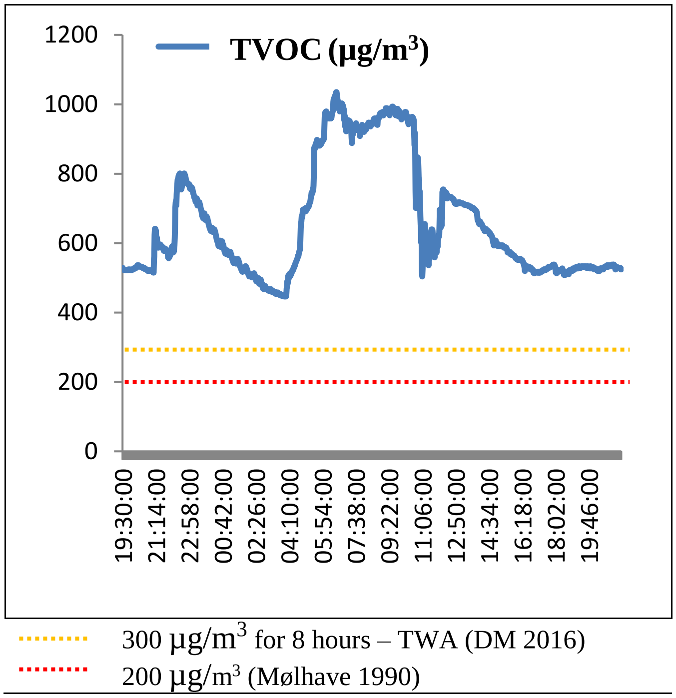


Figure ZZ-90: Compliance of indoor TVOC levels with established standards (House 18)

### *House (19)*

Table ZZ-55: Levels of continuously measured variables indoor House (19)

| | **TVOC (µg/m$^3$)** | **CO$_2$ (ppm)** | **CO (ppm)** | **PM$_{2.5}$ (µg/m$^3$)** | **PM$_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 117.3 | 477.0 | 0.0 | 2.5 | 10.0 | 22.8 | 39.8 |
| **Mean** | 337.3 | 580.2 | 0.6 | 566.7 | 593.4 | 25.1 | 48.1 |
| **Max** | 1469.7 | 1283.0 | 2.5 | 1420.2 | 1499.5 | 27.2 | 59.9 |

Table ZZ-56: Spot measured variables in outdoor air of House (19)

| | **TVOC (µg/m$^3$)** | **CO$_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 105.8 | 476.0 | 0.5 | 27.5 | 71.3 |

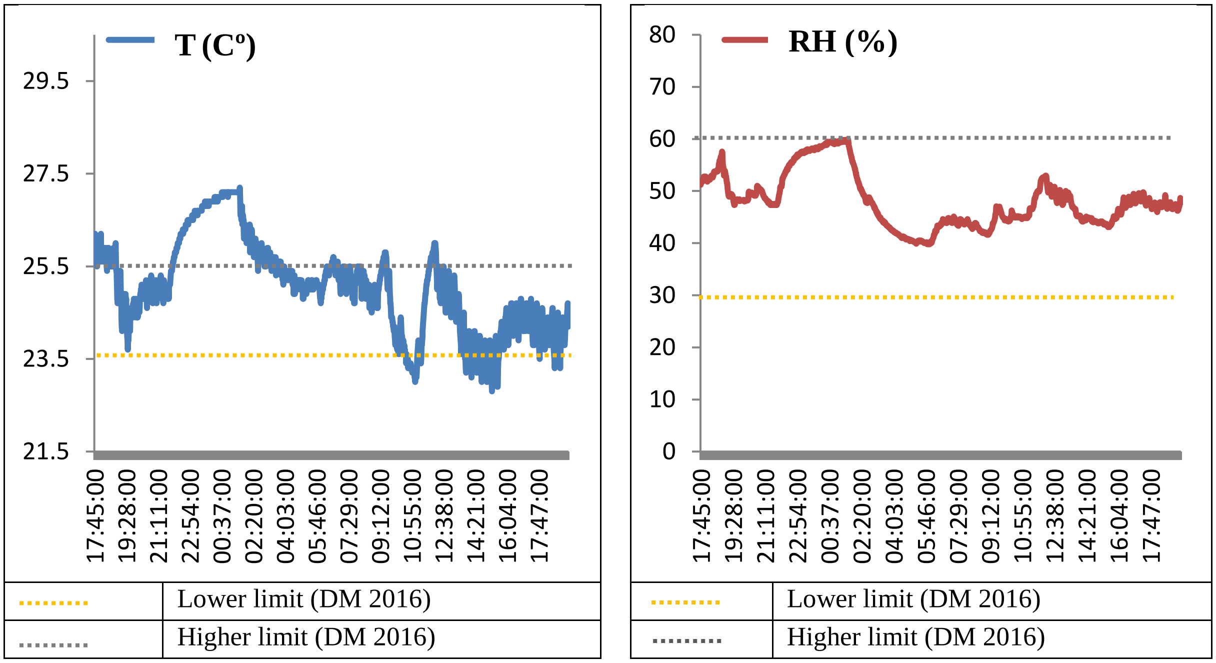


Figure ZZ-91: Continuously measured indoor levels of T and RH in House (19)

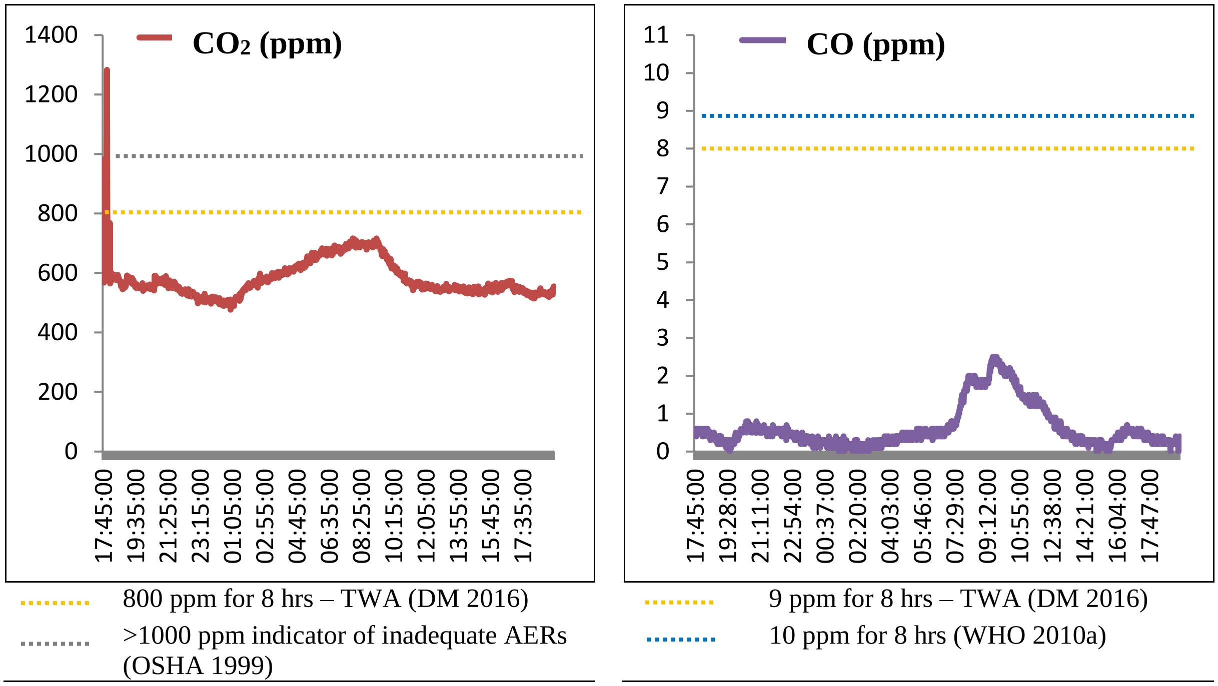


Figure ZZ-92: Compliance of $CO_2$ and CO levels in House (19) with established standards

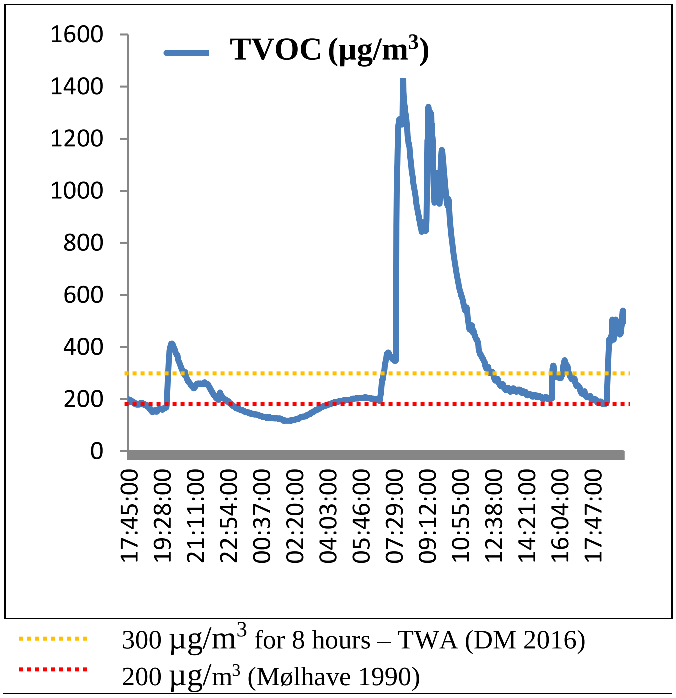


Figure ZZ-93: Compliance of indoor TVOC levels with established standards (House 19)

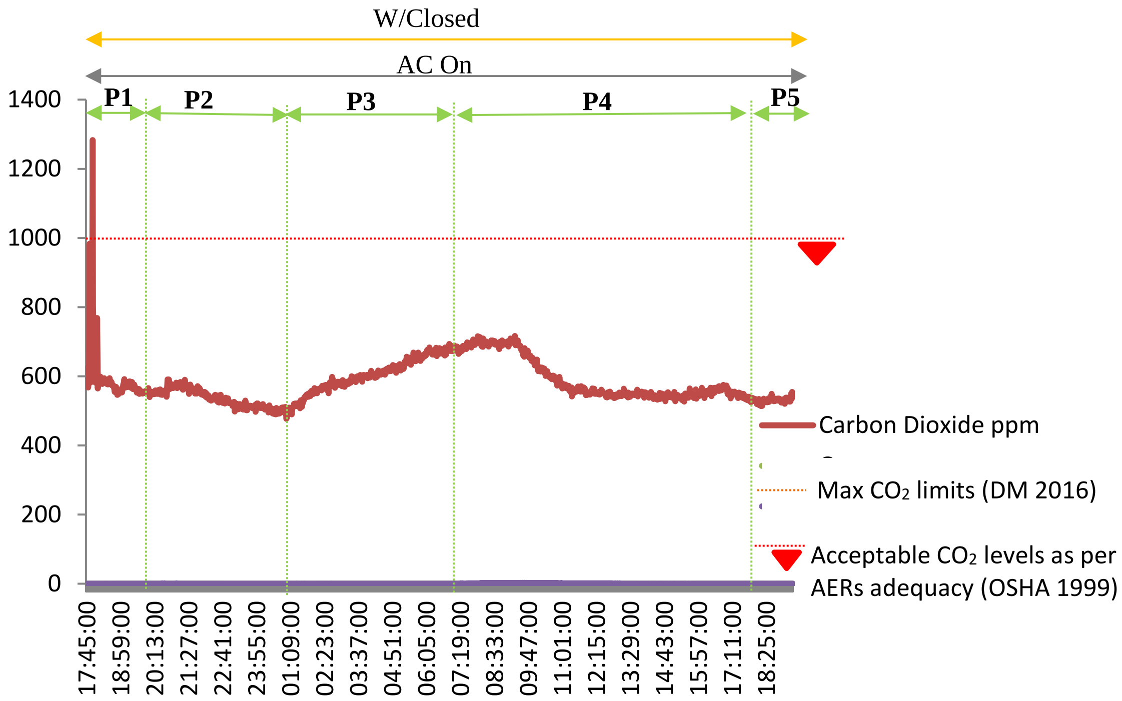


Figure ZZ-94: Occupancy profiles of the living hall projected on $CO_2$ levels (House 19)

Table ZZ-57: Occupancy profiles of the living hall during measurement period (House 19)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 17:45 – 20:00 | 3 | Mechanical | Having visitor, cooking. dinner<br>3 persons in other rooms |
| **P2** | 20:00 – 01:00 | 0 | ,, ,, ,, ,, | 3 persons in other rooms |
| **P3** | 01:00 – 07:00 | 2 | ,, ,, ,, ,, | Sitting, 3 persons in other rooms |
| **P4** | 07:00 – 17:45 | 3 | ,, ,, ,, ,, | Cleaning, cooking, breakfast, lunch |
| **P5** | 17:45 - 19:25 | 2 | ,, ,, ,, ,, | Sitting |

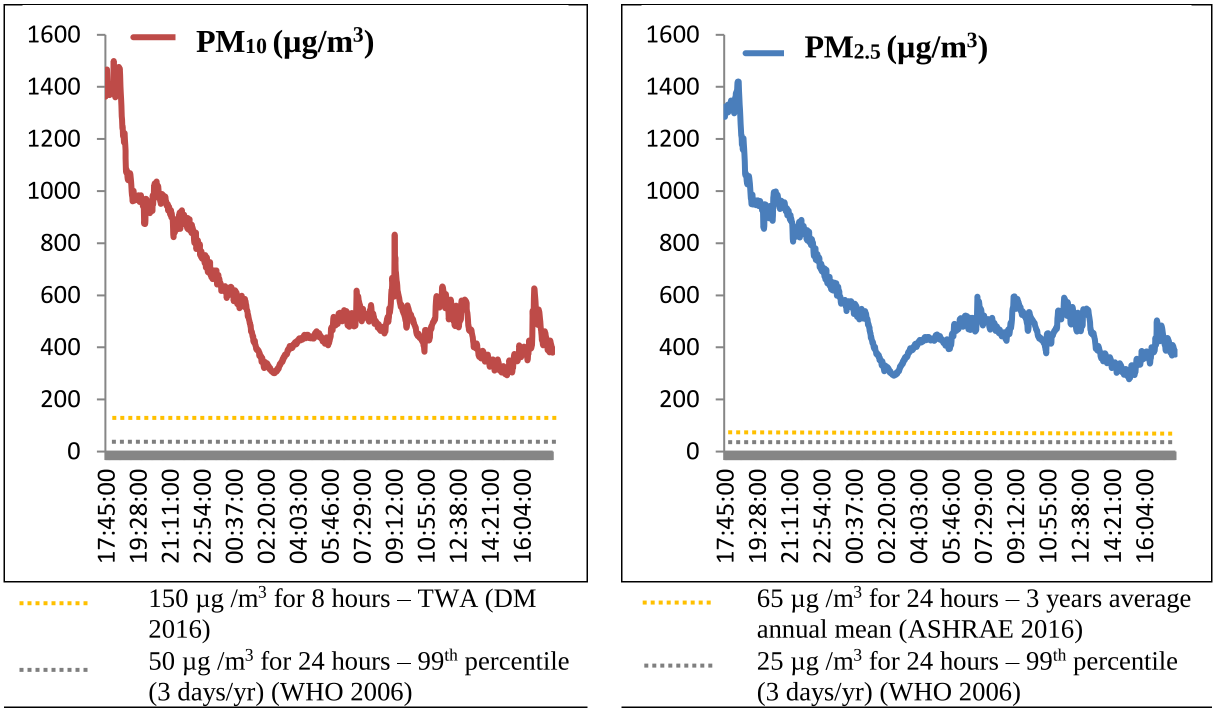


Figure ZZ-95: Compliance of $PM_{10}$ and $PM_{2.5}$ levels with established standards (House 19)

### *House (20)*

Table ZZ-58: Levels of continuously measured variables indoor House (20)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 138.0 | 457.0 | 0.0 | 2.5 | 10.0 | 24.6 | 34.9 |
| **Mean** | 801.1 | 686.8 | 1.2 | 606.8 | 681.7 | 25.5 | 43.6 |
| **Max** | 4330.9 | 899.0 | 8.1 | 1901.6 | 4391.3 | 27.9 | 62.7 |

Table ZZ-59: Spot measured variables in outdoor air of House (20)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 133.4 | 448.0 | 0.7 | 27.8 | 71.7 |

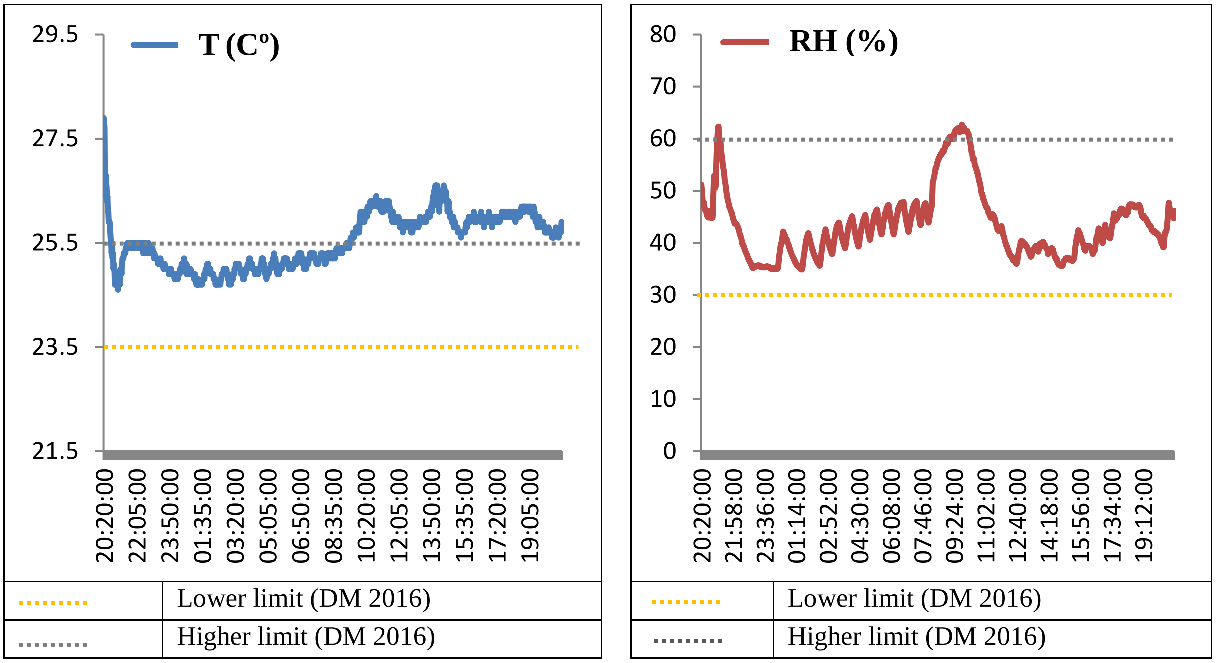


Figure ZZ-96: Continuously measured indoor levels of T and RH in House (20)

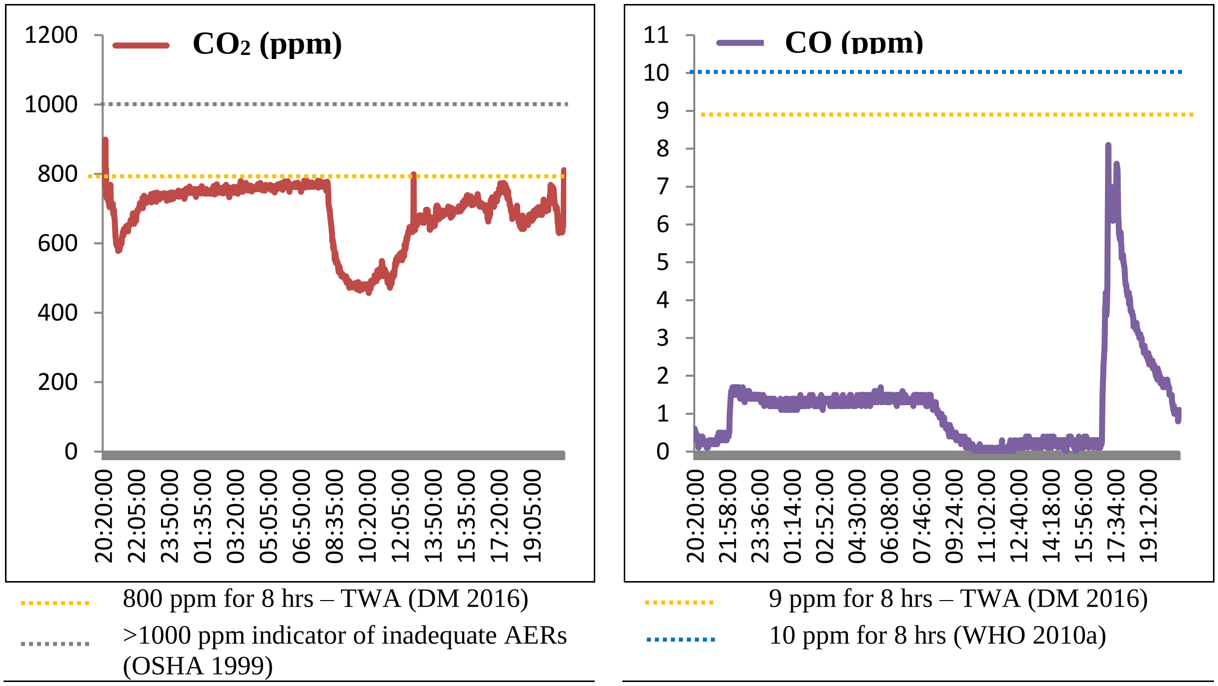


Figure ZZ-97: Compliance of $CO_2$ and CO levels in House (20) with established standards

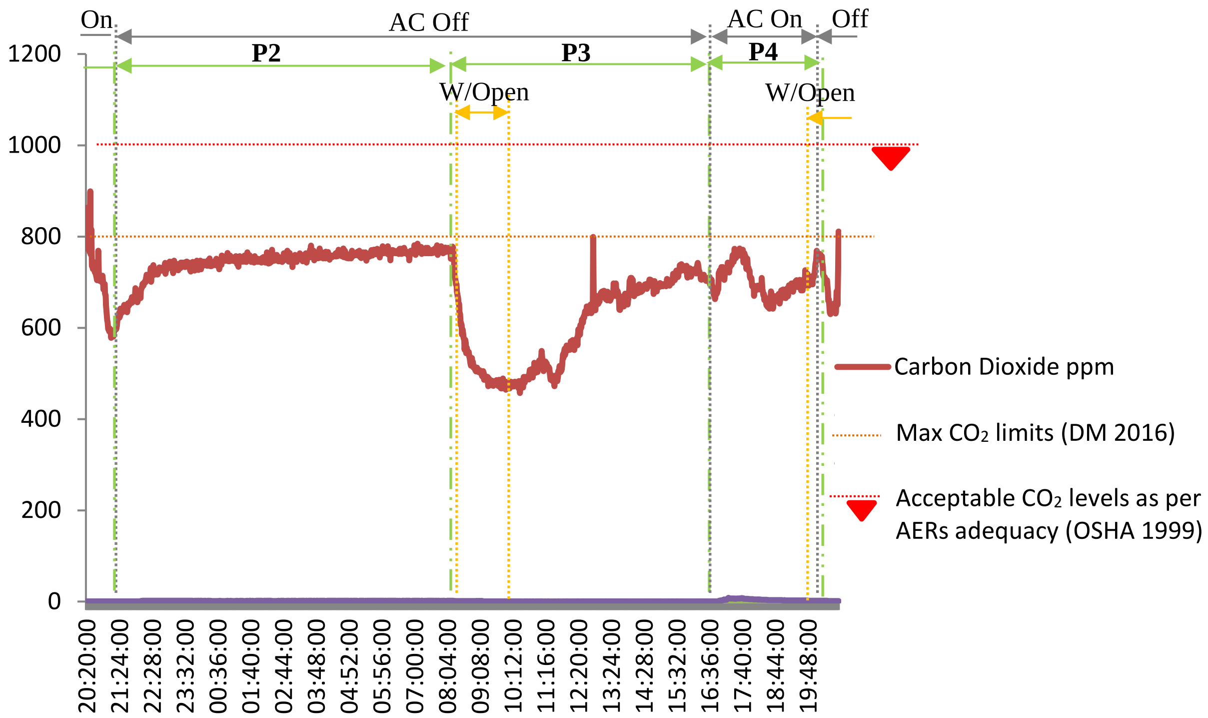


Figure ZZ-98: Occupancy profiles of the living hall projected on $CO_2$ levels (House 20)

Table ZZ-60: Occupancy profiles of the living hall during measurement period (House 20)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 20:20 – 21:12 | 5 | Mechanical | Sitting |
| **P2** | 21:12 – 08:00 | 0 | Natural (Infiltration) | 5 persons in other rooms |
| **P3** | 08:00 – 16:30 | 3 | Natural:<br>08:00 – 08:15 Natural (Infiltration)<br>08:15 – 10:00 Natural (Window)<br>10:00 - 16:30 Natural (Infiltration) | Sitting<br>Daily cleaning<br>Cooking |
| **P4** | 16:30 – 20:15 | 6 | Mixed:<br>16:30 – 20:00 Mechanical<br>20:00 – 20:15 Natural (Infiltration) | Having visitors<br>Sitting |

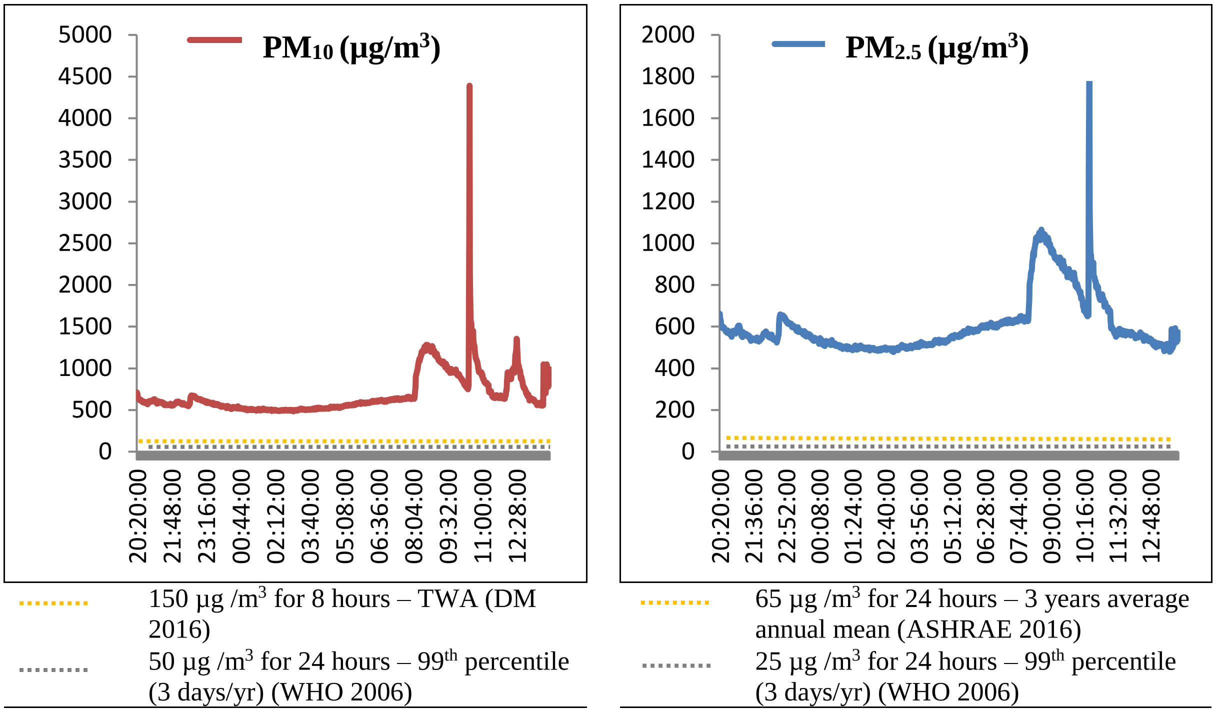


Figure ZZ-99: Compliance of PM$_{10}$ and PM$_{2.5}$ levels with established standards (House 20)

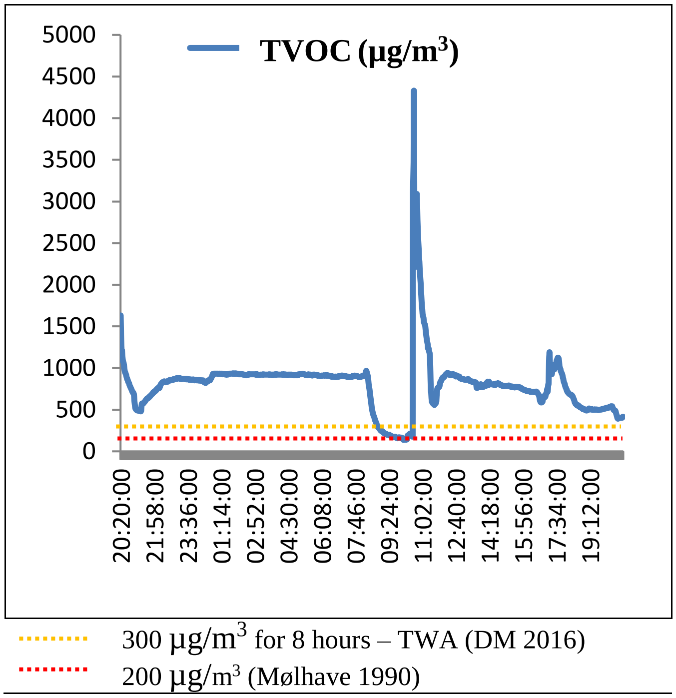


Figure ZZ-100: Compliance of indoor TVOC levels with established standards (House 20)

***House (21)***

Table ZZ-61: Levels of continuously measured variables indoor House (21)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m$^3$)** | **$PM_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 246.1 | 456.0 | 0.0 | 100.6 | 108.7 | 25.5 | 23.4 |
| **Mean** | 505.1 | 703.2 | 0.9 | 386.1 | 460.0 | 29.1 | 34.4 |
| **Max** | 4790.9 | 1299.0 | 4.0 | 1444.2 | 1673.3 | 30.8 | 47.1 |

Table ZZ-62: Spot measured variables in outdoor air of House (21)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 188.6 | 443.0 | 0.3 | 29.7 | 45.7 |

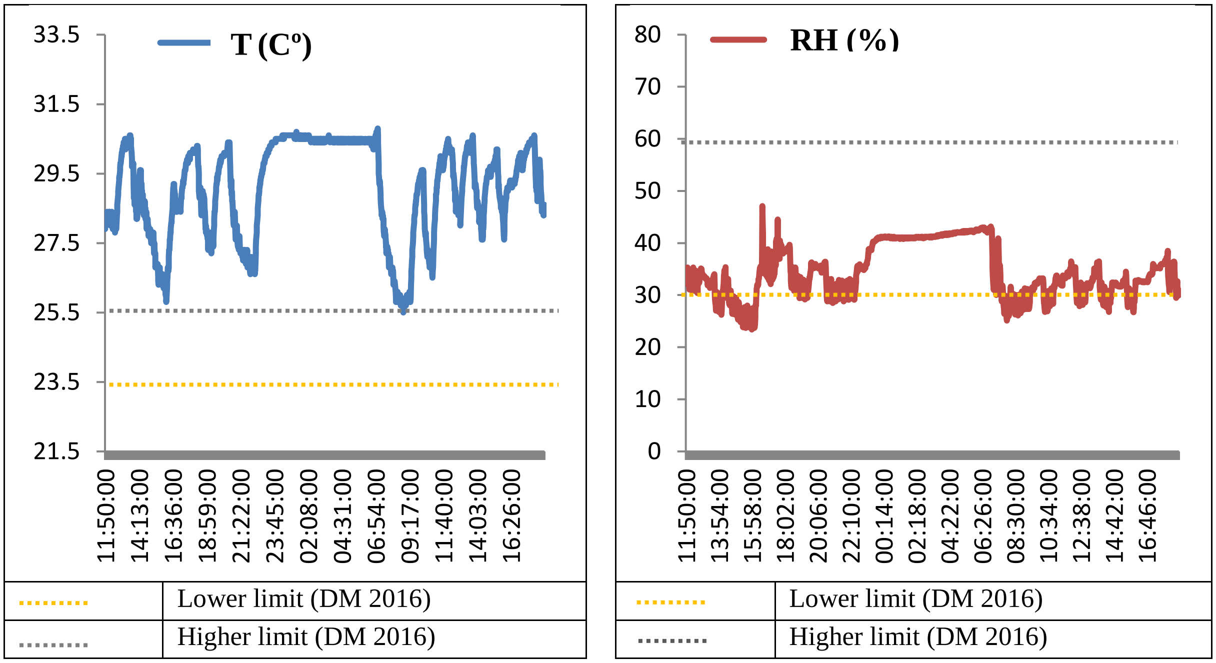


Figure ZZ-101: Continuously measured indoor levels of T and RH in House (21)

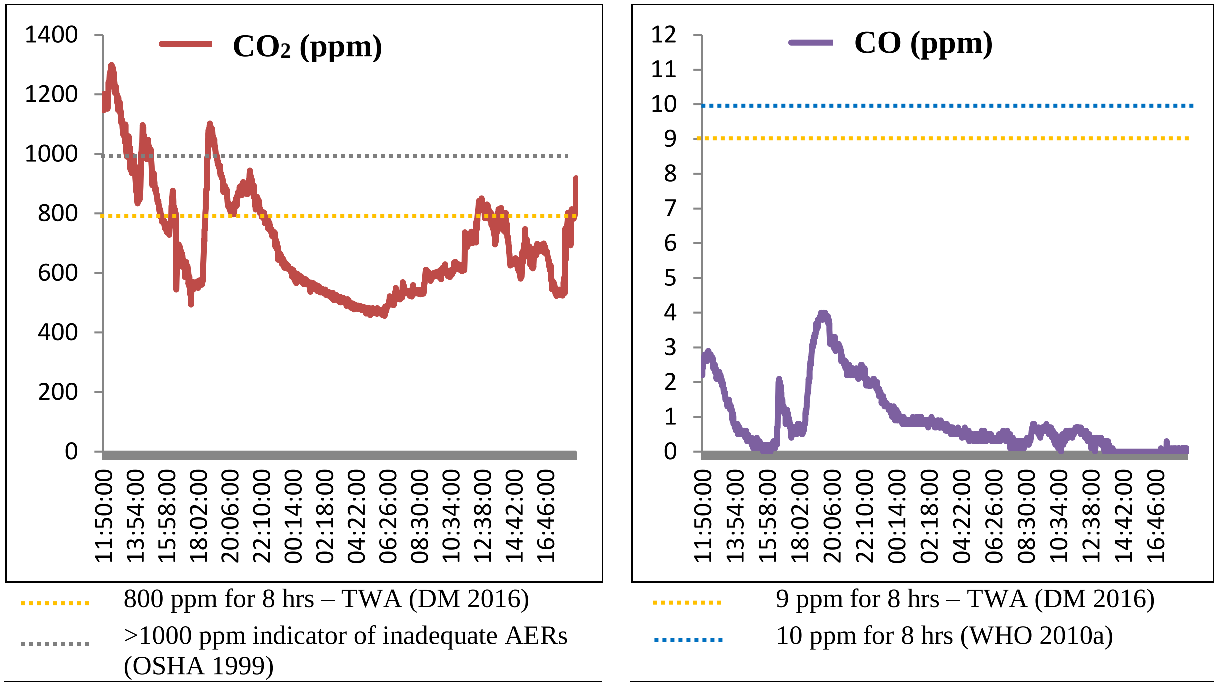


Figure ZZ-102: Compliance of $CO_2$ and CO levels with established standards (House 21)

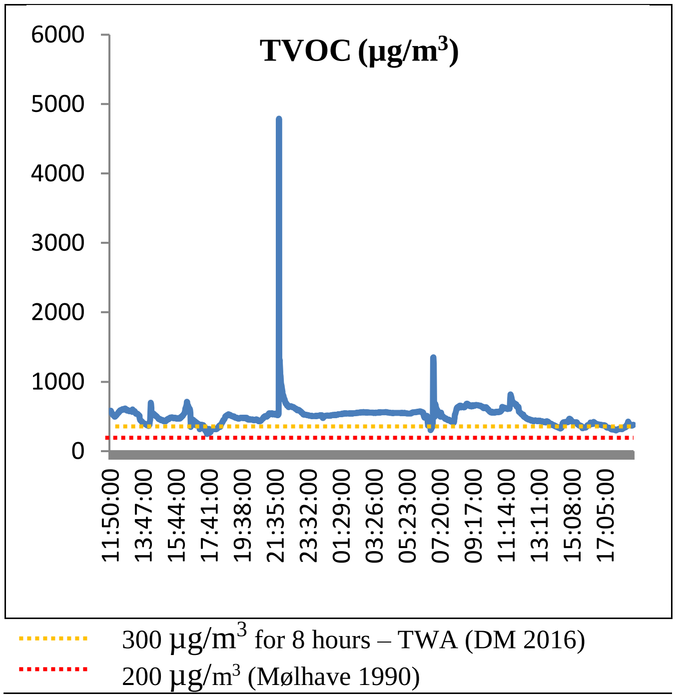


Figure ZZ-103: Compliance of indoor TVOC levels with established standards (House 21)

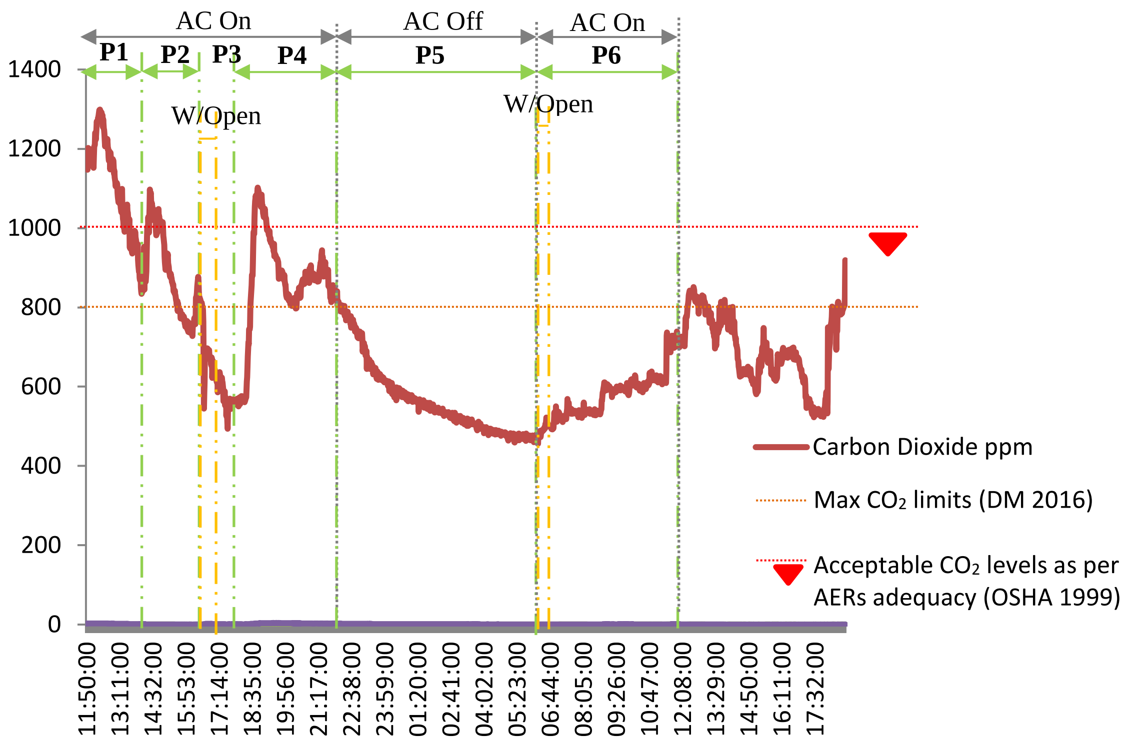


Figure ZZ-104: Occupancy profiles of the living hall projected on $CO_2$ levels (House 21)

Table ZZ-63: Occupancy profiles of the living hall during measurement period (House 21)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 11:50 – 14:00 | 6 | Mechanical | Sitting<br>Daily cleaning<br>Taking breakfast<br>Taking lunch<br>Cooking |
| **P2** | 14:00 – 16:30 | 9 | Mechanical | |
| **P3** | 16:30 – 18:00 | 1 | Mixed:<br>16:30 – 18:00 Mechanical<br>16:30 – 17:00 Natural (Window) | |
| **P4** | 18:00 – 22:00 | 8 | Mechanical | |
| **P5** | 22:00 – 06:00 | 0 | Natural (Infiltration) | 9 occupants in other rooms |
| **P6** | 06:00 – 12:00 | 2 | Mechanical | Sitting, dinner |

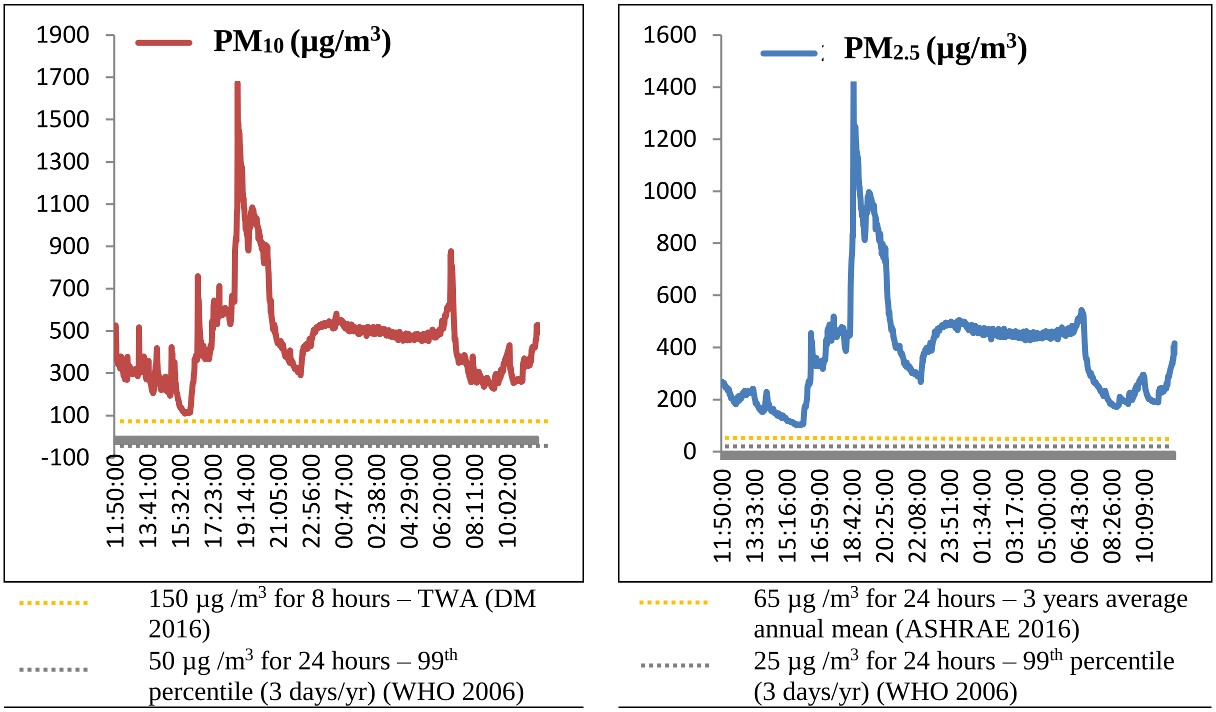


Figure ZZ-105: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 21)

### *House (22)*

Table ZZ-64: Levels of continuously measured variables indoor House (22)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 303.6 | 633.0 | 0.0 | 164.6 | 175.6 | 23.6 | 34.2 |
| **Mean** | 408.3 | 883.1 | 1.0 | 295.5 | 347.5 | 27.0 | 43.3 |
| **Max** | 784.3 | 1386.0 | 2.6 | 666.2 | 916.2 | 28.0 | 48.1 |

Table ZZ-65: Spot measured variables in outdoor air of House (22)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 276.0 | 507.0 | 0.8 | 29.4 | 46.4 |

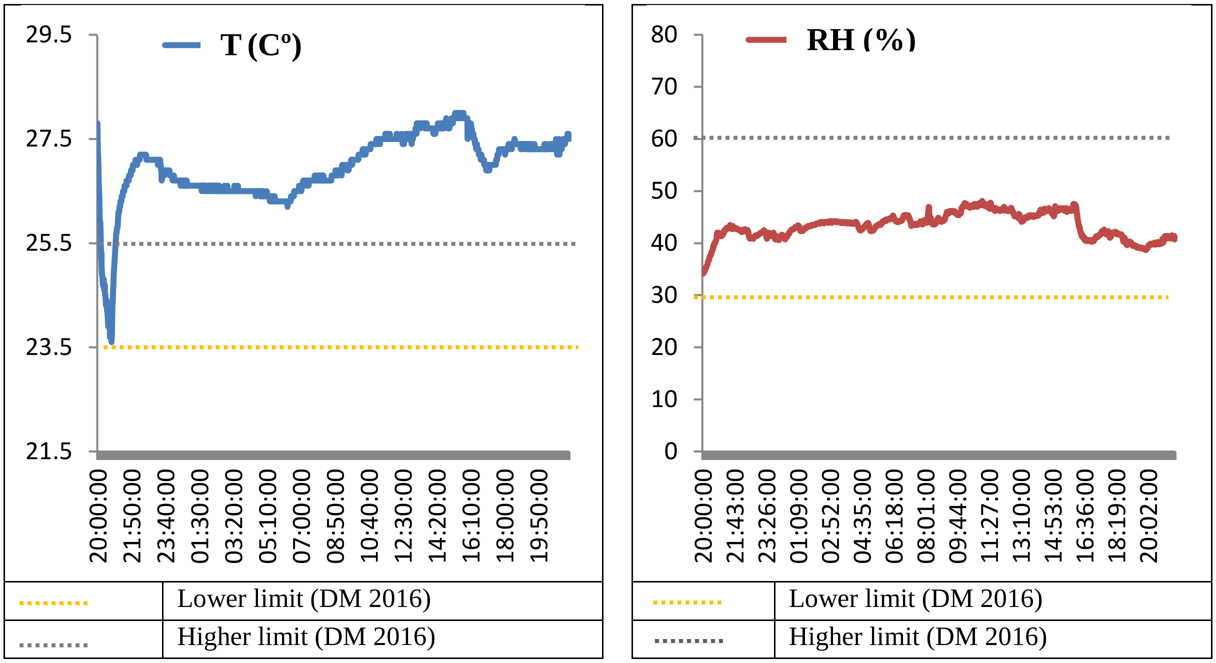


Figure ZZ-106: Continuously measured indoor levels of T and RH in House (22)

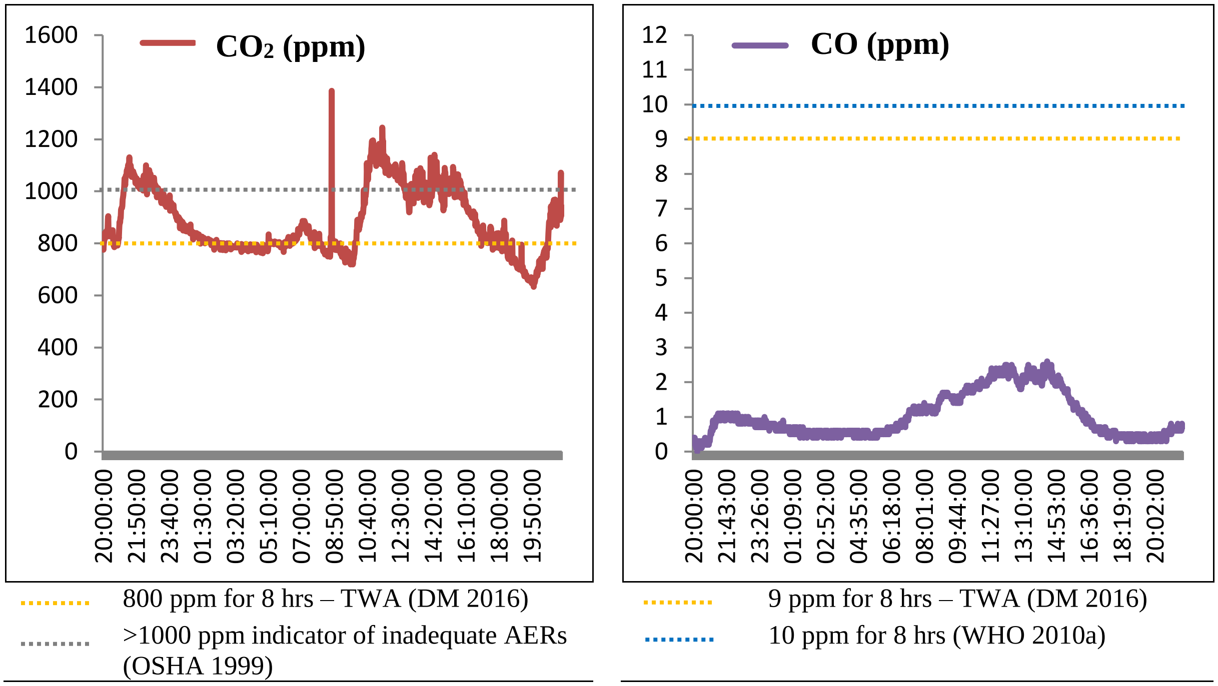


Figure ZZ-107: Compliance of $CO_2$ and CO levels with established standards (House 22)

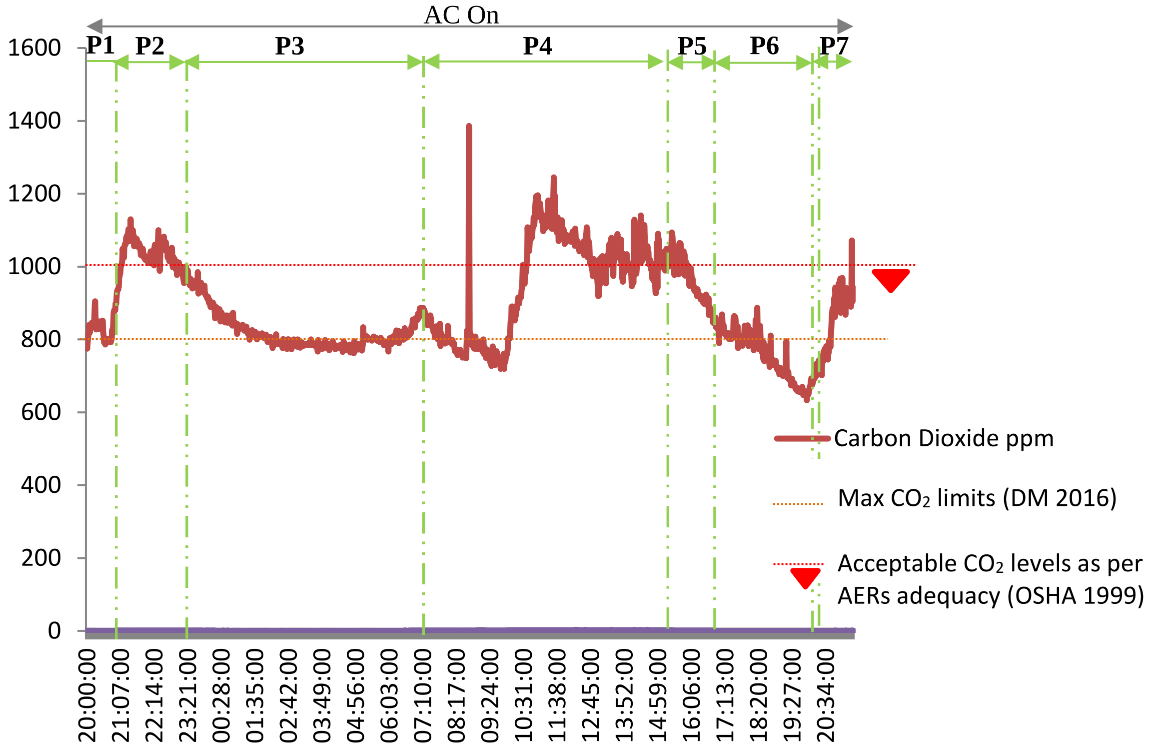
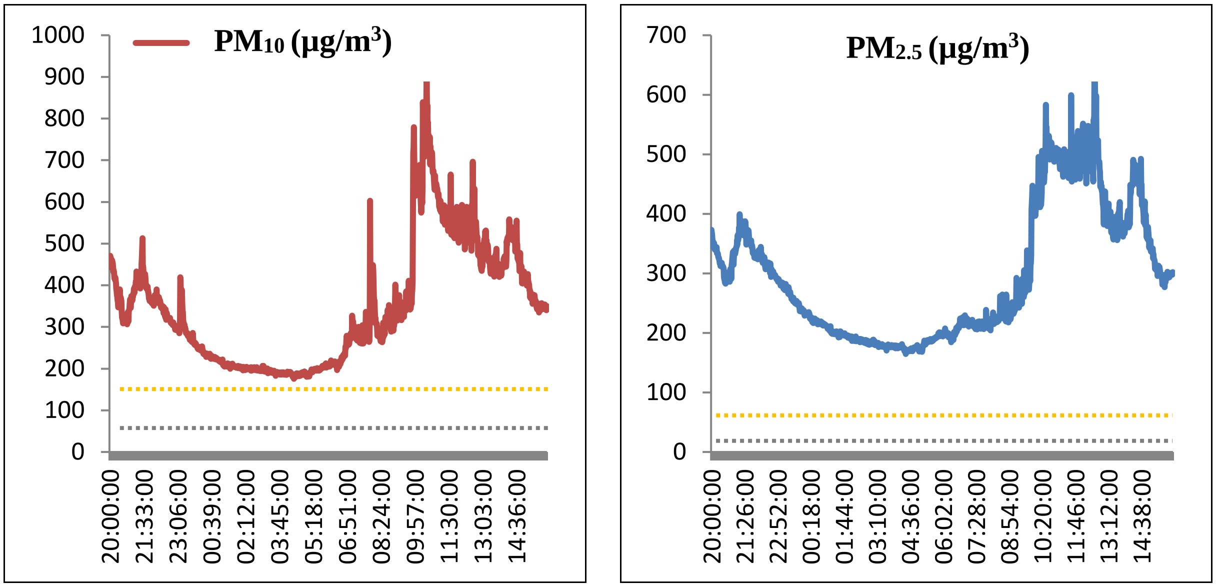


Figure ZZ-108: Occupancy profiles of the living hall projected on $CO_2$ levels (House 22)

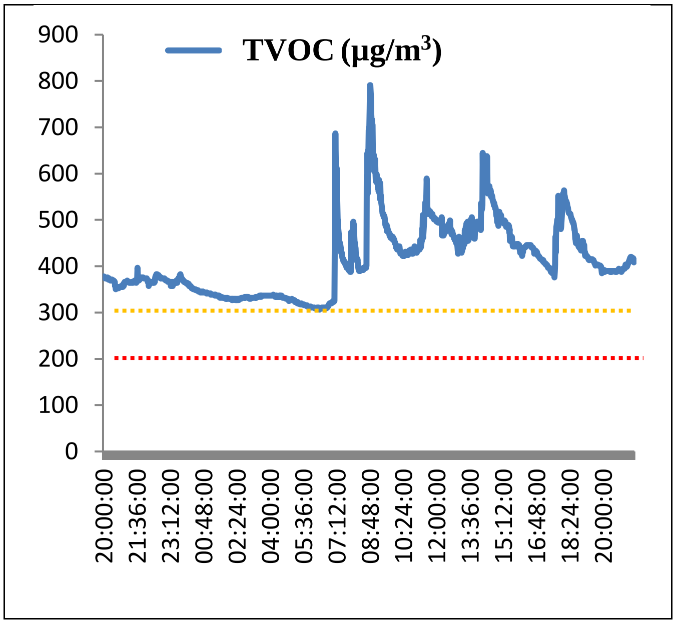
Table ZZ-66: Occupancy profiles of the living hall during measurement period (House 22)

| **Profile** | **Time** | **Occupants** | **System** | **Activities** |
|---|---|---|---|---|
| **P1** | 20:00 – 20:50 | 7 | Mechanical | Sitting |
| **P2** | 20:50 – 23:20 | 6 | ,, ,, ,, ,, ,, | Sitting, dinner |
| **P3** | 23:20 – 07:15 | 0 | ,, ,, ,, ,, ,, | 7 persons in other rooms |
| **P4** | 07:15 – 15:15 | 2 | ,, ,, ,, ,, ,, | Sitting, daily cleaning, breakfast, Cooking |
| **P5** | 15:15 – 17:00 | 5 | ,, ,, ,, ,, ,, | Sitting, lunch |
| **P6** | 17:00 – 20:00 | 4 | ,, ,, ,, ,, ,, | Sitting |
| **P7** | 20:00 – 21:30 | 7 | ,, ,, ,, ,, ,, | Sitting, dinner |



| | | | |
|---|---|---|---|
| ……… | 150 µg /m$^3$ for 8 hours – TWA (DM 2016) | ……… | 65 µg /m$^3$ for 24 hours – 3 years average annual mean (ASHRAE 2016) |
| ……… | 50 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) | ……… | 25 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure ZZ-109: Compliance of PM$_{10}$ & PM$_{2.5}$ levels with established standards (House 22)



| | |
|---|---|
| ……… | 300 µg/m$^3$ for 8 hours – TWA (DM 2016) |
| ……… | 200 µg/m$^3$ (Mølhave 1990) |

Figure ZZ-110: Compliance of indoor TVOC levels with established standards (House 22)

## *House (23)*

Table ZZ-67: Levels of continuously measured variables indoor House (23)

| | **TVOC ($\mu g/m^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ ($\mu g/m^3$)** | **$PM_{10}$ ($\mu g/m^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 756.7 | 785.0 | 1.9 | 395.9 | 398.3 | 25.4 | 58.2 |
| **Mean** | 991.9 | 964.9 | 3.0 | 680.1 | 698.0 | 25.6 | 60.3 |
| **Max** | 1322.5 | 3010.0 | 5.2 | 1418.1 | 1464.1 | 26.2 | 62.9 |

Table ZZ-68: Spot measured variables in outdoor air of House (23)

| | **TVOC ($\mu g/m^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 581.9 | 602.0 | 1.8 | 24.6 | 70.1 |

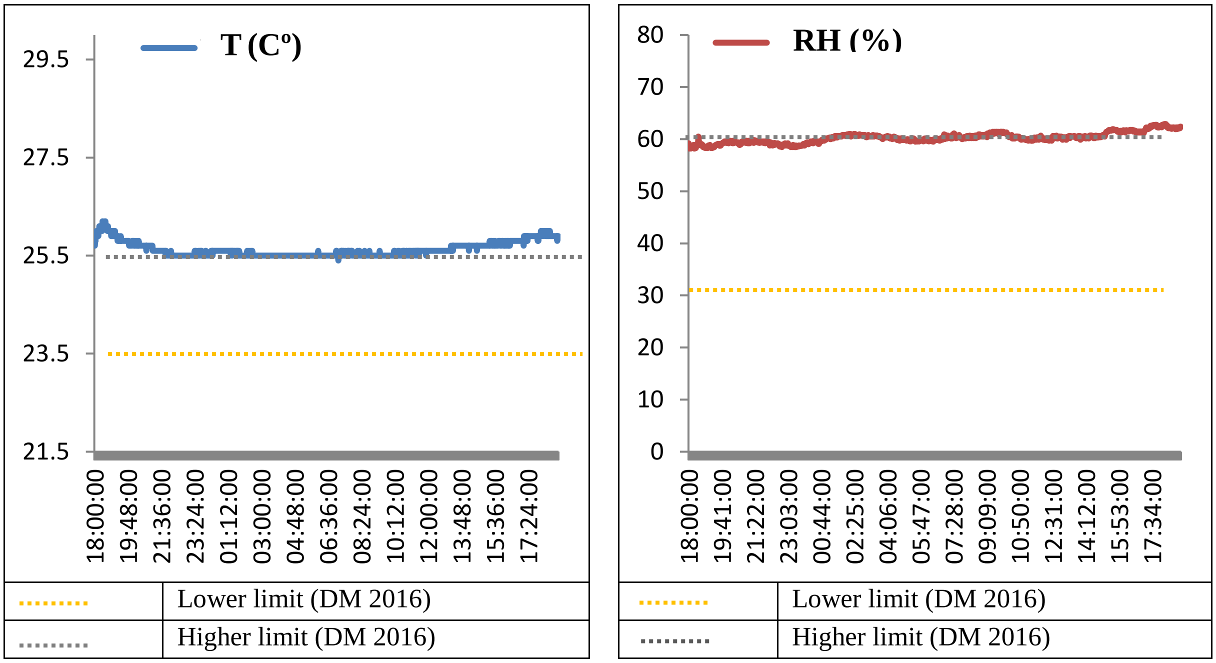


Figure ZZ-111: Continuously measured indoor levels of T and RH in House (23)

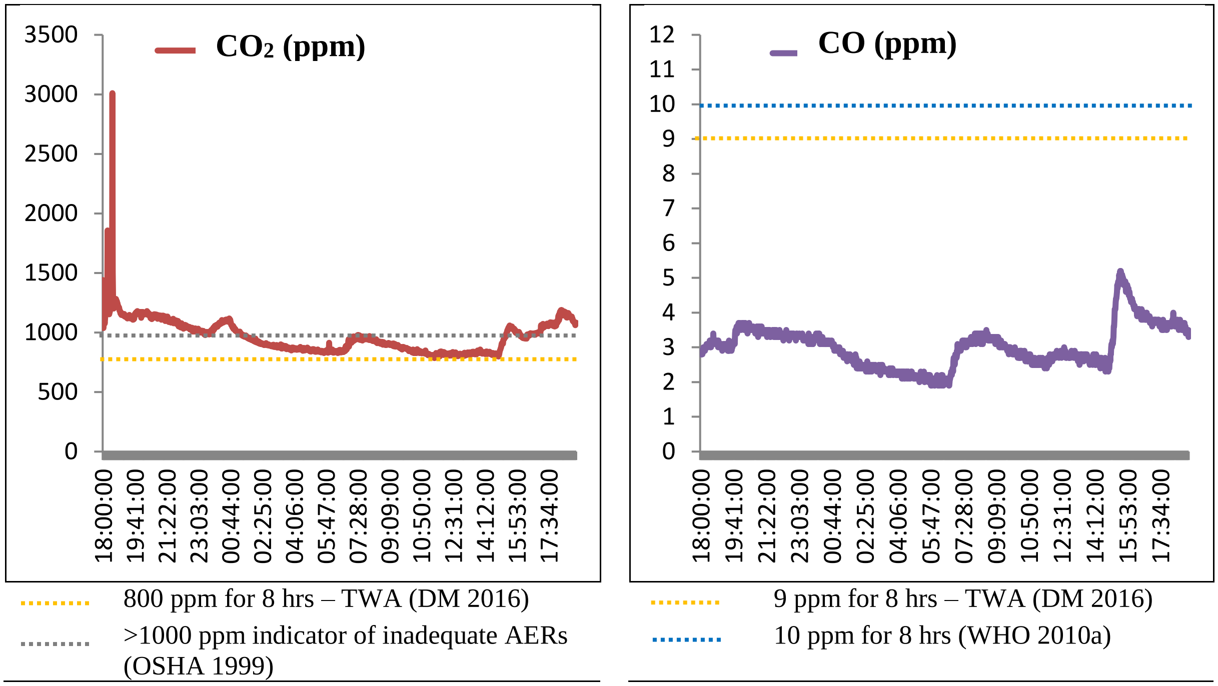


Figure ZZ-112: Compliance of $CO_2$ and CO levels with established standards (House 23)

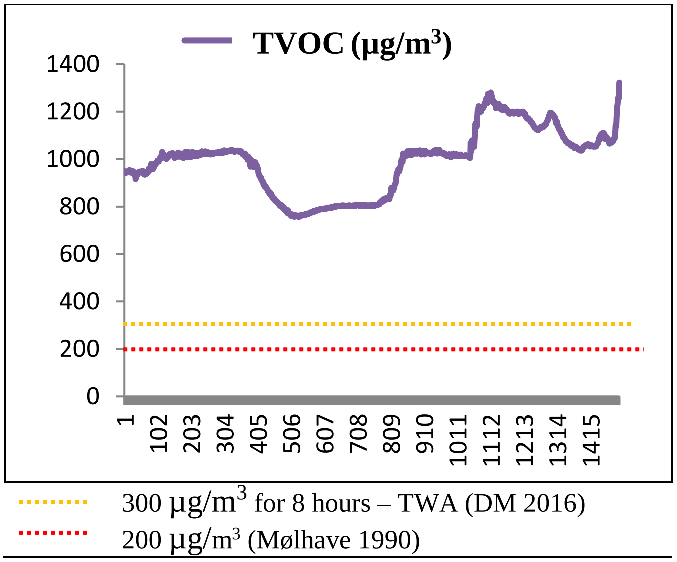


Figure ZZ-113: Compliance of indoor TVOC levels with established standards (House 23)

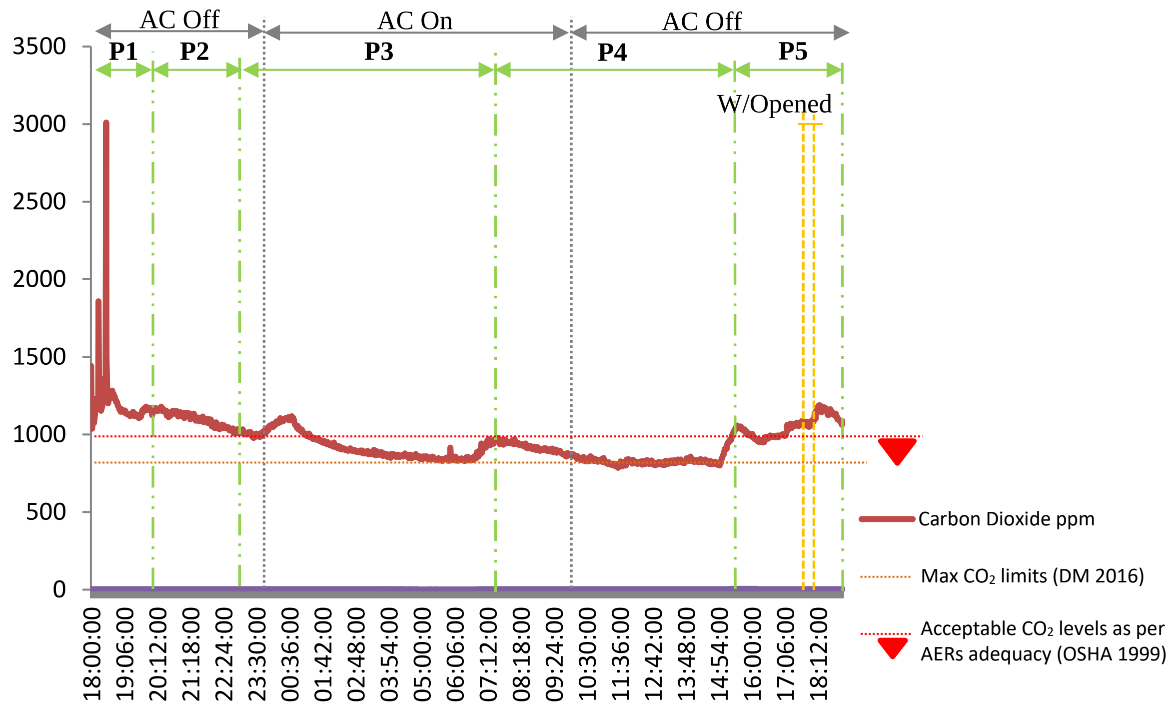
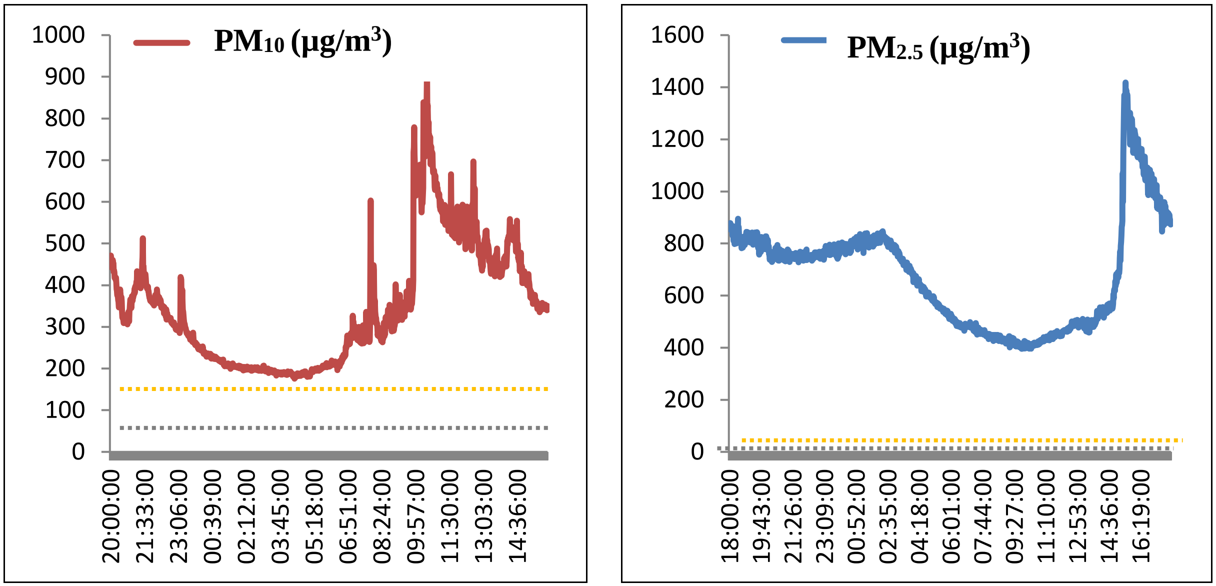


Figure ZZ-114: Occupancy profiles of the living hall projected on $CO_2$ levels (House 23)

Table ZZ-69: Occupancy profiles of the living hall during measurement period (House 23)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 18:00 – 19:54 | 3 | Natural (Infiltration) | Sitting |
| **P2** | 19:54 – 23:00 | 2 | Natural (Infiltration) | Sitting, dinner |
| **P3** | 23:00 – 07:20 | 0 | Mechanical | 3 persons in other rooms |
| **P4** | 07:20 – 15:30 | 2 | Mixed:<br>07:20 – 09:50 Mechanical<br>09:50 – 15:30 Natural (Infiltration) | Sitting, breakfast |
| **P5** | 15:30 – 20:00 | 3 | Natural:<br>15:30 – 17:30 Infiltration<br>17:30 – 18:00 Infiltration & Window<br>18:00 – 20:00 Infiltration | Sitting, cooking, lunch |



⋯ 150 µg /m³ for 8 hours – TWA (DM 2016)

⋯ 50 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006)

⋯ 65 µg /m³ for 24 hours – 3 years average annual mean (ASHRAE 2016)

⋯ 25 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006)

Figure ZZ-115: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 23)

***House (24)***

Table ZZ-70: Levels of continuously measured variables indoor House (24)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 841.8 | 7477.0 | 2.1 | 192.9 | 195.9 | 24.3 | 48.3 |
| **Mean** | 1930.9 | 7921.8 | 4.4 | 419.7 | 434.4 | 26.8 | 58.4 |
| **Max** | 2424.2 | 8400.0 | 6.6 | 1360.1 | 1400.2 | 27.8 | 63.5 |

Table ZZ-71: Spot measured variables in outdoor air of House (24)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 1306.4 | 6829.0 | 2.2 | 24.9 | 57.7 |

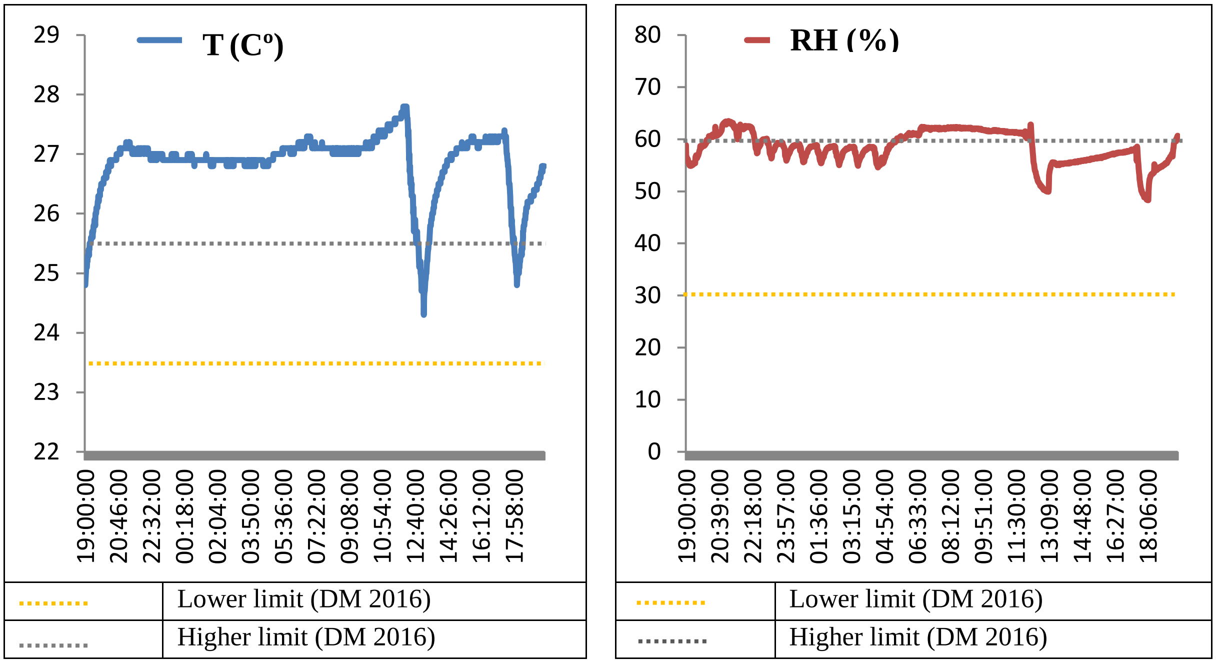


Figure ZZ-116: Continuously measured indoor levels of T and RH in House (24)

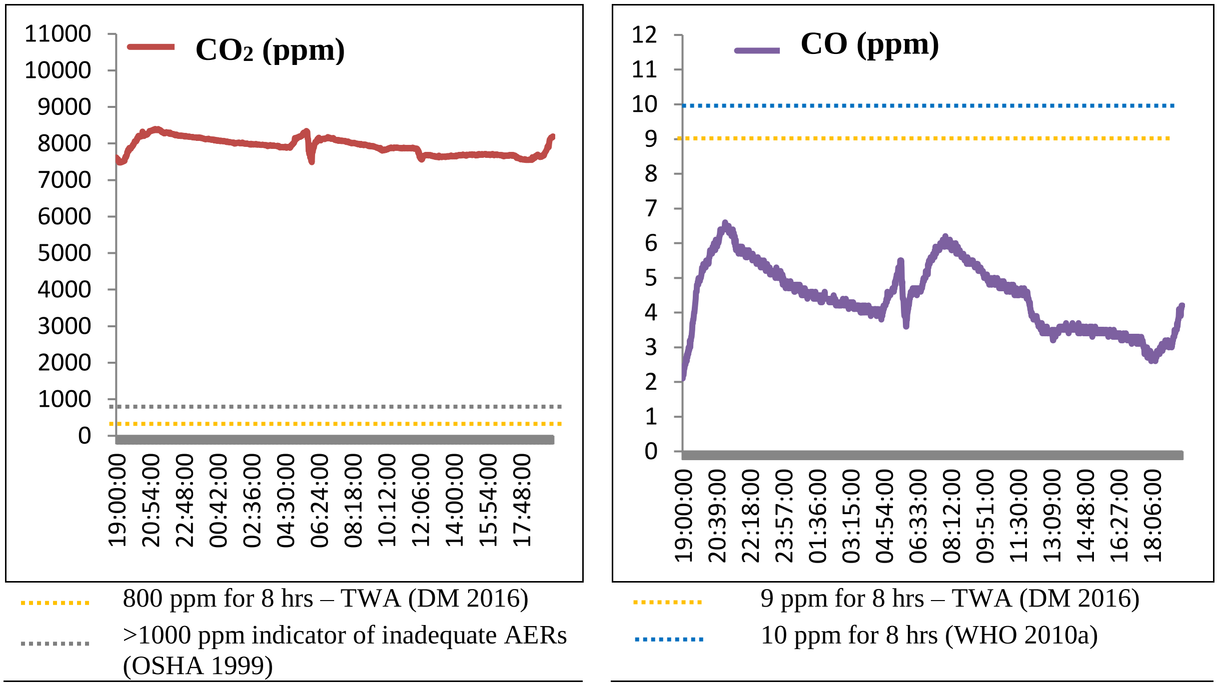


Figure ZZ-117: Compliance of $CO_2$ and CO levels with established standards (House 24)

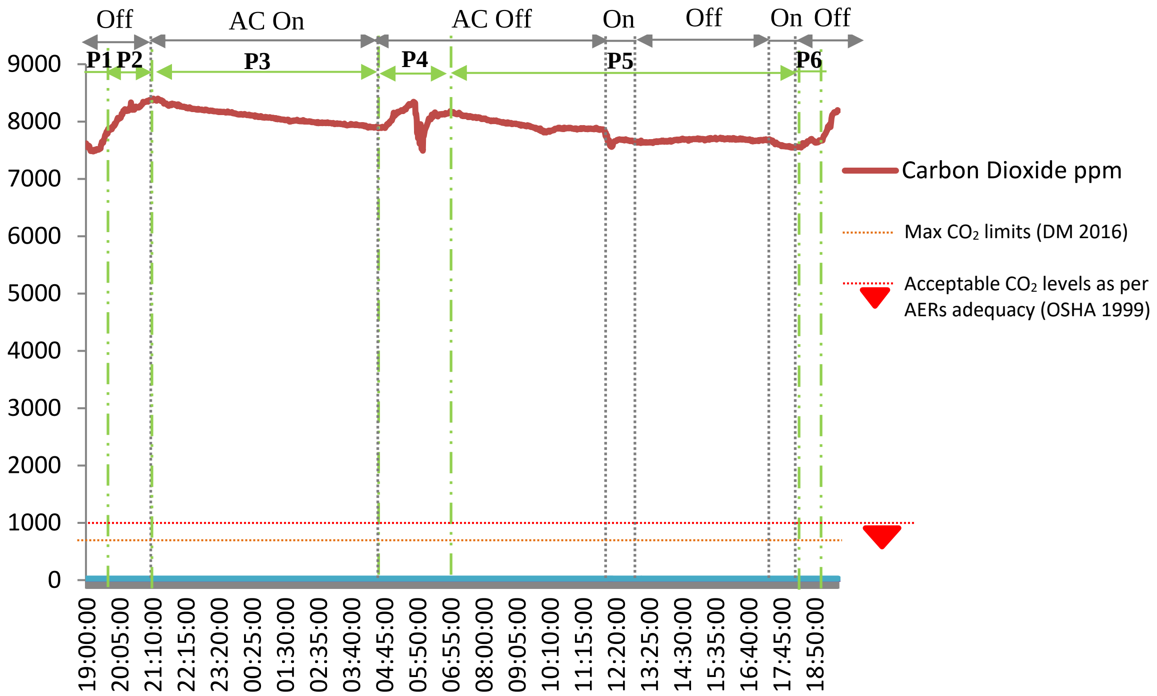
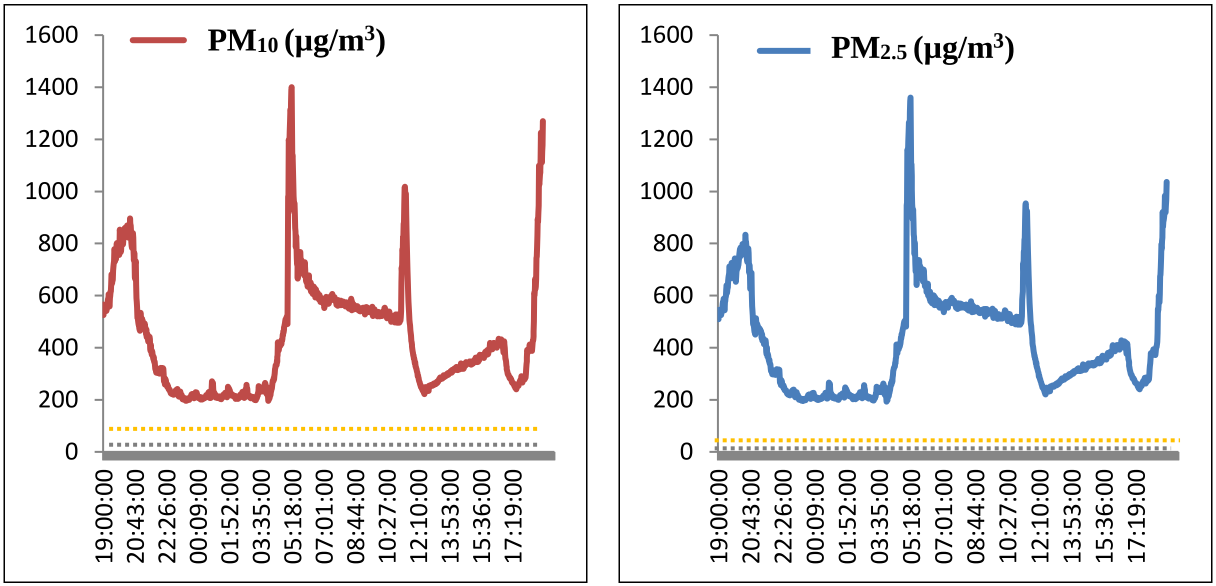


Figure ZZ-118: Occupancy profiles of the living hall projected on $CO_2$ levels (House 24)

Table ZZ-72: Occupancy profiles of the living hall during measurement period (House 24)

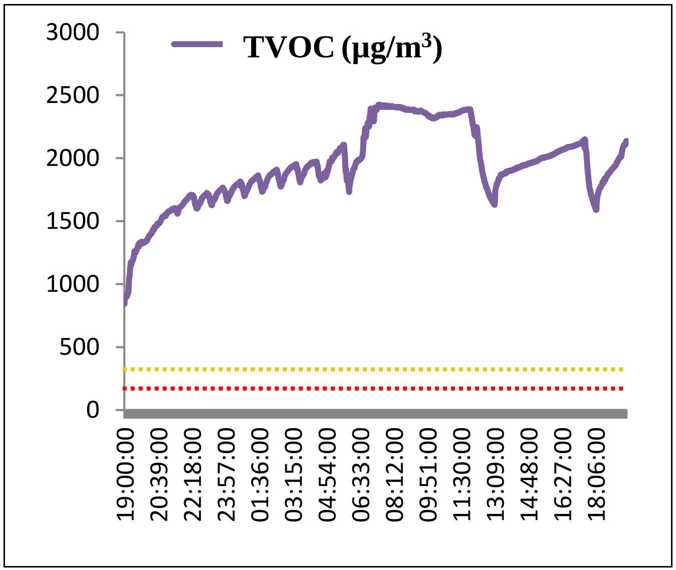
| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 19:00 – 19:30 | 2 | Natural (Infiltration) | Sitting |
| **P2** | 19:30 – 21:08 | 4 | Natural (Infiltration) | Sitting/ Dinner |
| **P3** | 21:08 – 04:30 | 0 | Mixed:<br>19:30 – 21:06 Natural (Infiltration)<br>21:06 – 04:30 Mechanical | 4 persons in other rooms |
| **P4** | 04:30 – 06:50 | 4 | Natural (Infiltration) | Sitting |
| **P5** | 06:50 – 18:14 | 2 | Mixed:<br>06:50 – 12:03 Mechanical<br>12:03 – 12:57 Natural (Infiltration)<br>12:57 – 18:14 Mechanical | Daily cleaning<br>Sitting<br>Breakfast<br>Lunch |
| **P6** | 18:14 – 19:00 | 4 | Mechanical | Sitting/ Dinner |



| | |
|---|---|
| ⋯⋯ | 150 µg /m$^3$ for 8 hours – TWA (DM 2016) |
| ⋯⋯ | 50 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

| | |
|---|---|
| ⋯⋯ | 65 µg /m$^3$ for 24 hours – 3 years average annual mean (ASHRAE 2016) |
| ⋯⋯ | 25 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure ZZ-119: Compliance of PM$_{10}$ & PM$_{2.5}$ levels with established standards (House 24)



| | |
|---|---|
| ⋯⋯ | 300 µg/m$^3$ for 8 hours – TWA (DM 2016) |
| ⋯⋯ | 200 µg/m$^3$ (Mølhave 1990) |

Figure ZZ-120: Compliance of indoor TVOC levels with established standards (House 24)

## *House (25)*

Table ZZ-73: Levels of continuously measured variables indoor House (25)

| | **TVOC (μg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (μg/m$^3$)** | **$PM_{10}$ (μg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 253.0 | 849.0 | 0.3 | 547.0 | 558.2 | 23.9 | 37.7 |
| **Mean** | 535.0 | 1170.8 | 1.7 | 762.4 | 777.5 | 24.8 | 43.4 |
| **Max** | 8774.5 | 1818.0 | 10.8 | 1341.7 | 1407.7 | 25.9 | 53.6 |

Table ZZ-74: Spot measured variables in outdoor air of House (25)

| | **TVOC (μg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 276.0 | 538.0 | 3.0 | 25.8 | 50.1 |

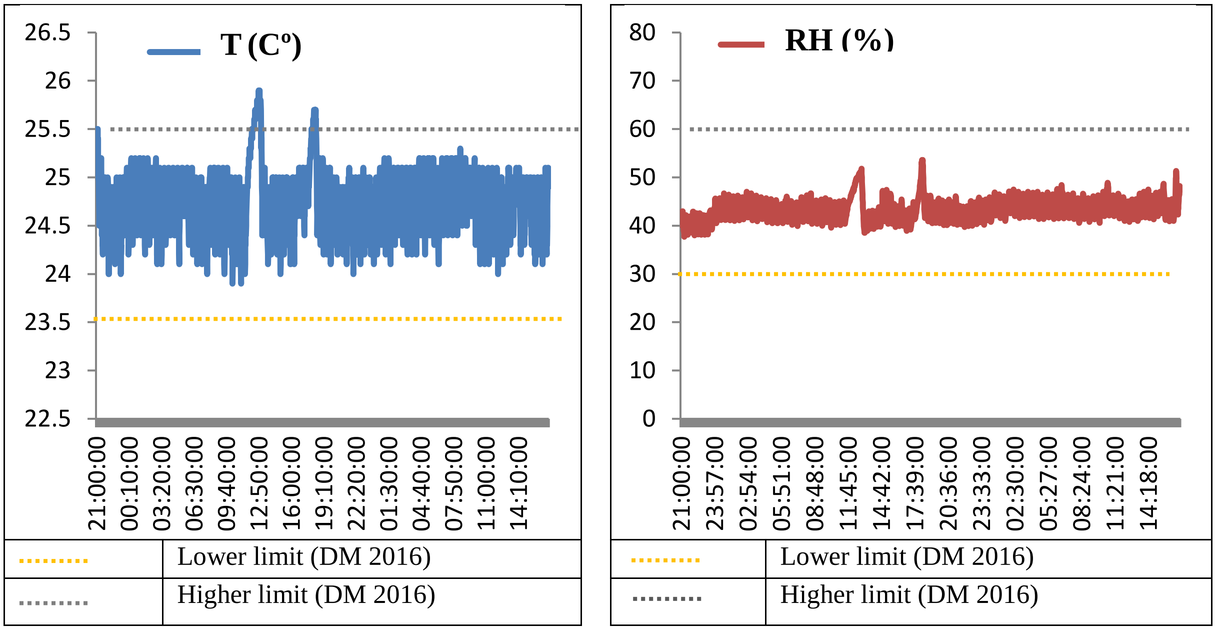


Figure ZZ-121: Continuously measured indoor levels of T and RH in House (25)

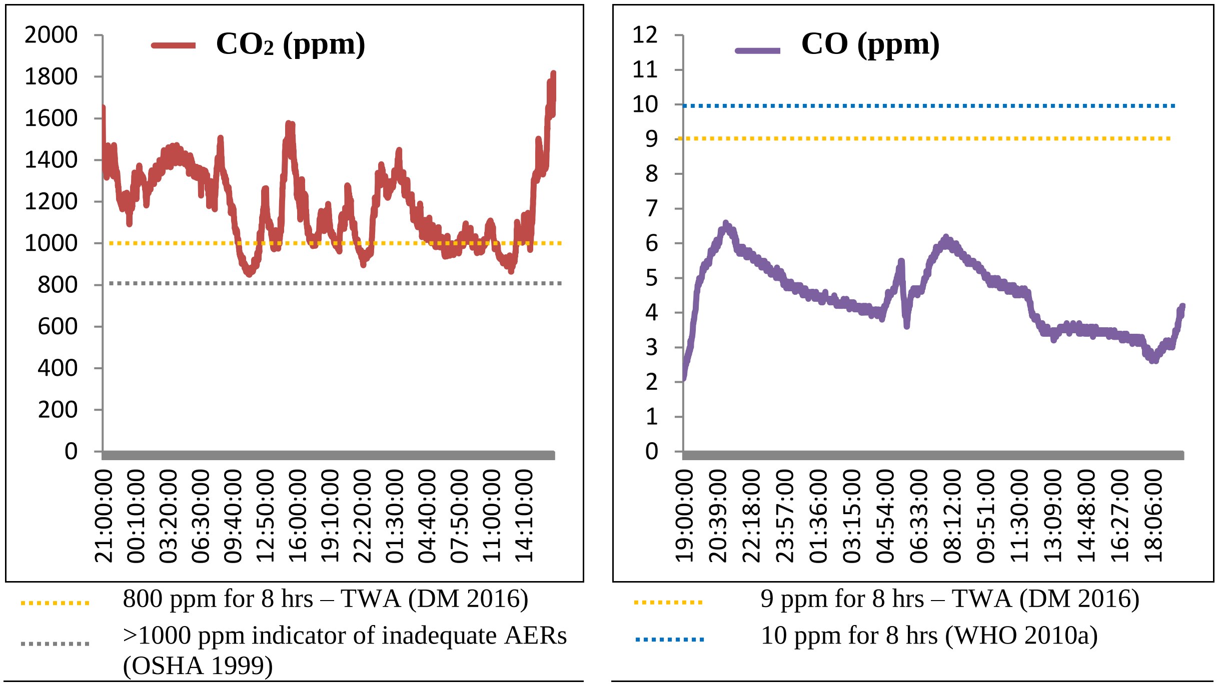


Figure ZZ-122: Compliance of $CO_2$ and CO levels with established standards (House 25)

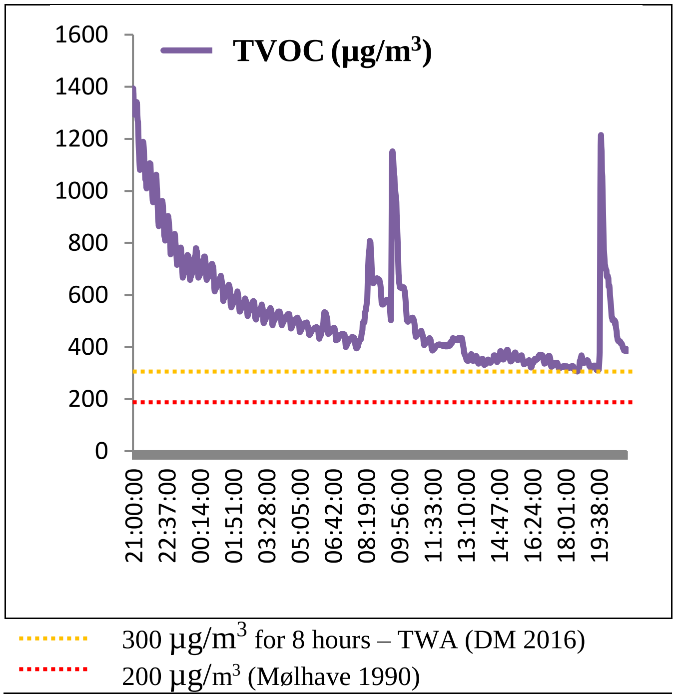


Figure ZZ-123: Compliance of indoor TVOC levels with established standards (House 25)

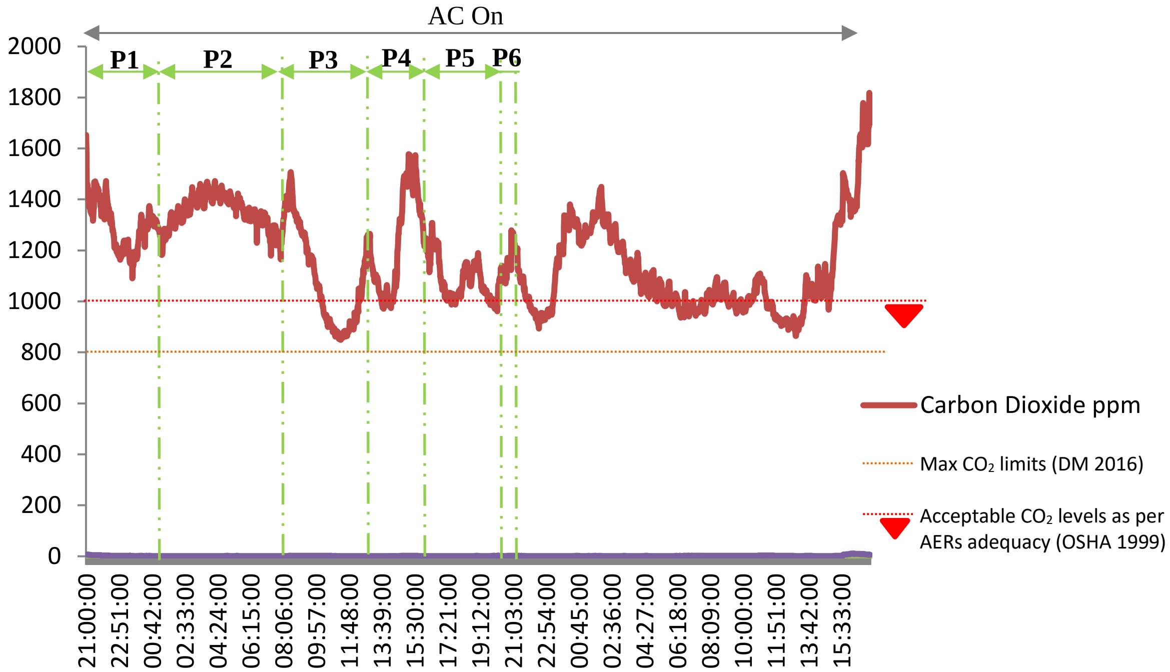
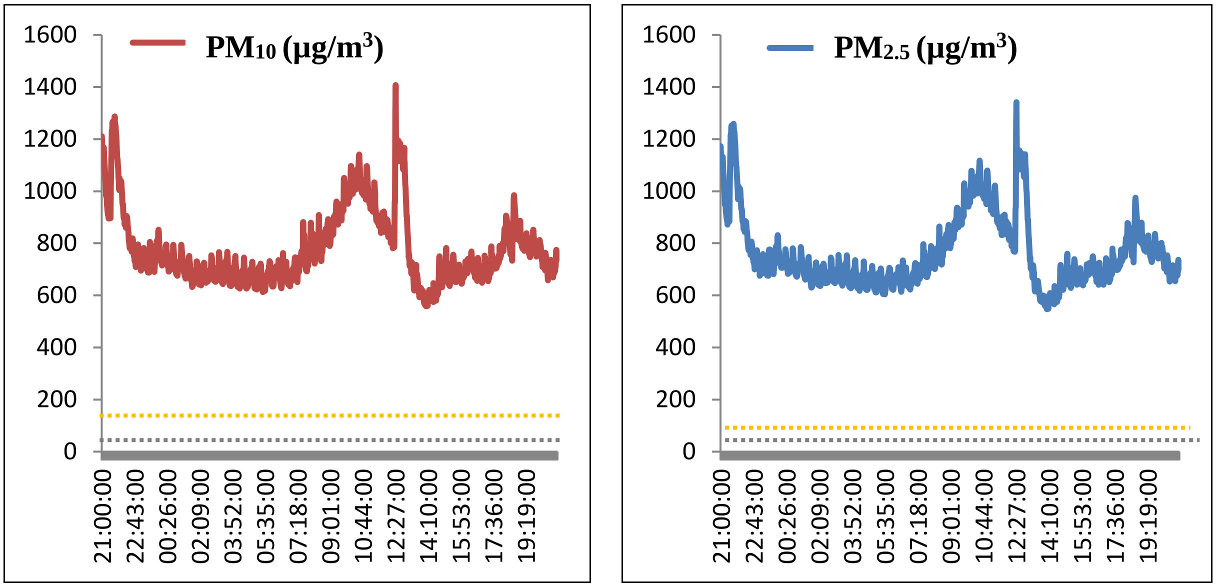


Figure ZZ-124: Occupancy profiles of the living hall projected on $CO_2$ levels (House 25)

Table ZZ-75: Occupancy profiles of the living hall during measurement period (House 25)

| **Profile** | **Time** | **Occupants** | **System** | **Activities** |
|---|---|---|---|---|
| **P1** | 21:00 – 24:00 | 8 | Mechanical | Sitting, dinner |
| **P2** | 24:00 – 08:00 | 1 | ,, ,, ,, ,, | Sleeping, 7 occupants in other rooms |
| **P3** | 08:00 – 13:00 | 6 | ,, ,, ,, ,, | Sitting, cooking in kitchen |
| **P4** | 13:00 – 16:00 | 7 | ,, ,, ,, ,, | Sitting, lunch |
| **P5** | 16:00 – 20:30 | 6 | ,, ,, ,, ,, | Sitting |
| **P6** | 20:30 – 21:00 | 8 | ,, ,, ,, ,, | Sitting |



| | | | |
|---|---|---|---|
| ⋯⋯ | 150 µg /m³ for 8 hours – TWA (DM 2016) | ⋯⋯ | 65 µg /m³ for 24 hours – 3 years average annual mean (ASHRAE 2016) |
| ⋯⋯ | 50 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) | ⋯⋯ | 25 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure ZZ-125: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 25)

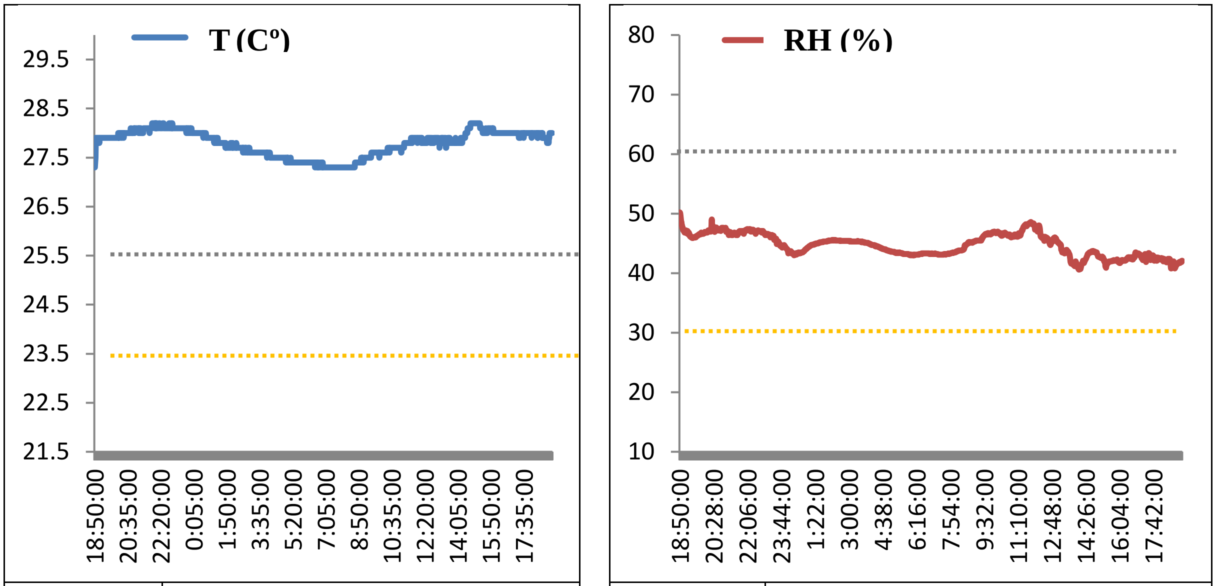
### *House (26)*

Table ZZ-76: Levels of continuously measured variables indoor House (26)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 121.9 | 516.0 | 0.2 | 148.3 | 228.7 | 27.3 | 40.6 |
| **Mean** | 172.7 | 629.9 | 0.9 | 296.1 | 411.5 | 27.7 | 44.6 |
| **Max** | 621.0 | 1007.0 | 1.7 | 1581.5 | 1834.4 | 28.2 | 50.2 |

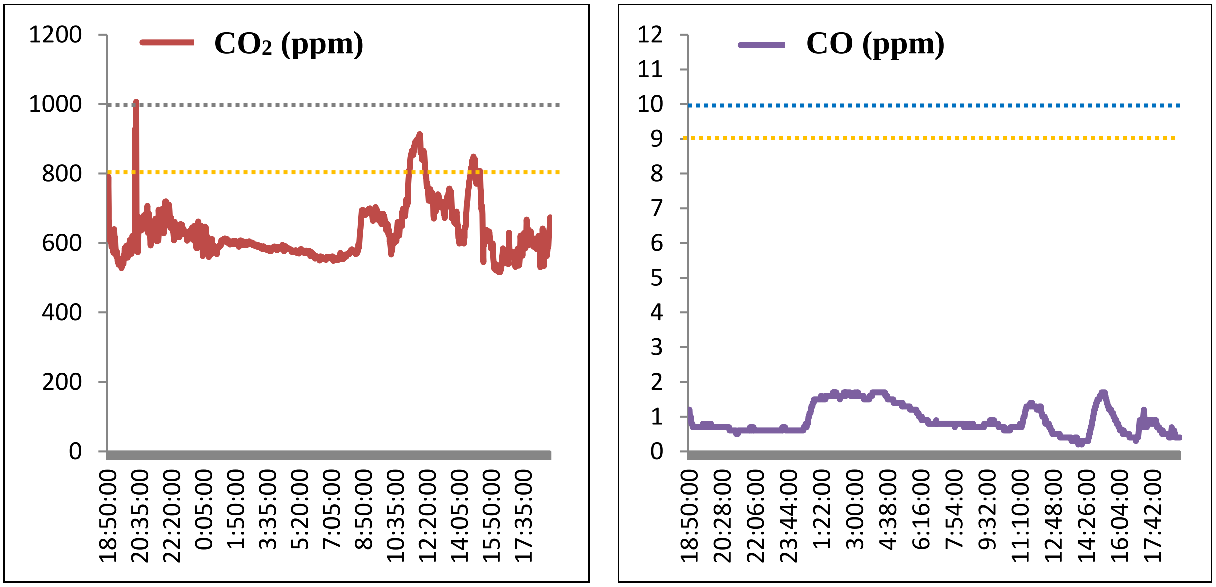
Table ZZ-77: Spot measured variables in outdoor air of House (26)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 142.6 | 513.0 | 0.6 | 26.2 | 40.1 |



| | | | |
|---|---|---|---|
| ········· | Lower limit (DM 2016) | ········· | Lower limit (DM 2016) |
| ········· | Higher limit (DM 2016) | ········· | Higher limit (DM 2016) |

Figure ZZ-126: Continuously measured indoor levels of T and RH in House (26)



| | | | |
|---|---|---|---|
| ········· | 800 ppm for 8 hrs – TWA (DM 2016) | ········· | 9 ppm for 8 hrs – TWA (DM 2016) |
| ········· | >1000 ppm indicator of inadequate AERs (OSHA 1999) | ········· | 10 ppm for 8 hrs (WHO 2010a) |

Figure ZZ-127: Compliance of $CO_2$ and CO levels with established standards (House 26)

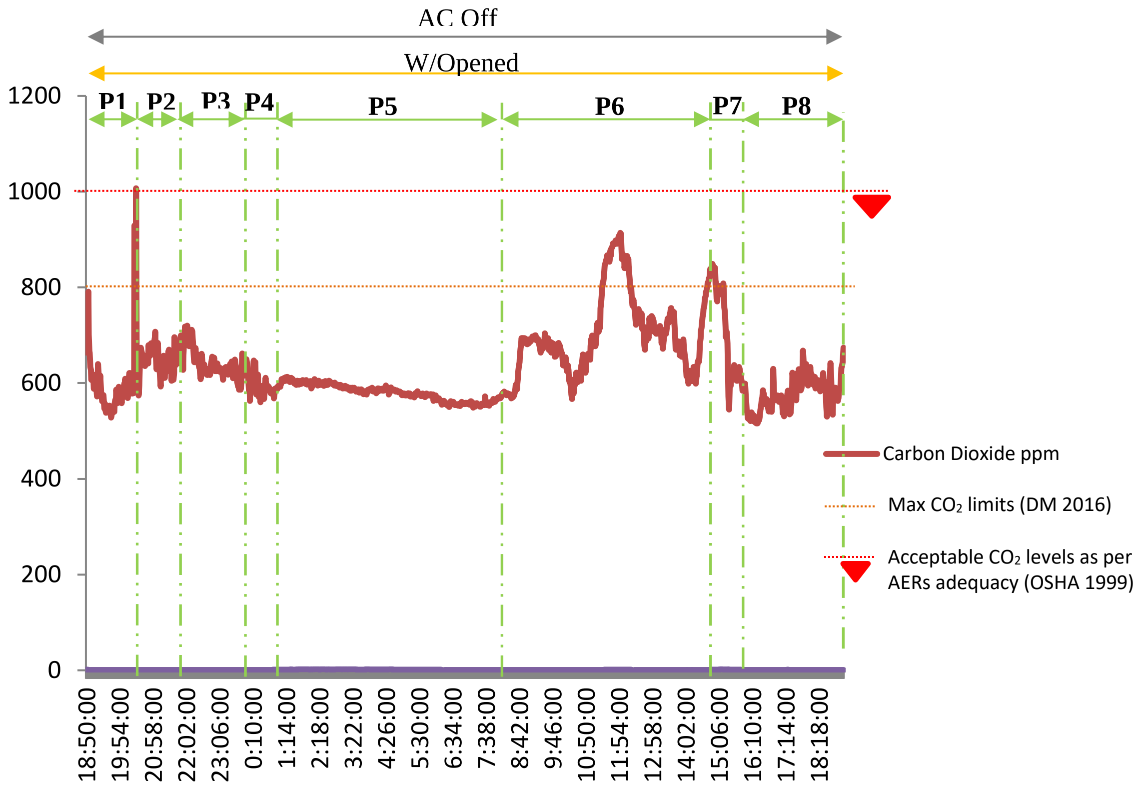
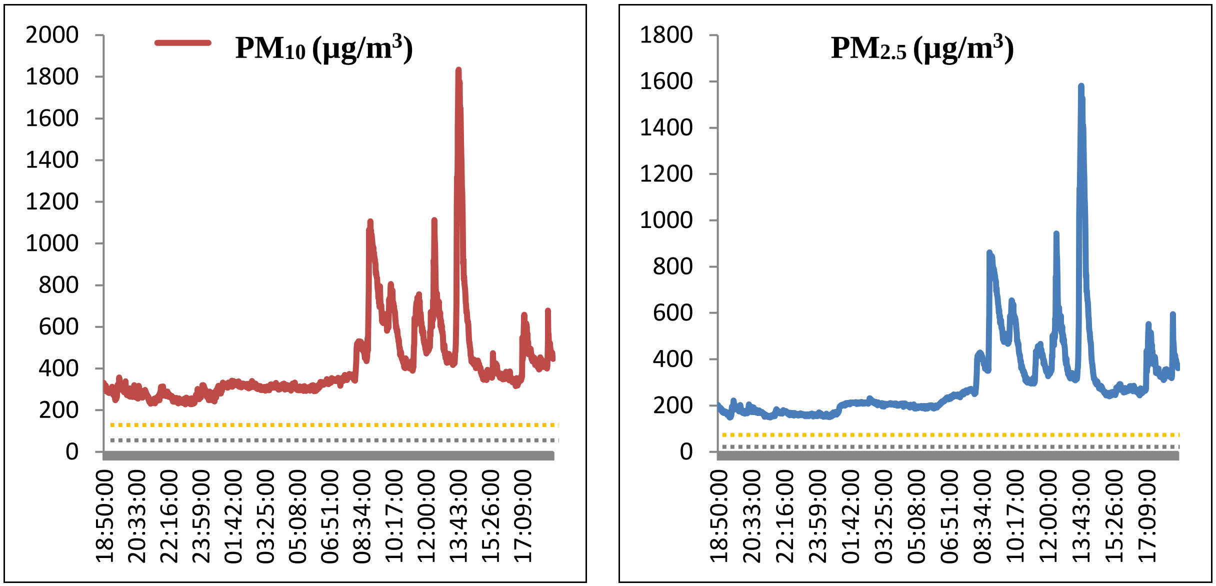


Figure ZZ-128: Occupancy profiles of the living hall projected on $CO_2$ levels (House 26)

Table ZZ-78: Occupancy profiles of the living hall during measurement period (House 26)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 18:50 – 20:30 | 10 | Natural (Window & Infiltration) | Sitting/ Dinner |
| **P2** | 20:30 – 21:45 | 5 | ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, | Sitting |
| **P3** | 21:45 – 23:40 | 6 | ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, | Sitting |
| **P4** | 23:40 – 01:00 | 10 | ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, | Sitting |
| **P5** | 01:00 – 08:00 | 1 | ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, | 9 occupants in other rooms |
| **P6** | 08:00 – 14:45 | 6 | ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, | Sitting/ Breakfast |
| **P7** | 14:45 – 15:40 | 7 | ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, | Sitting/ Lunch |
| **P8** | 15:40 – 19:00 | 5 | ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, | Sitting |



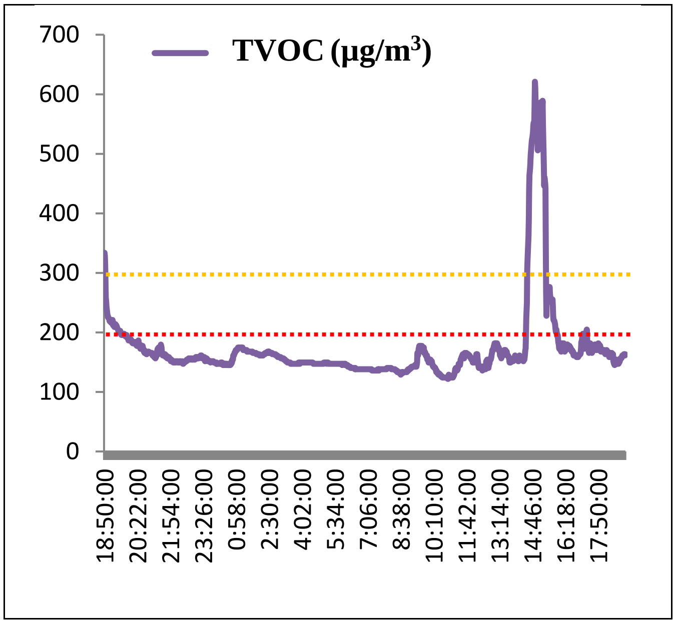
┈┈┈ 150 µg /m$^3$ for 8 hours – TWA (DM 2016)

┈┈┈ 50 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006)

┈┈┈ 65 µg /m$^3$ for 24 hours – 3 years average annual mean (ASHRAE 2016)

┈┈┈ 25 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006)

Figure ZZ-129: Compliance of PM$_{10}$ & PM$_{2.5}$ levels with established standards (House 26)



┈┈┈ 300 µg/m$^3$ for 8 hours – TWA (DM 2016)

┈┈┈ 200 µg/m$^3$ (Mølhave 1990)

Figure ZZ-130: Compliance of indoor TVOC levels with established standards (House 26)

## *House (27)*

Table ZZ-79: Levels of continuously measured variables indoor House (27)

| | **TVOC (µg/m$^3$)** | **CO$_2$ (ppm)** | **CO (ppm)** | **PM$_{2.5}$ (µg/m$^3$)** | **PM$_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 135.7 | 617.0 | 0.2 | 57.5 | 127.3 | 27.1 | 41.6 |
| **Mean** | 186.3 | 899.9 | 0.8 | 435.3 | 527.5 | 27.7 | 45.6 |
| **Max** | 448.5 | 1477.0 | 1.4 | 1036.0 | 1168.7 | 28.3 | 48.3 |

Table ZZ-80: Spot measured variables in outdoor air of House (27)

| | **TVOC (µg/m$^3$)** | **CO$_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 149.5 | 514.0 | 0.5 | 24.5 | 36.7 |

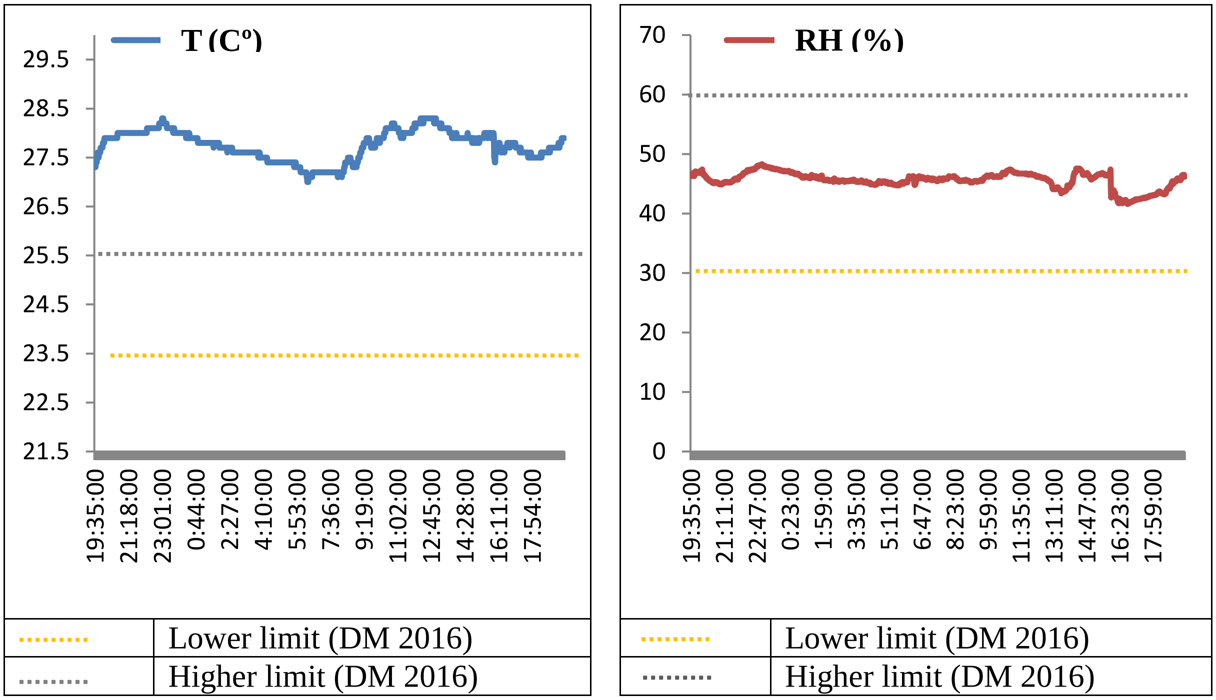


Figure ZZ-131: Continuously measured indoor levels of T and RH in House (27)

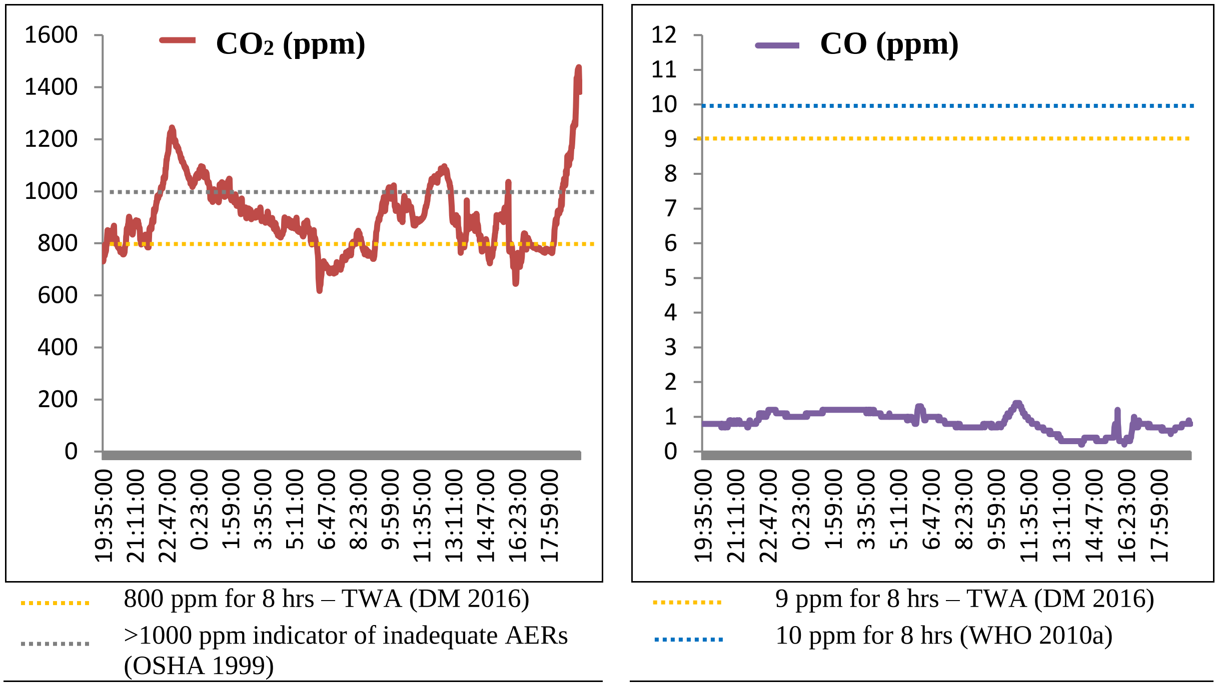


Figure ZZ-132: Compliance of $CO_2$ and CO levels with established standards (House 27)

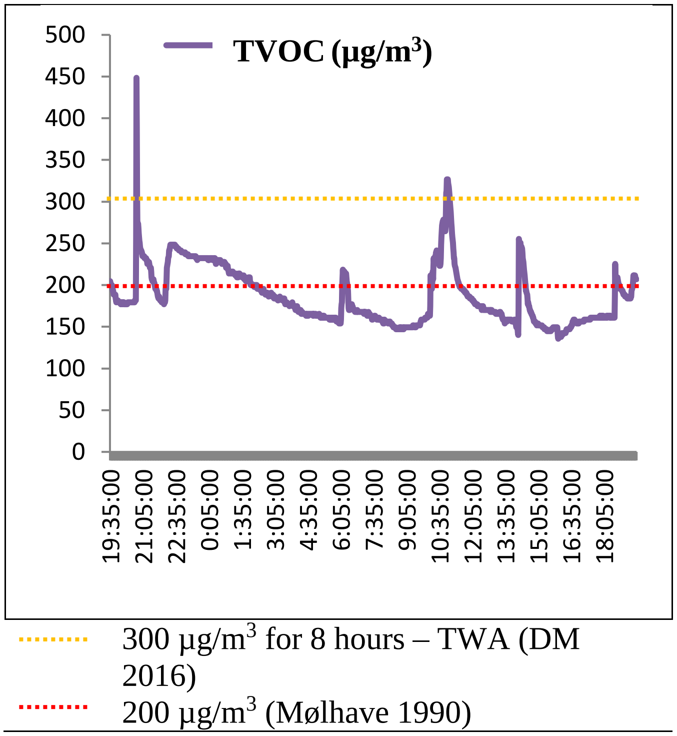


Figure ZZ-133: Compliance of indoor TVOC levels with established standards (House 27)

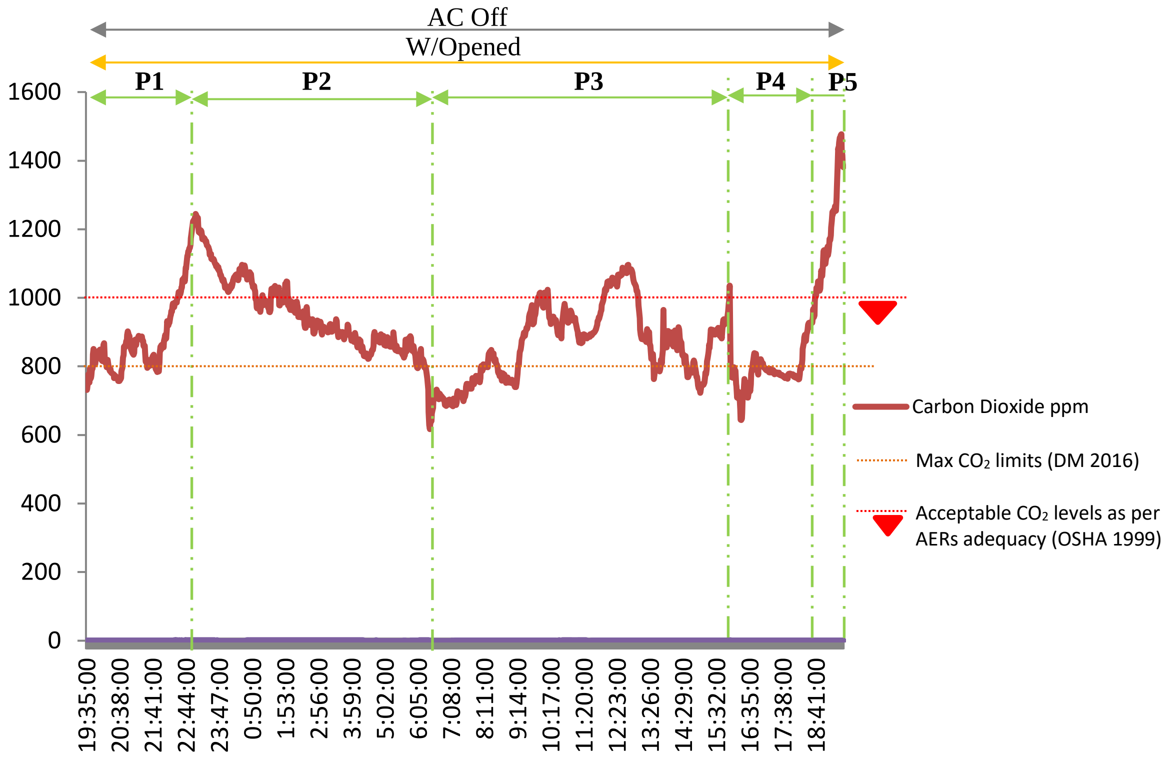
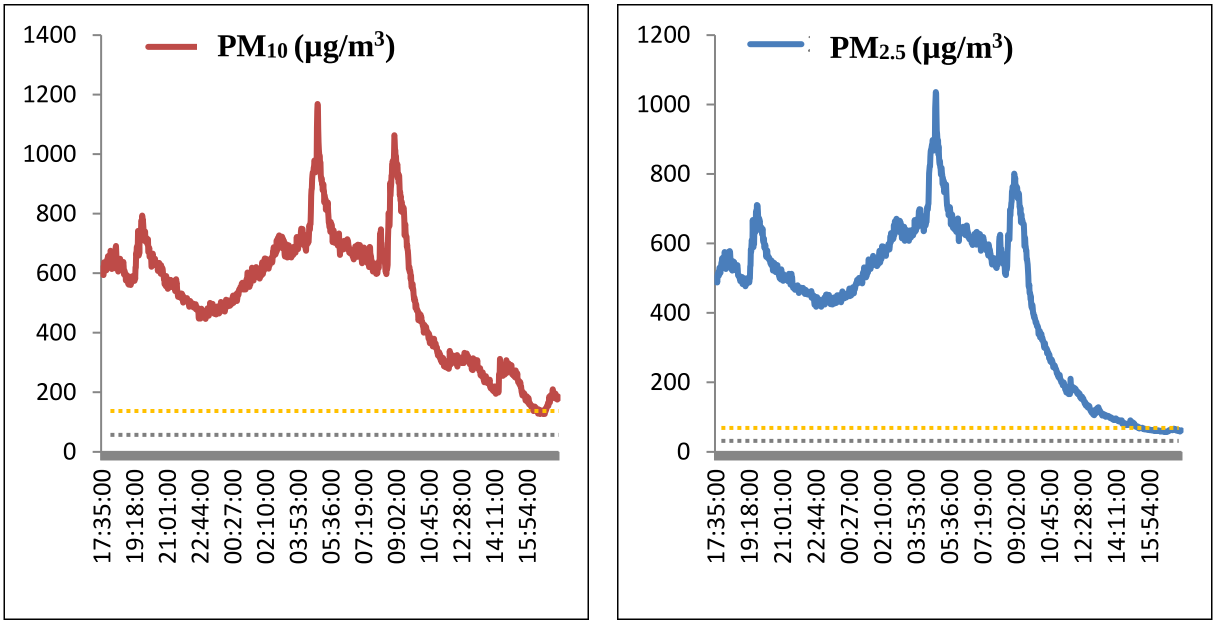


Figure ZZ-134: Occupancy profiles of the living hall projected on $CO_2$ levels (House 27)

Table ZZ-81: Occupancy profiles of the living hall during measurement period (House 27)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 19:30 – 23:00 | 4 | Natural (Window & Infiltration) | Sitting/ Dinner |
| **P2** | 23:00 – 06:30 | 0 | ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, | 4 occupants in other rooms |
| **P3** | 06:30 – 15:45 | 3 | ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, | Daily cleaning, cooking |
| **P4** | 15:45 – 18:45 | 4 | ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, | Sitting, lunch |
| **P5** | 18:45 – 19:30 | 5 | ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, | Having visitors |



| | | | |
|---|---|---|---|
| ········· | 150 µg /m³ for 8 hours – TWA (DM 2016) | ········· | 65 µg /m³ for 24 hours – 3 years average annual mean (ASHRAE 2016) |
| ········· | 50 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) | ········· | 25 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure ZZ-135: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 27)

### *House (28)*

Table ZZ-82: Levels of continuously measured variables indoor House (28)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 213.9 | 510.0 | 0.2 | 7.6 | 7.6 | 24.5 | 41.4 |
| **Mean** | 293.4 | 733.4 | 1.5 | 181.8 | 183.8 | 26.5 | 50.1 |
| **Max** | 402.5 | 1215.0 | 2.9 | 4709.9 | 4787.5 | 27.3 | 60.1 |

Table ZZ-83: Spot measured variables in outdoor air of House (28)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 151.8 | 501.0 | 0.6 | 23.4 | 43.4 |

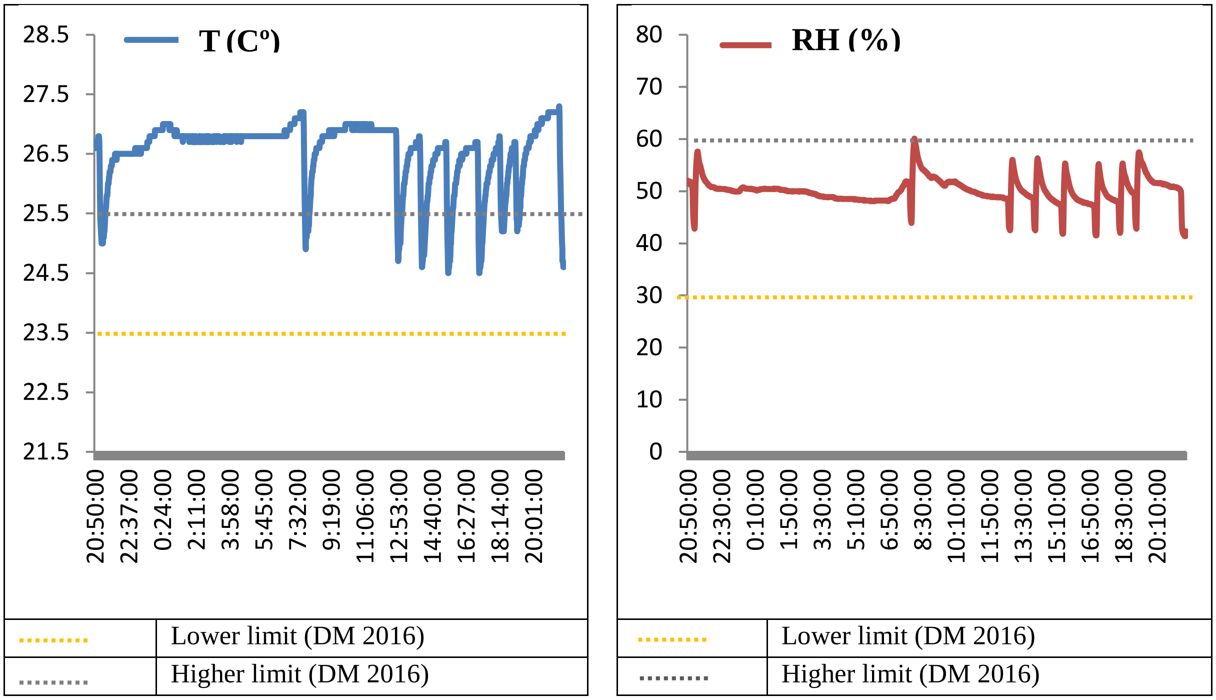


Figure ZZ-136: Continuously measured indoor levels of T and RH in House (28)

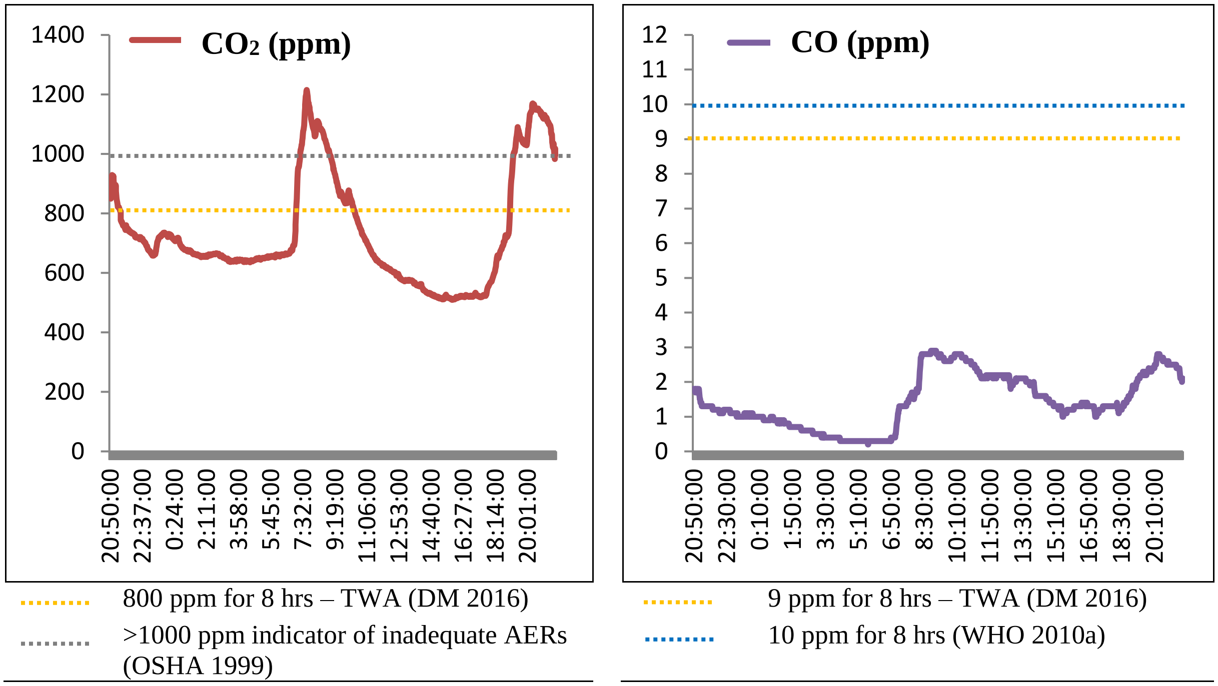


Figure ZZ-137: Compliance of $CO_2$ & CO levels in House (28) with established standards

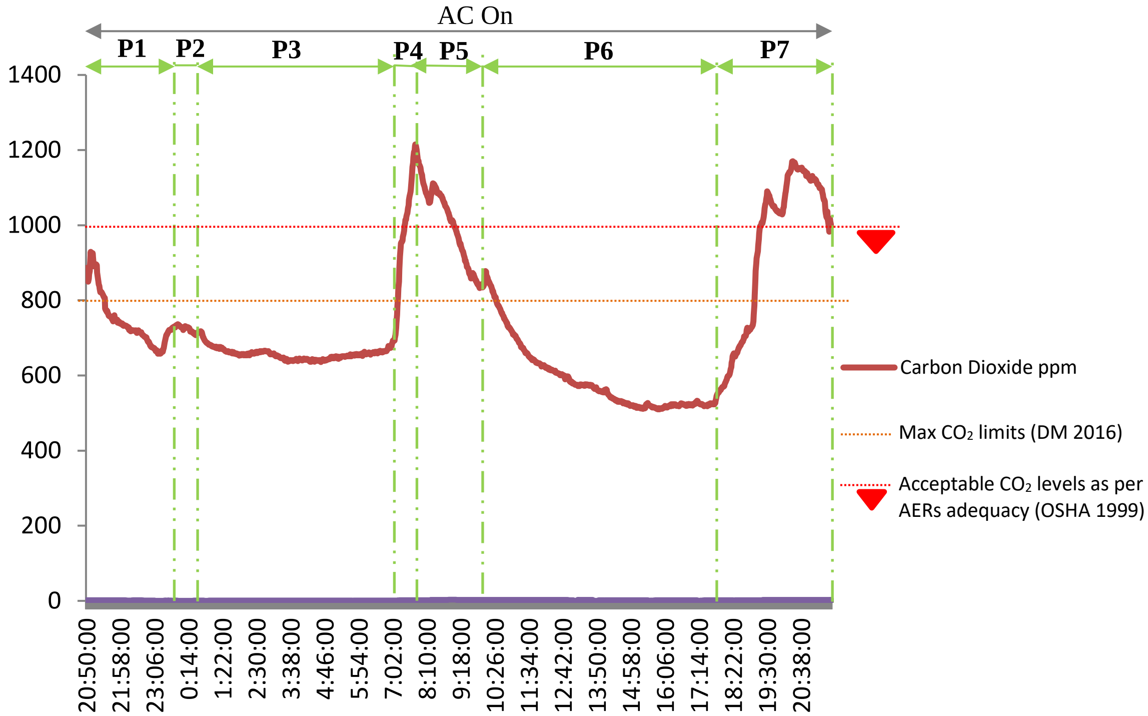


Figure ZZ-138: Occupancy profiles of the living hall projected on $CO_2$ levels (House 28)

Table ZZ-84: Occupancy profiles of the living hall during measurement period (House 28)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 19:50 – 23:30 | 2 | Mechanical | Sitting, dinner |
| **P2** | 23:30 – 01:00 | 3 | Mechanical | Sitting |
| **P3** | 01:00 – 07:00 | 0 | Mechanical | 3 persons in other rooms |
| **P4** | 07:00 – 07:45 | 2 | Mechanical | Sitting, cooking, breakfast |
| **P5** | 07:45 – 09:30 | 1 | Mechanical | Sitting |
| **P6** | 09:30 – 18:00 | 0 | Mechanical | Going outside |
| **P7** | 18:00 – 21:30 | 2 | Mechanical | Sitting, cooking |

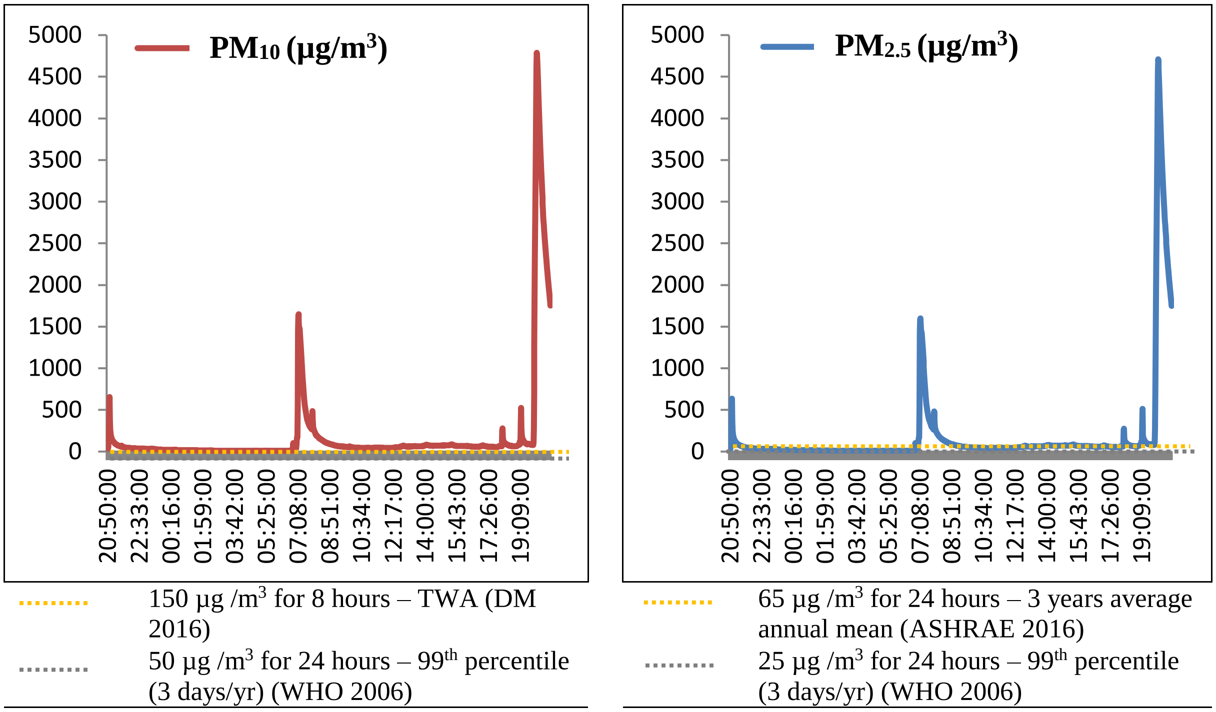


Figure ZZ-139: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 28)

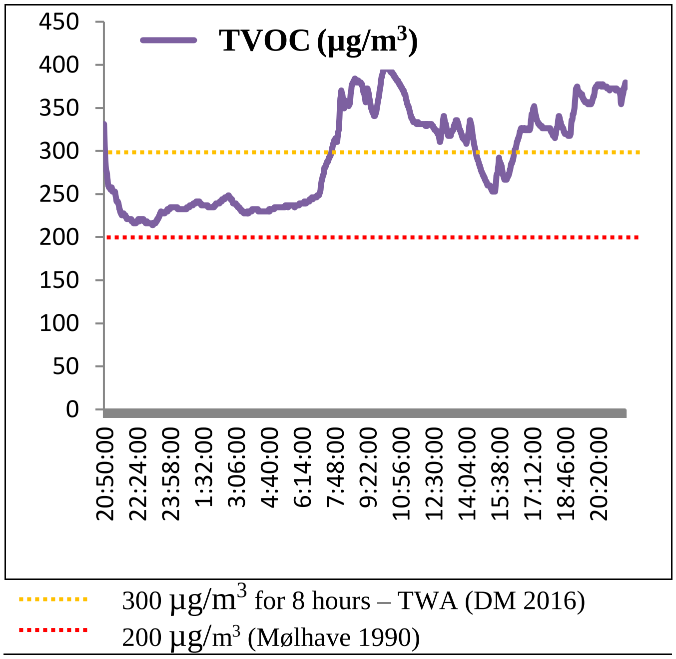


Figure ZZ-140: Compliance of indoor TVOC levels with established standards (House 28)

## *House (29)*

Table ZZ-85: Levels of continuously measured variables indoor House (29)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m$^3$)** | **$PM_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 512.9 | 954.0 | 0.7 | 99.5 | 104.2 | 24.4 | 51.9 |
| **Mean** | 922.9 | 1693.8 | 2.2 | 593.4 | 617.7 | 25.6 | 58.5 |
| **Max** | 1669.8 | 2649.0 | 3.9 | 2018.7 | 2050.7 | 26.9 | 63.4 |

Table ZZ-86: Spot measured variables in outdoor air of House (29)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 550 | 440 | 0.3 | 22.9 | 60.8 |

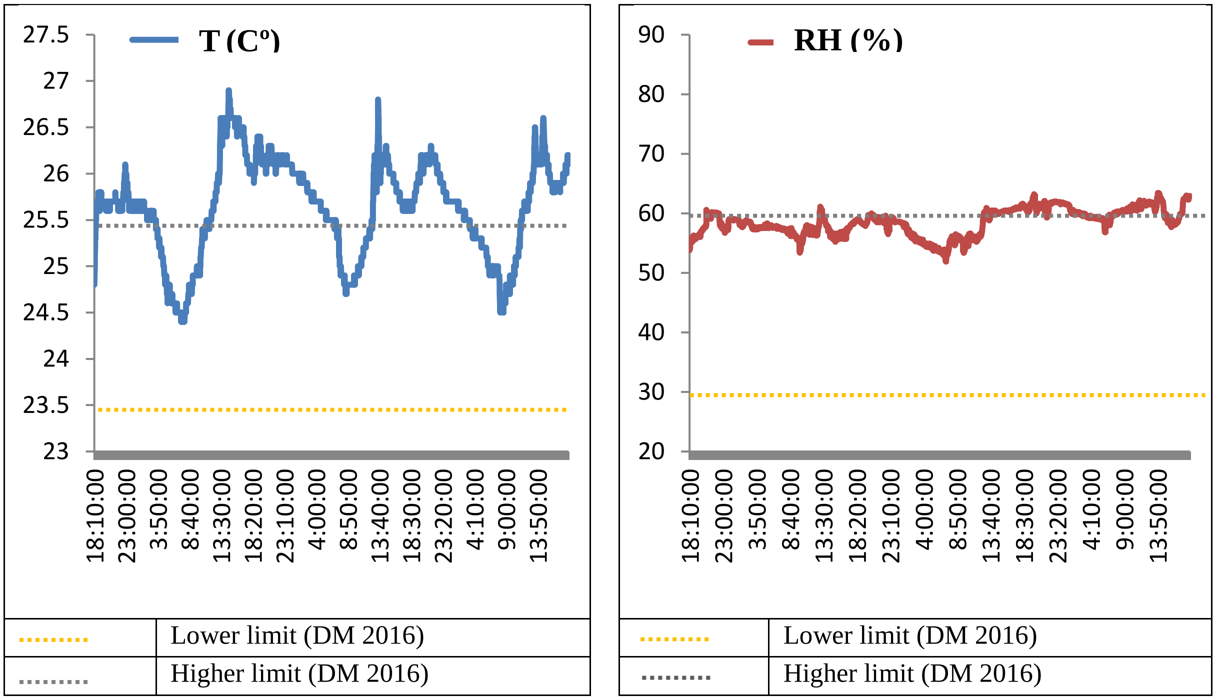


Figure ZZ-141: Continuously measured indoor levels of T and RH in House (29)

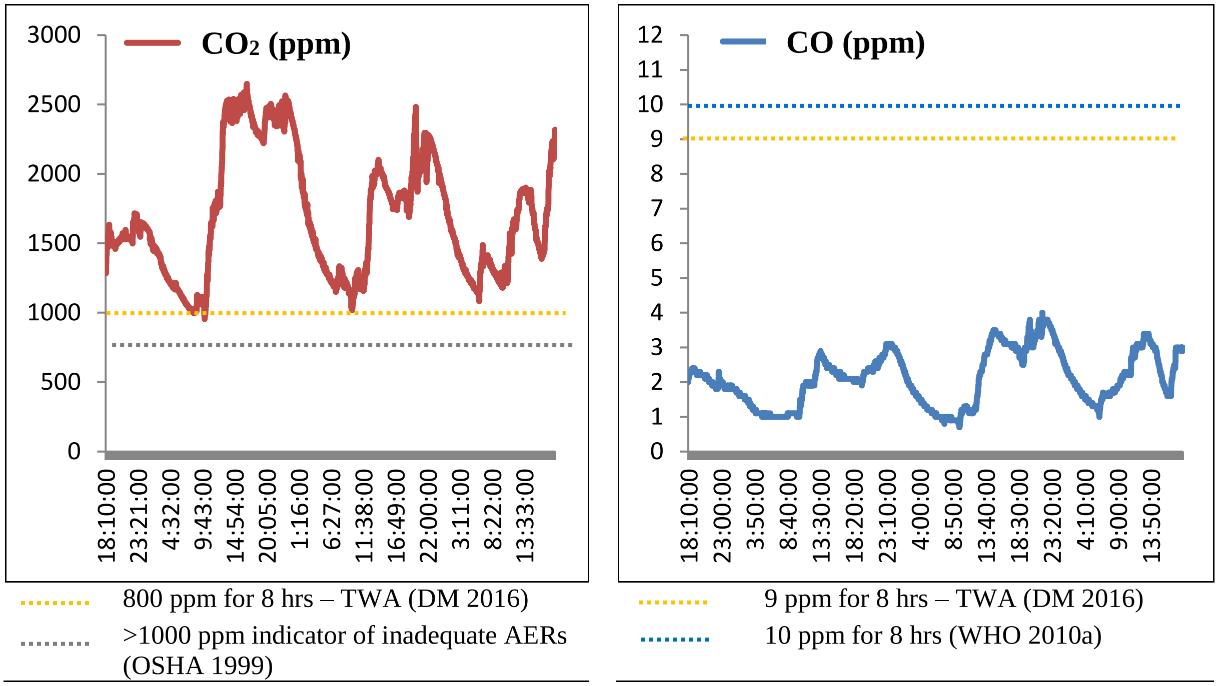


Figure ZZ-142: Compliance of $CO_2$ & CO levels in House (29) with established standards

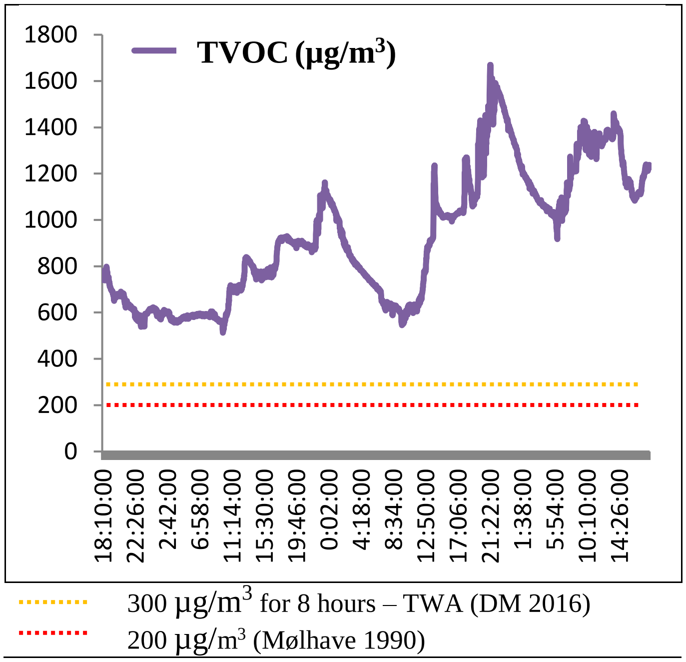


Figure ZZ-143: Compliance of indoor TVOC levels with established standards (House 29)

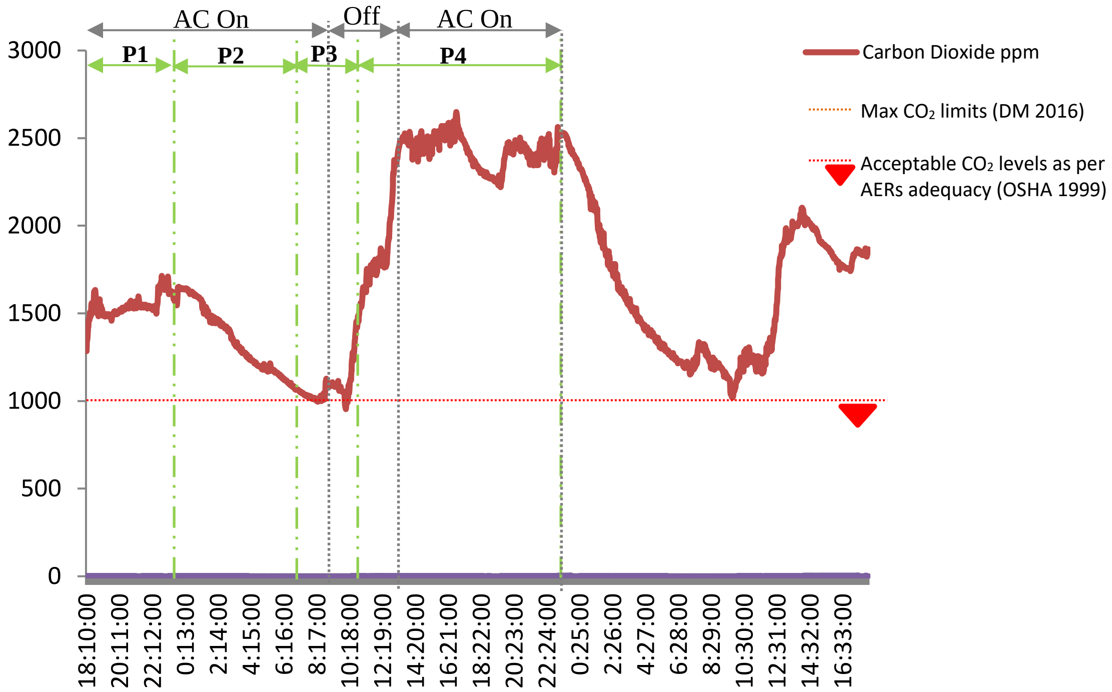


Figure ZZ-144: Occupancy profiles of the living hall projected on $CO_2$ levels (House 29)

Table ZZ-87: Occupancy profiles of the living hall during measurement period (House 29)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 18:10 – 23:30 | 5 | Mechanical | Sitting/ Having visitor |
| **P2** | 23:30 – 06:50 | 0 | Mechanical | 5 persons in other rooms |
| **P3** | 06:50 – 10:30 | 2 | Mixed:<br>06:50 – 09:00 Mechanical<br>09:00 - 10:30 Natural (Infiltration) | Sitting |
| **P4** | 10:30 – 23:00 | 4 | Mixed:<br>10:30 – 13:00 Natural (Infiltration)<br>13:00 – 23:00 Mechanical | Sitting, cooking, lunch, dinner |

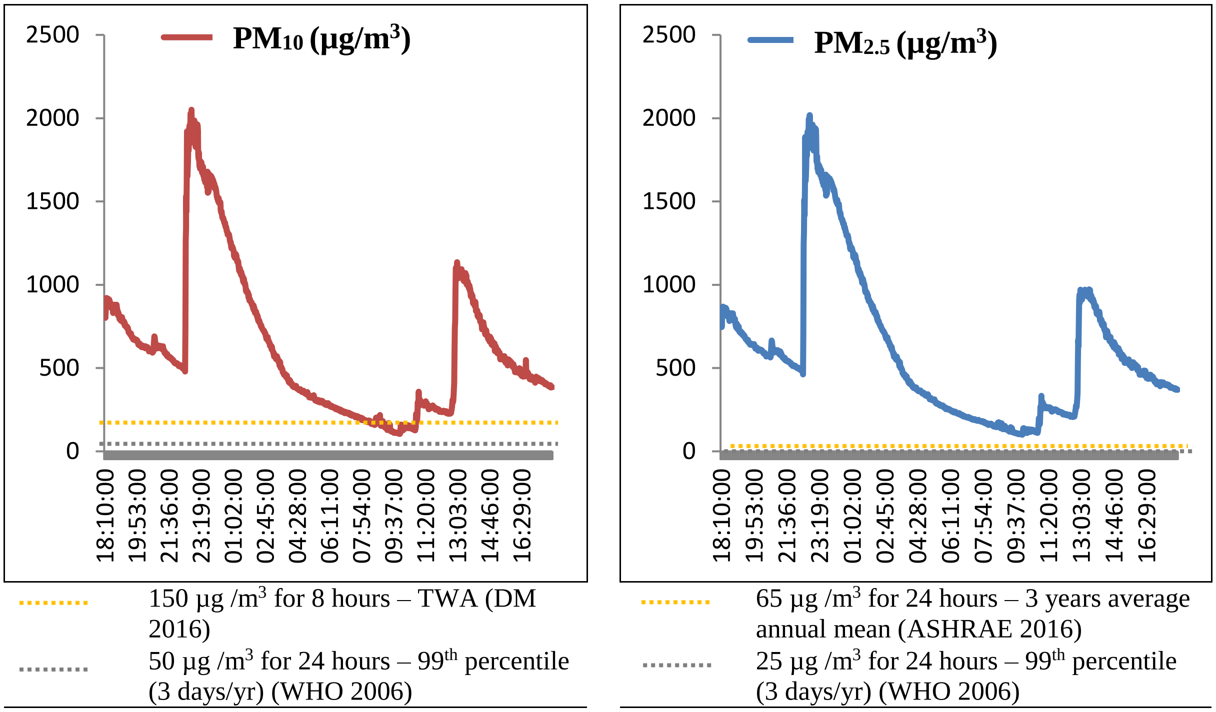


Figure ZZ-145: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 29)

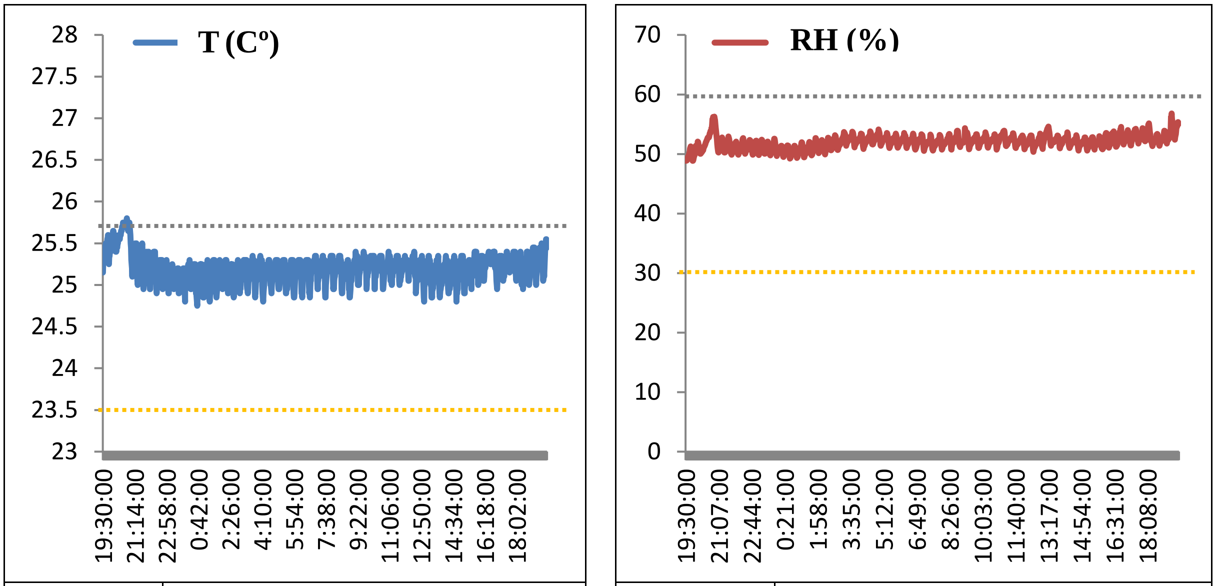
***House 30***

Table ZZ-88: Levels of continuously measured variables indoor House (30)

| | **TVOC (µg/m³)** | **CO₂ (ppm)** | **CO (ppm)** | **PM2.5 (µg/m³)** | **PM10 (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 526.7 | 847.0 | 1.6 | 130.3 | 139.7 | 24.8 | 48.9 |
| **Mean** | 752.0 | 1032.1 | 2.4 | 667.7 | 714.9 | 25.2 | 52.0 |
| **Max** | 4907.1 | 2021.0 | 7.3 | 5162.8 | 5863.0 | 25.8 | 56.8 |

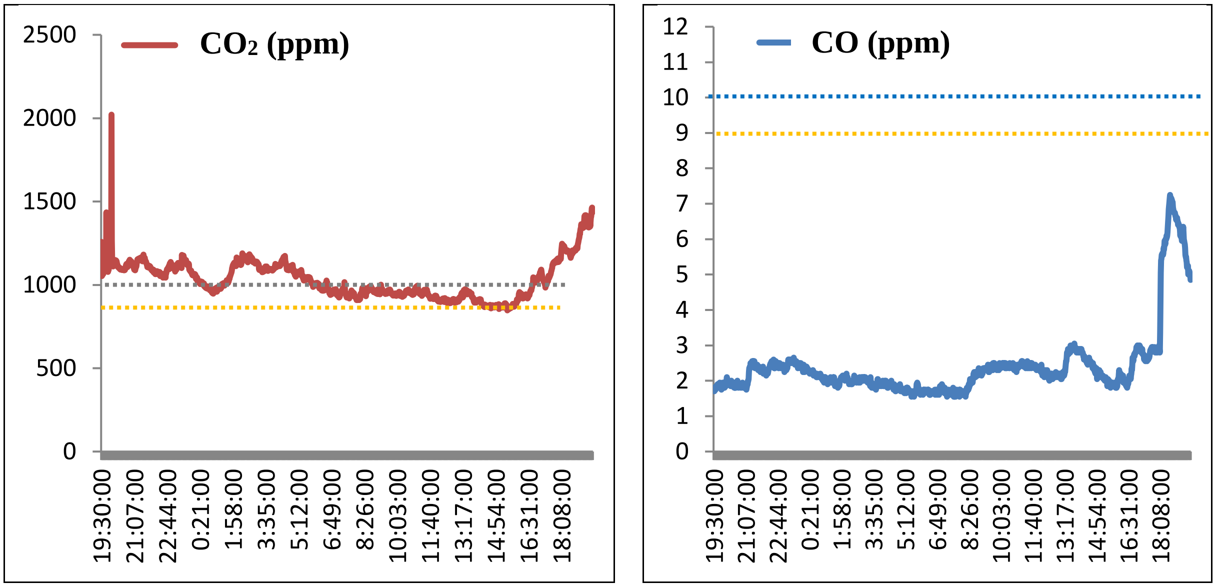
Table ZZ-89: Spot measured variables in outdoor air of House (30)

| | **TVOC (µg/m³)** | **CO₂ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 429.0 | 570.0 | 2.4 | 25.2 | 60.1 |



| | | | |
|---|---|---|---|
| ········· | Lower limit (DM 2016) | ········· | Lower limit (DM 2016) |
| ········· | Higher limit (DM 2016) | ········· | Higher limit (DM 2016) |

Figure ZZ-146: Continuously measured indoor levels of T and RH in House (30)



| | | | |
|---|---|---|---|
| ········· | 800 ppm for 8 hrs – TWA (DM 2016) | ········· | 9 ppm for 8 hrs – TWA (DM 2016) |
| ········· | >1000 ppm indicator of inadequate AERs (OSHA 1999) | ········· | 10 ppm for 8 hrs (WHO 2010a) |

Figure ZZ-147: Compliance of $CO_2$ & CO levels in House (30) with established standards

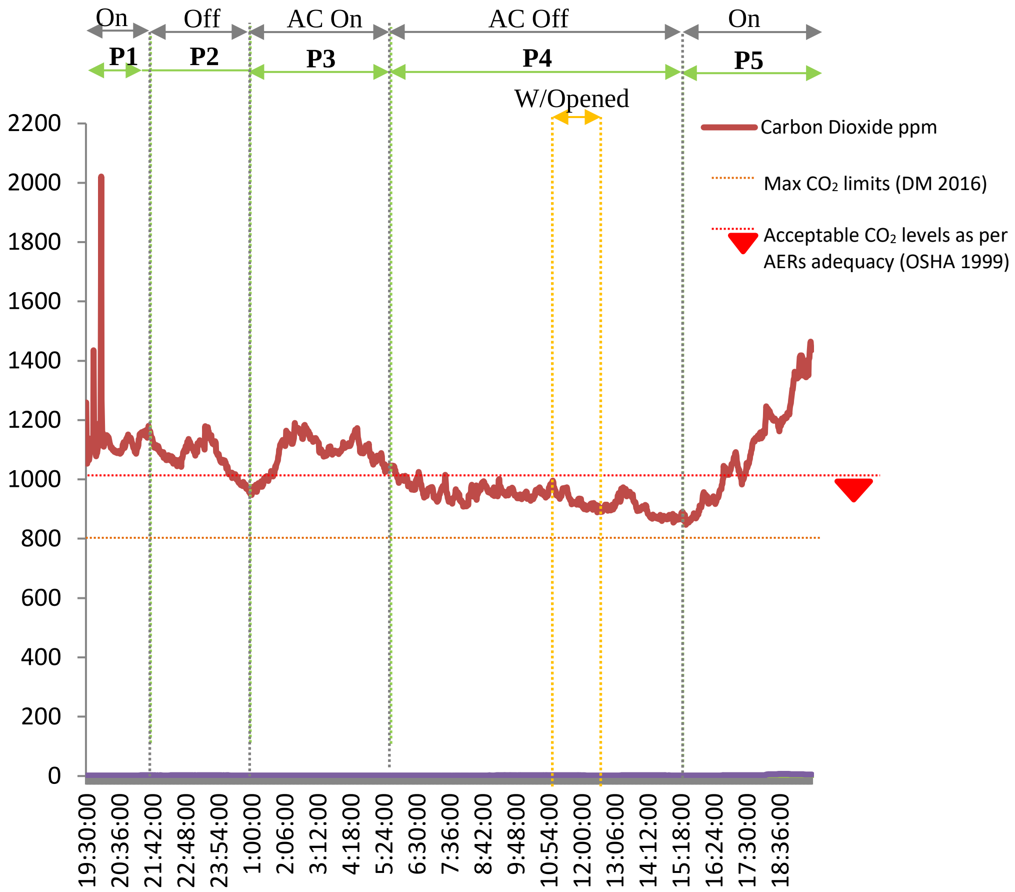
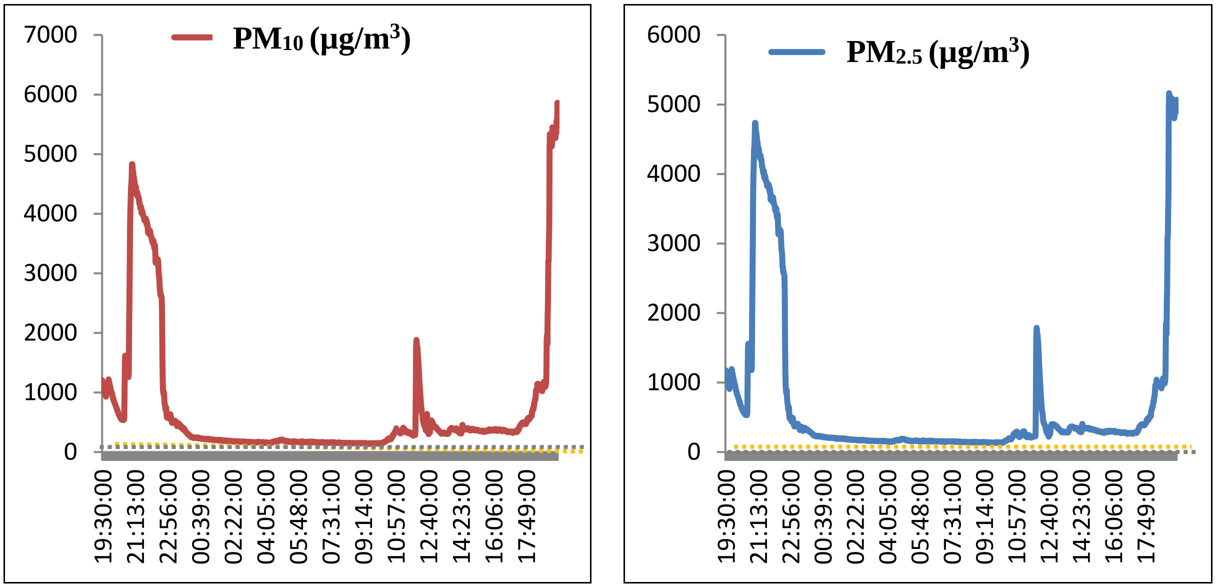


Figure ZZ-148: Occupancy profiles of the living hall projected on $CO_2$ levels (House 30)

Table ZZ-90: Occupancy profiles of the living hall during measurement period (House 30)

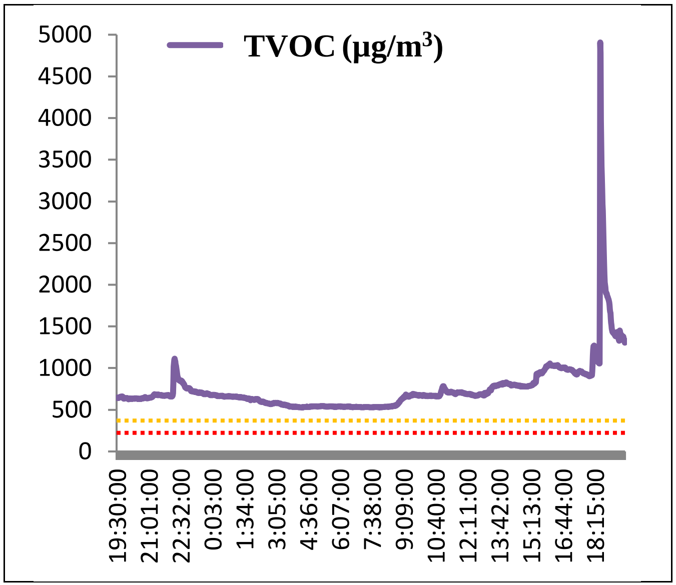
| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 19:30 – 21:00 | 7 | Mechanical | Sitting, having a visitor |
| **P2** | 21:40 – 01:00 | 2 | Natural (Infiltration) | 5 persons went outside |
| **P3** | 01:00 – 05:30 | 7 | Mechanical | Sitting |
| **P4** | 05:30 – 15:20 | 0 | Natural (Window & Infiltration) | 7 persons in other rooms |
| **P5** | 15:20 – 19:00 | 8 | Mechanical | Sitting/ cooking/ lunch/having another visitor |



| | |
|---|---|
| ┈┈┈ | 150 µg /m³ for 8 hours – TWA (DM 2016) |
| ┈┈┈ | 50 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

| | |
|---|---|
| ┈┈┈ | 65 µg /m³ for 24 hours – 3 years average annual mean (ASHRAE 2016) |
| ┈┈┈ | 25 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure ZZ-149: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 30)



| | |
|---|---|
| ┈┈┈ | 300 µg/m³ for 8 hours – TWA (DM 2016) |
| ┈┈┈ | 200 µg/m³ (Mølhave 1990) |

Figure ZZ-150: Compliance of indoor TVOC levels with established standards (House 30)

## *House (31)*

Table ZZ-91: Levels of continuously measured variables indoor House (31)

| | **TVOC ($\mu g/m^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ ($\mu g/m^3$)** | **$PM_{10}$ ($\mu g/m^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 92.0 | 414.0 | 0.0 | 169.2 | 255.7 | 23.9 | 35.2 |
| **Mean** | 177.3 | 546.9 | 0.3 | 277.0 | 364.4 | 25.1 | 42.2 |
| **Max** | 1311.0 | 1079.0 | 2.6 | 556.6 | 752.2 | 26.4 | 54.0 |

Table ZZ-92: Spot measured variables in outdoor air of House (31)

| | **TVOC ($\mu g/m^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 156.4 | 446 | 0.5 | 23.5 | 30.3 |

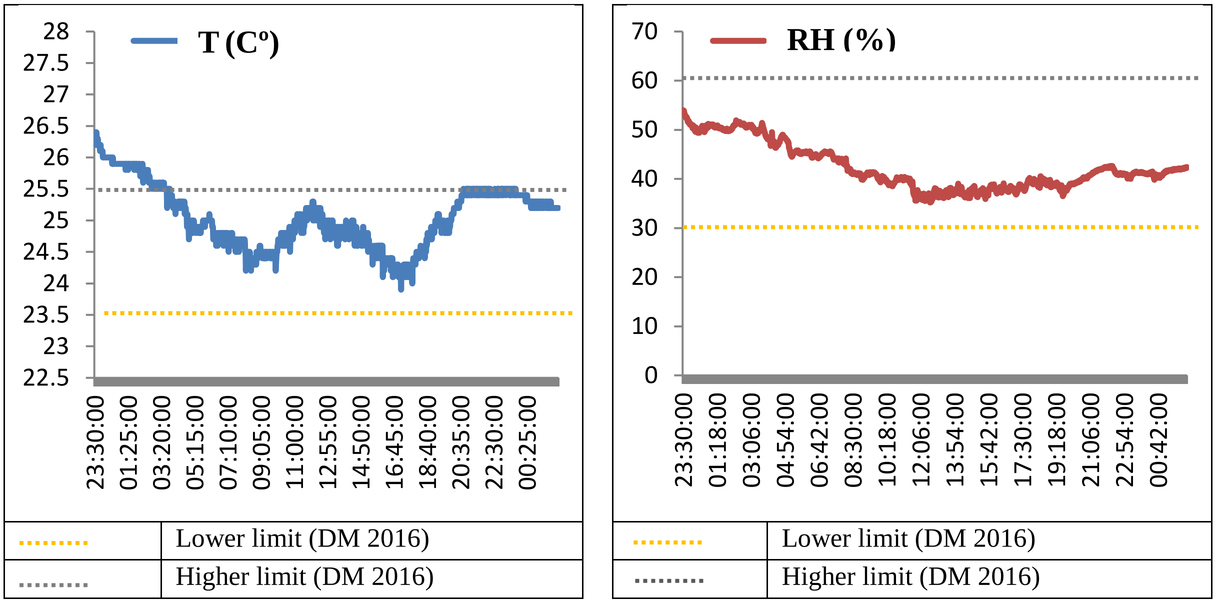


Figure ZZ-151: Continuously measured indoor levels of T and RH in House (31)

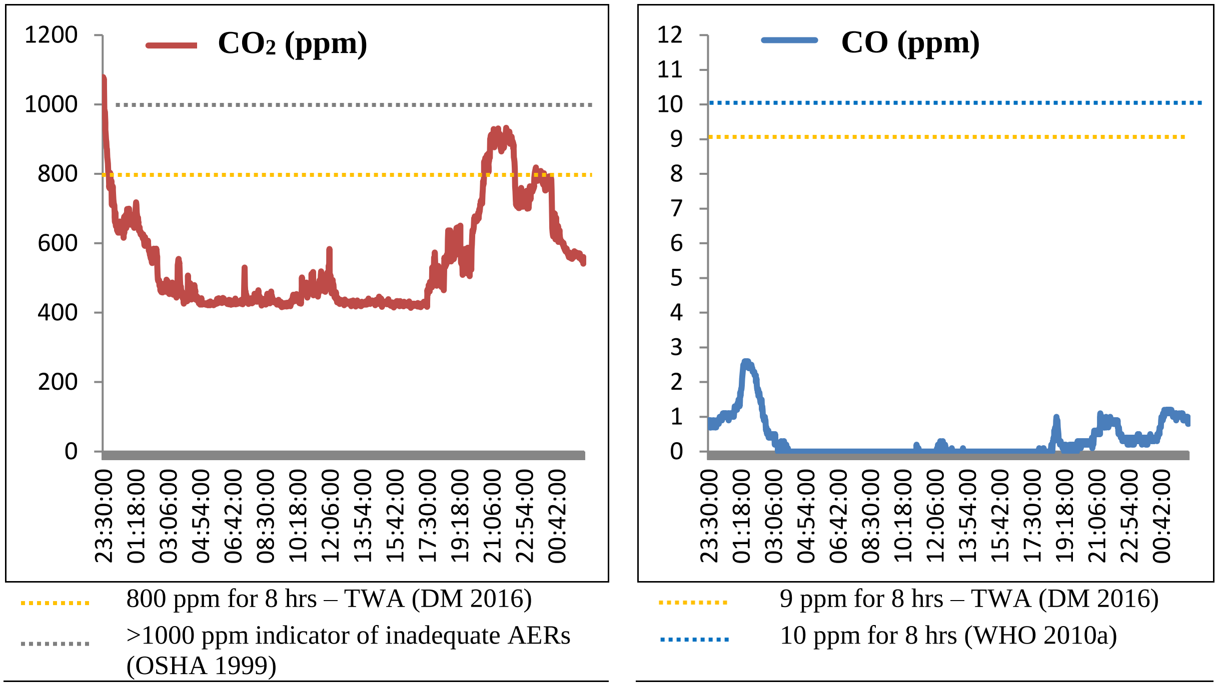


Figure ZZ-152: Compliance of $CO_2$ & CO levels in House (31) with established standards

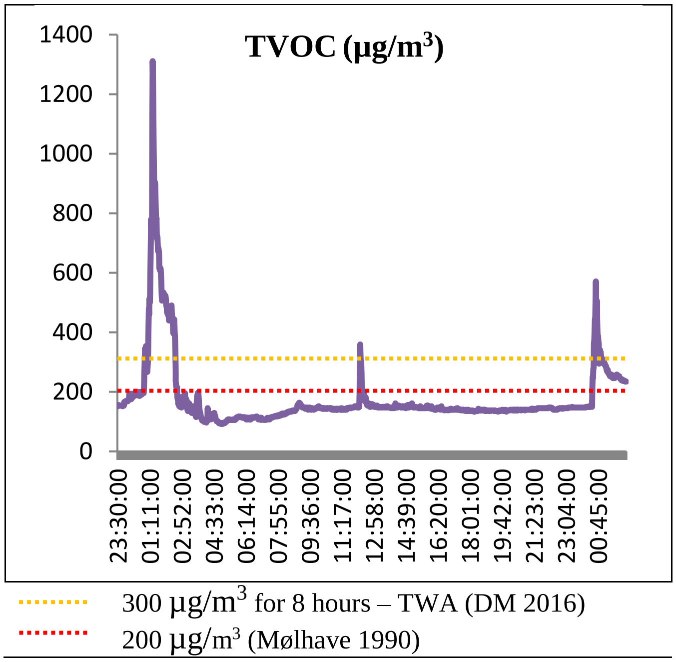


Figure ZZ-153: Compliance of indoor TVOC levels with established standards (House 31)

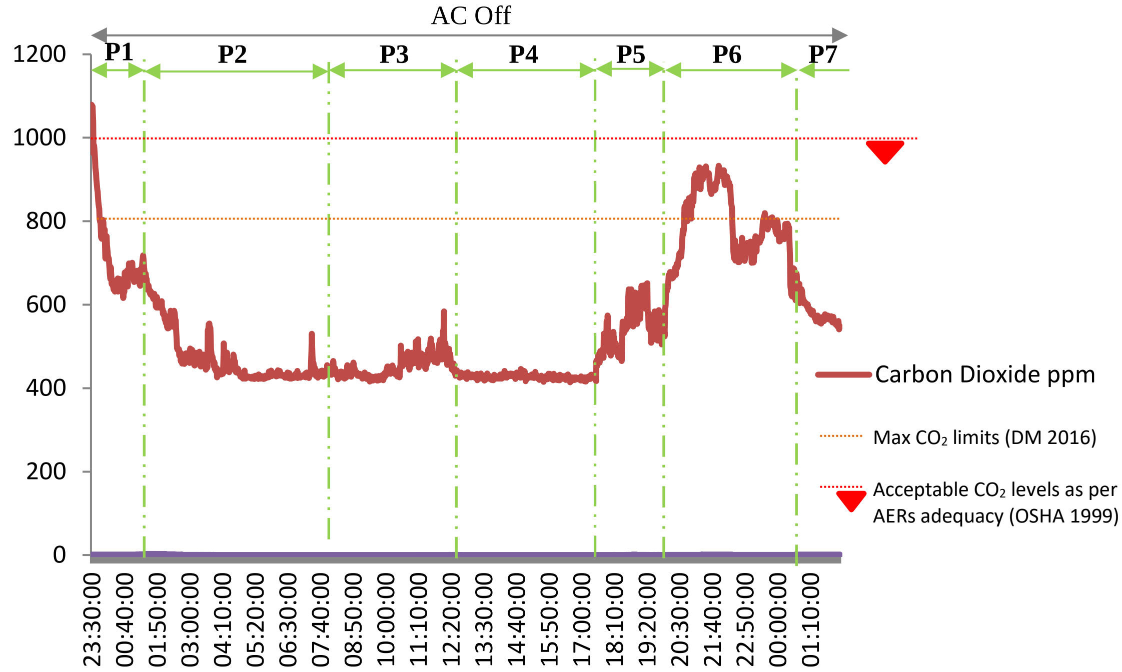
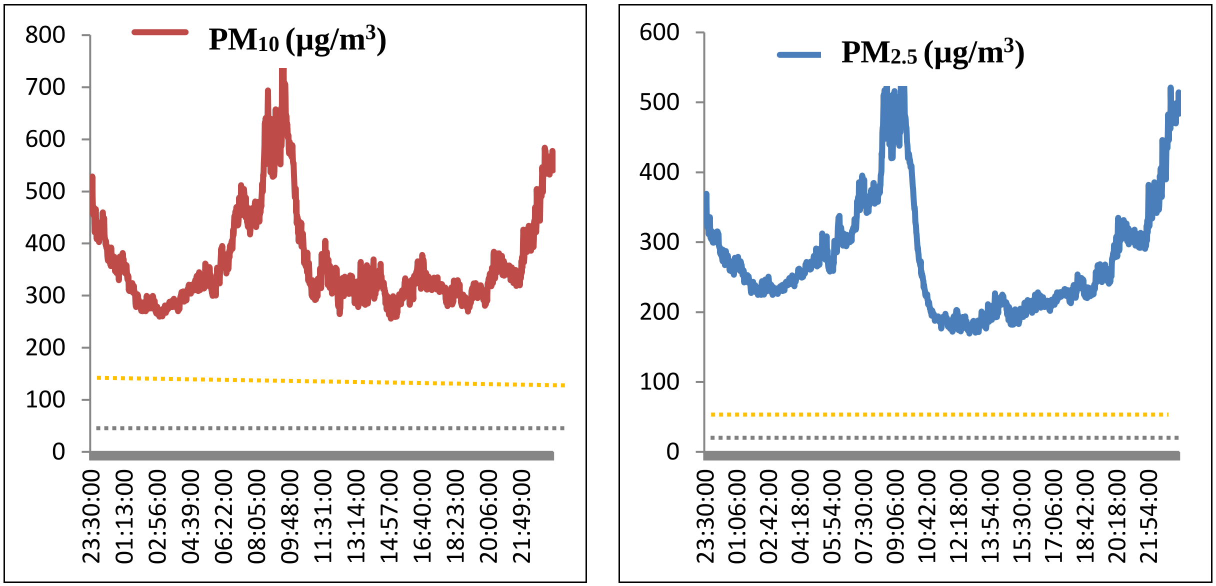


Figure ZZ-154: Occupancy profiles of the living hall projected on $CO_2$ levels (House 31)

Table ZZ-93: Occupancy profiles of the living hall during measurement period (House 31)

| **Profile** | **Time** | **Occupants** | **System** | **Activities** |
|---|---|---|---|---|
| **P1** | 23:30 – 01:30 | 3 | Natural (Infiltration) | Sitting |
| **P2** | 01:30 – 08:00 | 0 | ,, ,, ,, ,, ,, ,, | 3 persons in other rooms |
| **P3** | 08:00 – 12:30 | 1 | ,, ,, ,, ,, ,, ,, | Office work, breakfast |
| **P4** | 12:30 – 15:30 | 0 | ,, ,, ,, ,, ,, ,, | Went outside for work |
| **P5** | 15:30 – 20:00 | 1 | ,, ,, ,, ,, ,, ,, | Cooking |
| **P6** | 20:00 – 00:30 | 3 | ,, ,, ,, ,, ,, ,, | Sitting, dinner |
| **P7** | 00:30 – 08:00 | 3 | ,, ,, ,, ,, ,, ,, | 3 persons in other rooms |



| | | | |
|---|---|---|---|
| ⋯ | 150 µg /m³ for 8 hours – TWA (DM 2016) | ⋯ | 65 µg /m³ for 24 hours – 3 years average annual mean (ASHRAE 2016) |
| ⋯ | 50 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) | ⋯ | 25 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure ZZ-155: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 31)

### *House (32)*

Table ZZ-94: Levels of continuously measured variables indoor House (32)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 381.8 | 705.0 | 0.7 | 136.1 | 187.0 | 24.7 | 54.6 |
| **Mean** | 517.1 | 871.3 | 1.3 | 329.4 | 394.4 | 25.3 | 56.1 |
| **Max** | 639.4 | 1185.0 | 1.9 | 934.6 | 1034.7 | 25.9 | 58.7 |

Table ZZ-95: Spot measured variables in outdoor air of House (32)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 136 | 431 | 0.3 | 22.9 | 65.7 |

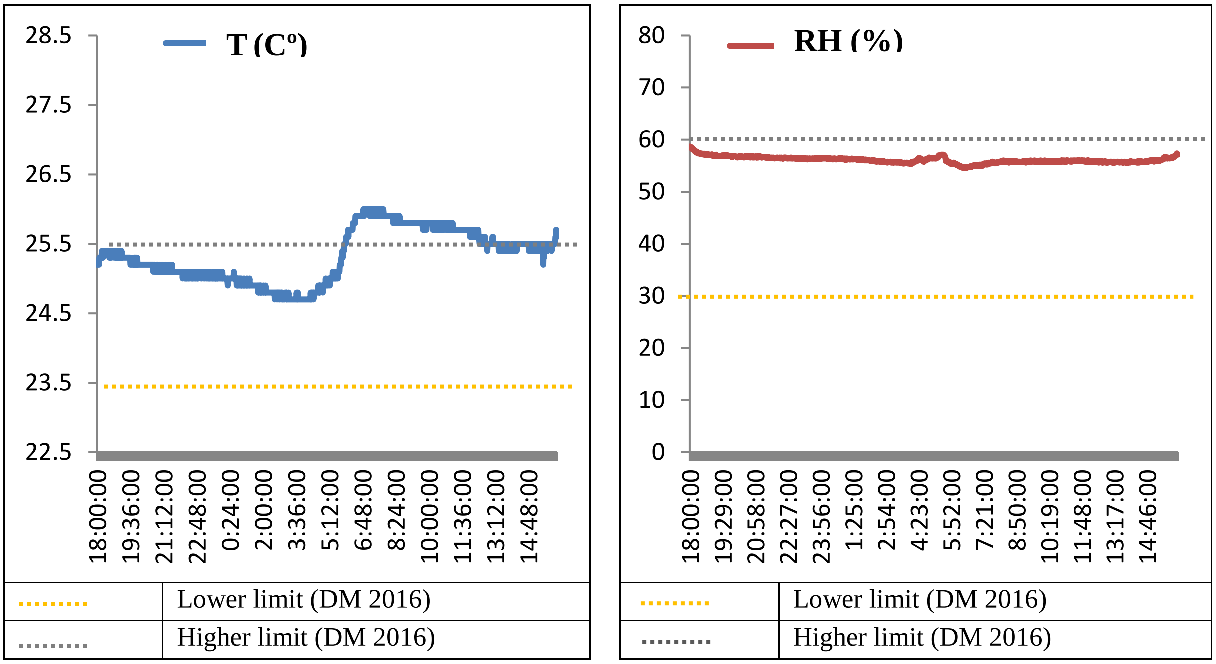


Figure ZZ-156: Continuously measured indoor levels of T and RH in House (32)

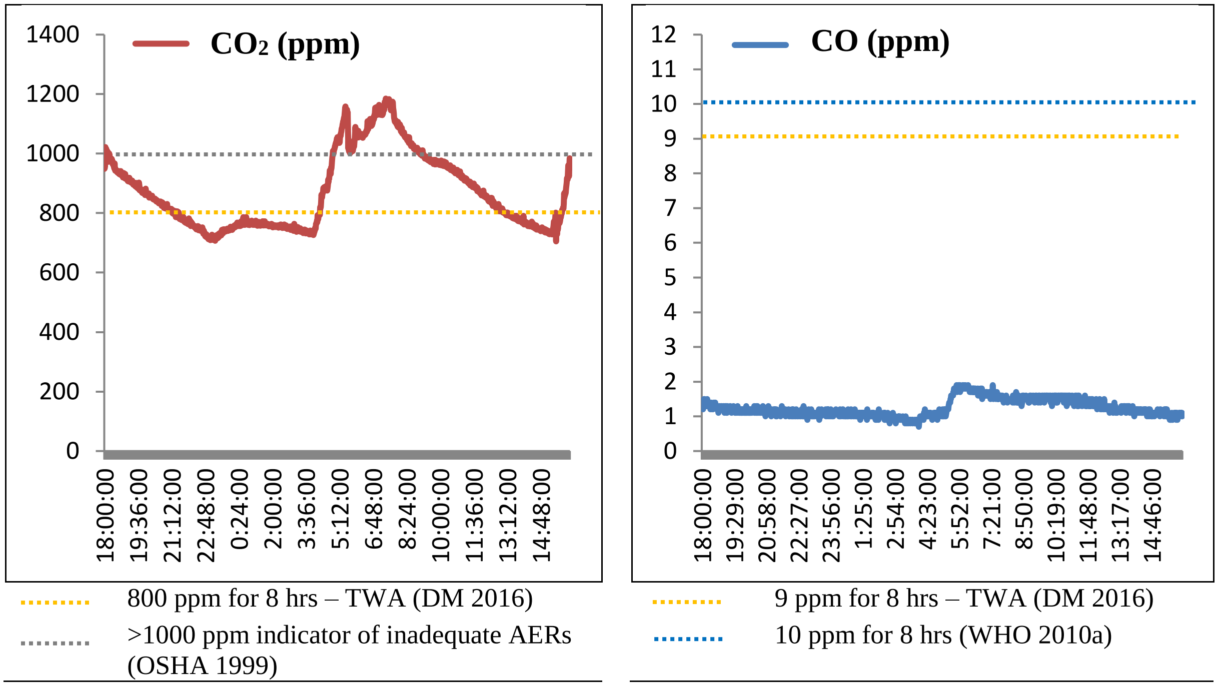


Figure ZZ-157: Compliance of $CO_2$ & CO levels in House (32) with established standards

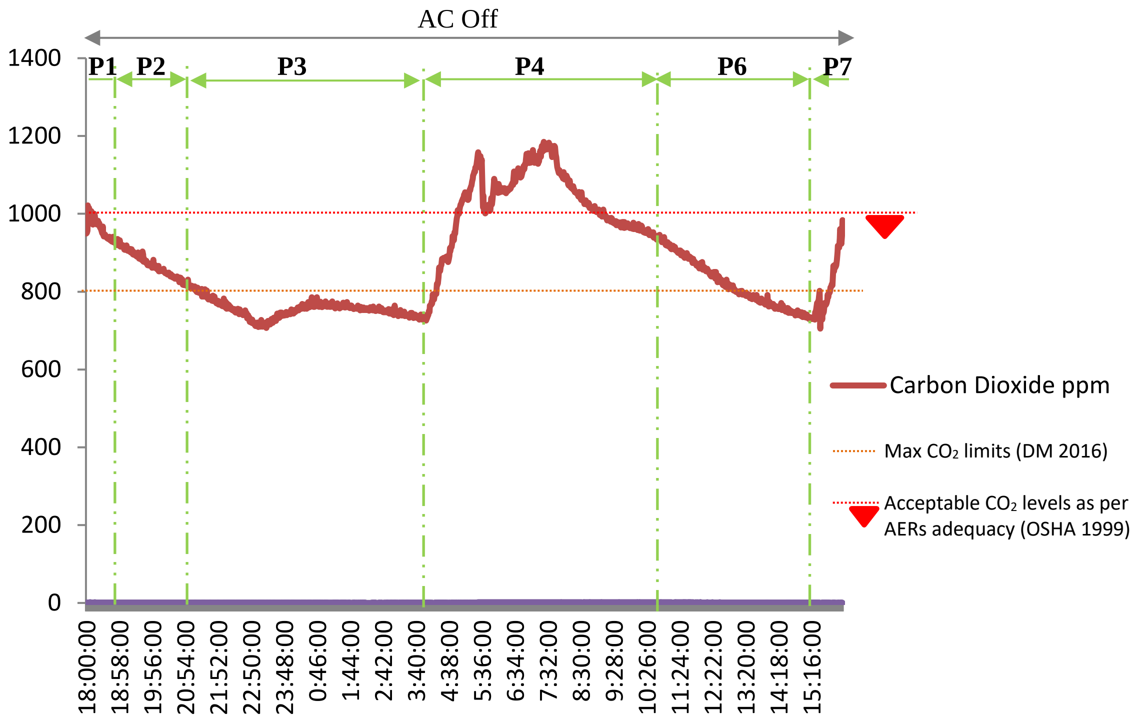
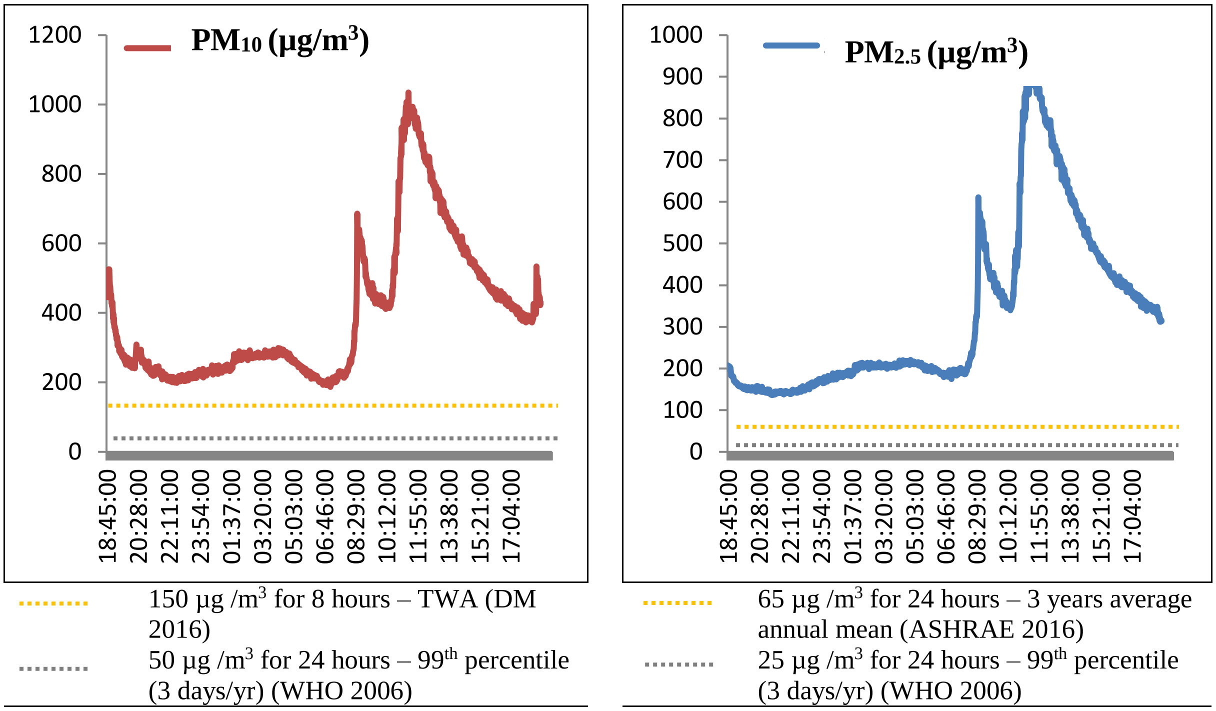


Figure ZZ-158: Occupancy profiles of the living hall projected on $CO_2$ levels (House 32)

Table ZZ-96: Occupancy profiles of the living hall during measurement period (House 32)

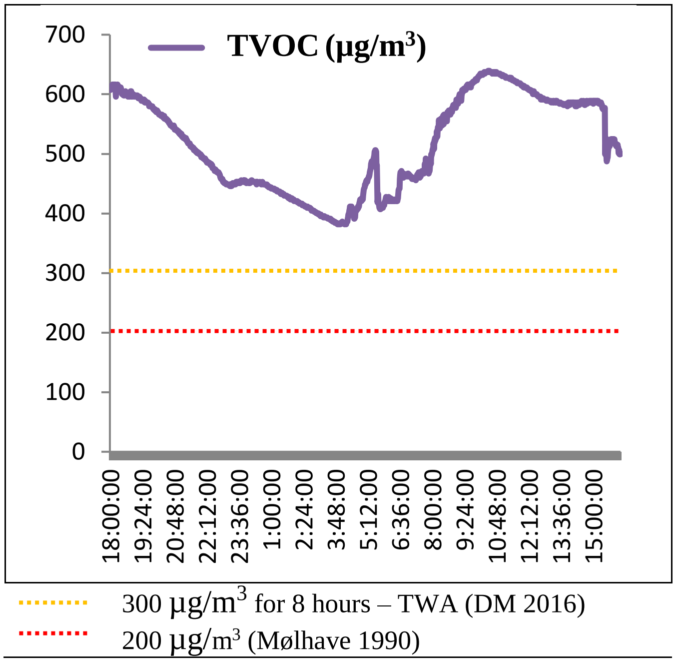
| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 18:00 – 18:45 | 3 | Natural (Infiltration) | Sitting |
| **P2** | 18:45 – 21:00 | 0 | ,, ,, ,, ,, ,, ,, | Went outside |
| **P3** | 21:00 – 04:00 | 0 | ,, ,, ,, ,, ,, ,, | 3 persons in other rooms |
| **P4** | 04:00 – 10:45 | 3 | ,, ,, ,, ,, ,, ,, | Cleaning, washing, cooking, breakfast |
| **P5** | 10:45 – 15:15 | 0 | ,, ,, ,, ,, ,, ,, | Went outside |
| **P6** | 15:15 – 19:00 | 3 | ,, ,, ,, ,, ,, ,, | Sitting/ lunch |



| | |
|---|---|
| ⋯⋯ | 150 µg /m$^3$ for 8 hours – TWA (DM 2016) |
| ⋯⋯ | 50 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

| | |
|---|---|
| ⋯⋯ | 65 µg /m$^3$ for 24 hours – 3 years average annual mean (ASHRAE 2016) |
| ⋯⋯ | 25 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure ZZ-159: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 32)



| | |
|---|---|
| ⋯⋯ | 300 µg/m$^3$ for 8 hours – TWA (DM 2016) |
| ⋯⋯ | 200 µg/m$^3$ (Mølhave 1990) |

Figure ZZ-160: Compliance of indoor TVOC levels with established standards (House 32)

### ***House (33)***

Table ZZ-97: Levels of continuously measured variables indoor House (33)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **PM$_{2.5}$ (µg/m$^3$)** | **PM$_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 17.0 | 408.0 | 0.1 | 197.8 | 239.9 | 23.9 | 27.7 |
| **Mean** | 107.4 | 657.6 | 0.8 | 255.1 | 404.7 | 25.0 | 41.6 |
| **Max** | 179.0 | 1325.0 | 2.8 | 811.7 | 1204.2 | 26.1 | 52.9 |

Table ZZ-98: Spot measured variables in outdoor air of House (33)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | <11.5 | 433 | 0.0 | 22.6 | 54.8 |

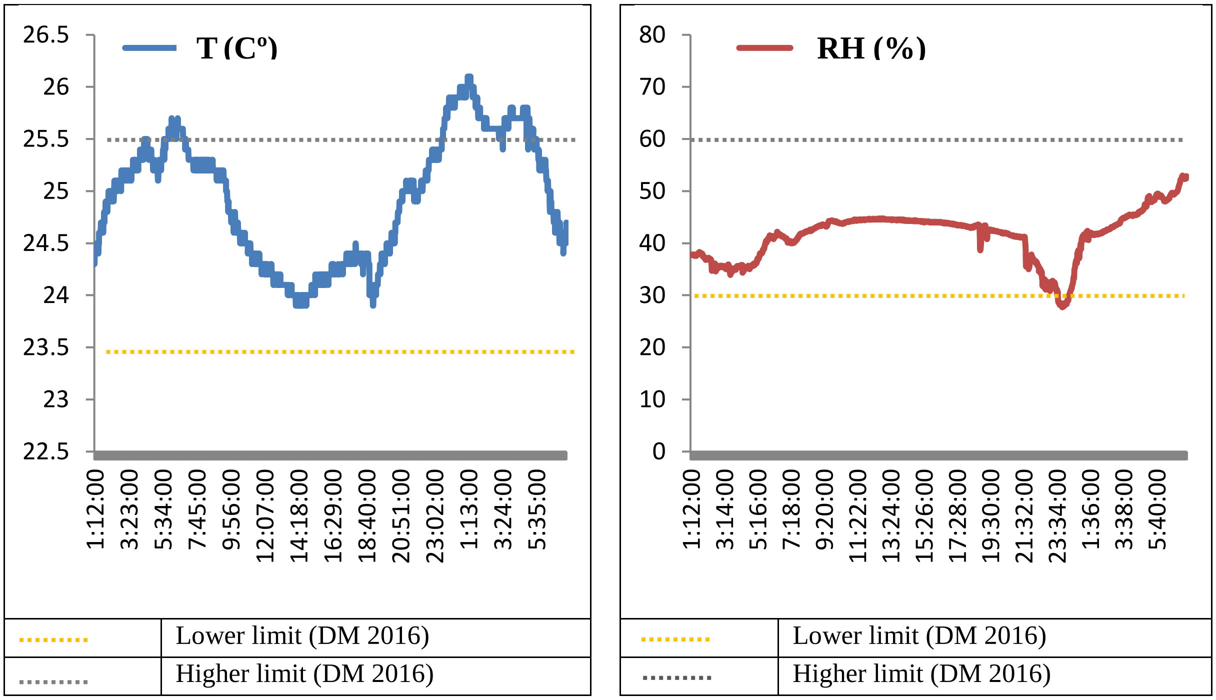


Figure ZZ-161: Continuously measured indoor levels of T and RH in House (33)

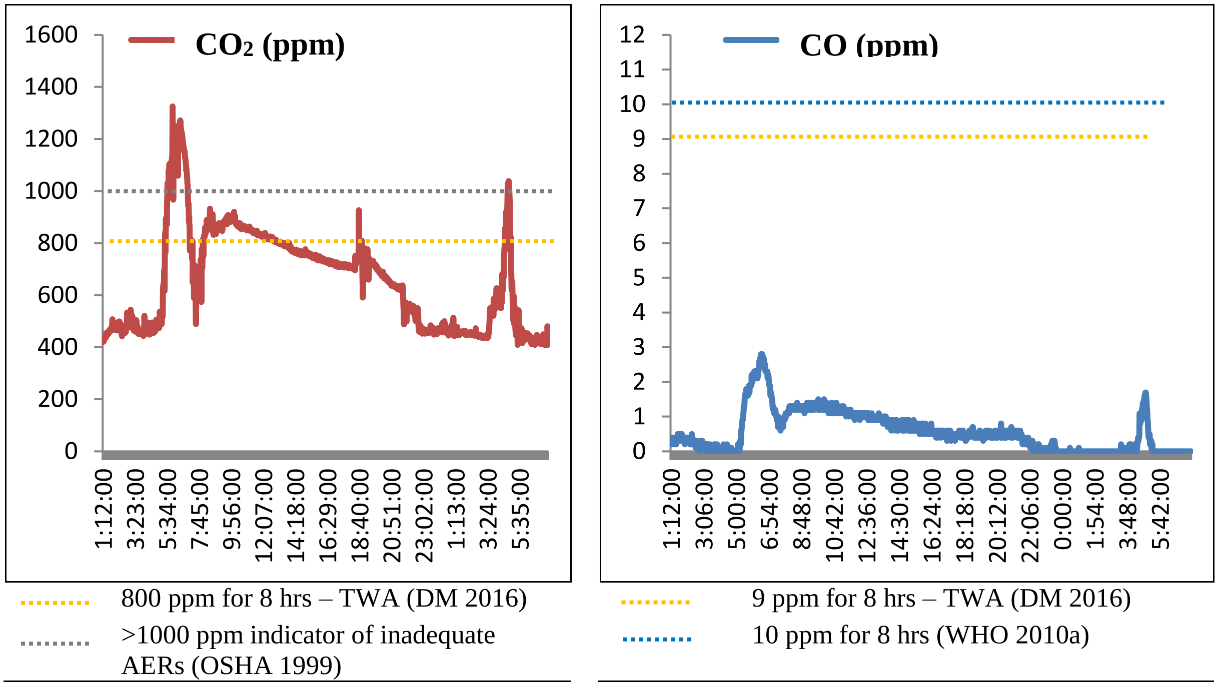


Figure ZZ-162: Compliance of $CO_2$ & CO levels in House (33) with established standards

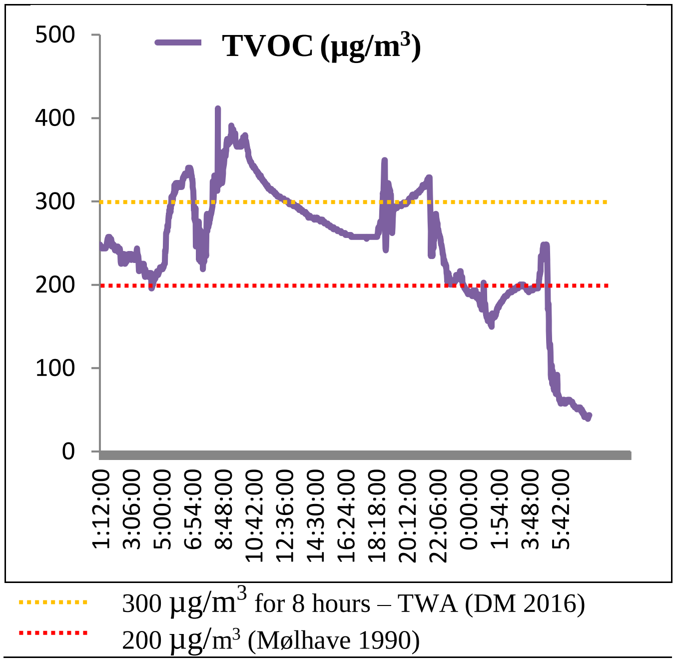


Figure ZZ-163: Compliance of indoor TVOC levels with established standards (House 33)

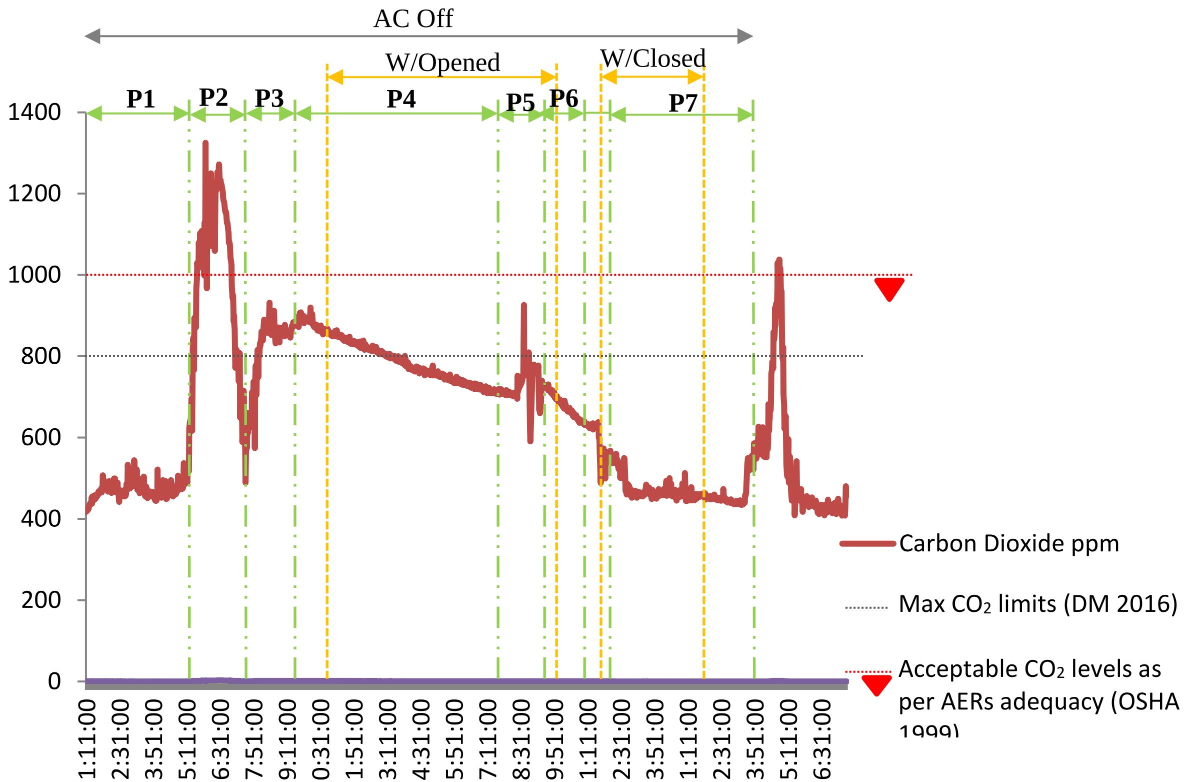


Figure ZZ-164: Occupancy profiles of the living hall projected on $CO_2$ levels (House 33)

Table ZZ-99: Occupancy profiles of the living hall during measurement period (House 33)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 01:11 – 05:30 | 0 | Natural (Infiltration) | 2 persons in other rooms |
| **P2** | 05:30 – 07:20 | 2 | Natural (Infiltration) | Sitting, breakfast |
| **P3** | 07:20 – 09:30 | 0 | Natural (Infiltration) | Went outside |
| **P4** | 09:30 – 17:30 | 0 | Natural:<br>09:30 – 10:40 (Infiltration)<br>10:40 – 05:30 (Infiltration & window) | 2 persons in other rooms |
| **P5** | 17:30 – 19:30 | 4 | Natural (Infiltration & window) | Watching TV, cleaning, cooking, dinner |
| **P6** | 19:30 – 21:00 | 1 | Natural:<br>19:30 – 19:55 (Infiltration & window)<br>19:55 – 21:00 (Infiltration) | Watching TV |
| **P7** | 21:00 – 22:00 | 2 | Natural:<br>21:00 – 21:45 (Infiltration)<br>21:45 – 22:00 (Infiltration & window) | Watching TV |
| **P8** | 22:00 – 04:00 | 2 | Natural:<br>22:00 – 01:45 (Infiltration & window)<br>01:45 – 04:00 (Infiltration) | 2 persons in other rooms |

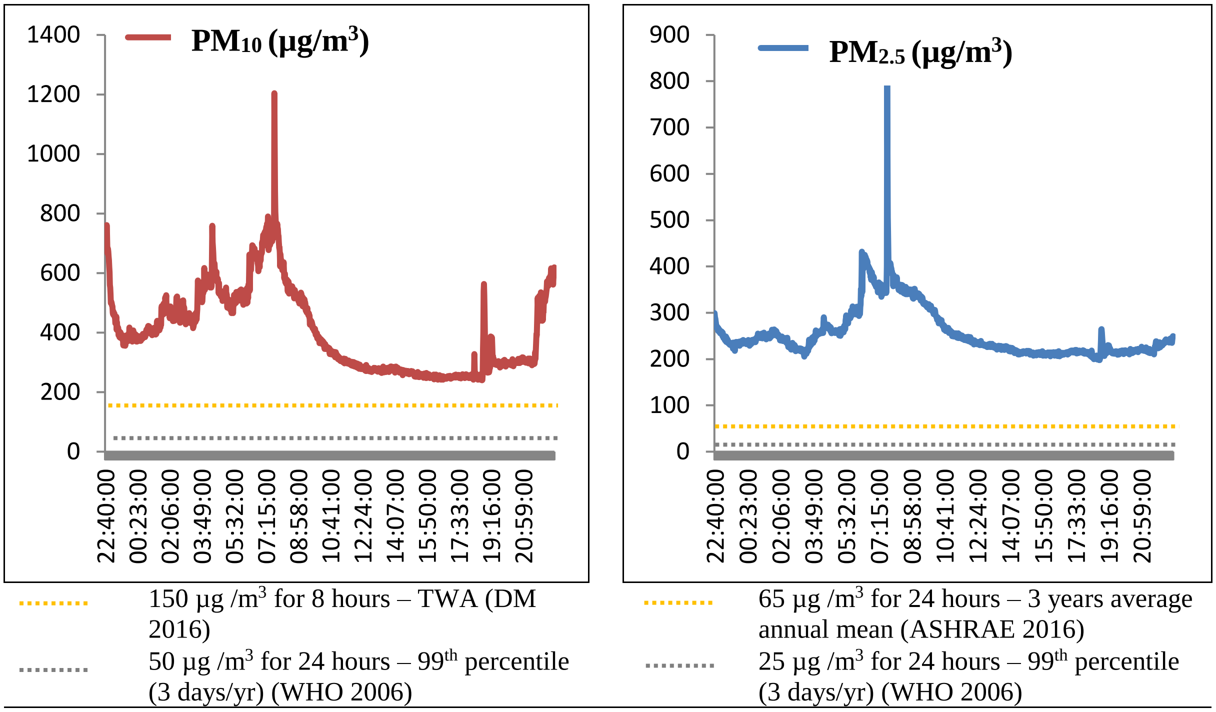


Figure ZZ-165: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 33)

### *House (34)*

Table ZZ-100: Levels of continuously measured variables indoor House (34)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 294.4 | 961.0 | 1.2 | 97.8 | 101.5 | 25.1 | 47.9 |
| **Mean** | 491.7 | 1371.5 | 4.6 | 1716.4 | 1818.5 | 26.6 | 55.0 |
| **Max** | 851.0 | 2105.0 | 10.3 | 5282.8 | 5772.9 | 27.2 | 59.5 |

Table ZZ-101: Spot measured variables in outdoor air of House (34)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 115 | 545 | 0.3 | 22.9 | 37.1 |

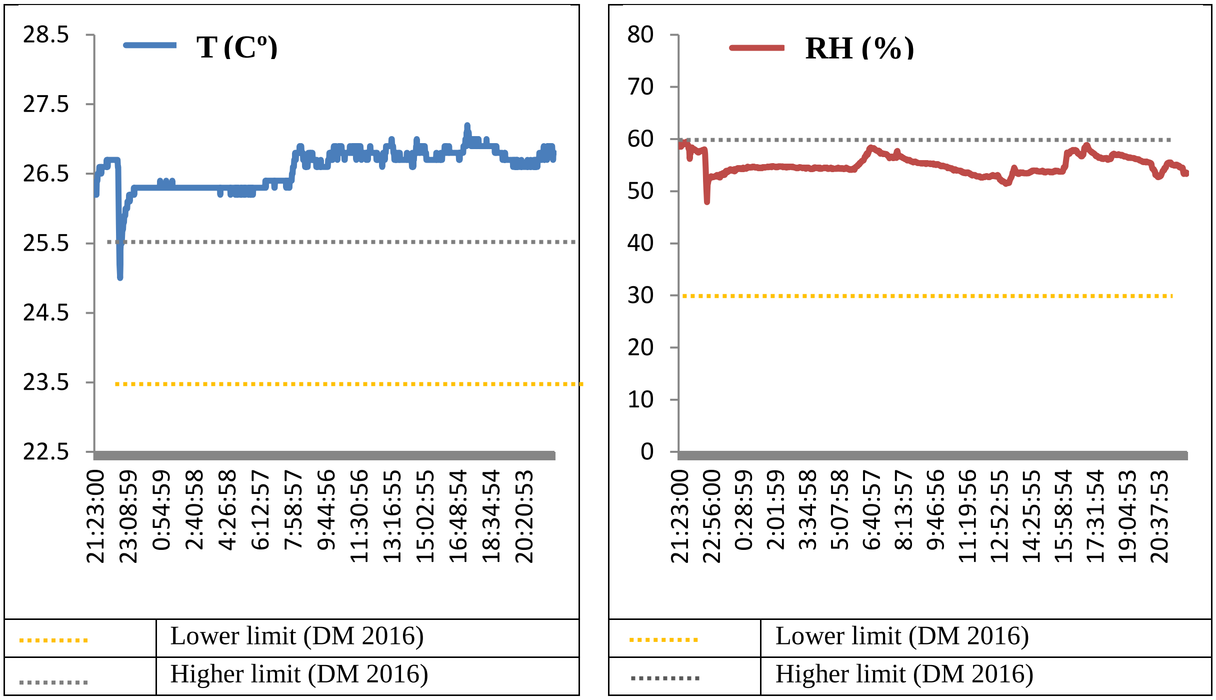


Figure ZZ-166: Continuously measured indoor levels of T and RH in House (34)

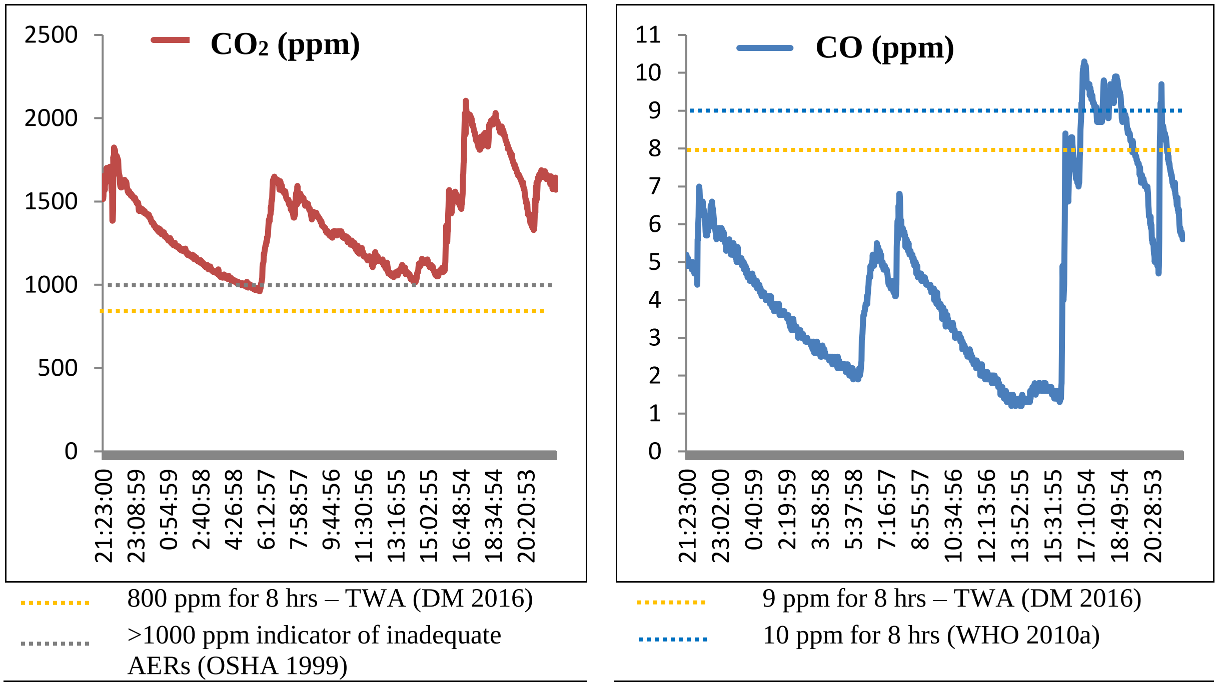


Figure ZZ-167: Compliance of $CO_2$ & CO levels in House (34) with established standards

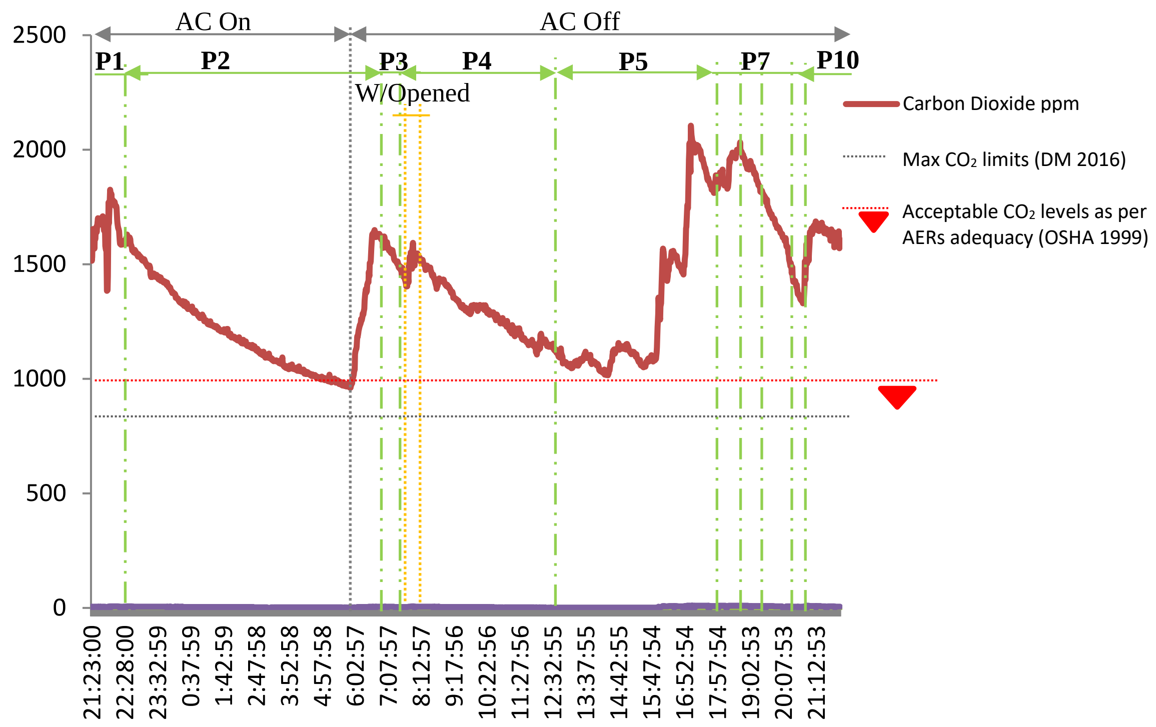


Figure ZZ-168: Occupancy profiles of the living hall projected on $CO_2$ levels (House 34)

Table ZZ-102: Occupancy profiles of the living hall during measurement (House 34)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 21:20 – 22:30 | 3 | Mechanical | Sitting/ Dinner |
| **P2** | 22:30 – 07:00 | 0 | Mixed:<br>22:30 – 06:00 Mechanical<br>06:00 – 07:00 Natural (Infiltration) | 3 persons in other rooms |
| **P3** | 07:00 – 07:30 | 2 | Natural (Infiltration) | Sitting |
| **P4** | 07:30 – 12:25 | 1 | Mixed:<br>07:30 – 08:05 Mechanical<br>08:05 – 12:25 Natural (Infiltration) | Sitting<br>Washing |
| **P5** | 12:25 – 18:00 | 2 | Natural (Infiltration) | Cooking |
| **P6** | 18:00 – 18:45 | 3 | ,, ,, ,, ,, ,, ,, | Sitting, lunch |
| **P7** | 18:45 – 19:00 | 2 | ,, ,, ,, ,, ,, ,, | Sitting |
| **P8** | 19:00 – 20:15 | 0 | ,, ,, ,, ,, ,, ,, | Went outside |
| **P9** | 20:15 – 20:45 | 2 | ,, ,, ,, ,, ,, ,, | Sitting |
| **P10** | 20:45 – 21:20 | 3 | ,, ,, ,, ,, ,, ,, | Sitting |

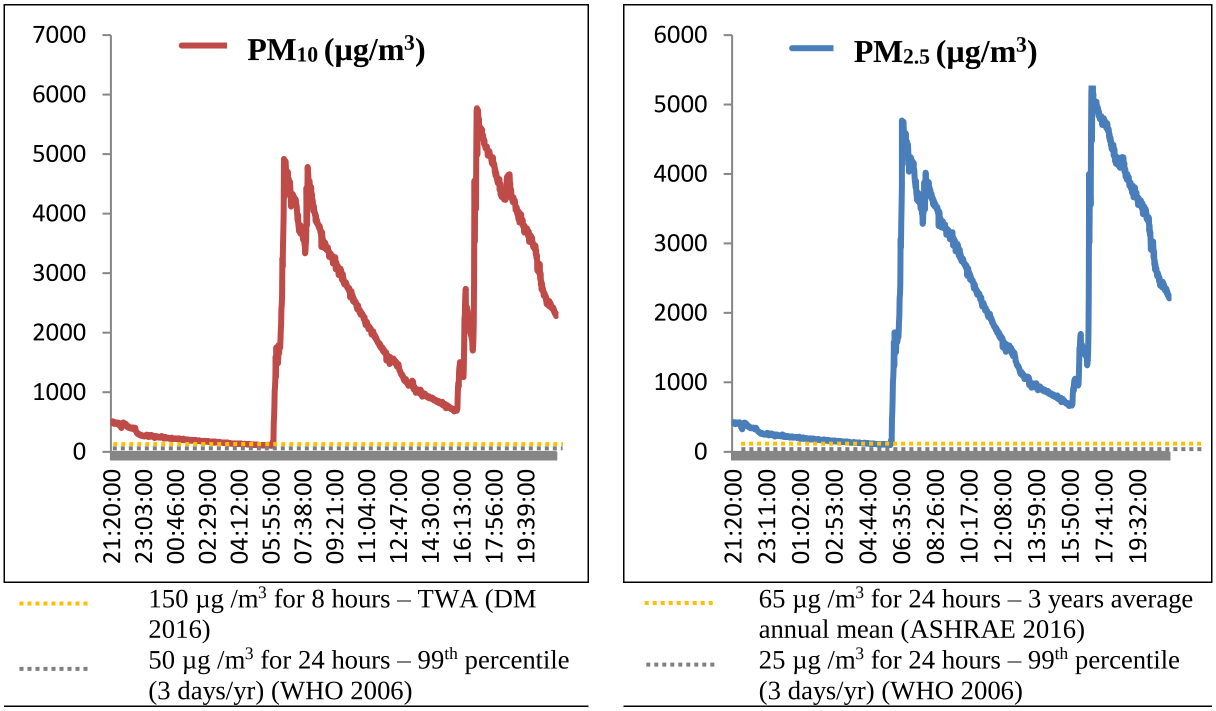


Figure ZZ-169: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 34)

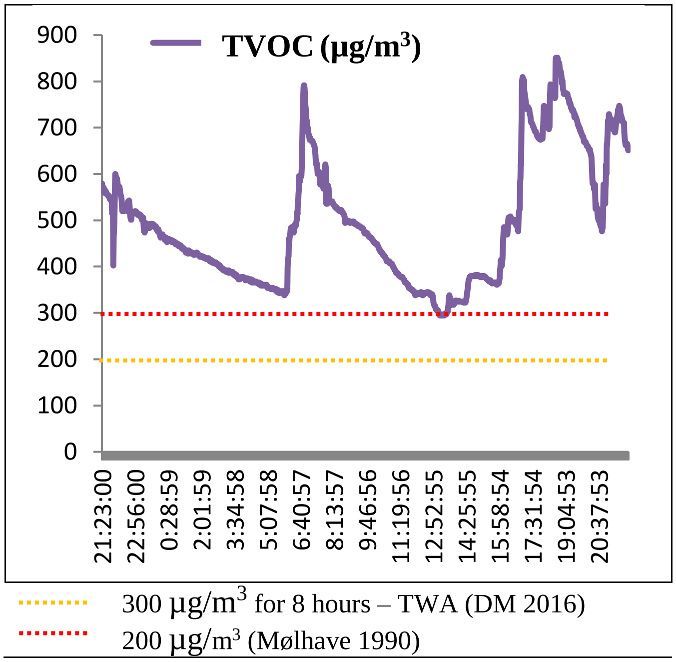


Figure ZZ-170: Compliance of indoor TVOC levels with established standards (House 34)

### *House (35)*

Table ZZ-103: Levels of continuously measured variables indoor House (35)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m$^3$)** | **$PM_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 87.4 | 430.0 | 0.1 | 67.7 | 75.3 | 22.7 | 27.3 |
| **Mean** | 151.8 | 604.2 | 0.3 | 118.9 | 195.7 | 26.0 | 39.7 |
| **Max** | 253.0 | 1250.0 | 1.1 | 394.8 | 1398.0 | 31.6 | 49.7 |

Table ZZ-104: Spot measured variables in outdoor air of House (35)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 135.7 | 431 | 0.3 | 22.9 | 65.7 |

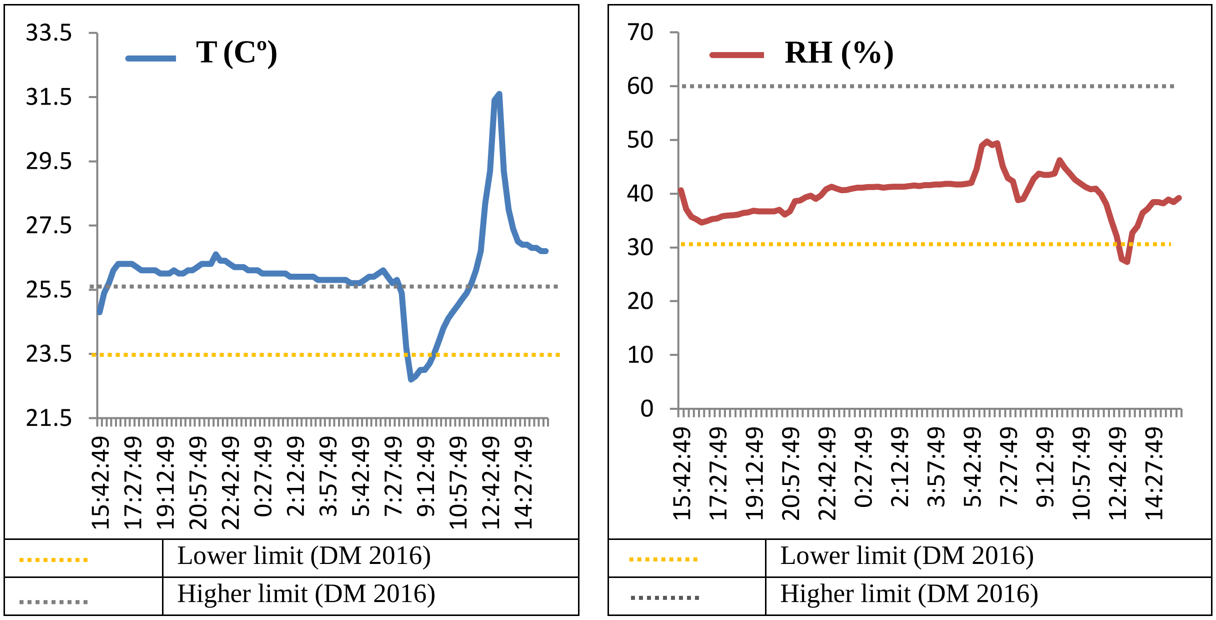


Figure ZZ-171: Continuously measured indoor levels of T and RH in House (35)

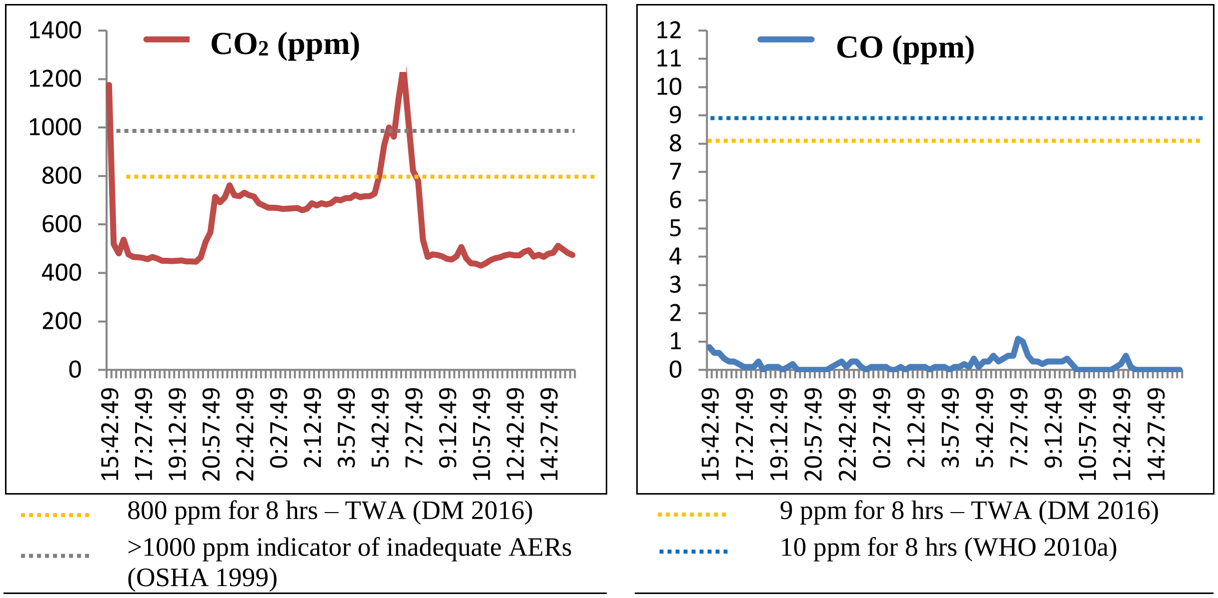


Figure ZZ-172: Compliance of $CO_2$ & CO levels in House (35) with established standards

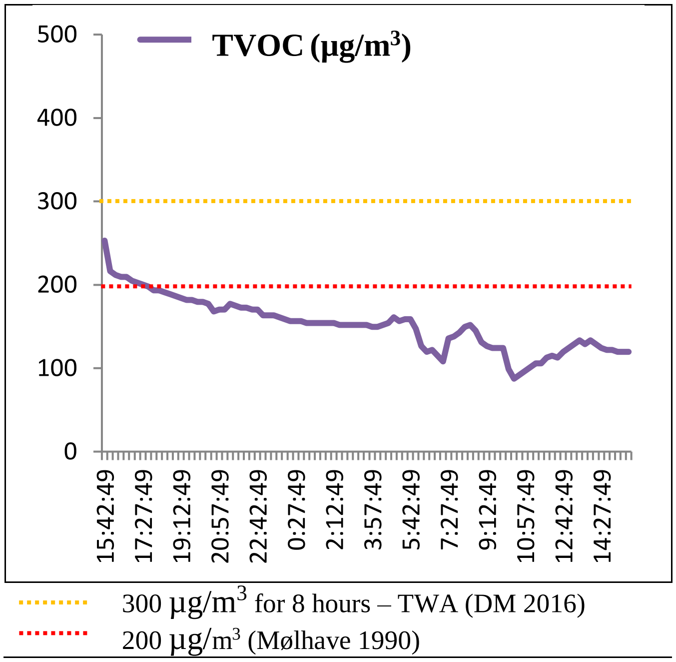


Figure ZZ-173: Compliance of indoor TVOC levels with established standards (House 35)

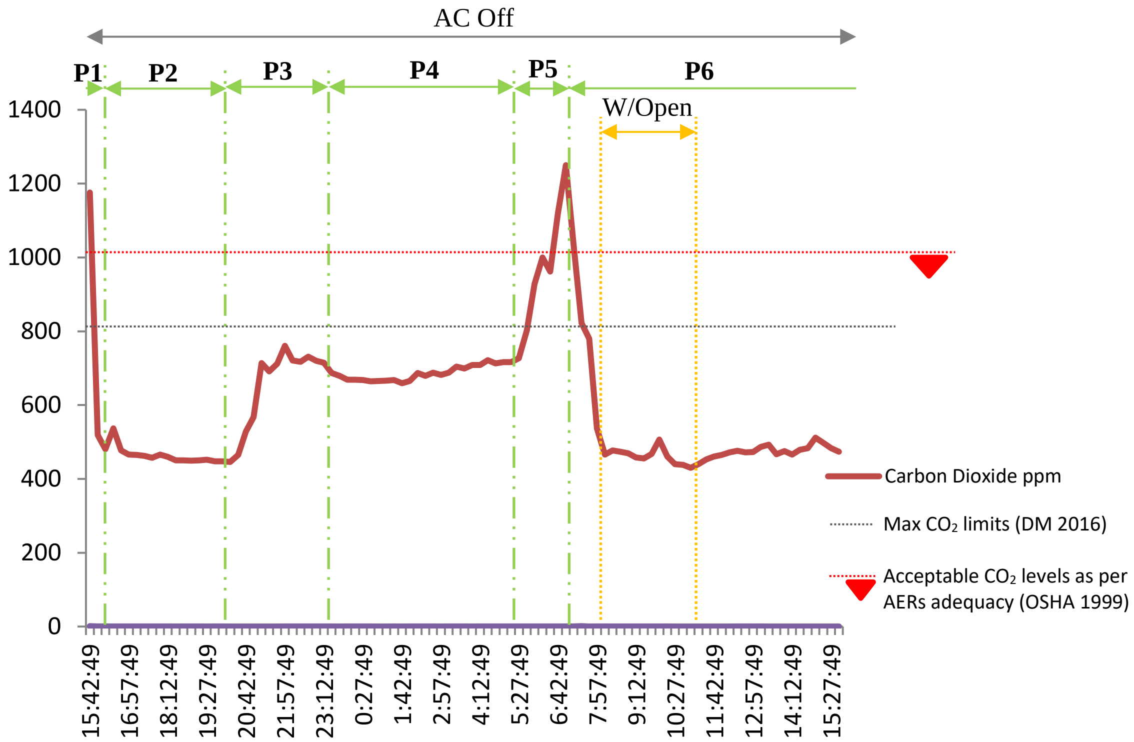


Figure ZZ-174: Occupancy profiles of the living hall projected on $CO_2$ levels (House 35)

Table ZZ-105: Occupancy profiles of the living hall during measurement (House 35)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 15:42 – 16:15 | 1 | Natural (Infiltration) | Daily cleaning, cooking |
| **P2** | 16:15 – 20:25 | 3 | ,, ,, ,, ,, ,, ,, | Sitting, lunch |
| **P3** | 20:25 – 23:15 | 5 | ,, ,, ,, ,, ,, ,, | Sitting, dinner |
| **P4** | 23:15 – 05:30 | 0 | ,, ,, ,, ,, ,, ,, | 5 occupants in other rooms |
| **P5** | 05:30 – 07:00 | 5 | ,, ,, ,, ,, ,, ,, | Cooking, breakfast |
| **P6** | 07:00 – 15:42 | 1 | Natural:<br>07:00 – 08:00 (Infiltration)<br>08:00 – 11:00 (Window)<br>11:00 – 15:42 (Infiltration) | Daily cleaning, cooking |

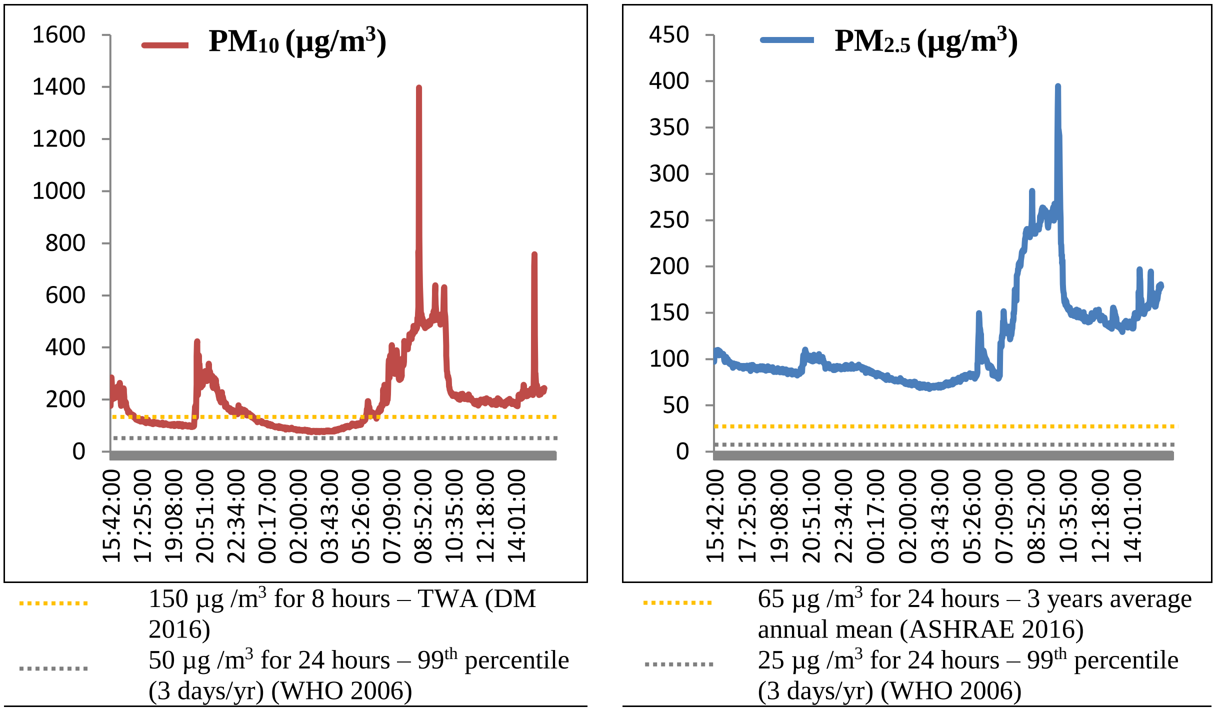


Figure ZZ-175: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 35)

### *House (36)*

Figure ZZ-176: Levels of continuously measured variables indoor House (36)

| | **TVOC (µg/m³)** | **CO₂ (ppm)** | **CO (ppm)** | **PM2.5 (µg/m³)** | **PM10 (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 236.9 | 508.0 | 0.1 | 213.7 | 270.1 | 27.1 | 25.1 |
| **Mean** | 302.9 | 662.5 | 0.7 | 354.0 | 489.6 | 27.6 | 37.2 |
| **Max** | 1009.7 | 1208.0 | 1.6 | 1073.8 | 1510.9 | 28.7 | 42.5 |

Table ZZ-106: Spot measured variables in outdoor air of House (36)

| | **TVOC (µg/m³)** | **CO₂ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 182 | 461 | 0.01 | 0.5 | 26.7 |

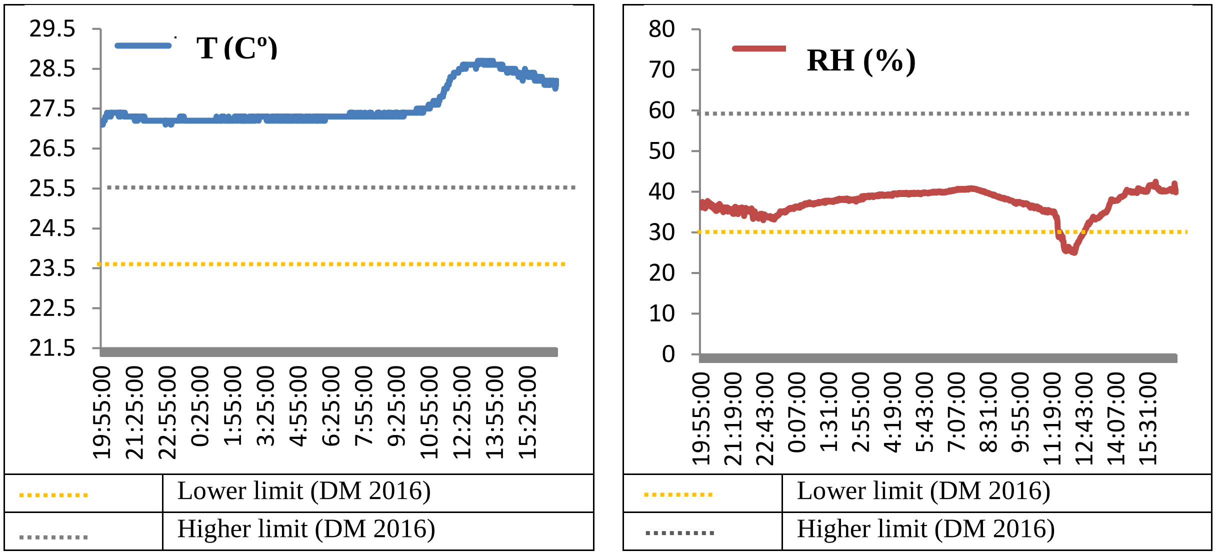


Figure ZZ-177: Continuously measured indoor levels of T and RH in House (36)

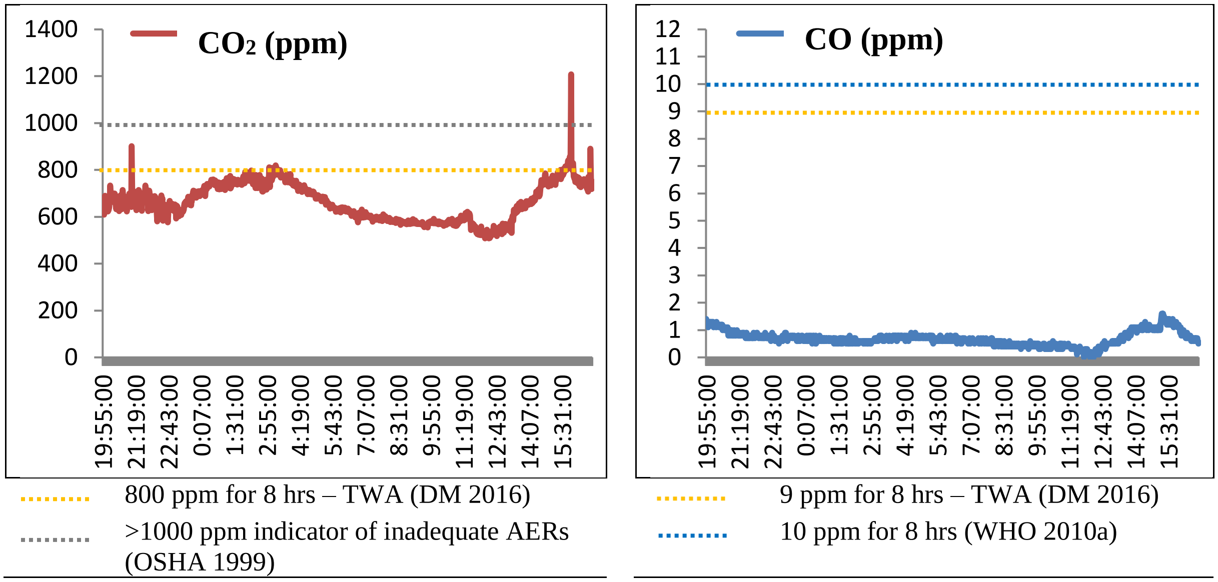


Figure ZZ-178: Compliance of $CO_2$ & CO levels in House (36) with established standards

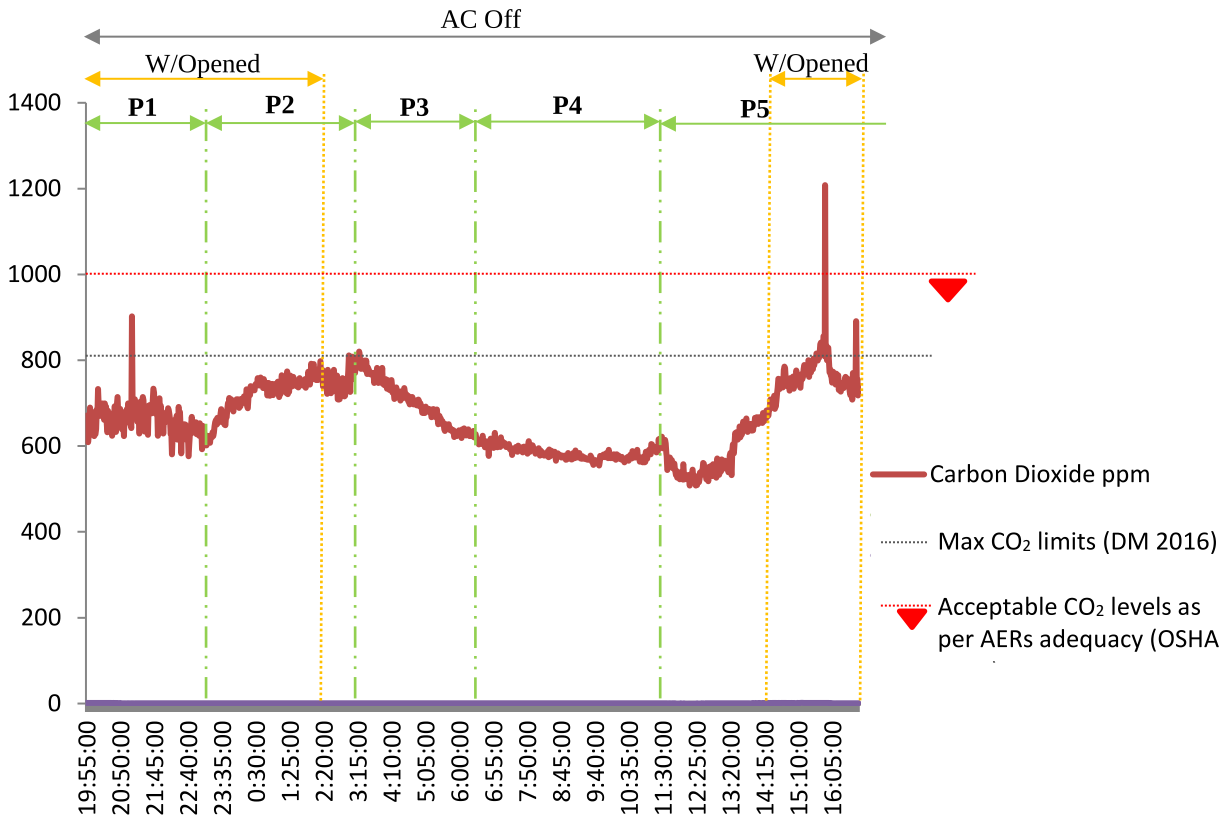


Figure ZZ-179: Occupancy profiles of the living hall projected on $CO_2$ levels (House 36)

Table ZZ-107: Occupancy profiles of the living hall during measurement (House 36)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 19:55 – 23:00 | 4 | Natural (Infiltration and Window) | Sitting |
| **P2** | 23:00 – 03:00 | 2 | Natural:<br>23:00 – 02:15 (Infiltration and Window)<br>02:15 – 03:00 (Infiltration) | Sitting/ Dinner<br>Other 2 in rooms |
| **P3** | 03:00 – 06:30 | 0 | Natural (Infiltration) | 4 persons in other rooms |
| **P4** | 06:30 – 11:30 | 0 | Natural (Infiltration) | 2 persons in other rooms |
| **P5** | 11:30 – 18:30 | 2 | Natural:<br>11:30 – 14:15 (Infiltration)<br>14:15 – 16:45 (Infiltration and Window)<br>16:45 – 18:30 (Infiltration) | Daily cleaning, cooking<br>Breakfast, lunch<br>Sitting |

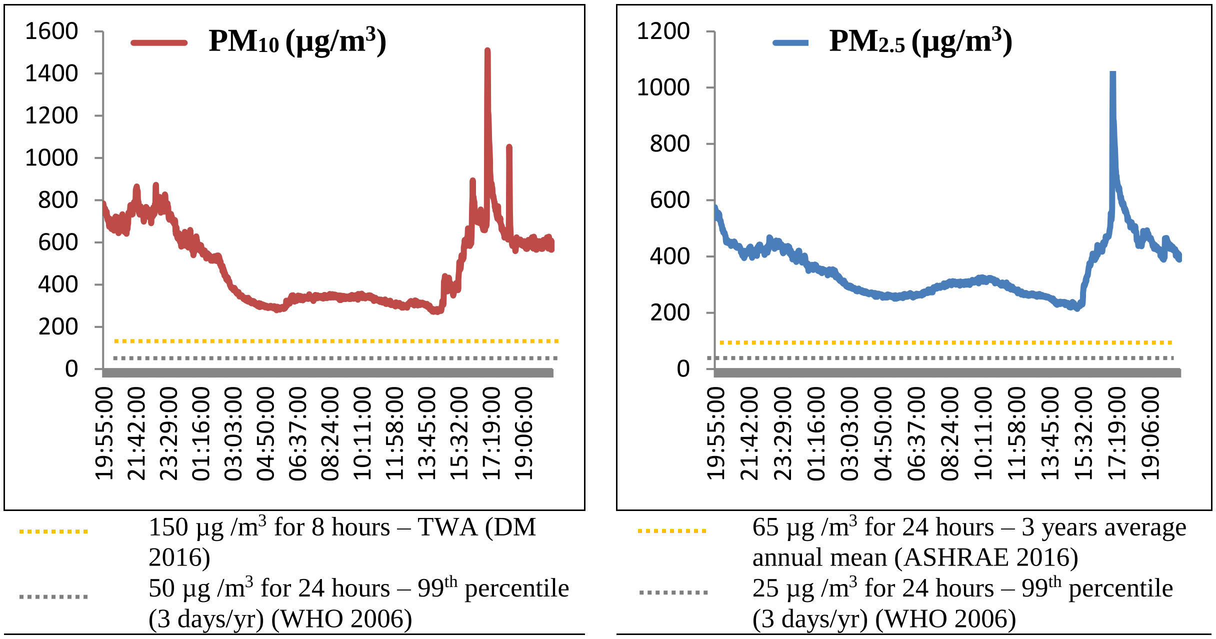


Figure ZZ-180: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 36)

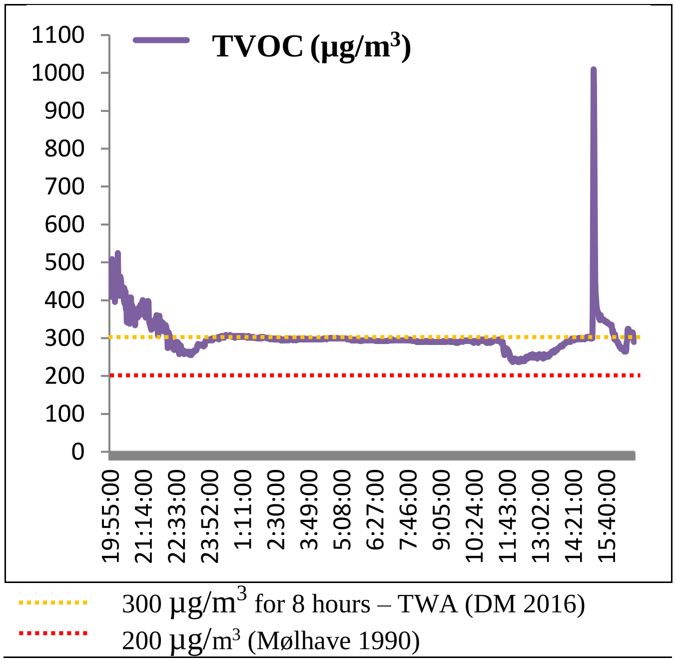


Figure ZZ-181: Compliance of indoor TVOC levels with established standards (House 36)

## *House (37)*

Table ZZ-108: Levels of continuously measured variables indoor House (37)

| | **TVOC ($\mu g/m^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ ($\mu g/m^3$)** | **$PM_{10}$ ($\mu g/m^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 29.9 | 409.0 | 0.1 | 281.7 | 383.6 | 24.9 | 40.8 |
| **Mean** | 144.5 | 543.7 | 0.7 | 820.6 | 955.1 | 26.8 | 51.4 |
| **Max** | 600.3 | 1164.0 | 3.2 | 7207.5 | 8255.7 | 27.8 | 58.9 |

Table ZZ-109: Spot measured variables in outdoor air of House (37)

| | **TVOC ($\mu g/m^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 124.2 | 454.0 | 1.2 | 25.7 | 46.2 |

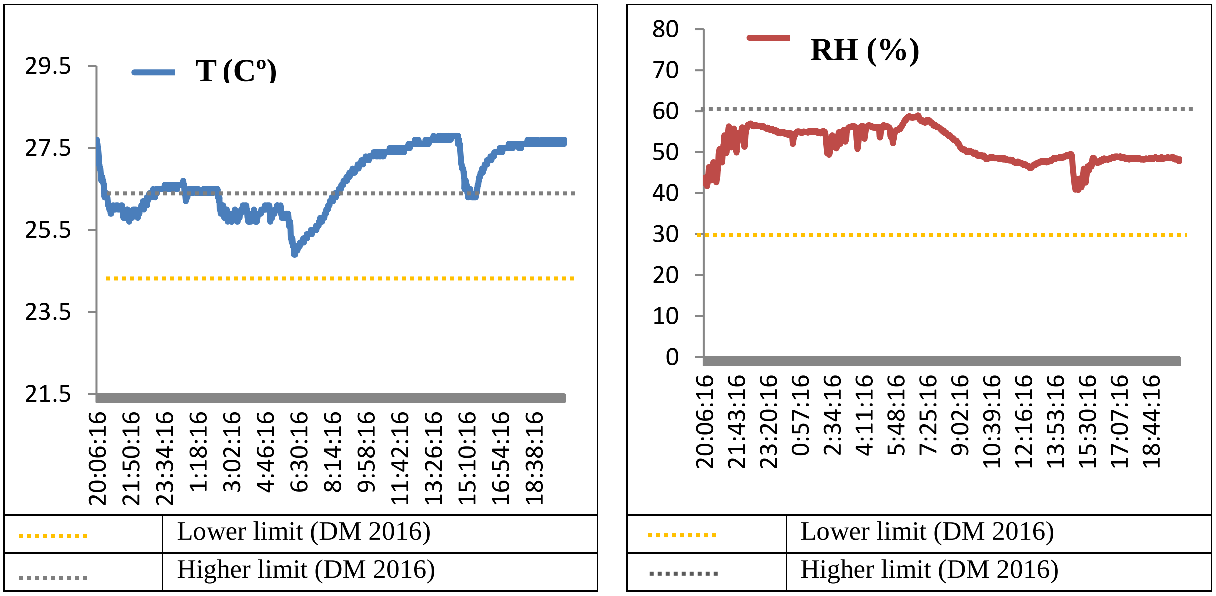


Figure ZZ-182: Continuously measured indoor levels of T and RH in House (37)

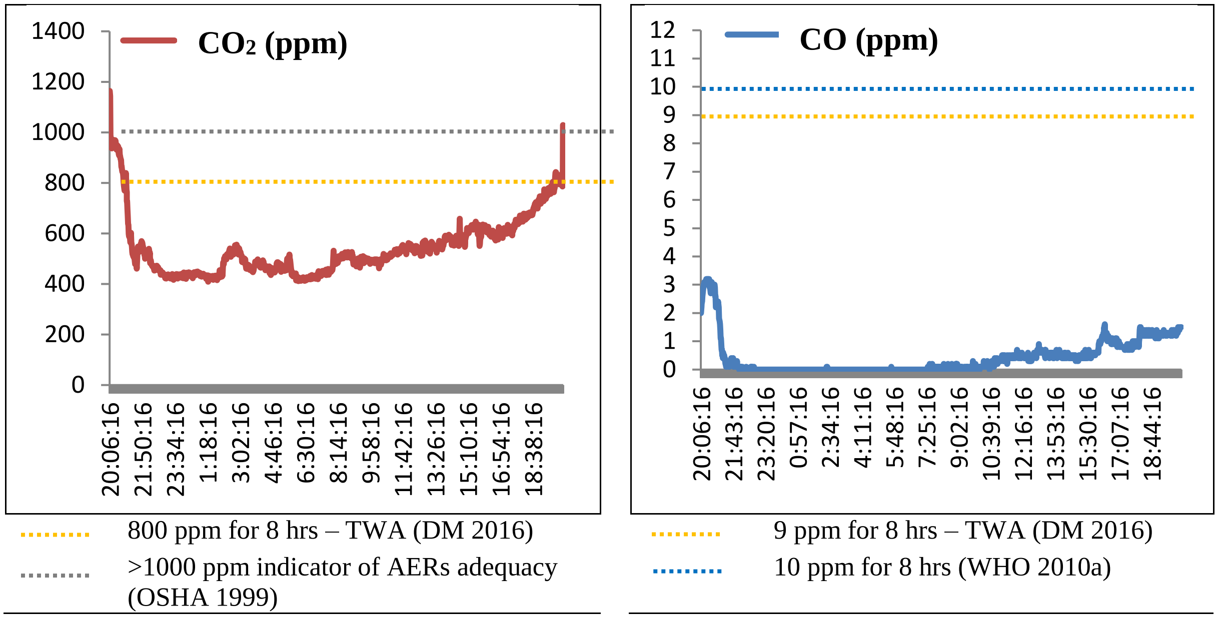


Figure ZZ-183: Compliance of $CO_2$ & CO levels in House (37) with established standards

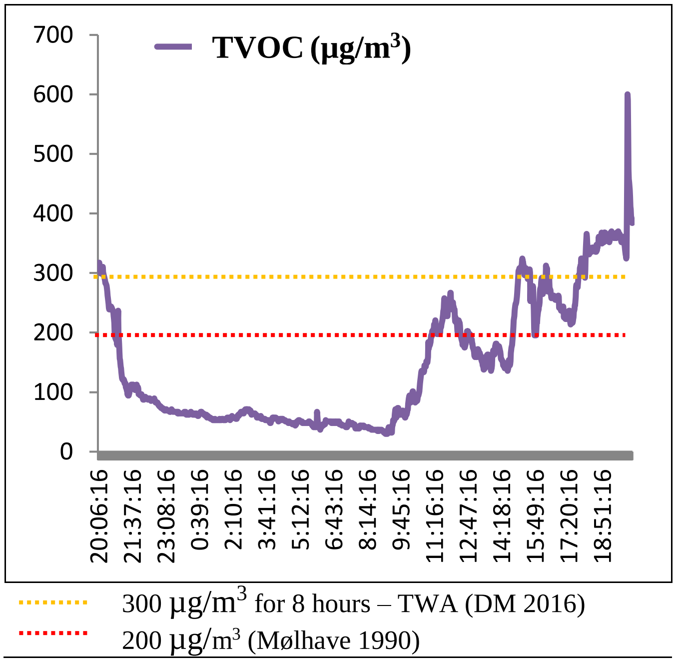


Figure ZZ-184: Compliance of indoor TVOC levels with established standards (House 37)

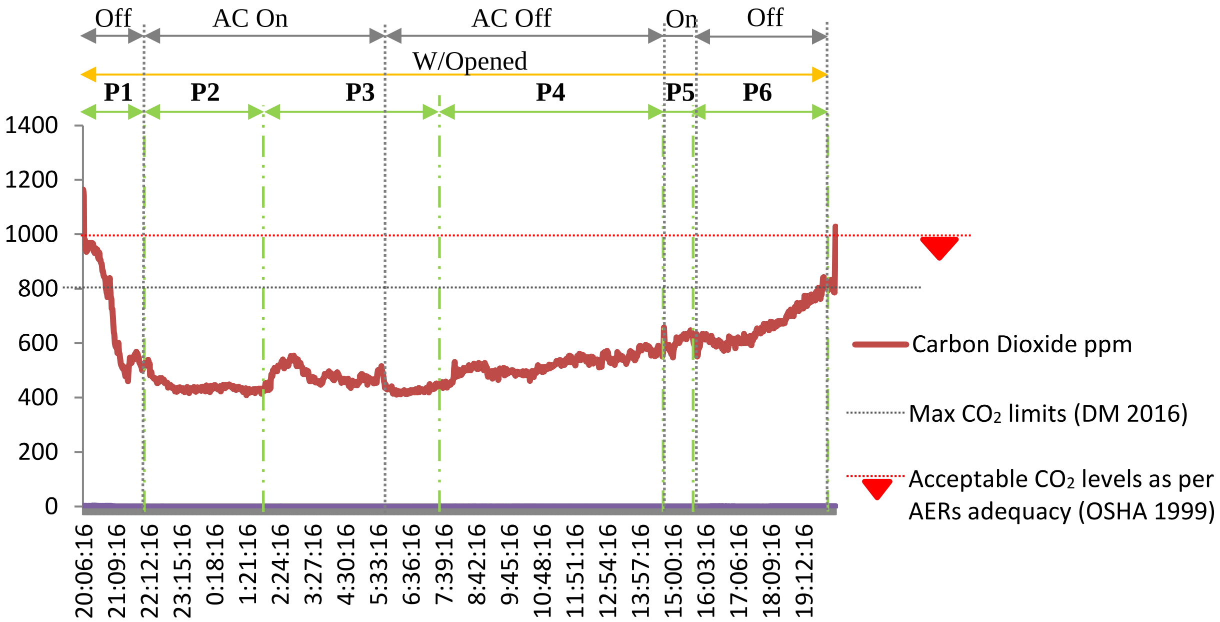
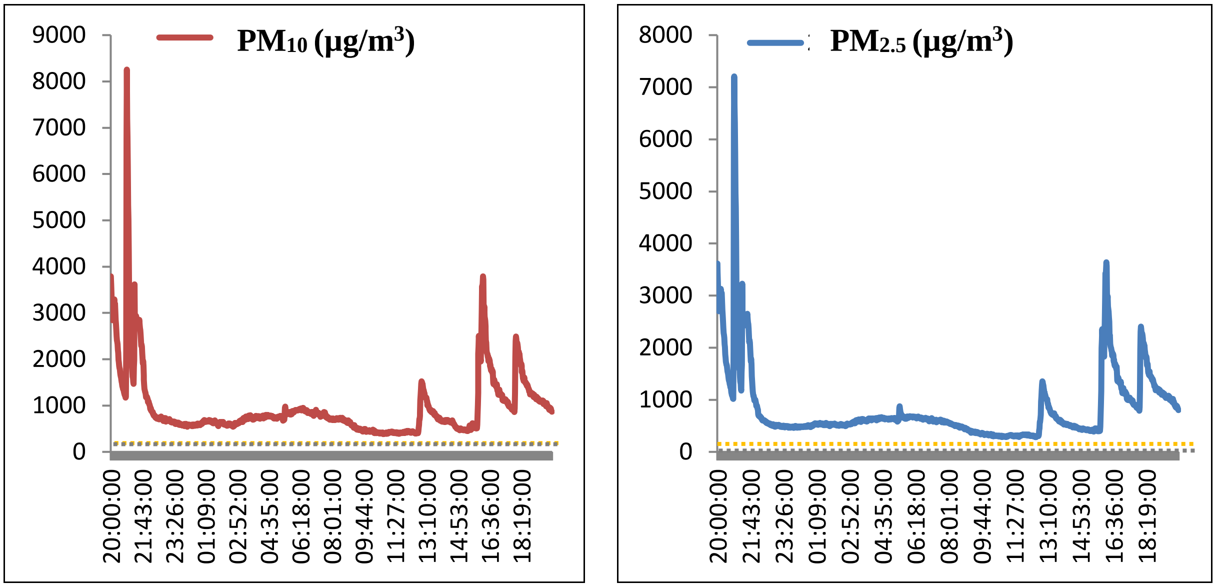


Figure ZZ-185: Occupancy profiles of the living hall projected on $CO_2$ levels (House 37)

Table ZZ-110: Occupancy profiles of the living hall during measurement (House 37)

| **Profile** | **Time** | **Occupants** | **System** | **Activities** |
|---|---|---|---|---|
| **P1** | 20:00 – 22:00 | 4 | Natural (Infiltration & Window) | Sitting, having a visitor |
| **P2** | 22:00 – 02:00 | 0 | Mixed:<br>Mechanical & Natural (Infiltration & Window) | 4 persons in other rooms |
| **P3** | 02:00 – 07:30 | 2 | Mixed:<br>02:00 – 05:41 Mechanical<br>05:41 – 07:30 Natural (Infiltration & Window) | Sleeping, another 2 persons in other rooms |
| **P4** | 07:30 – 14:45 | 1 | Natural (Infiltration & Window) | Daily cleaning, breakfast, sitting |
| **P5** | 14:45 – 15:37 | 2 | Mixed:<br>Mechanical & Natural (Infiltration & Window) | Sitting, lunch |
| **P6** | 15:37 – 20:00 | 1 | Natural (Infiltration & Window) | Cooking, sitting |



| | | | |
|---|---|---|---|
| ⋯⋯ | 150 µg /m³ for 8 hours – TWA (DM 2016) | ⋯⋯ | 65 µg /m³ for 24 hours – 3 years average annual mean (ASHRAE 2016) |
| ⋯⋯ | 50 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) | ⋯⋯ | 25 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure ZZ-186: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 37)

### *House (38)*

Table ZZ-111: Levels of continuously measured variables indoor House (38)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 906.2 | 470.0 | 0.1 | 119.2 | 138.7 | 23.9 | 32.6 |
| **Mean** | 4005.5 | 740.9 | 1.1 | 253.4 | 391.9 | 27.5 | 40.9 |
| **Max** | 7031.1 | 1568.0 | 5.1 | 419.9 | 806.1 | 29.4 | 49.8 |

Table ZZ-112: Spot measured variables in outdoor air of House (38)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 559 | 474 | 0.4 | 30.9 | 22.6 |

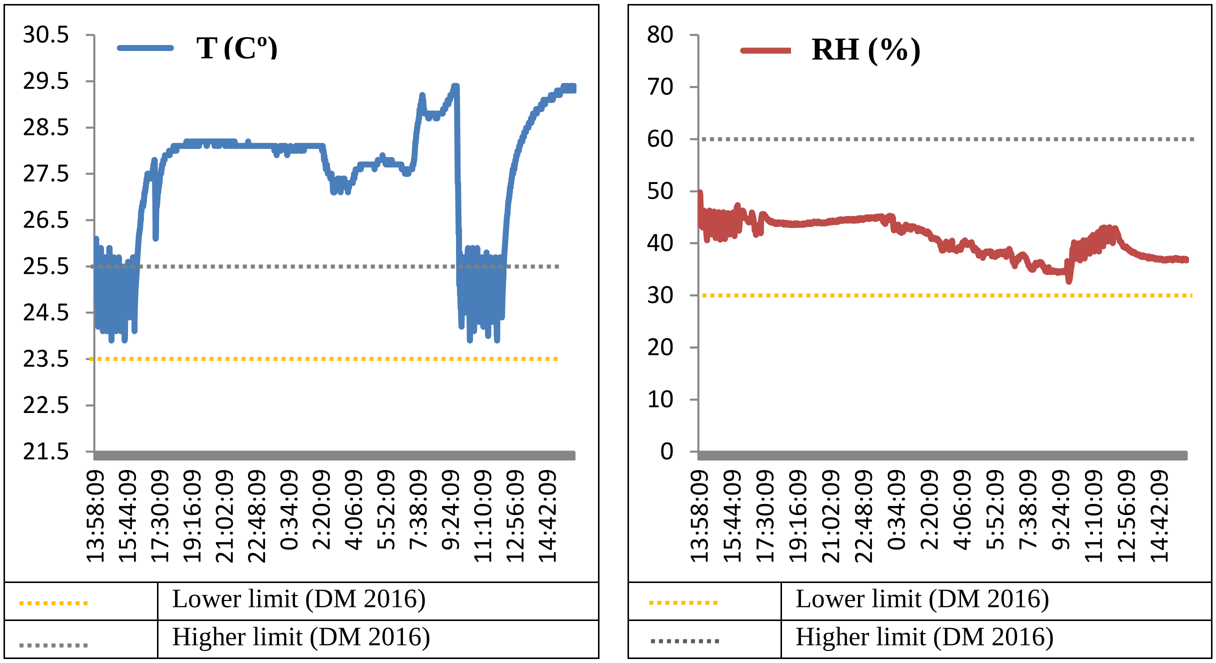


Figure ZZ-187: Continuously measured indoor levels of T and RH in House (38)

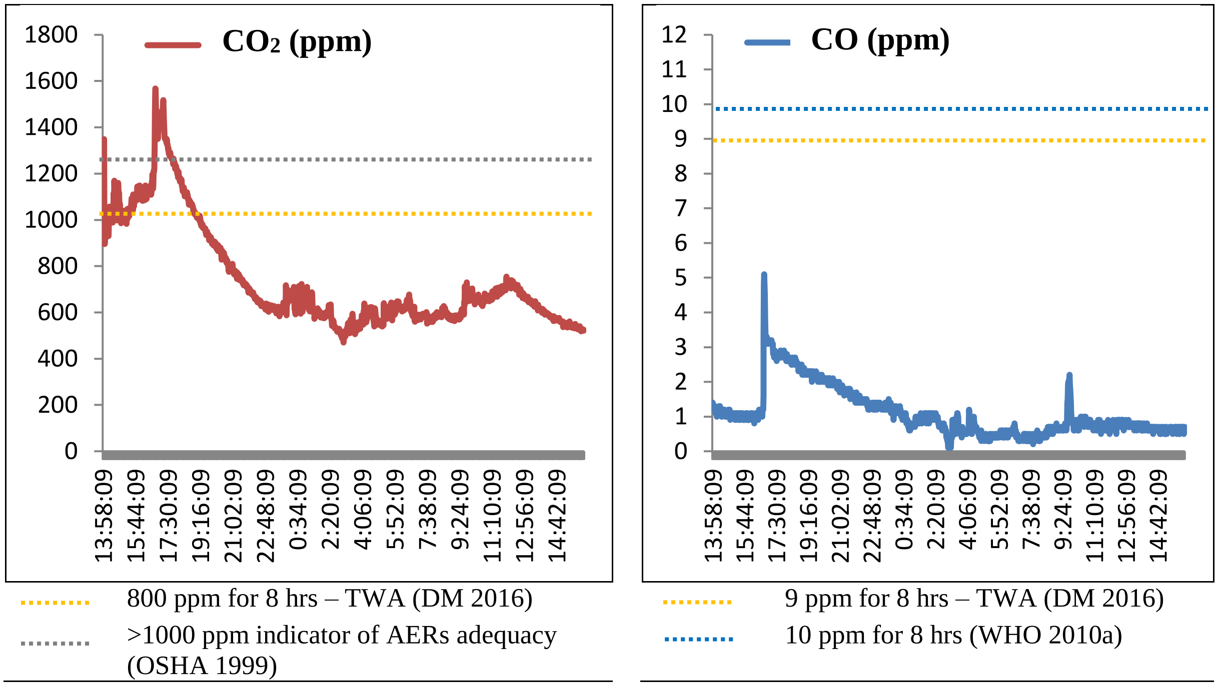


Figure ZZ-188: Compliance of $CO_2$ & CO levels in House (38) with established standards

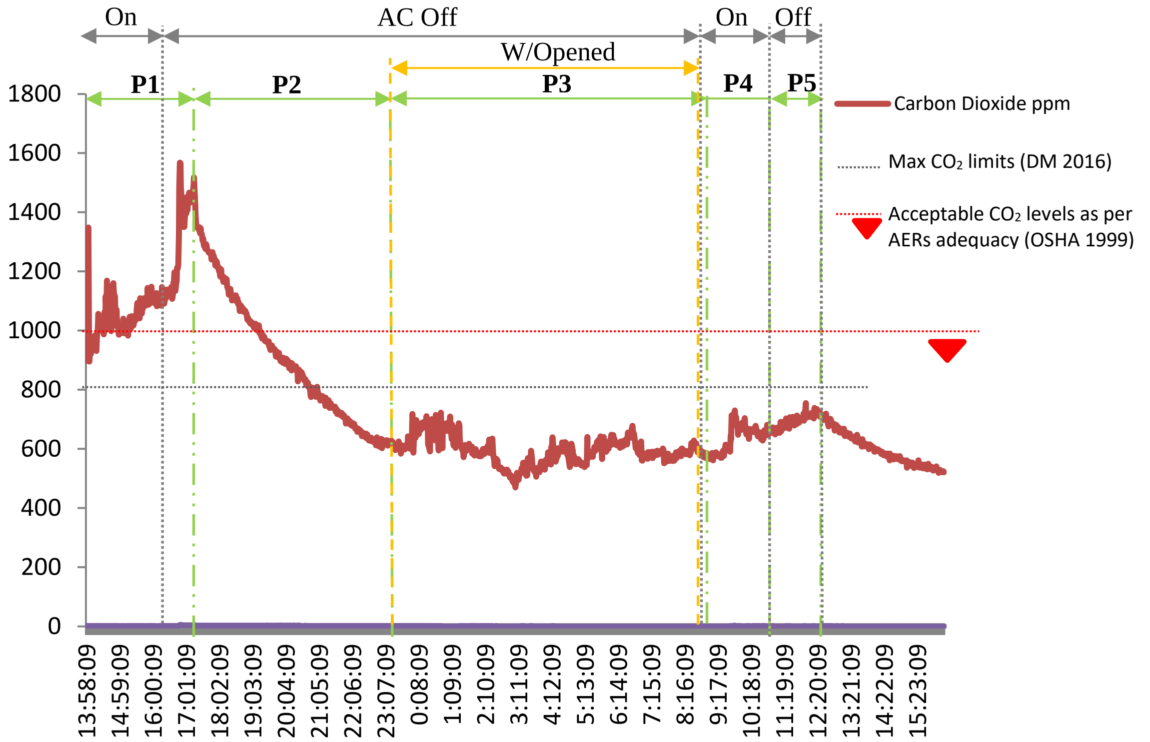


Figure ZZ-189: Occupancy profiles of the living hall projected on $CO_2$ levels (House 38)

Table ZZ-113: Occupancy profiles of the living hall during measurement (House 38)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 13:50 – 17:20 | 4 | Mixed:<br>13:50 – 16:20 Mechanical<br>16:20 – 17:20 Natural (Infiltration) | Sitting, daily cleaning, cooking, lunch, daughter experimenting i.e. Chemical games, making slime, & burning substances. |
| **P2** | 17:20 – 23:50 | 0 | Natural (Infiltration) | Went outside |
| **P3** | 23:50 – 10:05 | 0 | Mixed:<br>23:50 – 09:50 Natural (Infiltration & Window)<br>09:50 – 10:05 Mechanical | 4 persons in other rooms |
| **P4** | 10:05 – 12:15 | 1 | Mechanical | Sitting, daughter experimenting |
| **P5** | 12:15 – 14:00 | 0 | Natural (Infiltration) | Went outside |

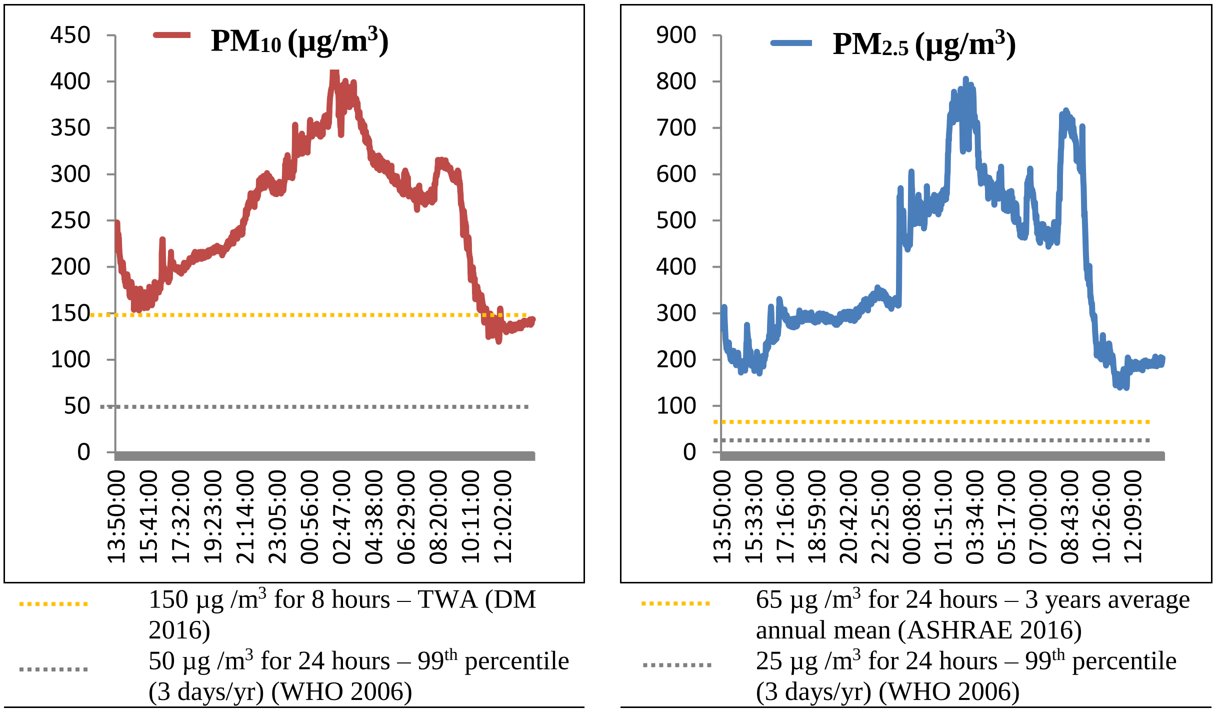


Figure ZZ-190: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 38)

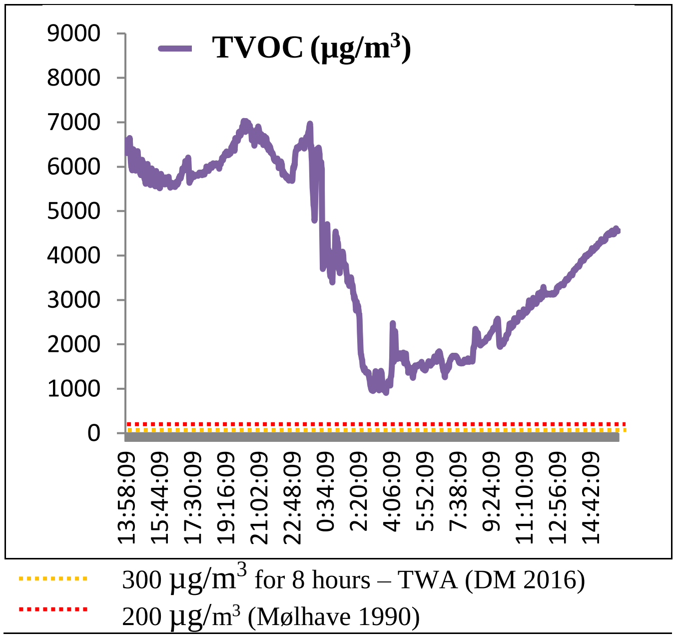


Figure ZZ-191: Compliance of indoor TVOC levels with established standards (House 38)

## ***House (39)***

Table ZZ-114: Levels of continuously measured variables indoor House (39)

| | **TVOC ($\mu g/m^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ ($\mu g/m^3$)** | **$PM_{10}$ ($\mu g/m^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 276.0 | 399.0 | 0.1 | 160.6 | 207.6 | 25.9 | 31.5 |
| **Mean** | 496.3 | 577.2 | 0.8 | 219.9 | 306.1 | 26.6 | 35.2 |
| **Max** | 1288.0 | 890.0 | 2.6 | 310.8 | 772.9 | 28.7 | 40.8 |

Table ZZ-115: Spot measured variables in outdoor air of House (39)

| | **TVOC ($\mu g/m^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 220.8 | 521.0 | 0.8 | 27.9 | 26.4 |

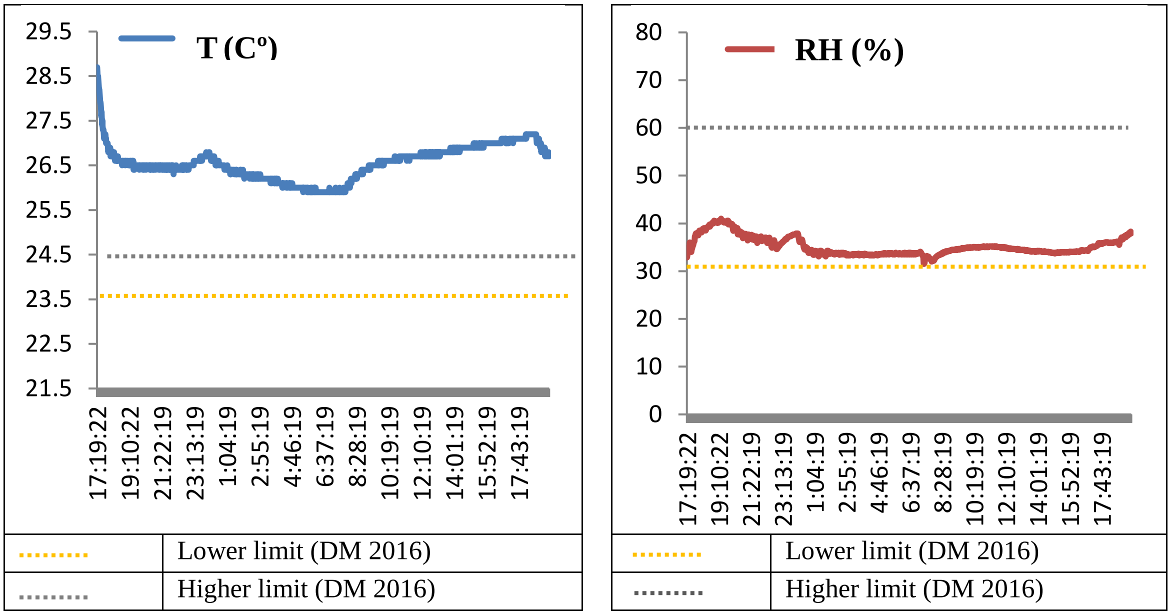


Figure ZZ-192: Continuously measured indoor levels of T and RH in House (39)

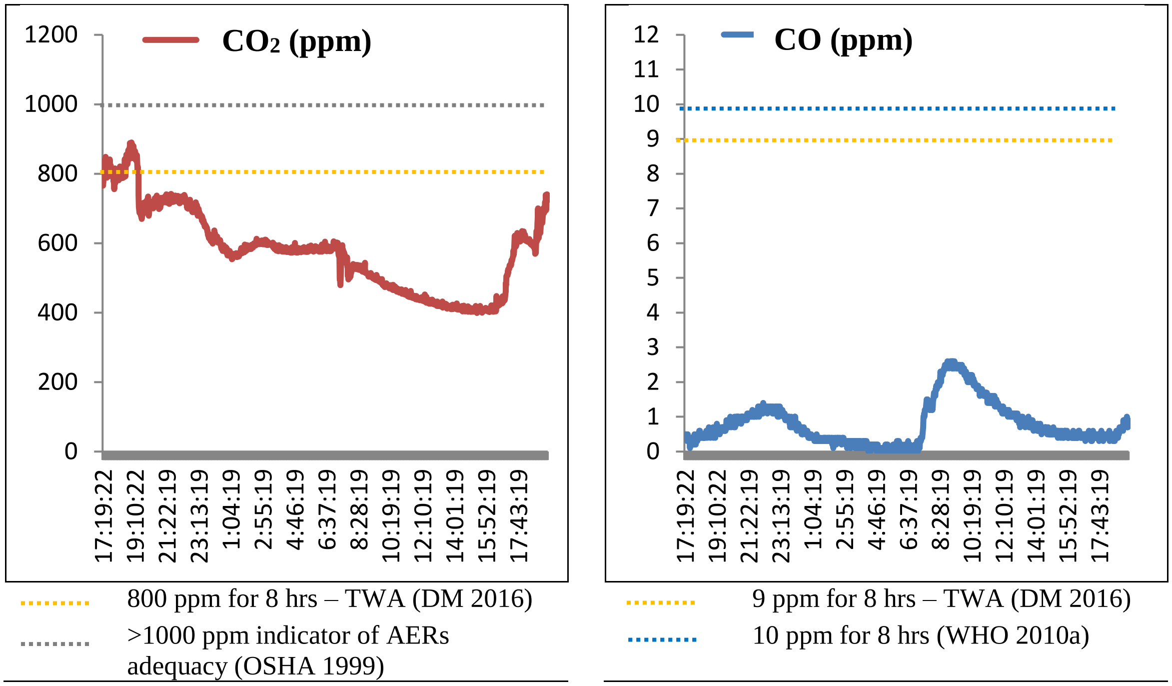


Figure ZZ-193: Compliance of $CO_2$ & CO levels in House (39) with established standards

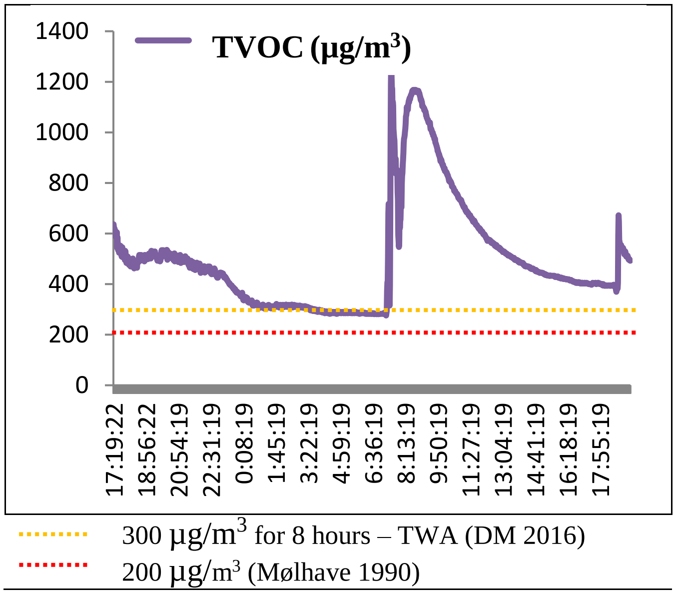


Figure ZZ-194: Compliance of indoor TVOC levels with established standards (House 39)

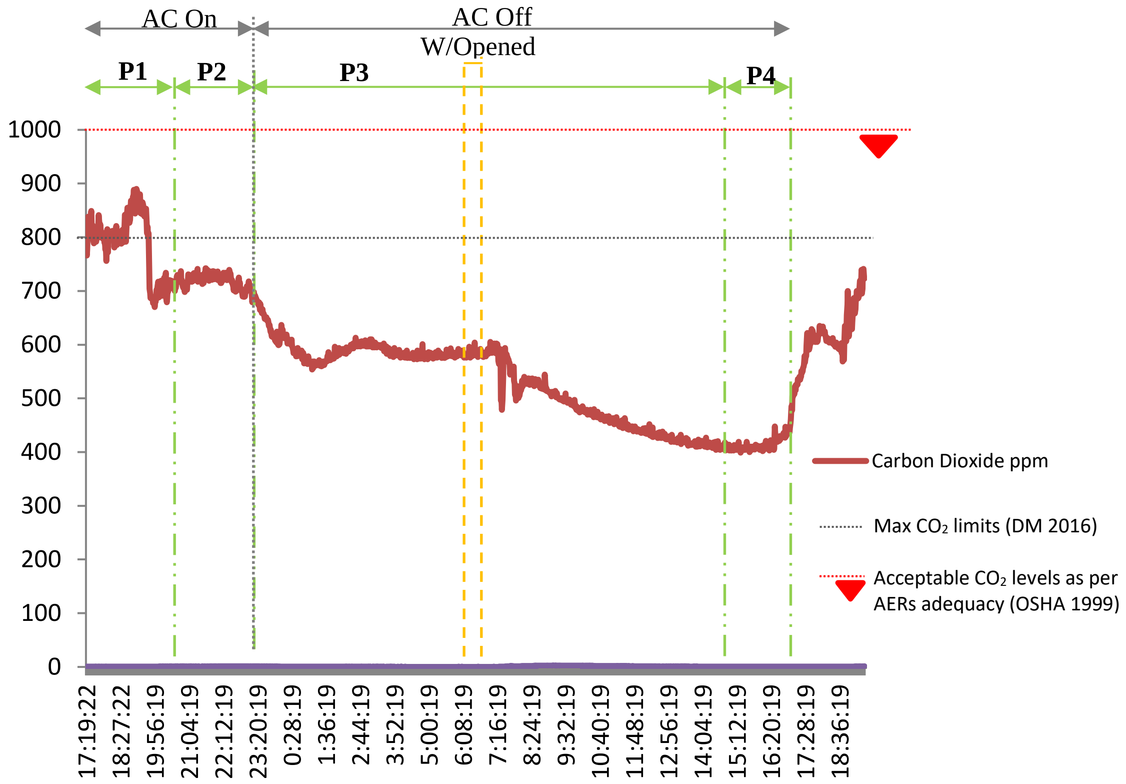


Figure ZZ-195: Occupancy profiles of the living hall projected on $CO_2$ levels (House 39)

Table ZZ-116: Occupancy profiles of the living hall during measurement (House 39)

| **Profile** | **Time** | **Occupants** | **System** | **Activities** |
|---|---|---|---|---|
| **P1** | 17:19 – 20:30 | 3 | Mechanical | Sitting |
| **P2** | 20:30 – 23:30 | 1 | Mechanical | Sitting |
| **P3** | 23:30 – 16:15 | 0 | Natural:<br>23:30 – 07:00 Natural (Infiltration)<br>07:00 – 07:15 Natural (Window)<br>07:15 – 16:15 Natural (Infiltration) | 2 persons in another room |
| **P4** | 16:15 – 18:30 | 2 | Natural (Infiltration) | Sitting |

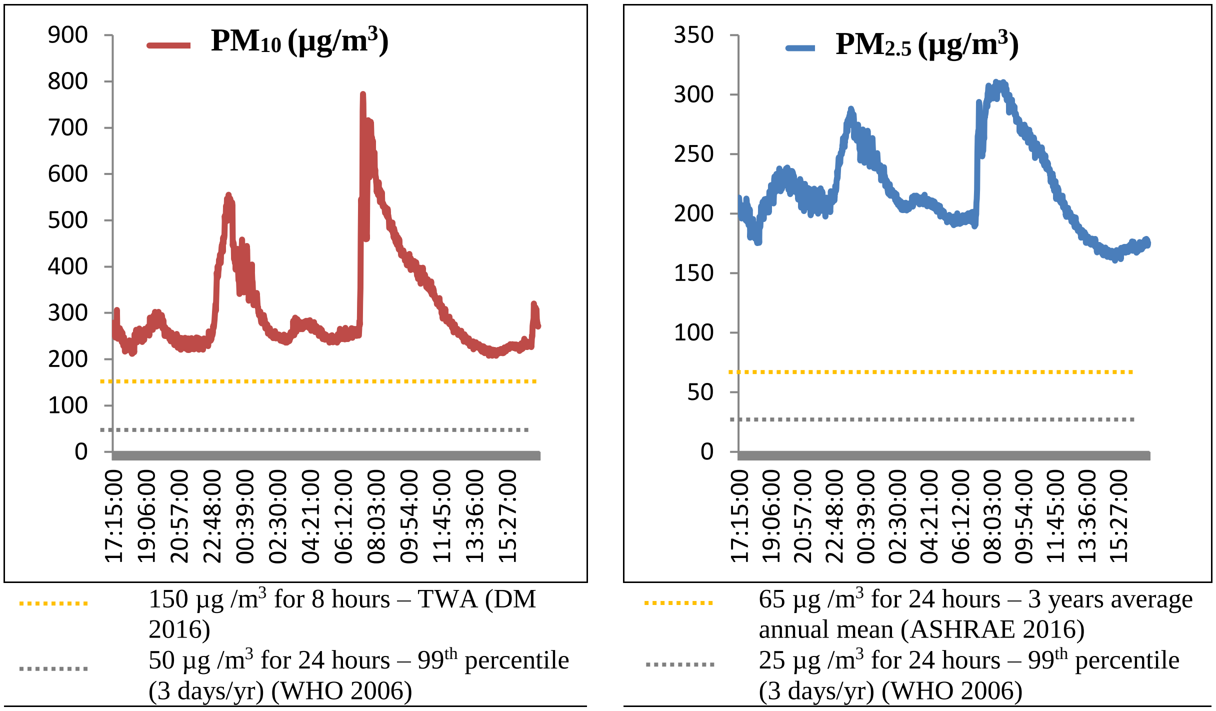


Figure ZZ-196: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 39)

### *House (40)*

Table ZZ-117: Levels of continuously measured variables indoor House (40)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 59.8 | 430.0 | 0.1 | 47.2 | 49.8 | 20.4 | 20.1 |
| **Mean** | 337.7 | 560.9 | 0.6 | 194.4 | 279.2 | 24.3 | 32.6 |
| **Max** | 483.0 | 846.0 | 1.3 | 2509.5 | 2864.0 | 27.6 | 60.4 |

Table ZZ-118: Spot measured variables in outdoor air of House (40)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 50.6 | 428.0 | 0.0 | 24.7 | 61.9 |

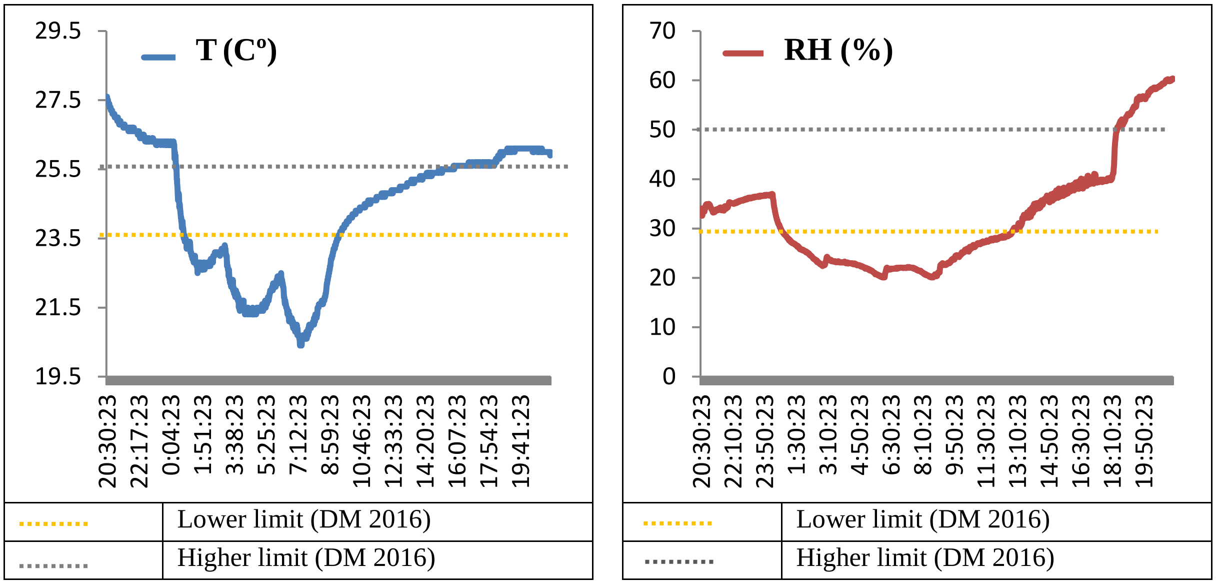


Figure ZZ-197: Continuously measured indoor levels of T and RH in House (40)

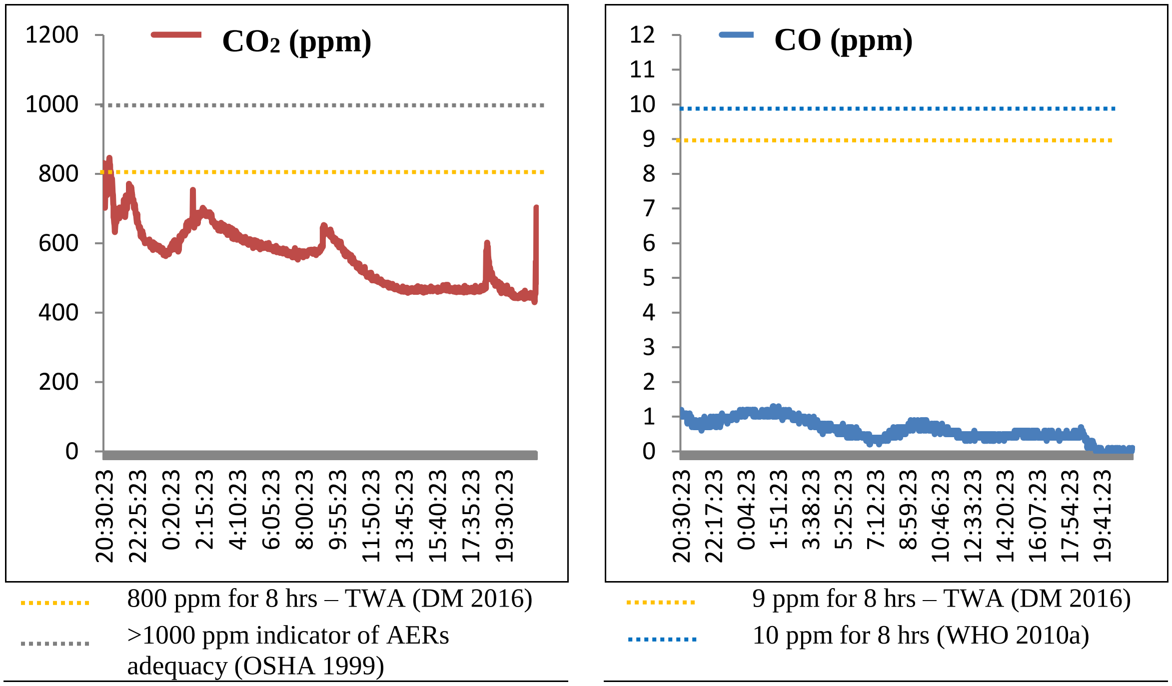


Figure ZZ-198: Compliance of $CO_2$ & CO levels in House (40) with established standards

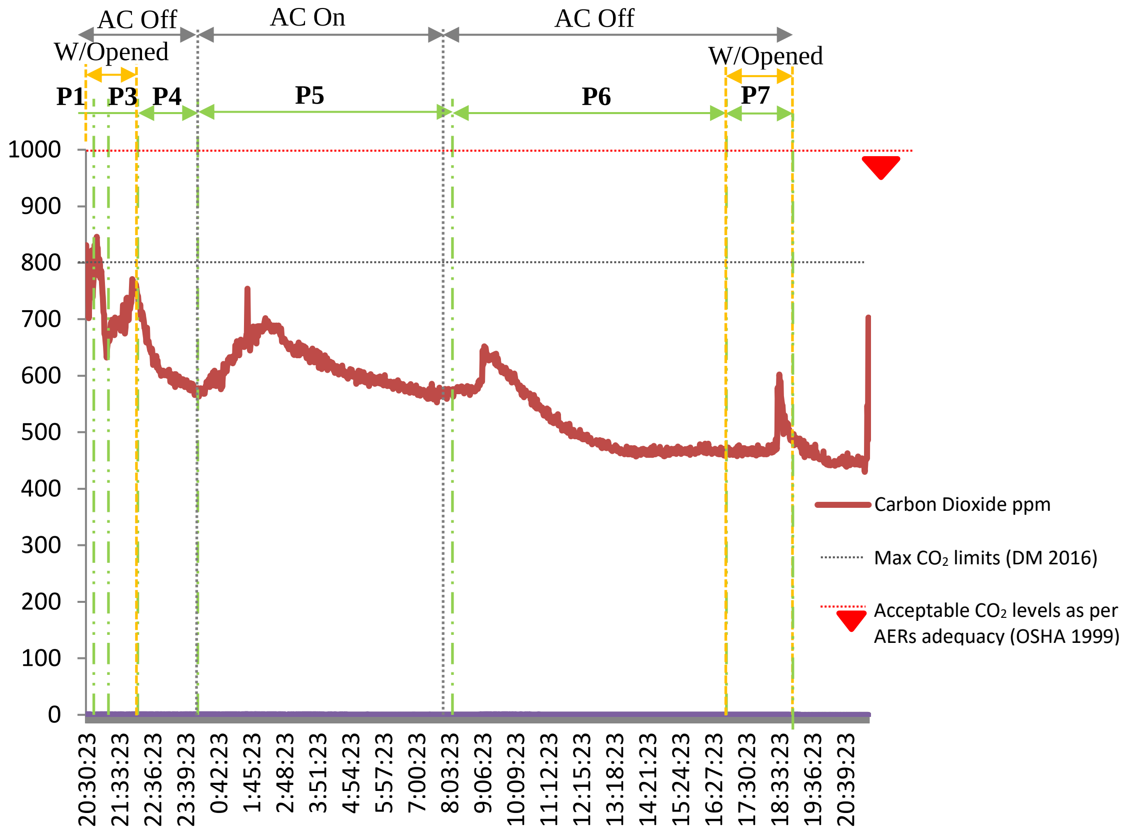


Figure ZZ-199: Occupancy profiles of the living hall projected on CO$_2$ levels (House 40)

Table ZZ-119: Occupancy profiles of the living hall during measurement (House 40)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 20:30 – 20:40 | 3 | Natural (Infiltration) | Sitting |
| **P2** | 20:40 – 21:09 | 1 | Natural (Infiltration & Window) | Sitting |
| **P3** | 21:09 – 22:02 | 2 | Natural (Infiltration & Window) | Sitting |
| **P4** | 22:02 – 00:18 | 0 | Natural (Infiltration) | Went outside |
| **P5** | 00:18 – 09:12 | 0 | Mixed:<br>00:18 – 08:47 Mechanical<br>08:47 – 09:12 Natural (Infiltration) | 1 person in another room |
| **P6** | 09:12 – 18:13 | 0 | Natural (Infiltration) | Went outside |
| **P7** | 18:13 – 20:25 | 1 | Natural (Infiltration & Window) | Sitting |

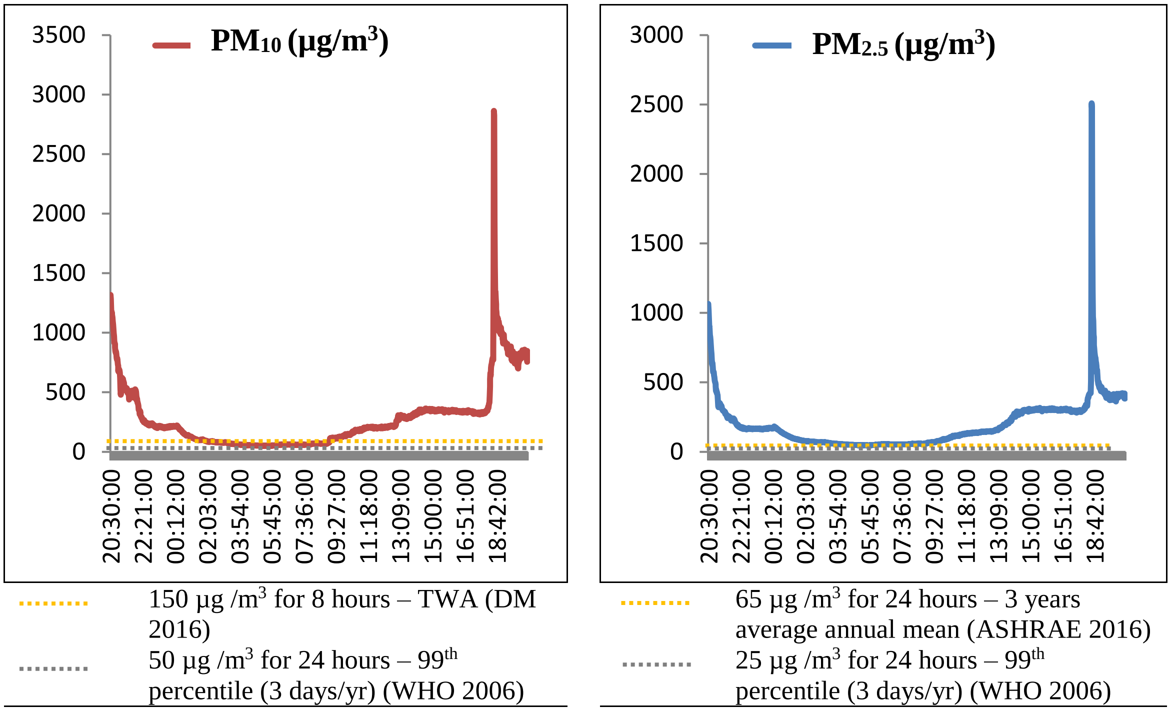


Figure ZZ-200: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 40)

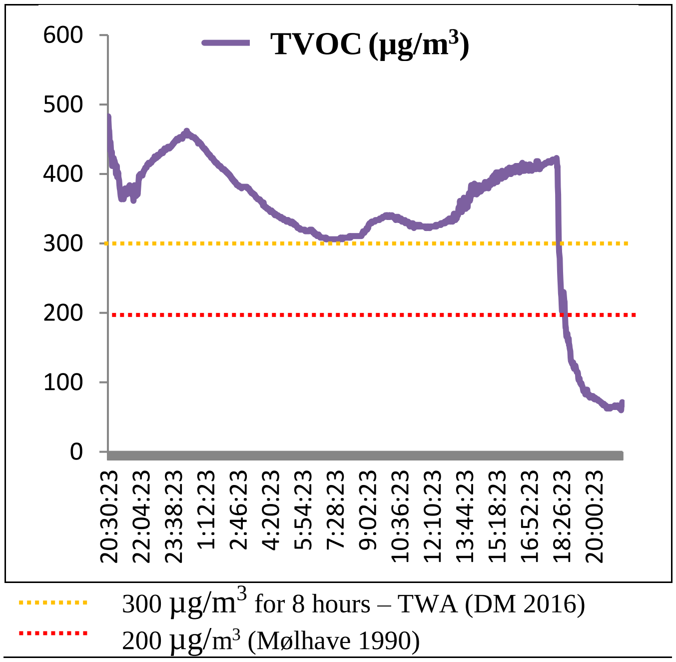


Figure ZZ-201: Compliance of indoor TVOC levels with established standards (House 40)

## ***House (41)***

Table ZZ-120: Levels of continuously measured variables indoor House (41)

| | **TVOC (μg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (μg/m$^3$)** | **$PM_{10}$ (μg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 170.2 | 420.0 | 0.1 | 179.9 | 275.3 | 22.3 | 33.9 |
| **Mean** | 397.2 | 681.0 | 2.6 | 2148.5 | 2600.8 | 26.1 | 52.2 |
| **Max** | 1104.0 | 1167.0 | 8.4 | 7617.6 | 11706.0 | 28.3 | 61.4 |

Table ZZ-121: Spot measured variables in outdoor air of House (41)

| | **TVOC (μg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 213.9 | 507 | 0.4 | 26.5 | 50.7 |

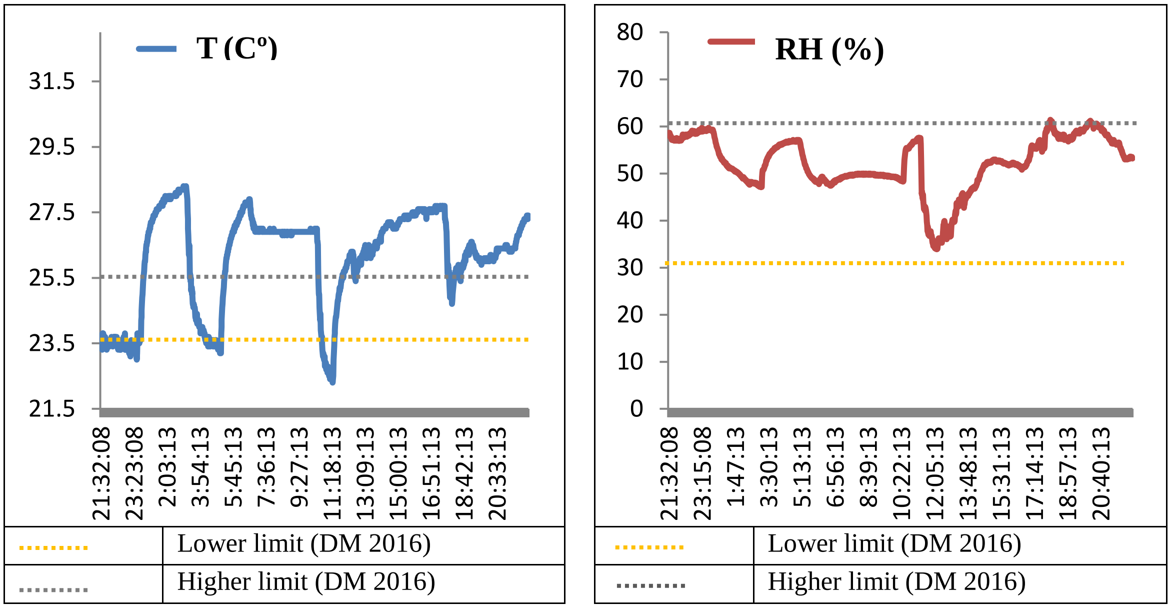


Figure ZZ-202: Continuously measured indoor levels of T and RH in House (41)

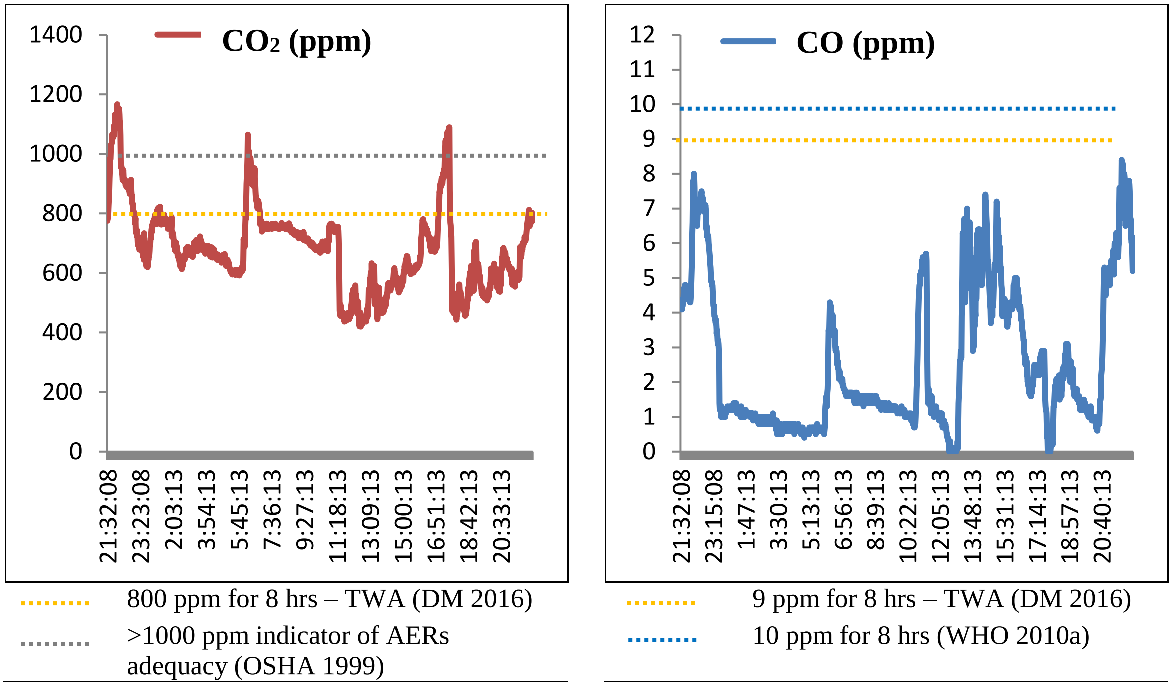


Figure ZZ-203: Compliance of $CO_2$ & CO levels in House (41) with established standards

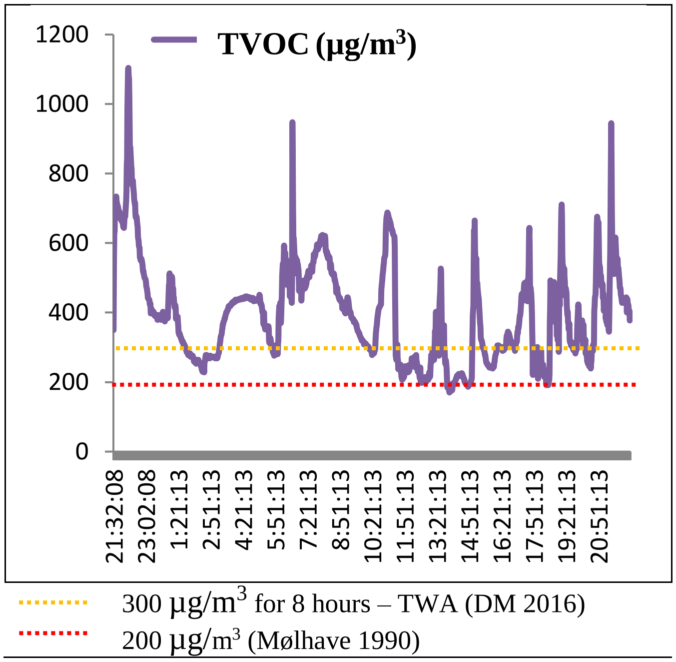


Figure ZZ-204: Compliance of indoor TVOC levels with established standards (House 41)

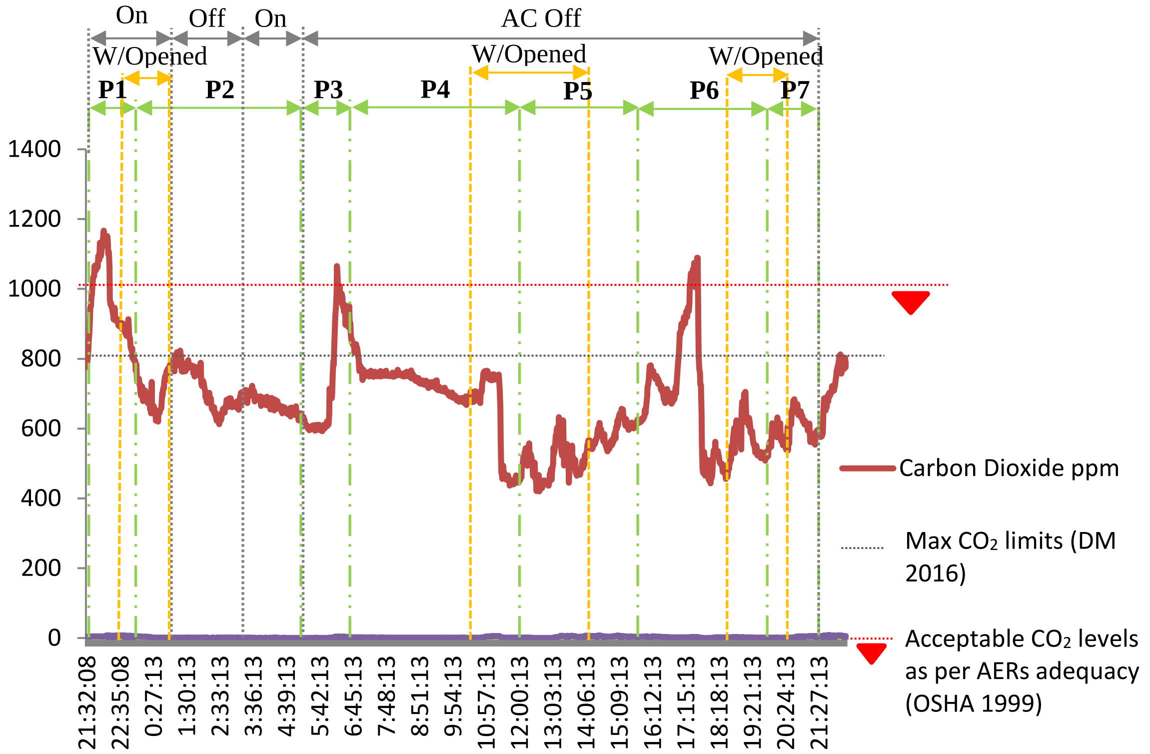


Figure ZZ-205: Occupancy profiles of the living hall projected on $CO_2$ levels (House 41)

Table ZZ-122: Occupancy profiles of the living hall during measurement (House 41)

| **Profile** | **Time** | **Occupants** | **System** | **Activities** |
|---|---|---|---|---|
| **P1** | 19:40 – 10:51 | 12 | Mechanical | Sitting, having visitors |
| **P2** | 10:51 – 05:05 | 0 | Mixed:<br>10:51 – 01:00 Mechanical<br>01:00 – 03:10 Natural (Infiltration)<br>03:10 – 05:05 Mechanical | Sleeping in other rooms<br>Window opening in BR<br>(10:30 – 01:00) |
| **P3** | 05:05 – 06:45 | 8 | Natural (Infiltration) | Sitting |
| **P4** | 06:45 – 12:00 | 6 | Natural (Infiltration) | Sitting |
| **P5** | 12:00 – 15:30 | 5 | Natural (Infiltration) | Sitting |
| **P6** | 15:30 – 19:45 | 6 | Natural (Infiltration) | Sitting, cooking |
| **P8** | 19:45 – 21:20 | 8 | Natural (Infiltration) | Sitting, dinner |

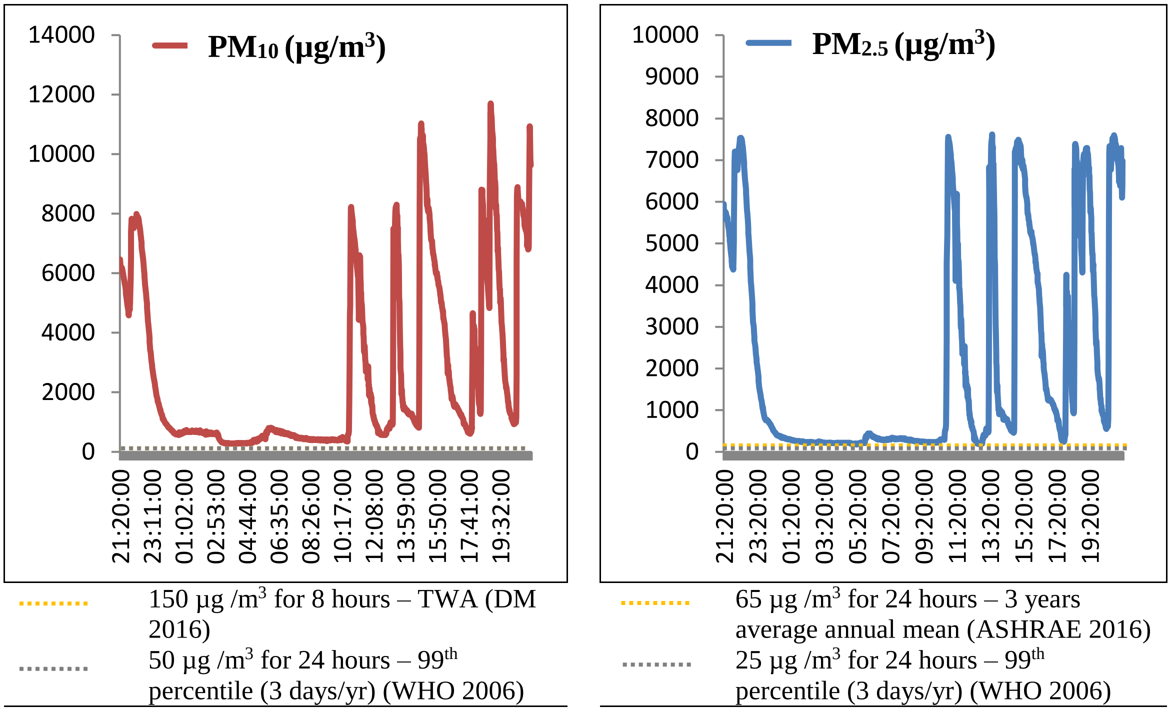


Figure ZZ-206: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 41)

***House (42)***

Table ZZ-123: Levels of continuously measured variables indoor House (42)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 167.9 | 443.0 | 0.1 | 77.5 | 86.1 | 21.7 | 45.2 |
| **Mean** | 403.3 | 765.7 | 0.5 | 194.1 | 266.5 | 24.4 | 54.0 |
| **Max** | 1522.6 | 1471.0 | 1.1 | 1290.7 | 1332.0 | 26.3 | 68.2 |

Table ZZ-124: Spot measured variables in outdoor air of House (42)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 117.3 | 477.0 | 0.8 | 28.6 | 49.2 |

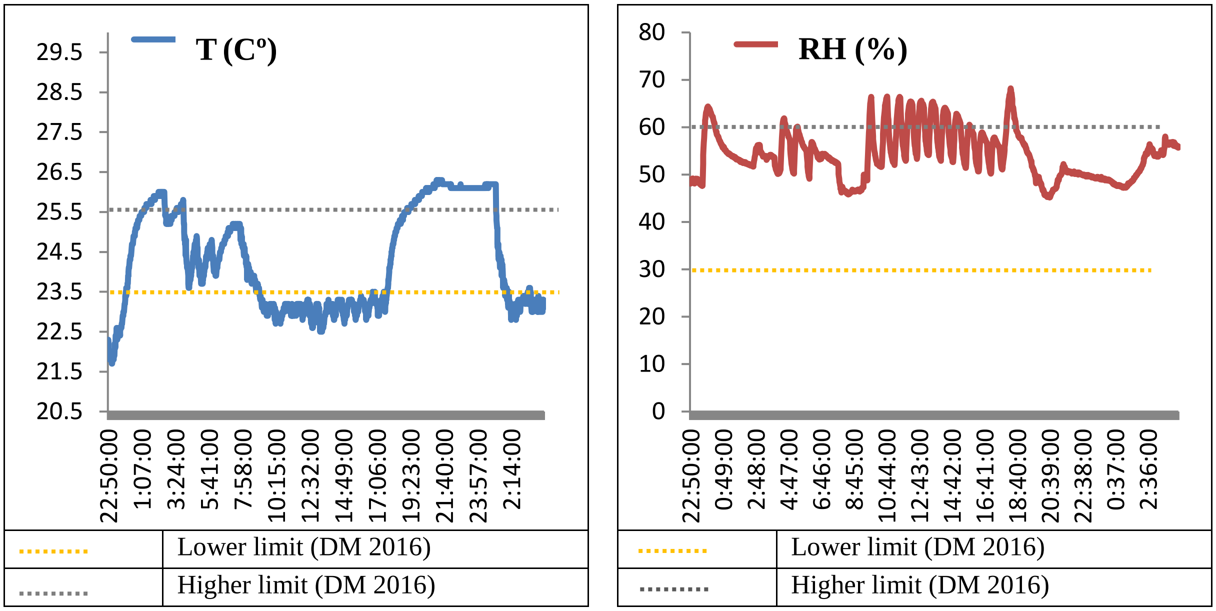


Figure ZZ-207: Continuously measured indoor levels of T and RH in House (42)

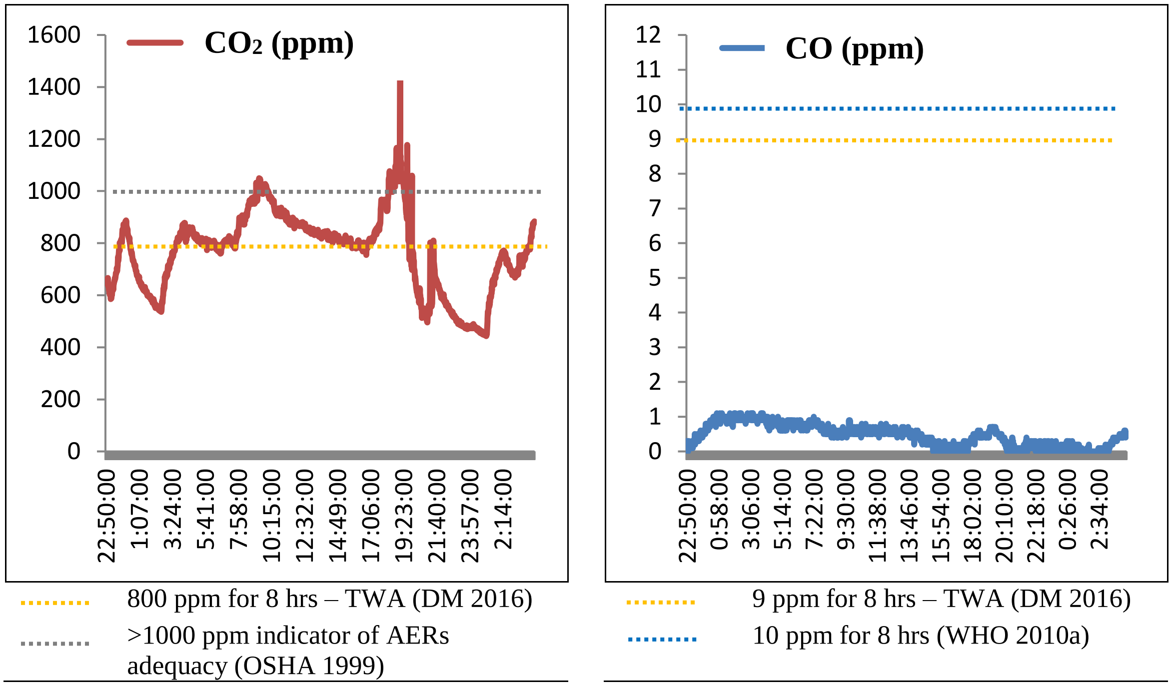


Figure ZZ-208: Compliance of $CO_2$ & CO levels in House (42) with established standards

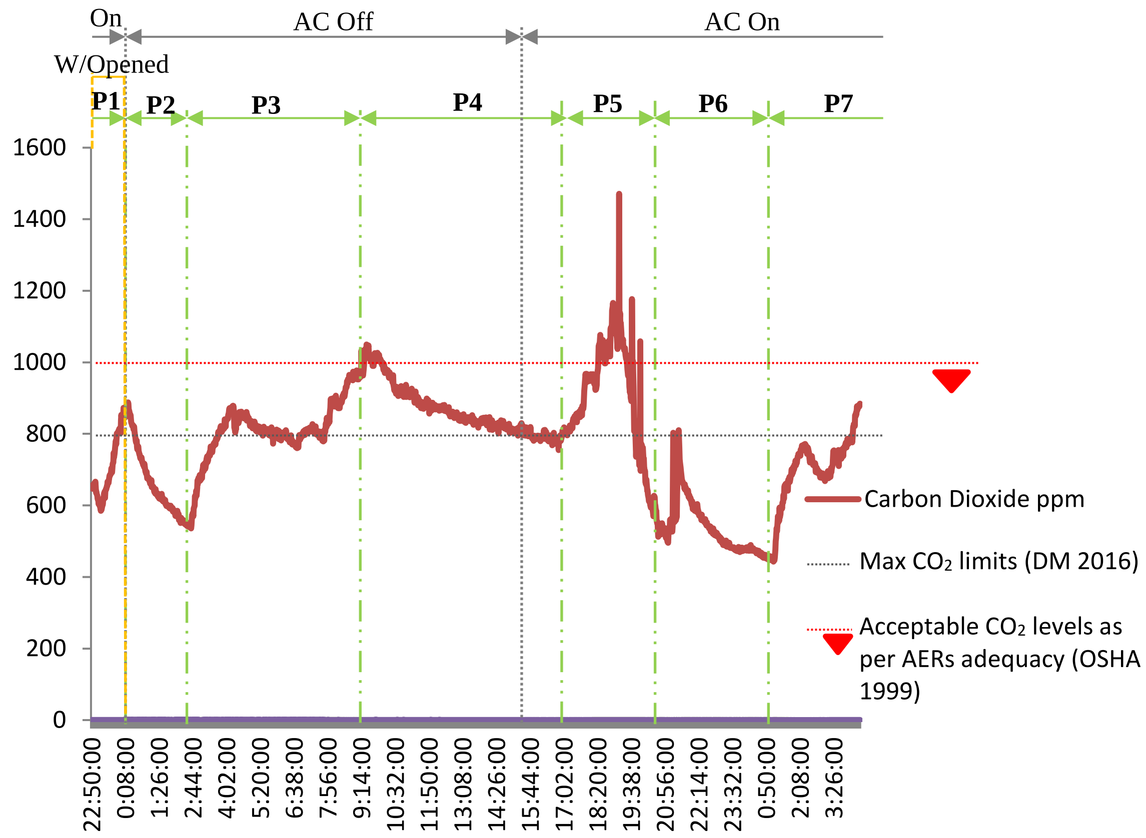
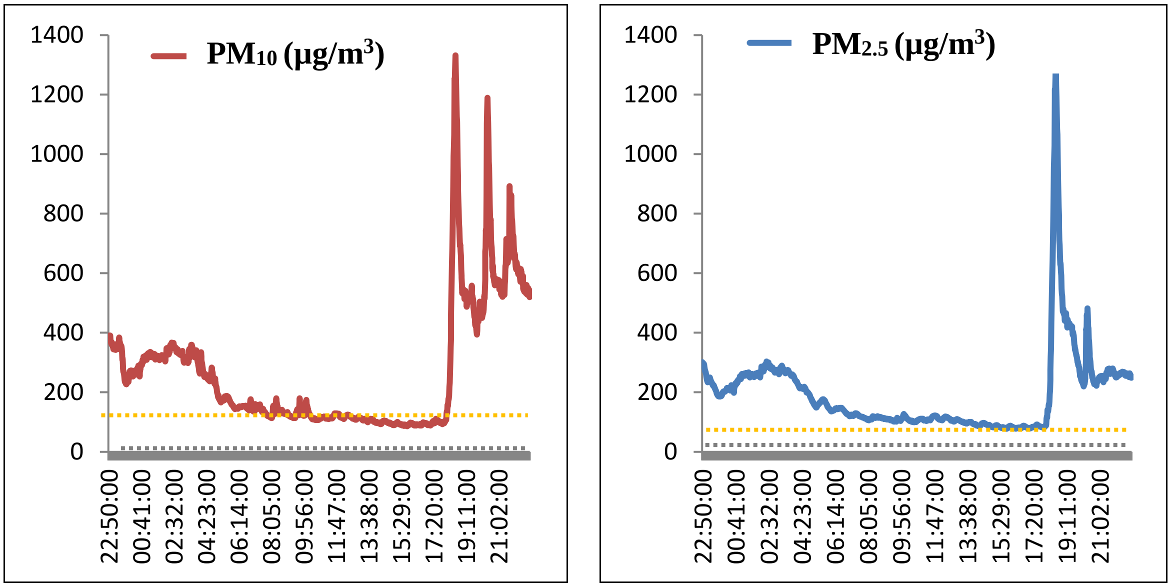


Figure ZZ-209: Occupancy profiles of the living hall projected on $CO_2$ levels (House 42)

Table ZZ-125: Occupancy profiles of the living hall during measurement (House 42)

| **Profile** | **Time** | **Occupants** | **System** | **Activities** |
|---|---|---|---|---|
| **P1** | 10:50 – 12:00 | 2 | Mechanical | Sitting |
| **P2** | 12:00 – 02:00 | 0 | Natural (Infiltration) | 2 persons in other rooms |
| **P3** | 02:00 – 09:15 | 2 | Natural (Infiltration) | Sitting |
| **P4** | 09:15 – 17:00 | 0 | Mixed:<br>09:15 – 15:15 Natural (Infiltration)<br>15:15 – 17:00 Mechanical | 2 persons in other rooms |
| **P5** | 17:00 – 20:25 | 3 | Mechanical | Sitting, cooking, lunch |
| **P6** | 20:25 – 01:00 | 0 | Mechanical | 2 persons in other rooms |
| **P7** | 01:00 – 07:00 | 4 | Mechanical | Sitting |



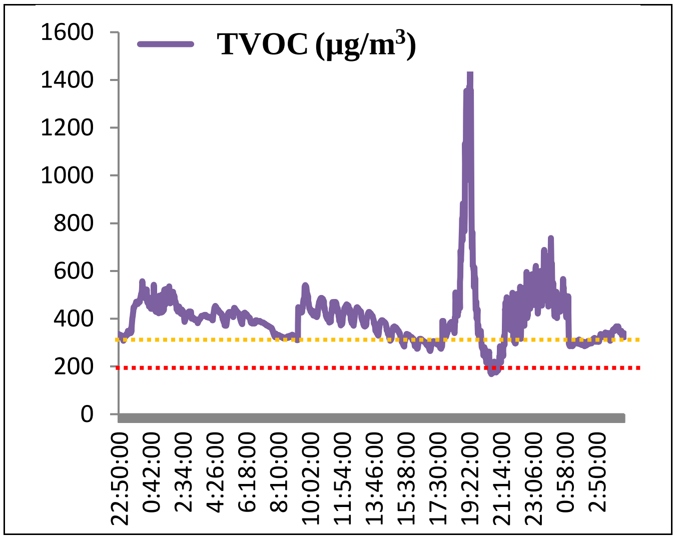
⋯ 150 µg /m$^3$ for 8 hours – TWA (DM 2016)

⋯ 50 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006)

⋯ 65 µg /m$^3$ for 24 hours – 3 years average annual mean (ASHRAE 2016)

⋯ 25 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006)

Figure ZZ-210: Compliance of PM$_{10}$ & PM$_{2.5}$ levels with established standards (House 42)



⋯ 300 µg/m$^3$ for 8 hours – TWA (DM 2016)

⋯ 200 µg/m$^3$ (Mølhave 1990)

Figure ZZ-211: Compliance of indoor TVOC levels with established standards (House 42)

***House (43)***

Table ZZ-126: Levels of continuously measured variables indoor House (43)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m$^3$)** | **$PM_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 0.0 | 393.0 | 0.1 | 9.6 | 10.1 | 22.5 | 39.1 |
| **Mean** | 216.7 | 569.6 | 3.9 | 860.1 | 926.1 | 26.0 | 43.2 |
| **Max** | 954.5 | 1988.0 | 31.9 | 7976.8 | 8230.3 | 27.6 | 47.2 |

Table ZZ-127: Spot measured variables in outdoor air of House (43)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | <11.5 | 477.0 | 0.3 | 23.9 | 54.0 |

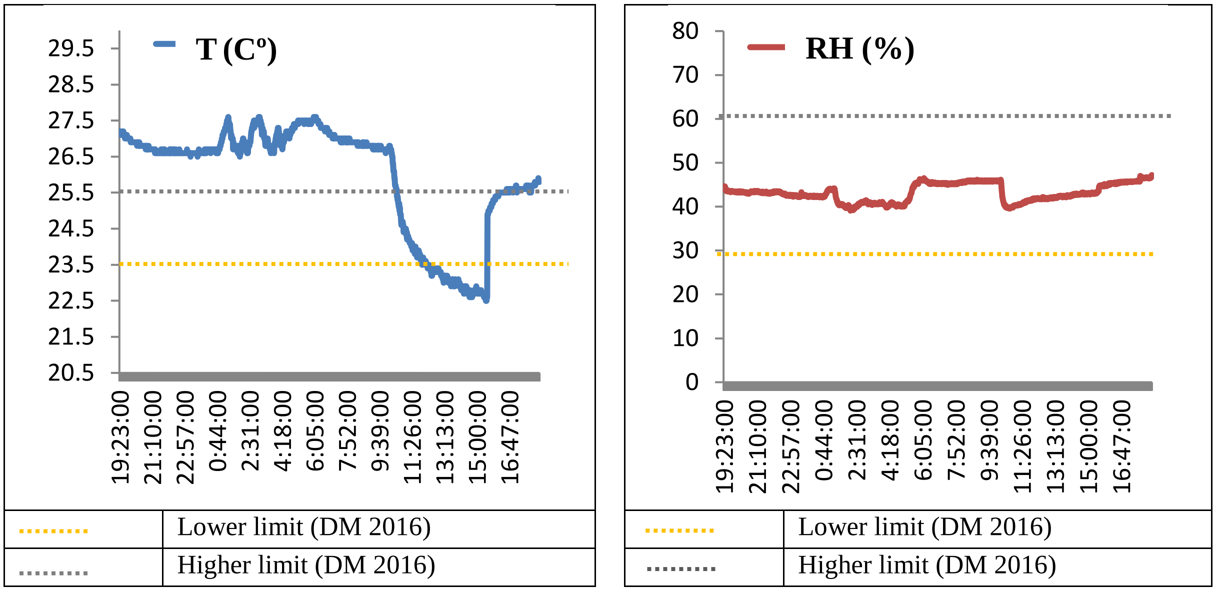


Figure ZZ-212: Continuously measured indoor levels of T and RH in House (43)

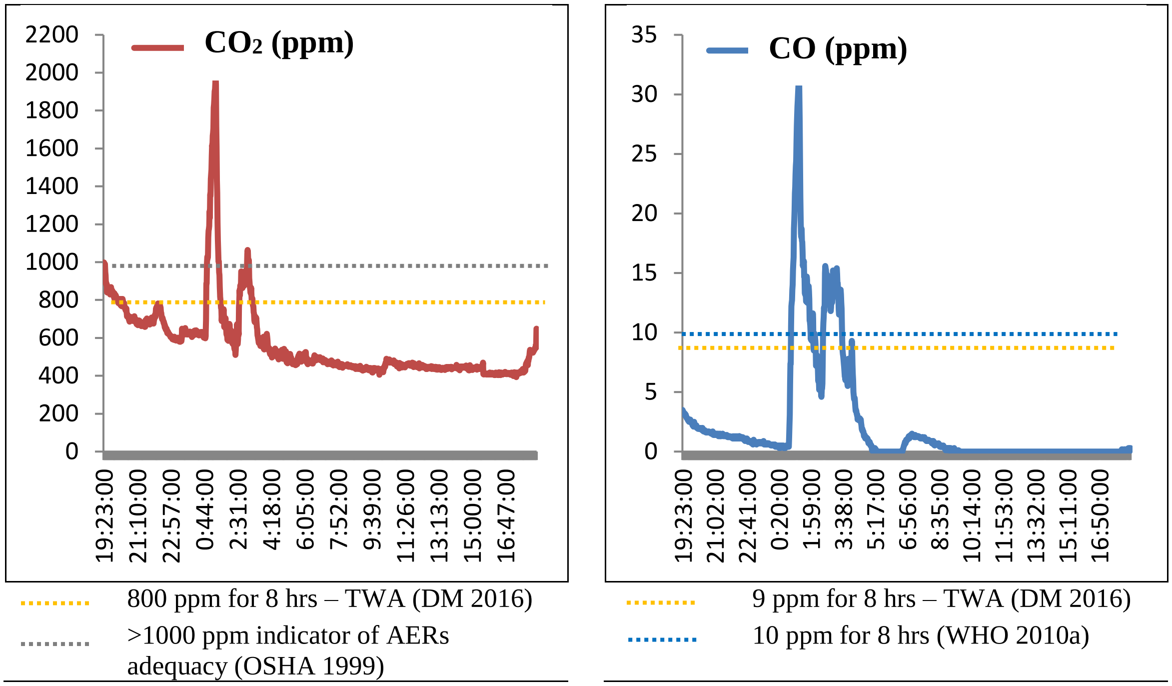


Figure ZZ-213: Compliance of $CO_2$ & CO levels in House (43) with established standards

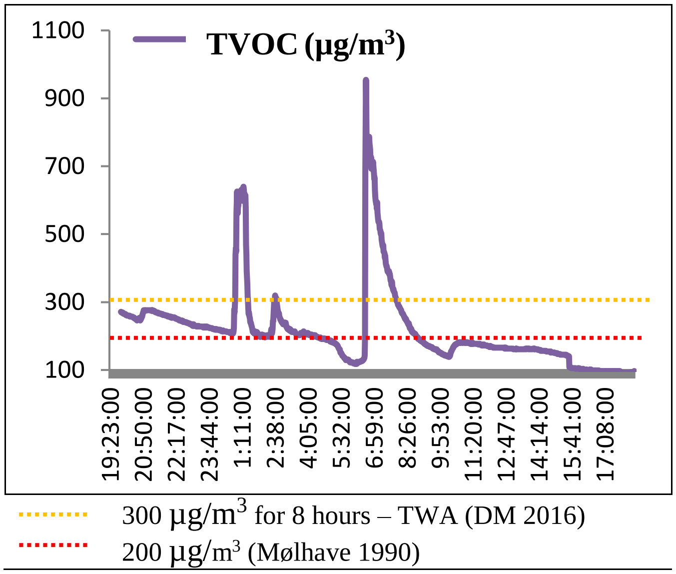


Figure ZZ-214: Compliance of indoor TVOC levels with established standards (House 43)

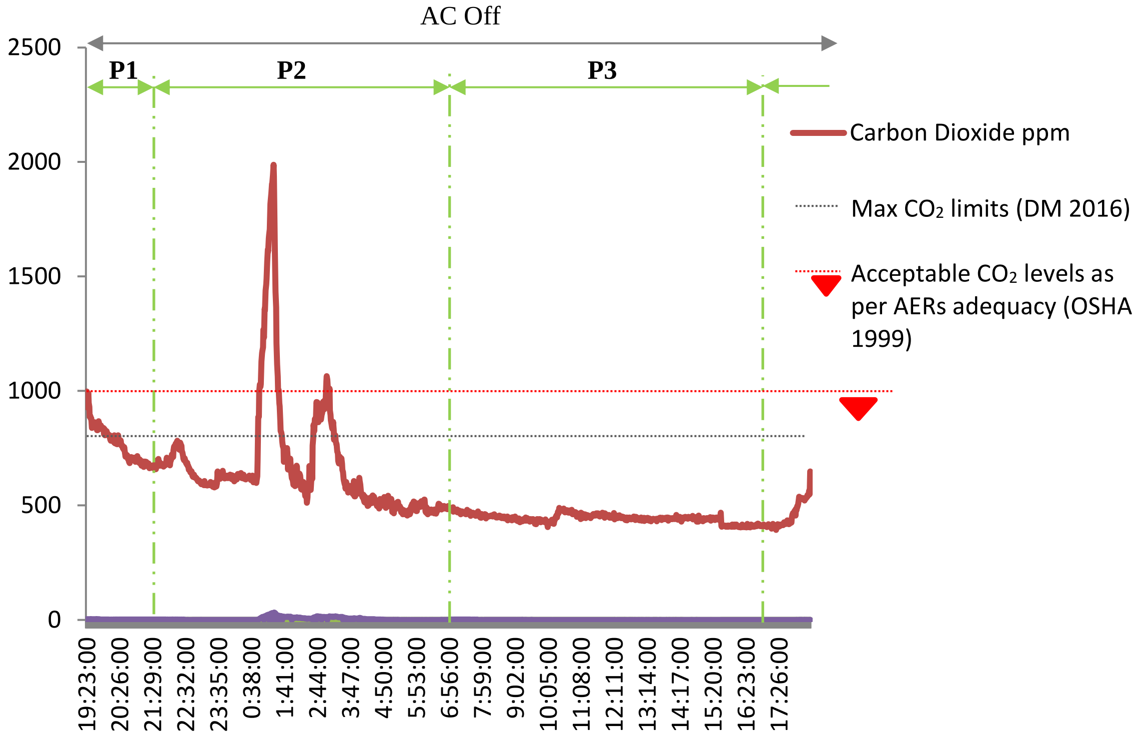
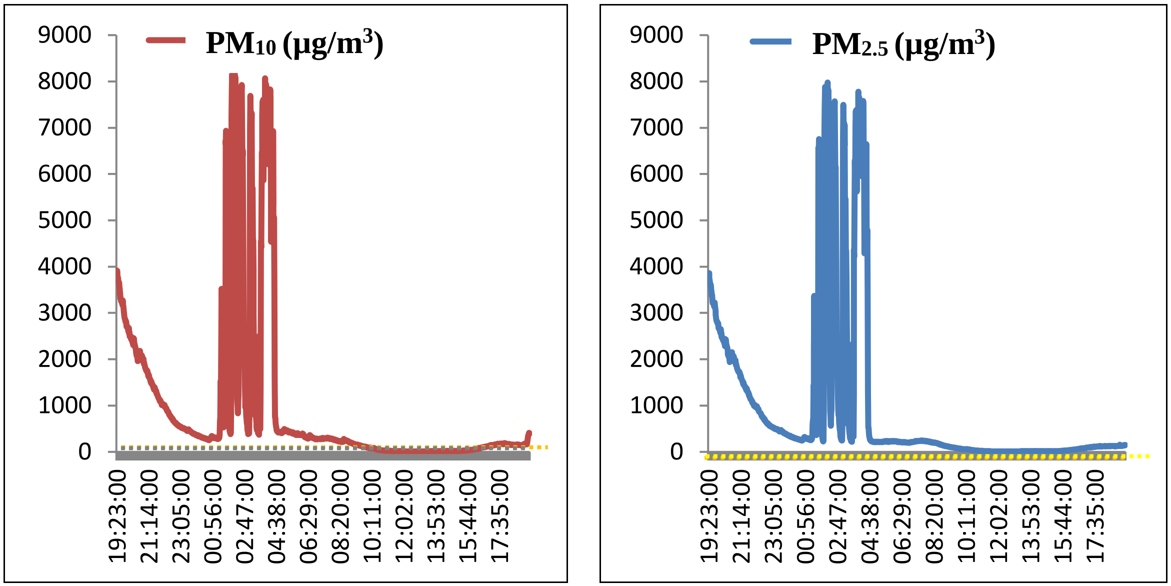


Figure ZZ-215: Occupancy profiles of the living hall projected on $CO_2$ levels (House 43)

Table ZZ-128: Occupancy profiles of the living hall during measurement (House 43)

| **Profile** | **Time** | **Occupants** | **System** | **Activities** |
|---|---|---|---|---|
| **P1** | 19:23 – 21:30 | 1 | Natural (Infiltration) | Sitting |
| **P2** | 21:30 – 07:00 | 0 | Natural (Infiltration) | 2 persons in other rooms |
| **P3** | 17:00 – 17:00 | 2 | Natural (Infiltration) | Sitting |



| | | | |
|---|---|---|---|
| ……… | 150 µg /m³ for 8 hours – TWA (DM 2016) | ……… | 65 µg /m³ for 24 hours – 3 years average annual mean (ASHRAE 2016) |
| ……… | 50 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) | ……… | 25 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure ZZ-216: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 43)

### *House (44)*

Table ZZ-129: Levels of continuously measured variables indoor House (44)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 159.9 | 500.5 | 0.2 | 38.1 | 39.8 | 26.1 | 25.1 |
| **Mean** | 209.4 | 590.7 | 0.7 | 103.9 | 127.2 | 27.1 | 44.7 |
| **Max** | 653.2 | 920.5 | 2.9 | 241.5 | 304.9 | 28.5 | 58.9 |

Table ZZ-130: Spot measured variables in outdoor air of House (44)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 153.0 | 457.5 | 0.9 | 26.2 | 41.3 |

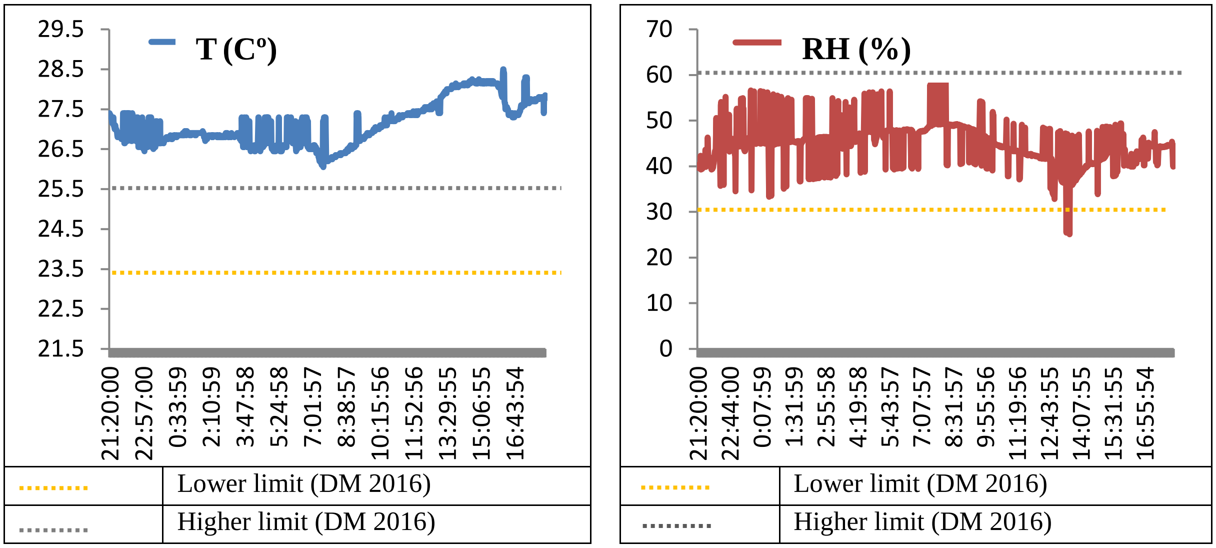


Figure ZZ-217: Continuously measured indoor levels of T and RH in House (44)

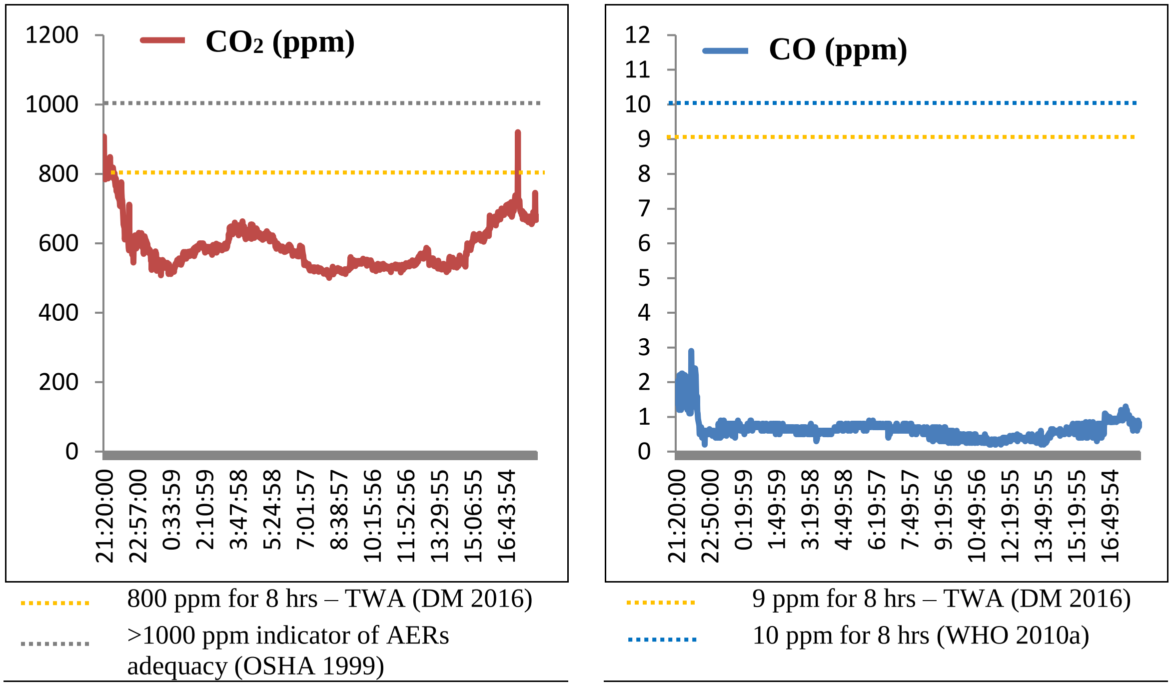


Figure ZZ-218: Compliance of $CO_2$ & CO levels in House (44) with established standards

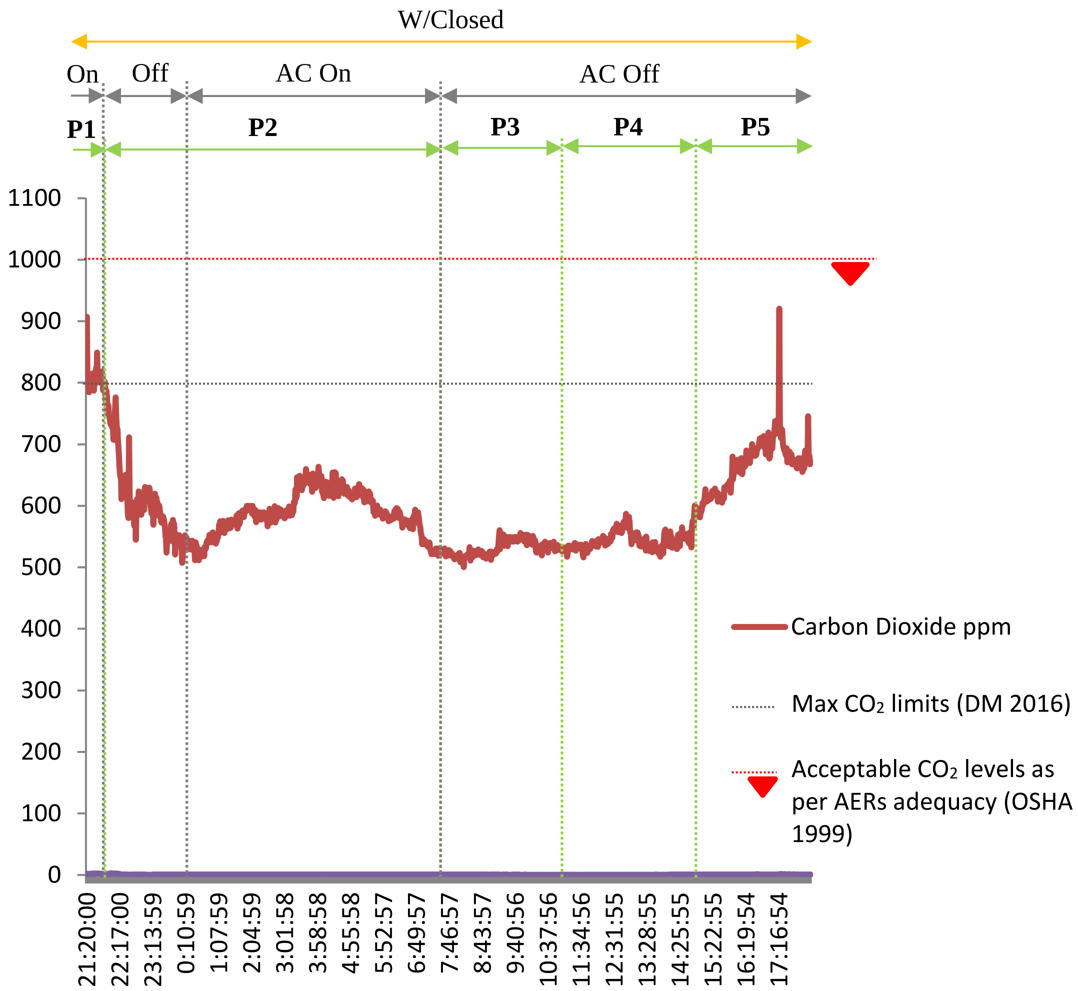
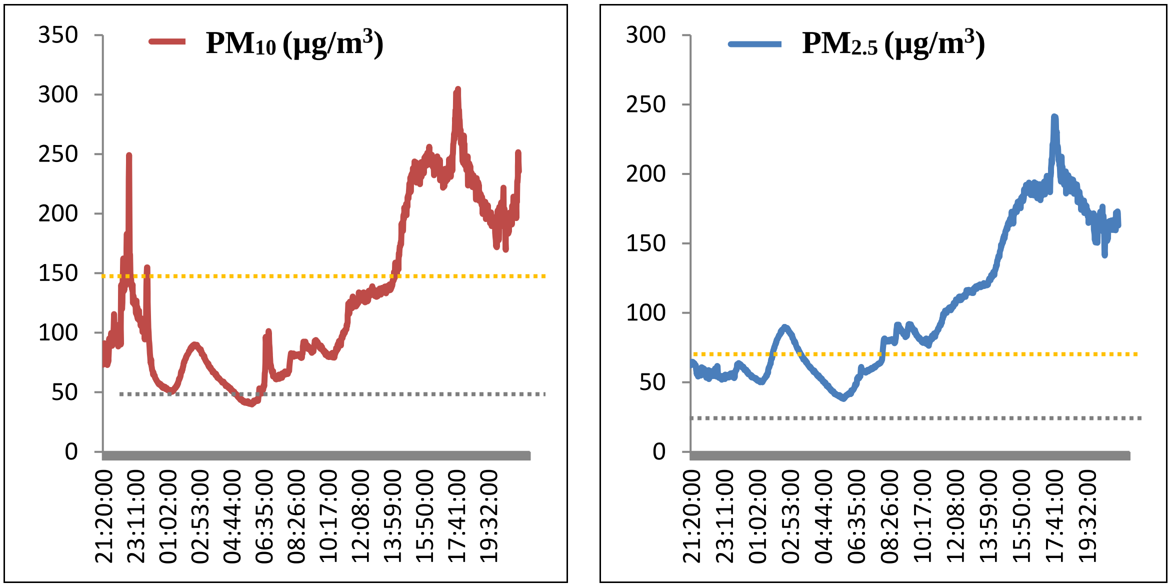


Figure ZZ-219: Occupancy profiles of the living hall projected on $CO_2$ levels (House 44)

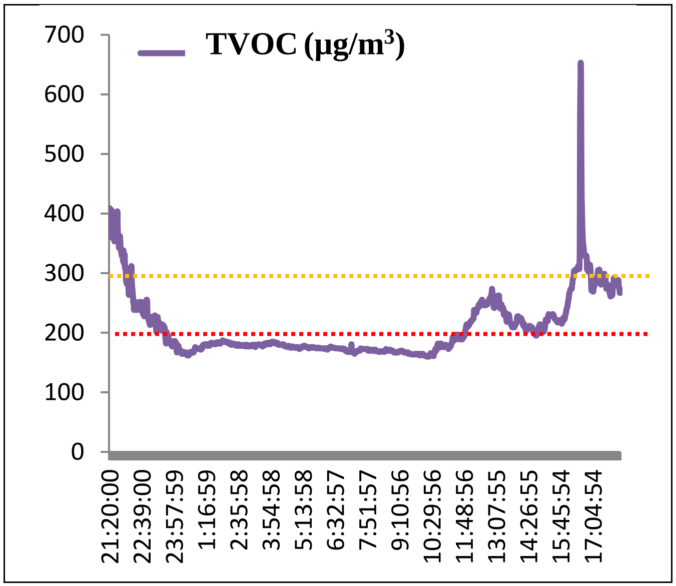
Table ZZ-131: Occupancy profiles of the living hall during measurement (House 44)

| **Profile** | **Time** | **Occupants** | **System** | **Activities** |
|---|---|---|---|---|
| **P1** | 21:20 – 21:45 | 3 | Mechanical | Sitting |
| **P2** | 21:45 – 07:30 | 0 | Mixed:<br>21:45 – 00:00 Natural (Infiltration)<br>00:00 – 07:30 Mechanical | 3 persons in other rooms |
| **P3** | 07:30 – 11:00 | 1 | Natural (Infiltration) | Sitting |
| **P4** | 11:00 – 15:00 | 0 | ,, ,, ,, ,, ,, | Went outside |
| **P5** | 15:00 – 20:30 | 1 | ,, ,, ,, ,, ,, | Cooking, cleaning |



| | | | |
|---|---|---|---|
| ……… | 150 µg /m$^3$ for 8 hours – TWA (DM 2016) | ……… | 65 µg /m$^3$ for 24 hours – 3 years average annual mean (ASHRAE 2016) |
| ……… | 50 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) | ……… | 25 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure ZZ-220: Compliance of PM$_{10}$ & PM$_{2.5}$ levels with established standards (House 44)



| | |
|---|---|
| ……… | 300 µg/m$^3$ for 8 hours – TWA (DM 2016) |
| ……… | 200 µg/m$^3$ (Mølhave 1990) |

Figure ZZ-221: Compliance of indoor TVOC levels with established standards (House 44)

***House (45)***

Table ZZ-132: Levels of continuously measured variables indoor House (45)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m$^3$)** | **$PM_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 34.5 | 465.5 | 0.1 | 148.0 | 158.5 | 22.8 | 44.1 |
| **Mean** | 123.3 | 696.1 | 0.7 | 993.2 | 1026.4 | 25.7 | 53.6 |
| **Max** | 435.9 | 904.5 | 3.8 | 5153.1 | 5171.1 | 27.5 | 66.7 |

Table ZZ-133: Spot measured variables in outdoor air of House (45)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 105.8 | 435.5 | 0.5 | 25.0 | 46.1 |

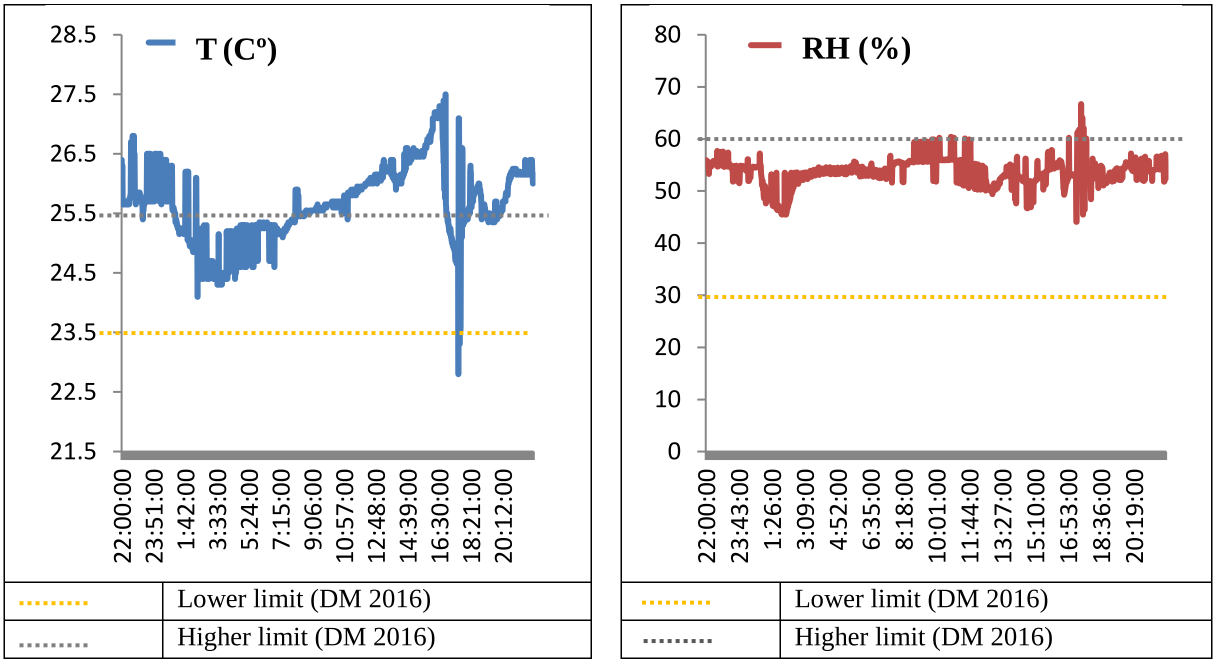


Figure ZZ-222: Continuously measured indoor levels of T and RH in House (45)

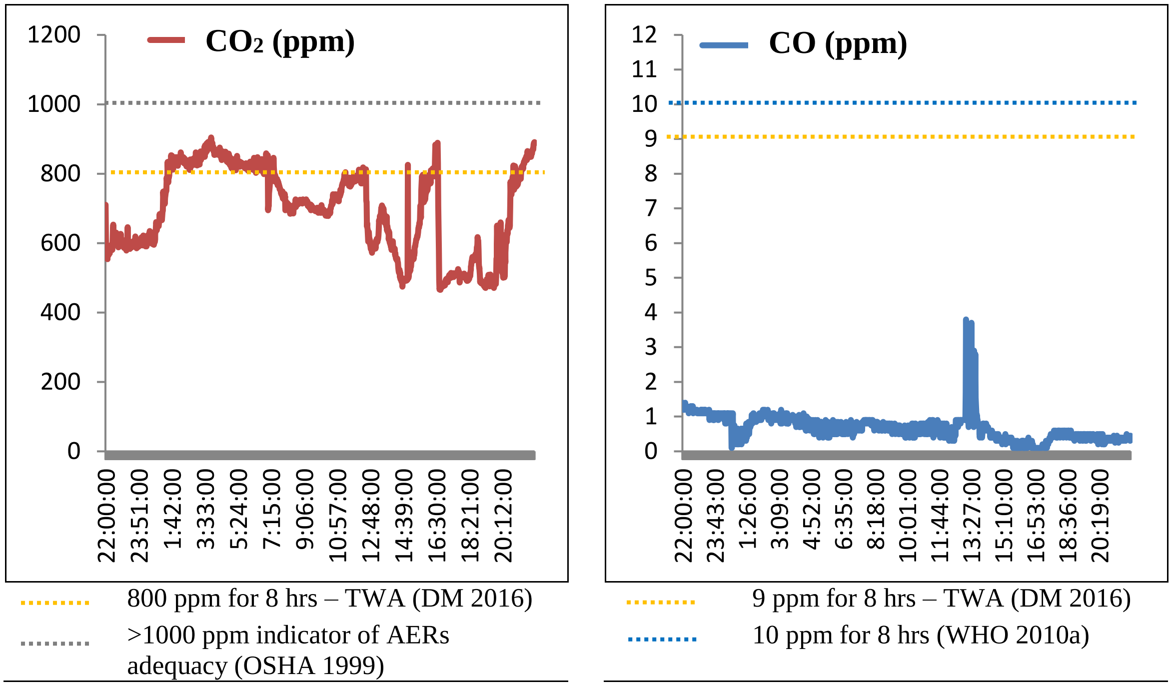


Figure ZZ-223: Compliance of $CO_2$ and CO levels with established standards (House 45)

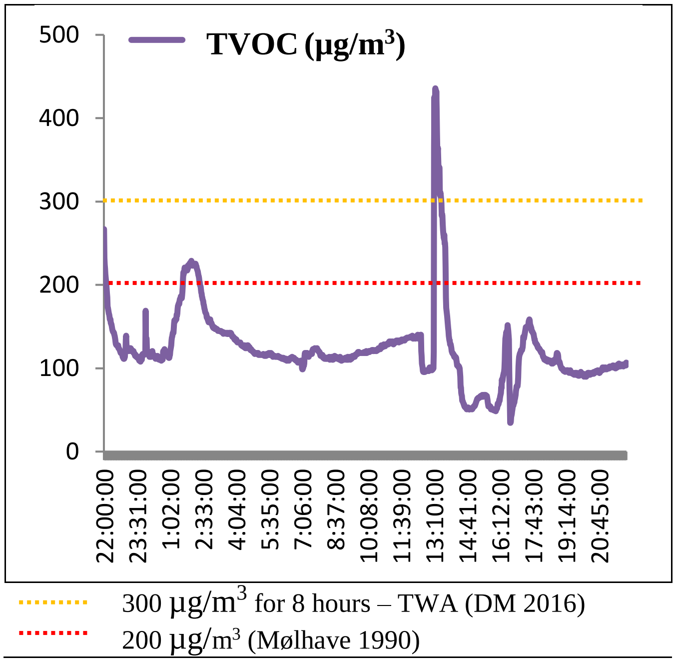


Figure ZZ-224: Compliance of indoor TVOC levels with established standards (House 45)

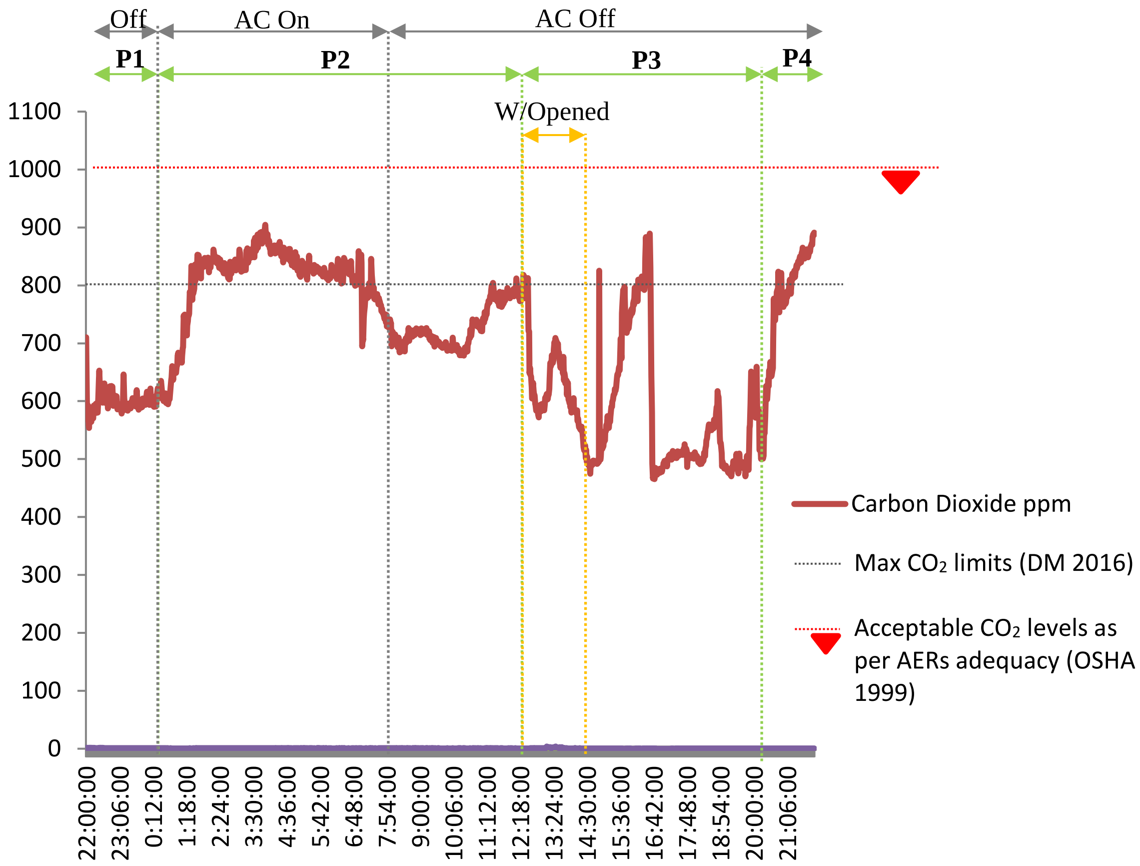


Figure ZZ-225: Occupancy profiles of the living hall projected on $CO_2$ levels (House 45)

Table ZZ-134: Occupancy profiles of the living hall during measurement (House 45)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 22:00 – 00:15 | 2 | Natural (Infiltration) | Sitting |
| **P2** | 00:15 – 12:15 | 4 | Mixed:<br>00:15 – 08:00 Mechanical<br>08:00 – 12:15 Natural (Infiltration) | Sitting, cooking, lunch |
| **P3** | 12:15 – 20:10 | 2 | Natural:<br>12:15 – 14:30 Window<br>14:30 – 20:10 Natural (Infiltration) | Sitting, cooking |
| **P4** | 20:10 – 22:00 | 4 | Natural (Infiltration) | Sitting, dinner |

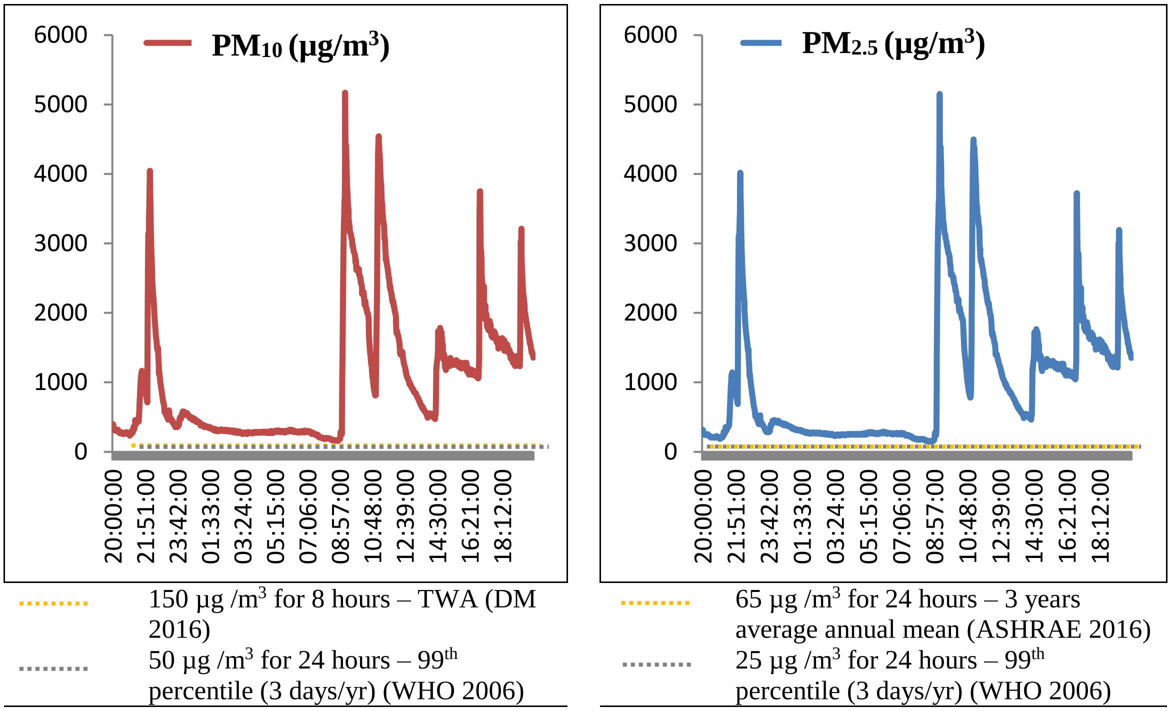


Figure ZZ-226: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 45)

### *House (46)*

Table ZZ-135: Levels of continuously measured variables indoor House (46)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 43.7 | 403.0 | 0.0 | 82.6 | 84.7 | 23.7 | 32.7 |
| **Mean** | 359.2 | 808.1 | 1.1 | 281.5 | 378.8 | 25.5 | 50.6 |
| **Max** | 722.2 | 1377.0 | 2.2 | 809.9 | 1430.1 | 26.9 | 58.1 |

Table ZZ-136: Spot measured variables in outdoor air of House (46)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 29.9 | 410.0 | 0.0 | 23.3 | 55.8 |

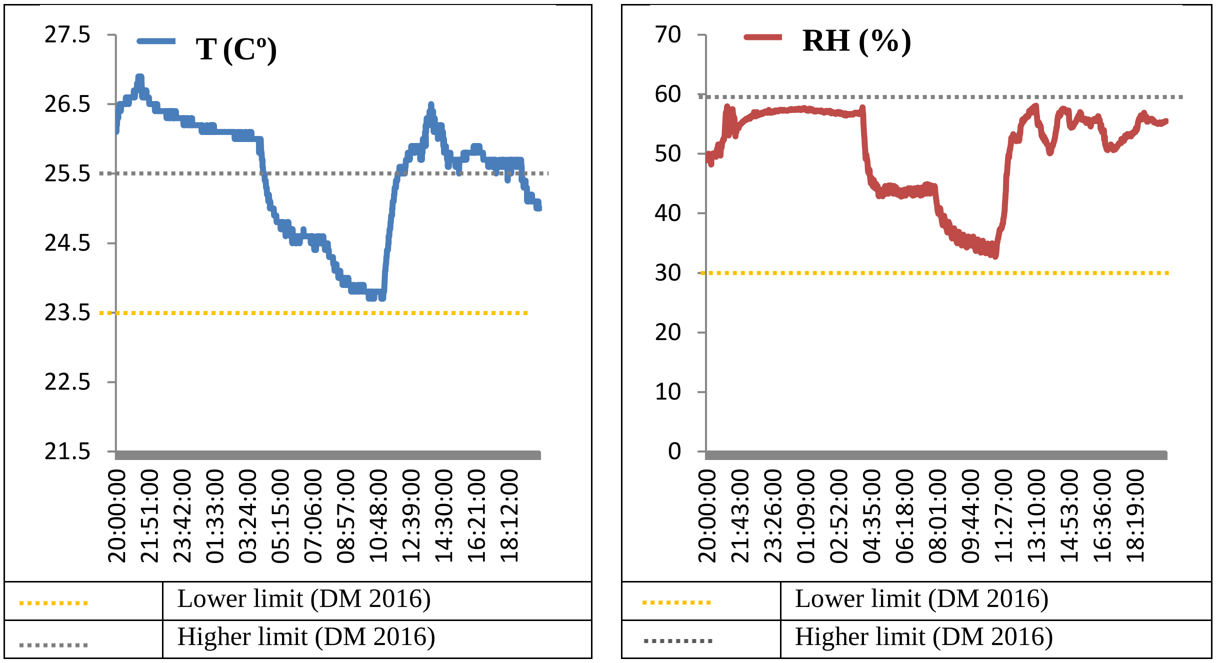


Figure ZZ-227: Continuously measured indoor levels of T and RH in House (46)

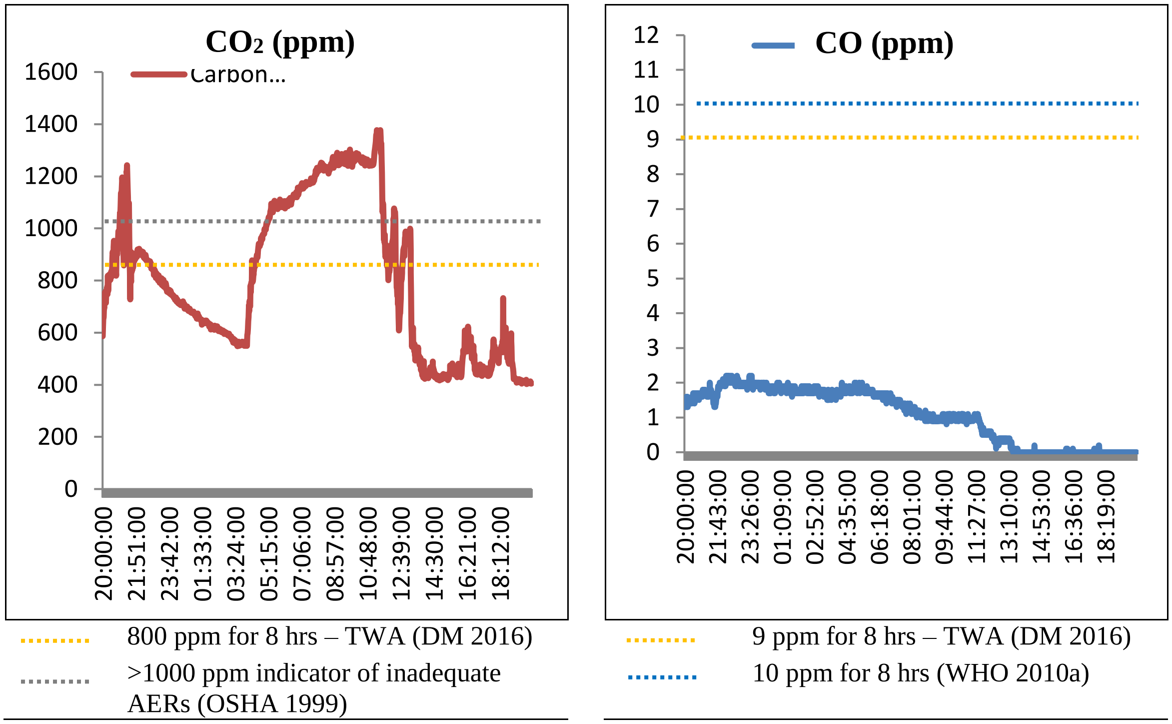


Figure ZZ-228: Compliance of $CO_2$ & CO levels in House (46) with established standards

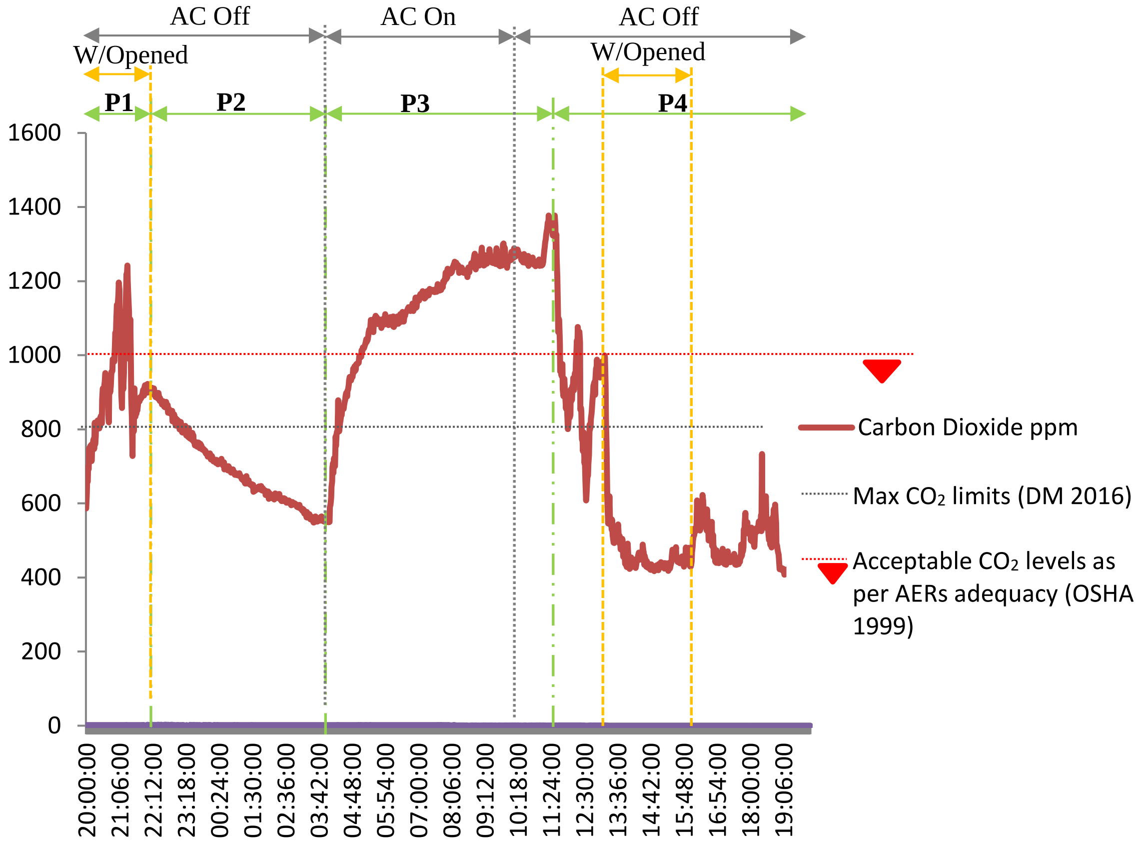


Figure ZZ-229: Occupancy profiles of the living hall projected on $CO_2$ levels (House 46)

Table ZZ-137: Occupancy profiles of the living hall during measurement (House 46)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 20:00 – 22:00 | 6 | Natural (Window & Infiltration) | Sitting, dinner |
| **P2** | 22:00 - 04:00 | 0 | Natural (Infiltration) | 6 occupants in other room |
| **P3** | 04:00 – 11:30 | 5 | Mechanical | Sleeping in hall |
| **P4** | 11:30 – 20:00 | 0 | Mixed:<br>11:30 – 13:00 Natural (Infiltration)<br>13:00 – 16:00 Natural (Window & Infiltration)<br>16:00 – 20:00 Natural (Infiltration) | 6 occupants in other room |

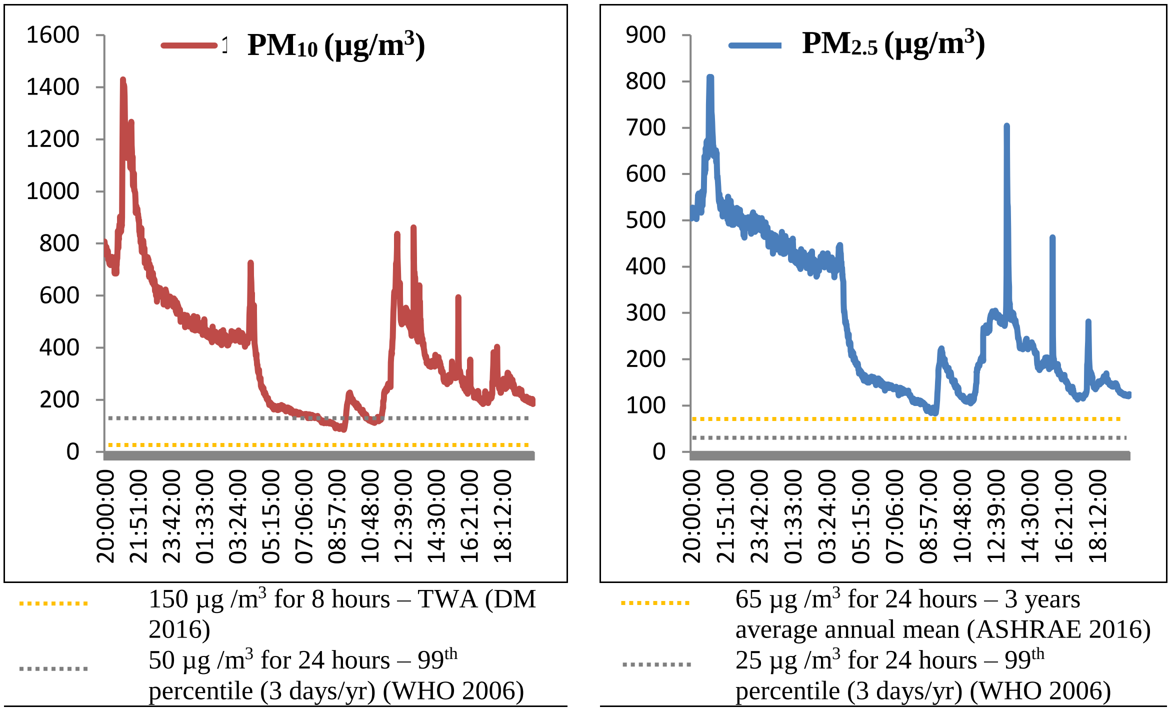


Figure ZZ-230: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 46)

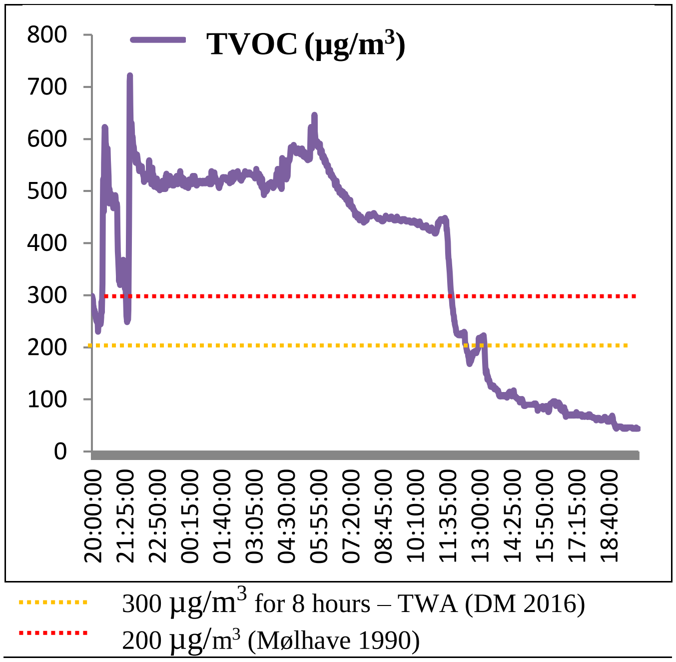


Figure ZZ-231: Compliance of indoor TVOC levels with established standards (House 46)

***House (47)***

Table ZZ-138: Levels of continuously measured variables indoor House (47)

| | **TVOC (µg/m$^3$)** | **CO$_2$ (ppm)** | **CO (ppm)** | **PM$_{2.5}$ (µg/m$^3$)** | **PM$_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 85.1 | 420.0 | 0.1 | 225.5 | 231.3 | 20.6 | 45.5 |
| **Mean** | 203.8 | 557.9 | 0.6 | 306.6 | 312.6 | 23.2 | 56.2 |
| **Max** | 588.8 | 799.0 | 1.3 | 460.3 | 474.2 | 25.5 | 61.4 |

Table ZZ-139: Spot measured variables in outdoor air of House (47)

| | **TVOC (µg/m$^3$)** | **CO$_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 117.3 | 435.0 | 2.1 | 22.9 | 58.5 |

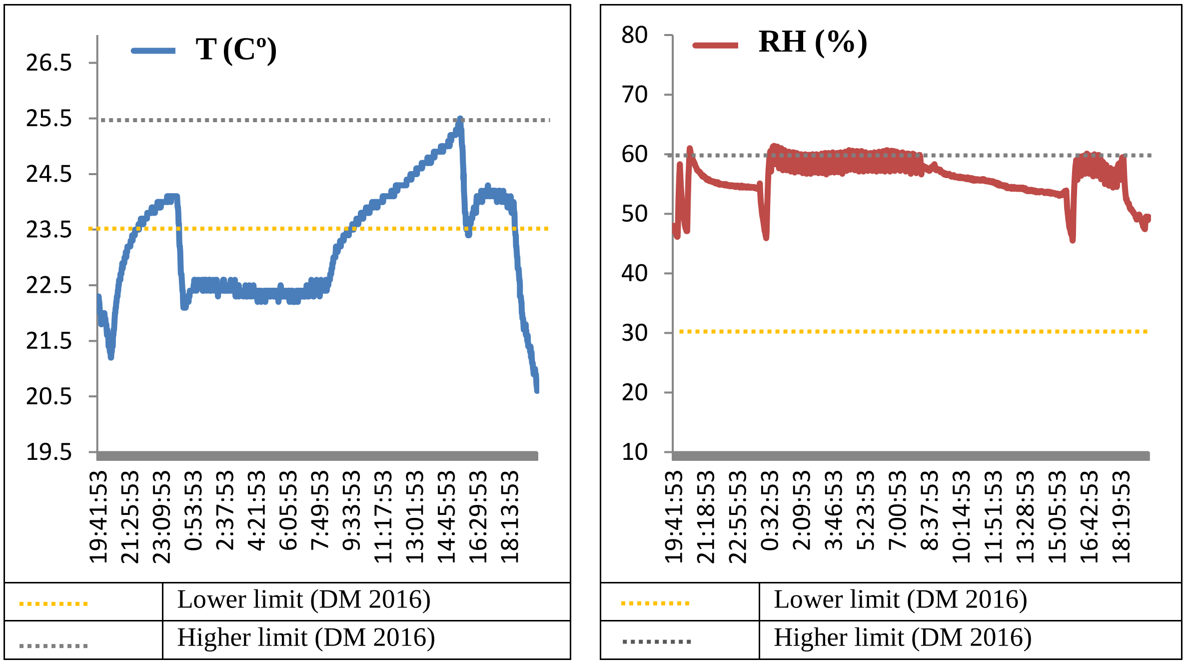


Figure ZZ-232: Continuously measured indoor levels of T and RH in House (46)

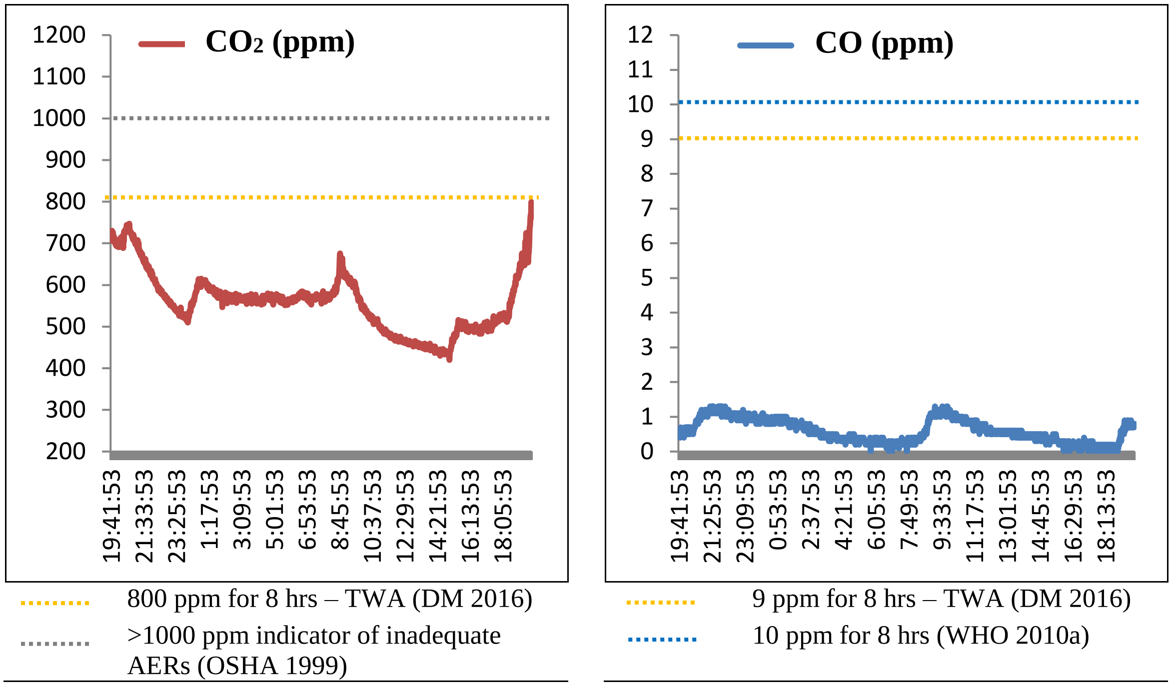


Figure ZZ-233: Compliance of $CO_2$ & CO levels in House (47) with established standards

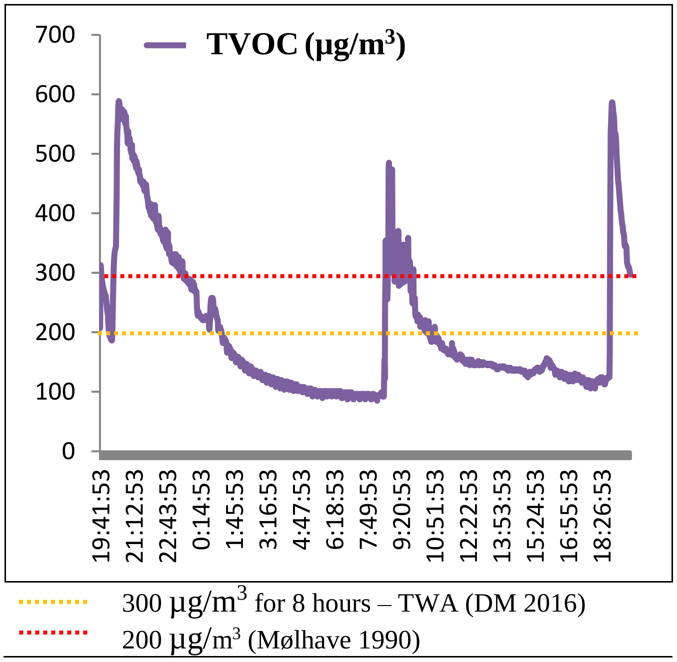


Figure ZZ-234: Compliance of indoor TVOC levels with established standards (House 47)

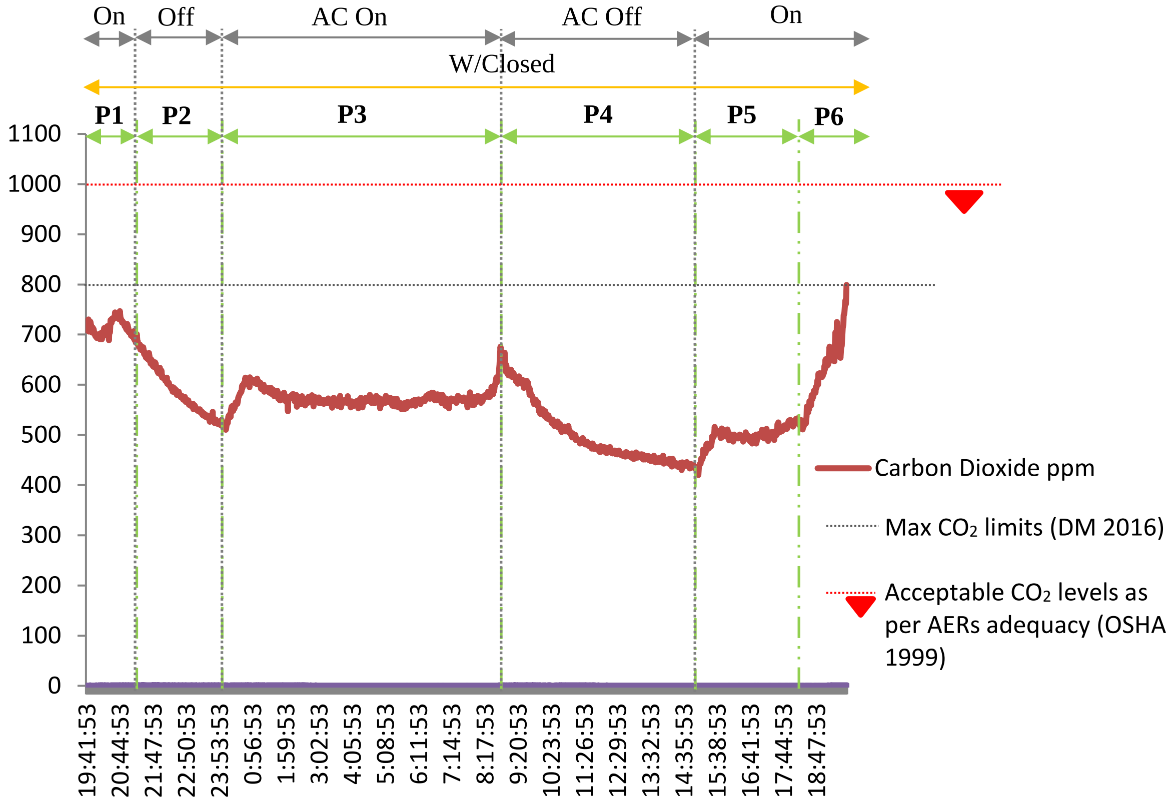


Figure ZZ-235: Occupancy profiles of the living hall projected on $CO_2$ levels (House 47)

Table ZZ-140: Occupancy profiles of the living hall during measurement (House 47)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 19:00 – 21:00 | 2 | Mechanical | Sitting |
| **P2** | 21:00 – 00:00 | 0 | Natural (Infiltration) | Went outside |
| **P3** | 00:00 – 08:45 | 0 | Mechanical | 2 persons in other room |
| **P4** | 08:45 – 15:00 | 0 | Natural (Infiltration) | 1 person in other room |
| **P5** | 15:00 – 18:15 | 1 | Mechanical | Sitting |
| **P6** | 18:15 – 19:30 | 2 | Mechanical | Sitting, cooking, dinner |

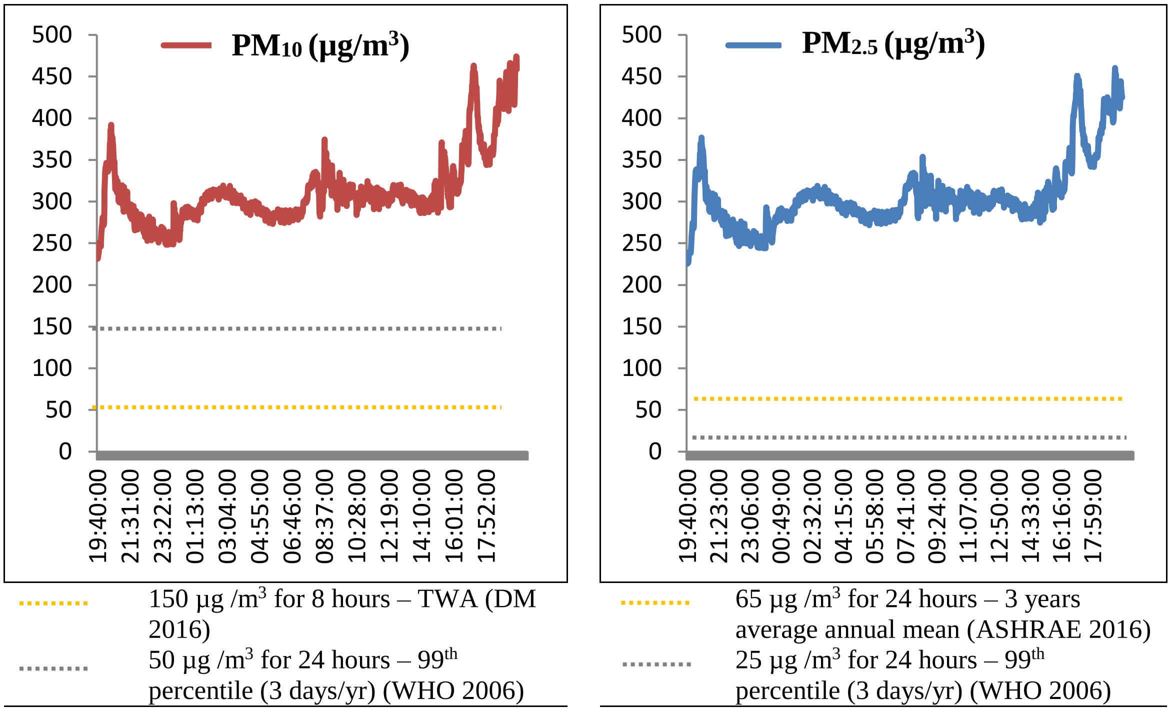


Figure ZZ-236: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 47)

### *House (48)*

Table ZZ-141: Levels of continuously measured variables indoor House (48)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 0.0 | 442.0 | 0.1 | 78.1 | 91.3 | 22.1 | 50.1 |
| **Mean** | 149.9 | 606.7 | 0.7 | 204.0 | 232.3 | 26.0 | 53.4 |
| **Max** | 503.7 | 979.0 | 1.4 | 743.2 | 855.2 | 27.3 | 66.7 |

Table ZZ-142: Spot measured variables in outdoor air of House (48)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 181.7 | 461 | 0.5 | 26.7 | 36.3 |

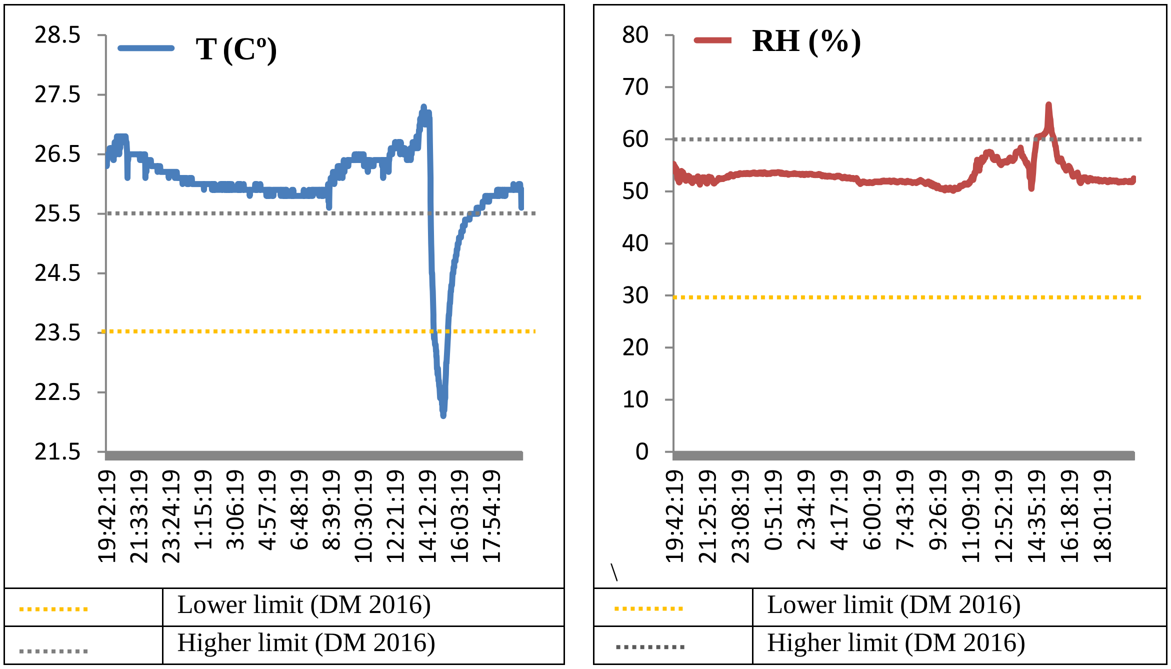


Figure ZZ-237: Continuously measured indoor levels of T and RH in House (48)

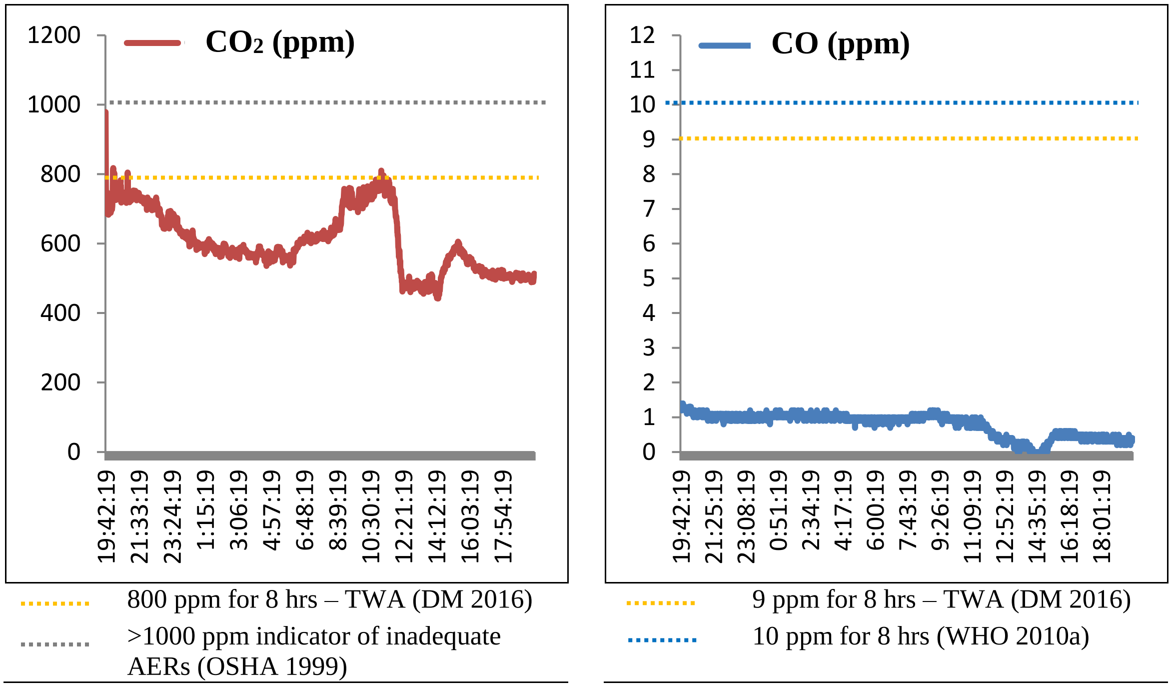


Figure ZZ-238: Compliance of $CO_2$ & CO levels in House (48) with established standards

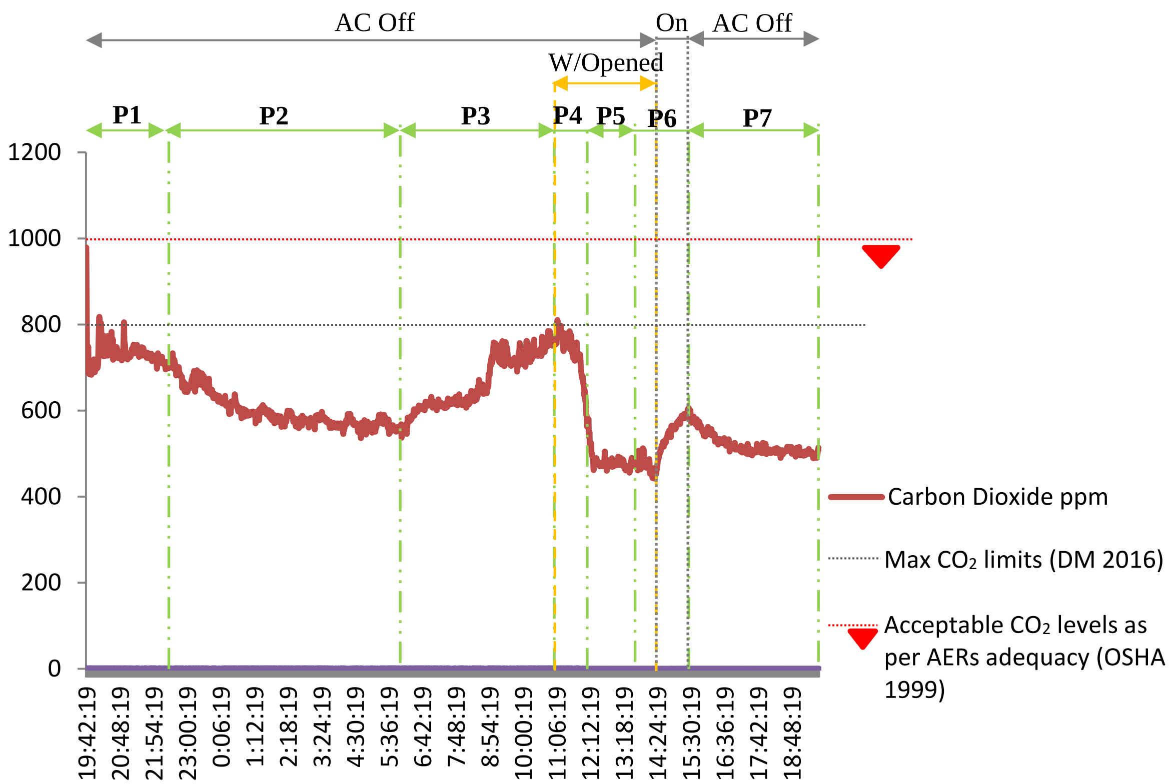
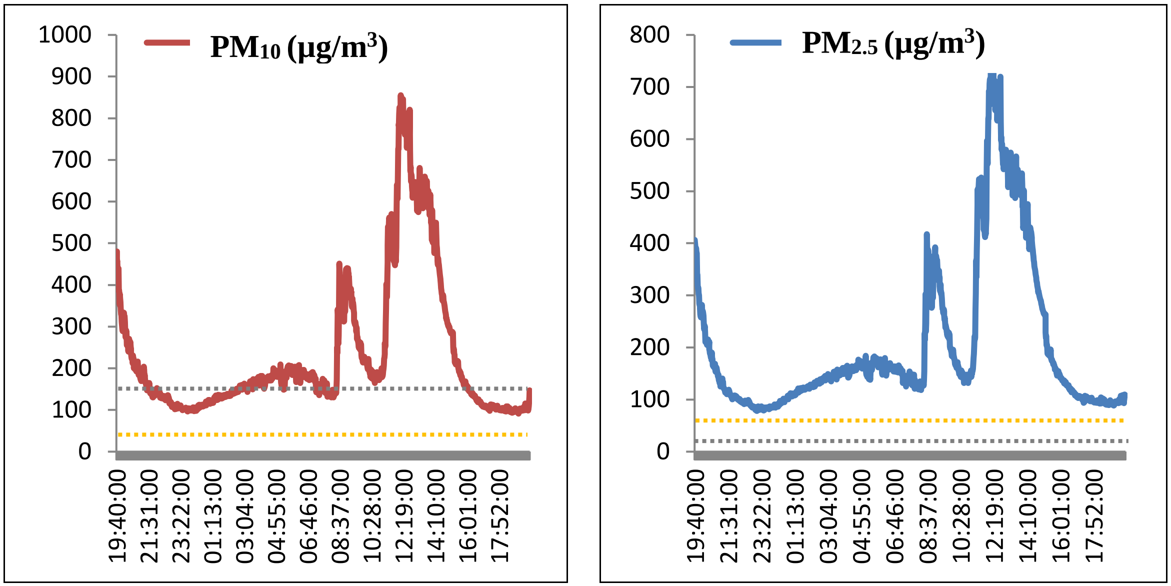


Figure ZZ-239: Occupancy profiles of the living hall projected on CO$_2$ levels (House 48)

Table ZZ-143: Occupancy profiles of the living hall during measurement (House 48)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 19:50 – 10:30 | 5 | Natural (Infiltration) | Sitting, AC opened in BR only |
| **P2** | 10:30 – 06:00 | 0 | Natural (Infiltration) | 5 persons in other rooms |
| **P3** | 06:00 – 10:47 | 5 | Natural (Window & Infiltration) | Sitting, cooking |
| **P4** | 10:47 – 12:00 | 4 | Natural (Window & Infiltration) | Sitting, cooking |
| **P5** | 12:00 – 13:30 | 3 | Natural (Window & Infiltration) | Sitting, cooking ,opened balcony |
| **P6** | 13:30 – 15:20 | 5 | Mixed:<br>13:30 – 14:25 Natural (Window & Infiltration)<br>14:25 – 15:20 Mechanical | Sitting ,opened balcony |
| **P7** | 15:20 – 19:40 | 1 | Natural (Infiltration) | Sitting |



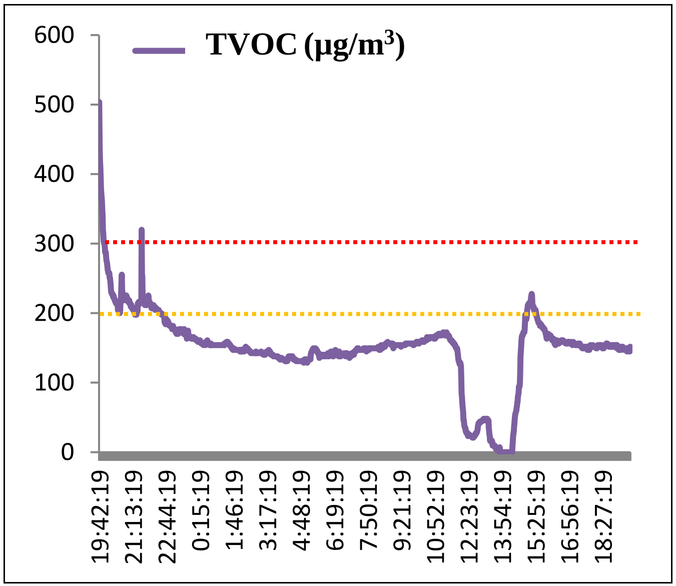
········ 150 μg /m³ for 8 hours – TWA (DM 2016)

········ 50 μg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006)

········ 65 μg /m³ for 24 hours – 3 years average annual mean (ASHRAE 2016)

········ 25 μg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006)

Figure ZZ-240: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 48)



········ 300 μg/m³ for 8 hours – TWA (DM 2016)

········ 200 μg/m³ (Mølhave 1990)

Figure ZZ-241: Compliance of indoor TVOC levels with established standards (House 48)

***House (49)***

Table ZZ-144: Levels of continuously measured variables indoor House (49)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **PM$_{2.5}$ (µg/m$^3$)** | **PM$_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 128.8 | 564.0 | 0.1 | 54.6 | 65.7 | 24.4 | 34.2 |
| **Mean** | 471.4 | 895.3 | 0.7 | 296.3 | 337.4 | 27.0 | 48.2 |
| **Max** | 7548.6 | 1179.0 | 1.6 | 899.9 | 967.1 | 28.5 | 56.1 |

Table ZZ-145: Spot measured variables in outdoor air of House (49)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 131.1 | 527.0 | 1.0 | 25.3 | 44.9 |

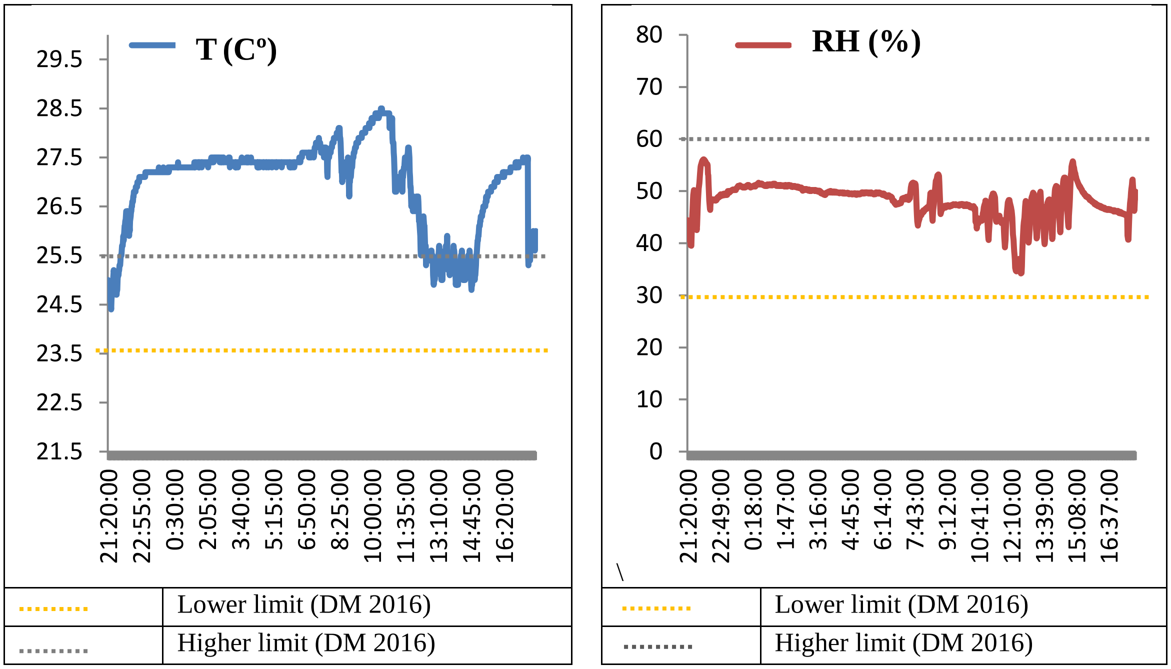


Figure ZZ-242: Continuously measured indoor levels of T and RH in House (49)

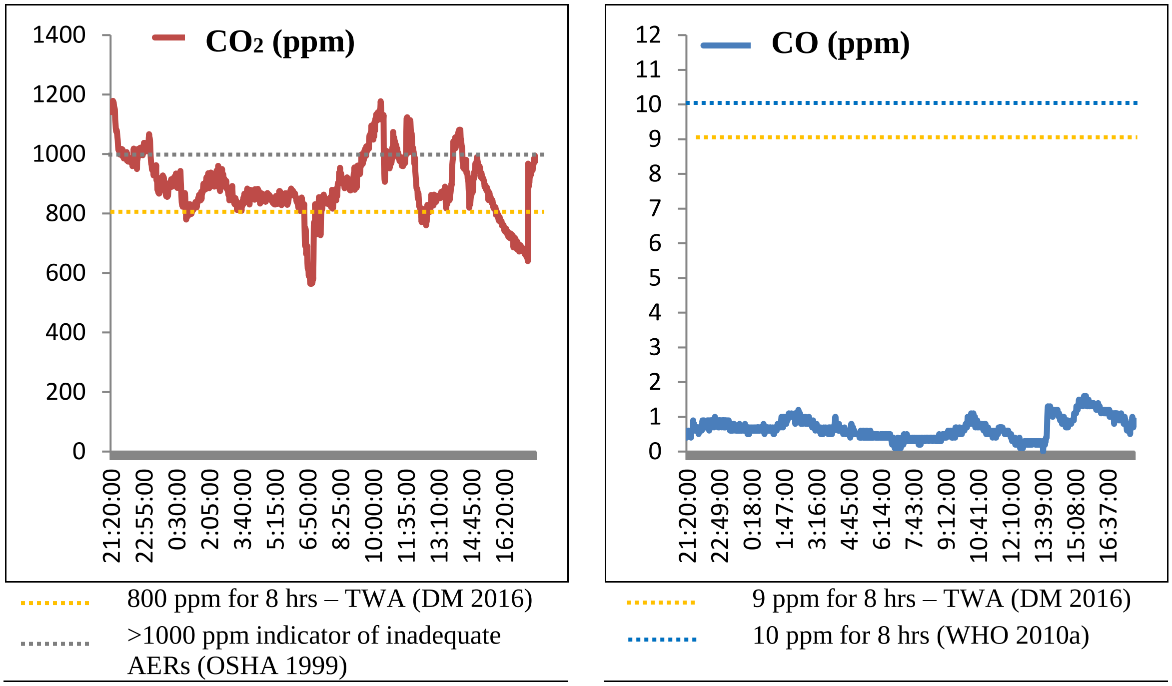


Figure ZZ-243: Compliance of $CO_2$ & CO levels in House (49) with established standards

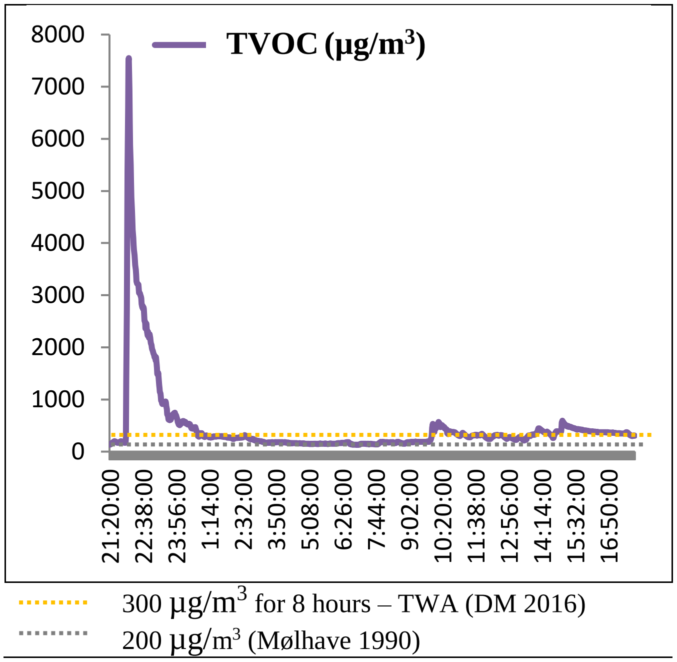


Figure ZZ-244: Compliance of indoor TVOC levels with established standards (House 49)

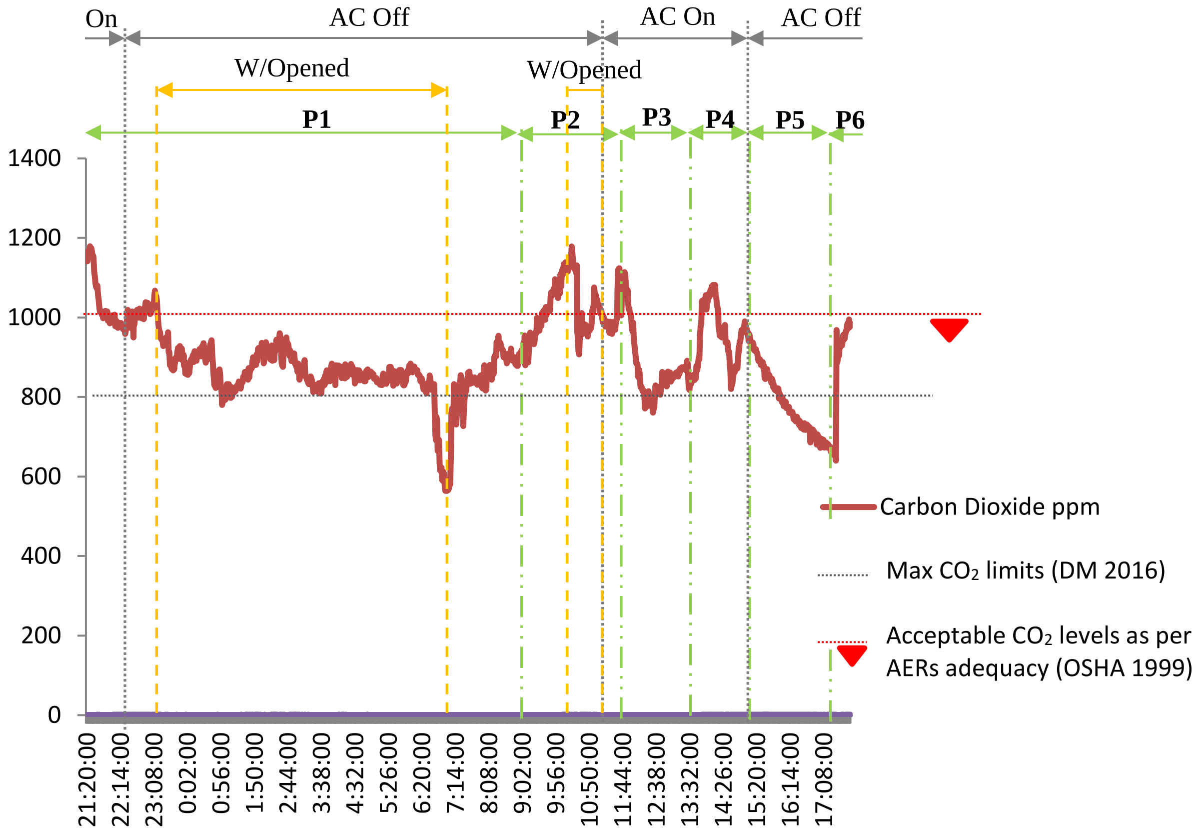
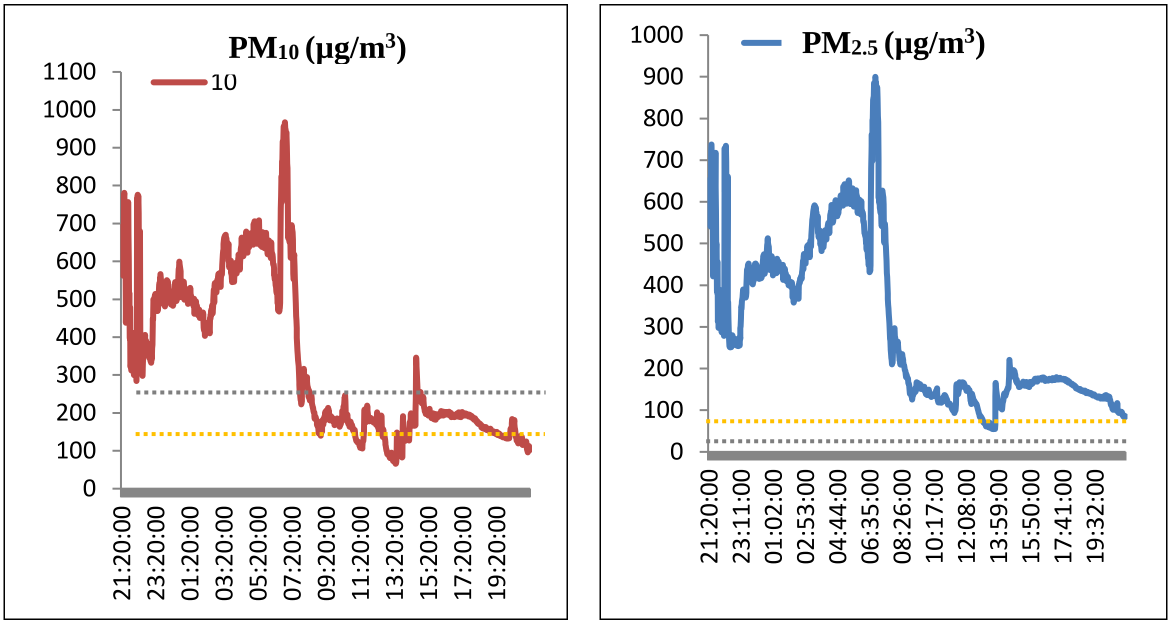


Figure ZZ-245: Occupancy profiles of the living hall projected on $CO_2$ levels (House 49)

Table ZZ-146: Occupancy profiles of the living hall during measurement (House 49)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 21:20 – 09:00 | 0 | Mixed:<br>21:20 – 22:20 Mechanical<br>22:20 – 23:00 Natural (Infiltration)<br>23:00 – 07:00 Natural (Window & Infiltration)<br>07:00 – 09:00 Natural (Infiltration) | 5 persons in other rooms |
| **P2** | 09:00 – 11:45 | 4 | Mixed:<br>09:00 – 11:20 Natural (Infiltration)<br>11:20 – 11:45 Mechanical | Sitting, breakfast |
| **P3** | 11:45 – 13:30 | 0 | Mechanical | 4 persons in other rooms |
| **P4** | 13:30 – 15:00 | 4 | Mechanical | Sitting, lunch |
| **P5** | 15:00 - 17:15 | 0 | Natural (Infiltration) | Went outside |
| **P6** | 17:15 – 17:52 | 5 | Natural (Infiltration) | Sitting |



| | | | |
|---|---|---|---|
| ········ | 150 µg /m³ for 8 hours – TWA (DM 2016) | ········ | 65 µg /m³ for 24 hours – 3 years average annual mean (ASHRAE 2016) |
| ········ | 50 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) | ········ | 25 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure ZZ-246: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 49)

### *House (50)*

Table ZZ-147: Levels of continuously measured variables indoor House (50)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 52.9 | 404.0 | 0.1 | 70.1 | 74.4 | 26.1 | 30.8 |
| **Mean** | 274.1 | 574.1 | 0.6 | 147.0 | 261.7 | 27.5 | 41.2 |
| **Max** | 798.1 | 1875.0 | 3.1 | 308.5 | 533.0 | 28.5 | 50.9 |

Table ZZ-148: Spot measured variables in outdoor air of House (50)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 39.1 | 443.0 | 0.5 | 24.6 | 49.8 |

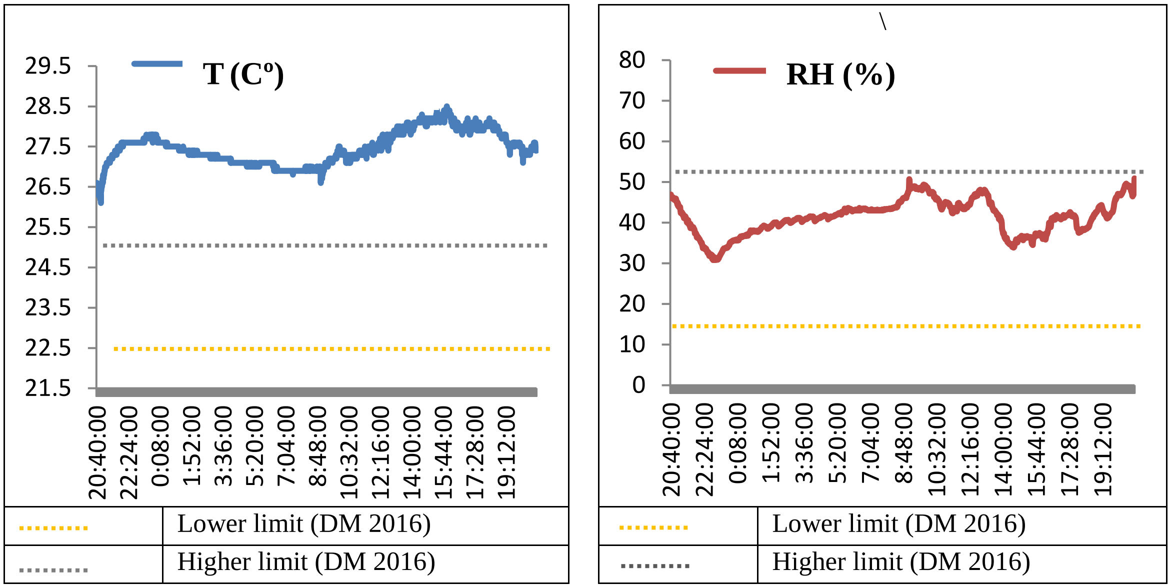


Figure ZZ-247: Continuously measured indoor levels of T and RH in House (50)

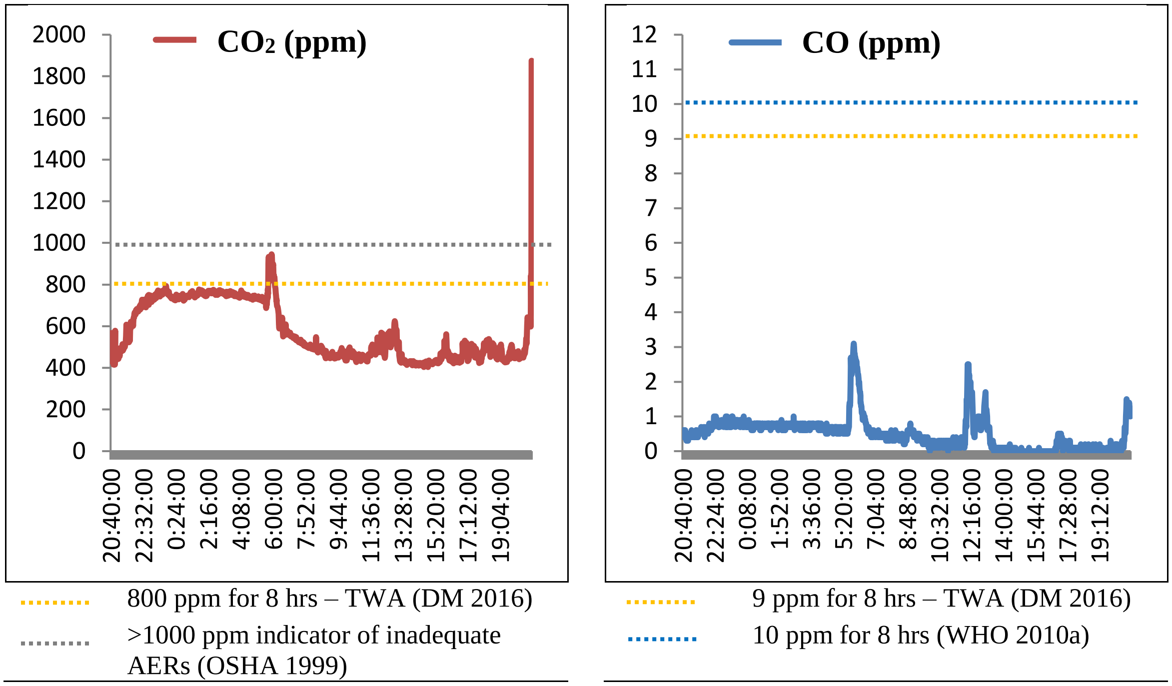


Figure ZZ-248: Compliance of $CO_2$ & CO levels in House (50) with established standards

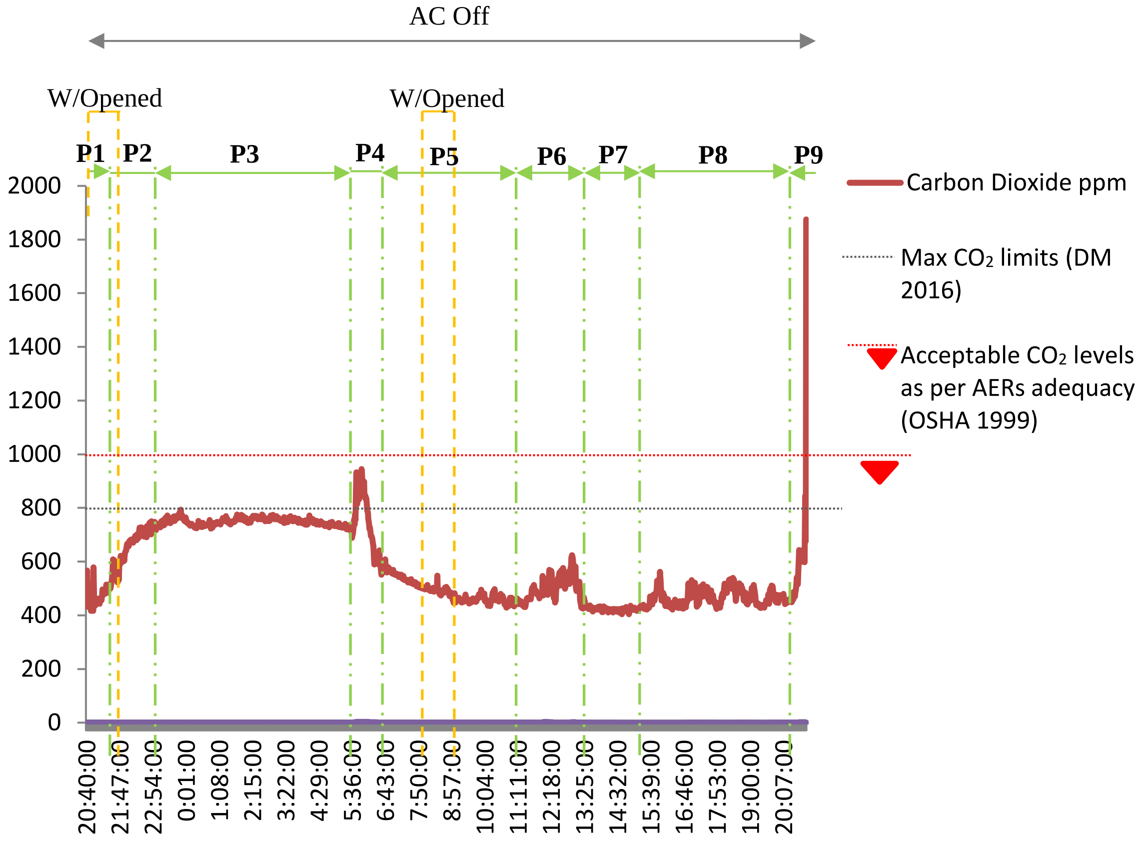
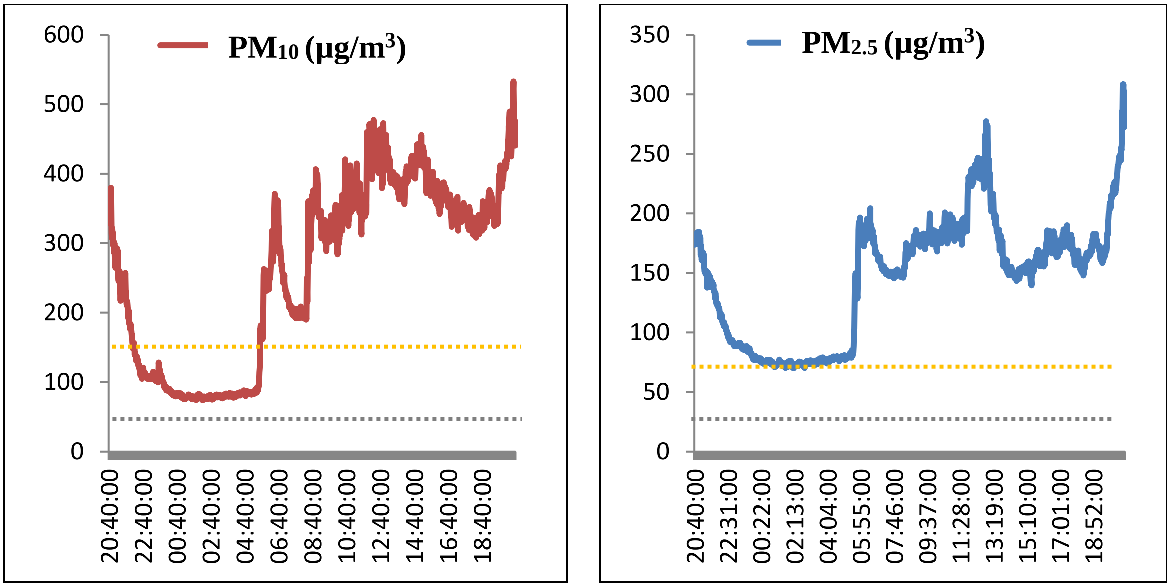


Figure ZZ-249: Occupancy profiles of the living hall projected on $CO_2$ levels (House 50)

Table ZZ-149: Occupancy profiles of the living hall during measurement (House 50)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 20:40 – 21:15 | 6 | Natural (Window & Infiltration) | Sitting |
| **P2** | 21:15 – 23:00 | 2 | Natural:<br>21:15 – 21:45 Natural (Window & Infiltration)<br>21:45 – 23:00 Natural (Infiltration) | Sitting |
| **P3** | 23:00 – 05:40 | 0 | Natural (Infiltration) | 6 persons in other rooms |
| **P4** | 05:40 – 06:45 | 5 | Natural (Infiltration) | Cooking |
| **P5** | 06:50 – 11:10 | 1 | Natural:<br>06:50 – 08:00 Natural (Infiltration)<br>08:00 – 09:00 Natural (Window & Infiltration)<br>09:00 – 11:10 Natural (Infiltration) | Daily cleaning, cooking |
| **P6** | 11:10 – 13:30 | 6 | Natural (Infiltration) | Sitting, lunch |
| **P7** | 13:30 – 15:15 | 0 | Natural (Infiltration) | 6 persons in other rooms |
| **P8** | 15:15 – 20:30 | 4 | Natural (Infiltration) | Sitting, studying |
| **P9** | 20:30 – 23:00 | 6 | Natural (Infiltration) | Sitting, dinner |



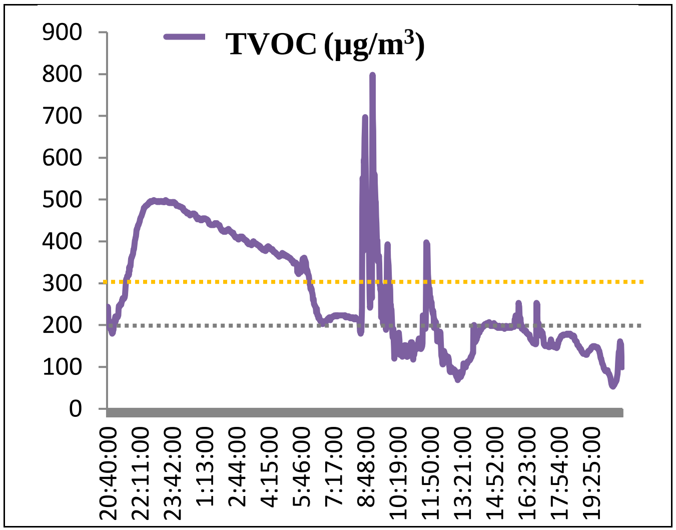
······ 150 µg /m$^3$ for 8 hours – TWA (DM 2016)

······ 50 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006)

······ 65 µg /m$^3$ for 24 hours – 3 years average annual mean (ASHRAE 2016)

······ 25 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006)

Figure ZZ-250: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 50)



······ 300 µg/m$^3$ for 8 hours – TWA (DM 2016)

······ 200 µg/m$^3$ (Mølhave 1990)

Figure ZZ-251: Compliance of indoor TVOC levels with established standards (House 50)

### *House (51)*

Table ZZ-150: Levels of continuously measured variables indoor House (51)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m$^3$)** | **$PM_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | <11.5 | 510.0 | 0.2 | 97.7 | 101.2 | 20.6 | 33.7 |
| **Mean** | 277.7 | 826.1 | 1.2 | 284.7 | 450.6 | 27.6 | 47.1 |
| **Max** | 646.3 | 1219.0 | 2.7 | 587.7 | 3071.5 | 30.6 | 66.1 |

Table ZZ-151: Spot measured variables in outdoor air of House (51)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 167.9 | 450 | 0.0 | 38.2 | 24.1 |

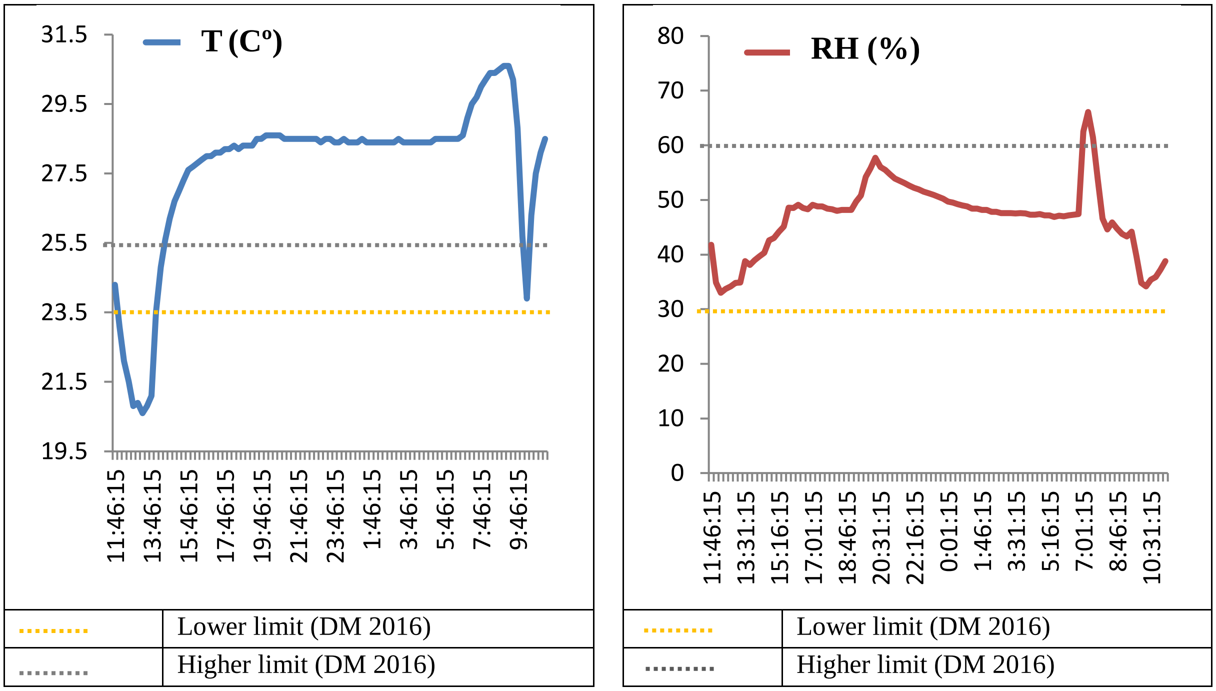


Figure ZZ-252: Continuously measured indoor levels of T and RH in House (51)

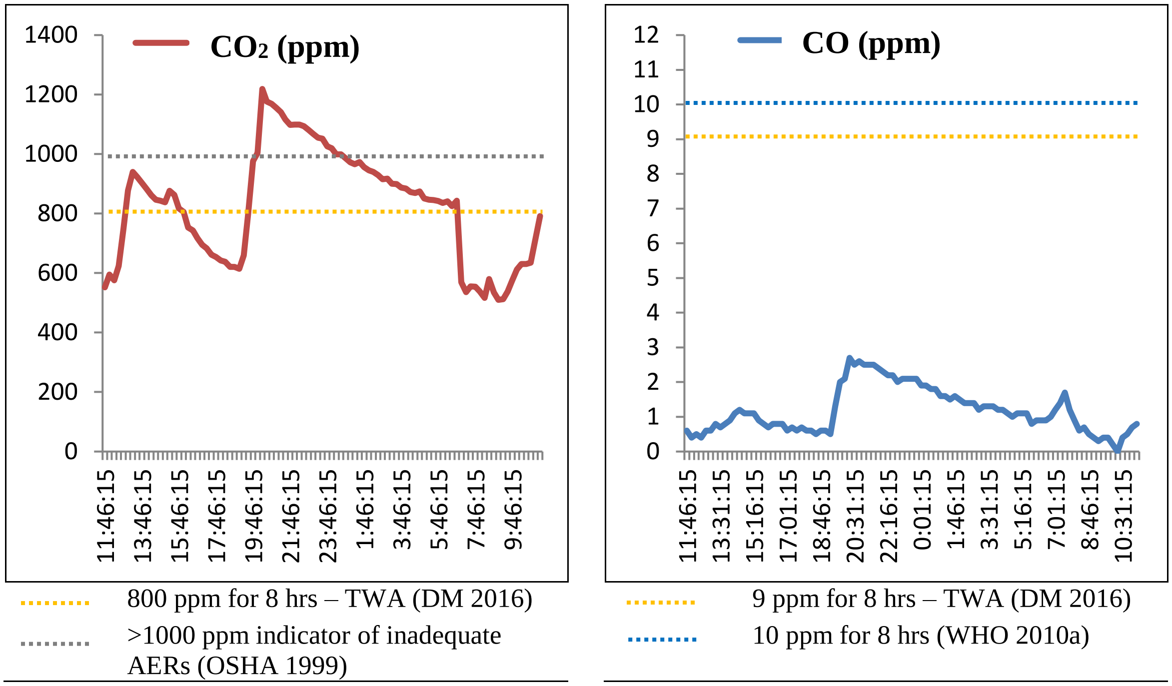


Figure ZZ-253: Compliance of $CO_2$ & CO levels in House (51) with established standards

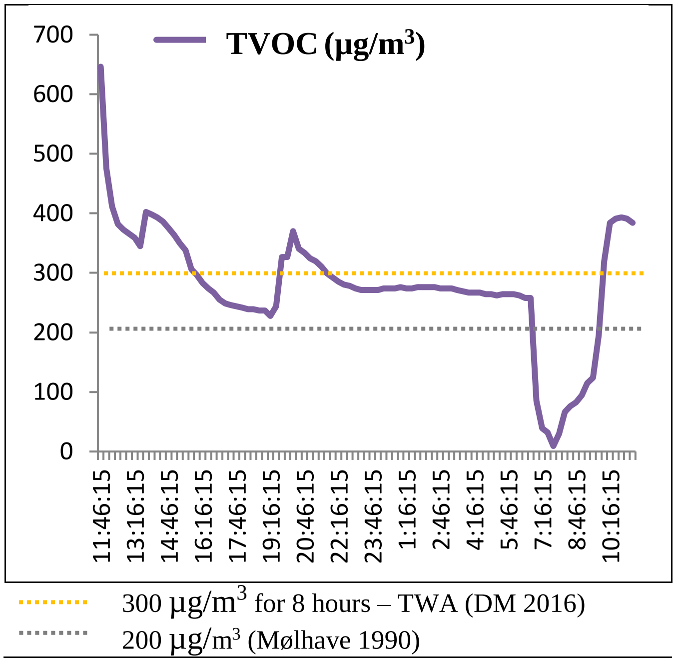


Figure ZZ-254: Compliance of indoor TVOC levels with established standards (House 51)

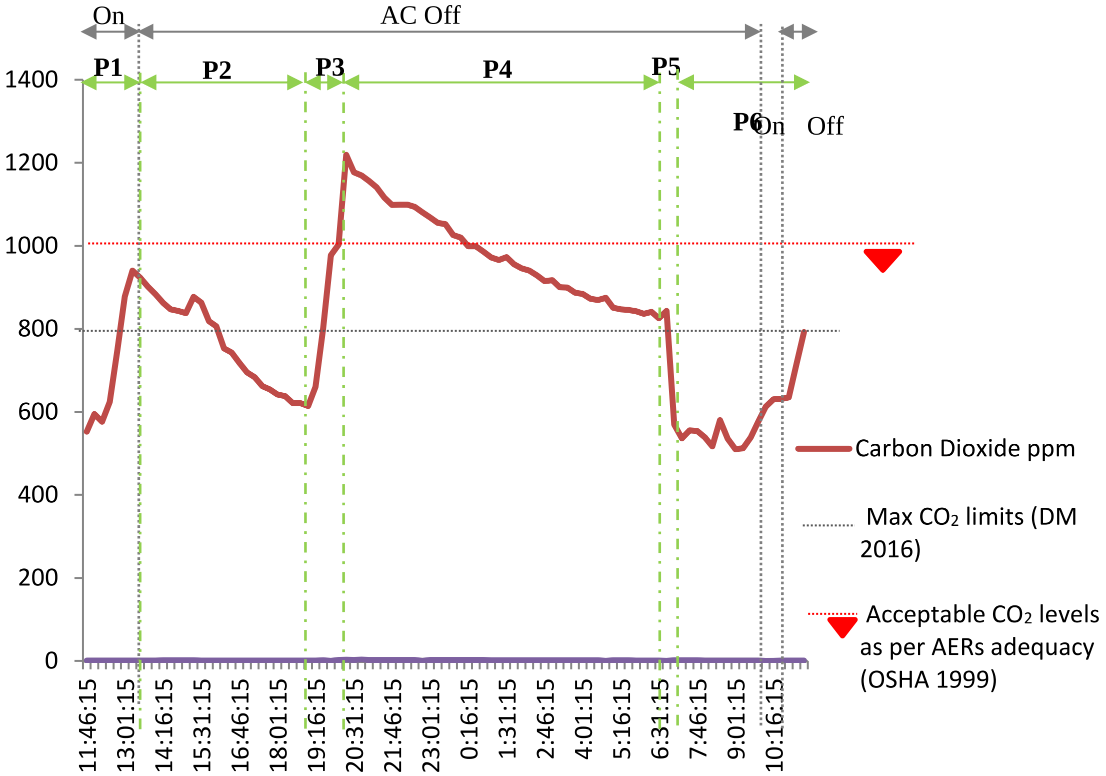
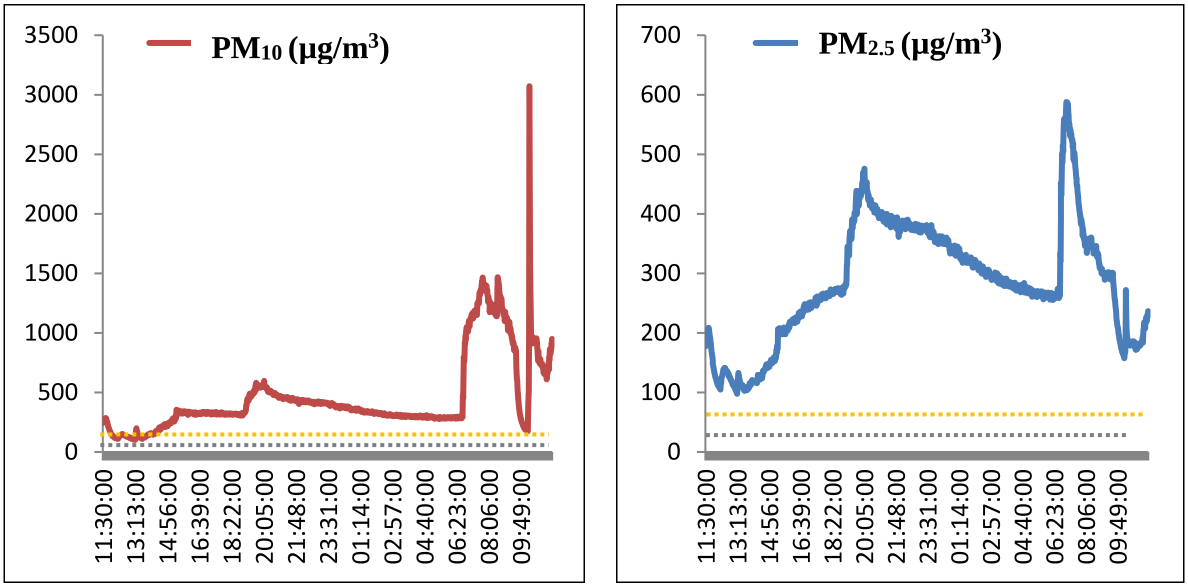


Figure ZZ-255: Occupancy profiles of the living hall projected on $CO_2$ levels (House 51)

Table ZZ-152: Occupancy profiles of the living hall during measurement (House 51)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 11:30 – 13:30 | 1 | Mechanical | Cooking, cleaning |
| **P2** | 13:30 – 19:00 | 0 | Natural (Infiltration) | Went outside |
| **P3** | 19:00 – 20:30 | 5 | ,, ,, ,, ,, ,, | Sitting, dinner |
| **P4** | 20:30 – 06:30 | 0 | ,, ,, ,, ,, ,, | 5 persons in other rooms |
| **P5** | 06:30 – 07:00 | 4 | ,, ,, ,, ,, ,, | Preparing to go outside |
| **P6** | 07:00 – 11:16 | 1 | Mixed:<br>07:00 – 10:30 Mechanical<br>10:30 – 11:16 Natural (Infiltration) | Daily cleaning, cooking, laundry |



| | | | |
|---|---|---|---|
| ⋯ | 150 µg /m³ for 8 hours – TWA (DM 2016) | ⋯ | 65 µg /m³ for 24 hours – 3 years annual mean (ASHRAE 2016) |
| ⋯ | 50 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) | ⋯ | 25 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure ZZ-256: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 51)

### *House (52)*

Table ZZ-153: Levels of continuously measured variables indoor House (52)

| | TVOC (µg/m³) | $CO_2$ (ppm) | CO (ppm) | $PM_{2.5}$ (µg/m³) | $PM_{10}$ (µg/m³) | T (°C) | RH % |
|---|---|---|---|---|---|---|---|
| **Min** | 55.2 | 518.0 | 0.1 | 63.3 | 88.7 | 18.7 | 25.2 |
| **Mean** | 168.6 | 685.1 | 0.9 | 148.7 | 239.9 | 26.4 | 43.5 |
| **Max** | 738.3 | 1102.0 | 3.3 | 892.5 | 1222.9 | 31.2 | 64.1 |

Table ZZ-154: Spot measured variables in outdoor air of House (52)

| | TVOC (µg/m³) | $CO_2$ (ppm) | CO (ppm) | T (°C) | RH % |
|---|---|---|---|---|---|
| **Outdoor levels** | <11.5 | 371 | 0.2 | 34.3 | 31.1 |

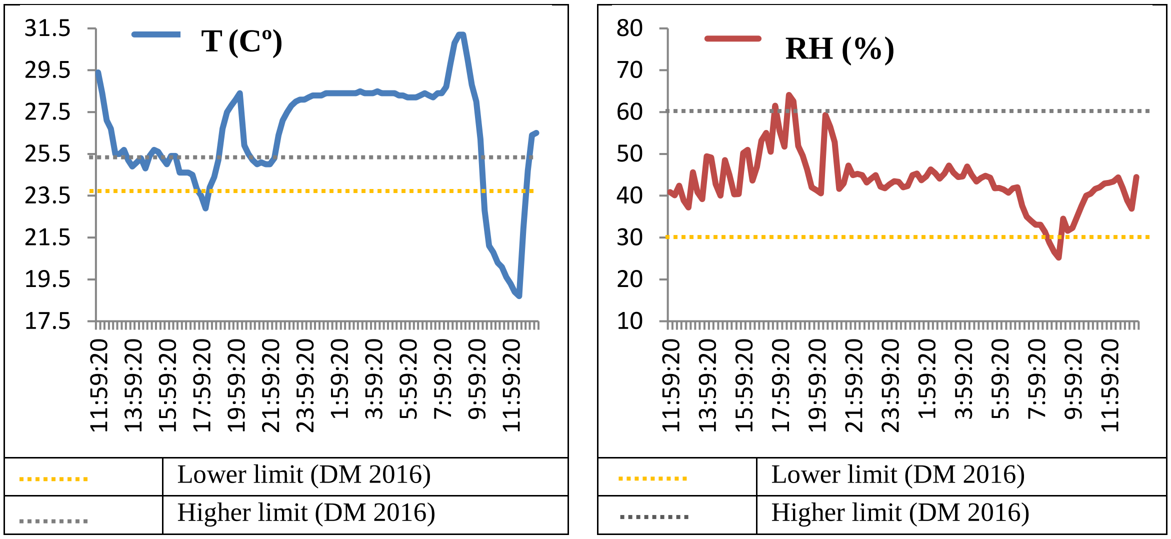


Figure ZZ-257: Continuously measured indoor levels of T and RH in House (52)

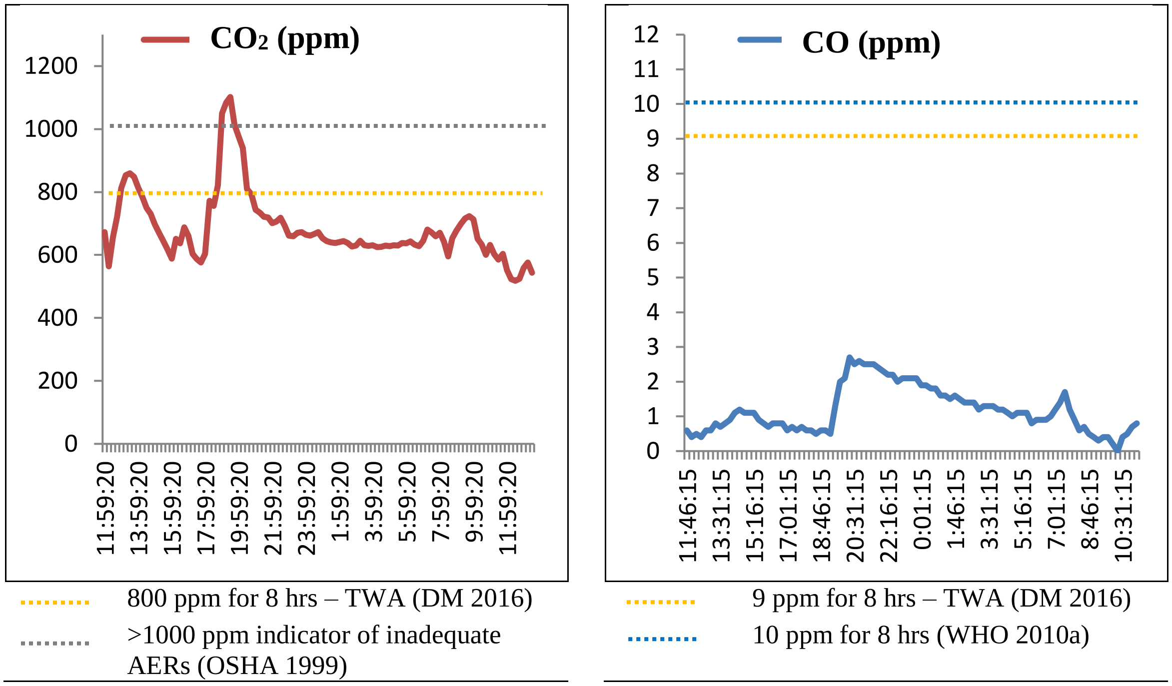


Figure ZZ-258: Compliance of $CO_2$ & CO levels in House (52) with established standards

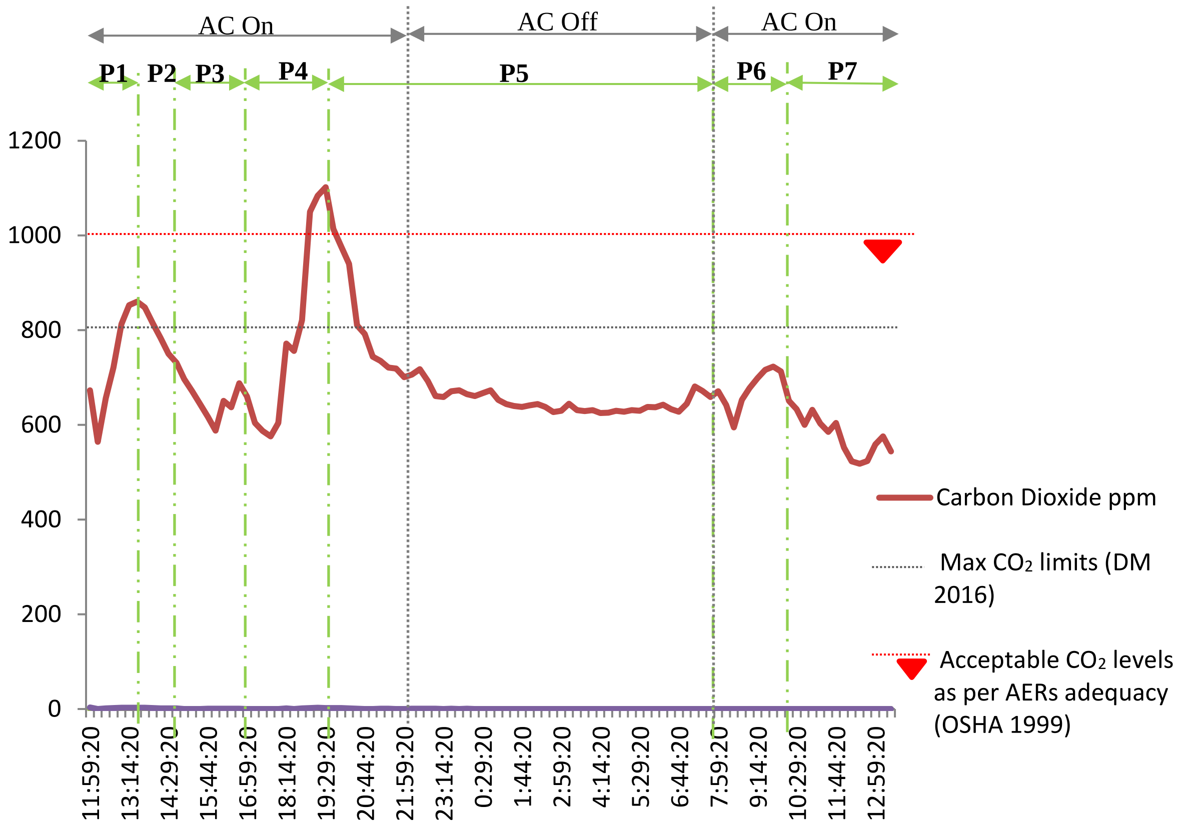
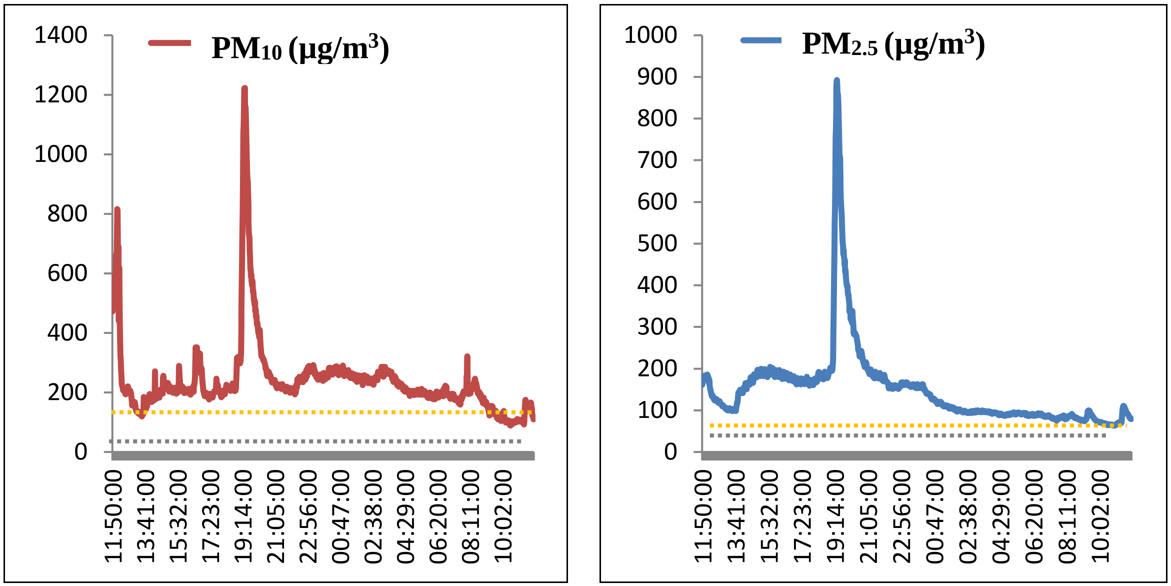


Figure ZZ-259: Occupancy profiles of the living hall projected on $CO_2$ levels (House 52)

Table ZZ-155: Occupancy profiles of the living hall during measurement (House 52)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 11:59 – 13:40 | 4 | Mechanical | Variable occupancy levels (2 – 6 persons), maintenance, cleaning, cooking |
| **P2** | 13:40 – 14:30 | 5 | Mechanical | Sitting, lunch |
| **P3** | 14:30 – 17:00 | 1 | Mechanical | 4 persons went outside |
| **P4** | 17:00 – 19:30 | 6 | Mechanical | Sitting, dinner |
| **P5** | 19:30 – 08:00 | 0 | Mixed:<br>19:30 – 22:00 Mechanical<br>22:00 – 08:00 Natural (Infiltration) | 6 persons sleeping in other rooms |
| **P6** | 08:00 – 10:00 | 6 | Mechanical | Sitting, breakfast |
| **P7** | 10:00 – 13:29 | 2 | Mechanical | Sitting |



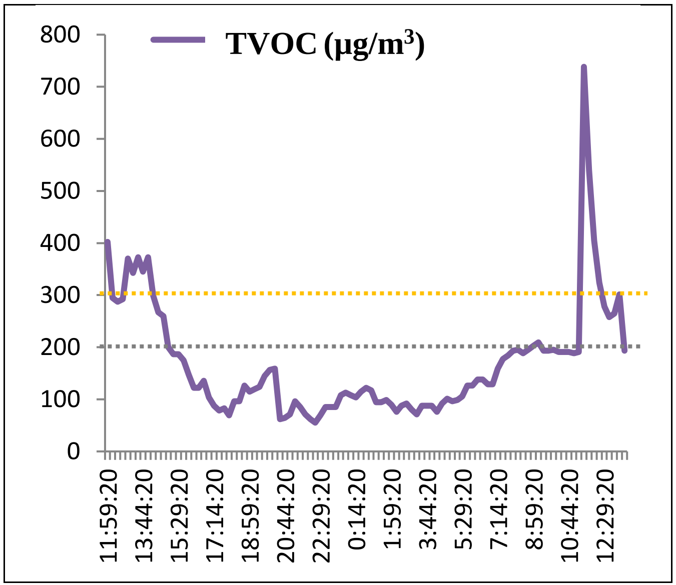
⋯⋯ 150 µg /m$^3$ for 8 hours – TWA (DM 2016)

⋯⋯ 50 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006)

⋯⋯ 65 µg /m$^3$ for 24 hours – 3 years annual mean (ASHRAE 2016)

⋯⋯ 25 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006)

Figure ZZ-260: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 52)



⋯⋯ 300 µg/m$^3$ for 8 hours – TWA (DM 2016)

⋯⋯ 200 µg/m$^3$ (Mølhave 1990)

Figure ZZ-261: Compliance of indoor TVOC levels with established standards (House 52)

***House (53)***

Table ZZ-156: Levels of continuously measured variables indoor House (53)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m$^3$)** | **$PM_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 271.4 | 492.0 | 0.1 | 54.7 | 69.5 | 25.9 | 31.2 |
| **Mean** | 314.4 | 574.8 | 0.2 | 73.2 | 103.0 | 27.2 | 36.2 |
| **Max** | 860.2 | 850.0 | 0.5 | 94.6 | 162.0 | 29.5 | 42.3 |

Table ZZ-157: Spot measured variables in outdoor air of House (53)

| | **TVOC (µg/m$^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | <11.5 | 447 | 0.1 | 35.8 | 48.1 |

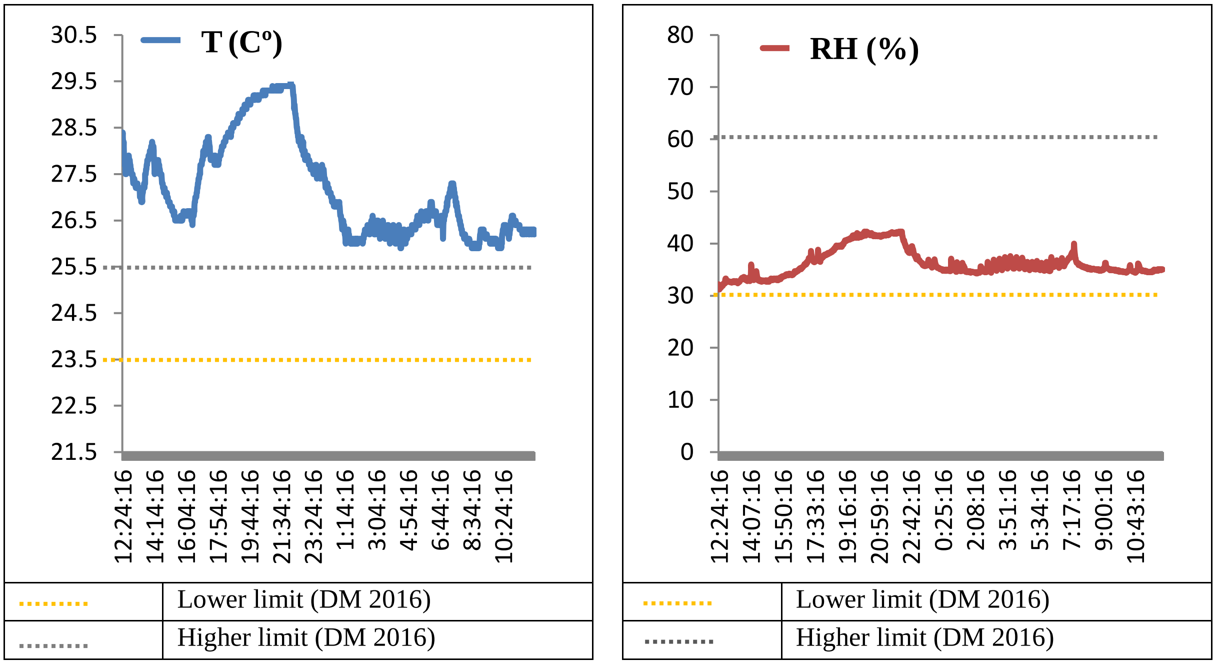


Figure ZZ-262: Continuously measured indoor levels of T and RH in House (53)

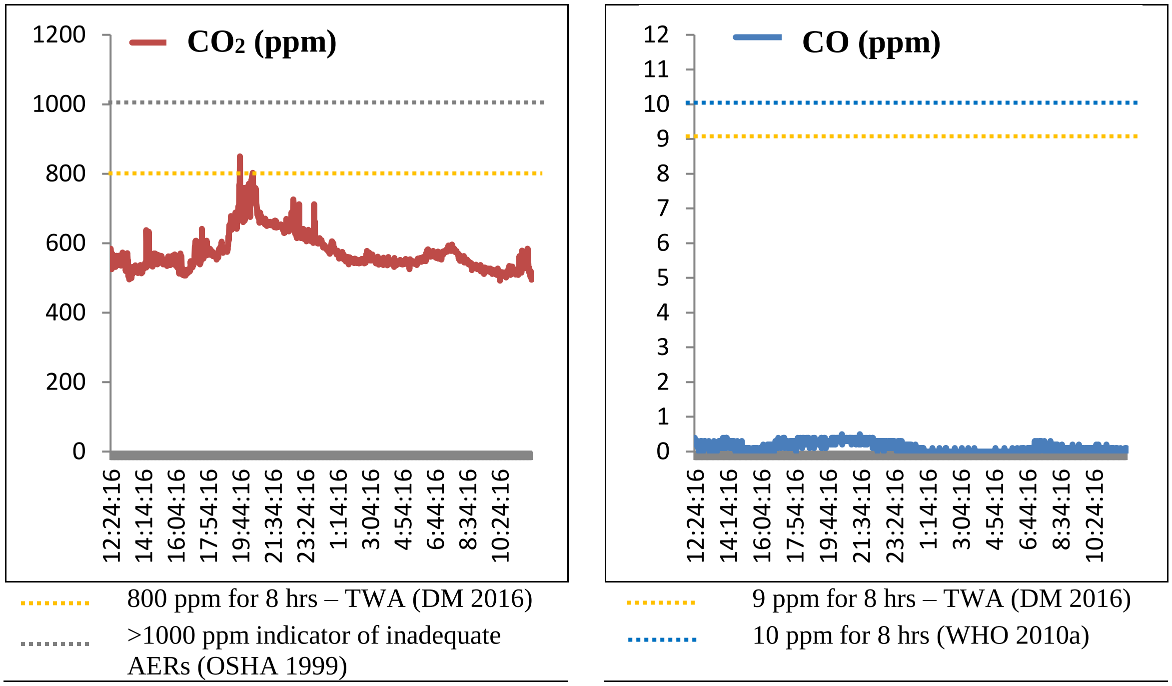


Figure ZZ-263: Compliance of $CO_2$ & CO levels in House (53) with established standards

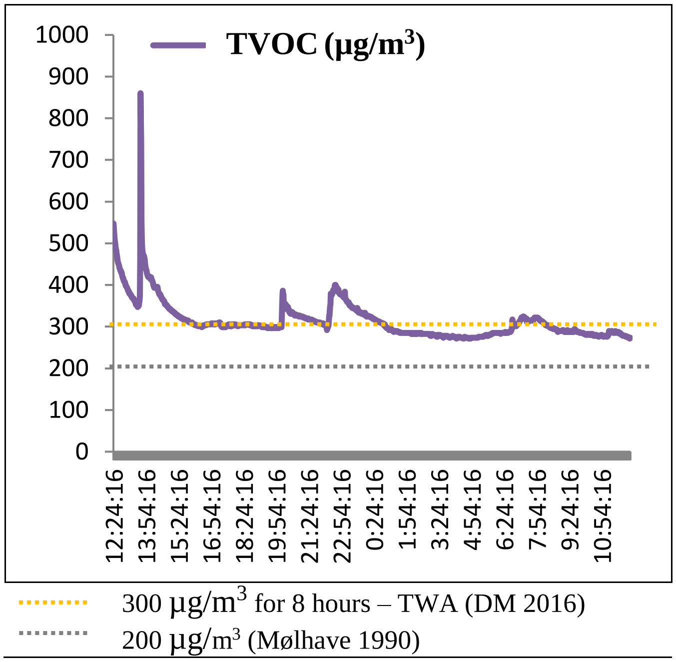


Figure ZZ-264: Compliance of indoor TVOC levels with established standards (House 53)

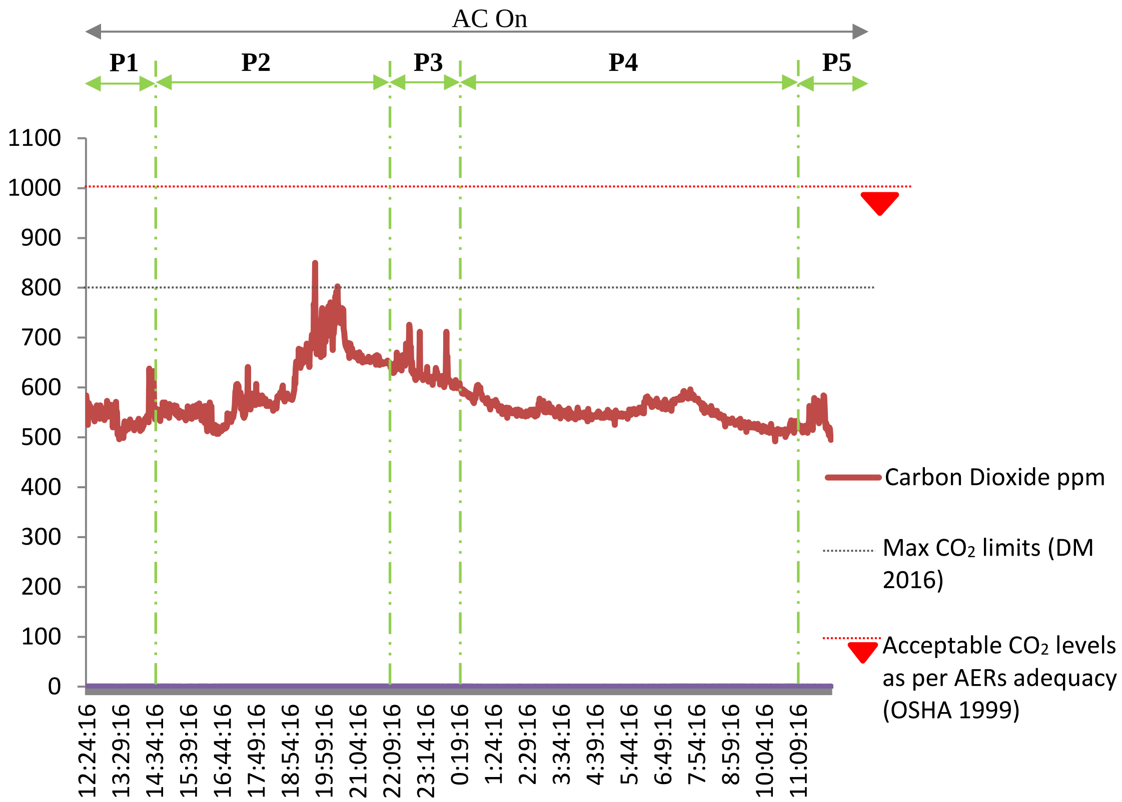


Figure ZZ-265: Occupancy profiles of the living hall projected on $CO_2$ levels (House 53)

Table ZZ-158: Occupancy profiles of the living hall during measurement (House 53)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 12:15 – 14:30 | 2 | Mechanical | Sitting |
| **P2** | 14:30 – 20:00 | 1 | Mechanical | Sitting, cleaning with vacuum and detergent |
| **P3** | 20:00 – 00:15 | 2 | Mechanical | Sitting |
| **P4** | 00:15 – 11:00 | 0 | Mechanical | 3 persons in other rooms |
| **P5** | 11:00 – 12:13 | 1 | Mechanical | Sitting |

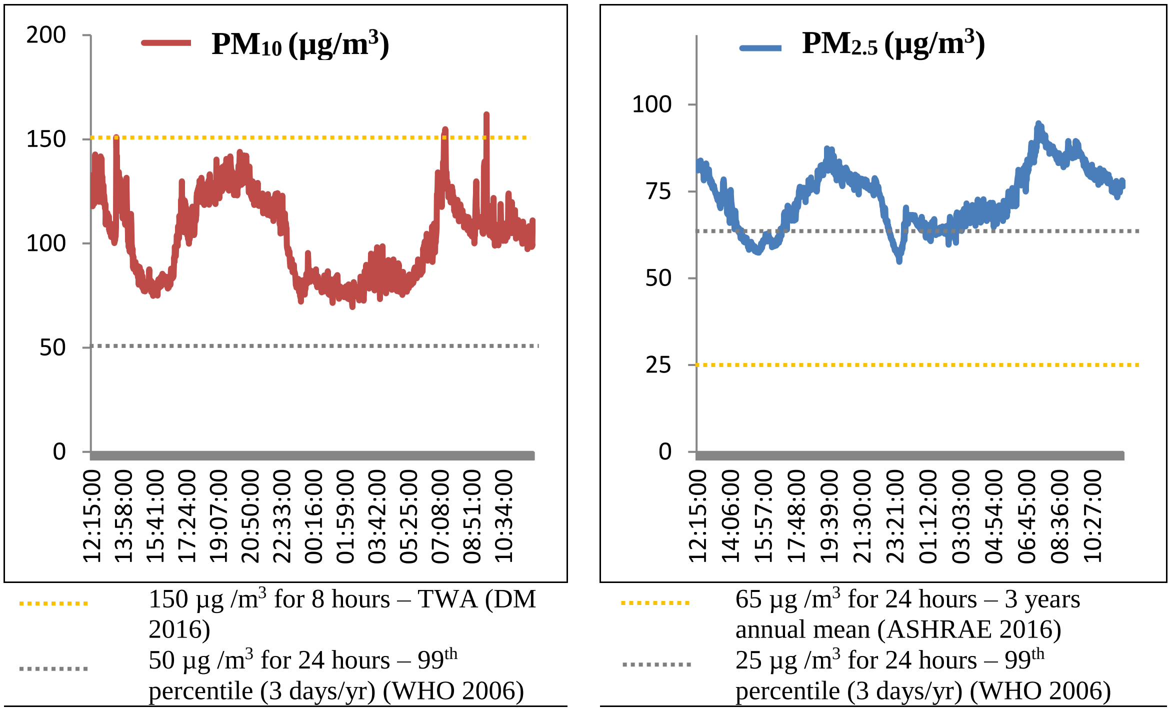


Figure ZZ-266: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 53)

### *House (54)*

Table ZZ-159: Levels of continuously measured variables indoor House (54)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | <11.5 | 499.0 | 0.1 | 48.3 | 52.7 | 26.3 | 32.1 |
| **Mean** | 203.0 | 759.9 | 0.4 | 96.9 | 131.5 | 28.0 | 43.1 |
| **Max** | 549.7 | 1524.0 | 1.1 | 711.0 | 1294.6 | 30.2 | 61.4 |

Table ZZ-160: Spot measured variables in outdoor air of House (54)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 135.7 | 401.0 | 0.3 | 28.6 | 48.4 |

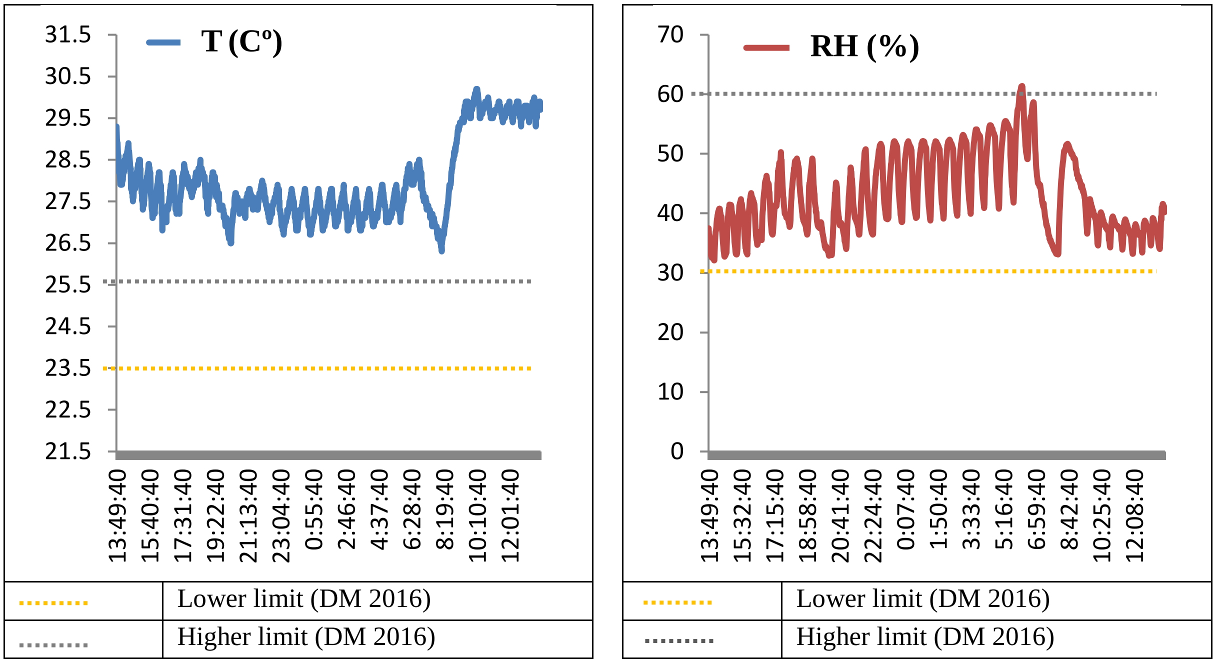


Figure ZZ-267: Continuously measured indoor levels of T and RH in House (54)

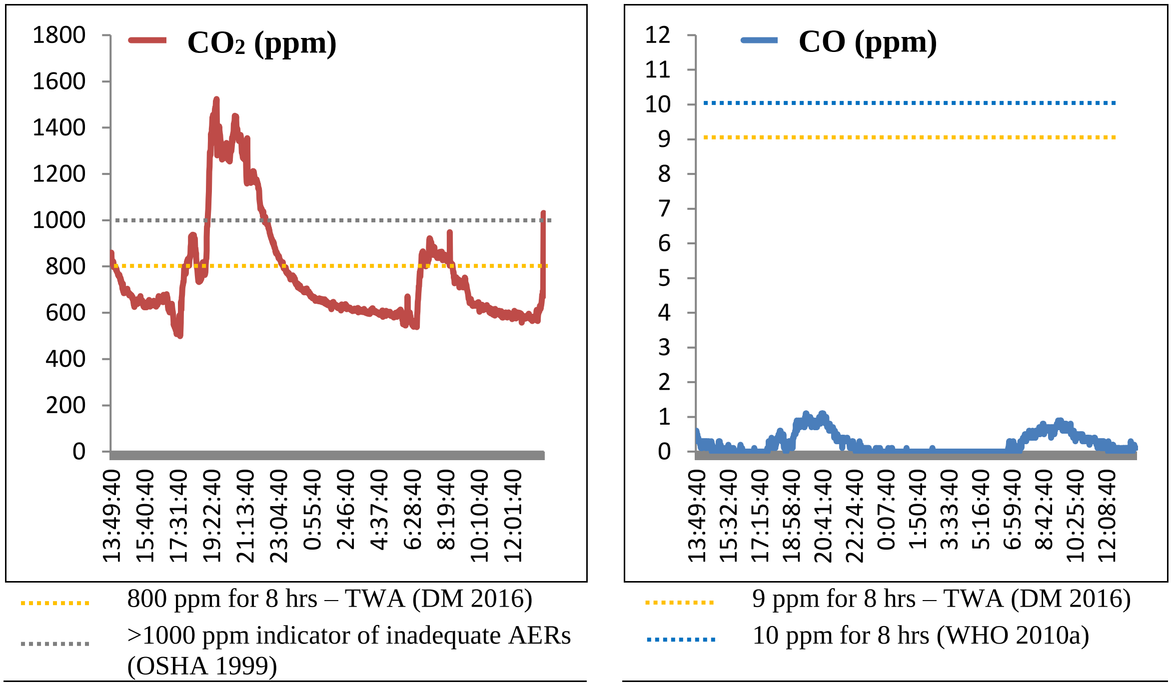


Figure ZZ-268: Compliance of $CO_2$ & CO levels in House (54) with established standards

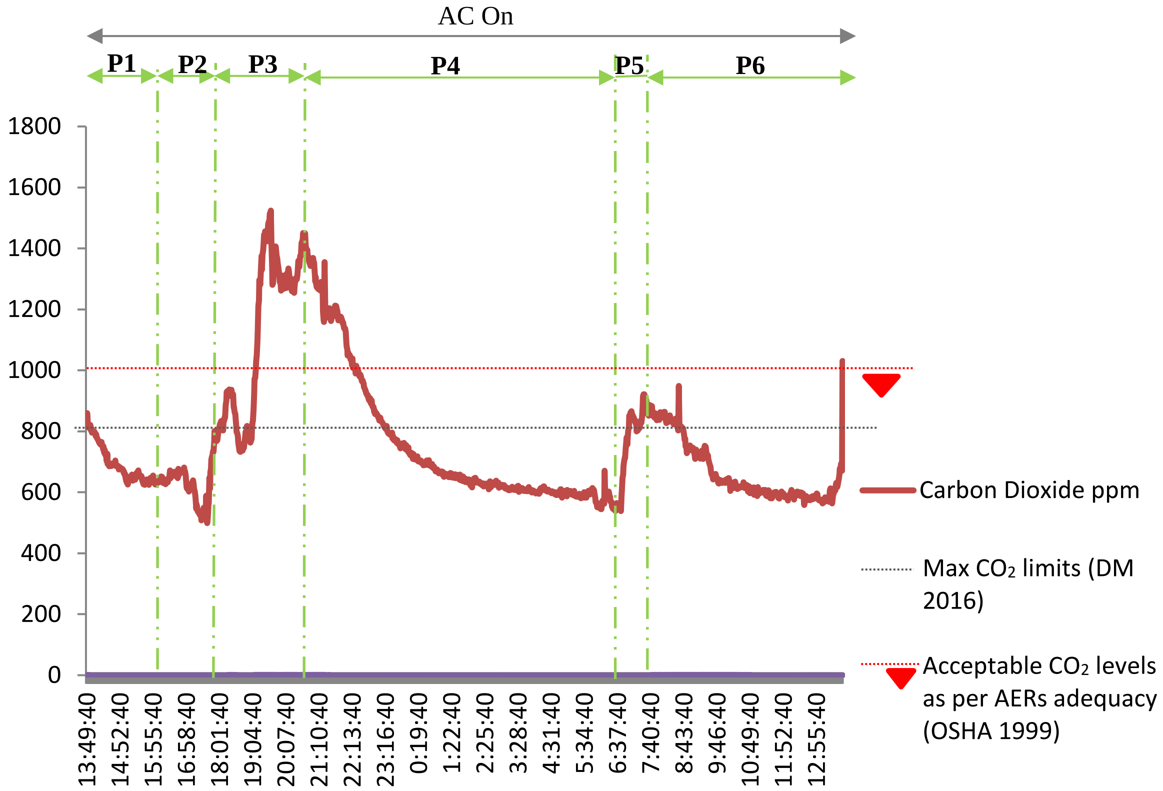
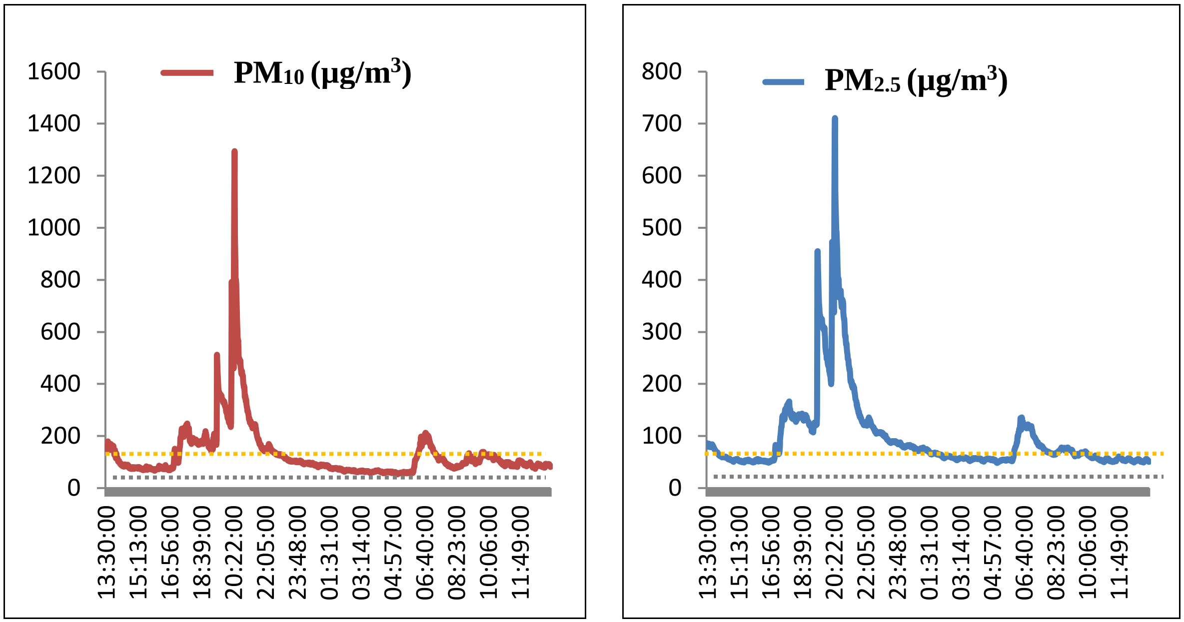


Figure ZZ-269: Occupancy profiles of the living hall projected on $CO_2$ levels (House 54)

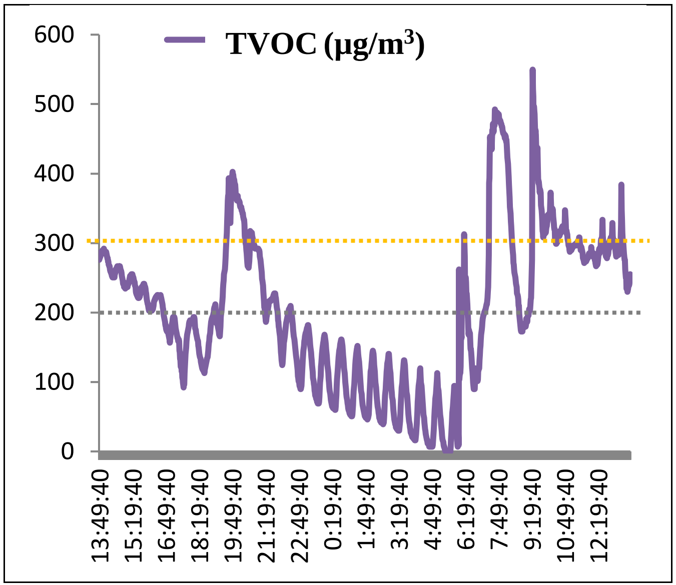
Table ZZ-161: Occupancy profiles of the living hall during measurement (House 54)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 13:30 – 16:10 | 2 | Mechanical<br>(16:00 – 16:10 Windows opened) | Sitting |
| **P2** | 16:10 – 17:40 | 3 | Mechanical<br>(17:20 – 17:25 Windows opened) | Sitting |
| **P3** | 17:40 – 20:30 | 4 | Mechanical<br>(18:00 – 18:05 Windows opened)<br>(18:30 – 18:45 Windows opened)<br>(19:45 – 20:00 Windows opened) | Sitting, cooking, dinner |
| **P4** | 20:30 – 06:30 | 0 | Mechanical | 6 persons in other rooms |
| **P5** | 06:30 – 07:30 | 5 | Mechanical | Sitting, breakfast |
| **P6** | 07:30 – 13:46 | 2 | Mechanical | Sitting, cooking |



| | | | |
|---|---|---|---|
| ········ | 150 µg /m$^3$ for 8 hours – TWA (DM 2016) | ········ | 65 µg /m$^3$ for 24 hours – 3 years annual mean (ASHRAE 2016) |
| ········ | 50 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) | ········ | 25 µg /m$^3$ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure ZZ-270: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 54)



| | |
|---|---|
| ········ | 300 µg/m$^3$ for 8 hours – TWA (DM 2016) |
| ········ | 200 µg/m$^3$ (Mølhave 1990) |

Figure ZZ-271: Compliance of indoor TVOC levels (House 54) with established standards

## *House (55)*

Table ZZ-162: Levels of continuously measured variables indoor House (55)

| | **TVOC (µg/m$^3$)** | **CO$_2$ (ppm)** | **CO (ppm)** | **PM$_{2.5}$ (µg/m$^3$)** | **PM$_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 23.0 | 490.0 | 0.1 | 35.9 | 40.7 | 27.3 | 25.1 |
| **Mean** | 148.2 | 757.2 | 0.6 | 239.9 | 347.2 | 31.4 | 49.0 |
| **Max** | 510.6 | 1097.0 | 1.7 | 835.4 | 10214.2 | 40.6 | 64.5 |

Table ZZ-163: Spot measured variables in outdoor air of House (55)

| | **TVOC (µg/m$^3$)** | **CO$_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 179 | 493 | 0.9 | 42.4 | 20.9 |

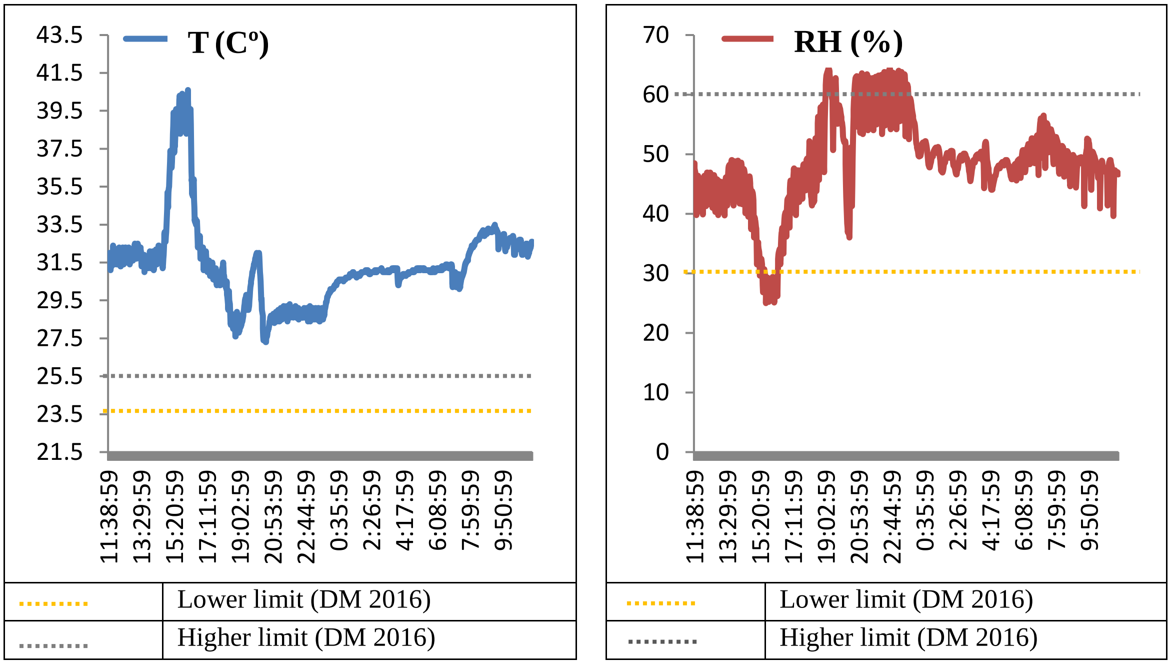


Figure ZZ-272: Continuously measured indoor levels of T and RH in House (55)

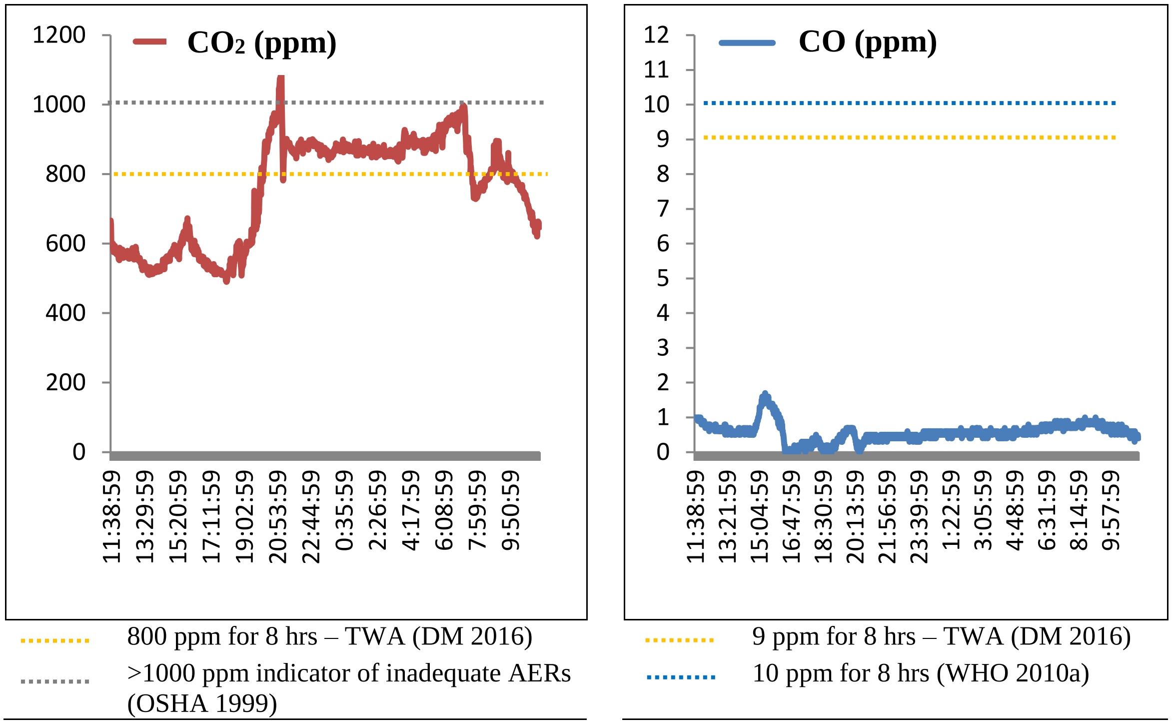


Figure ZZ-273: Compliance of $CO_2$ & CO levels in House (55) with established standards

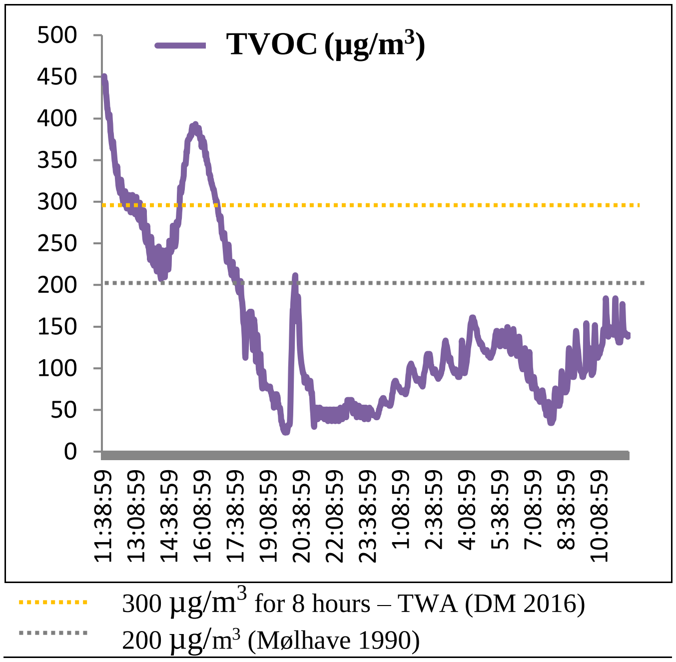


Figure ZZ-274: Compliance of indoor TVOC levels with established standards (House 55)

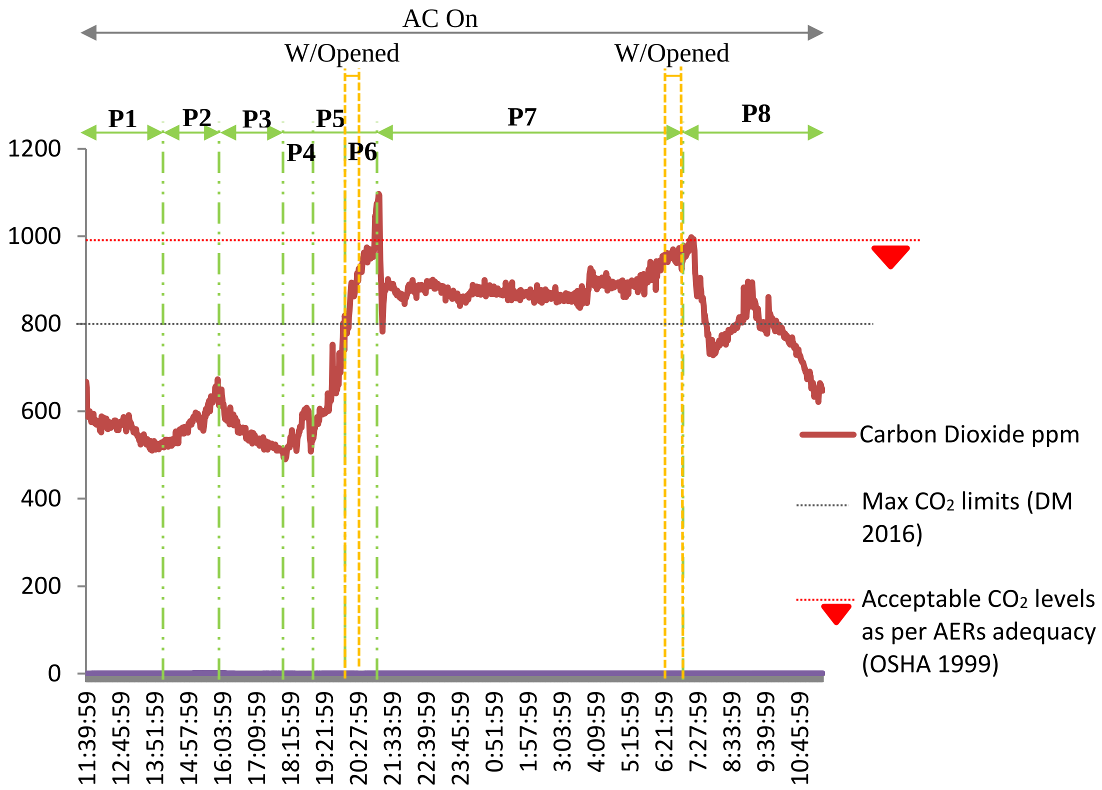


Figure ZZ-275: Occupancy profiles of the living hall projected on $CO_2$ levels (House 55)

Table ZZ-164: Occupancy profiles of the living hall during measurement (House 55)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 11:39 – 14:15 | 1 | Mechanical | Cleaning, cooking |
| **P2** | 14:15 – 15:50 | 3 | Mechanical | Sitting, lunch |
| **P3** | 15:50 – 18:00 | 0 | Mechanical | 1 person in other rooms |
| **P4** | 18:00 – 19:00 | 7 | Mechanical | 4 persons sitting, 3 persons for maintenance, curtains |
| **P5** | 19:00 – 20:00 | 5 | Mechanical | Sitting, Ramadan breakfast |
| **P6** | 20:00 – 21:00 | 3 | Mechanical<br>(20:00 – 20:25 Open windows) | Sitting, dinner |
| **P7** | 21:00 – 07:00 | 0 | Mechanical<br>(06:30 – 07:00 Open windows) | 5 persons in other rooms |
| **P8** | 07:00 – 11:30 | 2 | Mechanical | Sitting |

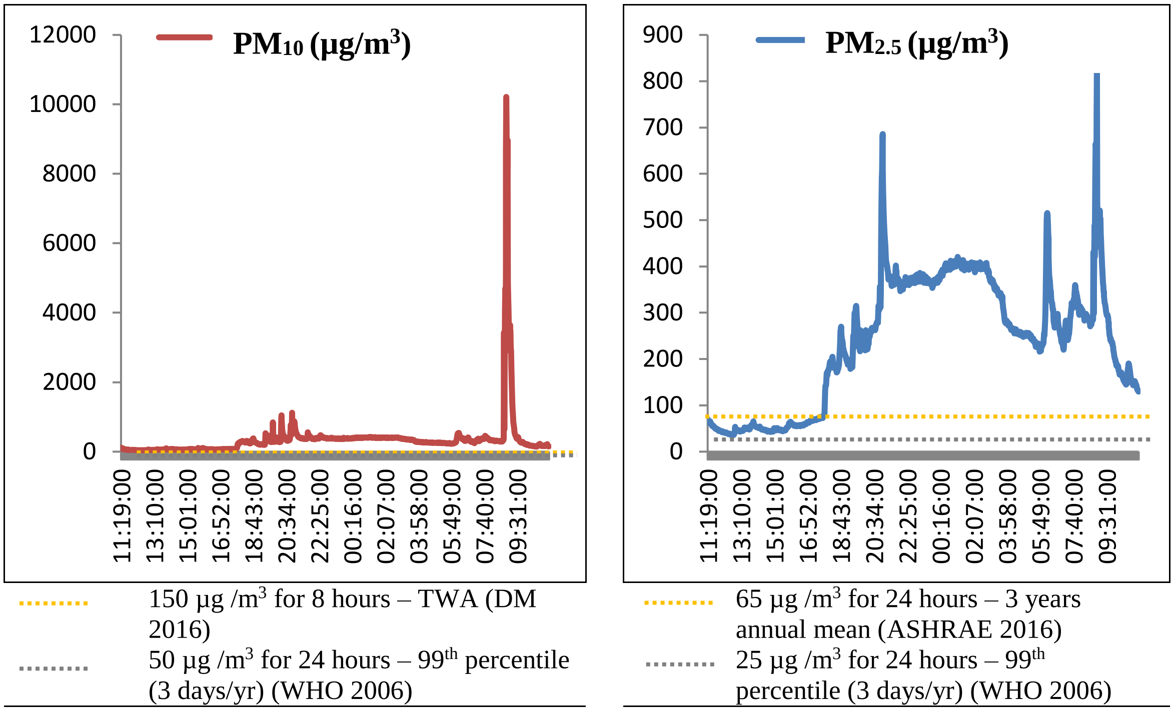


Figure ZZ-276: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 55)

### *House (56)*

Table ZZ-165: Levels of continuously measured variables indoor House (56)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 492.2 | 703.0 | 0.1 | 88.8 | 115.9 | 24.5 | 16.1 |
| **Mean** | 819.3 | 885.1 | 3.1 | 162.5 | 217.3 | 29.7 | 27.1 |
| **Max** | 1071.8 | 3953.0 | 8.9 | 562.0 | 735.6 | 31.8 | 47.9 |

Table ZZ-166: Spot measured variables in outdoor air of House (56)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 255.3 | 648.0 | 1.3 | 38.8 | 34.0 |

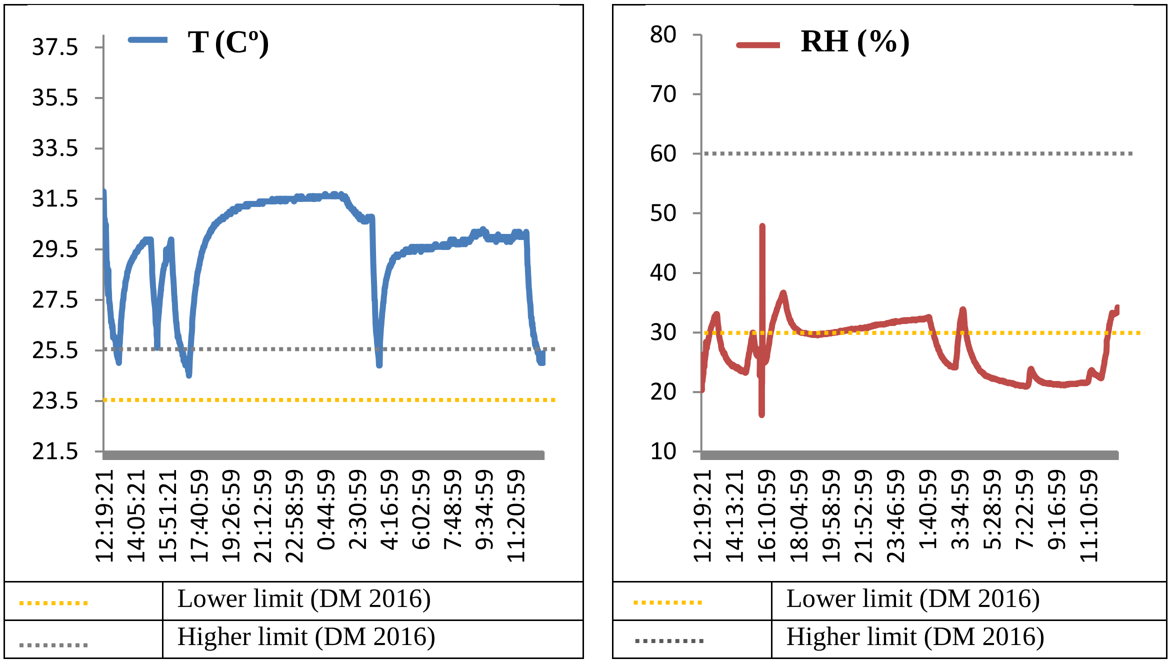


Figure ZZ-277: Continuously measured indoor levels of T and RH in House (56)

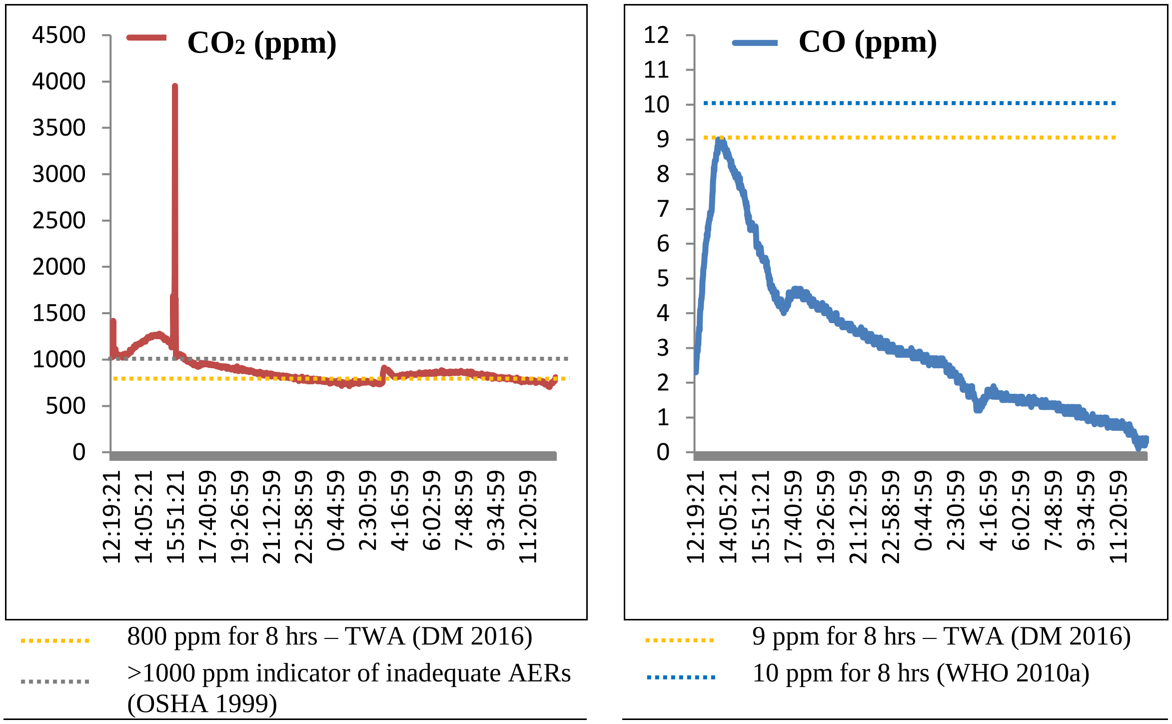


Figure ZZ-278: Compliance of $CO_2$ & CO levels in House (56) with established standards

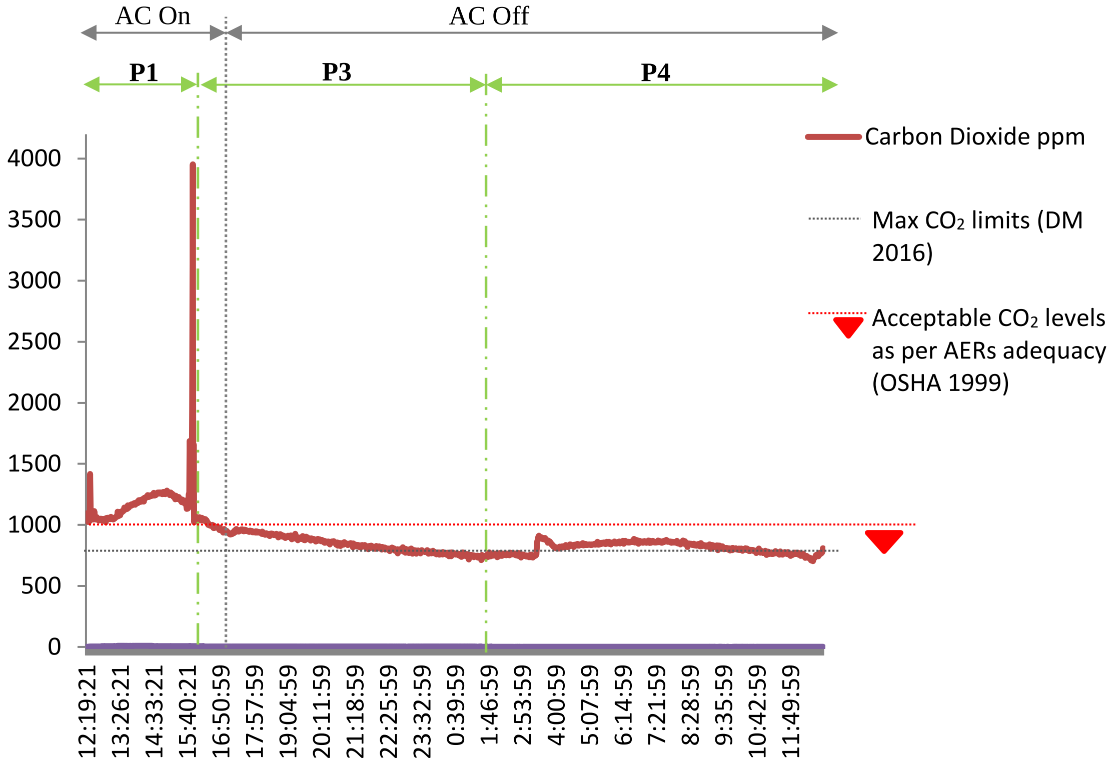


Figure ZZ-279: Occupancy profiles of the living hall projected on $CO_2$ levels (House 56)

Table ZZ-167: Occupancy profiles of the living hall during measurement (House 56)

| **Profile** | **Time** | **Occupants** | **System** | **Activities** |
|---|---|---|---|---|
| **P1** | 12:15 – 16:00 | 2 | Mechanical | Sitting |
| **P2** | 16:00 – 01:45 | 0 | Natural (Infiltration) | Went outside |
| **P3** | 01:45 – 12:55 | 0 | Natural (Infiltration) | 2 persons in other rooms |

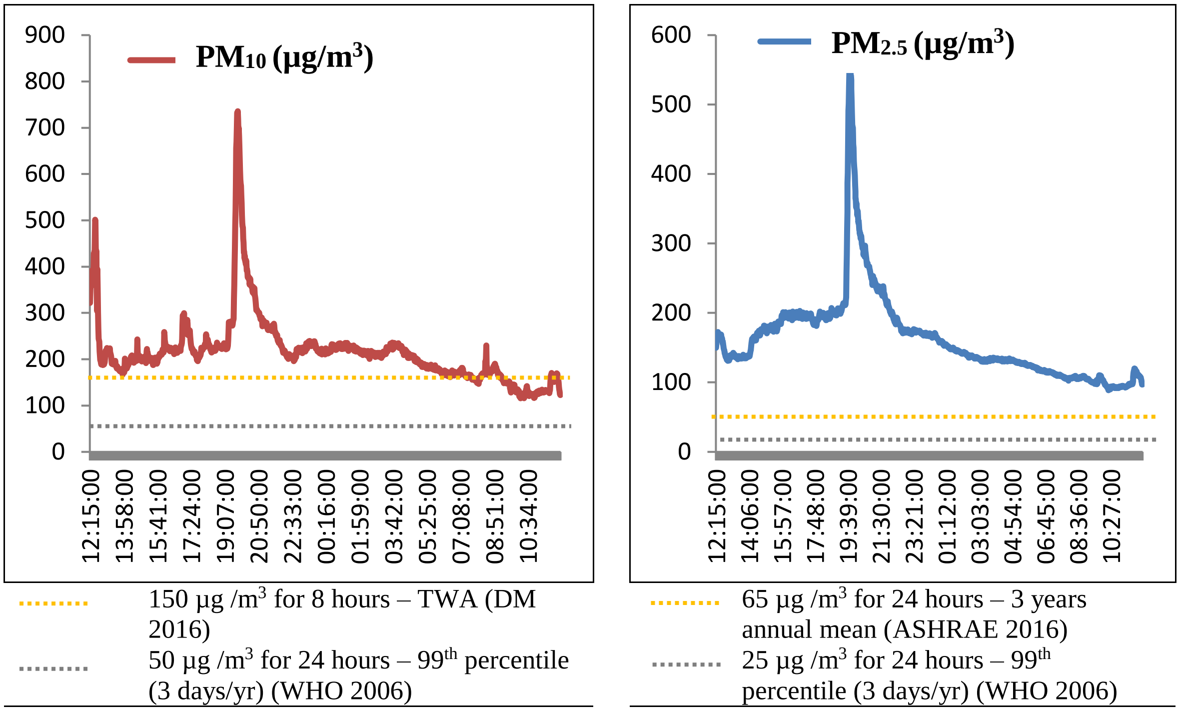


Figure ZZ-280: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 56)

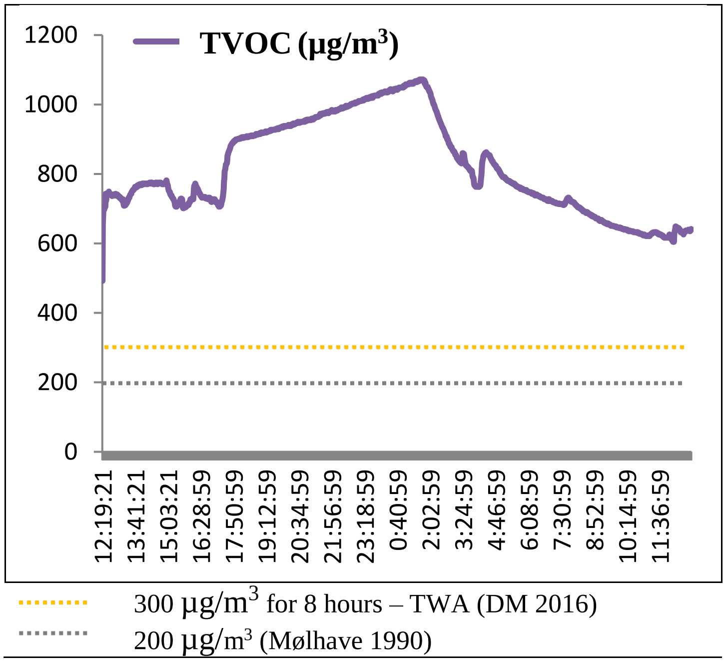


Figure ZZ-281: Compliance of indoor TVOC levels with established standards (House 56)

## *House (57)*

Table ZZ-168: Levels of continuously measured variables indoor House (57)

| | **TVOC (µg/m$^3$)** | **CO$_2$ (ppm)** | **CO (ppm)** | **PM$_{2.5}$ (µg/m$^3$)** | **PM$_{10}$ (µg/m$^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 425.5 | 7.0 | 0.4 | 104.8 | 118.1 | 27.9 | 24.4 |
| **Mean** | 535.4 | 1317.2 | 0.8 | 176.2 | 194.6 | 29.7 | 30.3 |
| **Max** | 726.8 | 3605.0 | 1.3 | 281.8 | 329.8 | 30.9 | 99.7 |

Table ZZ-169: Spot measured variables in outdoor air of House (57)

| | **TVOC (µg/m3)** | **CO2 (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | 217.4 | 570.5 | 1.1 | 40.6 | 27.5 |

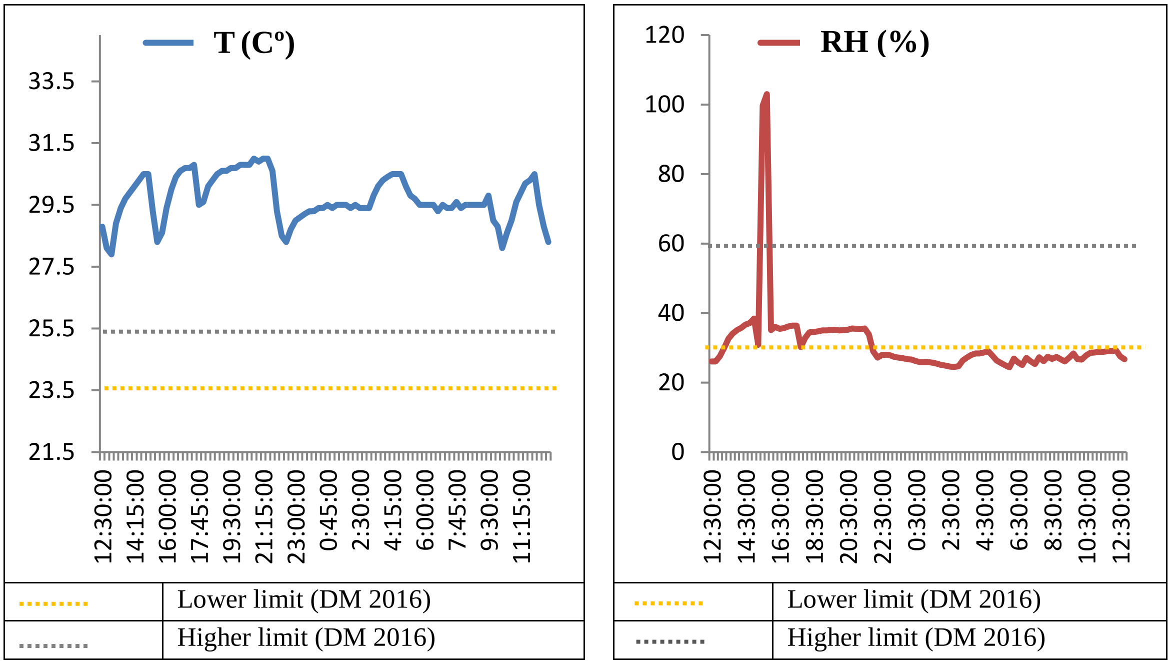


Figure ZZ-282: Continuously measured indoor levels of T and RH in House (57)

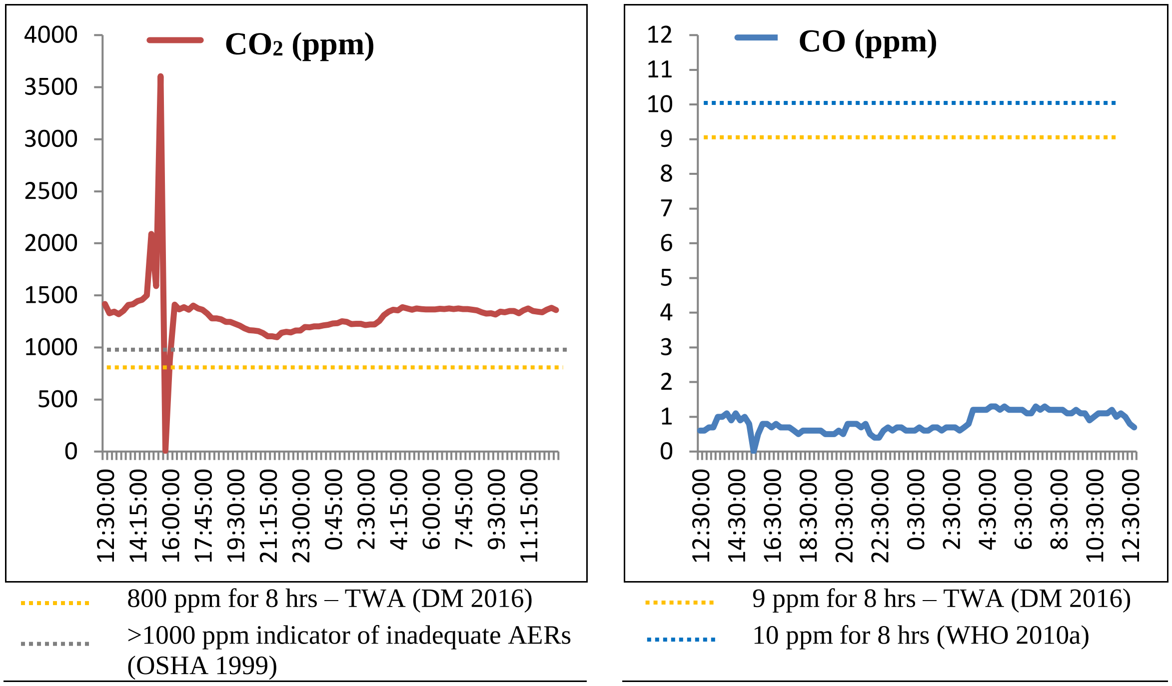


Figure ZZ-283: Compliance of $CO_2$ & CO levels in House (57) with established standards

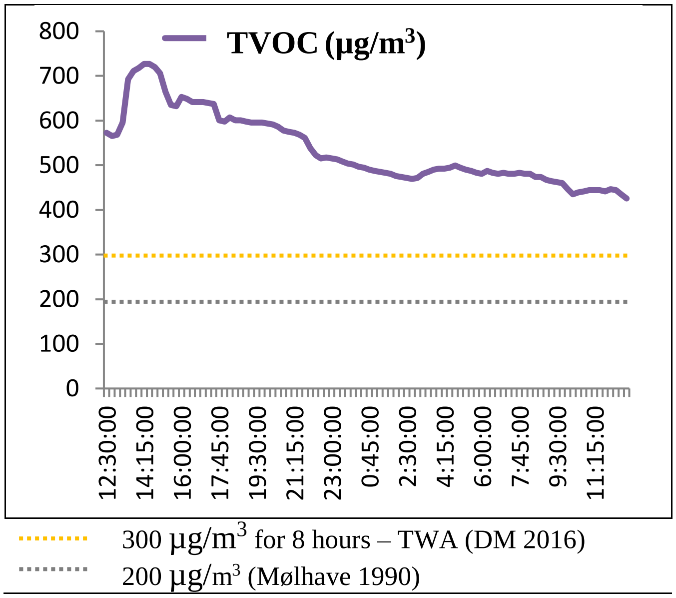


Figure ZZ-284: Compliance of indoor TVOC levels with established standards (House 57)

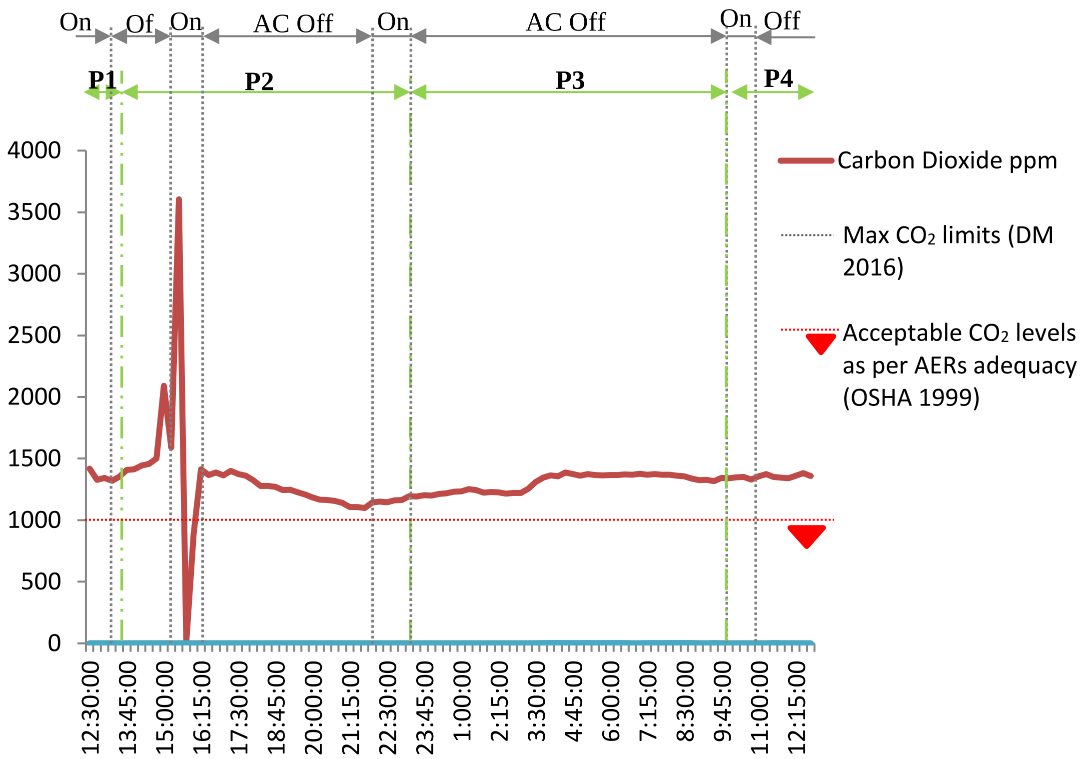


Figure ZZ-285: Occupancy profiles of the living hall projected on CO$_2$ levels (House 57)

Table ZZ-170: Occupancy profiles of the living hall during measurement (House 57)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 12:30 – 13:30 | 1 | Mixed:<br>12:30 – 13:15 Mechanical<br>13:15 – 13:30 Natural (Infiltration) | Laundry |
| **P2** | 13:30 – 23:00 | 4 | Mixed:<br>13:30 – 15:15 Natural (Infiltration)<br>15:15 – 16:15 Mechanical<br>16:15 – 18:15 Natural (Infiltration)<br>18:15 – 22:00 Natural (Infiltration)<br>22:00 – 23:00 Mechanical | Sitting/ Laundry |
| **P3** | 23:00 – 10:00 | 0 | Natural (Infiltration) | 4 persons in other rooms |
| **P4** | 10:00 – 12:45 | 3 | Natural (Infiltration) | 3 persons in other rooms |

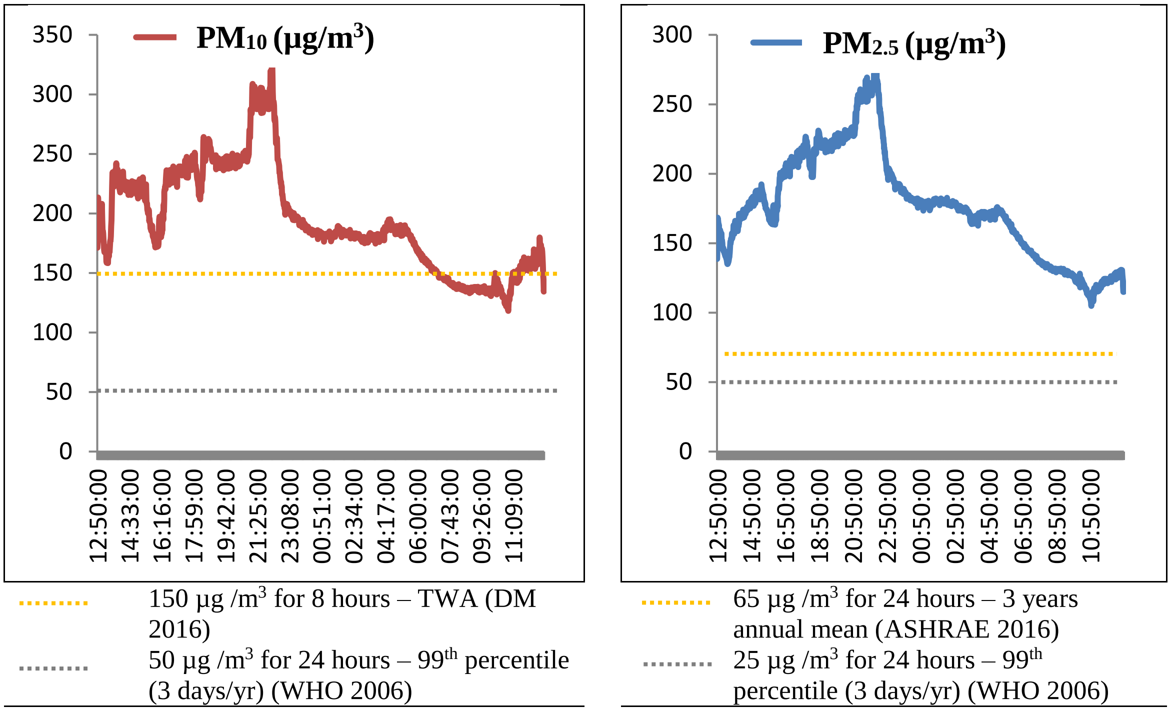


Figure ZZ-286: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 57)

### ***House (58)***

Table ZZ-171: Levels of continuously measured variables indoor House (58)

| | **TVOC ($\mu g/m^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ ($\mu g/m^3$)** | **$PM_{10}$ ($\mu g/m^3$)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 407.1 | 889.0 | 0.2 | 84.6 | 108.8 | 23.6 | 31.4 |
| **Mean** | 1079.5 | 1187.8 | 2.7 | 117.8 | 160.1 | 30.9 | 40.7 |
| **Max** | 6911.5 | 1510.0 | 8.4 | 322.4 | 434.1 | 33.1 | 63.8 |

Table ZZ-172: Spot measured variables in outdoor air of House (58)

| | **TVOC ($\mu g/m^3$)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | <11.5 | 379.0 | 1.6 | 41.2 | 40.8 |

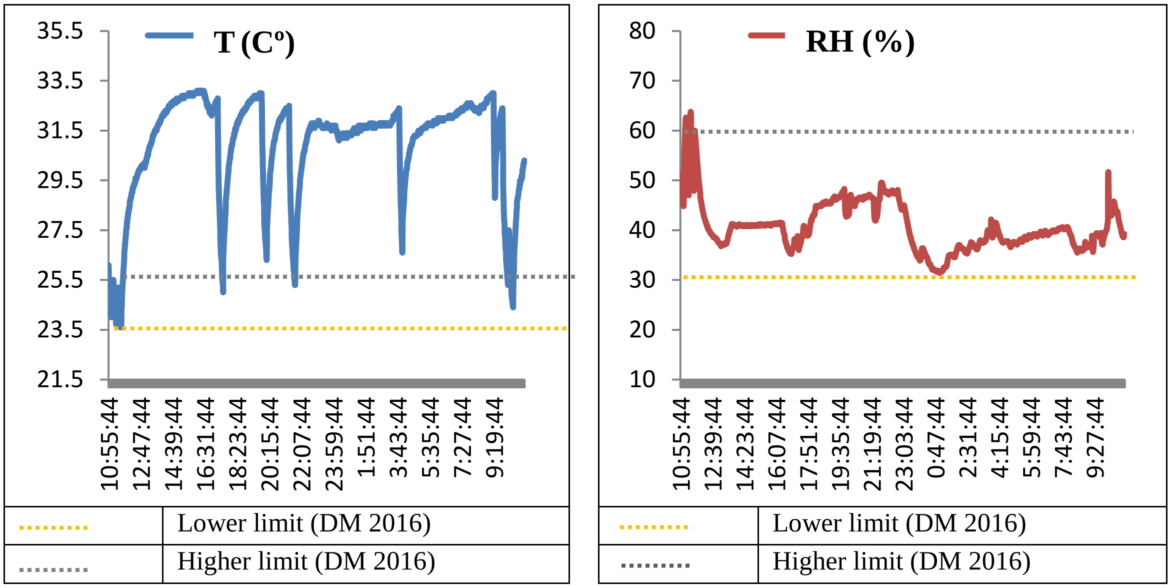


Figure ZZ-287: Continuously measured indoor levels of T and RH in House (58)

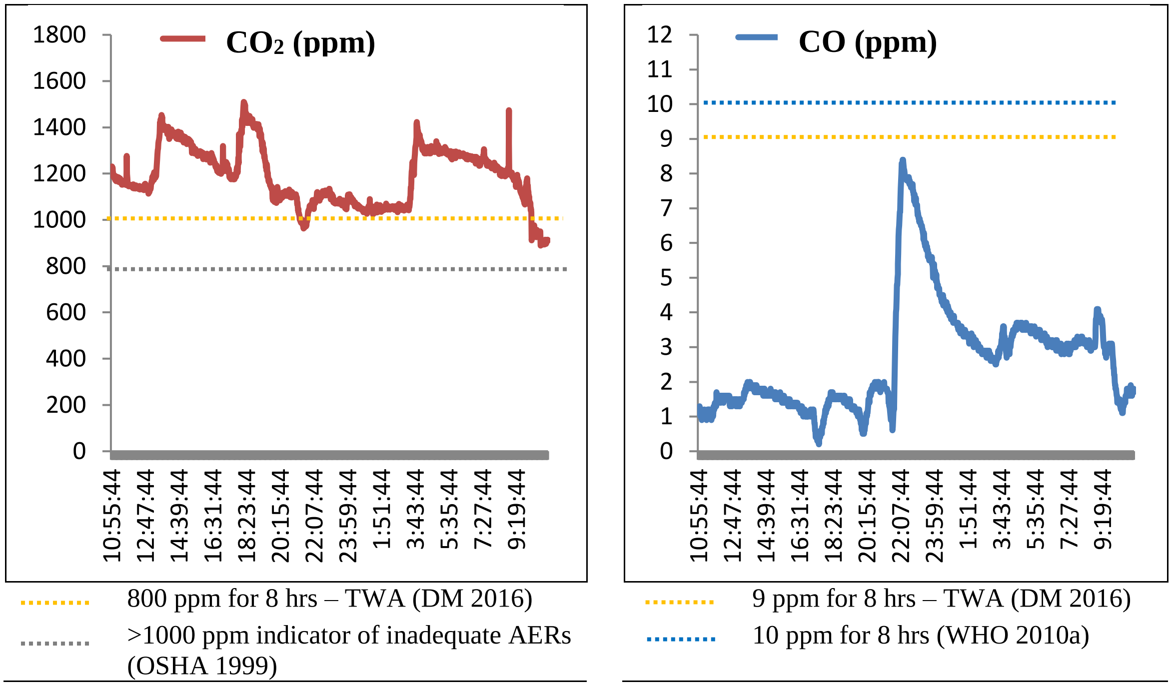


Figure ZZ-288: Compliance of $CO_2$ & CO levels in House (58) with established standards

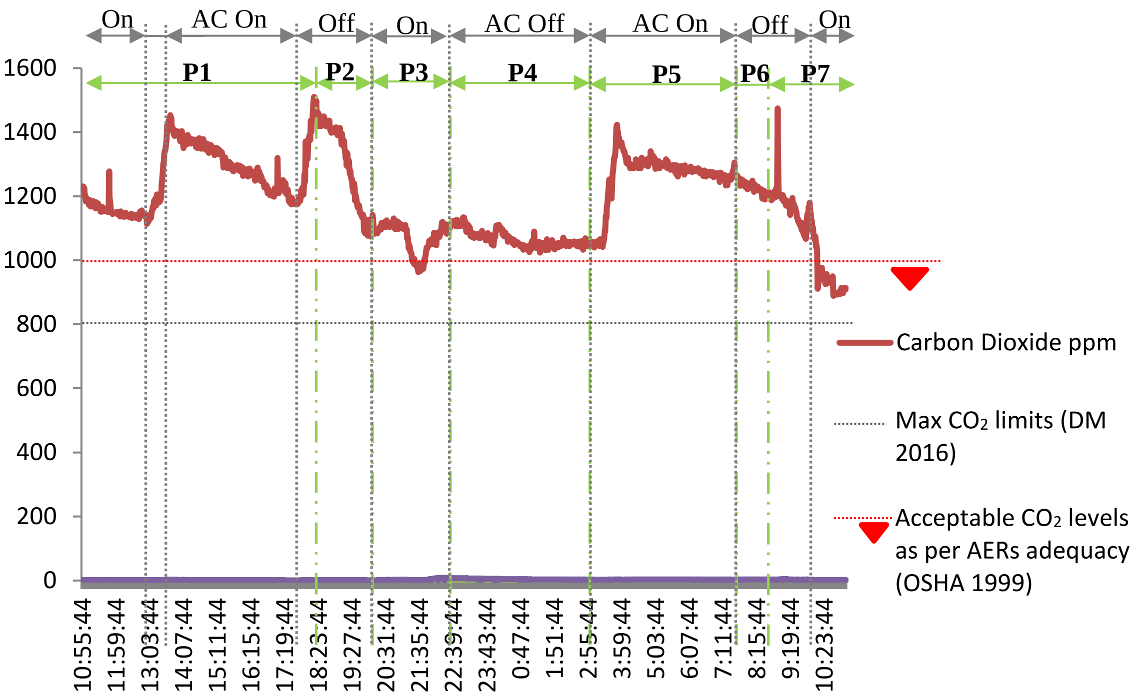


Figure ZZ-289: Occupancy profiles of the living hall projected on $CO_2$ levels (House 58)

Table ZZ-173: Occupancy profiles of the living hall during measurement (House 58)

| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 10:50 – 18:13 | 3 | Mixed:<br>10:50 – 13:00 Mechanical<br>13:00 – 13:30 Natural (Infiltration)<br>13:30 – 17:30 Mechanical<br>17:30 – 18:13 Natural (Infiltration) | Cleaning, cooking, sitting |
| **P2** | 18:13 – 20:00 | 2 | Natural (Infiltration) | Cooking, washing, sitting |
| **P3** | 20:00 – 22:30 | 1 | Mechanical | Cleaning, sitting |
| **P4** | 22:30 – 03:00 | 0 | Natural (Infiltration) | 4 persons in other rooms |
| **P5** | 03:00 – 07:30 | 4 | Mechanical | Sitting, Ramadan sahoor |
| **P6** | 07:30 – 08:30 | 0 | Natural (Infiltration) | 3 persons in other rooms |
| **P7** | 08:30 – 11:10 | 0 | Mixed:<br>08:30 – 10:00 Natural (Infiltration)<br>10:00 – 11:10 Mechanical | 2 persons in other rooms |

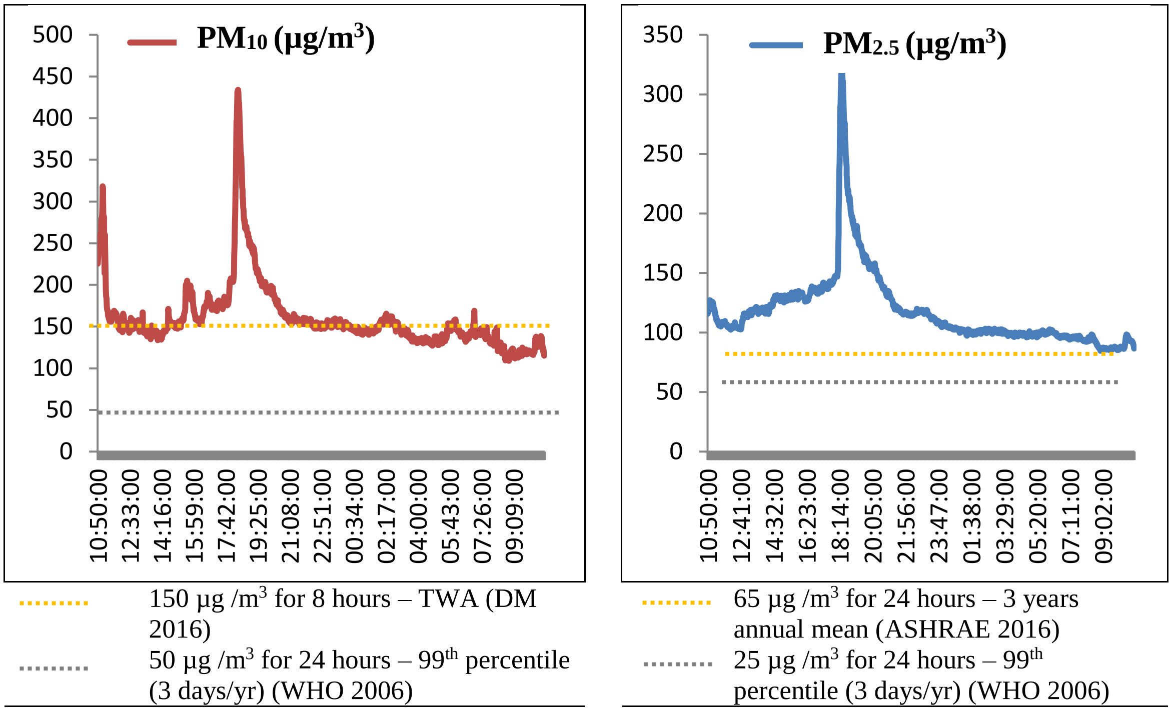


Figure ZZ-290: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 58)

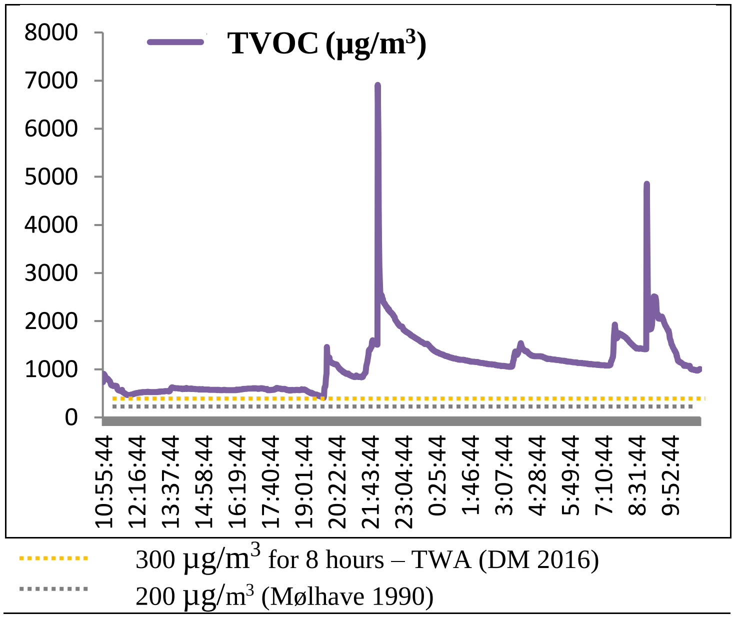


Figure ZZ-291: Compliance of indoor TVOC levels with established standards (House 58)

***House (59)***

Table ZZ-174: Levels of continuously measured variables indoor House (59)

| | **TVOC (µg/m³)** | **CO₂ (ppm)** | **CO (ppm)** | **PM2.5 (µg/m³)** | **PM10 (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 414.0 | 1054.0 | 0.2 | 47.8 | 62.5 | 27.3 | 20.1 |
| **Mean** | 1034.9 | 1451.2 | 1.9 | 215.4 | 249.1 | 31.7 | 25.8 |
| **Max** | 7725.7 | 2210.0 | 4.0 | 520.6 | 584.5 | 32.7 | 31.5 |

Table ZZ-175: Spot measured variables in outdoor air of House (59)

| | **TVOC (µg/m³)** | **CO₂ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | <11.5 | 507.0 | 0.0 | 37.6 | 45.0 |

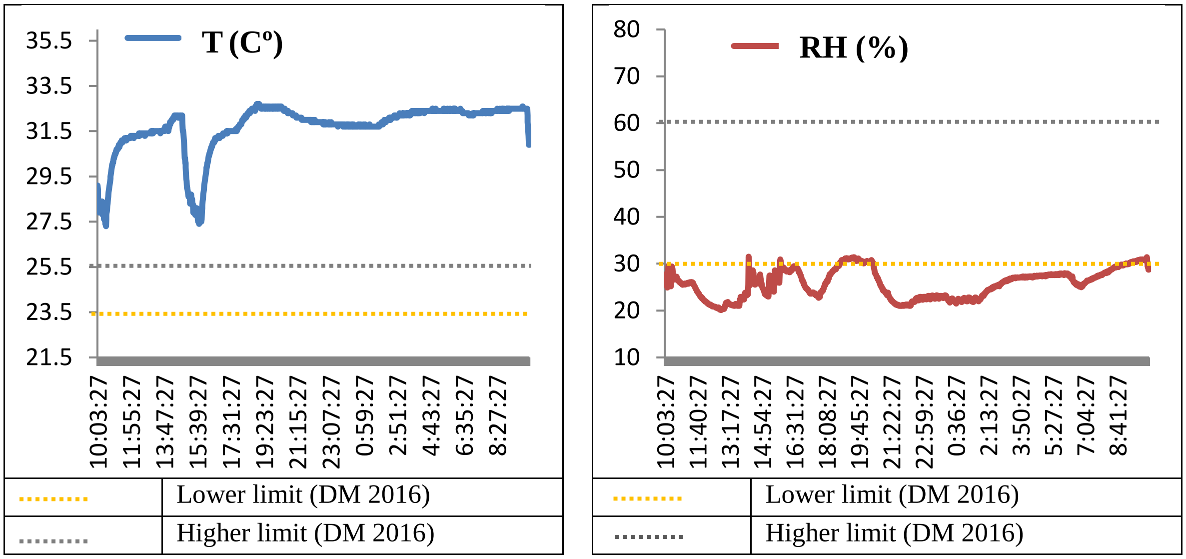


Figure ZZ-292: Continuously measured indoor levels of T and RH in House (59)

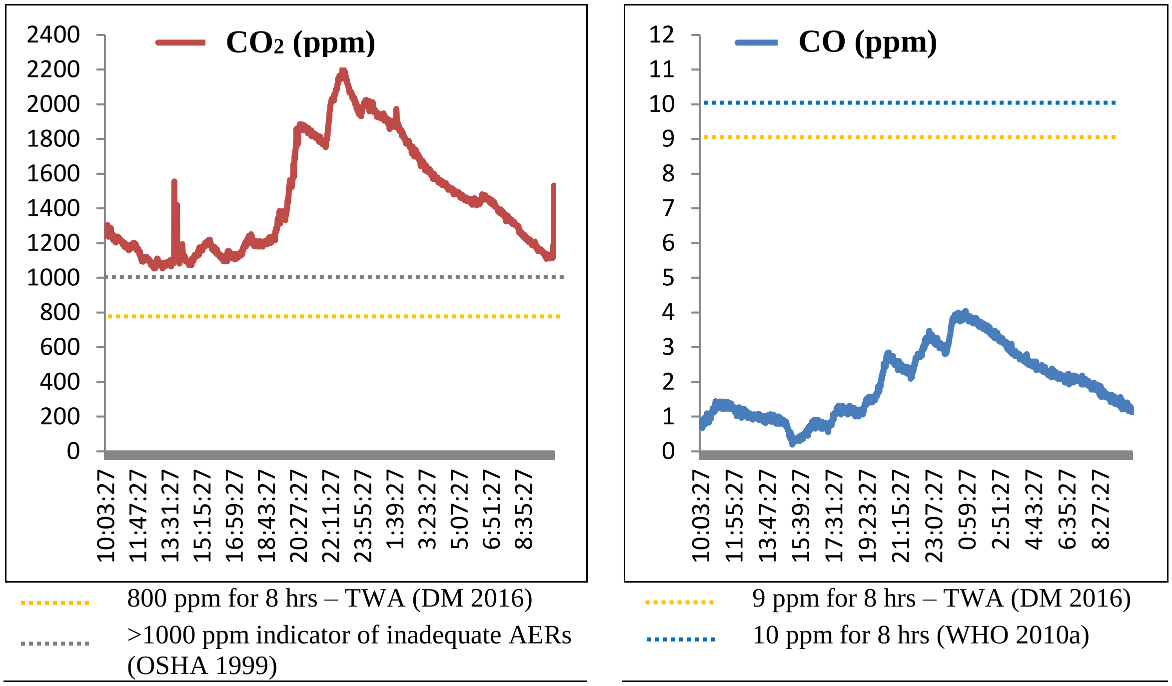


Figure ZZ-293: Compliance of $CO_2$ & CO levels in House (59) with established standards

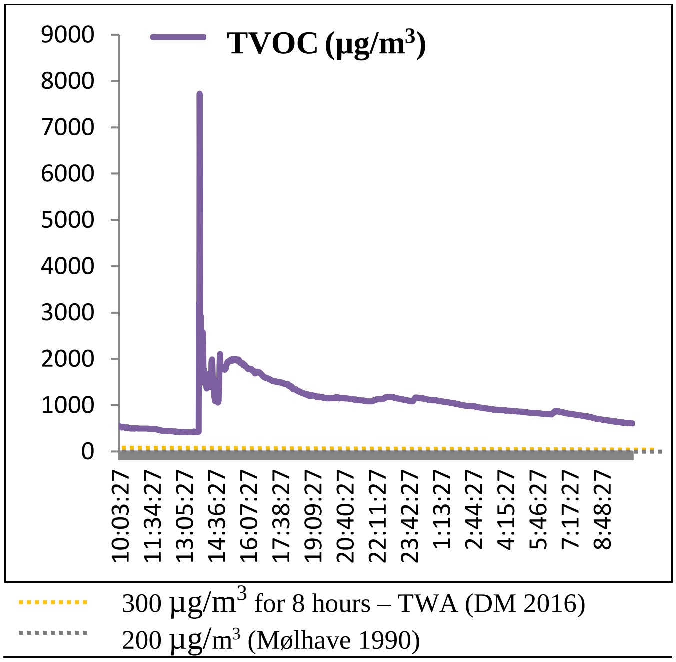


Figure ZZ-294: Compliance of indoor TVOC levels with established standards (House 59)

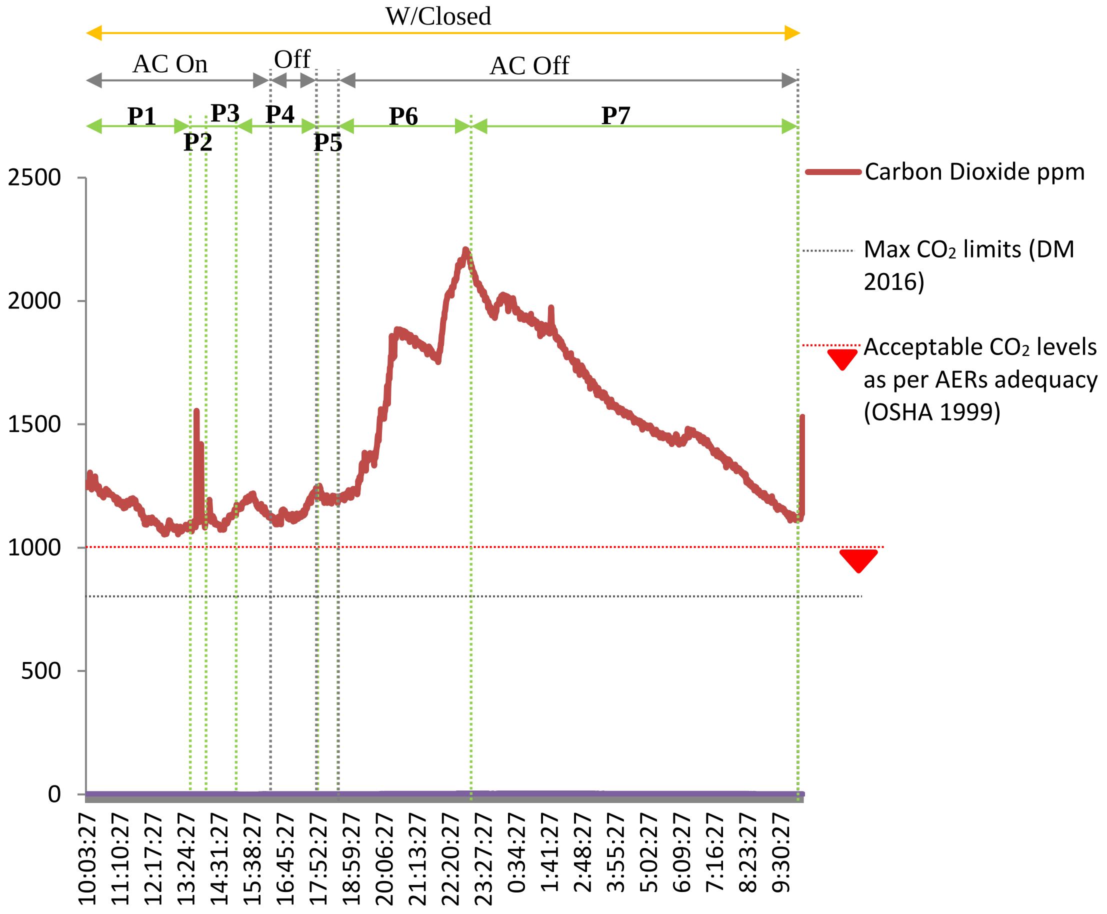


Figure ZZ-295: Occupancy profiles of the living hall projected on $CO_2$ levels (House 59)

Table ZZ-176: Occupancy profiles of the living hall during measurement (House 59)

| **Profile** | **Time** | **Occupants** | **System** | **Activities** |
|---|---|---|---|---|
| **P1** | 10:00 – 13:30 | 0 | Mechanical | 1 person in other rooms |
| **P2** | 13:30 – 14:00 | 1 | Mechanical | Cleaning |
| **P3** | 14:00 – 15:00 | 0 | Mechanical | Went outside |
| **P4** | 15:00 – 17:50 | 3 | Natural (Infiltration) | Studying |
| **P5** | 17:50 – 18:30 | 2 | Mechanical | Sitting |
| **P6** | 18:30 – 23:00 | 7 | Natural (Infiltration) | Sitting, cooking, Ramadan breakfast, dinner |
| **P7** | 23:00 – 10:00 | 0 | Natural (Infiltration) | 7 persons in other rooms |

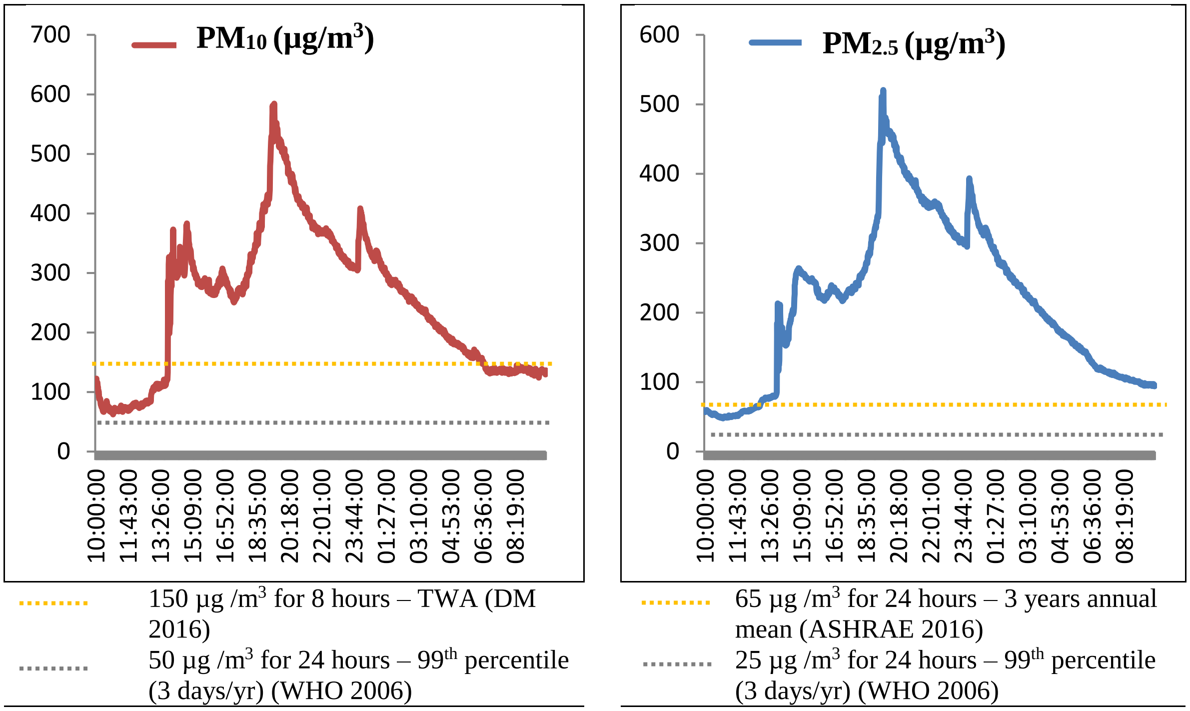


Figure ZZ-296: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 59)

### *House (60)*

Table ZZ-177: Levels of continuously measured variables indoor House (60)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **$PM_{2.5}$ (µg/m³)** | **$PM_{10}$ (µg/m³)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|---|---|
| **Min** | 190.3 | 505.5 | 0.0 | 60.5 | 64.8 | 22.4 | 41.0 |
| **Mean** | 119.6 | 428.0 | 0.0 | 85.6 | 95.9 | 21.4 | 33.6 |
| **Max** | 292.1 | 901.0 | 0.0 | 325.7 | 358.8 | 25.6 | 48.8 |

Table ZZ-178: Spot measured variables in outdoor air of House (60)

| | **TVOC (µg/m³)** | **$CO_2$ (ppm)** | **CO (ppm)** | **T (°C)** | **RH %** |
|---|---|---|---|---|---|
| **Outdoor levels** | <11.5 | 372.0 | 0.3 | 40.3 | 44.6 |

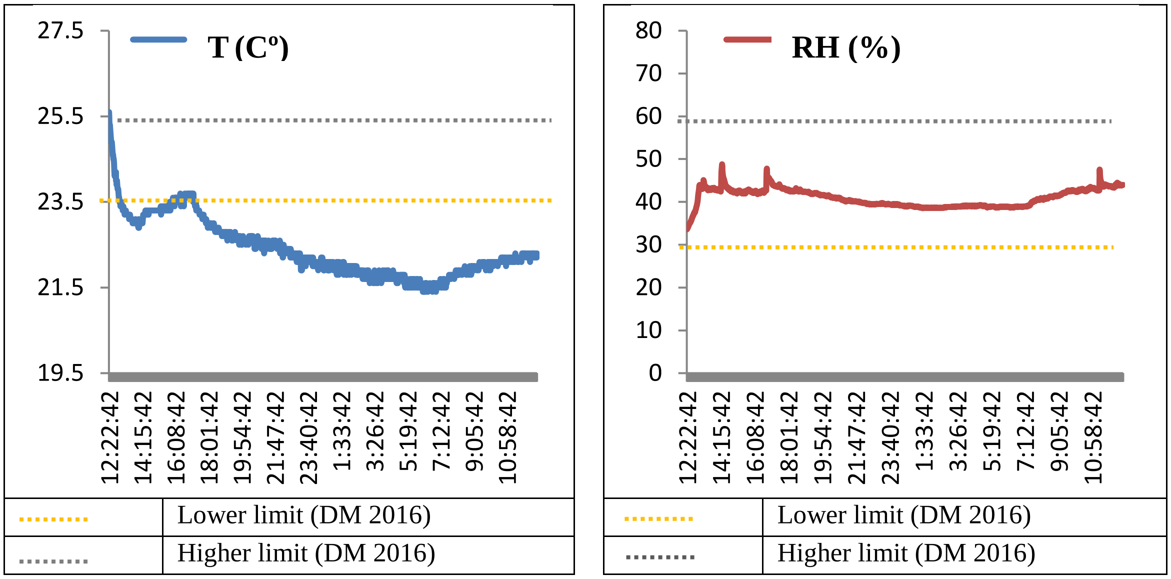


Figure ZZ-297: Continuously measured indoor levels of T and RH in House (60)

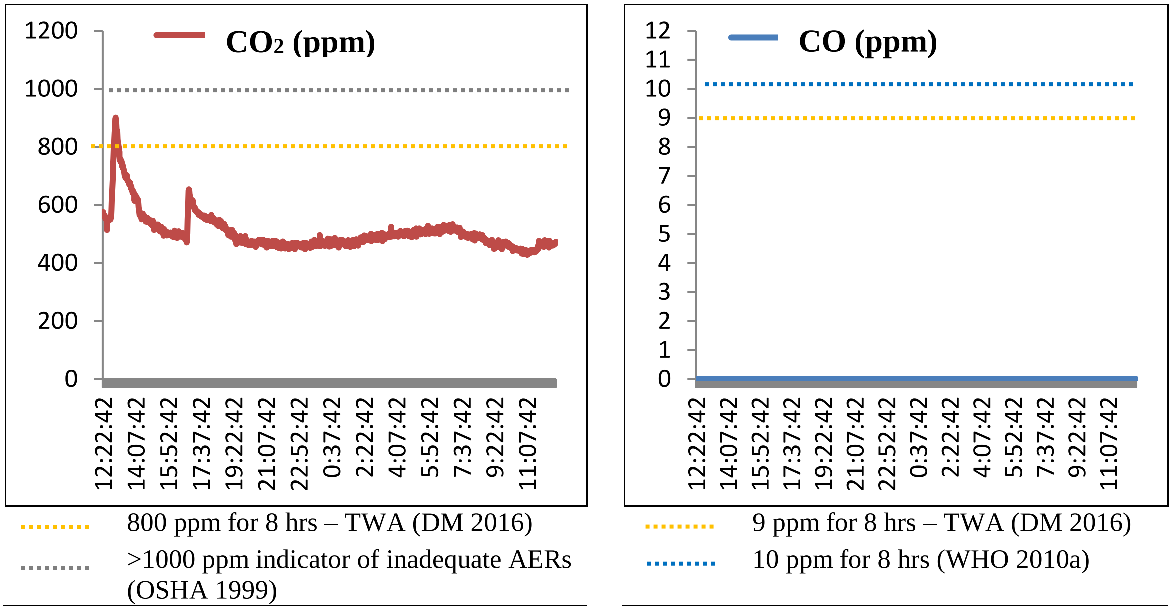


Figure ZZ-298: Compliance of $CO_2$ & CO levels with established standards (House 60)

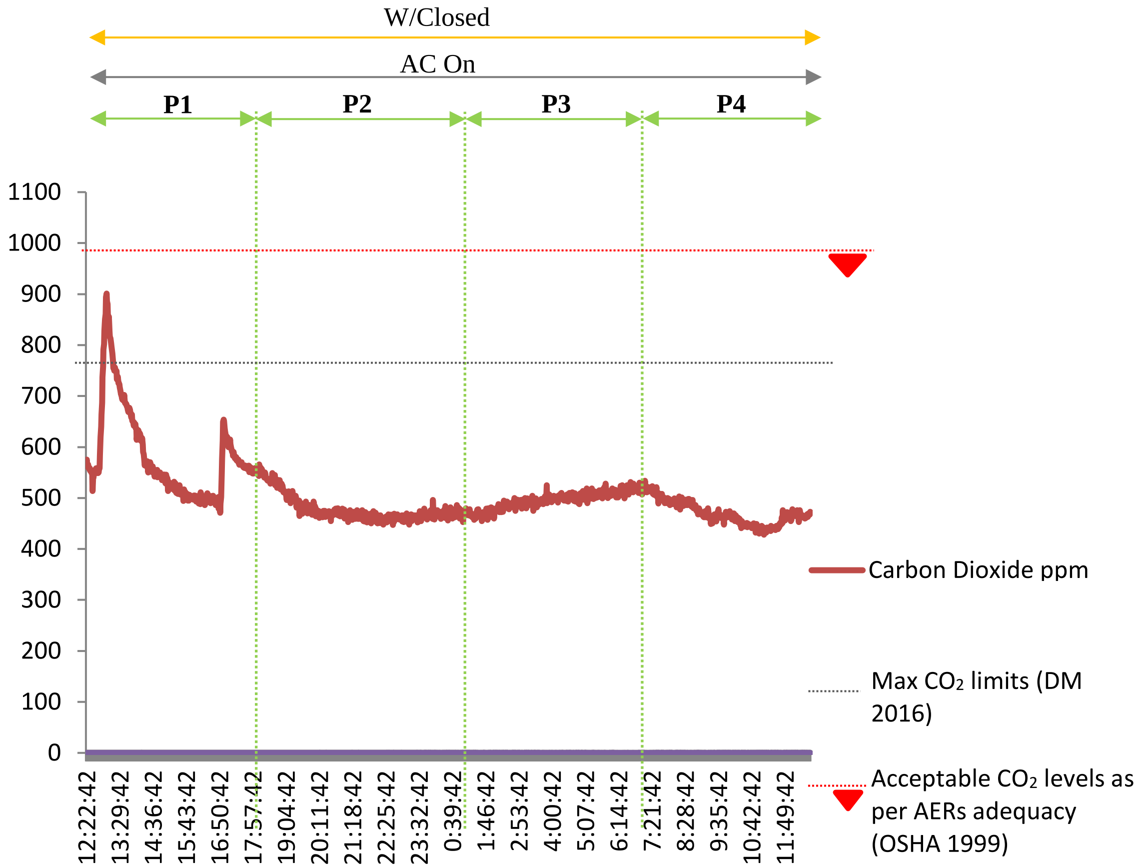
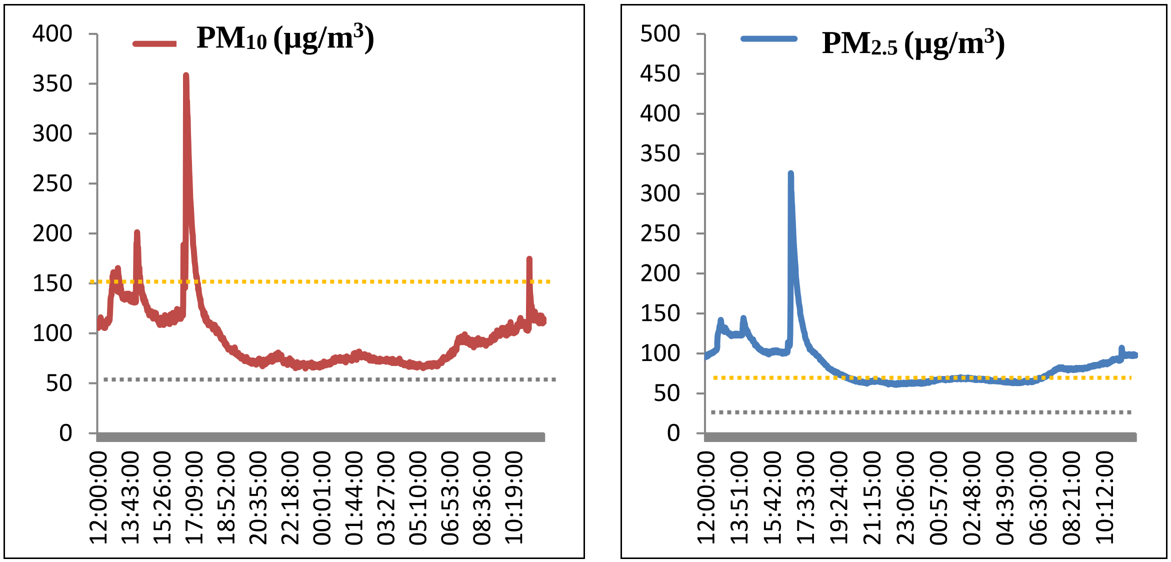


Figure ZZ-299: Occupancy profiles of the living hall projected on $CO_2$ levels (House 60)

Table ZZ-179: Occupancy profiles of the living hall during measurement (House 60)

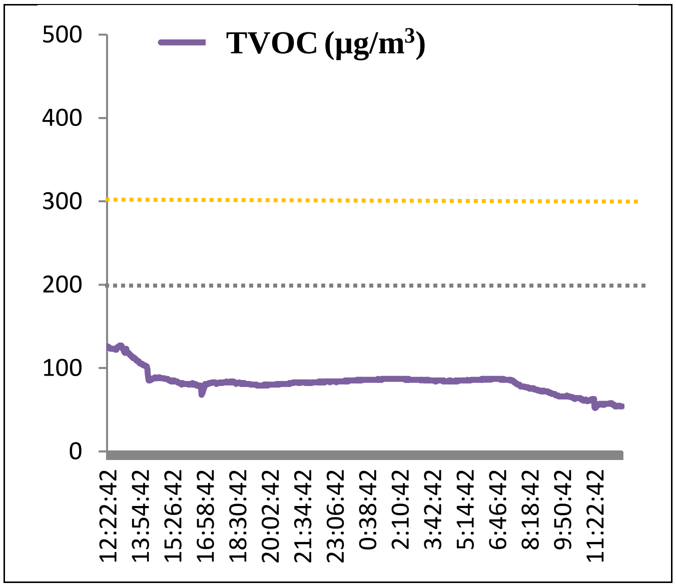
| Profile | Time | Occupants | System | Activities |
|---|---|---|---|---|
| **P1** | 12:22 – 18:00 | 1 | Mechanical | Sitting, cooking, cleaning |
| **P2** | 18:00 – 01:00 | 0 | ,, ,, ,, ,, | Went outside |
| **P3** | 01:00 – 07:00 | 1 | ,, ,, ,, ,, | Sitting |
| **P4** | 07:00 – 12:41 | 0 | ,, ,, ,, ,, | 1 person in other rooms |



| | |
|---|---|
| ⋯⋯ | 150 µg /m³ for 8 hours – TWA (DM 2016) |
| ⋯⋯ | 50 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

| | |
|---|---|
| ⋯⋯ | 65 µg /m³ for 24 hours – 3 years annual mean (ASHRAE 2016) |
| ⋯⋯ | 25 µg /m³ for 24 hours – 99th percentile (3 days/yr) (WHO 2006) |

Figure ZZ-300: Compliance of $PM_{10}$ & $PM_{2.5}$ levels with established standards (House 60)



| | |
|---|---|
| ⋯⋯ | 300 µg/m³ for 8 hours – TWA (DM 2016) |
| ⋯⋯ | 200 µg/m³ (Mølhave 1990) |

Figure ZZ-301: Compliance of indoor TVOC levels with established standards (House 60)