



Indoor Air Quality (IAQ) in labor housing in Dubai and its impact on occupants' health

نوعية الهواء الداخلي في مساكن العمال في دبي و تأثيره على صحة سكانها

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Abstract

Indoor Environmental Quality (IEQ) is very critical issue and necessary to be studied in the earliest stage of the design process. It has a huge impact on the occupants' comfort, health, productivity and performance. Low cost housing is one of the buildings that has many indoor environmental problems. In UAE, number of low cost housing are exist in different areas for the labors and people with low income. Indoor environment include four main aspects to be studied and evaluated in any building which are Indoor Air Quality (IAQ), thermal, visual and acoustic. Each aspect has number of parameters differs than the others. One of the simplest standards of living is having fresh air surrounding the occupants in their indoor space which need careful study for several indoor parameters.

This study aims to evaluate the IAQ, temperature and humidity in different labor housing in Dubai and its' impact on occupants' health. Thus, it aims to compare these housing with high quality houses in order to investigate whether labor housing has the same IAQ of high quality houses or lower. Three labor camps have been chosen according to their income level and the validity to access them. These camps are; Dulscio camp (low income), Beta Industrial camp (medium income) and TransGulf Cement Production camp (high income). Two houses in Mirdif have been selected for the comparison.

In order to achieve the aim of this study, two methodologies have been achieved which are questionnaire survey and field measurements. The survey included questions related to the building characteristics, occupants' information, housing conditions, satisfaction level in their rooms and health and wellbeing. Field measurements have been taken in four areas in each labor camp and in each house in Mirdif. Four types of indoor pollutants were measured in each area which are; Total Volatile Organic Compounds (TVOCs), Carbon dioxide (CO₂), Carbon monoxide (CO) and Ozone (O₃). Thus, the temperature and humidity level in each area were measured. Comparing between the pollutants average concentration in the three labor camps have been achieved. Then, comparison between the best labor camps with Mirdif houses have been done. Comparing between the results of the survey and the measurements will provide valuable results. The collected data from the survey have been justified the results of the field measurements.

The main findings of this study shows that TransGulf camp that has high income has almost the same level of IAQ, temperature and humidity of Mirdif houses. Thus, it has the same occupants' satisfaction level and health. None of the labor camps and Mirdif houses achieve the required level of TVOCs that stated by DM (243 ppb). However, it was noticed in Mirdif houses and TransGulf camp that the occupants still satisfied even when, the average concentration was 473.6 ppb. Dulsco camp has average concentration of CO₂ greater than Mirdif houses by 873.7 ppm which decrease the satisfaction level of the occupants. The lowest ozone concentration was found in Dulsco camp. Mirdif houses has higher CO average concentration than TransGulf camp but lower than the others and still has the same satisfaction level of TransGulf camp. The average temperature and humidity that has the best satisfaction level are 54% and 24.4 °C respectively which found in Mirdif houses and TransGulf camp.

Health issues were mostly found in low income labor camps (Dulsco and Beta camp) such as fatigue, dizziness, headache, eyes and skin problems due to the high concentration of CO, CO₂ and humidity.

By using Mirdif houses as a benchmark for good IAQ, humidity and temperature, main issues in the labor camps are found which are; their location, ventilation, high number of occupants in the same room, mildew on the interior materials. The main suggested improvements for these issues are; locate them in residential areas, provide central A/C and increase the ventilation rate, use low emission materials and ensure that each occupant has the required square meter which is 3.7 in their rooms.

الملخص

يُعتبر موضوع نوعية البيئة الداخلية (IEQ) مسألة حرجية جداً ومن الضروري القيام بدراساتها في المرحلة المبكرة من عملية التصميم. حيث تتمتع بتأثير كبير على أداء وإنتاجية وصحة وراحة السكان. إن السكن منخفض التكلفة يُعد أحد المباني التي تمتلك العديد من المشاكل البيئية في الأماكن المغلقة. في دولة الإمارات العربية المتحدة، يوجد عدد من المساكن منخفضة التكلفة في مناطق مختلفة للعمال والأشخاص ذوي الدخل المحدود. تشمل بيئة الأماكن المغلقة، أربع جوانب رئيسية يتعين دراستها وتقييمها في أي مبنى وهي نوعية الهواء الداخلي (IAQ)، والحرارية والبصرية والصوتية. يمتلك كل جانب من الجوانب عدد من المعايير التي تختلف عن الآخرين. واحدة من أبسط مستويات معايير العيش هي وجود الهواء النقي محيطاً بالسكان حيث يقطنون في مساحات الأماكن المغلقة والذي يحتاج إلى دراسة مُتأنية لعدة معايير في الأماكن المغلقة.

وتهدف هذه الدراسة إلى تقييم نوعية الهواء الداخلي، ودرجة الحرارة والرطوبة في مساكن العمال المختلفة في دبي وتأثيرهم على صحة السكان. وبالتالي، فإنه يهدف إلى مقارنة هذه المساكن مع المنازل ذات النوعية العالية من أجل التحقق ما إذا كانت مساكن العمال تحتوي على نفس الظروف المعيشية للمنازل ذات النوعية العالية. قد تم اختيار ثلاثة مُجمعات سكنية للعمال وفقاً لمستوى دخلهم وصلاحية الوصول إليهم. إن هذه المجمعات السكنية هي: مجمع دلسكو (ذوي الدخل المحدود)، ومجمع بيتا الصناعي (ذوي الدخل المتوسط) ومجمع ترانس جلف لإنتاج الإسمنت (ذوي الدخل المرتفع). وقد تم اختيار منزلين في مردف من أجل المقارنة.

من أجل تحقيق الهدف من هذه الدراسة، لقد تم اختيار طريقتين عمل وهي استبيان المسح والقياسات الميدانية. احتوى الاستبيان على خصائص المبنى ومعلومات السكان وحالة المسكن ومستوى الرضا عن عُرفهم ومستوى الرفاهية. لقد تم اتخاذ القياسات الميدانية في أربع مناطق من كل مجمع سكني و من كل منزل في مردف. تم قياس أربعة أنواع من الملوثات في كل منطقة وهي: مجموعة المركبات العضوية المتطايرة (TVOCs)، وثنائي أكسيد الكربون (CO_2)، وأول أكسيد الكربون (CO)، والأوزون (O_3). وبالتالي تم قياس درجة الحرارة والرطوبة في كل منطقة. وقد تحققت المقارنة بين تركيز متوسط الملوثات في المجمعات السكنية الثلاثة. وبالتالي، لقد تمت المقارنة بين أفضل مجمع سكني و بين المنزلين في مردف. ستقدم المقارنة بين نتائج المسح والقياسات، نتائج قيمة. قامت البيانات المُجمعة من استبيان المسح بتفسير نتائج القياسات الميدانية.

تُبين النتائج الرئيسية لهذه الدراسة أن مجمع ترانس جلف من ذوي الدخل المرتفع، لديه تقريباً نفس مستوى نوعية الهواء الداخلي (IAQ)، ودرجة الحرارة والرطوبة لمنازل منطقة مردف. وعليه، فإنه يتمتع بنفس مستوى رضا وصحة السكان. لم يحقق أي من مجمعات العمال السكنية والمنازل في مردف، المستوى المطلوب من مجموعة المركبات العضوية المتطايرة (TVOCs)، المذكور من قبل بلدية دبي (243 ppb). ومع ذلك، لقد لوحظ أن السكان في منازل مردف ومجمع ترانس جلف ما زالوا راضيين، بالرغم من أن معدل التركيز كان 473.6 ppb. كما يمتلك مجمع دلسكو معدل تركيز ثاني أكسيد الكربون أكبر مقارنةً بالمنازل الموجودة في منطقة مردف بعدد يُقدر بـ 873.7 ppm، والذي يُقلل من مستوى رضا السكان. تم العثور على أقل تركيز أوزون في مجمع دلسكو. تمتلك المنازل في مردف معدل تركيز أكسيد كربون أعلى من الموجود في مجمع ترانس جلف ولكن أقل من

غيرها وما زال يمتلك نفس مستوى رضا سكان مجمع ترانس جلف. إن متوسط درجة الحرارة والرطوبة الذي يمتلك أفضل مستوى رضا هو 54% و24.4 درجة مئوية على التوالي والذي تم العثور عليه في منازل مردف ومجمع ترانس جلف.

تم العثور على المشاكل الصحية في المجمعات السكنية لذوي الدخل المنخفض (مجمعي دلسكو وبيتا) مثل التعب والدوخة والصداع ومشاكل العيون والجلد وذلك نظراً إلى التركيز العالي لأكسيد الكربون وثنائي أكسيد الكربون والرطوبة.

باستخدام المنازل الموجودة في مردف كمعيار لمستوى جيد من نوعية الهواء الداخلي (IAQ)، والرطوبة ودرجة الحرارة، والمشاكل الرئيسية في المجمعات السكنية عُثر عليها في، موقعهم والتهوية والعدد الكبير من السكان في نفس الغرفة، والعفن على الأجزاء الداخلية من الغرفة. التحسينات المقترحة الرئيسية لهذه المشاكل هي، وضعهم في مناطق سكنية، وتوفير التكييف المركزي وزيادة معدل التهوية، واستخدام مواد ذات انبعاثات أقل وضمان حصول كل ساكن على المتر المربع المطلوب وهو 3.7 في غرفهم.

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List of abbreviations

ACH: Air Change per Hour

A/C: Air Conditioning

ASHREA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers

CO₂: Carbon Dioxide

CO: Carbon Monoxide

DF: Daylight Factor

DM: Dubai Municipality

EPA: Environmental Protection Agency

ETS: Environmental Tobacco Smoke

HVAC: Heating, Ventilating, and Air Conditioning

IAQ: Indoor Air Quality

IEQ: Indoor Environmental Design

LEED: Leadership in Energy & Environmental Design

OSHA: Occupational Safety and Health Administration

O₃: Ozone

PAQ: Perceived Air Quality

RH: Relative Humidity

SBS: Sick Building Syndrome

SHS: Sick House Syndrome

SVOCs: Semi Volatile Organic Compounds

TVOCs: Total Volatile Organic Compounds

WHO: World Health Organization

CHAPTER 1

INTRODUCTION

This chapter will include brief overview on the importance of Indoor Air Quality (IAQ) and IAQ in UAE's residential buildings. Thus, low cost housing and its impact on the occupants' health, dissertation aims and objectives and dissertation structure will be illustrated in this chapter.

1.1. Importance of IAQ in residential buildings:

Currently, a lot of factors affect the quality of indoor air and increased the pollutants concentration. These factors could include; the reduction in ventilation rate for cost and energy saving purpose, air tightness resulted from constructing more sealed buildings, heating, ventilating, and air conditioning (HVAC) system, excessive use of synthetic building material for furniture and furnishing, the use of pesticides and cleaning products and other factors can emit different types of pollutants (Lai et al, 2009). Diseases are widespread because of these pollutants which increase the sick building syndrome (SBS). These diseases could be severe for the people suffering from asthma and allergy. Thus, some of indoor pollutants increase the risk of cancer and chronic diseases beside the other symptoms such as; fatigue, headache, nausea, dizziness and others. The most people that are sensitive to indoor pollutants and could have severe impact are the vulnerable groups such as; elderly, infants, sick people and children. If the indoor environment has pollutants below the harmful concentration, and 80% of the occupants are satisfied so, it will have high quality of indoor air (Lai et al, 2009).

In addition to that, Environmental Protection Agency (EPA) stated that the concentration of the pollutants in indoor environment were higher than outdoor environment two to five times and could reach 100 times (ASHREA, n.d.). Thus, it ensured that people in their houses are exposed to high amount of pollutants more than any other places. Table 1.1 shows different types of pollutants with the acceptable level by EPA regulations and other guidelines such as; Occupational Safety and Health Administration (OSHA), World Health Organization (WHO), Canadian and others. The most comfortable place for the humans have 72% of the total pollutants that receives to them (Greenguard, 2015). Women that are working outside have 54% less risk of cancer death than the women that spend most of their times in home.

Table 1.1. Comparison of Regulations and Guidelines Pertinent to Indoor Environments (ASHREA, 2006).

	Enforceable and/or Regulatory Levels			Non-Enforced Guidelines and Reference Levels			
	NAAQS/EPA (Ref. B-4)	OSHA (Ref. B-5)	MAK (Ref. B-2)	Canadian (Ref. B-8)	WHO/Europe (Ref. B-11)	NIOSH (Ref. B-13)	ACGIH (Ref. B-1)
Carbon dioxide		5,000 ppm	5,000 ppm 10,000 ppm [1 h]	3,500 ppm [L]		5,000 ppm 30,000 ppm [15 min]	5,000 ppm 30,000 ppm [15 min]
Carbon monoxide ^c	9 ppm ^g 35 ppm [1 h] ^g	50 ppm	30 ppm 60 ppm [30 min]	11 ppm [8 h] 25 ppm [1 h]	90 ppm [15 min] 50 ppm [30 min] 25 ppm [1 h] 10 ppm [8 h]	35 ppm 200 ppm [C]	25 ppm
Formaldehyde ^h		0.75 ppm 2 ppm [15 min]	0.3 ppm 1 ppm ⁱ	0.1 ppm [L] 0.05 ppm [L] ^b	0.1 mg/m ³ (0.081 ppm) [30 min] ^p	0.016 ppm 0.1 ppm [15 min]	0.3 ppm [C]
Lead	1.5 µg/m ³ [3 months]	0.05 mg/m ³	0.1 mg/m ³ 1 mg/m ³ [30 min]	Minimize exposure	0.5 µg/m ³ [1 yr]	0.450 mg/m ³ [10-h]	0.05 mg/m ³
Nitrogen dioxide	0.05 ppm [1 yr]	5 ppm [C]	5 ppm 10 ppm [5 min]	0.05 ppm 0.25 ppm [1 h]	0.1 ppm [1 h] 0.0204 ppm [1 yr]	1 ppm [15 min]	3 ppm 5 ppm [15 min]
Ozone	0.12 ppm [1 h] ^g 0.08 ppm	0.1 ppm	j	0.12 ppm [1 h]	0.064 ppm (120 µg/m ³) [8 h]	0.1 ppm [C]	0.05 ppm ^k 0.08 ppm ^l 0.1 ppm ^m 0.2 ppm ⁿ
Particles ^e <2.5 µm MMAD ^d	15 µg/m ³ [1 yr] ^o 65 µg/m ³ [24 h] ^o	5 mg/m ³	1.5 mg/m ³ for <4 µm	0.1 mg/m ³ [1 h] 0.040 mg/m ³ [L]			3 mg/m ³ [C]
Particles ^e <10 µm MMAD ^d	50 µg/m ³ [1 yr] ^o 150 µg/m ³ [24 h] ^o		4 mg/m ³				10 mg/m ³ [C]
Radon	See Table B-2 ^f			800 Bq/m ³ [1 yr]	2.7 pCi/L [1 yr]		
Sulfur dioxide	0.03 ppm [1 yr] 0.14 ppm [24 h] ^g	5 ppm	0.5 ppm 1 ppm ⁱ	0.38 ppm [5 min] 0.019 ppm	0.048 ppm [24 h] 0.0192 ppm [1 yr]	2 ppm 5 ppm [15 min]	2 ppm 5 ppm [15 min]
Total Particles ^e		15mg/m ³					

For that reasons, improvements should be accomplished in order to provide solutions for indoor air pollutants reduction and therefore, reduced the SBS. Studies should focus on all indoor environments whether residential or commercial.

1.2. Indoor air quality in UAE's residential buildings:

UAE have a harsh climate mainly in summer and this will have an impact on the quality of indoor air. Sand storms occurs from one time to another which led to increase the pollutants concentration and their impact on the humans. Very fine and light dust can be emitted through the buildings' holes, windows and doors during the sand storm. Thus, air condition (A/C) will be affected with the outside pollution so, the filters must be cleaned.

In addition, it was stated by Van Dijk cited in Sarfraz (2013) that the UAE environment accelerate the growth of allergies, sinusitis, asthma and fever. Dust mites and dander are highly exist which considered the main cause of asthma risk. Thus, indoor allergens can cause many respiratory and airway problems.

Actually, high humidity in summer is the main reason behind the growth of mold, fungi and bacteria in interior environment. So during these days, health issues and occupants' dissatisfaction level increased continuously. While, during winter, the weather have less impact on indoor air pollutants because it has less humidity, dust and heat. Therefore, occupants are more satisfied in winter in their indoor environment and have less health symptoms (Sarfraz, 2013).

Environment Agency-Abu Dhabi (2013) declared that Abu Dhabi have been started to implement strategies to improve the quality of indoor air in order to reduce the health impact. This will be done by several steps which are; establish standards and regulations for the indoor air contaminations, continuous monitoring for the indoor air pollutants and their concentration, educate the people and increase their awareness for IAQ importance and conduct a research center for IAQ development in Abu Dhabi. There are number of entities started to implement strategies for IAQ management such as; Emirates Authority for Standardization and Metrology (ESMA), Federal Authority for Nuclear Regulation (FANR), Health Authority - Abu Dhabi (HAAD) and Abu Dhabi Education Council (ADEC). The government of Abu Dhabi have set targets to be attained in 2030 called "Environmental Vision 2030" related to IAQ and public health (EAD, 2013). Table 1.2 shows the main sector targets for IAQ in Abu Dhabi.

Table 1.2. Sector targets for IAQ in Abu Dhabi (EAD, 2013)

SECTOR	OUTCOMES	MEASURE	BASELINE (2011)	TARGETS	
				2018	2030
Building and Infrastructure	Improve indoor air quality in new building environments	Percentage of new residential buildings that meet Estidama Standard	40%	90%	100%
Asthma Awareness and Education	Reduce asthma prevalence among Abu Dhabi residents	Percentage of emergency room department visits of asthma patients due to asthma attacks, out of all health care facilities visits of asthma patients	10.7%	<8%	<5%

Dubai Municipality (2015) have set regulations for the ventilation and indoor air quality which will be discussed in literature review chapter.

1.3. Low cost housing and occupants' health:

Housing is one of the simplest fundamentals human rights. It can indicate for the quality of the life and the human health. Different housing will have different level and conditions depend on the location, building structure, age and many other factors. Each housing will have different exposures than the other and therefore different environmental risk. A lot of factors on housing will have an impact on the human health such as; thermal comfort, IAQ, noise level, humidity, visual comfort, mold, fungi, neighborhood, tobacco smoke, HVAC system, materials quality, etc. The level of health impact from one condition to another will be different for example; the relation between the human health and building characteristics were higher than its relation with housing location (Braubach & Fairburn, 2010).

Actually, Low income houses should be available in any country in order to correspond all residents' with different income level. But, it shouldn't have poor quality of construction materials and services which have an impact on the residents' comfortable level and health. High quality of services is very important to be provided for the housing whether low income or high. Labor housings are one of these low income houses and suffer from poor living conditions.

Unfortunately, Low income housing are always exposed to more environmental problems than others. This is due to the building structure, characteristics, location and materials that differs than the houses with high income. A lot of health issues associated with these low income housing such as; respiratory illness, asthma, allergy, mental health, chronic diseases and increased the infectious diseases. The main cause of these issues is the quality of the air that surrounded the residents all the time. Pollutants from different sources can emit and degrading the IAQ.

Nowadays, several strategies have been implemented to raise the quality of low income housing. This has been done by increasing the efficiency of several factors such as; ventilation rate, HVAC system, building structure, interior materials, IAQ and others. Dubai one of the countries that have been started to improve the quality of these houses especially labor housings. New regulations and standards have been accomplished.

1.4. Research problem:

Most of the time, the way of constructing and designing the labor housing especially low cost housing differs than the other housing. Location of these houses, low cost materials and low efficient equipment that used in these houses strongly affect the indoor air quality. IAQ can be affected by increasing the concentration level of indoor pollutants which make a health problems for the labors. Actually, a lot of labors may have many health symptoms without conscious that the main reason could be the IAQ. For that reason, this study will increase the awareness of the IAQ issues even in the houses that has low cost.

1.5. Importance of the study:

Labors have achieved huge effort in our countries and they have the right to live safely and comfortably all the time. This study will highlight the importance of the labor housing indoor living which neglected most of the time. It will increase the awareness on the way of constructing and designing the labor housing to be in optimal conditions. The study will investigate the most severe problems in labor housing and suggested some improvements to be considered in the design phases. These improvements will help in increase the level of IAQ in labor housing and avoid the health problems that caused by the indoor pollutants.

1.6. Knowledge gap (Motivation):

After conducting the literature review that will be shown in chapter 2, it seems that there is a lot of studies conducted in order to evaluate and assess the IAQ in different buildings. This is due to the importance of IAQ and its impact on occupants' health and comfort level. They studied the types of indoor pollutants, their sources and their impact on indoor environment and on occupants' health. Most of the studies were focused on the office environment and residential building in different countries. But, the main issue that lack of them are focusing on low cost housing or labor housings however, these housings have the priority to be studied. Because, they have different construction materials, furniture arrangements, HVAC system, ventilation rate, room sizes, occupant number, indoor materials and other factors that differ than other high quality housing. These factors will affect negatively the indoor environment and degrading the living conditions. Thus, IAQ will differs and affect the occupants' health. In addition, this type of study were missing

for UAE so, the research will focus on IAQ in labor housing and its impact on occupants' health. Then, it will be compared with housing that have the optimal conditions for living.

1.7. Aims and objectives:

The aim behind this study is to evaluate the IAQ, temperature and humidity in different labor housing in Dubai and its impact on occupants' health. It will investigate the actual living conditions in term of IAQ, how impact on their health and provide the required suggestions. This will be achieved by the following objectives:

- Select three labor housing that have different income.
- Assess the concentration level of different pollutants, temperature and humidity in indoor environment in these housing through field measurements.
- Identifying the pollutants' sources.
- Conduct a questionnaire survey in order to compare the occupants' indoor air perception with the pollutants' concentration.
- Select high quality houses in Dubai that have the optimal conditions of living.
- Assess the concentration level of different pollutants, temperature and humidity in these houses and conducting a questionnaire survey for them.
- Identifying the IAQ impact on occupants' health for both labor housing and high quality houses.
- Comparing the results of the measurements and surveys between the three labor housing and then, compare the best labor camp with the high quality houses.
- Using high quality houses as a benchmark for high level of IAQ and provide suggested improvements to be done in labor housing.

1.8. Dissertation structure:

This dissertation will include six main chapters; introduction, literature review, research methodology, data collection, results and discussion and conclusion and future recommendation. Each chapter will have number of topics to be discussed.

Chapter one: Introduction.

This chapter provided a brief overview on three topics which are; importance of indoor air quality in residential buildings, indoor air quality in UAE's residential buildings and low cost housing and occupants' health. Thus, it include the dissertation aims and objectives.

Chapter two: Literature review.

It will include review for indoor environment quality (IEQ) in residential buildings and main topics related to IAQ which are; types of indoor pollutants and their health impact, indoor air pollutants sources in residential buildings, impact of ventilation, humidity and temperature on IAQ, ventilation and air quality standards by Dubai Municipality (DM) and IAQ in residential dwelling with different incomes. Thus, it will include the knowledge gap of this study.

Chapter three: Research methodology.

This chapter will provide a literature review for different methodologies that have been used or could be used in evaluating the IAQ in low cost housing and their impact on occupants' health. Pros and cons for each method will be mentioned. Thus, Selection and Justification of the method chosen will be illustrated. Moreover, the required details of the selected methodologies will be stated.

Chapter Four: Results and discussion:

This chapter will include an information about the labor housing and high quality houses, comparison between the measurements of the three labor camps and comparison between the best labor camps with high quality houses. Thus, analysis for the questionnaire survey will be conducted in this chapter. Moreover, it will illustrates the suggested improvements that could be applied. The aim of this study will be achieved in this part. Thus, comparing the study results with other studies' results will be conducted.

Chapter Five: Conclusion and future recommendation.

This chapter will conclude the main findings of this study and the main improvements that could be achieved. Further studies to be conducted in the future will be suggested.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction:

This chapter will include a wide range of literature review for Indoor Environment Quality (IEQ) in residential buildings and several topics related to IAQ. Literature review will help in finding the main parameters that should be studied, identifying the knowledge gap and framing the research aims and objectives. The topics that will be studied are; types of indoor pollutants and their health impact, indoor pollutants sources in residential buildings, impact of ventilation, humidity and temperature on IAQ, ventilation and air quality standards by DM and IAQ in residential dwelling with different incomes.

2.2. Indoor Environmental Quality (IEQ) in residential buildings:

IEQ mainly study the quality of the interior environment that are surrounding the people in any building. Mostly, when constructing new buildings, the main focus be on how to make new and brilliant designs and cost effective buildings. While, the fact that people spend 90% of their time in indoor environment is always forgotten. Indoor environment can strongly affect the occupants' health, comfort, productivity and performance. Indoor environment one of the factors that should be determined from the initial stages of design. Some factors seems to be not important and it will influence the comfort level but, in reality people are affected with everything around them. People could be sensitive to temperature, humidity, heat, mold, fungi, air velocity, ventilation rate, air conditioning system, daylighting level, glare, colors, natural light, noise level, privacy, circulation, areas arrangement, furniture arrangement, materials emissions, ergonomics, communication facilities and many other factors. All of these factors can have a significant impact on occupants' satisfaction level in their indoor environment (WBDG, 2014).

In the past, IEQ problems are widespread and can be noticed in old buildings. But, with the time, it was found that the problems continuously increasing in newly constructed or renovated building (building related illness). Building envelope should protect the human from outdoor pollution and provide a comfortable environment for them. Unfortunately, sometimes the indoor environment

considered more dangerous from outdoor. The severity of IAQ problems can be extend from workers' low productivity to serious health problem such as; cancer (Spengler & Chen, 2000).

Recently, many modifications were accomplished in the buildings' construction and operation phases in order to increases the buildings' efficiency and energy conservation. This can be achieved by reducing the exchange between the outdoor air and indoor air which result in airtight building. Building insulations and synthetic building materials have been widely used for this purpose. Thus, it used to improve the building construction techniques and the indoor environment. This will provide a comfortable environment for the user. But, it have a negative side which is, providing the ideal environment for airborne pollutants production (Jones, 1998 & Zhang and Smith, 2003). Platts-Mills et al. (1996) ensure that these improvement will lead to spread the poor ventilation rates, 0.2 to 0.3 air changes/hour (ACH), which increase the concentration of indoor pollutants.

The IEQ is evaluated from the occupants' acceptance level in four main aspects: thermal comfort, indoor air quality (IAQ), visual comfort and acoustic comfort. Each of them have several factors to be studied and it could affect each other (Lai et al., 2009).

2.2.1. Thermal comfort:

Thermal satisfaction is very important to be achieved because it considered the most factor that have significant impact on human comfort. The main concerns in thermal comfort in any indoor environment are the temperature, humidity and air velocity. These parameters are connected to each other and proper combination of them will lead to comfortable thermal environment. Figure 2.1 shows thermal comfort status according to the air temperature and air velocity. People may express their satisfaction to thermal environment by how cold or warm they feel depend on the surrounding conditions. The building should give the occupant the ability to control their environment because the dissatisfaction level may increase if the control is not available. So, in air conditioning spaces, the air condition should be adjustable in order to have the ability to reach the comfortable level for the occupants. Occupants can also control their thermal comfort by adding or removing layers of clothing, moving from the heat source and others. This one of the process that used for individual adaptive to thermal environment. The other two techniques are the physiological adaption and psychological adaptation. Thermal comfort standards focus on providing a good climate in indoor environment even if the outdoor climate is hot and humid.

Good indoor climate can also reduce the energy consumption by the building (Nicol & Humphrey, 2002 and Behzadi, 2011).

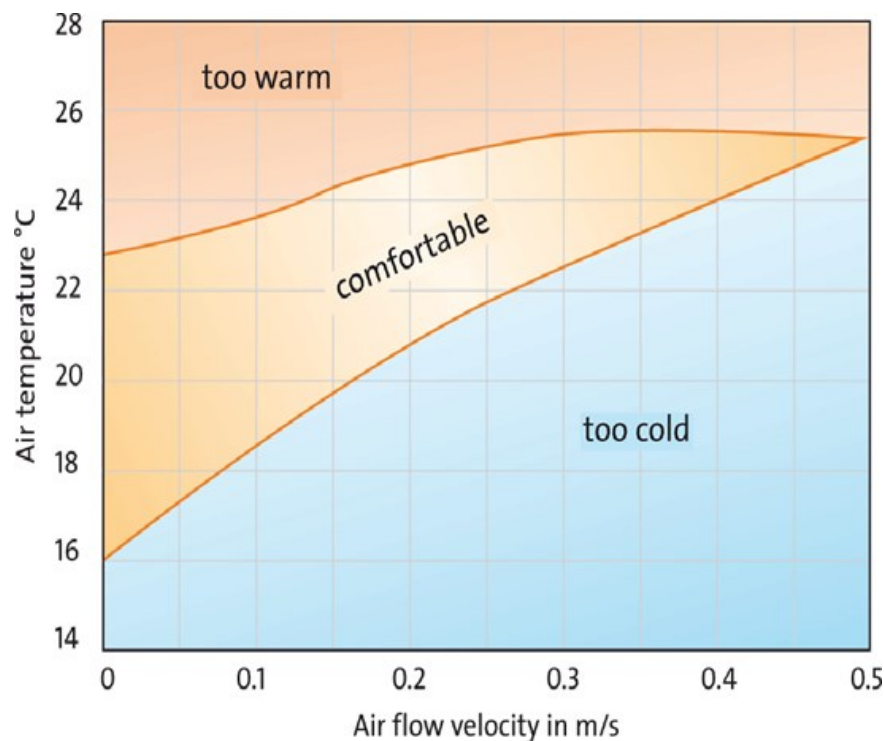


Figure 2.1. Thermal comfort status according to the air temperature and air velocity (Isover, 2010)

2.2.2. Indoor air quality (IAQ):

People in their houses are always surrounded with the air. The air should be clean, fresh and free from any pollutants (dusts, chemicals, particles, etc.) that can harm the occupants' health and degrading their ability to achieve their work. Air can be polluted because of different factors and from different sources. Each source can emit different types of pollutants under different concentrations. Figure 2.2 shows some indoor pollutants sources which could be the interior materials, occupants' activities (smoking, eating, cleaning, etc.), improper ventilation, humidity, HVAC system, pesticides, dampness, mold and many other sources. A lot of health issues will appear in the buildings that have low quality of air such as; fatigue, dizziness, nausea, headache, difficulties in breathing, dryness, irritation, respiratory issue and others. IAQ considered the most indoor environmental factor that can affect the occupants' health rather than thermal, acoustic and

visual. Studies by Environmental Protection Agency in U.S. showed that IAQ considered one of the top five environmental risk to public health (Huang et al., 2012).

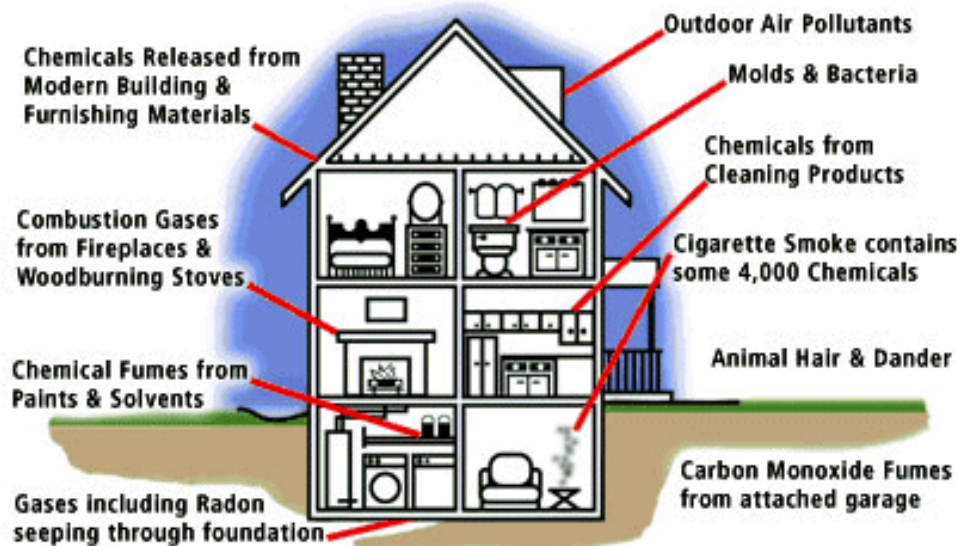


Figure 2.2. Indoor pollutants sources (Karl, 2014)

2.2.3. Visual comfort:

This factor are related to the psychological and physiological comfort. A lot of factors can affect the visual comfort such as; colors of the materials, walls and furniture, windows size and location (natural light), artificial light color, space cleanness and others. Lighting whether artificial or natural is very important factor and should be highly considered in the earliest stage of design process. Day lighting is the direct sunlight or diffused sky light in to a building. Providing natural light can improve the quality of the environment and enhance the occupants' health and wellbeing. Daylight factor (DF) is the ratio of outside illuminance over inside illuminance. The lower DF, the lower natural light in the space. Natural light should be in the comfortable level range (DF between 2% and 5%) to avoid any glare or darkness. Table 2.1 shows the room appearance and energy implication in different ratios of DF. Artificial light should have the proper color and amount in the indoor spaces. Each space has a specific amount of illuminance differs than the other depend on the building type and the activities in this space (Turrent, 2007).

Table 2.1. Room appearance and energy implication in different ratios of DF (Turrent, 2007)

Average DF	Appearance	Energy implications
< 2%	Room looks gloomy	Electric lighting needed most of the day
2% to 5%	Predominantly daylit appearance, but supplementary artificial lighting is needed	Good balance between lighting and thermal aspects
> 5%	Room appears strongly daylit	Daytime electric lighting rarely needed, but potential for thermal problems due to overheating in summer and heat losses in winter.

2.2.4. Acoustic comfort:

Acoustic is highly sensitive in offices environment more than residential buildings. Residential buildings need acoustic privacy between different apartments and between the rooms inside the apartment. Lack of acoustic privacy will make the occupants uncomfortable in their houses. People in offices can be annoyed with the workers communication, walking on the corridor, printer sound and others. This will lead them to feel dissatisfy with their environment and reduce their productivity and performance. Noise sources in residential building could be from HVAC system, kitchen equipment, occupants' communication, T.V sound and others. Health issues can be appear when the noise level is high such as; headache and hearing problems (Bonda & Sosnowchik, 2007). Same the other environmental factors, acoustic comfort can change the occupants' acceptance level of indoor environment, so it should be studied and evaluated well.

2.3. Indoor air pollutants types and their health impact:

There are different types of pollutants that emitting from the sources and causing a serious health problem for the occupants. Each pollutant has different negative impacts on the indoor environment. Several studies have been accomplished in order to study the pollutants' concentration in indoor environment, their impact on the occupants' health and the severity level. A study conducted by Yeatts et al. (2012) to determine the impact of several pollutants on

occupants' health in 628 household in UAE. It was found that SO₂, NO₂, HCHO and H₂S have concentration above the normal level. This result in increasing the number of occupants suffering from the asthma, wheezing symptoms, difficulty in concentration, headache and forgetfulness. Improvements for this study was conducted by Funk et al. (2014). This was done through questionnaire survey in order to identify the relation between the pollutants concentration and the housing demographics and human habits. Thus, measuring additional types of pollutants such as; CO and three size fraction of particulate matter (PM_{2.5}, PM_c, and PM₁₀) have been conducted. Field measurements revealed that the concentration of the pollutants recorded the same result of pollutants in developing countries which have been investigated by previous studies. Number of factors can affect the concentration of each pollutants in the indoor air. Carbon monoxide, PM_{2.5} and PM₁₀ were affected by the smoking, air conditioning and the attached kitchen. In addition, PM_{2.5} and PM₁₀ were sensitive to the vehicle parked within five meters of the home.

Another study was performed by Al-Rehaili (2001) to identify the level of indoor air pollutants and outdoor pollutant around different building in Riyadh. The study mainly evaluate three types of pollutants; SO₂, NH₃ and HCHO in different seasons. It was revealed that the concentration of SO₂ and NH₃ were above the recommended level. It was found that in winter the concentration of these pollutants increased in the indoor environment more than the outdoor. While, HCHO recorded moderate level of pollution and higher concentration in outdoor more than indoor.

It's very essential to study the main indoor air pollutants and their severity on the occupants' health because it will indicate for the quality of the environment that we lived in. The most popular pollutants that can emit the indoor environment and have a negative impact on the users are carbon monoxide, carbon dioxide, ozone, radon, formaldehyde, VOCs, nitrogen dioxide and hydrogen sulfide.

2.3.1. Carbon monoxide (CO):

This type of pollutants produced from the incomplete combustion of organic materials. Normally, in combustion process carbon combined with two atoms of oxygen, but in this case it will combined only with one atom (partial oxidation). It considered one of the toxic substances in United State, around 270 persons have been died in California because of CO poisoning from nonvehicle sources. The main properties of CO that it has no color, no taste, no odor and it doesn't cause any irritation symptoms. This leads to difficulty in detection which make it more risky.

Indoor CO can be mainly from the heaters, stoves, gas appliances, vehicle exhausts (attached garage) and environmental tobacco smoke (Bernstein et al., 2008 & Dales et al., 2008).

Many health issues can be caused by inhaling CO. When the inhalation occur, CO connected with the hemoglobin and prevent it from releasing the oxygen to the blood. This can lead for increasing the feeling of tiredness, dizziness, difficulty in breathing and nausea. Sometimes, mistaken in diagnosis could be happen because it has the same symptoms of flu. Exposed to CO for a long period can leads to coma and death. The level of riskiness associated with the period of exposure, the concentration level of CO and the person's health status. It can be responsible for many elderly heart failure more than other pollutants (Bernstein et al., 2008).

2.3.2. Carbon dioxide (CO₂):

Carbon dioxide is non-toxic gas, it naturally occur in the indoor environment or by human activities. It doesn't have any color or smell. Outdoor concentration can be in range of 350-400 ppm and it could be higher in industrial areas or in high traffic areas. The indoor concentration rely on different factors such as; ventilation rate (amount of fresh air entering the room), outdoor concentration, number of people in the space, occupied hours, size of the room and human activities (tobacco smoke). Measuring the level of CO₂ have been conducted nowadays, in order to evaluate the IAQ and human comfort in indoor environment. Since, humans are producing CO₂ by respiration process so, the amount of it can indicates for the effectiveness level of ventilation in the space (MDH, n.d.).

Increasing the CO₂ concentration in indoor environment will cause a health problems for the occupants. In proper ventilation and presence of other pollutants may increase the symptoms. These symptoms could be headache, tiredness, dizziness, nausea and others. It appears when the CO₂ level is between 2500 to 5000 ppm. At higher concentration (100,000 ppm), occupants could lose their conscious for 10 minutes and at 200,000 ppm glottis could be locked partially or fully (MDH, n.d.).

2.3.3. Ozone (O₃):

Ozone has a blue color and it has smell like chlorine. It consists of three atoms of oxygen. Main sources of ozone in indoor environment are outdoor air mainly in industrial areas and air purifiers. Air purifiers that kills microbes, reduce the offensive odors and prevent respiratory problems can

increase the level of ozone in indoor environment from 16 to 453 ppb. Indoor concentration of ozone depends on the ventilation rate, surface removal rate, ozone concentration in outdoor air, indoor material emission and the interaction between ozone and other air pollutants.

Ozone like other indoor pollutants leads for many health issues. High exposure to this type of pollutant can cause severe problems for the lung function. Thus, it affect the airway tract for the normal persons which can make it very risky for the person that have asthma and lung diseases. Ozone can stimulate the allergic symptoms when the allergens are inhaled, in other words, it aggravate the allergic problems. Thus, combination between ozone and particulate matter will be cause problems. The severity of ozone rely on the concentration, the period of exposure, the inhaled amount and the ventilation rate (Bernstein et al., 2008).

2.3.4. Radon gas:

Radon gas is a very toxic and radioactive pollutant. It has no color, no taste and no smell. The natural decay of uranium in the soil is the main source of radon. It can enter the indoor environment through the small holes in the building foundation. Thus, domestic water supply and building materials can be considered as a sources for radon. Environmental Protection Agency (EPA) in U.S. state that around 21,000 deaths happen annually because of the high concentration of radon in residential building. The risk mainly occur because radon when inhaled, it connected with the lung tissue and cause a damage for it. This may lead to a lung cancer which will take 5 to 25 years to develop after the exposure occur.

The average concentration of radon in outdoor environment is around 37 Becquerel per cubic meter (Bq/m^3), Becquerel is a measurement unit of radioactivity. The EPA in U.S. achieved a study to evaluate the radon concentration in homes in 50 states. The mean concentration was ranging between 24 Bq/m^3 multi-family homes to 54 Bq/m^3 in single family homes. The concentration in the basement was higher than the first floor. According to meta-analysis of 7 case-control studies in North America, people that have the possibility to have lung cancer are increased with the increasing of radon concentration in indoor air. For that reason, continuous measurements and prevention procedures should be taken (Dales et al., 2008).

2.3.5. Formaldehyde (HCHO):

Formaldehyde has no color, flammable and highly reactive at room temperature. It is quickly photo-oxidized in carbon dioxide. Thus, it can react with hydroxyl radicals very quickly. It can be found in the environment naturally or by human activities. Human activities mainly occur in the industrial sites, vehicle emission and it can be used in the resin for antiseptic and fixation purposes. Indoor sources could include any combustion process such as heating, cooking, smoking and candles. Thus, furniture, textiles, wood works, cleaning products, electronic equipment and indoor materials can emit formaldehyde such as; adhesive, carpet, paints, wallpaper, lacquers, varnishes, detergents, photocopier, antiseptic and others.

It considered one of the pollutants that are carcinogenic. Long period of exposure will increase the risk of nasopharyngeal cancer. At lower concentration (0.36 mg/m^3), it can cause eye, nose and upper airway irritation. Symptoms such as; eye redness may increase at higher concentration (0.6 mg/m^3). Humans can perceive the formaldehyde when the concentration is below 0.1 mg/m^3 , which is not considered adverse health affect. Asthma and respiratory problems that caused by formaldehyde is debatable. Using low material emission, preventing smoking in indoor spaces, reducing the combustion process and increasing the ventilation rate will reduce the exposure for formaldehyde (WHO Guidelines, 2010).

2.3.6. Volatile organic compounds (VOCs):

VOCs are organic compounds, have offensive odor in non-industrial environment and it can vaporize quickly at room temperature. It contains around 300 compounds, each compound have specific concentration and health impact differs than the others. The total compounds together called TVOC and measured in $\mu\text{g/m}^3$. It indicates the level of VOCs concentration in indoor air and can reflect the occupants' comfortable level in their indoor environment. Health symptoms have been recorded but not proofed that it caused by VOCs compounds. These symptoms include; an irritation in mucous membranes, tiredness, straying and could lead for cancer. Irritation in mucous membranes associated strongly with VOCs.

VOCs in indoor environment have a lot of sources from building materials and components such as; wall covering, furniture, paint, vinyl tiles and coving, carpets, particleboard, cleaners and cabinetry. Occupants' presence in the building and their activities influence the concentration of

VOCs. Complaints about odor or some health problems occurs when TVOC concentration reach 3000 $\mu\text{g}/\text{m}^3$ or higher. IAQ guidelines have been establish a regulations to set a limit for VOCs amount in the homes in order to prevent the negative impact on the health (Bernstein et al., 2008).

2.3.7. Nitrogen dioxide (NO_2):

Nitrogen dioxide responsible for indoor and outdoor pollution and have a negative impact on human health. The main indoor sources for NO_2 are the cooking and heating appliances. A lot of studies have been conducted to evaluate the relation between NO_2 exposure and respiratory problems, but the findings were indecisive. Some evidences showed that infants, children and adults that have asthma and respiratory problems are more sensitive in exposure to NO_2 .

In United States, high concentration of NO_2 found in low cost housing. This is due to the poor ventilation, small size of the rooms and heating equipment. The concentration level of NO_2 in the houses rely heavily on the source, while the exposure rely on the nearness to the source. There are some difficulties in evaluating the health impact of NO_2 mainly the individuals' exposure especially in children because, they can't express their feelings. Nitrous acid is a secondary pollutant from NO_2 and other nitrogen oxide and water. It can exist in indoor environment and affect the respiratory function for the occupants that suffering from asthma at concentration of 650 ppb (Bernstein et al., 2008).

2.3.8. Hydrogen sulfide (H_2S):

This type of pollutant is toxic and doesn't has any color but it has offensive strong odor. Similar to all types of pollutants, toxicity rely on the period of exposure and the concentration. At low concentration (<10 ppm), it can has a rotten eggs smell but, at higher concentration (>100 ppm), the smell nerves can't capture any odor which is more risky. Dry drain traps or broken sewer lines are the main sources for increasing the level of H_2S in the indoor environment. It can affect the lung function but, in lower concentration (20-50 ppm), only the eye and respiratory tract will be irritated. Exposure to hydrogen sulfide for long period will aggravate many symptoms such as; headache, nausea, diarrhea and tiredness. Sometimes, symptoms can increase to reach bronchitis and bronchopneumonia. When the concentration reach more than 2000 ppm, loss of consciousness can occur. Thus, this could lock the respiratory tract and it will prevent the oxygen reaching the lung which will cause a death in few minutes. Adults are the most affected persons in high

concentration. After the investigation of H₂S in indoor space, solution should be immediately applied in order to prevent any negative impact (IVHHN, 2015).

2.4. Indoor air pollutants sources in residential buildings:

Indoor air pollutants can be emit from a wide range of sources. According to Jones (1999) the main sources are those related to the occupants' activities inside the building, biological and non-biological sources, building material emissions, fuel combustion, poor ventilation, humidity, HVAC system and other pollutants that escape from outside through water, air or soil. The concentration of these pollutants rely heavily on outdoor pollutants concentration, volume of the air inside the interior space, the amount of the pollutants inside this space, the mechanism of pollutants removal, the air exchange between outside and inside (Maroni et al., 1995 cited in Jones, 1999).

Buildings that are located in industrial areas near the factories or heavy traffic street are more exposed for indoor pollutants that emit from outside. This source of pollutants considered non-biological source. The level of impact can be determined from the ventilation rate per hour, the ventilation type (mechanical or natural), the pollutants concentration outside and the type of these pollutants (Wanner, 1993 cited in Jones, 1999). Major indoor pollutants, their sources and their health impact on occupants have been identified by several studies. The main indoor sources of indoor air pollutants are the following:

2.4.1. Solid fuel combustion:

Solid fuel combustion considered a major indoor pollutants source in traditional building in developing countries. Figure 2.3 shows an example of solid fuel combustion for cooking in developing country houses. This type of combustion predominantly done in low quality stoves which is leading to low efficient combustion. Similarly to in complete combustion, solid fuel combustion didn't convert the carbon to carbon dioxides (CO₂). But, it produce other compounds such as; carbon monoxide (CO), fine particles, VOC and SVOC. Direct and continuous exposure to these compounds will contribute to chronic and acute diseases mainly for children. In contemporary houses, the main concerns are the building material emission, finishes and others rather than the fuel combustion for cooking. Because, they have electrical oven for cooking and other modern ways for heating. Carbon monoxide and nitrogen dioxide can emit from these

sources due to improper ventilation but still it considered low comparing with the solid fuel combustion (Zhang and Smith, 2003).



Figure 2.3. Solid fuel combustion for cooking in developing country houses (Ezzati & Kammen, 2002)

2.4.2. Tobacco smoke:

Human activities can produce pollutants mainly from the tobacco smoke. Cigarettes is a major source for indoor pollution. The level of impact can be measured by personal monitoring and monitoring the particles concentration in indoor air. In 2000, 4% of the burden diseases are caused by the direct exposure to tobacco smoke. It has more than 4000 chemicals in form of gases and chemicals which are carcinogenic. Thus, it can cause several health impact for the adults, children and enfant such as; respiratory diseases. A lot of issues have been increased related to Environmental Tobacco Smoke (ETS) which affect the non-smoking people. ETS indicates for the mixture between the mainstream (MS) which is the smoke that exhaled by the smoker directly and sidestream (SS) which is the smoke that emit from burning tobacco between puffs. It exposed the non-smokers for the chemicals and the harmful substances that inhaled by the smokers. Due to the complexity in ETS measurement, they tend to measure the particles concentration in the cigarettes itself to determine the level of indoor pollution. Several studies have been conducted to found the

relation between ETS and chronic respiratory tract problem and other diseases that infect the adults, children and infants. Thus, these studies have been conducted to identify whether these diseases occurs pre-birth or after the birth. It shows that ETS exposure in houses can increase the risk of asthma. While there is no evident study shows that ETS have negative impact on adult lung function (Zhang and Smith, 2003, Bernstein, 2008 & Jones 1999).

2.4.3. Interior materials:

Interior materials inside the building have a significant impact on indoor air quality. There are several indoor materials either structural materials or furnishing can emit large amount of pollutants as shown in Fig. 2.4. These materials included; paints, carpets, vinyl tiles, asbestos used in insulation, cleaning products, pressed or treated wood that used in carpentry and furniture, adhesive, rubber and many others. The amount of each material in the space and concentration of emissions that emitted from each material are the most important factors in measuring the level of impact. Thus, it is important to determine if the emissions from these materials are continuously or intermittently depend on the interior conditions (EPA, 2014). Many of organic compounds are associated with building materials and increase the level of VOCs concentration in indoor environment rather than outdoor. VOCs can cause a health problems for the occupants in their houses like the other emissions (Zhang and Smith, 2003). Proper choosing for the interior material and finishes is very essential while designing. The selected material should have less emissions and chemicals in order to increase the building efficiency and improve the ventilation rate. This can be achieved by study the material characteristics, what emissions and pollutants is produced, the severity of these pollutants and its impact on human health. All of these issues should be studied and evaluated in the design phase (Lee et al., 2012).

Studies have been conducted to determine the impact of interior materials and finishes on the IAQ performance. The study that conducted by Lee et al. (2012) carried out research on a system that can be utilized while selecting an interior finishes based on indoor air quality performance. Detailed process to assess each material and IAQ impact have been determined. The pollutants that associated with interior finishes have been described and identified. The ways of grading the material after assessment and evaluation were identified in order to help in materials selection.

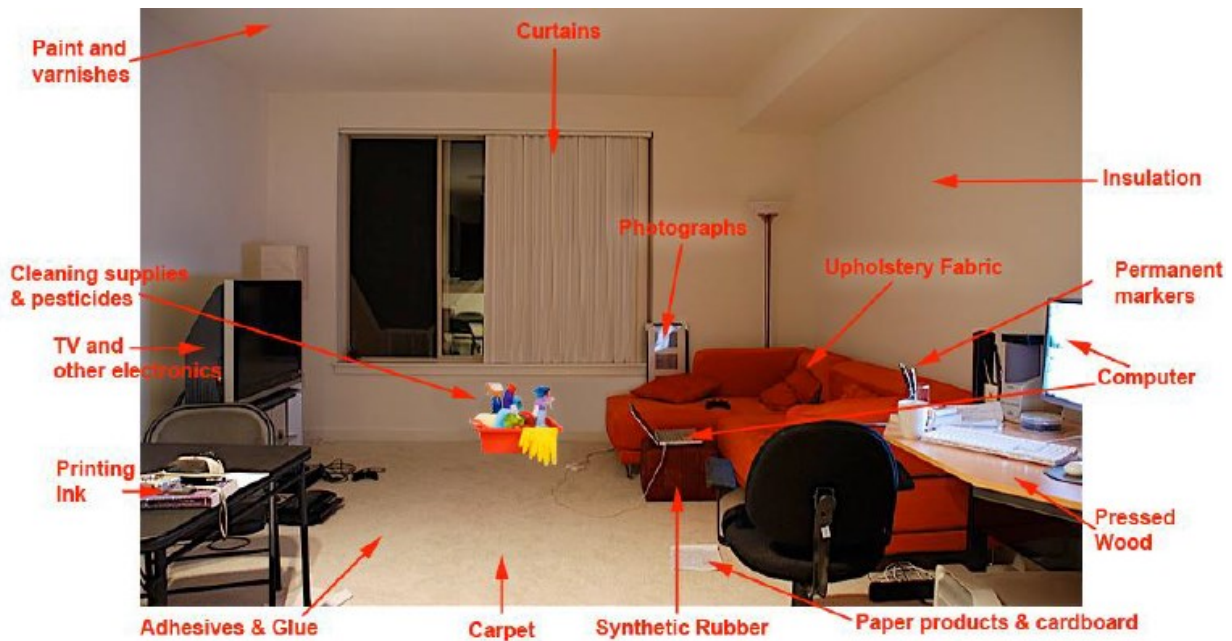


Figure 2.4. Indoor air pollution from interior materials (Turrent, 2007)

2.4.4. Dampness and mold:

It is very essential to control the humidity level inside the space in order to achieve the comfortable level for the occupants. Relative humidity inside any house should be in the comfortable range (differs from one country to another) in order to avoid any negative impact such as; degrading the occupants' health and affect the ventilation rate. Indoor humidity is affected by several factors such as; the moisture source (human, activity, plants, etc.), moisture absorption and desorption from the interior materials and surfaces, air speed, air temperature, ventilation rate per hour and the outdoor absolute humidity (Zhang and Yoshino, 2010). Beside the uncomfortable environment, humidity can have a significant impact on the material emissions. The emitted pollutants from a specific material is increased frequently when the materials are wet.

Dampness and mold can occur in a lot of building that are overcrowded and have several problems, such as; plumbing pipes damage or leakage, condensation in HVAC system, mold in furniture and building material, poor insulation, poor ventilation and other problems. Over cooling the rooms can cause condensation and mold growth on the furniture as shown in Fig. 2.5. Mold can grow on the poor insulated pipes in the ceiling as shown in Fig. 2.6. Usually, indoor air have amount of chemicals, volatile organic compound, microorganism, toxin and others. The concentration of these particles are increased in the areas where the mold and dampness are exist. Poor ventilation,

bacteria and viruses growth and increasing fungi, dust mites and endotoxins concentration in any building is associated with the increasing of mold and dampness. Sometime, dampness is responsible for the mold growth as shown in Fig. 2.7. This will result in increasing the health problem for the occupants in the building. Studies shows that 30% to 50% of the houses that always have mold or dampness are suffering from respiratory symptoms. Thus, there are significant evidences ensure that dampness and mold increased the allergens, toxins and irritants (Dales et al., 2008 & WHO Guidelines, 2009).



Figure 2.5. Mold growth on furniture (ASHREA, 2009)

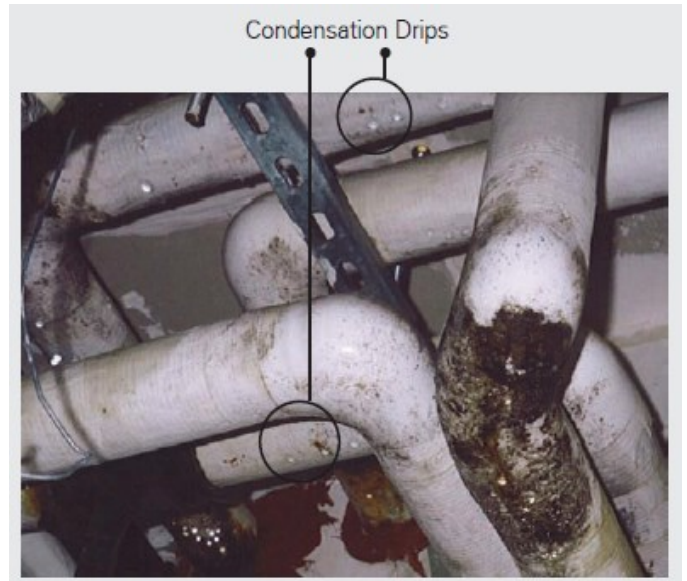


Figure 2.6. Mold growth and condensation drip on the pipes in the ceiling (ASHREA, 2009)



Figure 2.7. Mold growth due to the dampness (ASHREA, 2009)

More chemicals can emit from different materials in the building when they are moist. Mold and dampness may be a proxy for pests growth such cockroach, rodents and termites. These pests increased the indoor pollutants which caused an infectious diseases and degrade the occupants' health. Termites works to damage the building structure and threaten the occupants' safety and health. Termites may not affect the houses' air quality directly but it will be the reason to use the hazardous pesticides continuously which affect the indoor air (WHO Guidelines, 2009).

It was mentioned by WHO Guidelines for Indoor Air Quality (2009) that several studies proved that the main reason behind presence of dust mites in the houses is the humidity. The range of relative humidity that the dust mite can growth and develop is 45-50%. When this percentage increased, it unleashes to more growth of dust mites.

Fungi can be found on different areas in the house such as; surface of new material or clothing. Moreover, ventilation weather passive or active can be the reason to prevalence of fungi in the indoor environment. Although, the building doesn't have any damp problem, still the fungi can be grow in it. Surface that are wet or moist facilitate the fungal growth especially when the relative humidity is below the saturation point (below 100%). Fungi also cause a severe problem for the wooden building structure mainly in temperate region (Europe, Japan and Australia) not only affect the human health.

Bacteria also can be found in indoor surfaces and materials because of mold and dampness. Even without these problems, it can be found like fungi. Outdoor air, humans and indoor bacterial growth are the major factors that stimulate the proliferation of bacteria in indoor environment. Indoor bacterial growth is considered more harmful than the other sources. Bacteria can cause a health problem for the occupants (WHO Guideline, 2009).

An investigation for numbers and types of airborne microorganisms in three residential houses in Al-Ain city in UAE have been conducted by Jaffal e al. (1997). They found that fungal colony forming unit (CFU) were associated with the housing type and category. Thus, it illustrated that, the houses with high level of hygiene recorded less microbial growth which considered as the same cleanness of hospitals' rooms. While, houses with low quality recorded higher amount of microbial growth similar to that in slums houses. Those houses that have poor ventilation rate, less hygiene awareness and have high number of occupants in limited space are more expected to have microorganism growth. Moreover, they studied the level of human-related microorganism and the

environmentally-related microorganism in different spaces in the house. It found that human-related microorganism is higher in the bedroom than the living room. The reasons behind this, that the area of bedroom is smaller than the living and the occupants spend more time in their bedrooms. The bedrooms are less exposed to the outdoor air than the living room, so it has less environmentally-related microorganism. Both human-related and environmentally-related microorganism were higher in the low quality houses. Even with the high number of microbial growth, they found that the human health doesn't affected in high rate.

2.4.5. HVAC system:

A lot of studies have been conducted to investigate the relation between the HVAC system and the IAQ. Ventilation and HVAC system are highly affect the IAQ and pollutants' concentration in any space. Bonetta et al. (2010) studied the bacterial and fungal level in three offices in Italy equipped with HVAC system. The results found that daily trend of indoor pollution with bacterial and fungal was related to the human activity in switching on the HVAC system during the day and switching it off during the night. So, the fungal and bacteria can flourished when the HVAC system is switched off and it enter to the indoor air when they open it. While, the seasonal trend of indoor pollution was related to the air circulation in the space and the intermittent use of the HVAC system during different seasons.

The aim of the HVAC system in any place is to provide comfortable environment for the user which is can be achieved by producing high quality of the air. For that reason, HVAC system must designed, installed, maintained and operated efficiently in order to prevent the sick building syndrome. Lack of HVAC continuous maintenance will affect the occupants' health and increase the pollutants concentration. In designing and planning stage, the operator must choose accessible location for the HVAC system for cleaning and maintenance. Humidity and ventilation rate must be checked properly to maintain the required level for satisfaction (Townsend, 2007).

Filtration process and gaseous air cleaning are very essential to keep the level of viruses and bacteria low as much as required. There are different types of filters as shown in Fig. 2.8 and the suitable filter should be carefully selected. The exhausted air should be cleaned like incoming outdoor air in order to avoid any cross contamination of air uptake. Two types of particulate filters should be used; one with medium efficiency to prevent the heat exchange, cut the opportunity for biological growth and also it reduce the cost of maintenance. The other one should be in high

efficiency to prevent inhaling the particulate matter and control disease-bearing organism. Organic and non-organic compounds can be prevented by using gaseous filters with high efficiency (Townsend, 2007).

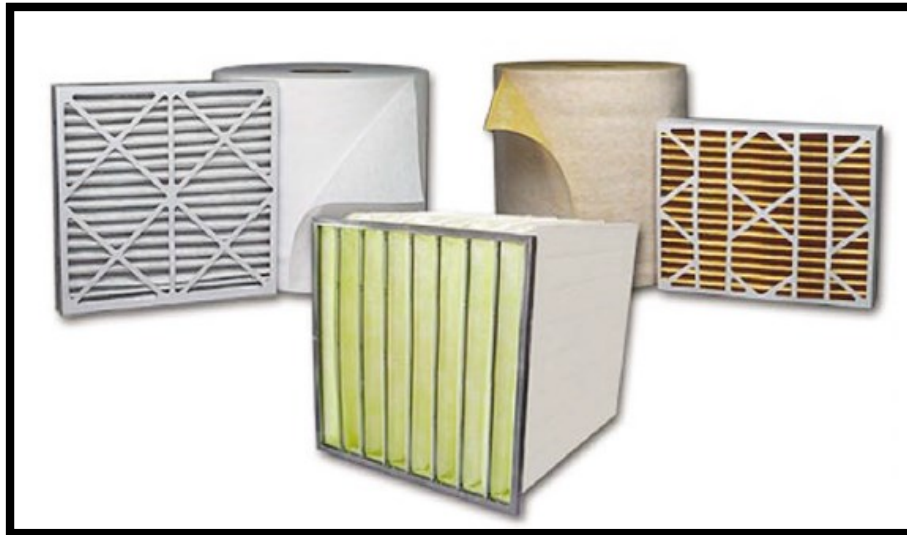


Figure 2.8. Different types of filters (Townsend, 2007)

2.5. Impact of ventilation on IAQ:

In the past, they often refer the main reason behind the indoor air pollution to the improper ventilation. In the present, it was insured that ventilation have a huge impact on IAQ and pollutants concentration. Because the main function of ventilation is to dilute the indoor pollutants by entering a clean air from outside. So, providing high efficient ventilation for the building will enhance the IAQ and therefore, reduce the occupants' health problems (BRANZ Ltd, 2007). Some buildings in order to reduce their energy consumption, they reduce the ventilation rate which degrading the IAQ in the space. Ventilation is very essential to keep the RH in the target level and achieve a high quality of indoor air (Woloszyn et al., 2009).

When the ventilation rate reach 15 L/s per person, the occupant dissatisfaction level with the perceived air quality (PAQ) reduced to be below 10%. The dissatisfaction level with the PAQ reach 5%, when the ventilation rate is increased and reaches 25 L/s per person. While, increasing the ventilation rate above the recommended level, will cause adverse effect on the occupants. Increasing the level of clean air in the indoor environment will enhance the PAQ. Thus, it will

reduce the health symptoms and sick building syndrome (SBS). It's preferable to keep the ventilation rate constant and directly focused on the breathing zone (Melikov et al., 2008).

Currently, Occupants' perception of IAQ is the primary issue that used to determine the ventilation rate standard rather than risk-related aspects of indoor pollutants exposure. Thus, focusing on PAQ will provide much more data than focusing on the health risk and indoor pollutants exposure. The collected data determined the relation between the ventilation rate and the occupants' perception of IAQ (Sundell et al., 2011).

Studies shows that raising the temperature in indoor environment will negatively affect the PAQ and could prevent the air movement to reach the comfortable level for the occupants. For that reason, Arens et al. (2008) evaluate this issue by conducting a test on humans. The test was done in neutral air temperature (24.5° C) and in high temperature (28° C, 30° C) environment with different air speeds. One of their finding illustrate that, air movement can improve the PAQ and recirculate the air in the room. When the temperature was high and the air speed reached 1 m/s, the PAQ was increased to reach the comfortable level equivalent to that in the neutral temperature.

Wong & Huang (2004) attained a study to investigate the level of IAQ in three residential building in Singapore. One of the study objectives was studying the IAQ in the bedrooms with natural ventilation (NV) and bedrooms with different types of air conditioning (A/C). It was found that the concentration of CO₂ level in the bedrooms that use A/C without NV was higher than the bedrooms that only utilizing NV. Rooms that have higher concentration of CO₂ level, those that utilizing A/C with no fresh air intake (1600 ppm). When the air vent is open in the windows unit, the CO₂ concentration degrading from 1200 ppm to 1000 ppm. Portable A/C have lower concentration (750-800 ppm), while the least was recorded in the NV bedrooms (550-600 ppm). So, most of A/C types have CO₂ concentration above the recommended level which is 1000 ppm unless the portable one. This may result to increase the headache, tiredness and dizziness for the occupants. In contrast, the NV bedrooms recorded higher concentration of particulate than the bedrooms utilizing A/C. However, those bedrooms that have the air vent in the A/C is open having the same particulate concentration of NV rooms. This finding can indicate that the source of the particulate was mainly from outside and the filtration system for the A/C was not efficient.

Similar study was conducted by Guo et al. (2004) in Hong Kong to evaluate the IAQ in air-conditioned and non-air-conditioned markets. It aims to evaluate the concentration of carbon

monoxide, nitric oxide, nitrogen dioxide, sulfur dioxide, total bacteria count and PM₁₀ inside these markets. Results showed that all of these pollutants have concentration below the Hong Kong Indoor Air Quality Objectives (HKIAQO) standards except PM₁₀ and total bacteria count. Markets that located beside high traffic have higher concentration of PM₁₀ than the others. Vehicle exhaust particulate can emit through the filtration system in the A/C. Indoor bacteria is highly related to the humidity and temperature. The air conditioning doesn't have a noticeable impact in reducing the level of pollutants in the markets. While, the higher outdoor/indoor ratio revealed the level of bacteria in the markets was affected by the air conditioning operation.

Sundell et al. (2011) attained a study in order to evaluate the impact of ventilation on the occupants' health through conducting wide range of literature review. Most of the reviews ensure that low ventilation rate accelerate the flourishing of health problems and SBS. Thus, results revealed that the ventilation rate should be higher than 0.5 air change per hour in order to reduce the risk of allergic manifestations among children.

2.6. Impact of temperature and humidity on IAQ:

Relative humidity (RH) can considered one of the most important parameter to be studied in term of IAQ perception. Because, the perceived IAQ are strongly affected by the RH, temperature and VOCs level inside any building. Moreover, it was proofed by different studies that the level of VOCs can directly influenced by RH and temperature. It's seems that, at low RH and temperature, the level of VOCs emission from building materials will be decreased. Wolkoff & Kjærgaard (2007) accomplished a study to evaluate the level of RH impact on the perceived IAQ mainly the level of odors and irritation symptoms. It was conducted by reviewing number of papers and studies. Studying the immediate and long term exposure impact of RH on IAQ in term of VOCs, ozone and particles were difficult to achieve. This is due to the relation between the building material emission and the demographic conditions with these pollutants. Studies related to clinical, epidemiological and human exposure showed that decreasing the level of RH will increase the eye irritation and change of the of the precorneal tear film. Thus, results illustrate that the best condition of eyes and airway are achieved when the RH is 40%. Although, differences between the optimal RH for eyes and the airway could be occur.

Fang et al. (1998) performed a study to identify the impact of temperature and RH on PAQ, odor intensity and pollutants emission from different building materials. The results illustrate that both temperature and RH have little impact on perception of odor intensity of air polluted by building materials. While, they have a large impact on the perception of IAQ. When the pollution level was constant, the PAQ was decreased with the increase of temperature and RH. However, their impact decreased with the increase of air pollution and the impact level of air pollution on PAQ decreased with the increase of temperature and RH.

Most of the time, humans can feel the changes of temperature level in their environment due to the sensory receptors that they have. In contrast, they can't feel exactly the alteration of RH due to the lack of these receptors. Because of that, most of the studies are concentrating on the temperature impact on IAQ rather than RH. Also, in the building design stages, RH is neglected and the main focus on the temperature. Although, RH can affect the human thermal comfort and health, perception of IAQ, the durability of building material, building emissions and energy consumption (Simonson et al., 2002).

Some studies on human exposure to fresh and humidified indoor air was conducted. Some of them illustrated that air with low RH (10%) doesn't increase the risk of eye and respiratory tract dryness. Although, these symptoms mainly occur in dry air and when the amount of VOCs in the indoor air is high. Thus, increasing the level of formaldehyde can accelerate the feeling of dryness of mucous membrane. Recently, in epidemiological studies, dry air have been considered and evaluated because it stimulate the indoor air pollution and cause some health issues. High RH and high temperature can affect the quality of the perceived air because it stimulate in emissions from different building materials (Wolkoff & Kjærgaard, 2007). It was stated by Kalamees et al. (2009) that cold climate can decreases the level of RH in indoor environment which is accelerate many health symptoms (dryness of some body parts). In addition, it was mentioned that low RH (5-30%) can increase the prevalence of dry air which is increasing the eye and upper airway irritation

Although, a lot of studies have been conducted to set a standard level for RH in office environment or others, but still it's not clearly identified. Eyes and nose can be affected by RH and temperature alteration in the indoor environment but, each organ may be affected in different way. In cold and not humid environment, nose have the ability to rise the RH in the nasopharynx to reach 100%. Even if the indoor environment become cool to reach 18 °C and RH still low, it seems to be no

problem and it can reach RH of 100%. In contrast, the eyes seems to be more affected in low RH (Wolkoff & Kjærgaard, 2007).

Controlling the moisture in the indoor environment means to retain the RH at the comfortable level. Moisture (high RH) is highly affected the building performance in term of IAQ. It can accelerate the growth of bacteria, microorganism and dust mites. So, high RH can be revealed when visible mold and condensation are occurred. A lot of factors can stimulate the indoor moisture and affect the stability of indoor RH. These factors are humans' activities and existence in the space, indoor temperature, the amount of air flow, ventilation and infiltration air change rate, potential condensation, the absorption and emission of moisture by hygroscopic interior surfaces (walls, floor, ceiling and furniture) and the outdoor moisture and absolute humidity level (Kalamees et al., 2009 & Woloszyn et al., 2009) . Moisture production rely heavily on the human activities. Beside the moisture, CO₂ concentration can be increased in the presence of human odors. Moisture cab be absorbed by the indoor materials which have an impact on the RH in the indoor environment (Woloszyn et al., 2009).

Bornehag et al. (2001) stated that several epidemiological investigations which is focusing in indoor environment proved that dampness are interrelated with many health issues. These issues could include; respiratory symptoms, asthma, allergy, airway problems (coughing and wheezing), tiredness and headache. Dampness can occur due to the leakage of rain and snow in to the building which is considered outdoor source, moisture from human activities which is considered indoor source and leakage from pipes.

A study conducted by Plathner & Woloszyn (2002) to investigate tracer gas dispersion and the airborne movement of the moisture in two-story house which are fully equipped. The test of airborne movement of moisture measured the vapor pressure level in the kitchen, bedroom and living area during the moisture production for 1 h. Thus, it measure the vapor pressure after 1 h of moisture production. The results revealed that the vapor pressure levels in the kitchen, living room and bedrooms are widely overestimated when the absorption is neglected. The humidity measurements in the kitchen after 2 h of production showed that most of the moisture that produced was left. Ventilation can be the reason but it recorded only 2/3 of the air humidity reduction in the kitchen. The humidity level in the living and bedrooms were increased less than 10% of the actual

value. It was found that large amount of the moisture was absorbed by the walls and furniture in the kitchen while, small amount was distributed to the other parts of the house.

Woloszyn et al., (2009) stated that, a lot of factors are related to the indoor air humidity which make it complex to be evaluated. So, simulation tools should be very accurate. It should evaluate the whole building and taking into consideration the moisture exchange between the indoor air and the indoor materials. Thus, their study ensured that using moisture buffering-materials is very preferable in order to reduce the moisture amount in the space. Kalamees et al. (2009) declared that keeping the RH variation in the target level in order to improve the IAQ and save energy will occur by using moisture-buffering material. Furthermore, Simonson et al. (2002) assured that indoor humidity can be better when the moisture transfer between the indoor air and the hygroscopic building structure. Therefore, this will improve the quality of indoor air and the quality of the life.

Kalamees et al. (2009) performed a study to evaluate the impact level of ventilation rate and using of moisture-buffering materials on the stability of indoor humidity and temperature. This was achieved by conducting long term exposure field measurements in 170 detached houses in Finland. Air temperature, RH and absolute humidity were measured and analyzed in subgroups according to the ventilation rate, hygroscopic materials used and the vapor permeance of the envelope. They concluded that the ventilation rate had higher impact on the indoor climate than using moisture-buffering materials. The dampening effect of hygroscopic materials was obviously noted in the simulation results more than the field measurements. Some rooms with hygroscopic materials showed high variation in indoor humidity and other rooms with non-hygroscopic materials showed low variation in indoor humidity. This illustrate that in reality fully hygroscopic and totally non-hygroscopic houses didn't exist. Another possibility is that the current rough classification system doesn't have the ability to differentiate between the hygroscopic and the non-hygroscopic materials. The hygroscopic properties of the indoor materials play a major role in modifying the indoor RH.

So, achieving a comfortable level of temperature, RH and providing the required level of ventilation in the indoor environment is very essential and need a lot of studies to be accomplished.

2.7. Ventilation and indoor air quality standards by DM (2015):

DM have been established a new regulations and standards for green buildings to be applied in all buildings in Dubai. The new regulations will ensure having a healthy city with sustainable environment. One of their concerns are the ventilation rate and the IAQ. These factors will highly influence the occupant's satisfaction level especially in Dubai climate. So, some of the regulations that related to these factors are:

- Mechanical and mixed mode ventilation should be applied for all new and existing building with minimum requirements of ASHRAE standards 62-2007.
- Occupants should be protected and avoided from indoor pollutants which include toxic substances such as; fumes, dust, asbestos, lead, mold, etc. that emitted during the construction or renovation.
- All HVAC system must be closed during the construction or renovation phase in order to prevent the dust and debris from collecting in the supply and return openings. Temporary return air filters with Minimum Efficiency Reporting Value (MERV) could be used if HVAC system is needed during the construction phase.
- Doors and windows (outdoor air intake) should be located in suitable location in all new and existing buildings. Thus, proper distance from the contamination source should be determined as required by DM and ASHRAE Standard 62-2007.
- All existing buildings should have proper ventilation and indoor air quality in compliance with DM regulations. This will be done by conducting a test that measure the concentration of indoor air pollutants. The concentration shouldn't exceed the standard limits as shown in table 2.2 Air testing should be done by companies or laboratories accredited by DM. Equipment for measuring indoor air pollutants should have initial and periodical calibration certificates in order to ensure its accuracy.

Table 2.2. Pollutants standard concentration (DEWA, 2011)

Sampling Schedule	Type of Samples	Maximum Acceptable	Sampling Duration
Initial test completed by 31 December 2011. Further testing within 5 years of last compliant test.	Formaldehyde	< 0.08 ppm	8- hour continuous monitoring (8 hour time-weighted average [TWA])
	Total Volatile Organic Compound (TVOC)	< 300 micrograms/ m ³	
	Respirable Dust (<10 microns)	< 150 micrograms/ m ³	
	Ozone	0.06 ppm (120 micrograms/ m ³)	
	Carbon Dioxide	800 ppm (1440 microgram/ m ³)	
	Carbon Monoxide	9 ppm (10 micrograms/ m ³)	
	Bacteria	500 CFU/ m ³ (Algar plate)	
	Fungi	500 CFU/ m ³ (Algar plate)	

- HVAC system must be checked and maintained in all new and existing building as require by DM.

2.8. IAQ in residential dwelling with different incomes:

A lot of studies and investigations have been accomplished to evaluate the IAQ level in different housing in different countries. Each housing have different conditions, in term of materials used, furniture arrangement, rooms size, windows size, occupants activities, type of ventilation, HVAC system, number of occupants and others. All of these factor influence the quality of the air and affect the pollutants' concentration in the space. Thus, occupants' health and comfort level will be affected and strongly related to IAQ.

Lee et al. (2002) have been done a study in residential homes in Hong Kong. The aim behind this study was to assess the current situation of IAQ by evaluating the concentration of different pollutants. These pollutants are; CO₂, formaldehyde, PM₁₀, VOCs and airborne bacteria. Their findings illustrated that the concentration of CO₂ and PM₁₀ in the domestic kitchens were higher

14% and 67% than their concentration in the living areas. CO₂ concentration have been affected strongly by the smoking and inadequate ventilation. Domestic kitchens recorded serious air pollution caused by PM₁₀. The average concentration of airborne bacteria in domestic kitchens and living areas were higher than 500 CFU/m³. But, the mean total bacteria count was higher in the kitchens by 23% than the recorded level in the living areas. Airborne bacteria were influenced by in proper ventilation, crowded indoor environment and hygienic lifestyle. Housing that have smoking occupants showed higher level of some pollutants such as; benzene, toluene and m; p-xylene which affect the IAQ negatively. Liquefied petroleum gas (LPG) stove stimulate the increasing of VOCs level in the kitchen more than the natural gas cooking stoves.

Similar study achieved by Takeda et al. (2009) in order to evaluate the air contaminates and its association with SBS in newly built dwelling in Japan. This was achieved through questionnaire survey for the occupants and measurements for some type of pollutants. Thus, dampness presence or absence have been studied. They conclude that formaldehyde, dampness and alpha-pinene have severe effect on SBS. Therefore, studies, measurements and prevention strategies should be accomplished.

Kanazawa et al. (2009) estimated the levels of semi volatile organic compounds (SVOC) in residential dwelling in Japan and whether it's related to SBS. Questionnaire survey and air sampling were used to achieve the aim of their study. Results illustrate that some chemicals were strongly interrelated with mucosal symptoms of SBS such as tributylphosphate and s-421. On the other hand, diethylphthalate and TBEP doesn't recorded any relation.

Nowadays, green regulations have been applied in number of housing to achieve high level of IAQ. Study was conducted by Colton et al. (2014) to compare between IAQ in conventional and green low income housings in United State. Their aim was to identify the effectiveness of green strategies on indoor exposure profile. Home inspection, air sampling and health questionnaire survey have been done for both conventional and green low income housing in two years. Moreover, occupants that moved from conventional housing to green housing and vice versa have been questioned. They mainly focus on PM_{2.5}, NO₂, CO₂, nicotine and air exchange rate (AER) in their measurements. The findings showed that PM_{2.5}, NO₂ and nicotine in green housing were lower 57%, 65%, and 93% (respectively) than the conventional one. Mold, dampness, pests, stuffiness and in proper ventilation were found in conventional housing in higher rate. There was

not significant differences in formaldehyde and CO₂ level between the two housing. Regarding the SBS, occupants in green housing recorded 47% fewer symptoms than the others. Increasing the quality of life, improving in health outcomes and reduction of human exposure to the indoor pollutants have been noticed in the occupants that moved to the green housing. These results ensure that new regulations should be implemented to improve IAQ and occupants' health.

Few studies were accomplished to evaluate the occupants' sleeping comfortable level in their rooms. Sekhar & Goh (2011) evaluated the thermal comfort and IAQ in naturally/mechanically ventilated bedrooms (NMV) and air-conditioned (A/C) bedrooms in hot humid climate. Objective measurement was accomplished in 12 NMV rooms and 12 A/C rooms over a period of 2 months. At the end of the objective measurements, questionnaire survey have been answered by the occupants in order to assess their sleeping conditions and their satisfaction level. Occupants comfort was in the accessibility level range for the both thermal comfort and IAQ in NMV rooms and A/C rooms. Although, results found NMV rooms was more preferable for sleeping than A/C rooms. Thus, there was increasing in CO₂ level in A/C bedrooms comparing with NMV bedrooms. Therefore, sleeping duration was decreased with the increasing of CO₂ level in the room even if there is no evidences to proof that.

CHAPTER 3

METHODOLOGY

3.1. Introduction:

This chapter will study different methodologies that have been used to evaluate the IAQ in different housing with different outcomes and their impact on residents' health. Literature review for each methodology will be achieved. Pros and cons for each methodology will be stated. This will assess in choosing the best methodologies that could be used to achieve the aims of this research. Thus, this chapter will illustrate the required details for applying the selected methodologies and reach an effective results.

3.2. Review of previous methodologies:

A lot of researchers have the motivation to conduct a study for evaluating the quality of indoor air in different dwelling. This could be achieved by studying different factors that related to IAQ such as; assessing the pollutants types, sources, concentration and their impact on the occupants' health and comfort level. Each of these studies have different aims behind their investigation and it will achieve different results. In order to attain valuable results, best methodologies should be chosen. The selection criteria will depend on the research aims and on the available condition to conduct the methodology. So, each study will have different methodologies or different ways in applying their methodologies. The Methodologies that have been used or could be used in this topic are experiment, questionnaire survey and literature review.

3.2.1. Experimental Method:

Experimental methods have been done by several studies. For this topic area, most of the experiments have been achieved by field measurements while, others could be done in laboratory depend on the required data. The experiment required real dimensions and real life conditions or it could be done by selecting a small model that have the same conditions to be studied. The main advantages of this method that it measure the variables in reality which is ensure the validity of the collected data. Thus, the researcher can choose the most suitable time and conditions to conduct the experiment. But, this also could be considered one of the disadvantages that the collected data

will be influenced with the weather conditions so, the experiment time could be delayed according to the season. Moreover, the cons of this method, that most of the time it required some tools and measurement equipment which is costly. Literature review and questionnaire survey could be used as a support for the experimental method.

Guo et al. (2009) achieved a study for several homes in Hong Kong by conducting an experiment to evaluate the concentration of VOCs and formaldehyde level. Some factors that affect the concentration level have been studied such as; human activities. The tool that has been used to measure the VOCs level was passive charcoal tube sampler. While, diffusive 2, 4-dinitrophenylhydrazine cartridge was used for measuring the formaldehyde level. The diffusive sampling of indoor air have been used in one area in each house. Mostly, this area was the living room but, when this doesn't exist, they took the bedroom. The sampling took place on the floor with specific height at the middle of the room. Kanazawa et al. (2010) used the field experimental method to evaluate the level of SVOC in Japan housing and its relation with SBS. Air and dust sampler have been used in the living area. Air sampler took place at height 1-1.5m and away from the wall 1m. Dust samples have been done on different surfaces such as; shelves, doors, floor, cupboard and others. Thermo-recorder was used to observe the relative humidity and air temperature during the air and dust sampling and the average reading was calculated. The relation between the floor dust and chemicals on material surfaces was evaluated by Pearson's test. The same test was used to evaluate the SHS symptoms such as; eye irritation, respiratory issues and headache. As mentioned before, interior materials can emit different chemicals and emissions which affect the quality of indoor air and pollutants concentration. So, Senitkova (2014) evaluate the impact of interior materials on IAQ and its impact on the health. This has been done by experimental method, sensory assessment and chemical analysis have been used after exposing the interior materials for the standard conditions. Controlling the standard conditions have been achieved by parameters of supply air. Four types of floor covering and two types for walls and ceiling covering have been studied in the experiment. Glass test chamber have been used to perform the measurements.

Field experiments were conducted by Sekhar and Goh (2011) in 4 homes in Singapore which has hot humid climate. In order to assess the IAQ and thermal comfort during the sleeping period in the bedrooms. Some of the bedrooms were naturally/mechanically ventilated and others used the

air conditioner. Objective and subjective measurements have been conducted, some factors were kept constant in order to prevent the errors during the experiment. The air temperature, relative humidity and carbon dioxide have been measured. The measurement tools were located at the middle of the room with 1.2 m height. Gallego et al. (2009) measured the VOCs concentration and identified its sources in dwellings' indoor environment through field experiment. Thus, they identify their impact on health and SBS symptoms. Three low cost experimental phases have been achieved, the outdoor conditions were constant during the three phases. Thermal Desorption (ATD) coupled with capillary gas chromatography-mass spectrometry detector were used as an analysis methods.

A controlled experiment was achieved by Dasgupta et al. (2009) in order to study the relation of different factors with IAQ in Bangladesh housing. These factors include; occupants' activities, ventilation system, areas arrangement and construction substances. Climatic change and neighborhood pollution were taken in to consideration during the experiment because it can affect the results. The data were collected in different seasons, and it seems that there was differences from one season to another. PM₁₀ concentration was measured by MiniVol Portable Air Sampler and Thermo Electric personal DataRAM.

3.2.2. Questionnaire survey:

This method was the most popular method and has been used by several papers. Due to its importance in getting the occupants' perception and comfortable level directly in their housing. It can be done by two ways, either by distributing the survey directly in the field or to be online which is mostly required more time. Climatic conditions and the season should be determined while the survey is taken because it can influence the results and residents' satisfaction level. Most of the surveys that have been done in this topic area, started with general questions and then go deeply to reach the target such as; Missia et al. (2009), Osawa & Hayashi (2009) and Kanazawa et al (2010). Some of them use Likert type of questions such as; Sekhar and Goh (2011).

Likert scale is used to measure the occupants' attitude directly by asking them to respond to a series of statements about a topic, in terms of the extent to which they agree or disagree with them (McLeod, 2008).

Osawa and Hayashi (2009) used the questionnaire survey method to determine the alteration of the quality of indoor air because of the increasing level of VOCs. The questionnaire have been distributed for 10,000 newly built houses in Japan from 2000 to 2005. The survey include questions related to the building characteristics such as; the classification of the building (Apartment, detached or others), building structure (reinforced concrete, prefabricated wooden structure, prefabricated steel or others) and number of the stories. Thus, it asked about the walls, floors and ceiling finishes. Residents' activities and ventilation system have been identified in the survey. All the questions that achieved the aim of the study have been asked. Most of the houses (60%) that were selected by the government are answered the survey in 2000. While, the others answered the survey online.

Comparing the IAQ level, pollutants' concentration and occupants' health between low cost conventional housing and green housing in United States have been conducted by Colton et al. (2014). These green building are certified by the Leadership in Energy & Environmental Design (LEED) and have many green characteristics. The survey include questions related to housing characteristics and health issues such as; tiredness, respiratory and mucosal symptoms. The survey was supplemented with field measurement for different types of pollutants for both types of housing. Number of the residents that are available to answer the survey was around 50 households. In 2012, direct survey was distributed for 30 families in two low cost conventional public housing. In 2013, the same survey were answered by the residents that moved from conventional to green housing. Visiting these two types of housing in hot seasons between February and may have been done. Participants that are above 18 years old and spoke English, Spanish, Mandarin Chinese, or Cantonese have the priority to answer the survey. If there is two persons have these criteria at the same house, they ask the available one. The same person have been asked after moving from the conventional housing to the green house.

The relation between IAQ and SBS have been studied by several researchers, Takeda et al. (2009) studied this relation through questionnaire survey distributed for the residents in Japan housing. Detailed questions related to the housing characteristics have been answered by the head of the house such as; the presence of dampness, mold, fungi and bacterial growth, materials of the walls, floors and ceiling, occupants' activities (smoking, use of pesticide, cooking, etc.), water leakage and others. While, other residents have been asked about their health history and if they suffer

from asthma or allergy. They conducted a similar survey in 2003, so they benefit from the data which is related to the building age and structure from it. The same method and questions was attained by Kanazawa et al. (2010) in order to assess the impact of SVOCs on SHS in residential housing in Sapporo, Japan during the period of 2006 and 2007. More detailed questions related to the SHS symptoms have been asked such as; presence of eye, nose, throat and skin symptoms, difficulties in breathing, respiratory problems and general symptoms (headache, fatigue, dizziness, nausea, difficulties in concentration and itching). The answers that have been used for such a questions were often (every week), sometimes and never.

Questionnaire survey also have been used by Singh and Jamal (2012) to study the IAQ in low cost housing with low socio-economic in Aligarh in India. Beside the questionnaire survey, interviews have been achieved for 533 households. It aims to investigate the sources of indoor pollutants in these housing. So their questions were related to the fuel used for cooking and living conditions such as; number of families that lived in the same housing, family size, dampness and mold, water leakage, ventilation system and rate, cooking location, types of exposure (smoke and heat) and others. Thus, presence of diseases have been asked. Through their survey, they identify the factors that are related to indoor air pollution. The survey illustrate that occupants most of the time were cook and eat inside their room due to the unavailability of kitchen area inside their housing. This will accelerate the growth of pollutants inside their room. Moreover, they rely heavily on conventional fuel for cooking such as; wood, dung and coal. This will increase the health problems for the residents mainly the cancer and chronic diseases.

3.2.3. Literature review:

Similar to other methodologies, literature review have been used widely by a lot of papers as a main method to reach the aim of the study. This method need a huge amount of papers to be reviewed in order to achieve effective results. Comparing between different results from different papers should be attained adequately. For this topic area, most of the paper were used this method as a supportive for other methodologies. They can't use it as a main method, because each study have different parameters to be studied. Thus, the IAQ conditions differs from one housing to another, so each study will have different conditions. These conditions depend on many factors such as; location, climate data, surrounding areas, housing size and occupants' activities. Moreover, the data and results that were collected by other studies became old, new parameters

and investigations are required. Literature review can help in avoiding repetition and get the benefit from others mistakes. Thus, it's useful in framing the research question and elaborate the aims and objectives of the study.

Sundell et al. (2011) used a literature review as a methodology to study the ventilation rate and systems in indoor environment and how it will influence the human health. Environmental Sciences, Pollution Management and other databases have been used to collect the required information. Papers that published in peer-reviewed scientific journals and evaluate the ventilation rate and human health have the priority to be used in their research. The researchers collected the required information from the papers such as; building characteristics, population, data analysis methods, equipment to measure the ventilation rate and health outcomes. The same methodology was used by Sandel et al. (2010) to evaluate the level of chemical agents (pesticides, VOCs and lead) in different housing that caused by improper ventilation rate. Thus, the health problems related to ventilation issues have been studied. US Environmental Protection Agency database have been used to extract the related published and peer reviewed papers. Some of these papers have effective results and evidence to be used, others should have improvements for their data and others have very weak results and cannot be used. Sarigiannis et al. (2011) work to collect as much as possible evidences and data related to human exposure to VOCs and carbonyl in their housing. Residents have the potential to have a cancer because of this exposure which also have been studied. The papers that have been selected was published between the period 1990 and 2008. Different parameters and factors were studied and analyzed to achieve an effective results.

3.3. Selection and justification of the methods chosen:

From the above literature review, it seems that three types of methodologies were used to study the IAQ in housing in different locations with different conditions and outcomes. Thus, the impact of indoor air on human health and comfort level. In this section the selected methodology and the selection criteria will be identified.

Experimental method can be used in this topic through field measurement to evaluate the concentration of different pollutants in indoor environment. Because the main issues in IAQ studies are to assess the pollutants types and its concentration. The main advantage of this method that, it insure the validity of the collected data because it's done on the reality as mentioned above.

It can give an accurate results for the measurement, but the accuracy will rely on several factors. These factors can include; the efficiency of the equipment that have been used, the bias level and the timing that the measurements have been taken. Season and climatic conditions will highly influence the results of the experiment. So, the season should be identified from the beginning of the study. The measurements could be done in two different seasons, depend on the aims of the study. The experimental results can't be considered universal because each country have different climatic conditions, regulations and living standards, types of pollutants and concentrations. This can be one of the disadvantages that it has. Different parameters can be evaluated in the experiment depend on the study requirements. Increasing the number of the studied parameters will increase the accuracy of the study but, it will required more time to achieve the results. Limitations of this method can be because of three reasons which are; lack of equipment that measure the concentration of different pollutants, getting the permission to enter the housing and the availability of funding to attain the experiment.

Most of the papers used literature review method as a supportive method in order to collect the required data about the research topic. These data are essential to understand the topic area perfectly, identify the main problems, the required parameters, the analysis methods and different applied solutions. So, this method when used as a supportive method, work to add knowledge and avoid repetition but not to achieve new results and investigations like experimental method did. But, when it's used as a main method to achieve the aim of the study, it should collect a plenty of researches in order to reach effective results. Lack of papers that evaluate the IAQ in labor housing and its impact on human health will obstruct the use of this method as a main methodology. Thus, the conditions and situation between one studies to another will be different.

Questionnaire survey can reach directly to the most concerned people which are the residents of the housing (the labors). It can evaluate the occupants satisfaction level in their housing and how its affect their daily life and their health. It can be asked at the same time of the measurements. Errors can be occur if the occupants answer the questions randomly. Direct surveys are better than the online surveys because it may encourage the residents to answer more accurately. Also, the accuracy can be increased when the survey have more detailed questions about the building characteristics, living condition, occupants' activities and health issues. So, the researcher can determine the exact conditions that the occupants live in and get their perception to IAQ directly.

But, the problem with the more detailed surveys that, the respondent get bored quickly which affect the accuracy of the survey. Questionnaire survey may took long time until collecting the required number of subjects especially when it conducted online. Climatic conditions may have an impact on the respondents' answers but it doesn't have a notable effect on the results as much as experimental method.

The best two methodologies that will be used to achieve the aim of this research were the field measurements and the questionnaire survey. These two methods have the least limitation and complement each other. Pollutants types, concentrations and sources in labor housing cannot be determined without the field measurement equipment. While, human perception and health problems cannot be identified without the questionnaire survey. These will not be evaluated accurately with the other methods. Thus, some limitation will prevent using the other methods such as; longer time, more tools and more investment are needed to conduct big experiments which will not be applicable for this study. This study is very critical for the time, for that reason the selection of the methodologies was influenced with the time factor. Field measurements will be used to measure the quality of the air in labor housing and in high quality housing. Comparing the results between these two housing will be conducted in order to achieve an effective results. Occupants are the best people in identifying the living conditions in different housing and determining the main problems that they face it. Because they are only the one that exposed to these conditions. They will give an accurate answers in the survey if they aware of these problems and need improvements. Large amount of factors can be studied through the questionnaire survey.

3.4. Methodologies details:

As mentioned above combination of two methodologies will be achieved. This will increase the amount of the collected data and produce more effective results. This section will illustrate the details of each methodology and how it will be conducted.

3.4.1. Questionnaire survey:

The survey will include all the factors and parameters that affect the IAQ and cause a health issues for the residents. These factors could include; building age, building location, surrounding area, number of persons inside the room, residents' activities, HVAC system, ventilation rate, health problems, outdoor pollutants and maintenance. It will be answered directly by the occupants on

the field. Online survey may be hard to be attained by the labors because they may don't have the access to the internet. Thus, direct survey will encourage them to answer if they don't have the interest to give their opinion and reflect their satisfaction level. It will be distributed for three labor housing in different areas in Dubai with different outcomes. The selection will be according to the housing quality (low, medium and high) because the study need different qualities in order to compare the health issues and occupants' satisfaction level. The survey will be answered by 55 resident from each housing. The selection of the occupants was randomly in each housing because they all exposed to the same conditions. The selected housing will be the same that the measurements will be conducted in. Moreover, the survey will be answered by some residents living in higher quality houses in Dubai. In order to compare between the living conditions and IAQ between the labor housing and other people housing. These residents can answer the survey online but, in order to avoid any bias, direct survey will be distributed for them. The survey will have the same questions and parameters to be answered. It will be in English language but, some labors will need a person to translate for them the questions. Number of the subjects that will answer the survey will be the same for all labor housing. But, in high quality houses, it could have less number of subjects depend on the validity to access them.

The survey will include four main parts beside the general questions about the building characteristics that will be asked at the beginning of the survey (see appendix A). The four main parts will be related to the occupants' information, housing conditions, occupants' satisfaction level in their room and health and wellbeing. All the questions are multiple choice, because there are specific type of information required from this survey which require to limit the answers in it. While, the open questions will provide a wide range of information that may not be used in this study. Moreover, the occupants will get bored in answering the open questions which will make the answers not accurate compared with the multiple choice questions. Different studies were used to extract from them the questions that will be used in the survey. These studies are done by Osawa & Hayashi (2009), Missia et al. (2010), Kanazawa et al. (2010), Takeda et al. (2009) and Singh & Jamal (2011). Some of the questions have been added according to the study needs.

Building characteristics will include seven questions which will help in recognizing the living level in the housing. Building name, its location and building age will be asked. Number of each area in each housing is very essential to be asked such as number of kitchens, bathrooms and rooms in

each floor. Because, it will reflect the number of occupants that are using the same area in the same time.

The first part which is occupants' information will have seven questions as shown in Fig. 3.1. These questions include the age of each resident and number of hours that they spend it out of their housing. So, this will help in determining the period of exposure to indoor air pollutants and how it will affect in their health. The level of impact may differs from one to another according to the occupant's age. Number of persons in their room, smoking habit and number of smokers in their room will be identified in this part. Increasing the number of occupants in specific area will highly affect their comfortable level. Smoking strongly influence the quality of inhaled air. Occupants that are smoking will negatively affect their health and other non-smoking people health. Questions related to allergy and asthma will be asked. People that are suffering from these issue will be more sensitive for indoor pollutants than normal people.

Part A: Occupant information.

1- Age (years):

- Under 20
- 20 – 30
- 31 – 40
- Above 40

2- Hours spent out of your housing per day:

- < 6
- 7 – 9
- 10 – 12
- > 12

3- How many persons in your room?

- 2
- 3
- 4
- > 4

4- Are you a smoker person:

- Yes
- No

5- How many persons are smoking in your room?

- 2
- 3
- 4
- > 4

6- Self-Reported asthmatic:

- Yes
- No

7- Self-Reported allergic:

- Yes
- No

Figure 3.1. First part of the questionnaire survey

The second part will focus on the questions related to the housing conditions as shown in Fig. 3.2. It will have eight questions to be answered. It will start asking about the problems that the occupants may face in their housing in different areas such as; water pipes leakage or damage, mildew on the ceiling, walls or flooring, mildew on the furniture, wet or damp area, offensive odors, improper ventilation and others. Thus, the continuity of having these problems will be asked in order to determine the level of impact. All of these issues have a serious impact on the quality of the air especially if they are facing it usually. Sometimes, A/C can emit pollutants from outside especially when it does not work properly. So, this will be asked for the occupants if their A/C works efficiently or not and if it provides the required level of temperature inside their rooms. Occupants' activities will be identified in this part such as; use a cleaning product or chemicals, ventilate the room by opening the window, use air purifier, preparing food and eat in the room. Thus, the continuity of practicing these issues will be asked. Regular maintenance is very essential to be asked about because, it can influence the IAQ especially maintenance for the HVAC system. The

Part B: Housing conditions. 1- Have you experience any of these problems in your housing? (How often you have it) • Water pipes leakage or damage (usually – occasionally – rarely – never) • Mildew on the ceiling, walls or flooring (usually – occasionally – rarely – never) • Mildew on your furniture (usually – occasionally – rarely – never) • Wet or damp area (usually – occasionally – rarely – never) • Offensive odors (usually – occasionally – rarely – never) • Improper ventilation (usually – occasionally – rarely – never) • Other: <i>You can choose more than one answer.</i> 2- Which areas in your housing have this problem? • Kitchen • Room • Bathroom • Corridor <i>You can choose more than one answer.</i> 3- Do you feel your A.C. emit pollutants from outside? • Usually • Occasionally • Rarely • Never 4- Does your A.C. provide the required level of temperature? • Yes • No	5- Have you done any of these practices in your room? (how often you do it) • Use a cleaning product or chemicals (usually – occasionally – rarely – never) • Ventilate your room by opening the window (usually – occasionally – rarely – never) • Use air purifier (usually – occasionally – rarely – never) • Preparing food (usually – occasionally – rarely – never) • Eat in your room (usually – occasionally – rarely – never) <i>You can choose more than one answer.</i> 6- Do you have a proper maintenance for your housing? • Usually • Occasionally • Rarely • Never 7- Which season you considered the most comfortable? • Winter • Summer • Spring • Fall 8- Which season you considered the least comfortable? • Winter • Summer • Spring • Fall
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Figure 3.2. Second part of the questionnaire survey

last two questions in this part will be about the most and the least comfortable season. These two questions will illustrate how the outside climate affect the indoor environment.

The third part of the survey will be about the occupant's satisfaction level in their rooms as shown in Fig. 3.3. This part evaluate the satisfaction level by rating the temperature level, humidity level, air freshness, air quality and the overall satisfaction level in the room. This will give an indication for the quality of IAQ in their housing.

Part C: Occupant's satisfaction level in their rooms.

1- Rate your room temperature:

- Fully satisfied
- Satisfied
- Dissatisfied
- Fully dissatisfied

2- Rate the humidity level in your room:

- Fully satisfied
- Satisfied
- Dissatisfied
- Fully dissatisfied

3- Rate the air freshness in your room:

- Fully satisfied
- Satisfied
- Dissatisfied
- Fully dissatisfied

4- Rate your satisfaction level in your room:

- Fully satisfied
- Satisfied
- Dissatisfied
- Fully dissatisfied

5- How do you assess the air quality in your housing?

- Clearly acceptable
- Just acceptable
- Just unacceptable
- Clearly unacceptable

Figure 3.3. Third part of the questionnaire survey

The forth and the last part will be about the health and wellbeing in the housing as shown in Fig. 3.4. This part will study the sensitivity level for the smoke odors, dust, mold or any chemicals. Because people that are sensitive will have different impact on their health than the others and cannot take it as a gauge. From the literature review that conducted in the beginning of this study,

it was found that several health problems can be caused by indoor pollutants. These problems could be fatigue, dizziness or headache, difficulties in breathing, irritated or itching eyes, dry or runny nose, dry throat or cough and dry or red skin. So, the occupants will be asked about these problems, how usually they feel it and in which areas these symptoms are appeared. From these questions, the relation between the indoor air pollutants, temperature and humidity with these health issues will be identified. The last question will ask the occupants if they need any improvements for their housing and what are these improvements.

Part D: Health and wellbeing.

1- *Are you sensitive to the smoke odors, dust, mold or any chemicals?*

- Yes
- No

2- *Have you ever feel any of these symptoms in your housing? (how often you feel it)*

- Fatigue, dizziness or headache (usually – occasionally – rarely – never)
- Difficulties in breathing (usually – occasionally – rarely – never)
- Dry, irritated or itching eyes (usually – occasionally – rarely – never)
- Dry, stuffy or runny nose (usually – occasionally – rarely – never)
- Dry throat or cough (usually – occasionally – rarely – never)
- Dry, itching or red skin (usually – occasionally – rarely – never)
- Other:

You can choose more than one answer.

3- *Which areas in your housing you feel these symptoms?*

- Kitchen
- Room
- Bathroom
- Corridor

You can choose more than one answer.

4- *Rate your health comfort level in your housing:*

- Fully satisfied
- Satisfied
- Dissatisfied
- Fully dissatisfied.

5- *What are the improvements that you prefer to be added to make your housing more comfortable?*

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Figure 3.4. Forth part of the questionnaire survey

Accurate analysis for the collected data from the questionnaire survey will be achieved in order to evaluate all the factors that have an impact on IAQ and occupants' health. The analysis of the data will be conducted on Microsoft Excel.

3.4.2. Field measurements:

This methodology is very necessary to be conducted due to its advantages in determining the exact level of pollutants in indoor environment. Thus, it can examine the current situation of IAQ in different times. Field measurements can be achieved in different ways with different tools depend on the aim of the study. Most of IAQ studies use specific tools to measure different types of pollutants. These tools can measure the concentration level for different period of time. Types of pollutants will differs from housing to another depend on the materials that used, HVAC system efficiency, occupants' activities, etc.

There are several factors can affect the results of the measurement, all these factors should be determined. The location of each housing should be studied well and analyzed. Surrounding area is highly affect the pollutants' types and concentrations especially when it's industrial area. Outdoor pollutants can emit easily through the ventilation system or cracks in the wall. The location of the housing with respect to the main street should be determined. Outdoor climate have a significant impact on the measurements especially in Dubai in dusty and high humidity days. Thus, Wind direction should be specified because it may influence the indoor particles concentration. Thus, the location of the windows and doors inside the housing should be studied. Occupants' activity (smoking, cooking, cleaning, etc.) during the field measurements can affect the results.

The type of pollutants that will be taken in these housing should be identified in order to select the suitable tools for taking the measurements. The tools will be provided by the university. The available tools in the university are:

- Formaldehyde data logger, model no. ADL-51-1185-E-3101: it's a movable data logger for ozone range between 0 to 10 ppm. It has a large storage and electrochemical sensor technology.
- VOC probe 984 for low VOC concentrations (ppb) and temperature: this instrument is used for determining the IAQ and investigating the source of different pollutants. It can measure the temperature and VOCs level in ppb. It has a range from -10 to 60°C for the temperature, while it range from 10 to 20000 ppb for the VOCs level. TSI VOC probes are pre-calibrated for different reasons; meters Models 7575 Q-Trak monitor and 9565 VelociCalc meter.

- TSI 982 indoor air quality for CO, CO₂, temperature and humidity: it has different range for each of them. It range from 0 to 500 ppm for CO, 0 to 5000 ppm for CO₂, 5 to 95% for the relative humidity and -10 to 60° C for the temperature.
- IQ-610 probe and PCC_10 security case with IQ-610 probe: this instrument can measure six types of parameters which are; relative humidity, temperature, TVOCs, CO₂ and CO. it's very easy to use and to move from one place to another. It has a probe to measure the air velocity. Data logging can be done by screen shot or could be automatic. It has the ability to store data, photos, videos and notes. It provide the results with graphical or tubular format. The user can record the data and download it anytime for reporting by WolfSense® PC software. It has some accessories such as; hard-shell security case that protect the instrument during the long measurement and mobility, camera and more devices that can be used for further measurements (GrayWolf, 2014).
- TSI VelociCalc Model 9565X: it's used for measuring the ventilation rate and other measurements related to the ventilation. This instrument also can be used for HVAC testing and balancing and air flow examination. It can be easily carried by hand, ergonomic and easy to move from one place to another. The front screen can be locked in order to avoid any tampering by mistake. This tool cannot differentiate between different pressures because it doesn't have pressure sensors and plug-in probes. But, it has vane rotating probe and sensors for VOCs and CO₂. Thus, it has straight probe 960 for air velocity and temperature. It can display the data in graphical format and it has different data logging format. It can show maximum five different measurements at the same time.
- TSI Optical Particle Sizer Model 3330: it can be used for outdoor and indoor measurements, filter testing, workplace measurements, emission monitoring and industrial measurements. In indoor environment it used to measure the pollutants concentration and size. Its low price tool, easy to move, light unit and have a broad range of concentration reach up to 3000 particles/cm³. It has 3-10 microns size range. The temperature and pressure have been identified for each sample. It can produce a very accurate and fast

results. Different parameters can be displayed and controlled on a touch screen. It has a front panel that easily showed the Sampling time, alarm set point, real-time count and data displayed as a graph or tabular format. It has a big memory that can record the concentration of different pollutants in specific time. Thus, the way of downloading these data and records is very easy (TSI Incorporated, 2012).

Relative humidity and temperature are very essential parameters to be measured. Humidity in indoor environment can cause a lot of problems in terms of bacterial and fungi growth. Thus, it has several health issues for the occupants especially for the respiratory system. As mentioned above, carbon monoxide, carbon dioxide and ozone are considered from the most pollutants that have negative impact on occupants' health in indoor environment. Thus, TVOCs that emit from different sources in indoor environment have a significant impact on IAQ and residents' health. For that reason, the parameters that will be measured in this study for all the housing are relative humidity, temperature, carbon monoxide, carbon dioxide and ozone level. The most suitable tool and will be used is IQ-610 probe for taking these measurements.

Three labor housing will be taken with different income and quality in Dubai. Beside the quality of the housing, the selection will be according to the validity to access these housing. The first housing will have low quality of indoor air, bad areas arrangement, low efficiency of HVAC system, etc. and the second one will have medium level. The last one will be chosen from the housing that are newly built and have new regulation for the HVAC system, areas arrangement, construction materials, pollutants concentration, etc. This will be done in order to differentiate between the IAQ in these three types of housing and compare the occupants' health and their satisfaction level.

The same measurements will be taken in two high quality houses in Mirdif/Dubai. The selection of these houses will be according to their quality and validity to access them. This will be achieved in order to compare the quality of the air in these houses with the labor housing. From the comparison that will be conducted between the three labor camps, one of them (the highest quality) will be chosen for the comparison with Mirdif houses. This comparison will illustrate if the labor housing could reach the same level of normal houses. These houses will be taken as a benchmark for good IAQ because they are located in good area in Dubai, considered from the high cost

housing and the occupants were satisfied in their living. So, by using Mirdif houses as a benchmark for high quality of indoor air, number of improvements for labor housing will be suggested.

The measurements will be taken in different areas in the housing where the occupants spend most of their time in it. Probably, the areas will be the bedrooms, kitchen, dining hall and corridor. The measurements will be attained three times in each area in the same day. From these measurements, the concentration of each pollutant in each area will be identified. Thus, the sources of these pollutants could be defined.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1. Introduction:

This chapter will illustrate the results of the labor housing and Mirdif houses visits. Thus, it will show the results of the field measurement and the questionnaire survey that had been conducted for the three labor camps (Dulsco camp, Beta industrial camp and TransGulf cement production camp). For the field measurements, the average concentration for each pollutant (TVOCs, CO₂, CO, O₃), temperature and humidity in the three camps will be illustrated. Comparison between these average concentrations will be conducted in order to investigate the level of IAQ, temperature and humidity in each camp. Then, compare the best labor camp with Mirdif houses will be achieved. Moreover, the impact on labors' health will be shown through the questionnaire survey. Questionnaire survey will also give an indication for the occupants' satisfaction level in their camps. By using Mirdif houses as a benchmark for good IAQ, issues and suggested improvements will be stated.

4.2. Labor's housing site visit results:

According to the criteria that mentioned above in chapter 3 (pg. 49), the three housing that have been selected are:

4.2.1. Dulsco village camp

Dulsco camp has low indoor quality compared with the other camps, located in Al Qouz Industrial area no. 4 in Dubai. It has been built since 2007 and has area of 101,266 sq ft. It has 9 blocks, each block has ground floor and two stories. Each of them has around 46 rooms so, the total number of the rooms are 412. Each room has one toilet with shower and each 18 rooms have one kitchen and one dining hall. Split A/C was used in this camp. Around 55 occupants were chosen to answer the questionnaire survey. 53% of them has age between 31 and 40, 26% above 40 and 21% between 20 and 30.

Figure 4.1 shows the exact location of Dulsco camp in Dubai. Figures 4.2-4.4 shows the building outside view.

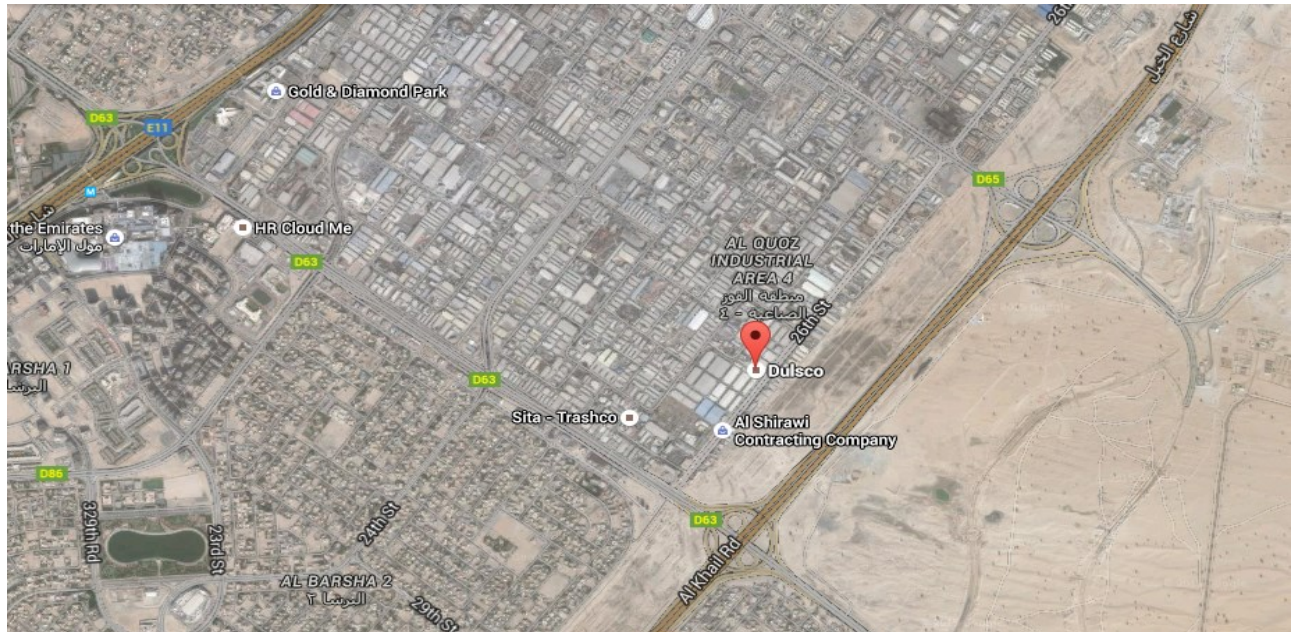


Figure 4.1. Dulsco camp location map



Figure 4.2. Dulsco camp outside view 1



Figure 4.3. DulSCO camp outside view 2



Figure 4.4. DulSCO camp outside view 3

Figure 4.5 shows the measurement tools in the labor's room. It seems that their rooms full of stuffs above the cabinet and on their beds. Each room can accommodate 10 occupants. Ceramic tiles and white paint are used. Figure 4.6 shows the dining hall where the occupants eat their food in this area. Ceramic tiles, white paint, regular ceiling tiles and white fluorescent light are used.



Figure 4.5. Bedroom area in Dulsco camp



Figure 4.6. Dining hall area in Dulsco camp

Figure 4.7 shows the measurement tools in the kitchen area. From the picture, it seems that the area has some dirt which affects the cleanness of the food. Corridor area is shown in Fig. 4.8, open ceiling and ceramic tiles for the flooring and walls are used.

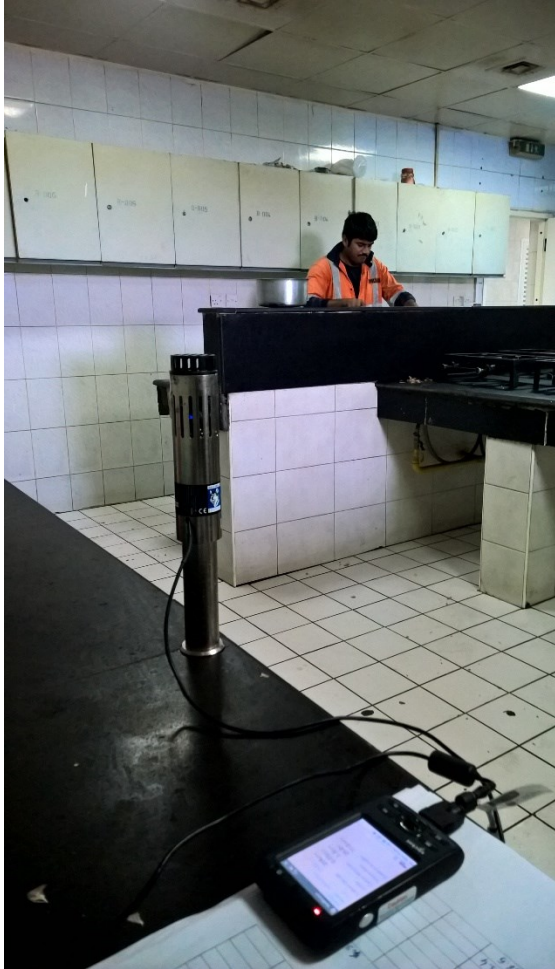


Figure 4.7. Kitchen area in Dulsco camp

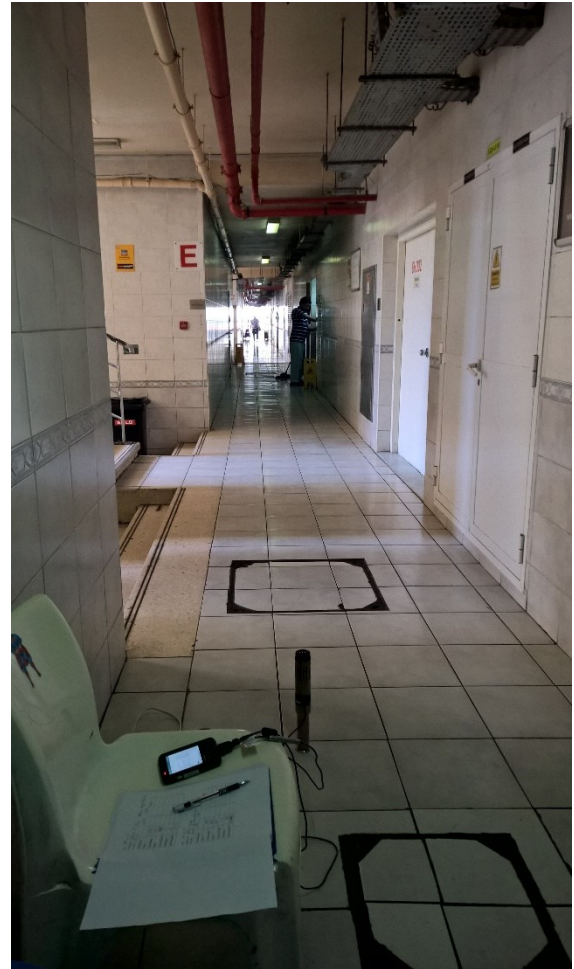


Figure 4.8. Corridor area in Dulsco camp

4.2.2. Beta industrial camp

Beta camp has medium level of indoor quality, located in Jebel Ali industrial area #1 in Dubai. It has been built since 2008 and has area of 51383.46 square feet. It has ground floor and three stories, each story has 29 rooms, 22 bathrooms and 22 showers. Ground floor has 7 rooms, 7 bathrooms and 7 showers. Big kitchen and wide dining hall are exist in the ground floor. This camp is using window A/C which allow the air exchange between outdoor and indoor. Around 46 occupants

were answer the questionnaire survey in this camp. 46% of them has age between 31 and 40 while, 43% between 20 and 30.

Figures 4.9 and 4.10 shows the outside view of this camp. Dulsco camp has better architectural design than Beta camp but, this doesn't indicate that the indoor environment will be better.



Figure 4.9. Beta camp outside view 1



Figure 4.10. Beta camp outside view 2

Figure 4.11 shows the measurements tools in the room located at the middle of the room on the ground. Each room can accommodate 8 persons. White paint and ceramic tiles are used in the rooms. Figure 4.12 shows the dining hall, it seems that it's wide area and should has more tables. Ceramic tiles are used on the walls and floor. Fridges are available for the occupants to store their foods.



Figure 4.11. Bedroom in Beta camp



Figure 4.12. Dining hall in Beta camp

Figure 4.13 shows the corridor between the rooms and Fig. 4.14 shows the kitchen area. Kitchen seems very dirty and some pipes are not covered so, any leak will affect the occupants directly. Ceramic tiles for the flooring and walls are used.

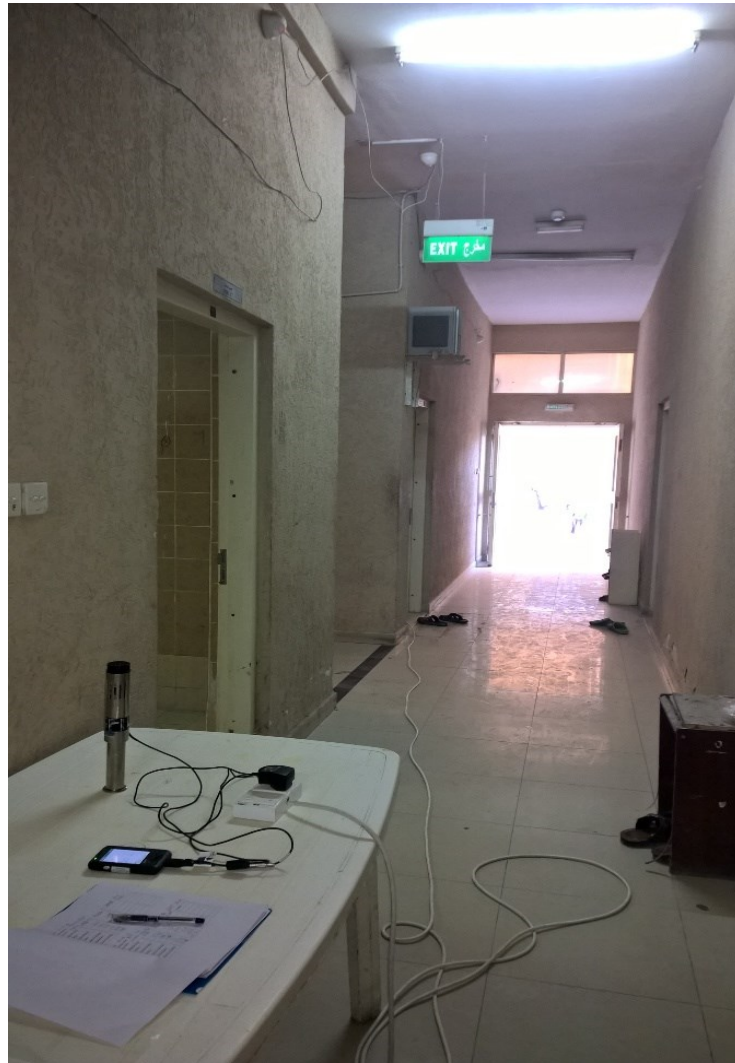


Figure 4.13. Corridor in Beta camp



Figure 4.14. Kitchen in Beta camp

4.2.3. TransGulf cement production camp

TransGulf camp has high indoor quality compared with the others, located in Dubai Investment Park (DIP). It has been built since 2010 and has ground floor with three stories. The total number of the room are 83. Ground floor has 17 bathrooms with showers and 14 in the other stories. The total number of persons in this camp are 412. Central A/C is used in this camp. Around 38 occupants were answered the survey. 67% of them has age between 20 and 30, 22% between 31 and 40 and 9% are under 20.

Figure 4.15 shows the outside view of TransGulf camp. There are some plants around their camp which can decrease the amount of the pollutants outdoor and indoor.



Figure 4.15. TransGulf camp outside view

Figure 4.16 shows the measurements tools in the room. It can accommodate 6 persons. It's obvious from the picture that the occupants can prepare some drinks in their room. Figure 4.17 shows the corridor between the rooms. False ceiling, white fluorescent light, colored ceramic tiles and white paint are used.

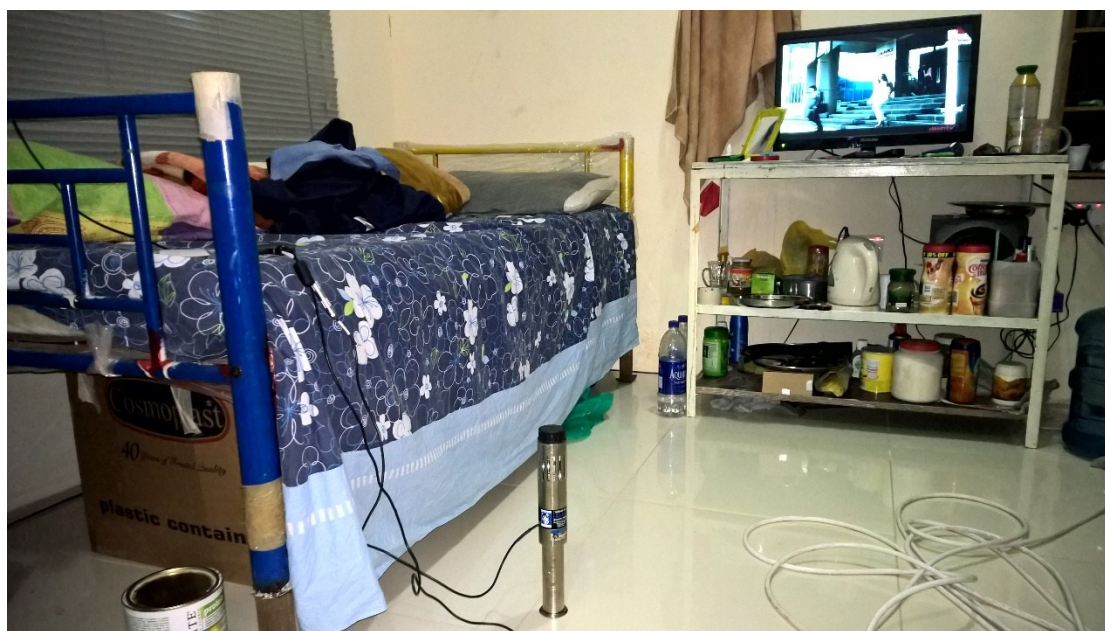


Figure 4.16. Bedroom in TransGulf camp



Figure 4.17. Corridor in TransGulf camp

Figure 4.18 shows the kitchen and the dining hall. It's obvious that this area is cleaner than the kitchen and dining hall in Dulsco and Beta camp. Ceiling, walls and flooring have a good and clean finishing.

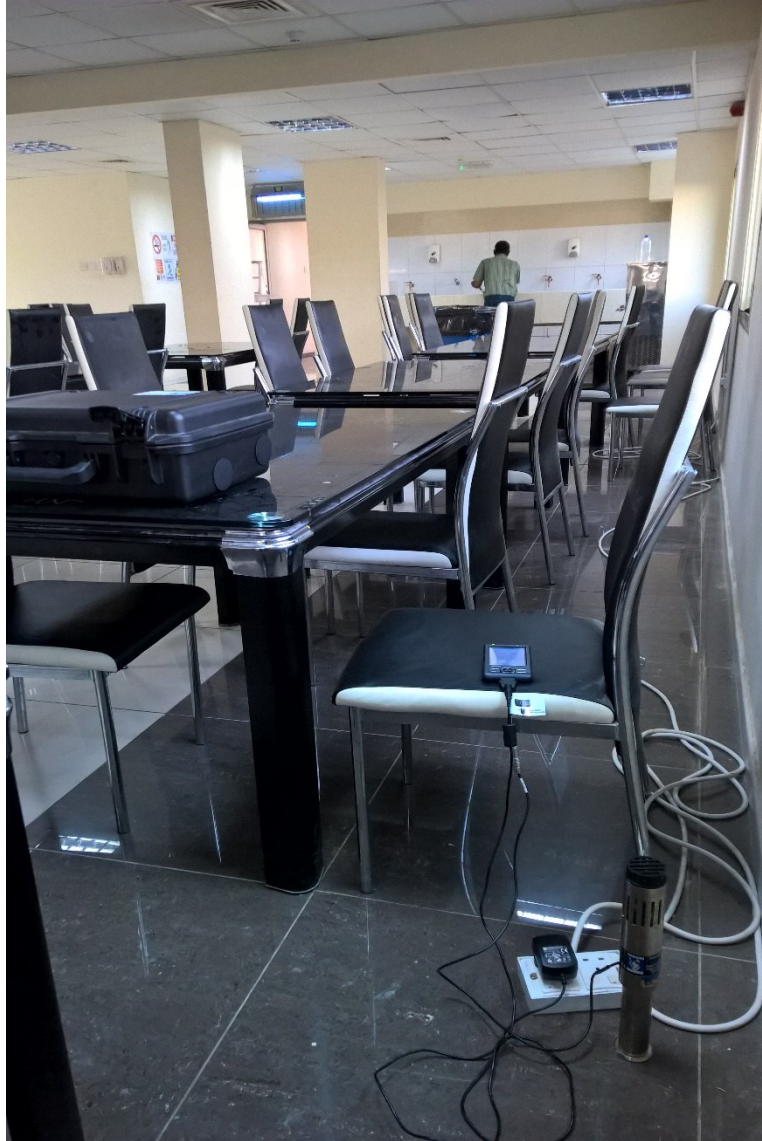


Figure 4.18. Kitchen and dining hall in TransGulf camp

After conducting the required measurements and the questionnaire survey for all housing, the impact of different factors on IAQ for each housing will be studied. The concentration of the above mentioned pollutants and their sources will be revealed. Then, the impact of IAQ on occupants' health and satisfaction level will be identified. After that, comparing between the average concentration of different pollutants, temperature and humidity in different levels of labor housing will be conducted. Thus, suggested improvements to make these housing in better conditions will be provided.

4.3. Mirdif houses site visit results:

This part will show the information of the houses that have been selected in Mirdif to be used as a benchmark for good IAQ as mentioned above in chapter 3 (pg. 49 & 50). These houses are:

4.3.1. Mirdif house 1:

Mirdif house 1 has been built since 2010. It has two stories that include three bedrooms and one of them is master, kitchen, living room, store and saloon. Total number of persons are 5. Central A/C is used in this house. Four persons were answered the survey. Two of them have age above 40 and the rest have age below 18. Figure 4.19 shows the outside view of Mirdif house 1 which has attached garage.



Figure 4.19. Mirdif house 1 outside view

Figure 4.20 the bedroom area. It can accommodate 2 persons. Occupants use this room only for sleeping and studying. Figure 4.21 shows the corridor area between the rooms. Marble and ceramic tile flooring, gypsum board ceiling and white paint were used.



Figure 4.20. Bedroom area in Mirdif house 1

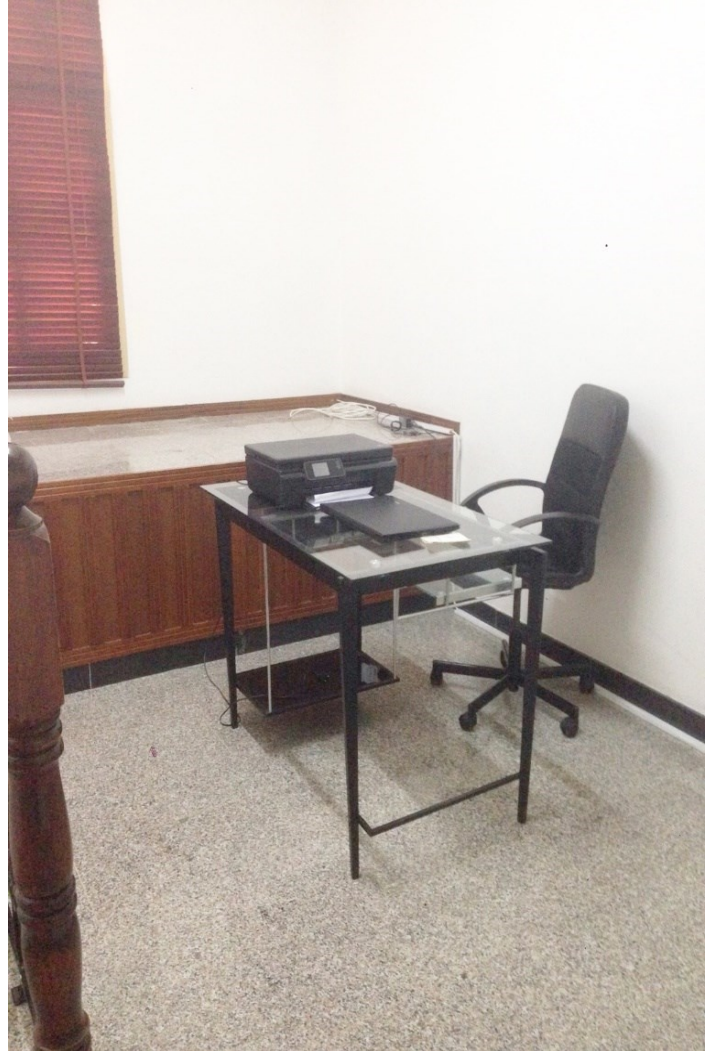


Figure 4.21. Corridor area in Mirdif house 1

Figure 4.22 shows the kitchen and figure 4.23 shows the dining area. Ceramic tiles for the walls and flooring are used in the kitchen. Marble flooring and white paint are used in the dining area.



Figure 4.22. Kitchen area in Mirdif house 1

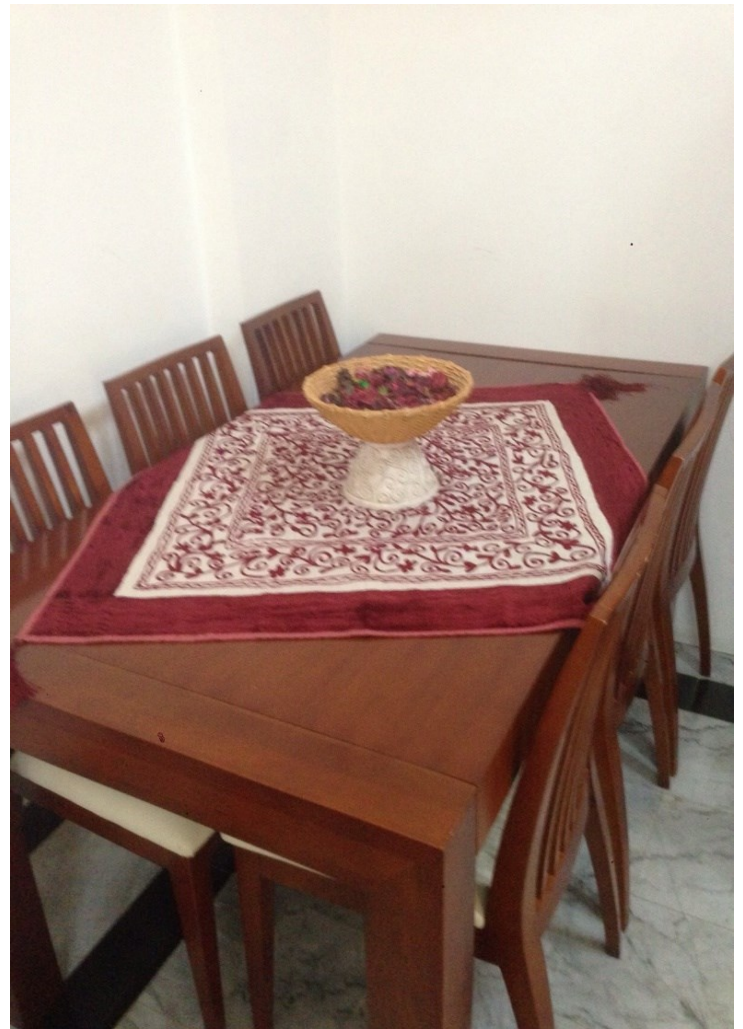


Figure 4.23. Dining area in Mirdif house 1

4.3.2. Mirdif house 2:

Mirdif house 1 has been built since 2005. It has two stories that include four master bedrooms, kitchen, dining area, living room, store and saloon. Total number of persons are 6. Central A/C is used in this house. All occupants were answered the survey. Two of them have age above 40 and the rest have age between 20 and 30.

Figure 4.24 shows the outside view of Mirdif house 2. There are plants in the outside area of tas shown in fig. 4.25-4.27 which can decrease the amount of the pollutants outdoor and indoor.



Figure 4.24. Mirdif house 2 outside view

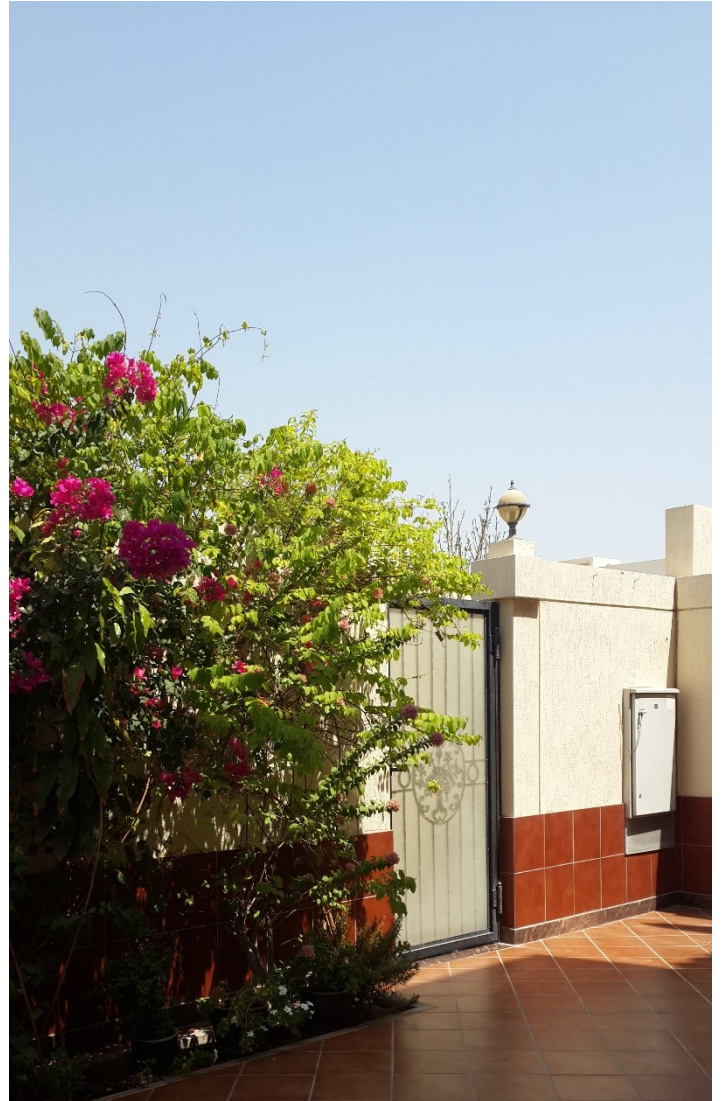


Figure 4.25. Plants surrounded Mirdif house 2



Figure 4.26. Plants surrounded Mirdif house 2



Figure 4.27. Plants surrounded Mirdif house 2

Figure 4.28 the bedroom area. It can accommodate 2 persons. Similar to house 1, occupants use this room only for sleeping and studying. Figure 4.29 shows the corridor area between the rooms. Marble and ceramic tile flooring, gypsum board ceiling and colored paint were used.



Figure 4.28. Bedroom area in Mirdif house 2



Figure 4.29. Corridor area in Mirdif house 2

Figure 4.30 shows the kitchen and figure 4.31 shows the dining hall which are attached to each other. Ceramic tiles for the walls and flooring are used in this two areas.



Figure 4.30. Kitchen area in Mirdif house 2



Figure 4.31. Dining area in Mirdif house 2

4.4. Field measurement results and discussions:

As stated above, field measurement have been conducted in four areas (room, kitchen, dining hall and corridor) for each camp. The measurements were taken three times in the same day for each area in each camp (see appendix B-D). Average concentration for each parameter in each area for the three camps will be summarized in one graph to be compared and analyzed. The camp that have the best conditions will be compared with the high quality houses that located in Mirdif. In order to investigate that it has the same conditions of these houses or lower. The results of the field measurement will be justified with the collected data on the questionnaire survey. By taking Mirdif houses as a benchmark for good IAQ and from the results that will be stated, number of suggestions will be provided to be attained in the labor camps.

4.4.1. Comparison of TVOCs concentration between labor camps:

From the literature review that had been achieved, it was concluded that TVOCs mainly can emit from interior materials, finishes and furniture. This can include; carpets, ceramic tiles, paints, adhesive, vinyl, wood and other materials. Cleaning products and air purifiers can also have an impact. It affected by the indoor environment conditions rather than outdoor environment (EPA, 2014). As stated by DM (2015), that indoor concentration of TVOCs should be less than 300 microgram/m³ (approximately 243 ppb). Figure 4.32 shows the average concentration level of TVOCs in the four areas in the three camps. Obviously, Dulsco camp have the higher average concentration in the four areas. The lower concentration was recorded in TransGulf cement production camp. Beta industrial camp had average concentration that falls between Dulsco and TransGulf cement production camp. There are big difference in the readings between Dulsco and other camps for all areas e.g. the kitchen in Dulsco camp had average concentration of 1424 ppb while, in Beta industrial camp and TransGulf cement production camp was 820 ppb and 473.6 ppb respectively. The gap between the readings in Beta industrial camp and TransGulf camp was lower especially in the corridor, room and dining hall.

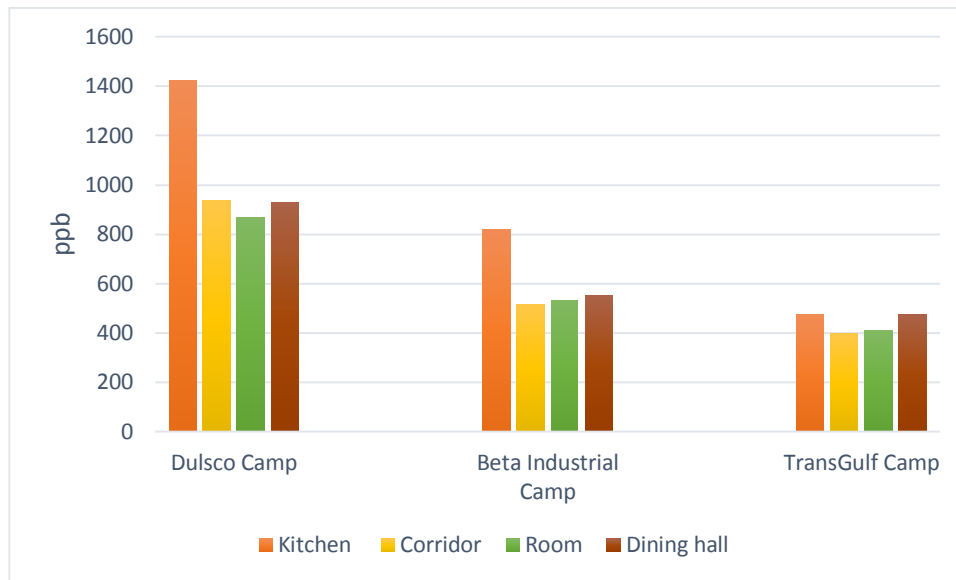


Figure 4.32. TVOCs average concentration in ppb

Several factors in Dulsco camp can accelerate the emission of TVOCs in their indoor environment. Materials that were used in this camp for the furniture, ceiling and walls (ceiling tiles, fabric, adhesive for flooring tiles and paint) can develop mildew growth. This was proved through the questionnaire survey; 40% of the occupants that were asked suffer from the mildew on their furniture. Thus, a lot of stuff were stored above their cabinet such as; bed covers and cartoons which can emit these pollutants. Moreover, around 55% of the occupants use cleaning products continuously for their room and 40% use air purifiers. Open ceiling was used for the corridor, so all the occupants was exposed for the pipes that should be covered. So, any leak from these pipes or mildew will affect directly the occupants. This camp use split A/C which is only circulate the air in the indoor environment without exchange it with the outdoor air. This could be one of the reasons that lead to increase the pollutants level in this camp. Offensive odors was found in this camp.

Beta industrial camp has lower average concentration than Dulsco camp which could indicate that the conditions in this camp is better than Dulsco but not necessary. Occupants in this camp suffer from the mildew on the ceiling and walls rather than furniture. So, the materials that were used for the furniture could be better than Dulsco camp because it's not accelerating the growth of mildew. Window air conditioner is used for this camp which could be the reason behind the lower concentration of TVOCs even if the materials that used in the camp emit these pollutants. Because

the window type works to exchange the air between indoor and outdoor. Thus, around 71% of the occupants that were asked, ventilating their room by opening the window consciously, which also can decrease the amount of TVOCs in their rooms. The occupants in this camp use the cleaning products and air purifier but not regularly like DulSCO camp.

TransGulf cement production camp have the least average concentration of TVOCs. The occupants in this camp didn't suffer from any problems related to the mildew on furniture, ceiling and walls. The materials that were used in this camp are newer than the others and could be better quality in order to prevent any mildew growth. Approximately all the occupants that were asked used the cleaning product and 30% of them use air purifier. This camp is used central A/C which have more efficient ventilation than the others. So, using the cleaning product will have less impact than using it in DulSCO camp. Moreover, more than the half of the occupants that were asked ventilating their room continuously. So, the low concentration of TVOCs in this camp mainly refer to the proper ventilation.

From the results above, it was obvious that all the areas in all camps exceeded the required level of TVOCs by DM (2015) especially the areas in DulSCO camp and the kitchen area in Beta industrial camp. It was proofed that the amount of TVOCs in indoor environment was related to the interior materials that used. This was ensured by several studies such as; EPA (2014), Niu & Burnett (2001), Dales et al. (2008), Kim & Paulos (2009) and Lee et al. (2012). Cleaning products and air purifiers recorded a relation with the increase of TVOCs, similar to a study conducted by Solal et al. (2008). Ventilation in the indoor environment is very essential and can reduce the amount of pollutants even if there is some factors emit them. This was obvious in Beta industrial camp, when they have mold on their ceiling and wall but because they have proper ventilation, the amount of TVOCs was decreased. While, in DulSCO camp the ventilation was not sufficient, so the amount of TVOCs was increased. Platts-Mills et al. (1996), BRANZ Ltd (2007) and Woloszyn et al. (2009) ensured that the concentration of pollutants affected by the ventilation rate and Grimsrud et al. (2009) stated that TVOCs require high amount of ventilation to be eliminated. Bernstein et al. (2008) mentined that TVOCs can cause offensive odors in the indoor environment and this was noticed in DulSCO camp that have the higher average TVOCs.

4.4.2. Comparison of CO₂ concentration between labor camps:

CO₂ concentration can indicate for the efficiency of the ventilation rate in indoor environment, so inadequate ventilation will lead to increase the amount of CO₂ (MDH, n.d.). CO₂ concentration is also affected by the period of human presence in specific area and their odors (Woloszyn et al., 2009). Thus, it can be influenced by the number of the occupants in the space. Smoking is another factor that increase the CO₂ concentration. Outdoor concentration have an impact on indoor concentration of CO₂. DM (2015) have been reported that the concentration of CO₂ in indoor environment shouldn't exceed 1440 microgram/m³ (800 ppm as mentioned by DM). Figure 4.33 shows the average concentration level of CO₂ in the four areas in the three camps. It illustrate that Dulsco camp have the higher average concentration in the four areas. Corridor and dining hall in Beta industrial camp have average concentration lower than TransGulf camp. Kitchen in Beta industrial camp and TransGulf camp almost has the same level of CO₂ which is 328.7 ppm and 328 ppm respectively. While, in Dulsco it has average concentration little bit higher which is 354 ppm. Corridors in Dulsco camp and Beta industrial have average concentration of 215.7 ppm and 211.3 ppm respectively. While, TransGulf camp have higher concentration of 265.7 ppm. The rooms in TransGulf camp has the least average concentration (452.3 ppm). Rooms in Dulsco camp has average concentration of 1283.7 ppm which considered very high level. There is big difference in the rooms' readings between Dulsco camp and other camps.

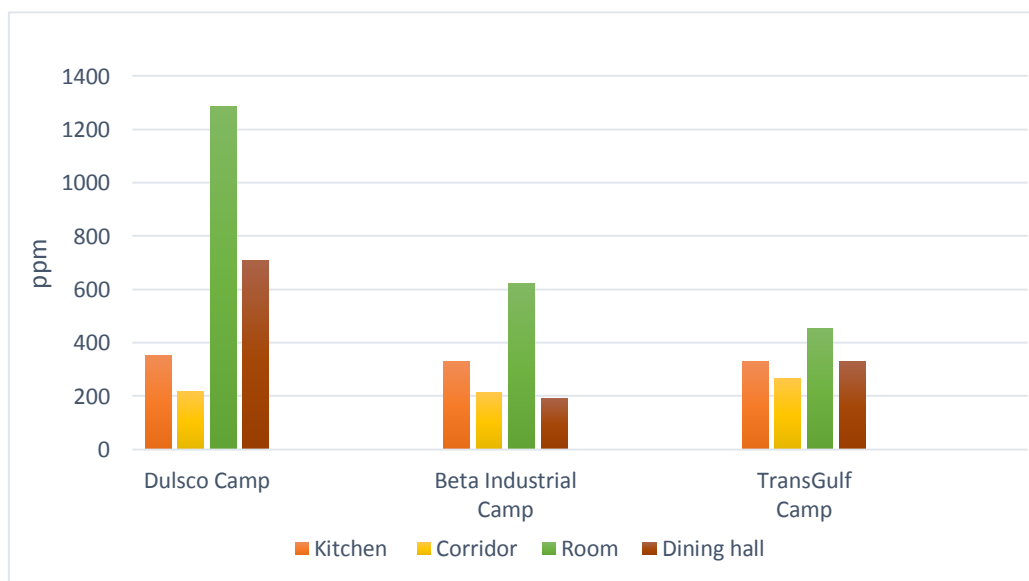


Figure 4.33. CO₂ average concentration in ppm

As mentioned above, Dulsco camp has the higher average concentration in all areas. The area of each room is approximately 32.4 meter square and can accommodate 10 persons. So, the meter square for each person in the room is 3.24. Around 44% of the occupants that were asked spend more than 12 hours out of their housing and 22% spend between 7 and 9 hours. Most of the occupants in this camp are smoking in their housing which affect the indoor air and the other occupants' health. Improper ventilation were recorded in this camp because of the A/C type and most of the occupants didn't ventilate their rooms naturally. Thus, some of the occupants didn't have window in their rooms which strongly affect the CO₂ concentration in indoor air. The most areas that have improper ventilation which is stated by the occupants are dining hall and the rooms which is obviously shown in Fig. 4.33. Around 67% of the occupants that were asked ensured that there is no proper maintenance for their housing which is strongly required.

Beta industrial camp have average concentration of CO₂ lower than Dulsco camp. Dining hall and corridor have average concentration lower than TransGulf camp. The areas for each room in this camp is approximately 32.2 meter square and the number of occupants are 8. So, each occupant have around 4 meter square. Most of the occupants that were asked spend more than 12 hours out of their housing. Most of them are smoking and 48% of them have smoking persons in their rooms. Some occupants suffer from the improper ventilation but less than Dulsco camp. Because this camp have the window type of A/C so, the ventilation will be better than the split type. Most of the occupants that were asked are ventilating their room naturally. Thus, around 61% of them ensured in the survey that they have proper maintenance for their camp.

There is no big differences in the readings between the areas in TransGulf cement production camp. The area of each room in this camp is approximately 24.61 meter square and the number of occupants are 6. So, the square meter for each person is 4.1. Around 84% of the occupants spend 7 to 9 hours out of their housing. Most of the occupants that were asked are not smoking. This camp use central A/C which mean that it has proper ventilation for the camp and this was ensured by the occupants. Thus, the occupants ventilate their rooms regularly which help in maintain the fresh air in their indoor environment. In the survey, the occupants ensured that they have regular maintenance for their housing.

TSI incorporated (2013) stated that American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHREA) standards 62 recommended that the level of CO₂ in the indoor

environment shouldn't exceed 700 ppm. Thus, Dubai municipality (2015) recommended 800 ppm which is higher than ASHREA. Almost all the areas in all camps have below 700 ppm except the rooms in Dulsco camp which have 1283.7 ppm. This high average concentration is due to the improper ventilation, number of occupants in the room and smoking habit. From the results above, it ensured that the CO₂ level was highly influenced by the number of occupants in specific area. This obviously was shown in Dulsco camp and Beta industrial camp where they have almost the same room area but, Dulsco camp have higher number of occupants and therefore, higher average concentration of CO₂. This was ensured by Woloszyn et al. (2009) and MDH (n.d.) which stated that human odors and respiration affect the CO₂ level. No clear relation was noticed between the spending hours in the camp with the CO₂ concentration. Natural ventilation is very important to decrease the amount of CO₂ which was obvious in Beta industrial camp and TransGulf camp. Wong & Huang (2004) attained a study which ensured the importance of natural ventilation in degrading the CO₂ level in indoor environment. Ventilation by the air conditioner in the camp recorded a relation with the CO₂ concentration. It seems that window type is better than the split unit in ventilating the space and surely the central A/C is the best. The relation between the smoking habit and CO₂ concentration was noticed in this study. According to Lee et al. (2002) that achieved a study on IAQ in residential building, smoking and inadequate ventilation are the main reasons behind the CO₂ concentration in indoor environment. Proper maintenance for the camp and especially for the A/C could have an impact on CO₂ concentration.

4.4.3. Comparison of ozone concentration between labor camps:

Ozone can emit from different sources in indoor environment. Interior materials, air purifiers and cleaning product could influence the ozone concentration. Thus, ventilation rate mechanical or natural can affect its concentration. Outdoor concentration strongly influence the indoor concentration especially in the industrial area (Weschler, 2000). Ozone concentration in indoor environment as described by DM (2015) shouldn't exceed 120 microgram/m³ (0.06 ppm as mentioned by DM). Figure 4.34 shows the average concentration level of ozone in the four areas in the three camps. It illustrate that Dulsco camp have the lower average concentration in all areas except the corridor. The three areas in this camp (kitchen, room and dining hall) have the same average concentration which is 0.043 ppm. Corridor has lower average concentration in TransGulf camp (0.057 ppm) and higher average concentration in Beta industrial camp (0.067 ppm). Kitchen

in Beta industrial camp and TransGulf camp has the same average concentration of 0.06 ppm. All other areas in Beta camp have higher concentration than TransGulf camp, for example; room in Beta camp has average concentration of 0.06 ppm while in TranGulf camp 0.047 ppm.



Figure 4.34. O3 average concentration in ppm

DulSCO camp use the split type of A/C, for that reason, ozone from outdoor environment can't emit the indoor environment to pollute the indoor air. In other words, ventilation in this camp is not proper, even the occupants didn't open their windows to ventilate their rooms. This will decrease the amount of indoor ozone. The occupants in this camp could use some cleaning products and air purifiers but less than TransGulf camp. All the pipes and the ducts in the corridor are exposed to the occupants, this could be the reason for the high concentration of ozone in this area.

Beta industrial camp have two areas that have high concentration of ozone which are corridor and dining hall. This camp use window A/C which emit pollutants from outside and one of them could be ozone. This was obvious in the survey, when 67% of the occupants that were asked ensured that they feel that their A/C emit pollutants from outdoor environment. Around 71% of the occupants are open their windows to ventilate their rooms. Moreover, 40% of the occupants ensured that there is no proper maintenance for their A/C which increase the potential of indoor pollution with ozone. Number of occupants that used cleaning products and air purifiers are relatively small when compared with TransGulf camp.

TransGulf camp use the central A/C which also can emit several pollutants to the indoor environment. The occupant that were asked in this camp are satisfied with their A/C and none of them complained that their A/C emit pollutants. Most of the occupants in this camp are ventilating their rooms naturally in regular way. Thus, they ensured that they have proper maintenance for their camp. Most of them are using cleaning products and air purifiers.

Several organizations have been established limits for ozone concentration in indoor environment. Each organization have different standards than the others, for example; in World Health Organization, ozone concentration shouldn't exceed 0.064 ppm in 8-hours monitoring while, in Canadian standards, it shouldn't exceed 0.12 ppm in 1-hour monitoring (ASHREA Standards 62.1, 2007). As mentioned above that DM (2015) set standard limit for ozone concentration to not exceed 0.06 ppm in 8 hours monitoring. Approximately, all the areas in all camp have the standard limit or below except two areas in Beta camp which are; the dining hall and corridor. It was obvious from the results above that the main reason behind the presence of ozone in indoor environment was the type of A/C used. Outdoor ozone concentration was responsible for indoor ozone because it can emit the indoor environment through ventilation. This was ensured by number of researchers and studies such as; Weschler (2000), Bernstein et al. (2008), Britigan et al. (2006) and Health Canada (2010). In Weschler (2000) study, it was noticed that there is positive relationship between the outdoor ozone concentration and indoor concentration. Air purifiers and cleaning products have recorded relation with the ozone concentration as stated by Health Canada (2010). This was clear in TransGulf camp where most of the occupants use them regularly. Occupants in Dulsco camp use them more than Beta camp but because of A/C type, ozone concentration in Dulsco camp was lower.

4.4.4. Comparison of temperature level between labor camps:

Temperature level in indoor environment strongly influenced by the HVAC system efficiency and the outdoor air temperature. Outdoor temperature can have high impact when natural ventilation is occur (open the window) as found in study conducted by Andersen et al. (2009). The recommended level of temperature in indoor environment by ASHREA Standards 55 (2004) is in the range of 22.8 to 26.1 °C in summer and 20.0 to 23.6 °C in winter. While, Dubai Municipality set the limit to be between 22.5 °C and 25.5 °C. Figure 4.35 shows the average temperature level in the four areas in the three camps. It illustrate that TransGulf camp have the lowest average

temperature in all areas except the dining hall which has average temperature of 25.4 °C. The lowest average temperature for the dining hall was recorded in Dulsco camp (24 °C). Kitchen and room in Dulsco camp have average temperature of 26.6 °C and 24.2 °C respectively. While, in beta camp the average temperature for the same areas was higher which is 27.8 °C and 25.2 °C respectively. Corridor in Dulsco camp have the higher average concentration in all camps which is 27.6 °C.

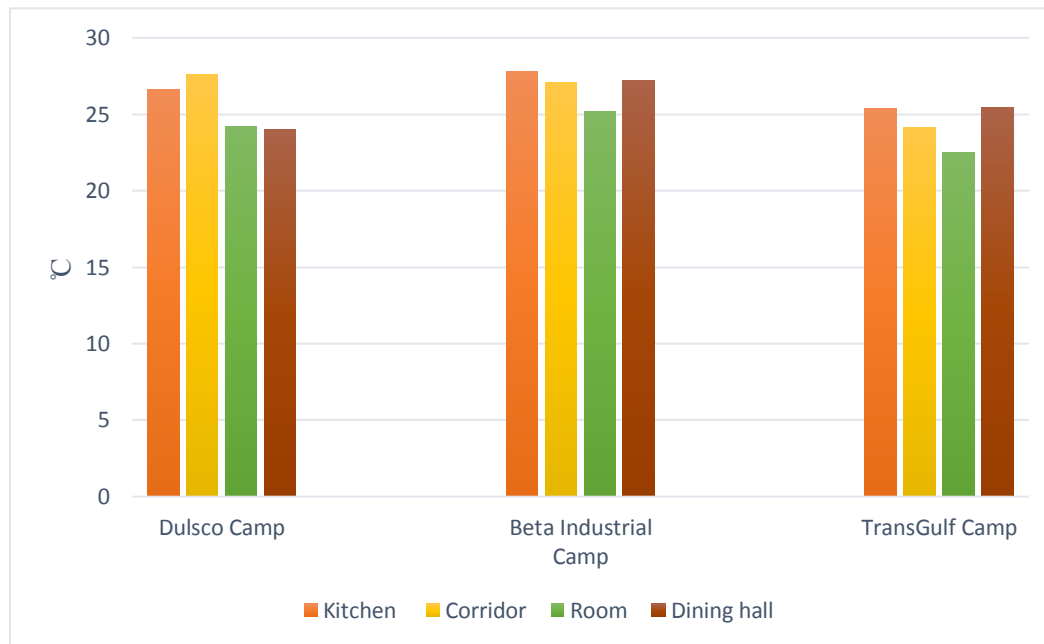


Figure 4.35. Average temperature in °C

Dulsco camp have two areas which have average temperature considered relatively high compared with the TransGulf camp. Occupants that were asked in this camp complain from their A/C because they feel that it's not work properly which was obvious in some areas (kitchen and dining hall). While, around 87% of them ensure that it provide the required temperature in their rooms and this was clear in Fig. 4.35. Split A/C didn't emit pollutants from outside which was ensured by some occupants in the survey. Maintenance for their camp occur occasionally but not regularly which affect the A/C performance. Most of the occupants ensure that winter season is the most comfortable season for them.

Beta industrial camp have high average temperature for all areas except the rooms. Most of the occupants that were asked in this camp suffer from their A/C because it emit pollutants from outside. Thus, around 67% of the occupants ensure that there A/C didn't provide the required level

of temperature. While, they are satisfied with their room temperature which has average temperature of 25.2 °C. Most of the occupants ensure that they have maintenance for their camp which should make their A/C in a better condition than DulSCO camp. Also in this camp, occupants ensure that the most comfortable season is summer and the least is winter.

TransGulf camp have the best conditions in term of indoor temperature. Even if the dining hall in DulSCO has lower average temperature, but in TransGulf camp it considered normal. Occupants in this camp are satisfied with the temperature in their rooms and other areas. They didn't complain about their A/C that it emit pollutants from outside. Thus, they ensured that proper maintenance for their camp is occur regularly which affect their A/C performance. Like the other camps, occupants feel that the most comfortable season is winter.

According to ASHREA Standards 55 (2004) and DM (2015) standards, TransGulf camp achieved the required optimal conditions for the indoor temperature level in all areas. While, DulSCO camp have two areas (kitchen and corridor) that have average temperature above the standards and Beta camp have three areas (kitchen, corridor and dining hall) above the standards. From the results above, it was obvious that temperature was strongly influenced by the A/C type that used in the camp. The best indoor temperature was provided by the central A/C in TransGulf camp and the worst one is the window type in Beta industrial camp. But, it cannot be generalized that the central A/C will provide better indoor conditions than the others. Because it depend on the efficiency, maintenance and other indoor environmental factors. Thus, the results illustrates that the outdoor climate could influence the indoor conditions as similarly proofed in study conducted by Frontczak & Wargocki (2011). Wolkoff & Kjærgaard (2007), Kalamees et al. (2009) and Woloszyn et al. (2009) ensured that temperature could have an impact on the indoor materials emissions. This was noticed when the TVOCs emission in DulSCO camp and Beta industrial camp were higher than TransGulf camp. Maintenance for the A/C is very important to be done regularly. This is in order to maintain its efficiency by providing the required temperature for the occupants and decreased the pollutants concentration as stated by Townsend, 2007. Maintenance was one of the factors that make TransGulf camp have the required level of temperature.

4.4.5. Comparison of CO concentration between labor camps:

Carbon monoxide produced from the incomplete combustion of organic materials. It emit from different indoor sources such as; smoking, gas stoves and boilers. Outdoor sources also could be responsible for the indoor pollution of carbon monoxide such as; attached garage or living beside high traffic street (TSI Incorporated, 2013). Average concentration for CO in homes without gas stoves should be in range of 0.5 to 5 ppm. While, homes with efficient gas stove should be in range of 5 to 15 ppm and with poorly gas stoves, the range will increased to reach 30 ppm or higher (EPA, 2013). National Ambient Air Quality Standards (NAAQS) set limit for CO concentration to be 9 ppm while, WHO standards set limit to be 10 ppm in 8-hours monitoring (ASHRAE Standard 62.1, 2007). DM (2015) set limit for the CO concentration in their indoor environment to not exceed 10 microgram/m³ (approximately 9 ppm as mentioned by DM). Figure 4.36 shows the average CO concentration in the four areas in the three camps. It's obvious that Dulsco camp have the higher average concentration for all areas. While, TransGulf camp have the lowest average concentration for all areas except the dining hall which has average concentration of 0.433 ppm. Dining hall in Beta camp has average concentration of 0.33 ppm which is lower than TransGulf camp. Dulsco camp has very high average concentration of CO in dining hall (7.33 ppm) compared with the others. Kitchen area in Dulsco camp and Beta camp have average concentration near to each other (2 and 1.93 ppm respectively). While, kitchen area in TransGulf camp has average concentration of 0.43 ppm. The lowest area that has CO between all the camps is the room in TransGulf camp which has average concentration of 0.033 ppm. There is gap in the readings between Dulsco camp and other camps.

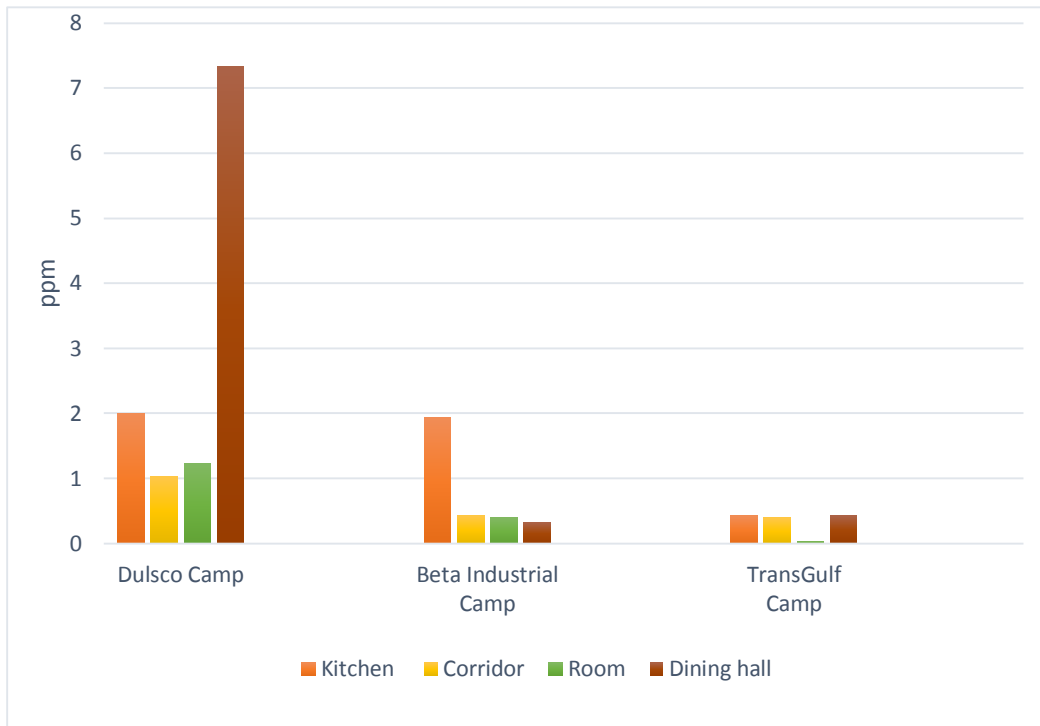


Figure 4.36. CO average concentration in ppm

DulSCO camp has lowest average concentration of CO in the corridor which has 1.03 ppm. Rooms has average concentration of 1.23 ppm which is higher than the corridor but lower than the kitchen and dining hall. This camp has high number of occupants that are smoking which affect the concentration of CO especially in the rooms and dining hall. Around half the occupants didn't ventilate their rooms naturally and their A/C (split) didn't provide fresh air for the indoor environment. Windows in dining hall could face the main street or bus parking area which highly increase the concentration of CO. Gas stove in the kitchen could be the reason behind the CO concentration in it.

Beta industrial camp has small differences in the reading between the corridor, room and dining hall (0.43ppm, 0.4 ppm and 0.33 ppm respectively). While, the kitchen has average concentration of 1.93 ppm which is higher than the other areas. This camp have less number of occupants that are smoking which make the concentration of CO lower than DulSCO camp. Moreover, the ventilation in this camp is better whether it's done naturally or by the A/C.

TransGulf camp has lowest average concentration of CO in the rooms (0.033 ppm). Other areas almost has the same average concentration around 0.4 ppm. This camp have number of occupants that are smoking. But, the ventilation is done efficiently in this camp which assess in make the CO

concentration lower than the other camps. Moreover, the occupants ventilate their rooms regularly which also have an impact on the concentration. In this camp, they could have more efficient gas stove which make the concentration of CO in the kitchen lower than the others.

All the areas in all camps have below the standard limit for WHO, NAAQS, EPA and DM. Only the dining hall in Dulsco camp has noticeable concentration (7.33 ppm) compared with the others. But, still it considered below the standard limit. The indoor sources of CO concentration in these camps could be smoking, gas stove and improper ventilation. Australian Government Department of Environment (2005) ensured that tobacco smoke is one of main factors in increasing the CO concentration in indoor air. Thus, nearby road, main street and bus parking or living in industrial area can influence the concentration of CO in indoor environment. This was stated by AGDE (2005), EPA (2013) and TSI Incorporated (2013).

4.4.6. Comparison of humidity level between labor camps:

Humidity one of the main problems in indoor environment, it accelerate the growth of bacteria and fungi. Humidity in indoor environment can be affected by several factors such as; human activity, presence of plants, interior materials, ventilation rate, air temperature, air speed and the outdoor humidity (Zhang and Yoshino, 2010). Materials emissions in indoor environment can be affected by the humidity level. Thus, mold and dampness can be increased in the areas that have high humidity (WHO Guidelines, 2009). Indoor humidity according to ASHREA Standards 55 (2004) should be in the range of 30% to 65%. DM (2015) have set standard limit for indoor humidity same of ASHREA standards for the lower limit (30%) while the upper limit to not exceed 60%. Figure 4.37 shows the average humidity level in the four areas in the three camps. It illustrated that Dulsco camp has average humidity for the kitchen, corridor and room higher than the others. Dining hall in Beta industrial camp has the higher average concentration (57.57%) while, the lower average concentration was found in Dulsco camp (52.47%). Beta industrial camp has average concentration for the kitchen and corridor of 60.9% and 57.15% respectively which is higher than TransGulf camp which has almost the same average concentration (52.9%) for these two areas. While, the room in TransGulf camp has average concentration of 57.23% which is higher than Dulsco camp that has average concentration of 51.63%. The higher average humidity between all areas in all camps was found in the kitchen area in Dulsco camp (78.17%). Small gap was found in the readings between Dulsco camp and other camps.

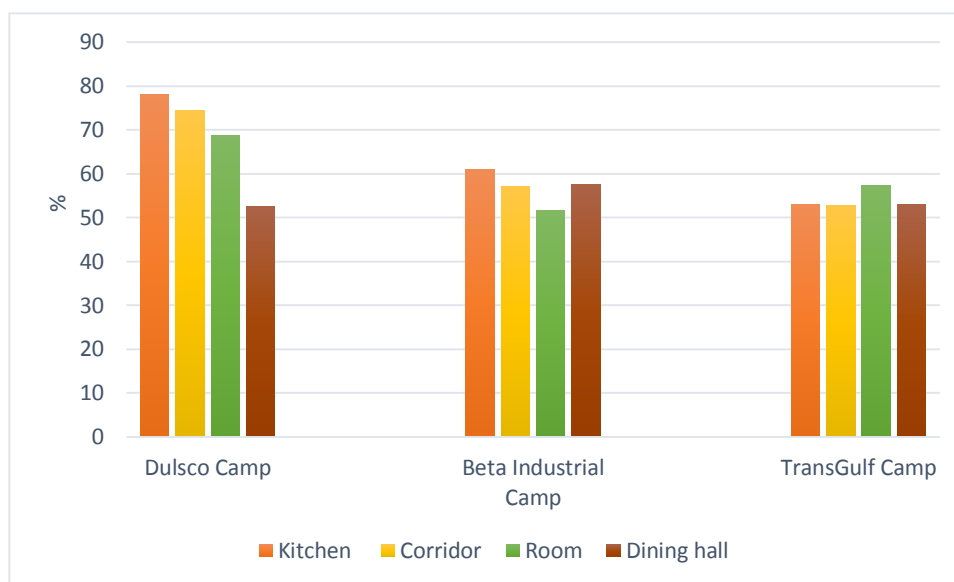


Figure 4.37. Humidity level in percentage

The lowest average humidity in DulSCO camp was found in the dining hall (52.47%) and the highest in the kitchen. Room has average humidity level of 68.6% where most of the occupants spend their time in it. Most of the occupants that were asked in this camp ensure that they have mildew on their furniture rather than in the ceiling or walls. This mainly occur in the kitchen as stated in the survey and obviously shown in Fig. 4.37. The humidity level in their camp is under the optimal conditions in some areas. Moreover, they ensured in the survey that they face problems in leaking pipes from one time to another. As mentioned above, the corridor in this camp has open ceiling where all the pipes is exposed directly for the occupants. So, any pipe leak happen will affect negatively the humidity level and therefore, affect their satisfaction level and their health. This was obvious in the measurement where the humidity level in the corridor was 74.4%. Ventilation in this camp is not proper due to the window type and the occupants didn't ventilate their rooms naturally. Some of the occupants suffer from wet or damp area in their camp. High humidity in some areas in this camp can be the reason behind the high concentration of TVOCs that affected by the mildew growth. Moreover, moist materials can emit more pollutants than the dry materials.

Beta industrial camp has lower average humidity than DulSCO in all areas except the dining hall which has average humidity of 57.57%. The occupants in this camp suffer from the mildew on the ceiling and walls rather than furniture. Same of DulSCO camp, 48% of the occupants ensured that they have pipes leak and lake of them ensured that they have wet or damp areas in their camp. This is occur in the kitchen and dining hall where the humidity level is high compared with the other

areas and as mentioned in the survey. The ventilation in this camp is better than Dulsco camp because they have window A/C and occupants ventilate their rooms naturally in regular way. This was obvious in their rooms that has the lowest average humidity in this camp which is 51.63% and this could be because of the natural ventilation. So, ventilation have an impact on indoor humidity level. Proper maintenance for this camp is occur more than Dulsco camp which could affect the humidity level to be lower.

TransGulf camp has three areas that have approximately the same average humidity level which are kitchen, corridor and dining hall. The room has average humidity higher than them which is 57.23%. The ventilation in this camp is better than the other camps because of the central A/C and the occupants ventilate their room naturally. Occupants that were asked in this camp didn't complain about pipes leak and wet or damp areas. Thus, they didn't suffer from any mildew on furniture, ceiling and walls. Maintenance for this camp occur regularly which affect the humidity level in the indoor environment. So, humidity level in this camp considered in the acceptable range which will not have a negative impact on the occupants' satisfaction level and health.

All the areas in the three camps have the standard limit for ASHREA Standards 55 and DM standards except three areas in Dulsco camp which are; kitchen (78.17%), corridor (74.4%) and room (68.8%). High humidity level can accelerate the growth of mildew on the furniture, walls and ceiling therefore, high concentration of TVOCs is occur. This was obviously shown in this study and ensured by Dales et al. (2008), WHO Guidelines (2009), Kalamees et al. (2009) and Woloszyn et al. (2009). Moreover, this study shows that ventilation can affect the humidity level when it's done regularly and in proper way. This was proofed by Kalamees et al. (2009) when they conducted a study to compare between the level of impact of ventilation rate and using of moisture-buffering materials. The results showed that ventilation have higher impact on indoor humidity than using moisture-buffering materials. Indoor humidity could be affected by the outdoor RH which stated by Zhang and Yoshino (2010).

4.4.7. Comparison of all the parameters between high quality houses and TransGulf camp:

As mentioned above, two houses in Mirdif were selected to be used as a benchmark for good IAQ. The same measurements were taken for the same areas, three times in the same day for each house (see appendix E&F). This part will show the comparison between the average concentration of the

pollutants, humidity and temperature in TransGulf camp and Mirdif houses. TransGulf camp was chosen for the comparison because it has the best indoor environment compared with the other camps. This is in order to determine if they reach the same level of high quality houses or they have lower indoor environment. The Discussions that have been done above will help in determining the reasons behind the results that will be stated.

TransGulf camp has the best TVOCs average concentration compared with the other camps so, it will compared with Mirdif houses as shown in Fig. 4.38. It shows that, it has higher average concentration than the two houses in Mirdif for all areas. This means that the materials that used in these houses could have less emission of TVOCs. The camp is newly built compared with Mirdif houses which make the material's TVOCs emission is higher. It was clear that kitchen and dining hall in TransGulf camp has higher concentration than Mirdif houses (473.6 ppb). This could be due to the ventilation rate in these areas lower than Mirdif houses. The level of cleanliness in Mirdif houses could be better than the labors camp. They ventilate their houses naturally in regular way. As proved above in the discussion that, interior materials and ventilation rate have high impact on TVOCs concentration in indoor environment. All the areas in the camp and Mirdif houses have average concentration above the required level by DM. Although, they have concentration above the standards but, all the occupants were satisfied. The highest average concentration of TVOCs that still express the satisfaction level was found in TransGulf camp which is 473.6 ppb.

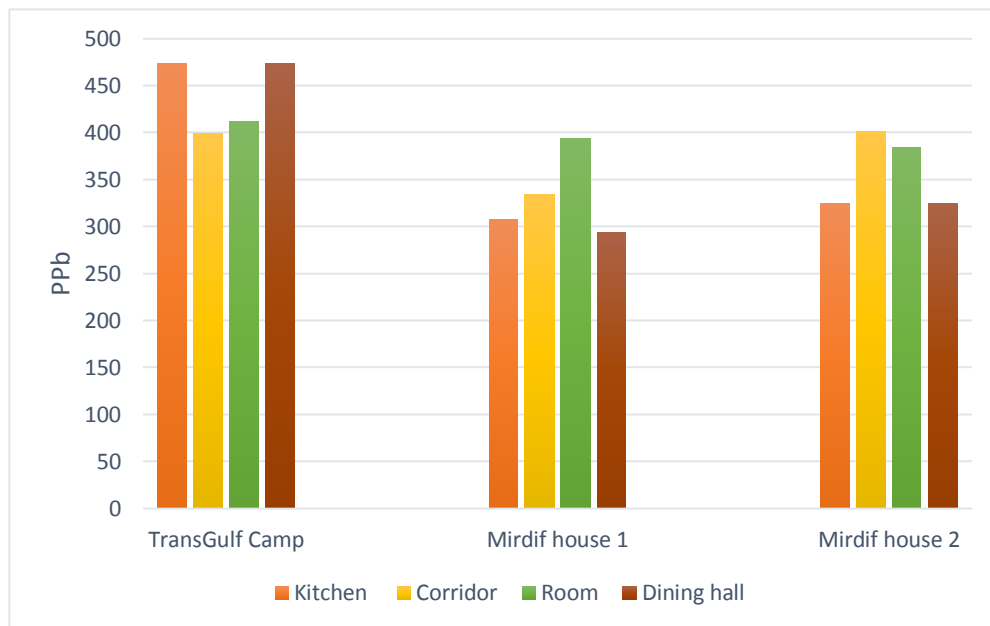


Figure 4.38. Comparison between TVOCs average concentration in TransGulf camp and Mirdif houses

The same for carbon dioxide average concentration, TransGulf camp has the lowest indoor CO₂ concentration compared with the others. Figure 4.39 shows the comparison between CO₂ average concentration in TransGulf camp and two houses in Mirdif. It shows that the readings are almost close to each other especially in TransGulf camp and Mirdif house 1. This can indicate that TransGulf camp has the same level of Mirdif houses ventilation whether naturally or mechanically. Thus, the number of occupants in the camp is suitable for the room's size. Low number of smokers in the camp and Mirdif houses can be one of the reasons behind the low concentration of CO₂. Mirdif house 2 has the lowest average concentration in the room and kitchen area. While, Mirdif house 1 has the lowest average concentration in the dining hall. This variation in the readings due to the different ventilation rate and number of occupants in each area. But, in general all the areas have the required level of carbon dioxide average concentration as required by DM.

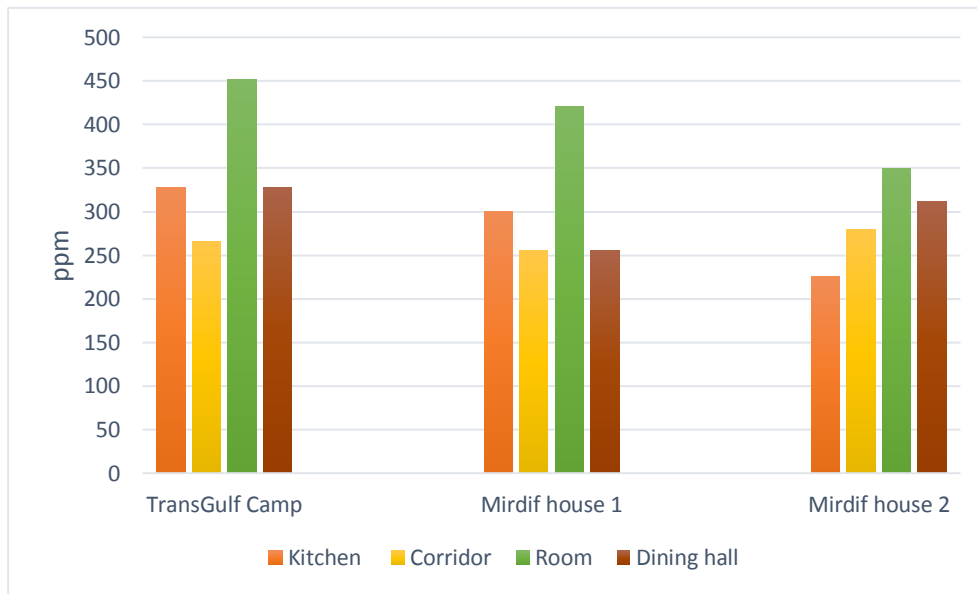


Figure 4.39. Comparison between CO₂ average concentration in TransGulf camp and Mirdif houses

Figure 4.40 shows the comparison between ozone concentration in TransGulf camp and Mirdif houses. It illustrates that TransGulf camp has higher ozone average concentration than Mirdif house 2 in small amount (0.004 ppm) for kitchen, dining hall and corridor. Room area in Mirdif house 2 has very low ozone concentration (0.016 ppm) compared with the others. This is because of the proper ventilation in this area and they could make the natural ventilation less than the others which prevent the outdoor ozone to enter the indoor area. Mirdif house 1 recorded the same average concentration for all its areas which is 0.05 ppm. It has lower average concentration than the others except the room. Occupants in this house use air purifiers and cleaning products less than the others as stated in the questionnaire survey. This affect the indoor ozone concentration as proved above. Ozone average concentration in TransGulf camp considered in the acceptable range compared with Mirdif houses. All the areas have the required level of ozone average concentration as required by DM.

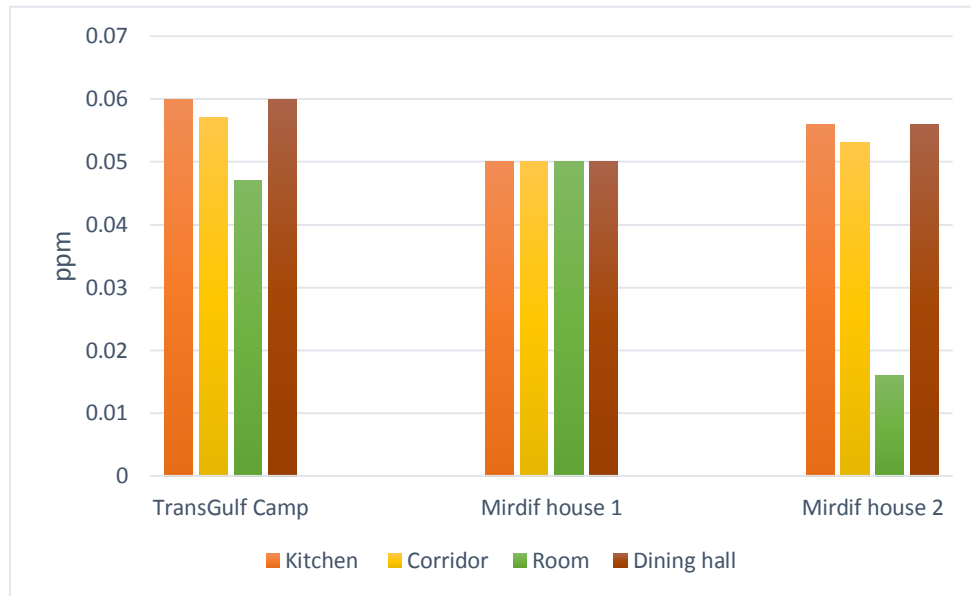


Figure 4.40. Comparison between O₃ average concentration in TransGulf camp and Mirdif houses

Figure 4.41 shows a comparison between the average temperature in TransGulf camp and Mirdif houses. It shows that the temperature in the labor camp close to the temperature in Mirdif house 2. Mirdif house 1 has two areas that have average temperature higher than TransGulf camp which are corridor and room (25.5 °C and 25.8 °C respectively). This could be modified by the occupants in house in order to save energy or other reasons. Regular maintenance was recorded in TransGulf camp and house 2 which enhance the temperature level in their indoor environment. Temperature level in TransGulf camp approximately has the same level of these high quality houses. All the areas have the standard limit of the temperature that stated by DM. All the occupants were satisfied in these houses and TransGulf camp as stated in the survey which ensure that the DM standards for indoor temperature represent the comfortable level (22.5 °C to 25.5 °C).

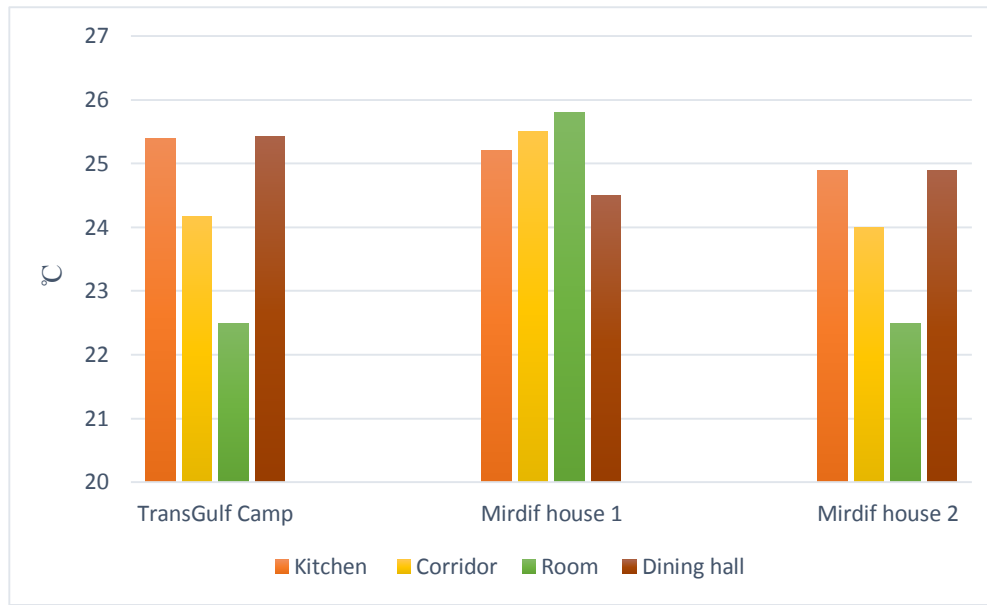


Figure 2.41. Comparison between average temperature in TransGulf camp and Mirdif houses

As stated in the discussions above, carbon monoxide strongly affected by the gas stoves, boilers, smoking and parking area or high traffic area. Figure 4.42 shows a comparison between average CO concentration in TransGulf camp and Mirdif houses. It shows that TransGulf camp has the lowest average concentration. Mirdif houses have attached garage which increase the amount of CO in their indoor environment. Kitchen and dining hall in Mirdif house 2 which are attached to each other have high CO concentration (1.46 ppm) because they faced the outside garage as shown in fig 4.43 & 4.44. While, the windows in the corridor and the room in this house are not overlooking the garage area so, they have less concentration but still have higher than TransGulf camp (0.73 ppm and 0.53 ppm respectively). Natural ventilation in this case can be the reason behind the high concentration of CO especially when the windows overlooking the parking area. TransGulf camp has average CO concentration better than the two houses in Mirdif. Room area in TransGulf camp has very low average concentration which is 0.033 ppm. All the areas have the standard limit that stated by DM.



Figure 4.42. Comparison between CO average concentration in TransGulf camp and Mirdif houses



Figure 4.43. Kitchen overlooking the attached garage



Figure 4.44. View from the door in the kitchen

Figure 4.45 shows a comparison between the average humidity in TransGulf camp and Mirdif houses. Almost TransGulf camp has average humidity very close to Mirdif house 2. While, Mirdif house 1 has the lowest average humidity for all areas. No leaking pipes, damp areas and mildew were found in TransGulf camp and Mirdif houses. Ventilation rate and materials quality can be the reason behind the different levels of humidity in these three buildings. All the areas have the standard limit that stated by DM. The occupants in the three buildings were satisfied with their indoor humidity. So, all the areas falls in the comfortable zone which is between 30% and 60%.

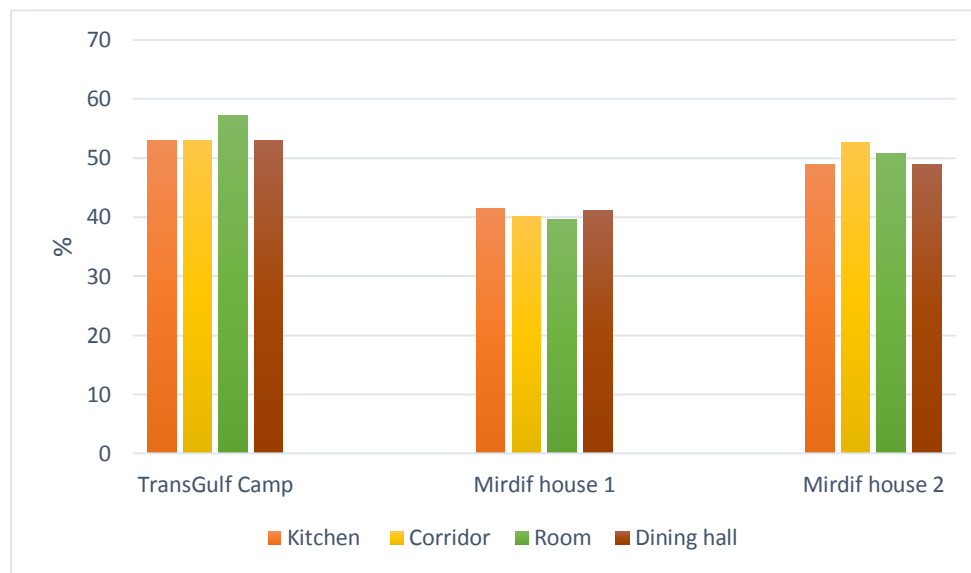


Figure 4.45. Comparison between average humidity in TransGulf camp and Mirdif houses

4.5. Survey results and discussions:

Through the questionnaire survey that have been conducted for the labors in the three camps and occupants in Mirdif houses, satisfaction level of the occupants in their indoor environment will be illustrated. Thus, the impacts of the above mentioned parameters on the occupants' health will be analyzed and studied.

It will include the satisfaction level with the room temperature, humidity and air freshness. Thus, the overall satisfaction in their rooms and their assessment of indoor air quality in their housing.

4.5.1. Occupants' satisfaction level with their room temperature:

The most important area in the camp and should have the required standards for living are the rooms, where the occupants spend most of their time in it. Occupants' satisfaction and comfort level affected by the indoor temperature as stated by Frontczak & Wargocki (2011). Figure 4.46 shows the occupants satisfaction level with their room temperature in DulSCO camp. It illustrated that most of the occupants were fully satisfied, some of them were satisfied and 6% only were dissatisfied. The rooms have average temperature of 24.2 °C which is in the range of the standard limit for DM. Figure 4.47 shows occupants' satisfaction level with their room temperature in Beta industrial camp. It illustrated that around half of the occupants that were asked are satisfied with their room temperature. Around 33% were fully satisfied and 11% were fully dissatisfied. The rooms in this camp have the highest average temperature between all the camps which is 25.23 °C but still it achieve the standard limit for DM (between 22.5 °C and 25.5 °C). While, the rooms in TransGulf camp has the lowest average temperature which is 22.5 °C, the satisfaction level of the occupants was increased. Figure 4.48 shows the occupants satisfaction level with their room temperature in TransGulf camp. Around 74% of the occupants that were asked are fully satisfied with their room temperature and none of them were dissatisfied. So, it can be concluded that, when the room temperature rises, the satisfaction level started to be decreased and vice versa. Arens et al. (2008) proofed that in their study that conducted to evaluate the occupants' comfortable level in different indoor air temperature and speed.

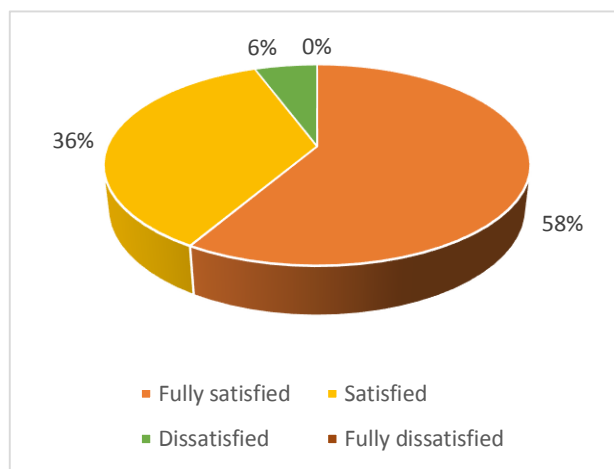


Figure 4.46. Occupants' satisfaction level with the room temperature in DulSCO camp

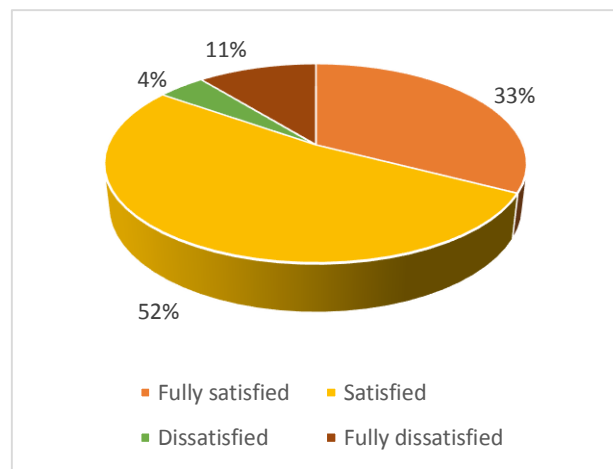


Figure 4.47. Occupants' satisfaction level with the room temperature in Beta camp

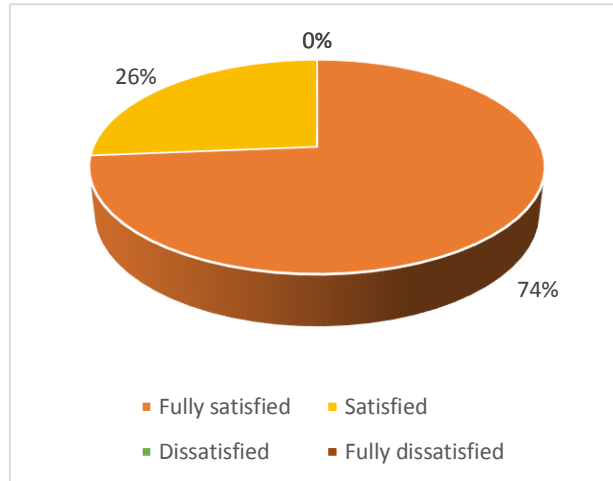


Figure 4.48. Occupants' satisfaction level with the room temperature in TransGulf camp

4.5.2. Occupants' satisfaction level with their room humidity:

Figure 4.49 shows the occupants satisfaction level with their room humidity in Dulsco camp. It shows that less than half of the occupants that were asked (37%) are fully satisfied with their room humidity while, 24% are dissatisfied. The room average humidity in this camp was 68.6% which is above the standard limit for DM. Figure 4.50 shows the occupants' satisfaction level with their room humidity in Beta industrial camp. More than half of the occupants were fully satisfied with their room humidity and none of them were dissatisfied. Room humidity in this camp was 51.63% which is achieve the standard limit for DM. The satisfaction level was increased in Beta camp when the humidity level was decreased. Figure 4.51 illustrated the occupants' satisfaction level with their room humidity in TransGulf camp. Satisfaction level was less than Beta camp but more than Dulsco camp. Around 51% were fully satisfied with their room humidity. Room humidity in this camp was 57.23% which is achieve the standard limit for DM. The best satisfaction level was in Beta camp where the humidity level was the lowest. It can be concluded that satisfaction level increased with the decreasing of the room humidity. Indoor air humidity can affect the indoor air quality therefore, the occupants' satisfaction level in their indoor environment will be affected (Kalamees et al., 2009).

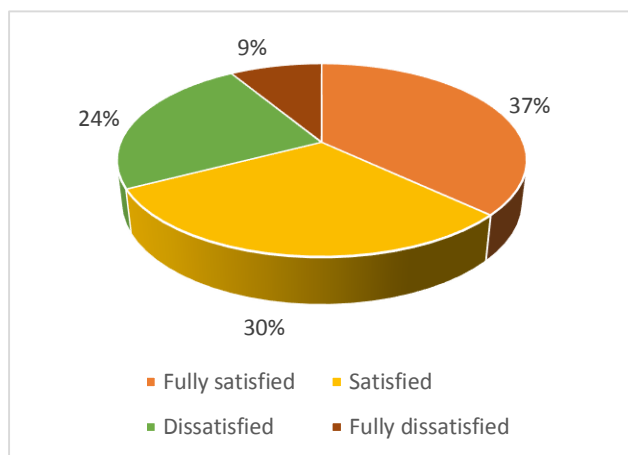


Figure 4.49. Occupants' satisfaction level with the room humidity in Dulsco camp

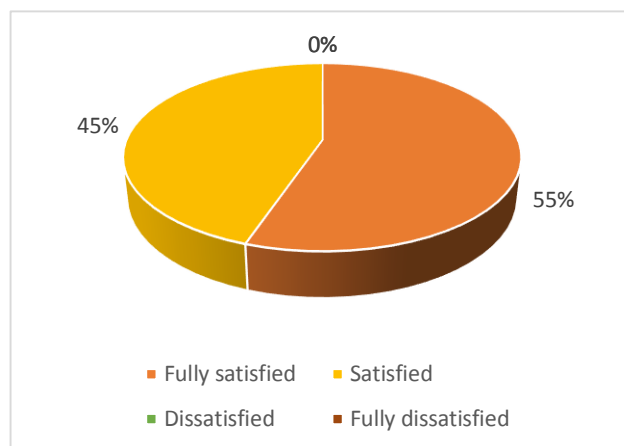


Figure 4.50. Occupants' satisfaction level with the room humidity in Beta camp

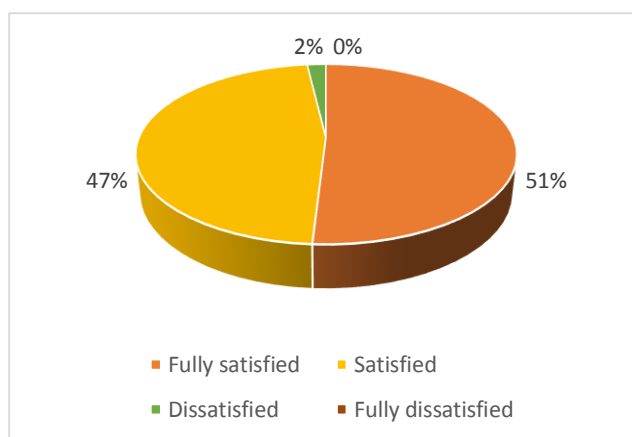


Figure 4.51. Occupants' satisfaction level with the room humidity in TransGulf camp

4.5.3. Occupants' satisfaction level with the air freshness in their rooms:

Ventilation and pollutants concentration can be indication for the air freshness in the rooms. Figure 4.52 shows the occupants' satisfaction level with the air freshness in Dulsco rooms. It illustrated that 41% of the occupants that were asked are fully dissatisfied with their rooms' indoor air and only 26% were satisfied. Ventilation in this camp was poor as illustrated above due to the A/C type and lack of the natural ventilation. TVOCs recorded the highest average concentration in this camp thus, it has higher average concentration of CO and CO₂ in the rooms. Figure 4.53 shows the occupants' satisfaction level with the air freshness in Beta rooms. It showed that the satisfaction

level was increased in Beta camp that has more proper ventilation than Dulsco. Only 11% of the occupants that were asked are dissatisfied with their rooms' indoor air. Occupants in this camp ventilate their rooms naturally. The average concentration of CO and CO₂ in the rooms was lower than Dulsco and achieve the standard limits for DM. Moreover, TVOCs average concentration was lower than Dulsco but, above the standard limit for DM. Figure 4.54 shows the occupants' satisfaction level with the air freshness in TransGulf rooms. It illustrated that, none of them were dissatisfied and all the occupants either satisfied or fully satisfied. This camp has central A/C which could have more proper ventilation than the others. The average concentration of TVOCs, CO and CO₂ in the room were the lowest in this camp. So, it can be concluded that occupants' satisfaction level increased with the proper ventilation and low amount of indoor pollutants (TVOCs, CO and CO₂). This was insured by BRANZ Ltd (2007) and Melikov et al. (2008).

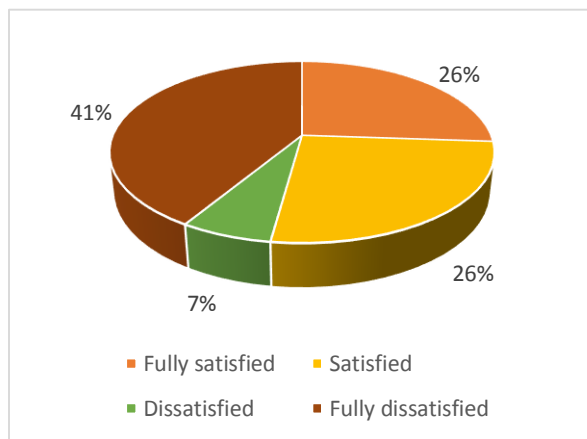


Figure 4.52. Occupants' satisfaction level with the room air freshness in Dulsco camp

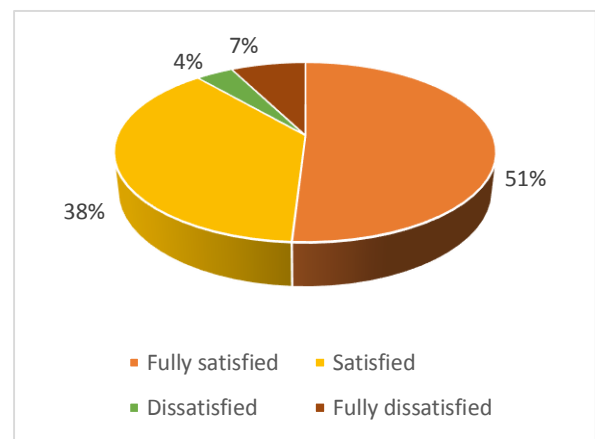


Figure 4.53. Occupants' satisfaction level with the room air freshness in Beta camp

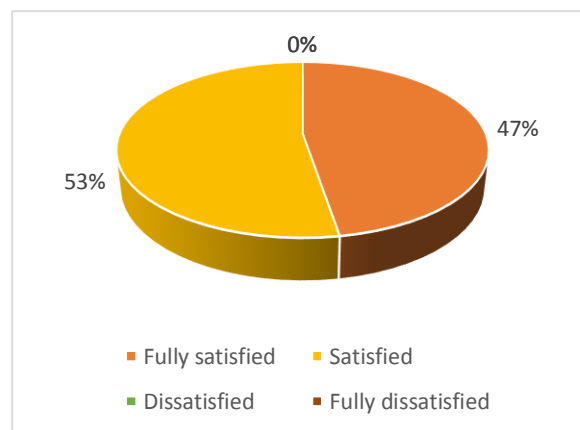


Figure 4.54. Occupants' satisfaction level with the room air freshness in TransGulf camp

4.5.4. Occupants' satisfaction level in their rooms:

Figure 4.55 shows the occupants' satisfaction level in their rooms in Dulsco camp. It illustrated that 32% of the occupants that were asked are dissatisfied with their rooms and 68% were satisfied. While, in Beta camp the satisfaction level was increased, only 6% of the occupants were dissatisfied as shown in Fig. 4.56. In TransGulf camp, none of the occupants were dissatisfied, 50% were satisfied and 50% were fully satisfied as shown in Fig. 4.57. So, indoor air can affect the overall satisfaction level of the occupants in their rooms.

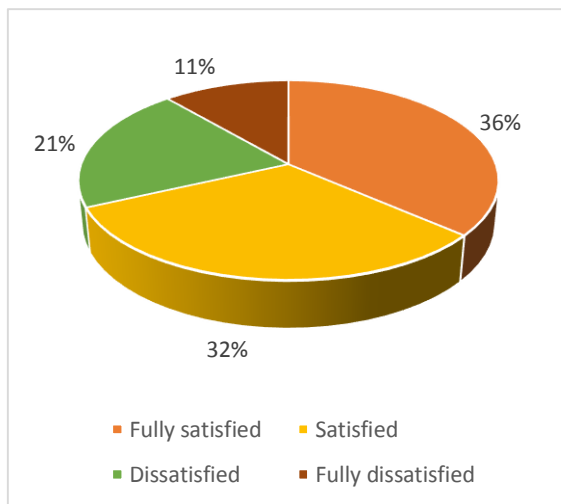


Figure 4.55. Occupants' satisfaction level in their rooms in Dulsco camp

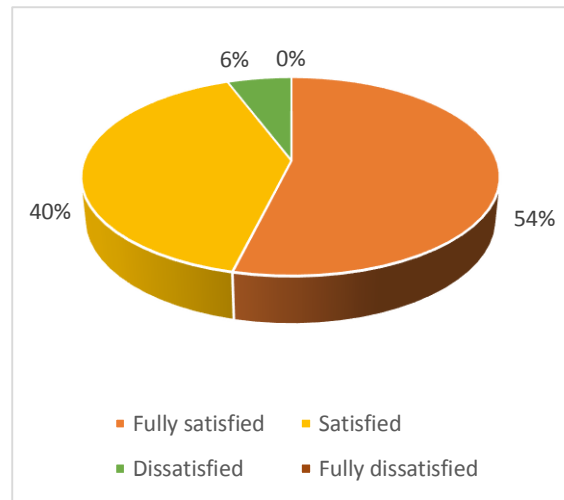


Figure 4.56. Occupants' satisfaction level in their rooms in Beta camp

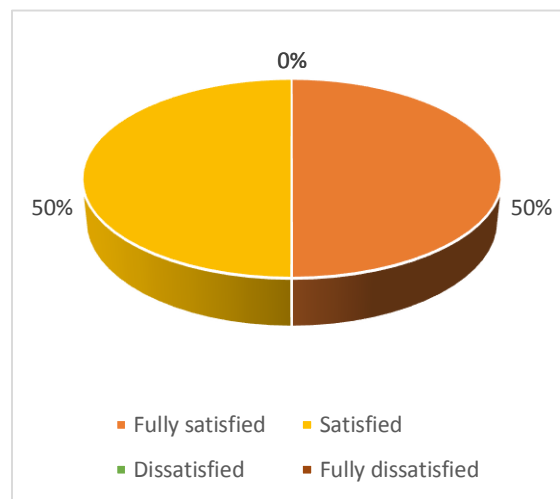


Figure 4.57. Occupants' satisfaction level in their rooms in TransGulf camp

4.5.5. Air quality assessment by the occupants:

Around 25% of the Occupants in Dulsco camp have stated that the indoor air quality was unacceptable as shown in Fig. 4.58. Figure 4.59 shows that in Beta camp, only 2% answered that their indoor air quality is unacceptable. While, in TransGulf camp, all the occupants were satisfied with their indoor air quality and most of them considered it clearly acceptable as shown in Fig. 4.60. This was expected due to the results that illustrated above.

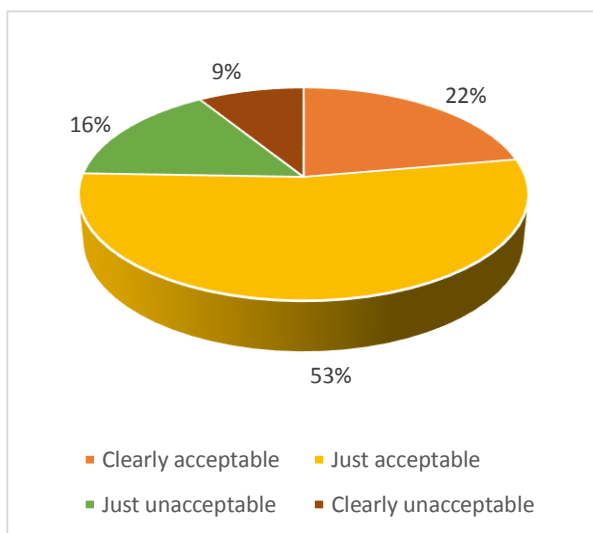


Figure 4.58. Air quality assessment in Dulsco camp

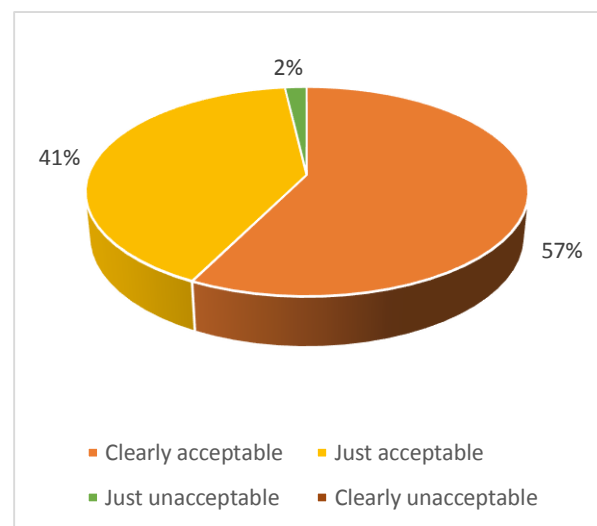


Figure 4.59. Air quality assessment in Beta camp

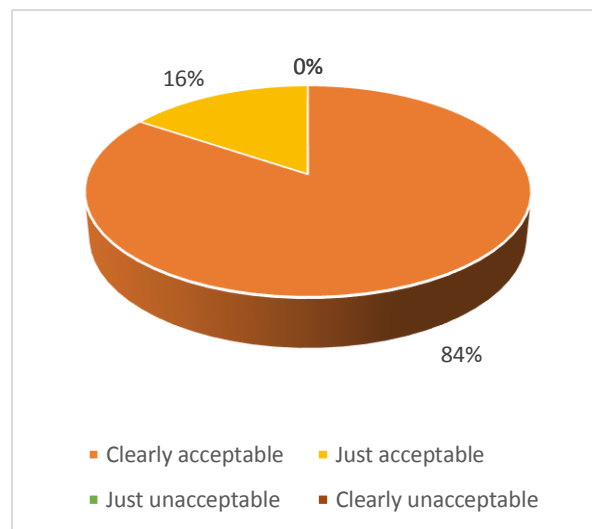


Figure 4.60. Air quality assessment in TransGulf camp

4.5.6. Occupants' satisfaction level in high quality houses:

All the occupants in both Mirdif house 1 and Mirdif house 2 ensured that they are satisfied with their room temperature, humidity and air freshness. Thus, they are satisfied with their room environment and indoor air quality in their house. None of them were dissatisfied like what's found in Dulsco camp and Beta camp. Almost transGulf camp has the same level of satisfaction to Mirdif houses.

4.5.7. Health impact:

Occupants in the three housing have been asked several questions about their health and the symptoms that they feel it in their housing. Figure 4.61 shows the number of occupants that are sensitive to the smoke, dust, mold or any chemicals in the three camps. It illustrated that Dulsco camp have the highest number of occupants that are sensitive to them. While, TransGulf camp has the lowest number of occupants that are sensitive. This could indicate that the health symptoms in Dulsco camp will be higher than others. Because the sensitive people are more exposed to the pollutants risk than other people.

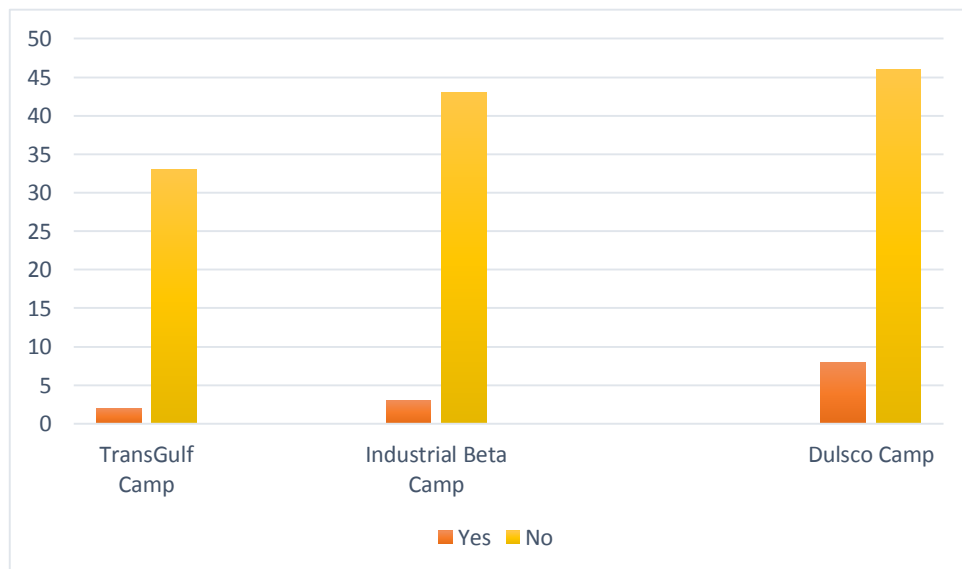


Figure 4.61. Number of occupants that are sensitive to chemicals and others

Figure 4.62 shows the number of occupants in the three camps that have asthma. It illustrated that Dulsco camp have the highest number and none of the occupants that were asked in TransGulf camp have asthma. Occupants that are suffering from asthma have higher risk when exposing to the indoor pollutants.

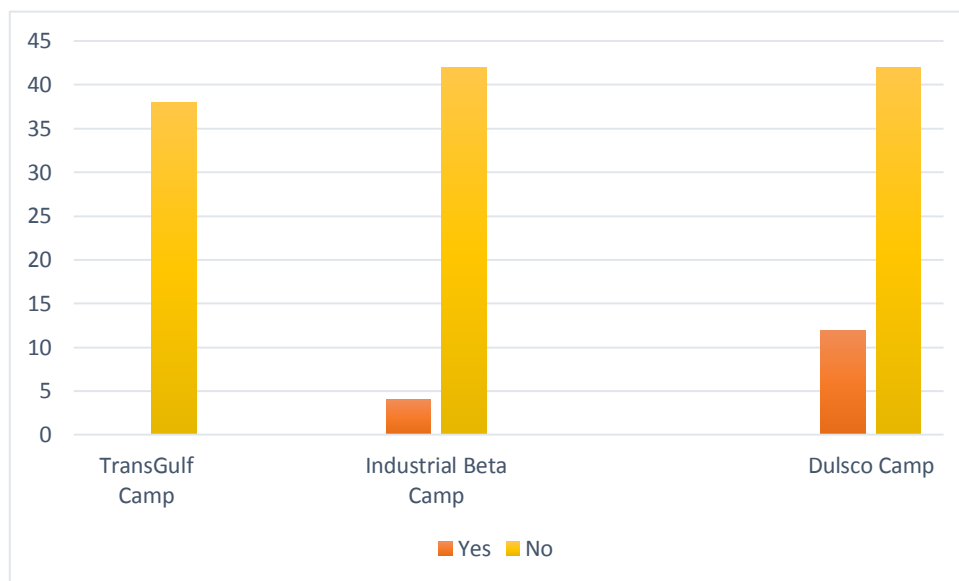


Figure 4.62. Number of occupants that have asthma

As mentioned above, a number of health related symptoms questions were asked of the occupants. These symptoms included fatigue, dizziness, headache, difficulties in breathing, dry and runny nose, dry and irritated eyes, dry throat, coughing and skin problems. Figure 4.63 shows the percentage of each health problem that occur in each camp compared with the others. It illustrates that Dulsco camp have the highest number of occupants suffering from the health problems compared with the other camps. This is due to the indoor pollutants which have the highest average concentration in Dulsco camp.

Bernstein et al. (2008) stated that high concentration of CO can cause tiredness, dizziness, difficulty in breathing and nausea. The same symptoms can occur in indoor environment with high concentration of CO₂ (MDH, n.d.). Dulsco camp has these symptoms because of the high average concentration of CO₂ and CO. Beta camp and TransGulf camp could have these symptoms but in lower percentage because they have lower average concentration.

High concentration of ozone can cause some problems in the airway tract so, it can be risky for the people that have asthma (Bernstein et al., 2008). It was noticed that most of the occupants that

suffer from asthma in Beta camp suffer from difficulties in breathing because of the ozone concentration in this camp. Bernstein et al. (2008) stated that TVOCs can increase the problems with the mucous membranes. DulSCO camp that has high concentration of TVOCs recorded problems in the mucous membranes such as dry and runny nose. Thus, this was noticed in Beta camp that have moderate concentration of TVOCs. Wolkoff & Kjærgaard (2007) ensured that humidity can affect the eyes and airway. Humidity has the highest average concentration in DulSCO camp which also has the highest health problems in the eye and difficulties in breathing.

Beta camp recorded some health problems such as difficulties in breathing, nose, eyes and skin problems. This is due to the temperature level, humidity and pollutants concentration (TVOCs, CO₂ and CO) in some areas. It has moderate health problems compared with other camps as shown in Fig. 4.63. Coughing, dry throat, headache and dizziness have less percentage than other health issues. While, TransGulf camp has the lowest health problems compared with the other camps as shown in Fig. 4.63. Occupants in this camp suffer from dry throat and coughing more than the other health problems. Few number of occupants complain about skin problems.

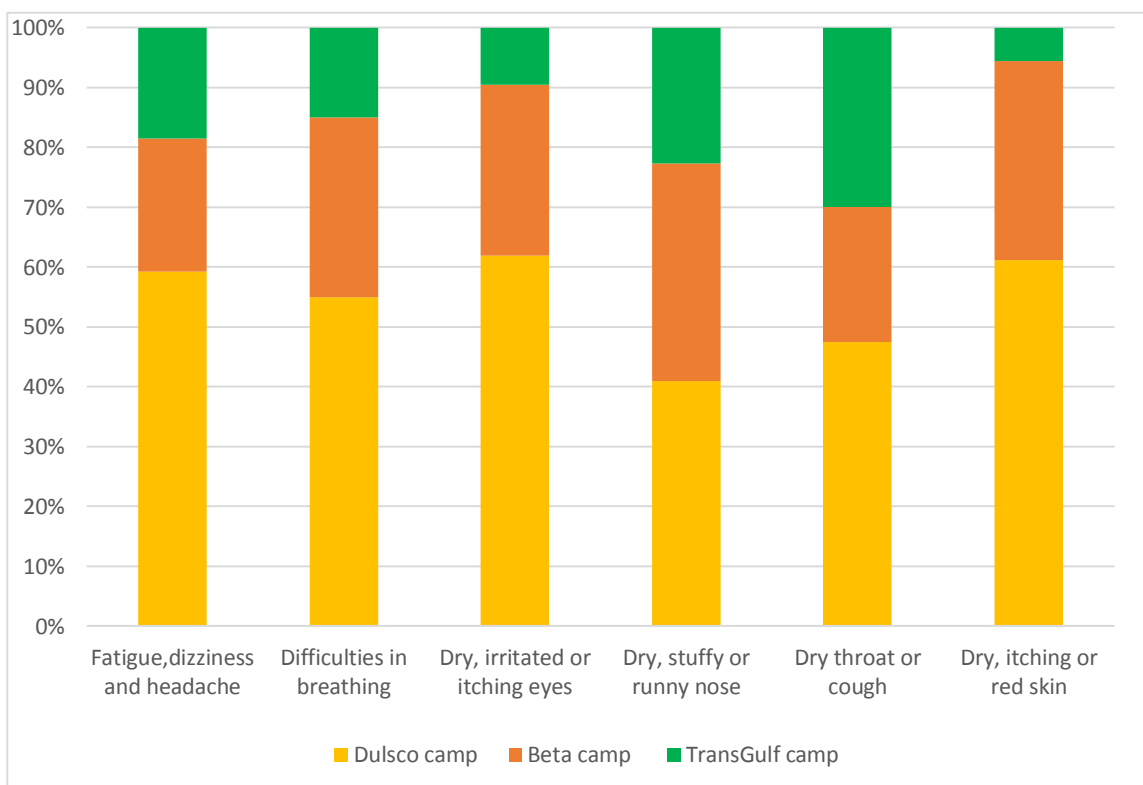


Figure 4.63. Percentage of each health problem that occur in each camp

These results were expected, because Dulsco camp was the most camp has pollutants and poor indoor environment. While, TransGulf camp has the best conditions compared with the others.

Occupants in Mirdif houses didn't record any health problems in the survey. This could be because of the proper ventilation and low concentration of pollutants. They could feel headache or coughing but not necessary to be from the indoor pollutants. TransGulf camp has the closest indoor environment to Mirdif houses.

4.5.8. Improvements required by the occupants in the questionnaire survey:

At the end of the survey, there was a question related to the improvements that the occupants need it, in order to make their indoor environment in better conditions. This question was added by the author to ensure the results that mentioned above by the occupants' answers. Most of the answers include; Wi-Fi, T.V., less number of occupants in their rooms, more proper ventilation and maintenance for their camp, providing central A/C, more stoves in the kitchen, more sealed pipes in the kitchen and bathrooms in order to avoid leakage, providing gym and areas for recreation, more tables in the dining hall and increase the area of the kitchen.

The occupants that answer Wi-Fi and recreational areas are from TransGulf camp and the rest of the answers are from Dulsco and Beta camp. TransGulf camp has the best indoor conditions as proved in the results above. This was ensured by the answers of this question which indicate that their requirements doesn't related to the IAQ while, the other camps, their requirements are related to IAQ problems.

4.6. Suggested improvements:

According to the results that mentioned above and by using Mirdif houses as benchmark for good IAQ, the author conclude some suggested improvements that could be achieved in order to enhance the quality of indoor air in these housing. Dubai Building Code Regulations & Construction Specifications (2004) have been established some regulations that can be used in these suggestions. The following points will show the issues and the suggested improvement for each issue:

- The location of the labor housing are in the industrial area which is full of outdoor pollutants that can emit the indoor environment easily through natural ventilation. This was

ensured in Beta camp that has high indoor ozone concentration (0.067 ppm) compared with the others. So, locate these housing in residential areas and away from the industrial areas and the factories same as Mirdif houses will make the concentration of the indoor pollutants lower.

- Dulsco and Beta camp have a high number of occupants (10 & 8 respectively) in each room which make the concentration of CO₂ high in the rooms and could reach 1283.7 ppm. Enlarge the size of the rooms, decrease the number of the occupants in each room and ensure that each occupant has the required square meter which is 3.7 should be achieved as stated by Dubai Building Codes.
- Some occupants in the camps can't make the natural ventilation because they don't have windows in their rooms. Each room should have at least one window and the location should be studied well in term of the outside view as done in Mirdif houses. Natural ventilation will decrease the concentration of some indoor pollutants.
- The corridor in Dulsco camp has open ceiling so, any problem in the pipes directly affect the occupants. Open ceiling will make the concentration of indoor pollutants (CO, humidity and TVOCs) higher in this area as shown in the results above. The corridor should have the standard width and well installed false ceiling as stated by Dubai Building Codes.
- Beta and Dulsco camp have one big kitchen for all the occupants which increase the concentration of the indoor pollutants such as; TVOCs. One or more kitchen should be available for preparing food and dining hall which can accommodate minimum of 1/3 of the occupants at one time as stated by Dubai Building Codes. Minimum area for the dining hall should be not less than 1.2 square meter per person.
- Some of occupants in Beta and Dulsco camp were dissatisfied with their room temperature which could reach 27.8°C due to the type of the A/C used (window and split). So, providing central A/C can achieve the required temperature (22.5° C and 25.5° C) as shown in TransGulf camp and Mirdif houses.

- Dulsco camp has poor ventilation which is one of the reasons behind the high concentration of the indoor pollutants. Increase the ventilation rate can decrease the concentration significantly as proved in Mirdif houses and TransGulf camp.
- Number of occupants in the camps are smoking which increase the concentration of the CO₂ in their indoor environment. So, increase the awareness of the labors in order to stop the activities that cause a negative impact on their indoor environment should be attained. Thus, provide for them areas for recreational facilities which should be at a minimum of 1/4 of total net area as stated by Dubai Building Codes.
- Dulsco camp suffer from mold growth on their indoor materials which increase the concentration of TVOCs and could reach 1424 ppb. Mirdif houses didn't suffer from this problem and they have lower concentration of TVOCs in their indoor environment. The interior materials should be carefully selected in order to avoid any mold, fungi and dampness in high humidity areas.

Additional suggestions related to IAQ stated by Dubai Building Code Regulations & Construction Specifications (2004) that should be done in the labor camps:

- Rooms' door shouldn't be directed to the road or alleyway.
- The corridor width should be 1.8 m in case the rooms on two sides and 1.4 m in case the rooms on one side.
- The garbage room should has suitable width (minimum 1.8 m) in order to allow for the containers to enter easily.
- Separate the lavatory, washbasins and showers from each other.
- One lavatory, washbasin and shower is the minimum requirement for every 10 occupants and laundry tray for every 30 occupants.
- The buildings/structures must be at least 6 meters away from the kitchen, workshops and stores.
- Start to implement the sustainable way of living in the existing housing such as using green cleaning products instead of the regular one that increase the pollutants concentration.

- Continuous monitoring for the pollutants concentration in these housing should be achieved regularly as mentioned in DM (2015).
- Provide for them the required maintenance for the HVAC system, water leakage, kitchen and bathrooms problems and others.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1. Introduction:

This chapter will illustrate the main findings of the study, the main issues that found in the labor camps and the main improvements that could be applied to enhance their indoor environment. Thus recommendation for future work will be stated.

5.2. Summary of the findings:

The aim of this study is to evaluate the indoor environment of three different level of labor housing and compare it with high quality housing. This has been done through field measurements for four types of indoor pollutants (CO, CO₂, ozone and TVOCs) as well as, temperature and humidity. Also, a questionnaire survey was distributed in order to get the occupants' direct perception of their indoor environment.

Main findings:

- TransGulf labor camp (high income) has almost the same level of IAQ, temperature and humidity. Thus, it has the same occupants' satisfaction level and health of Mirdif houses.
- None of the labor camps and Mirdif houses achieve the required level of the TVOCs (243 ppb) that stated by DM. However, the occupants in Mirdif houses and TransGulf camp were satisfied. The highest average concentration of TVOCs that still express the occupants' satisfaction was found in TransGulf camp which is 473.6 ppb.
- The highest concentration of CO₂ was found in Dulsco camp (1283.7 ppm) which is greater than Mirdif houses by 873.7 ppm. This concentration decreases the occupants' satisfaction level in their rooms.
- Dulsco camp (low income) has the lowest average concentration of ozone compared with Mirdif houses.

- Mirdif houses recorded high amount of CO (1.46 ppm) compared with TransGulf camp but lower than Dulsco and Beta camp that reach average concentration of 7.33 ppm. Occupants in TransGulf camp and Mirdif houses were satisfied unlike Dulsco and Beta camp.
- The average humidity and temperature that achieve the standard limits was found in TransGulf camp and Mirdif houses (54% and 24.4°C respectively). The highest average humidity and temperature that express the occupants' dissatisfaction are 68.41% and 26.8°C respectively.
- Occupants' health was affected by the indoor pollutants negatively in Dulsco and Beta camp. The main symptoms that found are; tiredness, dizziness, difficulty in breathing and nausea.

Main issues in labor camps:

- Location of the camps.
- High number of occupants in the rooms.
- One big kitchen for all the occupants.
- Poor ventilation.
- Mildew growth in the interior materials.

Main suggestions that should be applied:

- Located these camps in residential areas.
- Ensure that each occupant has the required square meter which is 3.7 in their rooms.
- One or more kitchen should be available for preparing food and dining hall which can accommodate minimum of 1/3 of the occupants at one time.
- Central A/C is required for these camps and increase the awareness of the natural ventilation.
- Select low TVOCs emission materials.
- Increase the ventilation rate to avoid any humid areas.

5.3. Recommendation for future work:

More studies and investigations could be achieved to evaluate the indoor environment of labor housing or low cost housing. Other indoor pollutants should be evaluated and studied such as; formaldehyde, nitrogen dioxide, hydrogen sulfide and radon. Their impact on occupants' health is very important to be achieved. Thus, Occupants performance and productivity in these housing with different pollutants' concentration could be studied.

This study was limited to be done in one season but it could be conducted in more than one season in order to study the pollutants concentration in different weather conditions and how it will affect the occupants' satisfaction level and health. Winter season in UAE could be better than summer season because of the humidity and temperature. Different countries will have different level of pollutants in each season.

In addition, the study was limited to measure the pollutants in one area in the same room for one period but, it could be taken in more than one area in the rooms and in different times for example away from the window or the door and near them in different times. In order to study the impact of ventilation and air movement on the pollutants concentration in indoor environment in different location and time.

Materials that used in the indoor environment affect the pollutants concentration. This study didn't show the impact of each specific material on the pollutants concentration due to the lack of the materials specification information for each building. In fact, each interior material has emissions differs than the other. Temperature and humidity level in indoor environment have a strong impact on the materials' emission. These issues could be studied and evaluate the level of impact on occupants' health and satisfaction level.

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APPENDCIES

Appendix A: Questionnaire survey

Questionnaire Survey for Indoor Air Quality in Labor Housing and Its Impact on Occupant's Comfort and Health

Date:

Building name and location:

Building age:

Building size:

Number of stories:

Number of rooms in each story:

Number of bathrooms in each story:

Number of kitchens in each story:

Please choose one answer for each question.

Part A: Occupant information.

1- Age (years):

- Under 20
- 20 – 30
- 31 – 40
- Above 40

2- Hours spent out of your housing per day:

- < 6
- 7 – 9
- 10 – 12
- > 12

3- How many persons in your room?

- 2
- 3
- 4
- > 4

4- Are you a smoker person:

- Yes
- No

5- How many persons are smoking in your room?

- 2
- 3
- 4
- > 4

6- Self-Reported asthmatic:

- Yes
- No

7- Self-Reported allergic:

- Yes
- No

Part B: Housing conditions.

1- Have you experience any of these problems in your housing? (How often you have it)

- Water pipes leakage or damage (usually – occasionally – rarely – never)
- Mildew on the ceiling, walls or flooring (usually – occasionally – rarely – never)
- Mildew on your furniture (usually – occasionally – rarely – never)
- Wet or damp area (usually – occasionally – rarely – never)
- Offensive odors (usually – occasionally – rarely – never)
- Improper ventilation (usually – occasionally – rarely – never)
- Other:

You can choose more than one answer.

2- Which areas in your housing have this problem?

- Kitchen
- Room
- Bathroom
- Corridor

You can choose more than one answer.

3- Do you feel your A.C. emit pollutants from outside?

- Usually
- Occasionally
- Rarely
- Never

4- Does your A.C. provide the required level of temperature?

- Yes
- No

5- Have you done any of these practices in your room? (how often you do it)

- Use a cleaning product or chemicals (usually – occasionally – rarely – never)
- Ventilate your room by opening the window (usually – occasionally – rarely – never)
- Use air purifier (usually – occasionally – rarely – never)
- Preparing food (usually – occasionally – rarely – never)
- Eat in your room (usually – occasionally – rarely – never)

You can choose more than one answer.

6- Do you have a proper maintenance for your housing?

- Usually
- Occasionally
- Rarely
- Never

7- Which season you considered the most comfortable?

- Winter
- Summer
- Spring
- Fall

8- Which season you considered the least comfortable?

- Winter
- Summer
- Spring
- Fall

Part C: Occupant's satisfaction level in their rooms.

1- Rate your room temperature:

- Fully satisfied
- Satisfied
- Dissatisfied
- Fully dissatisfied

2- Rate the humidity level in your room:

- Fully satisfied
- Satisfied

- Dissatisfied
- Fully dissatisfied

3- Rate the air freshness in your room:

- Fully satisfied
- Satisfied
- Dissatisfied
- Fully dissatisfied

4- Rate your satisfaction level in your room:

- Fully satisfied
- Satisfied
- Dissatisfied
- Fully dissatisfied

5- How do you assess the air quality in your housing?

- Clearly acceptable
- Just acceptable
- Just unacceptable
- Clearly unacceptable

Part D: Health and wellbeing.

1- Are you sensitive to the smoke odors, dust, mold or any chemicals?

- Yes
- No

2- Have you ever feel any of these symptoms in your housing? (how often you feel it)

- Fatigue, dizziness or headache (usually – occasionally – rarely – never)
- Difficulties in breathing (usually – occasionally – rarely – never)
- Dry, irritated or itching eyes (usually – occasionally – rarely – never)
- Dry, stuffy or runny nose (usually – occasionally – rarely – never)
- Dry throat or cough (usually – occasionally – rarely – never)
- Dry, itching or red skin (usually – occasionally – rarely – never)
- Other:

You can choose more than one answer.

3- Which areas in your housing you feel these symptoms?

- Kitchen
- Room
- Bathroom

- Corridor

You can choose more than one answer.

4- Rate your health comfort level in your housing:

- Fully satisfied
- Satisfied
- Dissatisfied
- Fully dissatisfied.

5- What are the improvements that you prefer to be added to make your housing more comfortable?

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Appendix B: Field measurements for Dulsco camp

Date: 28-4-2015

Housing name: Dulsco Camp (Al Qouz / industrial 4)

Area name: Kitchen (K 001)

Pollutant name	12:15 pm	2:15 pm	4:15 pm	Average
TVOCs	1566	1055	1651	1424
Carbon dioxide	408	313	341	354
Ozone	0.05	0.04	0.04	0.043
Carbon monoxide	2	2.3	1.7	2
Temperature	27.1	26.5	26.3	26.6
Relative humidity	80	71.5	83	78.2

Date: 28-4-2015

Housing name: Dulsco Camp

Area name: Dining hall (DH 001)

Pollutant name	12:30 pm	2:30 pm	4:30 pm	Average
TVOCs	1296	745	748	929.6
Carbon dioxide	807	681	638	708.6
Ozone	0.05	0.04	0.04	0.43
Carbon monoxide	6.2	9.6	6.2	7.3
Temperature	23.4	24.1	24.5	24
Relative humidity	56.5	49.3	51.6	52.5

Date: 28-4-2015

Housing name: Dulsco Camp

Area name: Corridor in the first floor

Pollutant name	12:45 pm	2:45 pm	4:45 pm	Average
TVOCs	1057	764	983	934.6
Carbon dioxide	220	225	202	215.6
Ozone	0.05	0.06	0.08	0.06
Carbon monoxide	1.3	1	0.8	1.03
Temperature	28	28.2	26.6	27.6
Relative humidity	72.3	69.9	81.1	74.4

Date: 28-4-2015

Housing name: Dulsco Camp

Area name: Inside the room (No. A007)

Pollutant name	1:00 pm	3:00 pm	5:00 pm	Average
TVOCs	955	620	1029	868
Carbon dioxide	949	1345	1557	1283.6
Ozone	0.05	0.04	0.04	0.043
Carbon monoxide	1.7	0.9	1.1	1.23
Temperature	24.7	23.3	24.6	24.2
Relative humidity	70	62	73.8	68.6

Appendix C: Field measurements for Beta Industrial camp

Date: 20-4-2015

Housing name: Beta industrial camp (Jebel Ali / industrial #1)

Area name: Kitchen

Pollutant name	1:37 pm	3:37 pm	5:37 pm	Average
TVOCs	871	735	854	820
Carbon dioxide	278	291	417	328.6
Ozone	0.06	0.06	0.06	0.06
Carbon monoxide	1.1	1	3.7	1.93
Temperature	28.4	28.2	26.8	27.8
Relative humidity	57.1	57	68.6	60.9

Date: 20-4-2015

Housing name: Beta industrial camp

Area name: Dining hall

Pollutant name	1:49 pm	3:49 pm	5:49 pm	Average
TVOCs	556	554	546	552
Carbon dioxide	207	198	174	193
Ozone	0.07	0.07	0.06	0.06
Carbon monoxide	0.4	0.1	0.5	0.3
Temperature	27.7	27.4	26.4	27.16
Relative humidity	54.9	58	59.8	57.6

Date: 20-4-2015

Housing name: Beta industrial camp

Area name: Corridor between rooms in the ground floor

Pollutant name	2:08 pm	4:08 pm	6:08 pm	Average
TVOCs	522	499	523	514.6
Carbon dioxide	215	210	209	211.3
Ozone	0.07	0.07	0.06	0.06
Carbon monoxide	0.9	0.1	0.3	0.43
Temperature	27.8	27.4	26	27.1
Relative humidity	54.1	57.3	60.1	57.2

Date: 20-4-2015

Housing name: Beta industrial camp

Area name: Inside the room in the first floor (No. 109)

Pollutant name	2:35 pm	4:35 pm	6:35 pm	Average
TVOCs	632	505	464	533.6
Carbon dioxide	725	531	606	620.6
Ozone	0.07	0.06	0.05	0.06
Carbon monoxide	0.4	0.2	0.6	0.4
Temperature	27.2	25.4	23.1	25.2
Relative humidity	53.3	52.4	49.2	51.6

Appendix D: Field measurements for TransGulf Cement Production camp

Date: 19-4-2015

Housing name: TransGulf cement production (DIP)

Area name: Kitchen + Dining hall

Pollutant name	2:25 pm	4:25 pm	6:25 pm	Average
TVOCs	474	535	412	473.6
Carbon dioxide	294	399	291	328
Ozone	0.07	0.06	0.05	0.06
Carbon monoxide	0.6	0.3	0.4	0.43
Temperature	26.5	25.6	24.2	25.4
Relative humidity	46.2	54.8	57.9	52.9

Date: 19-4-2015

Housing name: TransGulf cement production

Area name: Corridor between rooms in the ground floor

Pollutant name	2:38 pm	4:38 pm	6:38 pm	Average
TVOCs	408	386	402	398.6
Carbon dioxide	297	282	218	265.6
Ozone	0.06	0.06	0.05	0.056
Carbon monoxide	0.8	0.1	0.3	0.4
Temperature	24.3	23.7	24.5	24.2
Relative humidity	50.5	50.3	57.9	52.9

Date: 19-4-2015

Housing name: TransGulf cement production

Area name: Corridor between rooms in the first floor

Pollutant name	2:54 pm	4:54 pm	6:54 pm	Average
TVOCs	410	399	391	400
Carbon dioxide	377	363	395	378.3
Ozone	0.05	0.05	0.04	0.046
Carbon monoxide	0	0	0	0
Temperature	23	22	22	22.3
Relative humidity	49.6	53.2	54.8	52.5

Date: 19-4-2015

Housing name: TransGulf cement production

Area name: Inside the room (No. 29)

Pollutant name	3:11 pm	5:11 pm	7:11 pm	Average
TVOCs	361	410	463	411.3
Carbon dioxide	431	460	466	452.3
Ozone	0.05	0.04	0.05	0.046
Carbon monoxide	0	0	0.1	0.03
Temperature	23.2	21.5	22.8	22.5
Relative humidity	55.6	55.6	60.5	57.2

Appendix E: Field measurements for Mirdif house 1

Date: 12-5-2015

Housing name: Mirdif house 1

Area name: Bedroom

Pollutant name	11:20 am	3:26 pm	5:25 pm	Average
TVOCs	557	327	297	393.6
Carbon dioxide	597	540	519	552
Ozone	0.05	0.05	0.06	0.053
Carbon monoxide	1.5	1.1	1.0	1.2
Temperature	25.8	25.6	26.2	25.86
Relative humidity	40.2	38.6	40.2	39.6

Date: 12-5-2015

Housing name: Mirdif house 1

Area name: Kitchen

Pollutant name	11:40 am	4:00 pm	5:55 pm	Average
TVOCs	403	230	292	308.3
Carbon dioxide	653	541	732	642
Ozone	0.05	0.05	0.06	0.053
Carbon monoxide	1.1	0.6	1.0	0.9
Temperature	24.5	23.7	27.5	25.2
Relative humidity	43.2	40.4	41.1	41.5

Date: 12-5-2015

Housing name: Mirdif house 1

Area name: Dining room

Pollutant name	11:32 am	3:50 pm	5:45 pm	Average
TVOCs	394	230	258	294
Carbon dioxide	762	547	619	642.6
Ozone	0.05	0.05	0.06	0.053
Carbon monoxide	1.1	0.5	0.8	0.8
Temperature	23.7	22.9	26.9	24.5
Relative humidity	43.4	41.4	38.7	41.16

Date: 12-5-2015

Housing name: Mirdif house 1

Area name: Corridor

Pollutant name	11:25 am	3:35 pm	5:30 pm	Average
TVOCs	465	270	266	333.6
Carbon dioxide	598	556	593	582.3
Ozone	0.05	0.06	0.06	0.056
Carbon monoxide	1.5	0.9	1.0	1.13
Temperature	25.3	25.5	25.7	25.5
Relative humidity	41.8	38.9	39.3	40

Appendix F: Field measurements for Mirdif house 2

Date: 8-4-2015

Housing name: Mirdif house 2

Area name: Bedroom 1

Pollutant name	4:00 pm	6:00 pm	8:00 pm	Average
TVOCs	518	208	298	341.3
Carbon dioxide	535	466	470	490.3
Ozone	0.04	0.03	0.04	0.036
Carbon monoxide	1.2	1.0	0.9	1.03
Temperature	23.6	19.9	21.3	21.6
Relative humidity	58.2	47.9	48.4	51.5

Date: 8-4-2015

Housing name: Mirdif house 2

Area name: Kitchen and Dining hall

Pollutant name	10:00 am	12:00 pm	2:00 pm	Average
TVOCs	427	289	258	324.6
Carbon dioxide	900	943	640	827.6
Ozone	0.06	0.05	0.06	0.056
Carbon monoxide	2.2	1.3	0.9	1.46
Temperature	24.9	24.4	25.4	24.9
Relative humidity	48.1	50.2	48.5	48.9

Date: 8-4-2015

Housing name: Mirdif house 2

Area name: Corridor

Pollutant name	5:00 pm	7:00 pm	9:00 pm	Average
TVOCs	433	366	402	400.3
Carbon dioxide	480	513	569	520.6
Ozone	0.05	0.06	0.05	0.16
Carbon monoxide	0.8	0.7	0.7	0.73
Temperature	23.5	24.9	23.6	24
Relative humidity	53.9	52	52	52.6

Date: 8-4-2015

Housing name: Mirdif house 2

Area name: Room 2

Pollutant name	4:00 pm	6:00 pm	8:00 pm	Average
TVOCs	496	285	370	383.6
Carbon dioxide	490	525	469	494.6
Ozone	0	0	0.05	0.016
Carbon monoxide	0.6	0.2	0.8	0.53
Temperature	23.3	19.6	24.8	22.5
Relative humidity	48.9	51.8	51.9	50.8