The Effect of Indoor Air Quality on Occupants' Health and Performance in Office Buildings in Dubai

تأثير جودة الهواء الداخلي في المباني على صحة العاملين وأدائهم الوظيفي في دبي

By

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Table of Contents

Abstract

As people spend most of their time indoors, enough attention should be given to the indoor environment conditions including the air quality. A lot of parameters should be tested and measured to determine if the indoor environment in office buildings is healthy enough for the occupants or not. This study is focusing on how the Indoor Air quality (IAQ) has a great effect on the performance and productivity of employees working in office buildings. Moreover, IAQ is directly related to the way the building occupants perform their daily tasks. To elaborate, a healthy indoor environment will lead to a better performance and an increase in the employees' productivity.

This paper is a research document that demonstrates the importance of indoor air quality control on the employees' health, performance and productivity. In addition, it will thoroughly explain the major factors that affect the IAQ of the office environment, how to control the poor IAQ in an office and it will provide key guidelines to provide a healthier office with a high satisfaction rate of employees.

In this study, four offices were selected in various locations in Dubai. The study was done through various phases including: walk-through investigation, subjective and objective study phases. Moreover, special attention was given to the key industries in UAE market and the selection of the office types was aligned to the study of the market. This study can be described as a comprehensive analysis for the indoor air quality issue in Dubai offices for the major industries including: Financial institutions, Academic Institutions, Furniture suppliers and Lighting solutions.

This document clearly summarizes the previous researches completed in the same area of indoor air quality and shows the common design practices in Dubai. The detailed analysis of the four case-studies was the first step to identify the design errors in Dubai offices and propose some solutions to control the poor indoor air quality problem, considering the critical consequences on people's performance, productivity and most importantly health. Qualitative and quantitative measures are used to collect the study data and analyze the current practices in Dubai offices.

In the qualitative research, the behavioral actions of people towards several variables are tested and how they will react to given circumstances, in this case the IAQ. The methods used to perform this research are surveys, and observation. This method helped to collect data about people's perception of their office environment and the signs of their discomfort. In addition, in the qualitative research, the science and technology is used to generate data. Different machines and instruments were used to collect as much as data as possible to form the final results of the study. Spot and continuous measurements were completed in the different zones within the selected offices , in order to test the key IAQ parameters: TVOC, Carbon Dioxide ,Ozone ,Carbon Monoxide, Temperature, Relative Humidity and Toulene.

The findings of this paper will enhance the working environment in Dubai offices. This study is not only a study reference or a design guide, but also a solid framework that can be followed by actions and regulations. In addition, this study finding will increase the level of awareness of indoor air quality in this part of the region and develop the sustainability approach in office environment, to protect the occupants' health and increase their performance and productivity levels.

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ملخص

بما أن الناس يقضون معظم أوقاتهم داخل الأماكن المغلقة، فإنه لابد من إيلاء الاهتمام الكافي للظروف البيئية في تلك الأماكن، بما في ذلك جودة الهواء. وهناك الكثير من المؤشرات التي ينبغي اختبارها وقياسها لتحديد ما إذا كانت البيئة المغلقة في مباني المكاتب صحية بما فيه الكفاية لسكانها أم لا. تركز هذه الدراسة على مدى التأثير الكبير لجودة الهواء في الأماكن المغلقة (نوعية الهواء الداخلي) على أداء وإنتاجية الموظفين العاملين في مباني المكاتب. وعلاوة على ذلك، ترتبط جودة الهواء الداخلي ارتباطا مباشرا بطريقة شاغلي المبنى في أداء مهامهم اليومية. وللتوضيح، فإن البيئة الصحية في الأماكن المغلقة تؤدي إلى تحسين الأداء وزيادة الإنتاجية لدى الموظفين.

تتضمن هذه الورقة بحثا يوضح أهمية مراقبة جودة الهواء في الأماكن المغلقة على صحة وأداء وإنتاجية الموظفين، بالإضافة إلى ذلك، فإنها تقدم شرحا مستفيضا للعوامل الرئيسية التي تؤثر على جودة الهواء الداخلي في البيئة المكتبية وكيفية التحكم في الجودة المتدنية للهواء الداخلي في المكاتب، كما أنها تعرض المبادئ التوجيهية الأساسية لتوفير مكاتب صحية أكثر، مع معدل مرتفع من رضا الموظفين.

في هذه الدراسة، تم اختيار أربعة مكاتب في مواقع مختلفة من دبي. وقد تمت الدراسة من خلال مراحل مختلفة بما في ذلك: مرحلة التحقيق الميداني ومراحل الدراسة الذاتية والموضوعية. وفضلا عن ذلك، فقد تم إعطاء اهتمام خاص للصناعات الرئيسية في سوق الإمارات العربية المتحدة. كما تم اختيار أنواع المكاتب بما يتماشى مع دراسة السوق. ويمكن وصف هذه الدراسة بأنها تحليل شامل لمسألة جودة الهواء في الأماكن المغلقة في مكاتب دبي لمجالات العمل الرئيسية بما في ذلك: المؤسسات المالية والمؤسسات الأكاديمية وموردي الأثاث وشركات حلول الإضاءة.

تلخص هذه الدراسة ، بوضوح ، الأبحاث السابقة المنجزة في نفس مجال جودة الهواء ، كما تبين ممارسات التصميم العامة في دبي. لقد كان التحليل المفصّل لحالات الدراسة الأربع الخطوة الأولى لتحديد الأخطاء في تصميم مكاتب دبي واقتراح بعض الحلول للسيطرة على مشكلة تدني جودة الهواء في الأماكن المغلقة، مع الأخذ بعين الاعتبار العواقب الهامة على إنتاجية وأداء العاملين، والأهم من هذا وذاك، على صحتهم. لقد استُخدمت التدابير النوعية والكمية لجمع بيانات الدراسة وتحليل الممارسات الحالية في مكاتب دبي.

في الأبحاث النوعية، يتم اختبار تصرفات الناس السلوكية إزاء العديد من المتغيرات، وكيفية ردة فعلهم تجاه ظروف معينة، وفي هذه الحالة هي نوعية الهواء الداخلي. لقد كانت الطرق المستخدمة لإجراء هذا البحث هي الدراسات الاستقصائية والمراقبة؛ فقد ساعد هذا الأسلوب على جمع البيانات حول تصورات الناس عن بيئة المكتب وعلامات انزعاجهم منها. وبالإضافة إلى ذلك، فقد تم استخدام العلم والتقنية في البحث النوعي للحصول على البيانات، كما استخدمت مختلف الآلات والأدوات اللازمة لجمع أكبر قدر ممكن من البيانات للوصول إلى نتائج الدراسة النهائية. كما تم استكمال القياسات الميدانية والمستمرة في المناطق المختلفة داخل المكاتب المختارة، وذلك بغرض اختبار معطيات جودة الهواء الداخلي الرئيسية وهي : إجمالي المركبات العضوية المتطايرة (TVOC) ، وثاني أكسيد الكربون، والأوزون، وأول أكسيد الكربون، ودرجة الحرارة، والرطوبة النسبية ، والتولوين (Toulene).

ستحسّن النتائج التي توصلت إليها هذه الدراسة من بيئة العمل في مكاتب دبي. فهذه الدراسة ليست مرجعا دراسيا أو دليل تصميم فحسب، بل إنها إطار متين يمكن أن تليه إجراءات وأنظمة. ناهيك عن أن نتيجة هذه الدراسة ستؤدي إلى زيادة مستوى الوعي بجودة الهواء في الأماكن المغلقة في هذه المنطقة وتطوير نهج الاستدامة في البيئة المكتبية بغية حماية صحة العاملين من هذه البيئة وزيادة أدائهم ومستوياتهم الإنتاجية.

List of Table:

List of Figure:

Chapter 1: Introduction

1.1 Background and Motivation

For years passed, global development for underdeveloped countries remained the main goal to achieve. GDP's (Gross Domestic Products), income per capita, industrialization and human development index are the most known criteria to consider a country as a "Developed" country. Meaning, the more a certain country can produce a high numbers in any of these three criteria, the more the country would be considered a developed country. In other words, GDP—gross domestic product—combines in a single figure the total market value of all final goods and services produced within a country's economic territory during a given period (Weslink, et al 2007). Well, this might be true in a time that is known of the post WWII era. Countries like Germany, Japan and Russia and most recently China started moving from a War minded controlled countries, to a more industrialized ones i.e. developed ones (Books 2001, Linden 2004, Harrison 2006). However; recently, and after all the Climate Change fears that are dominating the news around the world's media, the developing criterion has just added sustainability to its list. The former U.N Secretary General Kofi Annan once said "A developed country is one that allows all its citizens to enjoy a free and healthy life in a safe environment" (Canberk 2009). To achieve a healthy life isn't only done by providing all the necessary drugs and medicines for the public, rather a healthy life would be giving all the public awareness campaigns about the importance of saving the environment. This means that a developed country shouldn't be considered developed ones unless a proving record of sustainable actions is taken in order to save the environment. One of these countries is the United Arab of Emirates. The so called a complete dessert in the early 70's, it is now considered to be one of the most and fast developing countries in the world having a high GDP of $ 202 Billion (Perkins 2009), yet sustainable issues were never forgotten.

The massive profits that the United Arab Emirates received from the trade of the oil industries has injected hefty amounts of money in to the country, making it one of the wealthiest countries in the world (Perkins 2009). This has given a great opportunity for a rapid development in various fields, without the need of going through the standard development phases that form the initial cycle. The development cycle has covered limitless sectors throughout, such as Economical, Social, Educational, Medical, Architectural and several other key areas (U.A.E Yearbook 2004). This great achievement can be listed as a universal record for the developed countries; in its pace towards achieving the highest standards in almost every sector. However, unplanned rapid development may and will cause severe and unexpected setbacks to a certain factor of development. In this case, the action done by humans to develop their country, and the re-actor will be the negative effect on the Environment due to this unplanned action. A lot of changes were forced and had to be done to the land to build the high rise buildings. In general, a lot of development activities have taken place to be able to reach the peak of development vision, which lead to many environmental and health issues. In other words, ''Industrialization and urbanization have lead to increased levels of air pollution'' (Prasad et al 2003). The latest study done by the International Energy Agency (IEA) has shown that the annual CO_2, emission has increased from 51.6 million tons in 1990 to 130.6 in 2007(International Energy Agency 2009). This vital increase in CO_2 emission level is a strong sign for a serious outdoor air pollution saga. Both visible and invisible air pollution forms are caused by either natural or man-made factors. Some of the natural pollution sources are: Forest fires, wind erosion and evaporation of organic compounds. On the other hand, burning fossil fuel, fertilizer dust, pesticides and smoking are all man-made sources of air pollution. Referring to the UAE, as it's the area of this study, various studies have shown that in the major cities: Dubai and Abu Dhabi; the greatest source of urban air pollution is the vehicle emissions (Lansari 2007).The air quality is affected by the emanate of various gases such as carbon monoxide (CO), oxides of nitrogen (NOx), volatile organic compounds (VOCs) and particulates (PM_{10}) .No matter what the source was, the air pollution is a crucial phenomenon that affects humans' health, in the first place. In fact, health-effects are not mainly "dependent on emissions and outdoor concentrations, rather they are dependent on doses received by individual". "Doses, in turn, depend on the outdoor and indoor concentrations and the duration the individual experiences it" (Prasad et al 2003).

This air pollution problem raises a major question: Does the effect of air pollution stop by the outdoor environment, or does this dangerous and fast spreading phenomenon invade the indoor environment? Unfortunately, most of the outdoor pollutants can be transferred to the indoor environment through different mediums, such as: the building openings (doors and windows) and ventilation system which is the main concern. Furthermore, there isn't much attention given to setting regulations/guidelines to the indoor air quality control, while focusing on the infrastructure development and outdoor air quality Rules. The indoor air quality is categorized as one of the major environmental hazards to national's health (EPA 1995, Hetes et al. 1995).

Various machines used in the office buildings can be considered as indoor pollutants such as photocopying machines, fax machines, digital duplicators and laser printers. Moreover, a lot of smaller products also can affect the IAQ of an office such as correction fluids, pens/markers, and carbonless copy paper (Hetes et al. 1995), besides the furniture pieces, textile, curtains, rugs, etc. Also, human activities, such as smoking, cooking, body odor and cosmetic odors can add to poor IAQ (EPA, 2006). All these factors that may be invisible, but can cause drastic effects on the IAQ which is directly relative to the occupants' health

Since pre-historic times, energy has been one of the major driving forces for the development of civilization (Apte et al. 2009). Worldwide, the use of energy is growing rapidly compared to the available supply. Various studies have stated that the total energy consumption in the UAE has increased from 122 thousand barrels of oil equivalent per day (boe/d) in 1980; to 530 thousand boe/d in 1998 (Organization of Arab Petroluim Exporting Countries 1999, El Raey 2006,). As a result, the 21st century has required introducing a new concept of energy savings. The two major parameters for saving energy are changing the mindset and lifestyle; by being more conscious and careful while using energy, such as switching off lights; or/and ''reducing the energy consumption of end products by the means of recycling'' (Apte et al. 2009). One of the energy saving plans applied in the UAE is reducing the residential and commercial space sizes. This could be an effective solution for energy reduction; however, the indoor health environment wasn't given much attention in all that matters. Imagine spending minimum 8 hours every day in a small office; with a very high concentration level of indoor pollutants, such as dust, perfumes, machines, VOCs, etc., besides the regular problems of the ventilation maintenance. The full picture explains the assumption of vital health issues due to the bad indoor air quality measures. Because of all the listed reasons, there is a strong need to explore the world of offices air quality to test, measure and evaluate the indoor environment effect on the occupants' health.

1.2 IAQ in United Arab Emirates

Researches have shown that the "UAE suffers highest rates of asthma, with a 13% diagnosis rate" (Dubai Health Authority 2010). Another research done by the Department of Health and Medical Services has shown that respiratory diseases have emerged as the dominant feature in ill health in Dubai (Statistical News 2007). These high statistics has encouraged the government to introduce a new Respiratory Education Project to ensure that the asthma diagnosis and care is managed efficiently by the doctors and the nurses available in the country. Thinking of the problem from wider perspective; in terms of money efficiency and time management, and as the old saying mentions, protection is better than cure. In other words, the problem should be solved from its roots, rather than waiting for the results, and then taking initiative to solve it. The studies have shown that poor Indoor Air Quality is the main reason for most asthma cases globally (World Health Organisation 2000). Moreover, it can be a reason for developing more chronic respiratory diseases, such as heart diseases and lung cancer (Kim and Paulos 2009). As people spend more than 90% of their time indoors, the issue is very crucial (EPA 2009). More often, in most of urban areas around the world, people tend to spend the greatest part of their time indoors (Carrer 2001). Thus, ensuring the ''good'' quality of air where most people spend their time in UAE is essential and warrant studying.

1.3 Motivation

It is strongly believed that thoughts, which are based on facts, are extremely vital and are considered first form of action capable of influencing a change in a certain matter. Therefore, various reasons had shed its impact on choosing the Indoor Air Quality in Dubai's office buildings as the core subject of this comprehensive research. One of the main reasons was the health risk an employee face due to bad IAQ. By having a closer look on the current health conditions in the U.A.E, and referring to the population's Health annual Reports; numbers has its impact on figuring out there is a direct relation between the health reports results, people's life-style common daily activities and IAQ. Although the bad IAQ effects are not physically numerated, but still the effects are dangerously serious and cant in any matter be neglected. A quick action needs to be taken to solve the indoor environment problem.

1.3.1 Life-Style

Studies have shown that the U.A.E offers excellent standards of living to the citizens whether Emiratis or Expats. Starting with the Emiratis, the most effective tool for the socioeconomic assessment is the monthly income scale. The average salary of a fresh university graduate for a U.A.E local is around ($4,000 to $6,000) per month; while in nearby countries such as Lebanon or Syria, the average salary of a fresh university graduate is ($100 to $200). A global survey distributed to test people's perception on the luxury-life, stated that 26% of the respondents believe that luxury is a lifestyle and not an extra to their way of living in UAE. While in Netherlands for instance, 49% of the respondents, believed that luxury is way beyond what is needed (Synovate, 2009). From the Expats point of view, a survey on the Expat Economics has stated that the expats in the UAE have a noticeable improvement in owning "luxury items". (HSBC Bank International Expat Explorer Survey 2009). Moreover, after questioning more than 3,100 expats living in the UAE, the results showed that 62% of the respondents have ''employed at least one member of staff and 55% own more than one car'' (HSBC Bank International Expat Explorer Survey 2009). All of the above results of testing the luxury level in the UAE for both: Emiratis and Expats clearly spot the fact that this oil rich country is overwhelmed and extremely concerned on achieving an easy lifestyle to its nationals.

With all the provided luxury, expected side effects and negative effects will take place.

For instance, Sheikh Zayed Road, a well known highway in Dubai stretching for roughly 4km, holds various numbers of aligned hotels, cafés, restaurants, offices and residential units; yet people still tend to use their cars, taxis or the metro to move from one point to another nearby point on the same side , rather than travelling on foot . If a comparison is to be made between the lifestyle in the UAE and a developing country like China, a crucial difference will be found in the travel method. China citizens usually travel on foot, use bicycles or motorcycles, rather than using cars intensively (Hamid, 2006). On the other hand, the statistics show that the increase in the number of vehicles between the year 2002 and 2003 is 9.2-thousand (Al-Zubaidi and. Sabie 2007). This huge difference is all due to the fact that owning a car in

U.A.E is considerably easy and affordable. Thus, using the car drastically has become a habit rather than a need even if it's a nearby distance. This means that people's activities are all indoors, which rings a bell for the essential need for the Indoor Air quality control plan.

Another parameter of UAE's life-style is the excessive use of air conditioning systems in an enclosed environment, due to the high temperature and humidity reaching 78% year round (Barnwell 2009). As mentioned previously, people spend 90% of their time indoors (EPA 2009), which introduces a new area of research for this region, to achieve a healthy and safe indoor environment

1.3.2 Energy Consumption

Sustainable development is a major strategy that has been implemented in the UAE in recent years, where "energy and carbon emissions per head are one of the highest in the world" (Wilen 2008), which by itself pose a very big issue in regards to the outdoor air pollution and its direct effect on the indoor air quality. Various statistics have shown a rapid growth in the total demand of the electricity by 10-15% on annual-basis, due to the fast population increase (Wilen 2008). Moreover, thinking of the long-term plan, many researches state that the estimation of the power shortage by 2010 is around 20 gigawatts, which is equal to 15 nuclear plants (Wilen 2008). As a result, the government has taken crucial steps towards saving energy, cutting cost and maintaining sustainability to achieve a healthy environment; especially indoors. These steps are and will help in decreasing the demand of energy thus yielding to increment in the sustainability of Dubai.

First of all, Dubai Department of Environment and Water has set new rules and policies to control the electricity consumption level by managing the power bill, and it is active since March 2008. The expatriates and nationals have different power rates, as for the expatriates, a covariant relation between the consuming amount and the rate for each 1 kWh (Wilen 2008). This could be a practical cost reduction method to change people's behavior, in regards of energy waste, even if the users' inceptive was to cut the power bill, rather than thinking of the energy condition . Due to the hot climatic condition, people in the UAE are familiar with the intensive use of air conditioning system throughout the year. Shutting off the outdoor air inlet is a good temporary solution for energy saving; however, it inevitably introduces high pollutants concentration indoors, which leads to a negative effect on the Occupants' health caused by the poor IAQ. Moreover, most of the office buildings depend on the central air conditioning system for ventilation. The temperature level is usually set to very low temperatures that can create thermal discomfort for the building's occupants (Fadeyi and Taha 2010), to the extent that they can spend their day wearing jackets in the offices. The usual solution for this problem is to switch off the air conditioning system completely, which will lead to another thermal discomfort condition because of the hot weather, and most importantly, poor indoor air quality due to the lack of ventilation.

1.3.3 Economic and Social

A bad indoor air quality has it various effects not only on health, but also on the social and economical aspects. People lack the awareness of the relation between the indoor Air Quality and Occupant's indoor activities (Kim and Paulos 2009). An office with extremely bad indoor air quality faces the challenges of making a loss by end of the year; not because any lack or tardiness from the employees ,but because they are taking more than the normal sick leaves days and skipping extra working days ,which relatively affect the growth of the company they work for. Researches have shown that the increase in CO_2 levels from bad IAQ has a direct impact on occupants' health and concentration levels (Samuel 2009). Although it may be a bit complicated to collect actual figures on the economical aspect of the Bad indoor Air Quality, but the massive increase in the staff sick leaves, besides the drop in the staff performance and productivity are all strong evidences for the high economical losses for any company (Fisk 2008).

However, not only the increase in CO_2 levels will cause such problems; but even an old piece of furniture or carpet will cause a significant decrease in an employee work output (Little and Johnson 2000). If this problem is not addressed and solved promptly, the consequences will cause huge economical loss. Fisk (2000) evaluated a study about bad indoor air quality in the U.S and came up with estimation that if sick building were to be cured from bad indoor air quality, the U.S would save a number between $10 to $30 billion a year (Little and Hodgson, 2008 and EPA, 1989).

The U.S isn't the only country facing this problem. Dubai, which holds numerous amounts of commercial offices due to its free zone law that is been dealt with in the city, faces the problem of poor indoor air quality ;in terms of extreme high number of employees being diagnosed with asthma (Dubai Health Authority, 2010). As these offices aren't concerned about the bad indoor air quality, due to the poor awareness campaigns about negative effects that bad indoor air quality posse on the people's health and the reign's economy. Therefore, bad indoor air quality is one of the major problems an office would face that could retain the employee serving his/ her job at the highest standards, thus causing an extreme economical loss to the organization that an employee is working for, leading to a catastrophe that won't be controlled unless a serious action is taken.

To address this concern, this study tends to examine the indoor air quality in various office buildings in Dubai, and create a link between the occupants' health conditions and the indoor environment standards.

1.3.4 Performance and Productivity

Historically speaking, the main function of the ventilation system was to maintain a comfortable indoor environment for the building occupants (Wyon 2004). However, with all the subjectively high level of pollutants available both indoors and outdoors, the specified function has shifted to a totally opposite direction, causing occupants discomfort, health problems and lesser amount of productivity produced. In regards to offices indoor environment, many researches stated that occupants' performance and productivity are directly linked to indoor air quality (Wargocki et al. 2000). For instance, offices should maintain a certain temperature so that no sweating or shivering acts are common between the employees. Too cold or too hot climates will cause discomfort that leads to terrible performance by the employees, which decreases the individuals' productivity. Various studies on the main three office tasks: typing, addition and proof-reading have shown that the good indoor air quality will positively affect the stated tasks speed and accuracy. Statistically, according to many assessments of IAQ, every decrease by 10% in the air quality dissatisfaction proportion will cause an average of 1.5% increase in the workers' productivity (Wargocki et al. 2000). The positive correlation found between the air quality and performance is a key issue to consider, especially that the effect is not only limited to the individual, but also the society and the economy in general. The indoor air quality problem shouldn't only be the employees' concern, in regards to the health and performance matters; however, every employer should be thinking of the indoor air quality level , to achieve a satisfactory positive report on the cost –benefit calculation, in which the society and the national economy are dependent on (Wyon , 1993, 2001, 2004). Having a regular maintenance for the air- conditioning system of the office is not the only method to assure maintaining a safe and healthy indoor environment, and as a result, a higher productivity and performance rate. The lighting, furniture, wall and floor coverings, equipment, textiles and ventilation system are all major sources for vital indoor pollutants that everyone is exposed to during the daily activities. Therefore, more attention should be given to the indoor air quality control to: maintain a healthy environment to achieve extreme work satisfaction and better personal development while hoping for a better economy.

1.4 Significance of the Study

1. Data collected from this study can be used by researchers for further studies that are related to building design, human health, Occupants' behaviour and Comfort Zones.
2. This study can help in reviewing the local policies and setting new policies to control indoor air pollution.
3. This study will expand people's knowledge in this area, and increase the awareness of monitoring the Indoor Air Quality in this region, especially that the architecture and Real estate field are facing a rapid development in the U.A.E

Chapter 2: Literature Review

2.1 Indoor Pollutants-Sources

Since 1970, massive amount of pollutants were found indoors, which cause a high number of complaints from buildings' occupants (Codey 2004). Various publications stated that the Indoor Air Quality (IAQ) is ranked as one of the top four problems that the public is facing (Smith and Bristow 1994). A lot of indoor air pollution sources that release gases or particles can be found in an office, from some interior design tools such as Upholstery, furniture and Carpets. Moreover, electronics and technology have had its impact on the environment as well. For instance, personal computers are compulsory in almost every commercial environment; their side-effects particularly on the office-environment must also be highlighted in regards with their effect on IAQ. Furthermore, the occupants' activities, such as talking, breathing, spraying perfumes are all very sensitive parameters to control in every environment, especially offices, where large groups of people are communicating, interacting and moving through different traffic flow. As a result; the study approach should be the pollution source reduction (Hetes et al 1995) rather than applying the treatment methodologies in a late phase after the pollution spread.

PCs. The recent decades has faced a rapid development in the electronic equipment market. Introducing the concept of connecting the people all around the world with what is called: Web, which in it turn created an extreme high demand of owning Personal Computers (PCs) or Laptops that will be used either at homes, offices, and hotels or even airports and coffee-shops with the availability of Wi-Fi or Wireless Connections. According to the Market research, 305 million computers were sold in 2009 worldwide, where the U.S bought 96 million of them (Gartner 2010). This technology has moved the whole society to an easier, technology-based phase; however, from a health-safety perspective - the PCs can be a vital source of indoor air pollution, especially in offices' environment (Bako'-Biro et al 2004)', where the application/use of such a technology is highly profound. PCs' parts and softwares are nowadays costumed to match various job categories and get involved in more than half of an employee's daily working hours (Burr 2000, Bako'-Biro et al 2004). Although the massive use of PCs has saved a lot of the work time and effort, many complaints were received from offices' users due to the "poor ergonomic design" of both the work-stations and PC part, which lead to applying major changes to the design (Swanson et al 1997, Cook et al 2000, Aras et al 2001, Lewis et al 2001, Bako'-Biro et al 2004). Despite all the modifications to the PC design, the users' complaints are still high (Bako'-Biro et al 2004), which can be explained as a physical discomfort due to indoor environment problems, including Indoor Air Quality (IAQ) parameters. Many researches stated that the computers emit higher pollution rate when they are on than when they switched off with an approximate rate of 10 to 120 times (Berrios et al 2004). Moreover, according to a study done on 30 females in a low polluted office by Bako-Biro et al (2004), it was discovered that the pollution from a 3 months old PC is three times the pollution of a brand new PC. It was also observed that the users' dissatisfaction level moved from 13% to 41%; when a new PC was replaced with an old one, besides the massive increase in the text-typing speed 9% more. It is important to note that the high level of indoor air pollution from the office equipment is not only caused by the PCs, as many other office equipments emit pollutants such as: photo-imaging machines (copiers, printers and faxes), mimeograph machines and digital duplicators (Hetes et al 1995).

Starting with the highest emission rates -Volatile Organic Compounds (VOCs), are mainly emitted from printers (laser and ink-jet). Furthermore, as the printers are commonly used in all the offices in Dubai, it is essential to dig into all the previous studies done in this area, and highlight the available solutions/alternatives provided by the market. The office equipment pollution emission is mainly caused by off-gassing, operation or both (Lee et al 2001). For instance, the equipment that doesn't require supplies such as ink and paper emissions are from "off-gassing of residual organics" only (Lee et al 2001). Various researches stated that the pollutants emission rate vary according to the printer type, as VOCs and Ozone from Laser printers is significantly higher than the ones from Ink-jet printers (Lee et al 2001). This could be due to the different fusing processes that in return create a difference in the temperature generated and control a certain evaporation level of the organic compounds" (Lee et al 2001). Ozone is another strong pollutant found indoors because of the office equipment which is emitted from dry and wet-process photocopying machines, computer terminals, printers, Fax machines and digital duplicators (Lee et al 2001).

Paint. Paint is made up of pigments, additives, solvent and carrier; it is simply used to add color to interior elements (Waitakere City Council 2008). Moreover, it is also known to protect surfaces or increase their functionality; however- these kinds of paints are colorless. There are a lot of types of paints available; they are paint for artistic purposes for the most part come in water-colors, oils and acrylics. Other types of paint include glazes, which are clear coatings for various surfaces; lacquers; wood stains; and primers. However, researches have shown that consumer products, such as paint, are considered as key source of indoor air pollution, in regards to the chemicals emission (Oston et al 1981, Wallace et al 1987, van Veen et al 1999, van Veen et al 2002). Paint is considered a harmful element if not treated. In support, a lot of studies done in the United States have stated that there is a massive difference between the amount and the duration of the pollutants emission of stainless steel and painted gypsum boards within a controlled chamber. Also, as a comparison of painted and not painted surfaces, various researches stated that in the painted gypsum board the pollutants were long-lived –Over 200 days, whereas it didn't exceed the 3-4 days in the stainless steel board (Sparks et al 1999), this imposes a serious harm to any office users exposed to this source of pollution. Therefore in order to get a full coverage of the paint as an indoor pollutant, Alkyd paint- also known as Oil-based paint, which is usually applied in wet areas such as bathrooms within some commercial spaces, must be examined to check the severity of its hazards. Many tests proved that more than 68% the toxic chemical compound, named as Methyl ethyl ketoxime (MEKO) is emitted immediately after the application of the Alkyd paint on a pine board (Chang et al 1998). It is important to mention that MEKO is a material that is usually added by the manufactures to" prevent oxidative drying and improve the stability of the paint in the can "(Chang et al 1998). A good example for this type of paints is the linseed-oil based paint that used to be applied outdoors only, and for some decorative zones indoors (Fjallstrom et al 2003). Nowadays, this category of paint has moved to indoors application on walls and ceilings. An experiment was held to examine the effect of the Linseed-oil based on five various materials which are as follows: Wood, glass, gypsum board, fiberboard and lime-mortar. After the application of equal amount of paint on all the selected materials and with controlling all the other external factors, the results detected a difference in the Carbonyls emission, including: Mathananal, Ethanal, Acrolein, Propanal and Hexanal from one surface to another (Fjallstrom et al 2003). Moreover, a research done by Chang et al (2002) showed that the biocide, chemical substance for killing germs, found in the water-based acrylic paint (Latex paint) is a major source of Formaldehyde emission. Chang (2002) also stated that the application of the Latex paint is done through various layering techniques, and changing the biocide type found in the paint can rapidly decrease the formaldehyde emission to 55% in the final stage of the paint application.

Carpeting. Carpets are used in most commercial spaces, not only to add a touch of Luxury and prestige, but also to add depth and warmth to the space and create the overall visual harmony between the furniture pieces and the flooring. It is essential to consider the indoor environment health when using any design element indoors, and study the space traffic flow to choose the right materials that are durable, clean and healthy. Various researches have stated that carpets are one of the key sources of indoor air pollution, due to the emission of Voltalie Organic Compound (VOCs) (Guo et al 2004, Molhave 1982, Wallace et al 1987, Levsen and Sollinger 1993, Sollinger et al 1993, Sollinger et al 1994, Black et al 1993, Kirchner et al 1993). As a result, the concept of having a “Green-Label” testing is introduced by the Carpet and Rug Institute (Nussbaumer, cited in Jones 2008). Moreover, many studies stated that many other compounds are emitted from the carpets, such as 4-Phenylcylohexene that is responsible for the smell of the carpet (Sollinger et al 1994). Other studies proved that carpets could emit VOCs due to a chemical re-action between ozone and Non-Volatile Organic Compounds (Uhde and Salthammer 2007). Many of the carpet specifications and components have a direct effect on the amount of pollutants emitted from a carpet, such as: yarn type, primary backing, Secondary backing and the pile weight. As a result, it is highly recommended to determine all the fibers and chemicals used in any carpet production. A study done by group of researches on eleven new carpets, following the Australian standards, to test the total emission of VOCs have shown that under 100% solution dyed olefin category of products, the Orkney carpets showed the highest emission rates ranging from 3.32 mg/m^2 to 25.4 mg/ m^2, while the double diamond carpets results ranged from 0.01 mg/m^2 to 1.54 mg/m^2 (Guo et al 2004). Moreover, carpets are considered as key habitat for dust, which contains Fungi and Bacteria. A study done on 16 carpeted rooms demonstrated that no significant difference is found for the dust level (Der p 1) between various rooms spots: centre, front of coach or room corners (Loan et al 2003). It is important to spot that the different environmental elements, such as the temperature can influence the pollutants' emission rate. Various researches have found that there is a direct relation between the temperature and the VOCs emission Rate (Tarvainen et al 2004). Increasing the indoor temperature, known as Baking-out, is sometime es used as a way to increase the VOCs emission rate from carpets, and reach a lower concentration rate in the near future (Jan et al 1997, Borazzo 1993, Girman et al 1993, Girman et al 1989, Girman et al 1990, Hayward and Waselowski 1993, Hicks et al 1990, Offerman et al 1993). Moreover, the regular maintenance cycle should be considered to assure that carpets are maintained clean to avoid any complains of health problems from the building's occupants (Nussbaumer, cited in Jones 2008).

Building Materials and Furnishings. Off-gassing building materials, besides the interior decoration materials are considered one of the highest risk factors affecting the health of the indoor environment. In general, the "re-active" components of the building materials emit VOCs (Uhde and Salthammer 2006). Starting with buildings' foundation, various studies showed that the stones, with various shapes and sizes, used for either construction masonry or concrete are vital sources of the emission of Radon gas (Toxics 2001). Besides, many analytical studies were prepared to estimate both primary and secondary indoor behaviors that cause VOCs from the source- Porus building materials (Lee et al 2005, Uhde and Salthammer 2006). Researches stated that high VOCs emission rate is found in both the new and the renovated buildings (Wolkoff and Nielsen 2001). As a result, it is essential to carefully select the interior materials, to avoid the vital consequences of the chemicals' emission.

Another very common material used in the commercial spaces – offices furniture is Wood. Since 1920, various studies have taken place to examine the heat-treatment process of wood, and further researches were introduced with a wider scope in the same area, as the heat degrades the wood components causing chemical reaction that ends up with the emission of VOCs. (Mannien et al 2002). A study held by EPA (2005) has stated that each furniture piece can either emit or support the emission of certain amount of pollutants, especially VOCs due to the finishes used or the top-coatings applied, or simply the particles chemical re-action with the air causing Ozone (O_3), which could be referred to as "Indoor Chemistry"

(Wolkoff et al 1997, Uhde and Salthammer 2006). Studies have proved that most of the furniture coatings are major sources of VOCs emission (Ohura et al 2009). As a result, selecting the green coatings with the proper hygienic properties for the wood according to the usage is essential, rather than narrowing the selection on how easy it is to clean it, or the look/finish of the final product of the furniture piece. It is noticed that the amount of pollutants emitted from the wood surface depends on the wood type and the production process. Various studies stated that the air-dried wood blocks are known to release a higher amount of VOCs compared to the heat-treated ones by an approximate estimation of 8 times (Mannien et al 2002).

Ventilation: It's important to realize that ventilation is one of the most crucial processes in determining the indoor air quality. However, people working indoors are heavily exposed to numerous air pollutants generated from the building (Wu et al 2009). One of the main causes of air pollutant generation is poor HVAC systems with its bad ventilation structure; as well as the decrease use of natural ventilation. (Jamriska, Morawska and Clark 2000, Kolarik and Wargocki 2003, Faulkner et al 2004, Seigel 2008). Studies proved that air pollutant varies in formation (Wargock et al 2004, Seigel 2008). Dust mites are the most common air pollutant to be generated from bad ventilation in an enclosed space, mites that are present in the dust of air-conditioner filters are potential indoor threat to asthma and allergy sufferers (Arlian 1991; Kaliner and White 1994, Wu et al 2009). A lot of studies linked mites to air condition filters, as it is thought to be a perfect habitat for mites breeding (Clausen, 2004, Grandenz et al 2005, Wu et al 2009). This is due to the low regular maintenance of the filters. However, poor maintenance of filters isn't the only the reason of increasing air pollutants in an interior space. Studies have shown that the process of increasing the rate at which outdoor air is supplied to the building decreases indoor air problems (Jamriska, Morawska and Clark 2000, Kolarik and Wargocki 2003, Faulkner et al 2004, Seigel 2008, Wu et al 2009). The other processes involved in ventilation however, are equally important. Buildings with high ventilation rates may suffer indoor air problems due to an uneven distribution of air, or insufficient exhaust ventilation. Even in a well-ventilated building, there may be strong pollutant sources which impair indoor air quality (Kolarik and Wargocki 2003 Mendell, Gomez, Seppanen, Brunner 2008). Although, HVAC system can promote indoor air quality, when proper/healthy procedures are not followed, indoor air problems may result. A lot of factors play a major role in malfunction performance of an HVAC; these include design aspects, condition, poor maintenance and misplacing of HVACs units (Mendell et al 2008, Seppanen et al 2005)

People Activities: The first phase of a space layout/design planning is identifying the use of the space according to the occupants' behavior/daily tasks. It is essential to understand that there is a strong direct relation between the indoor environment and the occupants. Most of the researches focus their study on the effect of the indoor pollution on the occupants' health or performance or both, without noting that the occupant-related activities can cause indoor pollution, in the form of VOCs and CO_2 (Luoma and Batterman 2001) , at the first place. With simple meaning, the respiratory events, such as sneezing, coughing, breathing and talking can all spread viruses in the indoor closed space (Gupta et al 2009), which as a result, could infect the rest of the space users. From a health protecting perspective, other habits such as smoking is easier to control, because they are categorized under self-driven habits. A fact sheet produced by World Health Organization (WHO) proved that tobacco smoke is the hidden reason behind most of "chronic obstructive lung diseases" leading to the death of "one in every ten adults worldwide". (WHO 2002). Moreover, various experiments have taken place to test the indoor pollution level in a smoking area, and the results have shown that the concentration of "five carcinogenic elements (Cr, Ni, As, Cd and Pb)" was massively higher; compared to a non-smoking area (Slezakova et al 2009). In addition, second-hand smoke that is inhaled by non-smokers is a vital issue that kills 53,000 non-smokers in the U.S every year (American Non-smokers Right Foundation 2006). As a result, indoors smoking ban policy was applied in the U.AE to protect people's health and save the environment. Moreover, the violators of the smoking fine will pay a fine that ranges between 1,000- 8,000 AED, while the establishments will be fined from 10,000AED to 80,000 AED (Ashfaq Ahmed 2007). Continuous researches must be held in this area with a quantitative and qualitative approach to update the smoke regulations on regular basis.

The table below summarizes the sources of indoor pollution in office buildings.

Table 2.1: Sources of indoor air pollution in offices

Source	Emission(s)	Reference(s)
A. Office Equipment (PCs, printers, photocopiers)	1. VOCs, Ozone 2. Styrene, Formaldehyde, toluene, Phenol, 2-ethylhexanol	1. Lee et al 2001 2. Bako-Biro el 2004
B. Paint	1. Methyl Ethyl Ketoxime (MEKO) 2. Matahnanal, Ethanal, Acrolein, Propanal and Hexanal (Carbonyls)	1. Chang et al 1998 2. Fjallstorm et al 2003
C. Carpets	1. VOCs 2. 4-Phenylcylohexene	1. Guo et al 2004, Molhave 1982, Wallace et al 1987, Levsen and Sollinger 1993, Sollinger et al 1993, Sollinger et al 1994, Black et al 1993, Kirchner et al 1993, Travainen et al 2004, Jan et al 1997, Borazzo 1993, Girman et al 1993, Girman et al 1989, Girman et al 1990, Hayward and Waselowski 1993, Hicks et al 1990, Offerman et al 1993 2. Sollinger et al 1994
D. Building Materials and furnishings	1. VOCs 2. Radon Gas 3. Ozone	1. Uhde and Salthammer 2006, Lee et al 2005, Wolkoff and Nielsen 2001, Mannien et al 2002, EPA 2005, Ohura et el 2009 2. Toxics 2001 3. Wolkoff et al 1997, Uhde and Salthammer 2006
E. Ventilation	1. Dust Mites	1. Arlian 1991; Kaliner and White 1994, Wu et al 2009
F. Smoking	1. Carcinogenice elements - Cr, Ni, As,Cb and Pb	2. Slezakova at al 2009

2.2 HVAC and IAQ

This section of chapter 1 will focus on the relationship between Indoor Air Quality and HVACs. It starts with a definition of HVAC systems and takes a look at some of the types of systems in use. This section then draws attention to the effects of HVAC systems on indoor air quality. Greater focus has been given to the negative effects as these ones can be dangerous to workers' health.

The following section will focus on filters and their effect on indoor air quality. A description of filters is then followed by an examination of some of the common types of filters. This is followed by an explanation of the effects of filters on indoor air quality. Moreover, an examination of how maintenance affects indoor air quality has been done. This has been followed by a comprehensive examination of the case studies done on HVACs and indoor air quality. A chapter summary on both sections has been provided.

2.2.1. What is HVAC?

A HVAC system works by drawing in fresh air from the external environment and mixes it with air in the internal environment. The mixture of air is then cooled or heated and then filtered before circulating it into the workplace. It is assumed that when HVAC systems are put in place, they replace the polluted indoor air through dilution (Wargocki, and Jukanovic 2005). There are three major functions that the HVAC serves. It prevents exposure of people to sources of pollutants by placement of physical barriers and use of pressure-air relationships. It also eliminates contaminants through dilution using ventilation mechanisms. Third, it focuses on cleaning air pollutants through filtration. There are certain components that are present in HVACs and these include: the supply fan, the water chiller, the cooling tower, the boiler, the control, the self contained cooling or heating unit, the exhaust fans and air outlets, the return air system, the terminal device, and the ducts.

There are a number of factors that must be considered when operating a HVAC system. The ventilation system design is an important aspect because the ability to deliver a certain capacity of air is dependent on the number of people that were estimated to occupy that building. A storage room that becomes an office space will necessitate corresponding changes in the HVAC system. Outdoor air supplies are another important concern in HVAC operations too. The system requires a sufficient supply of outdoor air so as to dilute the pollutants that may have been released from office equipment, people, products and furnishings (Bako-Biro et al 2004). Ventilation air distribution is vital in according these occupants a certain degree of comfort. Outdoor air quality must also be considered when operating a HVAC system. If there is dust, pollen, carbon monoxide or any other source of contaminant, then this could find its way into the ventilation system. HVACs that have the right filters are designed to trap such particles from outdoor supply. However, to control gaseous pollutants, one may require highly specialised equipment that cannot be accorded by the HVAC.

For HVAC systems to work, considerations need to be given to the degree of space planning. For example, if a computer or another heat generating device is placed directly under the HVAC's thermostat, the system will assume that the building is warm and will keep delivering too much cool air. Conversely, the use of certain partitions in a work area may block air flow and this minimise the indoor air quality of the system (Zhu et al 2006).

2.2.2. Types of HVAC

There are various types of HVAC systems. One such type is the single zone HVAC. It has only one air handling unit. Although it has the ability to serve more than one area, the other areas need to have similar cooling, ventilation and heating requirements. All areas that have the same control or thermostats are called zones and some accountability needs to be done for those cooling and heating load differences.

The second type of air filter is known as the multiple-zone. Such a system has the capacity to cater to several zones. It provides different temperatures to different zones by cooling and heating airstreams in those areas. Sometimes, these kinds of HVAC systems may deliver air through constant temperature but may vary the airflow volume. Alternatively, they may moderate room temperature through a supplementary system such as perimeter hot water piping.

A constant volume HVAC is also another classification. This one works by delivering a constant volume of airflow to particular spaces. The alterations in the temperature are handled by switching the air handling unit off or on. They are also done through heating or cooling the air.

The fourth type is the variable air volume system. This one works by changing the volume of the air delivered rather than changing the temperature of that air. It is only on a seasonal basis that variable air volume system temperatures can be reset. Adjustments are also made depending on the loads under consideration since overcooling or overheating can occur. Variable air volume HVACs tend to have many cases of under ventilations once a minimum quantity of outdoor air has not been set.

2.2.3. HVAC effect on indoor air quality

There are a number of challenges that emanate from HVAC systems. First, there's an inadequate amount of fresh external air that actually comes into the workplace. A large number of HVAC systems only allow 20% external air to mix with 80% of re-circulated internal air. This compromises on the indoor air quality that workers are subjected to. However, the number of HVAC systems that re-circulate air is dependent on the geographical region of the office building. Bell and Standish (2005) have shown that fifty percent of all office buildings in Europe re-circulate air. This contrasts sharply to about ninety percent of office buildings in the United States. The average number however is 80%.

The HVAC systems in use also have limited mechanisms for controlling contaminants. Consequently, continued use of HVAC systems will lead to accumulation of many contaminants in the workplace environment. The contaminants may sometimes come from moulds or microbial growth in the HVAC system. Alternatively, it may be high humidity or presence of water near the cooling, humidifying and dehumidifying components of the HVAC. Sometimes, oil residues may have been left behind during the manufacturing process. The systems may also have sound and insulation materials that eventually contaminate it (Burroughs 2005). For contaminant sources, HVAC systems are not effective in controlling these exposure levels because the contaminant is not directly ventilated. It has been noted that sometimes the quantity of air needed to remove contaminants is large; a HVAC system cannot cope with the air exchange volume. Furthermore, a number of HVAC systems do not have provisions that allow worker control of ventilation rates as most of them have fixed settings.

HVAC systems often start operating prior to workers' entry into the premises and may shut down before they leave. Some HVACs have exhaust and intake vents that have been placed too close together. This makes workers susceptible to poor ventilation rates (Lee and Chan 2004).

Sometimes HVAC systems may be located in outdoor environments that are dangerous to workers. For instance, they may be found in busy streets, near loading docks or standing water and this would definitely minimise the ventilation rate in that concerned building (Zhao et al 2006).

Sometimes there could be problems with the design or installation of the HVAC system. For instance, if a drain pan was constructed poorly, then it can lead to the accumulation of standing water. Alternatively, it may be the installation of that drain pipe that could cause the development of standing water. If a drain has not been properly dimensioned, then this could also lead to problems in the indoor air quality of the system. If the selection of equipment is poorly done, then this may create a number of problems. First, air filters may not fit well into the handling units. This may lead to the passage of unfiltered air in the workplace (Johnson et al 2009). Alternatively, it could be the roof top handling equipment that has a problem. In this regard, the equipment may be too close to the exhaust steam and this may lead to the re-entrapment of pollutants. If there are air leaks in heat exchangers, then this could cause pollutants to be transferred from the exhaust stream to the supply air stream.

The above mentioned problems are associated with the improper selection of certain equipments. Sometimes, HVAC challenges could be linked to their designs. If the HVAC has been made in a way that allows snow and rain to get into the system through the inlet louvers, then this could ruin the indoor air quality (Simoni et al 2010). If the equipment has been designed in a manner that does not offer access to it for maintenance, then this may eventually prevent one from rectifying problems inside it.

When fans or duct systems have been poorly designed, this may lead to the poor distribution of outside air inside the office. If ventilation rates have been poorly specified, then a HVAC system may create low ventilation rates in the workplace. In certain circumstances, this may be accompanied by high levels of recirculation. Pollutant transfer may also be necessitated if the exhaust air is designed to have a higher pressure than the supply air in the heat recovery system (Maynard and Kuempel 2005).

Poor installation can also create a number of challenges for users of HVAC systems. Once dust and debris from construction are left in the system, then this can be regarded as a pollution source that affects the indoor air quality. Alternatively, the improper balance of air flows at the installation process may cause leakages, blocking, thermal discomfort and poor ventilation. If a duct has been disconnected from a duct system, this could lead to ventilation and thermal challenges.

The operation of the HVAC system may also hamper its success. In certain circumstances, there could be improper set points which lead to indoor temperature that falls outside the thermal comfort levels of workers (Jensen et al 2005). Alternatively, it may be the excessive humidity that emanates from high temperature, which may prevalent at the cooling coils. If the HVAC system does not operate well, then this could lead to the development of microbial contaminants and high humidity if the office facility is located in a humid region.

All these problems may subject workers to a diminished level of oxygen and an increased level of carbon dioxide. Poor humidity and temperature control may also come about once the HVAC system develops excessive cooling or heating capacities. Additionally, biological and chemical contaminant may keep building up to the point of compromising the indoor air quality. Poorly maintained HVACs also lead to extreme temperature which may distract workers from their respective tasks. They may report excessive levels of discomfort and will keep on being fatigued when they are at their work premises (Breyssea et al 2005). The HVACs described earlier can also cause irritating workplace odours. Dirt and dust may keep accumulating in the affected office building. Perhaps a worrying trend is the development of Sick building syndrome, which is characterised by fatigue, eye irritations, colds and flu, headaches and irritations in the noise (Bräuner et al 2008). These symptoms tend to reduce once workers have left the building. Godwin and Batterman (2006) explained that this was the case because of low ventilation rates. When ventilation rates go below 10 Ls-1 per person, then chances are that the person will develop SBS. Low ventilation rates are found to be very common in office buildings that have mechanical ventilation. In Sweden, Bordass and Leaman (2004) explain that forty eight percent of the buildings had ventilation rates that were less than the mandatory code values in mechanically ventilated systems. Among the buildings analysed, it was also found that twenty five percent of all the mechanically ventilated systems that possess heat recovery had these low ventilation rates

There is increasing evidence to show that multiple chemical sensitivity (MCS) tends to develop when individuals are exposed to chemicals or a number of chemicals. Such persons will report symptoms such as skin rashes (Ramachandran et al 2005). Throat irritations, nose and eye irritations, problems in the central nervous systems are other symptoms that are linked to MCS.

2.3. Filters and IAQ

Filters are used to take out particles from air. When proper filtration exists, chances are that the rest of the HVAC may be protected. Furthermore, filters contribute towards maintenance of good indoor air quality in office buildings. All air filters need to be maintained and selected in order to offer maximum filtration. This implies that the supply fan should not be overtaxed. The supply fan can blow out when no air filter exists (Yoon et al 2008).

2.3.1. Types of filters

Filter designs normally determine the kind of energy that is required to push air through them. Low efficiency filters only have the ability to prevent dust and lint from clogging the cooling or heating coils (Qi et al 2008). Medium efficiency filters have the ability to tackle smaller particles. High efficiency particles can filter very small particles. The only problem is that they tend to clog quite quickly (Clausen 2004).

Alternatively, filters may be classified on the basis of their design. Here, one may have the roll filter which has a set of rolls on it. There is the bag filter, the panel filter and the pleated filter as well. Pleated medium efficiency filters are preferable in the workplace as they do not require regular maintenance; they do not clog easily and protect both the indoor environment as well as the rest of the HVAC system (Kennedy et al 2007).

Filters effect on IAQ

Filters need to be properly selected. If this is not done well, then unfiltered air will be allowed to pass through the filters and this could damage the indoor air quality. Additionally, low efficiency filters can lead to the prevalence of a high level of indoor concentration of particles. Sometimes, the problem may stem from missing filters, which may have been lost in the operational process. This can lead to the entrance of polluted air in the workplace owing to the presence of unfiltered air.

Filters need to be cleaned and maintained regularly (Zhang and Zhong 2009). As a filter continues to load up with particles, it tends to become more efficient at removal of particles, but keeps reducing the pressure drop in the system. This eventually minimises air flow. When the filters are excessively loaded, they may blow out of their filter racks. This can cause clogging of coils, it may make ducts to block and will seriously compromise the indoor air quality (Moritz et al 2004).

Sometimes filters can be the source of VOCs, in a study carried out by Bernstein et al (2007), it was found that air filters in VOCs are a significant source of VOCs, which lead to Sick Building Syndrome (Kuo-Pin et al 2006). The analysis involved unused and used air filters. These were taken in a test chamber and incubated there for some time. It was found that the test chamber that had used filters reported excessive levels of acetone and formaldehyde. A parallel test was also done in order to determine whether the continued use of filters led to accumulation of VOCs. In other words, tests were done before and after use of air filters. It was found that acetone and formaldehyde concentrations were much higher after use of those air filters than before, the tests also revealed that microorganisms tend to survive in air filters. These creatures are the ones that emit acetone and formaldehyde (McHugh et al 2007).

Panel filters that are made of cellulose fibres enclosed in a frame are the common types of filters used in HVACs. Most of them can rarely remove particles that are less than 5 micrometres in diameter. This means that microbes such as fungi cannot be removed by this method. Living and dead fungi can pass through the HVAC system of an office building and may result in extra sensitivities or infections among workers (Sublett et al 2010). Dampened filters can also harbour the growth of fungi in the HVAC. Moisture in these air filters normally comes from cooling coils. The condensate from that area can dampen filters and thus minimise its safety. Once the fungi have grown to a sufficient level, they can be released to the workplace environment and eventually cause diseases.

2.3.2. How maintenance affect IAQ

Some HVAC system may be blocked due to excessive dust in the air vents. Alternatively, renovations may have been done in a particular building, but the HVAC system may have been left intact. As a result, it may end up having the wrong structure for the new building. Even office planning can affect the degree of satisfaction with the HVAC system. Air flow can be reduced by the placement of different kinds of materials in the vicinity of the supply vents. Maintenance may be necessary to correct this poor planning (Bluyssen 2009). Placement of heat generating equipment like photocopiers can be altered in order to reduce excessive cooling of the workplace.

HVAC problems are usually multifaceted. These are normally related to their design, operation and equipment. For example, presence of standing water in a cooling coil within a HVAC system may lead to the growth of microorganisms which may cause diseases like Sick Building Syndrome (SBS). Failure to properly maintain such a system can indeed lead to these problems. Therefore, poor drainage can occur when one does not fully maintain HVAC system (Huizenga et al 2006).

If maintenance is not done frequently, then air filters may not be replaced as frequently as they ought to be, this makes the building susceptible to odours, and even reduces the level of airflows within (Zampoli et al 2004). The cooling coils, drain pans, and other parts of the HVAC system ought to be inspected from time to time. This would ensure that any blockage is easily detected or any microbial contaminants can be cleaned. Failure to inspect and calibrate temperature controls or other controls in the HVAC system has contributed towards low ventilation rates, and problems with temperature and humidity in the indoor environment (Sundell 2004). Sometimes, failure to inspect the areas near the humidification system can lead to accumulation of microbes. From time to time, an organisation needs to do a thorough check of the cooling tower water. In this process, there should be treatment of that water with biocides (Chase et al 2004). If this is not done, then microbial contamination can occur. Furthermore, that same water needs to have corrosion inhibitors or scale inhibitors so that HVAC system performance is not compromised. If the pumps, chillers, fans, compressors are not checked frequently, then a company may not be in a position to detect their failures. This may lead to poor ventilation rates, thermal and humidification malfunctions.

Maintenance of the systems needs to be done through frequent operational checks. It also needs to be carried out through proper training of operators. There are maintenance system procedures that have been outlined in various codes. For the US, ASHRAE 2004 is applicable; they can also use PECI (ASHRAE 2005, ASHRAE 2004a, ASHRAE 2004b). In Europe, these have been outline in the EN 2000. Once those procedures are used, then an organisation can easily avoid all the elementary challenges that stem from HVAC systems. It has been shown that the need to constantly cut costs, the prevalence of inadequate training, and ignorance has led to poor maintenance of HVAC systems.

Aside from regular maintenance procedures that directly affect the HVAC system, there ought to be certain maintenance problems that span across the entire building. For instance, if indoor space has been divided, the newly created rooms may not be adequately served by the HVAC system. Also, if a building is expanded without alteration of the HVAC capacity, then ventilation and thermal problems may arise. If a certain work area has added air supply ducts without considering the pressure imbalances and air distribution system then this could reduce the degree of distribution of the same. On the other hand, the HVAC system or building may have remained the same, but occupancy levels could have been changed. When this occurs, there will be alterations in the internal thermal loads and this could overwhelm the HVAC system. Replacement of such a system will therefore be necessary. These changes in numbers may sometimes introduce an unexpected pollutant source that could increase the level of pollutant concentrations (Pope and Dockery 2006). If the HVAC system was properly maintained, then the need to alter ventilation rates would have been detected and implemented.

Maintenance also involves correction of other external environments that directly contribute to the air supply in the HVAC system. This can be done through the cleaning up of water spills and drainage of stagnant water near the outdoor air supply (Wang et al 2004). It is a known fact that water is considered as an important source of mould or fungi growth. These microbes eventually cause several diseases.

Case studies

Mendell and Smith (1990) carried out an analysis of HVAC systems versus the prevalence of SBS systems. In their investigation, they classified all HVAC systems into five categories: water based humidification with air conditioning, air conditioning devoid of humidification, simple mechanical ventilation and natural ventilation. It was found that SBS symptom prevalence was much higher in buildings with air conditioning than in buildings with natural ventilation (Atthajariyakul and Leephakpreeda 2004). Odds rations of 1.3-5.1 were found for symptoms that are related to the central nervous symptoms; mucous membrane symptom prevalence and upper respiratory symptoms had odds ratios of 1.4-4.8. However, air conditioning systems that had steam humidification were not found to have greater levels of SBS symptom prevalence than those ones without humidification. Those air conditioning systems that had liquid water as the basis for humidification were found to be more associated with SBS prevalence than the ones that had no humidification (Magalhaes et al 2009). Simple mechanical ventilation systems were not found to have higher SBS symptoms than the ones with natural ventilation. The authors noted that HVAC systems types do not directly affect health symptoms; nonetheless, they believed that these systems tended to be surrogates for other exposures that directly affect SBS. In other words, when looking at the effect of HVAC systems with regard to indoor air quality and worker's health, one should analyse the risk factors of those HVAC types. It was explained that workers were subjected to certain risk factors when using particular HVAC types. For simple mechanical ventilation, HVAC systems could be dirty during the installation process or may acquire dirt along the way (Jinming 2005). This causes them to release bad odours and pollutants into the environment. Such a system also had poor control of temperature because it did not cool it. It also subjected workers to excessive noise and humidity. Air conditioning systems on the other hand were found to have condensed moisture. They also had the ability to harbour microorganisms and thus affect workers' health. Those systems that had duct fans, coolers and humidifiers posed the danger of harbouring microbial growth. They also contributed to the overflow or leakage of water from the humidifiers. Chemicals could also be prevalent in the steam generators during water treatment. For all HVAC systems with recirculation, there was the risk of draft, noise, the spread of indoor air pollutants and contaminations of the HVAC system through re-circulated pollutants (Lin et al 2004). For decentralised systems or systems that had cooling and heating coils in different parts of the room, equipment failures were likely to occur due to inadequate maintenance.

As stated earlier, HVAC systems are a threat to the workers' health because they contribute to recirculation of air. It has been shown by Jaakkola and Miettinen (1995) that Sick building syndrome symptoms are more prevalent among workers who have mechanically ventilated office buildings with recirculation of air than those who do not have any recirculation of air in their workplaces (Wargocki et al 2008). The authors found odds ratios of 1.6 for nasal discharge. They also found odds rations of 1.3 for allergic reactions. However, these effects are dependent on the external ventilation rates (Zagreus et al 2008). If external ventilation rates go below 13.6 L s-1 per person, then recirculation can actually have the opposite effect-it can reduce SBS symptom prevalence. Once outdoor ventilation rates are greater than the above mentioned figure then the effect is as expected, i.e., higher ventilation rates. The reason behind these observations is that although air recirculation has the ability to disperse indoor pollutants, it also has the capacity to reduce indoor air concentrations of pollutants near the sources (Graudenz et al 2005). Recirculation of air also has the ability to filter particular concentrations. This is why recirculation of indoor air creates certain benefits and risks too (Morawska et al 2009, Pui et al 2008).

The importance of having natural ventilation system cannot be underestimated in indoor environments. Zweers et al (1992) realised that many workplaces had greater numbers of noise complaints, temperature complaints and skin complaints when they had sealed windows. The opposite was true for places that had windows that could open.

Bjorkroth et al (1998) wanted to find out whether HVAC components and ducts have the ability to emit chemicals and other sensory emissions. They did this study through the use of microbial and chemical measures; they also utilised a trained sensory panel. In the analysis, they found that almost all parts of the HVAC were considered to be sources of pollution. However, used filter fibres were found to be the worst cases. Some surfaces in the HVAC were dusty, oily and dirty. This caused them to produce a lot of contaminants (Mossolly et al 2008). Even increasing the airflow did not in any way contribute to the improvement of these contaminants. This study therefore proves that HVACs can be serious sources of pollution of the indoor air environment.

Sometimes used filters can be sources of pollution. Hitchcock et al (2006) wanted to find out how susceptible HVAC air filters were to fungal colonisation. They got new and used air filers, and treated them with antimicrobials. However, some were left untreated. They were all suspended in an area with high levels of humidity. It was found that fungal colonisation of the untreated filters was significantly higher and faster than in the treated ones.

Shea et al (2005) carried out an analysis of how the HVAC systems can exacerbate the level of VOCs in an office building. They found that if a VOC source was somewhere near the building, the HVAC source could distribute the contaminant into the workplace though the internal air flow patterns. Their study also wanted to show how HVACs led to increased vapour intrusions. It was found that the presence of air exchange gradients and air pressure differences contributed to a greater level of vapour intrusion and this affected the indoor air quality.

2.3.3. Summary

This Section has explained that HVAC systems affect indoor air quality through a myriad of avenues. They cause recirculation of air which minimises ventilation rates. They have limited ways of controlling contaminants and thus cause the indoor air environment to have pollutants. They may sometimes be associated with bad outdoor air supply and this leads to the spread of contaminants in the indoor air environment. HVAC systems also facilitate pollutant transfer through air streams. Alternatively, they cause excessive humidification if that component of the system has operational challenges. Excessive humidity also leads to growth of microbes. Generally speaking, it was found that poorly functioning or poorly maintained HVACs can lead to thermal discomfort, excessive humidity, poor ventilation rates and prevalence of microbes. These may lead to the development of SBS, lower work productivity, worker discomfort and Multiple Chemical Sensitivity (MCS).

It was also found that three major factors may contribute towards low indoor air quality and these include: A HVAC system that is contaminated (through dust, VOCs and other particles), and this ends up contaminating the air that is flowing through the HVAC. Alternatively, the system may be okay, but it could be the air that is being drawn through it. The air is normally contaminated through a wide range of outdoor sources. Lastly, it may be a HVAC system that keeps re-circulating indoor air; that is, providing a mixture of outdoor air and return air. This may contribute towards the spread of contaminants throughout the building and may eventually compromise the health of workers in the building.

Furthermore, the second section stated that air filters ought to be selected on the basis of their ability to protect the HVAC system as well as the indoor environment. An analysis of some case studies was carried out. It was found that most of these prevalence rates for SBS symptoms were much higher in air conditioning HVAC systems (without or with humidification) compared to those workplaces that used natural ventilations. For HVAC system with humidification, it was difficult to assess whether they had an actual effect on SBS symptom prevalence. The reasons identified for the existence of greater SBS symptoms in air conditioned HVAC systems and mechanically ventilated ones included: the inadequate maintenance, operation, design and construction of the system. In the case studies, it was also found that HVACs are problematic because they cause recirculation of air. They also increase the quantity of VOCs in the indoor air environment. HVACs increase fungal colonisation, reduce ventilation rates and can emit chemical pollutants.

Maintenance was found to be an important component of proper HVAC performance because it allows one to detect temperature control issues, blockages, water spillages, poor planning capacity and many other components that may not be working well. Lack of proper maintenance leads to poor temperature control, poor ventilation rates and even poor humidification levels.

2.4 IAQ effect on occupant's health and comfort in offices

2.4.1. Overview

A number of diseases have been associated with the office environment like sick building syndrome (SBS) and building related symptoms (BRS); in this section, they will be analysed first. Thereafter, a comparison of SBS and BRS will be done in order to comprehend the two types of diseases fully. This will be followed by an analysis of asthma as another effect (causes and facts on the disease will be examined). The next sub section will cover respiratory diseases. Other side effects will be analysed, and examples will be given. The chapter will end with a summary of the findings.

2.4.2. Sick building syndrome (SBS)

The term sick building syndrome refers to "all non specific vegetative and central nervous symptoms of the mucous membranes and the skin that occur in a building and normally disappear when the affected person leaves the building" (Engelhart et al., 1999). Examples of central nervous symptoms include: lack of concentration, fatigue, and headaches. It can be stated that workers' health and comfort are largely affected by indoor air quality through manifestation of SBS.

It may be difficult to identify specific causative factors of SBS, but Jaakkola (1998) propose an Office Environment Model that attempts to forge a relationship between SBS and the environment. In this model, it has been explained that all the symptoms used to describe the sick building syndrome are indicative of different health outcomes. Furthermore, the signs and symptoms may belong to a single environmental determinant or many of them (Heslop, 2002). There is a very complex relationship between environmental determinants and health outcomes in SBS so that one exposure can lead to several results. In this model, three major realms of the environment have been identified, and they include: the physical, the social and the psychological. In the physical environment, biological, chemical and mechanical factors can lead to the prevalence of SBS symptoms. However, the relationship is not as direct as one may expect. For example, an eye irritation in a worker may be a result of pollen, or it may be caused by the presence of formaldehyde in another individual. Therefore, the underlying mechanism for physical causes can be explained by toxicity, mechanical irritations, infections or allergic reactions (Skove et al., 1990).

One environmental factor will lead to different results owing to the level of exposure or the traits of the individual. Psychological factors such as perceptions of a certain disease or prevalence of stress may also lead to different results. In fact, work-related stress is an important determinant of SBS complaints. If employees feel that certain job demands or external factors place them in a reduced sense of control where they cannot take decisions freely, then they are bound to manifest symptoms of stress. Sometimes the stressor can be job-related, or it may be a physical quality such as poor indoor ventilation (Baker, 1989). One's social environment usually determines the rules and norms of how to react to SBS symptoms. Even rumours and organisational factors have a large role to play in this process. It is possible for psychological and physiological outcomes to affect the social environment, and this leads to different SBS complaints. A complex mix of air has the potential to mediate through dissimilar mechanisms and thus lead to different outcomes in SBS.

An analysis done by Engelhart et al. (1999) indicated that use of an office for previous storage and production of pharmaceutical goods may spoil indoor air quality. Some of the SBS effects that were reported by participants in this latter study included: eye irritations, headaches, unpleasant odours, dry mucous membranes as well as objectionable tastes.

A number of business owners have been creating office environments that are designed to consume or use up less energy. In doing so, these people have increased the degree of air tightness in buildings and thus created conditions that are conducive for the spread of microorganisms (Sundell, 1994). Biological agents may also lead to the development of SBS and if air quality is not adjusted to incorporate these components, then chances are that workers will develop symptoms. Those symptoms will show up when they are located in a building, and they will see them disappearing when they leave the building (Theodore, 1996).

Fisk et al. (2009) explain that the degree of ventilation affects SBS prevalence. This was illustrated through a secondary analysis of SBS prevalence rates. When the ventilation rates were decreased by half – say from 10-5 l/s-person – SBS symptoms increased by about 23 percent. On the other hand, when rates increased from 10 to 25 l/s-person, prevalence of SBS symptoms reduced by about 29%. A point of diminishing returns can be reached after which any increase in ventilation rates only leads to marginal decrease in SBS prevalence. Indoor air quality is assessed through the degree of ventilation (Teculescu et al., 1998). High ventilation implies a great degree of airflow rates, few tracer gases and low amounts of carbon dioxide (Kaczmarczyk et al., 2004). Once these qualities are present, then chances are that workers will not suffer from SBS symptoms (Teinjonsalo et al., 1996).

Utmost consideration needs to be given to objective causes of SBS since subjective factors can significantly increase SBS reports. Women tend to report higher instances of SBS than men. This may be as a result of differences in work-related and job-related characteristics encountered by men and women. In a sample collected by Brasche et al. (2001), it was found that men tended to work in better workplace environment conditions than women. For instance, they were exposed to natural lighting and had superior equipment than women. Additionally, men tended to be older and more educated than women. This had a significant effect on the work-related characteristics and the perception of the subjects on SBS. Gender differences at the workplace with regard to SBS sensitivity are directly affected by differences in work characteristics between the genders. Stenberg (1994) appears to support these findings as well. He also found that women tended to have greater paperwork loads and worked in conditions that made their psychosocial load unfavourable when compared to that of men. However, even when these work-related factors were held constant for men and women, it was still found that more women complained about sick building syndrome. Brasche et al. (2001) explain that this may be as a result of the psychic disposition of women to SBS. Therefore, a second theoretical model has been proposed to understand the prevalence of SBS. It starts from the prevalence of a "sick building" or an indoor office environment with certain air qualities. These are then perceived by workers; perception may be determined by work-related factors or one's psychical disposition. The latter factors may independently lead to SBS complaints or may do so indirectly by affecting perception, which then causes the complaints (Brasche et al., 2001) and (Stenberg, 1994).

2.4.3. Building related symptoms (BRS)

Building-related symptoms also refer to a set of symptoms that are associated with the office environment but diminish away from the workplace (Buchanan et al., 2008). BRS has several causes just like SBS, but is largely caused by poor indoor air quality. Ventilation systems are just part of this overall system (Seltzer, 1994). The rate of airflow between the external and internal environment must be taken into consideration when looking at ventilation systems. Buchanan et al. (2008) explain that there is a great link between air conditioning quality and BRS prevalence, especially when compared to natural ventilation. BRS may increase by figures between thirty percent and two hundred percent when offices switch between natural ventilation and air conditioning. Furthermore, the rate of fibre emissions also plays a role. Niemela et al. (2006) carried out an intervention strategy in an insurance company where they adjusted the ventilation system to eliminate contaminants. They also stabilised airflows and replaced duct linings. Building-related symptoms were measured prior to the intervention and before. It was found that general symptoms of BRS reduced from 15.6% to 6.8%. Fatigue, heavy headedness, headaches, concentration difficulties reduced by 15%, 22%, 2% and 5% respectively. Irritation symptoms reduced by 4.3%; irritation of the eyes increased by 6%; stuffy or irritated nose symptoms reduced by 20% while dry throats reduced by 1%. Lastly, coughs increased by 8%. These results indicate that there is indeed a serious value in the quality of indoor air. Since those changes can be measured quantitatively, then one can assert that BRS is highly dependent on the nature of the indoor environment. Building-related symptoms are highly prevalent when indoor environment quality parameters are unfavourable (Niemela et al. 2006). These can include high room air temperature, dust concentration on surfaces and on the air and concentration of volatile organic compounds (VOCs). These VOCs work by oxidisation. Oxidising agents such as ozone may initiate a chemical reaction that eventually creates a highly irritating product. Indoor chemistry has a great effect on BRS prevalence. Examples of the VOCs include formaldehyde, submicron particulate matter and certain low molecular weight organic compounds (Wallace, 1996). The products formed after the completion of these chemical reactions is even worse than the precursors in terms of effects created. BRS can be linked either to the indoor environment or specific building traits such as low ventilation, presence of contaminated carpets and air conditioning. Associations have been found between construction materials of certain buildings and prevalence of SBS. Alternatively, some unconventional indoor environmental quality traits also lead to these health problems; some of them include light quality.

Buchanan et al. (2008) explain that air filters are particularly dangerous because they tend to act as sites for chemical reactions between ozone and other chemicals. This creates hazardous products that eventually enter buildings. Workers are then exposed to chemicals that irritate them. Air filters contain a number of matrices that interact with ozone; they also possess certain particulate matter that may have been trapped inside. Once this matter interacts with ozone, it creates a dangerous environment for workers (Weschler, 2000). The reaction may occur in air filters alone, but also takes place in furnishings, internal building surfaces. In the study done by Buchanan et al. (2008), workers had a high level of sensitivity to air filters that had been used. These were manifested through certain symptoms that were associated with BRS, and they include: dizziness and headaches. As workers continued to be exposed to that kind of air, the above symptoms continued to increase. In fact, new filters substantially reduced susceptibility of workers to nose and eye irritations thus denoting that old filters affect employees' health. Concentration of ozone in the internal office environment is much lower than it is in the outside environment (Wolkoff et al., 2000). Consequently, ozone is incapable of creating visible BRS symptoms on its own, but it is its interaction with other compounds that leads to these adverse effects. Used filters are important sites for those reactions (Buchanan et al., 2008). In fact, these authors could quantify the degree to which ozone and filter mediums were related to the prevalence of BRS. Through the use logistic regression models, it was found that if polyester synthetic fibre (PS) was prevalent alone without interaction with ozone, or ozone existed without PS, then difficulties in concentrating and dizziness (some BRS symptoms) would occur. Corresponding odds ratios of 1.93 and 1.54 would be recorded. However, if workers were exposed to ozone and PS combined, then several other building related symptoms would occur such as coughs, headaches, fatigue and respiratory discomfort. The Odd ratios for these symptoms started from 2.26 and continued to 5.9. There was a multiplicative effect of ozone and PS, especially in terms of headaches, lower and upper respiratory symptoms. Therefore, BRS is highly related to the nature of air filters used.

General building related symptoms like heavy headedness, nausea, fatigue, dizziness and headaches are associated with high thermal discomfort. There is a building related symptoms' index that has been used to show how workers are affected by BRS as postulated by Brightman et al. (2008). In this index, four divisions of the factors have been identified. The first factor is classified as tiredness. A worker who has BRS may report any of the following symptoms: headache, stiffness of the back, neck and shoulder stiffness, dry eyes, strained eyes, itching eyes, drowsiness, fatigue, body itchiness or unusual tiredness. The second classification is mucosal irritation; this encompasses irritations to the skin, throat and the nose. The third one consists of neuropsychological factors. Some of the symptoms included here are: tension, dizziness, nausea, nervousness and difficulties in concentrating. The fourth one is lower and upper respiratory symptoms; it encompasses chest tightness, wheezing, and shortness of breath. Brightman et al (2008) did a survey of one hundred random buildings in the United States. It was found that 20% of all the participants reported one of the major symptoms identified by the researchers. This implies that employees' health is seriously affected by BRS at work.

2.4.4. Comparison of SBS and BRS

Both SBS and BRS are not associated with a certain etiology, and both tend to vanish once individuals leave a particular work building. Sometimes these terms are used interchangeably, but there are certain differences that are still prevalent. SBS and BRS are affected differently by ventilation rates. The incremental factor between SBS and ventilation differs from BRS and ventilation incremental factors. Furthermore, there are several differences in the symptoms identified as SBS and BRS. Mechanisms for detection of the two types of indoor air quality diseases are quite different with SBS being more complicated than BRS. SBS is more dependent on air-filter quality than BRS. Different classifications exist for these two concerns. A BRS index exists for all symptoms while an environmental model can be used to classify SBS symptoms. Ozone and the use of air filters adversely increase the possibility of developing BRS symptoms even more than SBS.

These two health issues are quite similar because they have very common effects upon workers. Some of them include: headaches, dizziness, nausea, eye irritations, mucosal irritations and fatigue. They are both caused by poor indoor air quality. All health complications respond to alterations or interventions in air quality. They are confined to buildings and office environments and usually go away when subjects leave the affected premises. Shown below is a summary of the similarities and differences.

Table 2.2: Comparison between SBS and BRS

SBS	BRS
Ventilation rate decreases of fifty percent lead to 23% increases in SBS	Reduction of 8.8% of BRS when ventilation is increased
General symptoms not classified	Classified through the BRS index
Chest complications not as common	Chest tightness and wheezing may occur
Air filter quality and ozone increase SBS	BRS and air filter quality link not fully understood
Both respond to poor air filter quality	
Not associated with any etiology	
Symptoms include headaches, dizziness, nausea, eye irritation, mucosal irritations and fatigue	
Confined to buildings	
Caused by poor indoor air quality	

2.4.5. Asthma

Asthmatic workers can be dramatically affected by the degree of dampness in their workplace (Ostro et al., 1994). Cox-Ganer et al. (2008) proved this when they analysed the respiratory health of employees in a hospital against the backdrop of their indoor environment. An assessment of the degree of dampness in floor dust, the air, furniture, and general surroundings revealed that workers reacted negatively to the water incursions and renovations being carried out in that environment. This was because new cases of asthma were reported at the time. Dampness usually comes from a series of sources; sometimes it may be the way a building was constructed (Koren and Utell, 1997). If this was done without sealing underground walls or protecting concrete slabs on the ground from water, it would eventually lead to the development of damp conditions within an office (Johnston et al., 2000). Additionally, prevalence of certain allergic factors in the environment such as dust led to these conditions (Molhave et al., 2002), (Nathell et al., 2004) and (Shwartz et al., 1993).

2.4.6 Respiratory diseases

When certain buildings are rich in moulds, one is likely to find those spores in the air. The spores can sometimes lead to very serious allergic reactions. They can take the form of a runny nose, throat irritations, sneezing and coughing or certain chronic illnesses like sinusitis (Davis, 2001). Dampness is the number one cause of moulds in the office environment. Sahakian et al. (2009) found that workers who complained much about dampness in their offices often had to ask for sick leave owing to respiratory symptoms. Their complaints were confirmed by an assessment of the degree of water damage in the home, water damage in the office, musty odour or presence of visible mould. It was found that these workers experienced upper and lower respiratory ailments and symptoms such as bronchitis, sinus infections, colds, seasonal allergies as well as fever. There was a positive correlation between the presence of mould and their health status. About seven percent of the workers had reported nasal symptoms, 3% suffered from low respiratory symptoms while 25% percent of the workers needed to leave their place of work in order to attend to their respiratory illnesses. It was also found that 5% has seen a pulmonologist while 10% had seen allergists. 12% had visited an otolaryngologist. It can therefore be said that damp office environments lead to development of the following conditions: colds and flu, sinus infections, runny or itching nose, bronchitis, lower respiratory symptoms such as chest tightness, shortness of breath, wheezing and coughing; constitution symptoms like fevers, fatigue, chills and muscle soreness also occur (Sakakian et al., 2009).

The presence of environmental tobacco smoke leads to the development of certain respiratory ailments like flu-like symptoms (one example is coughing); even more severe illnesses like bronchitis or lung cancer may arise (Leuenberger, 1995). When offices and other work buildings have poor ventilation, this exposes workers to ETS gases and particles that may increase their sense of discomfort at work (Strachan and Cook, 1997). In the end, this may lead to the above mentioned respiratory diseases. It has been shown that increasing the degree of ventilation can minimise the presence of ETS particles in an office, although the best remedy should be source control (Johnston et al., 2000). Exposure to indoor tobacco smoke has a much greater effect than outdoor tobacco smoke. When workers are not expected to be working inside an office, most of them will only suffer from respiratory illnesses as a result of active tobacco smoking or indoor ETS exposure at home (Mishra, 2003). Respiratory illnesses are often confounded by other factors such as age and exposure to passive smoke outside of work (Strachan and Cook, 1997). Since employees spend most of their time in the office, then their vulnerability to these respiratory ailments often increases when they are exposed to tobacco smoke at work.

Rhinitis and alveolitis can come about when an office environment is highly saturated with mould. Usually, the fungi from the air enter the nasal passages and then colonise workers' airways (Dockery and Pope, 1994). At this point, employees can develop inflammatory responses or allergic responses as seen through rhinitis. When a person has this disease, one is likely to develop an unremitting cough, display continuous wheezing and posses other symptoms that look like hay fever. Alternatively, continued exposure of workers to fungi can lead to the development of allergies in the alveoli and thus lead to a condition known as lymphocytic alveolitis. Sometimes this may even develop into fibrosis. Most fungi are found in repeatedly damp environments in the workplace (Fink, 1998).

2.4.7. General side effects

Indoor air quality can affect individuals' health through a series of illnesses, signs and symptoms. The major illnesses that are known are: SBS, BRS, asthma, and respiratory ailments like bronchitis, rhinitis and sinus infections (Hauschildt et al., 1999). All these diseases usually take the form of a number of common symptoms like: colds and flu, sinus infections, runny or itching nose, bronchitis, lower respiratory symptoms such as chest tightness, shortness of breath, wheezing and coughing, fevers, fatigue, chills and muscle soreness headaches, dizziness, nausea, eye irritation, mucosal irritations, heavy headedness, sensitivity of odours and tastes, skin irritations, throat irritations, nervousness, difficulties in concentrating, dry eyes, strained eyes, stiff back and stiff shoulders (Smedbold et al., 2002).

2.4.8. Others

Moulds can be a source of respiratory diseases in the office environment. Although many human beings respond differently to mould depending on sensitivity and susceptibility of the concerned person, this type of fungus can still be highly detrimental to workers' health. Moulds often produce certain volatile organic compounds, which are useful in indicating that foods have been spoilt by moulds (McNeel and Kruetzer, 1996). When these compounds are found in the air around an office, they can lead to irritations in the mucous membranes. They can also target the central nervous system and lead to symptoms such as dizziness, attention deficit and headaches. Moulds may also lead to other health complications such as vomiting, diarrhoea, liver damage, coughing blood nose bleeds and even impaired immune functions (Davis, 2001). It should be noted that the relationship between mould and BRS is not fully understood as it has not been studied. However, this is obviously a serious cause of concern. Some people's health status may make them highly vulnerable to mould and this heightens its effects in the workplace (Pirhonen et al., 1996). If a person has a disease like HIV/ AIDS, then that person is likely to respond adversely to the presence of mould. This is because the individual's immune system has already been compromised. The same thing applies to those patients who may be undergoing chemotherapy or certain medical procedures such as bone marrow transplants. A vast number of people will be exposed at the workplace and may develop the above-mentioned symptoms while at work. Those symptoms may disappear once they leave the mould infected area (Friedman et al., 1993). Furthermore, some types of mould are more powerful than others and may create adverse effects on the affected people. Consideration of mould as an indoor air quality issue represents a shift in the field. During the 1980s to the mid 1990s, most air quality contaminants were chemically based. Nonetheless, an interdisciplinary approach has been adopted by stakeholders in the field because now physical, biological and chemical constituents are acknowledged as sources of poor indoor air quality (Smith, 2002) and (Spengler and Samet, 2003). This is the reason why moulds are now taken seriously.

Some particles such as dust can lead to the development of particular irritations, discomforts and illnesses (Preuss and Mariotti, 2000). For example, nose and throat irritations may come about, and eye lining irritations can also be recorded. This occurs because dust exposure minimises the tear film stability, and adds to the eosinophil cells in one's naval lavages (Brunekeef, 1992). In other words, dust leads to inflammatory responses. It does also contribute to weak allergic responses. Molhave (2008) illustrated this when they carried out an experiment in an office to investigate the health effects of indoor dust exposure. It was found that if more than 75mg/m3 of dust particles were suspended in the air, then any of the above-mentioned effects would result (Murray et al., 2004).

Influenza is also another health effect determined by indoor air quality. If a certain office environment is rich in viral particles, then chances are that the concerned workers would be affected by the disease. Chen et al. (2009) carried out an analysis of the rate of viral transmission among workers whose co-workers sneezed and coughed around them. It was found that there was a link between the particle size of the droplets exhaled by already infected persons and the rate of new infections. Office owners can therefore protect workers from these effects by availing masks or certain barriers that can protect other non infected individuals from catching the disease. Gupta el al. (2009) also agree with these assertions because they studied the fluid dynamics of coughs. In their analysis, they used linear regression analysis to assess the kinetics of coughs to determine the dangers posed by these coughs to others in the office environment.

2.4.9. Summary

This section of the chapter has focused on how the health and comfort of workers are compromised through indoor air quality. SBS was the first illness identified. It causes a series of symptoms that have an unknown etiology such as mucous irritations, headaches and fatigue. Their causes are not directly known but are associated with physical, chemical and biological factors in the office environment and are specifically linked to poor ventilation. BRS was the next health complication, and its symptoms are somewhat similar to those of SBS. It is caused by a series of conditions in the atmosphere such as thermal discomfort. Development of asthmatic symptoms is highly affected by indoor air quality owing to conditions of dampness and prevalence of mould. Presence of dust, tobacco smoke and mould increase the chances of developing respiratory ailments like bronchitis, rhinitis and other allergic responses. Bronchitis and alveolitis are common respiratory ailments that may come from the above-mentioned air quality contaminants. Other effects of poor indoor air quality include inflammatory and allergic responses, influenza, attention deficit, diarrhoea and vomiting.

2.5 IAQ effect on occupant's performance and productivity in offices

SBS symptoms cause workers to be distracted from their work (Milton et al., 2000). Furthermore, if a businessman has very severe cases of SBS among his workers, then chances are that some investigations will need to be done in the building. This will take a toll on the performance of the occupants in the office because funds will be diverted away from operational needs and will be directed to health and safety personnel or the building engineers (Woos, 1989). Usually, when too much SBS is prevalent in a certain building, some employers have to alter their ventilation systems, remove their carpets and also clean out moulds. Sometimes, it may be necessary to relocate to another building as the damage may be excessive. This can cost a company huge sums of money. One must not also forget litigations that may arise from other employees who have developed severe symptoms of SBS or poor indoor air quality. When employers must meet all these costs, the productivity of the company is bound to reduce because funds will be diverted to all the SBS-related expenses (Fisk and Rosenfield, 1997).

The above-mentioned losses can be felt by the whole firm and are indirectly associated with SBS, BRS, asthma or any other health conditions that may result from poor indoor air quality. However, specific focus should be given to the direct effect of air quality on work performance and productivity in offices. In order to understand this correlation, it will be necessary to look at some case studies on the issue. The first case study was carried out by Bako-Biro et al. (2004). It encompassed thirty female subjects. Blind interventions were done so that polluting and non polluting conditions were introduced to the subjects unknowingly. The subjects continued to perform simulated work. The source of the pollution in this case study was a three-month old computer placed behind a screen that hid it away from the subjects. It was found that the personal computers emitted a range of chemicals such as styrene, formaldehyde, toluene, phenol, and 2-ethylhexanol. However, the researchers realised that the amount of these chemicals that was released into the atmosphere was not sufficient enough to cause any health effects on the workers. They concluded that it might have been other hidden sources in the PCs that may have contributed to the problems (Lioy, 1990). Changes in work performance were noted prior to the intervention and after the intervention. This was analysed through the nature of text typing done by the individuals. The analysis was done by counting all the mistakes that workers made when typing texts. The type of mistakes noted included: poor punctuation, wrong spelling, and number of words skipped. It was found that these mistakes were much lower without the pollutants, and they increased when the pollutants were introduced. P values of less than 0.014 were reported in the presence of the pollutants. Another performance measure was typing speed. It was found that the difference before and after the experiment, was small. Here, p values of less than 0.03 were reported. The time taken to edit and proofread the answers was measured prior to introduction of the PCs and after. It was found that the number of false positives increased by one percent after the introduction of PCs. Missed errors also increased by one percent; reading speeds reduced by 0.5 lines per minute after polluting the office environment. Overly, it took the workers 9% longer to process the text in the presence of a pollutant. This case study was one of the most comprehensive ones done on indoor air quality and work pollution. Any decreases in work rate and quality (as denoted using quantifiable measures) are highly indicative of the effect of poor indoor air quality on work performance.

A very similar case study was also done by Wargocki et al. (1999) to determine the effect of indoor air pollution through a specific pollution source on the work productivity of individuals. The conditions in this experiment were similar to the former ones because tests were simulated too. An old carpet (20 years old) was placed behind a screen where the six female subjects could not see it. The difference between this analysis and Bako-Biro et al. (2004) was that the pollution source had been changed, and the work performance analysis was measured using different parameters. Subjects were fewer, and the results were analysed through a range of factors (not just typing performance). First, the number of characters typed in a simulated test was counted. It was found that 6.5% fewer characters were typed when the old carpet was present. This result corresponded to a p value of 0.003, which was similar to the Bako-Biro et al. (2004) analysis. The number of errors was found to increase by 5% when the pollution source was introduced. The p value was 0.01 for that parameter. Besides text processing, addition, logical reasoning, stroop and serial addition were also assessed. Added units increased by 3.8% when a pollution source was present. Reaction time for logic reasoning increased by 3.4% when workers performed the task in the presence of the hidden carpet. Workers' serial addition of correct digits increased by 2.5 % after the introduction of the carpet. There was a 3.1% increase in the speed of stroop performance when the pollution source was present. It was explained that the pollution source did not have a negative effect on the workers' performance of adding, stroop, addition and logical reasoning because improvements of performance in successive tests were reported. The first task was typing while the other tests were done subsequently. Furthermore, the statistical significance of these increases in task performance in the presence of the pollution source was not sufficient. Addition, logical reasoning, serial addition and stroop corresponded to p values of 0.045, 0.08, 0.06, and 0.01 respectively. In fact, text typing was the only task that elicited a statistically significant p value; this was 0.003 (Montgomery, 1991). Therefore, focus should be given to this task, and it should be concluded that pollution sources minimise work productivity at the workplace. In order to ascertain that these results are accurate, then the same conclusions should be made in different settings.

Wargocki et al. (2002) carried out an experiment designed to compare results in different geographical settings concerning the relationship between indoor air quality (as altered by a pollution source) and work performance. One of the experiments was a Danish study, and the other one was a Swedish experiment. Although the temperature and air humidity were not kept at the same level, the basic components of the study still remained the same. The same pollution source was used in both settings. Furthermore, equal numbers of subjects were also employed in the Danish and Swedish experiments. Participants were expected to perform typing task in both settings. However, in the Danish tests, participants were expected to carry out psychological tests while the Swedes did proofreading. Other tests included creative thinking and addition. All the tests were administered using the same sequence to ensure that responses were not affected by order of tasks. After the tasks were analysed, it was found that the conditions had improved in almost all task performances when the pollution source had been eradicated. This was true in the Danish and the Swedish analyses. The number of characters typed increased in both locations and so did creative thinking tasks. Proofreading increased in one of the locations but was not measured in the other. Addition tasks also improved in the absence of the pollution source. The presence of similar results in both locations was proof of the fact that all aspects of performance had a tendency to decrease when a pollution source was introduced. The aim of the experiment was not to replicate the magnitude of the results, but it was to show the overall direction of the performance effects of a pollution source on air quality (Wargocki et al., 2002).

As noted earlier, SBS, BRS and many other health complications in the work area are largely caused by poor ventilation, presence of certain pollutants, moulds or dampness, and low temperature (Wolkoff et al., 1997). Bako-Biro et. al. (2004) and Wargocki et al. (1999) carried out their experiment using a pollutant as a source of poor indoor quality. Another study done by Seppanen et al. (2005) focused on ventilation rates as a source of poor indoor quality. In this analysis, the researchers focused on the relationship between ventilation rate and work performance. Although they did not carry out the experiments themselves, the writers obtained data from a number of sources that had measured work performance and ventilation. It was found that there were significant increases in performance for almost all the sources of data reported. Average performance improvements of 1-3% were reported when air ventilation rates increased by 10 l/s-person. However, there were limits to the benefits that workers could enjoy with regard to ventilation rates. If ventilation rates exceeded 45 l/s-person, negligible improvements in work performance were observed. Sometimes when the ventilation rates were excessive, performance was found to reduce because of the noise and the thermal discomfort. On the other hand, when ventilation rates fell below 45 l/s-person, work performance increased by a factor that was greater than 3%. The analysis indicated that there is indeed a dramatic relationship between indoor air quality and average work productivity.

Another interesting case study was carried out by Wyon et al. (2004). While the earlier mentioned analyses focused on air ventilation and air pollutants, this particular one dwelt on new parameters in indoor air quality, and they are: air temperature and humidity. In this analysis, subjects were placed in an office of 22°C. This was subsequently increased to 26 and 30 degrees after three-hour intervals. Work performance was also affected by noise distractions. A source of noise was introduced in the work area to confound the condition. Noise tended to decrease the effect of temperature increases. However, it was generally found that creative tasks tended to reduce at a higher temperature of 30 degrees. Therefore, indoor air quality as measured through increased temperature minimises work performance. Tham (2004) also carried out a very significant analysis between temperature and work performance. The difference between this case study and the one carried out by Wyon et al. (2004) was that work performance was assessed through the call centre talking time. The centre focused on offering billing inquiries; productivity within the firm is directly affected by the talking time each employee can provide. Blind interventions were done so that workers could not be biased with the results. Temperature was placed at 22.5°C and 24.5°C. Decreasing temperature in the room showed significant increases in talk time. P values of less than 0.01 were recorded. The talk time increased from 187 seconds to 216 seconds; this was a percentage increase of 15.5%. Workers talking time reduced from 201 seconds to 187 seconds when the reverse occurred; that is, when temperature was increased. The percentage decrease was about 11% in that instance. P values of less than 0.01 were recorded for temperature increases. These results are indicative of the fact that indoor air quality adversely affects work performance hence work productivity in the office environment.

A significant relationship between humidity and work performance was also found by Wyon et al. (2004). The participants were exposed to four different humidity levels. In these conditions, they were all expected to carry out certain computer simulated tasks for a period of five hours. These tasks included typing texts, proofreading or editing text as well as carrying out serial additions of numbers (two digits) as they appeared on a screen. It was found that in low humidity (Relative humidity of below 25%), text typing reduced by three percent while proofreading efficiency reduced by seven percent. The ability to do serial additions was also minimised by five percent. These results are in contradiction to what one would expect in an office environment. High humidity is indicative of a damp environment and one that is likely to harbour a range of contaminants that may lead to BRS. These experimental results were contradictory because of two main reasons. First of all, it may be that the humidity levels were reduced to an excessive level to the point of creating dry air in the office. The writers assert that eye irritations, eye dryness, and tear film mucous quality were all compromised in this condition of low relative humidity (Wyon et al., 2004). Consequently, one can assert that humidity can reduce efficiency of work performance either way; when it is excessive and when it is quite low. The researchers focused on the latter conditions more than the former. Another explanation is the confounding effect of temperature on the subjects. Thermal discomfort may have undermined their ability to perform work tasks as expected.

Fang et al. (2004) also carried out an experiment in which they intended to find out the effect of humidity (and other factors) on work performance. Minimal correlations were found between humidity adjustments and work performance. The writers affirmed that one should not assume that in the real world, no relationship exists between work performance and humidity. This was because there was an increase in headaches and fatigue among the concerned workers at a relative humidity of 60% (which was a relatively high level). It was asserted that over-motivation may explain why the results appeared contradictory. The participants may have placed too much effort in the tasks in the simulated environment to the point of overcoming the minor discomforts that were created by the high relative humidity. This scenario was compared to an experiment carried out by Tanabe (2003). These authors found that work productivity was not compromised in poorly illuminated work environments. In very dark rooms of 3lx, workers produced the same results that they did in 8000 lx environments. It was found that mental fatigue increased tremendously in the poorly illuminated conditions. The author concluded that maintenance of equal levels of productivity came at the cost of physical and mental well being. The same thing can be said about what had been found by Fang et al. (2004). It is likely that with continued exposure, mental fatigue may increase, and this may translate into lower productivity. Workers may no longer be willing to put in as much effort when the experienced mental strain is prolonged.

2.5.1 Summary

In this section, the focus was on the effect of indoor air quality on office workers' health and comfort. Sick building syndrome was identified as one of the health effects of poor indoor quality. It was noted that SBS has no known etiology and soon disappears after workers depart from the ‘sick building’. Two models were discussed on the causes of SBS with the first being the office environment model and the second being the psychic disposition model. In the office environment model, three major parameters can lead to SBS and they include: physical, social and psychological factors. Some of the common symptoms associated with SBS include; eye irritations, headaches, unpleasant odours, dry mucous membranes as well as disagreeable tastes. SBS detection is sometimes dependent on the gender under consideration as women tend to report more of it than women. This is the reason why the psychic disposition model is useful in understanding SBS. Some of the indoor qualities that are likely to lead to the prevalence of SBS in any office include low ventilation rates and prevalence of a pollution source such as use of the building for storage of pharmaceuticals.

The next assessment was on building related symptoms (BRS). It may be caused by a range of factors in the internal and the relevant external environment. For instance, air ventilation systems highly determine whether BRS will exist within a building or not. Here, natural ventilation is preferred to air conditioning. When air conditioning is used, the type of filter medium also determines whether workers will develop BRS or not. This occurs when ozone combines with volatile organic compounds emitted from the air filters to form dangerous compounds. The level of thermal comfort or discomfort in the building can also lead to BRS and the same thing applies to the nature of materials used to construct it. Additionally, BRS can be caused by changes in humidity within the concerned building or prevalence of a contaminant in the materials used to construct the building or the interior components. Some of the common symptoms of BRS include: heavy headedness, nausea, fatigue, dizziness and headaches, chest tightness and wheezing. A comparison of BRS and SBS was done. It was found that the terms are more similar than different because symptoms are quite common, causes are analogous; they all have unknown etiology and are linked to particular buildings. However, BRS is highly associated with ozone and air filters. Symptoms such as chest tightness are associated with it, and classification systems differ. SBS factors are classified using the office environmental model while a BRS index is used to understand causative factors.

Thereafter, an analysis of how indoor air quality causes asthma was analysed. It was found that mould and dampness affect susceptibility to asthma. Presence of other allergic particles in the office environment can also cause certain people to be susceptible to asthma. In terms of respiratory diseases, it was found that bronchitis, sinus infections, colds, seasonal allergies, fever, runny nose, throat irritations, sneezing and coughing or certain chronic illnesses like sinusitis can occur when a building contains fungi or other contaminants that may get into the body's respiratory system. Other general side effects that emanate from poor air quality include influenza, dizziness, vomiting and diarrhoea. The last four effects may be created by the presence of moulds.

Section two focused on the effect of indoor air quality on work performance and productivity. This was done by an analysis of various case studies on the topic. Focus was given to the relationship between work performance and different components of air quality. First, a case study on the relationship between productivity and presence of pollutants was done. It was found that less work was done in the presence of a pollutant. When similar experiments were done in different geographies, it was still found that presence of pollutants reduced workplace performance. The next case study related work productivity and ventilation rates. When ventilation rates increased, greater work output and fewer errors were reported. Thereafter, a case study of performance and air temperature was analysed. It was found that talking time in a call centre increased when temperature decreased, and the reverse was true. Lastly, the relationship between productivity and humidity was analysed. In both experiments, none of the information was conclusive. In one of the studies, no relationship was found between work performance and humidity. However, the authors explained that the observation may have been brought on by over motivation of the workers as seen through excessive fatigue and headaches experienced in the high humid environments. The second case study found that work performance actually decreased when relative humidity reduced, yet this contradicts previous assertions on dampness and its effect on worker's health. It was found that the effects of temperature may have neutralised the low humidity effects. Furthermore, the relative humidity may have been reduced beyond reasonable parameters to the point of causing eye irritations. Generally, the case studies illustrated that elevated humidity (dampness), high temperature, low ventilation rates and presence of contaminants all reduced work productivity.

2.6 Effect of Climatic Condition on IAQ

Climatic conditions have an adverse effect on indoor air quality, and hence the health of the individuals under consideration. When a certain location possesses extremely hot summers, then this condition is likely to increase indoor temperature as well (Muhamad et al., 2011). This can lead to certain health complications. It has also been shown that pollen grain production tends to increase during hot weather; it may find its way into buildings through windows or other ventilation systems (Burroughs et al., 2011). Workers may be exposed to the contaminant, and thus develop respiratory illness.

Conversely, if the climate of a tropical area is such that there's more rain or flooding, then this increases the chances of having blackouts (Mann, 2011). Eventually, more households may end up buying generators; these machines all rely on carbon-based fuels to operate. The generators produce carbon monoxide, and might poison people. In fact, statistics concerning carbon monoxide incidents are always high after a storm has taken place. Most users are unaware that they should not be placing generators inside an enclosed space as this exposes them to greater levels of the gas.

Excessive rain may also cause moisture accumulation or wetness in certain parts of a building. This acts as a prime area for the growth and development of mould (Meyer and Wutz, 2004). Workers and other occupants can be adversely exposed to these contaminants and may develop sick building syndrome or other allergies and illness associated with the prevalence of mould (Magalhaes et al., 2009), (Park and Schleiff, 2004), (Wang et al., 2004)

Perhaps one of the most notorious sources of indoor air pollution in warmer weather is the heat and ventilation air system (Chase et al., 2004). When temperatures are high inside a building, occupants tend to utilise more air conditioning. This means that air will get cooled or temperatures will go down; however, humidity will definitely increase (Li and Leung, 2007). There will be more moisture in the HVAC systems and if filtration systems are not in order, then the dust in there becomes mould (Moritz et al., 2004). People with allergies are likely to be severely affected by this occurrence.

2.6.1 IAQ in Tropical Regions

Tropical regions present building owners with a series of challenges concerning indoor air quality. First, tropical regions often have excessive sunlight. Consequently, when too much of it gets into a building, it tends to increase the level of temperature in the building (Lin et al., 2004), (Nughoro, 2011). This occurs when the parts that make up the entire building (like walls) acquire heat from the sun; they then reradiate it to the internal parts of the office (Ismail et al., 2010). Excessive sunlight also affects visibility for some workers who may find that kind of lighting disturbing. Buildings must therefore be designed to handle this problem (Chella et al., 2007).

Tropical regions tend to have higher humidity levels than other parts of the world. This occurs because of the evaporative effects of the sun. Vapour levels in the tropics are usually between 19-24 g/m3 yet other areas like England have half that amount of vapour in the summer (Zain et al., 2007). This means that occupants in buildings need to need to have good ventilation systems that can induce air flow and facilitate cross air movement. If that fails to occur, then chances are that there will be excessive indoor humidity, and possible building related illnesses. Additionally, high humidity levels also tend to increase the level of exposure to bacteria, funguses and other indoor air pollutants in the office environment. When that concerned building does not possess a well maintained ventilation system, then chances are that the occupants will get sick or report immense discomfort (Fisk et al., 2007).

2.6.2 IAQ in the UAE

Indoor air pollution is now recognised as one of the most devastating problems to the environment. In recent rankings carried out by Environmental Agency Abu Dhabi (EAD), indoor air quality was placed second among the health risks prevalent in the UAE. This increased awareness of the importance of indoor air pollution has been accelerated by the realisation that many individuals spend most of their time inside buildings than outside (Government of Hong Kong Special Administrative region, 2004). It has also been necessitated by the continual discovery of pollutants within the indoor environment. The awareness that these pollutants can have adverse repercussions on occupants' health has also contributed to this interest

(Breysse et al., 2005). Furthermore, some stakeholders now know that energy efficiency is not always a good thing. Since the concept requires minimisation of internal and external environmental interactions, then this leads to a greater level of contaminants in the environment. These concerns have made local authorities prioritise indoor air quality.

One of the positive achievements being made in this area can be attributed to the Environment Agency (EAD). It has established service stations in different parts of the country such as Abu Dhabi City, Bida Zayed, Mussafah Civil defence centre, and many more. These stations are supposed to monitor the level of particulates in the air such as carbon monoxide, ozone, sulphur dioxide, nitrogen monoxide and methane (EAD et al., 2009).

Despite these accomplishments in the area of indoor air quality management, much remains to be done in the sector. First, the various emirates need to step-up their levels of pollution control (EAD et al., 2009). Abu Dhabi and Dubai are spearheading these changes, but other emirates are yet to follow. There is a need to strengthen current regulations, and to make those regulations applicable to all the emirates in the UAE.

The state of research on indoor air quality is in need of some improvements. Although plenty of progress has been achieved so far, including inter-governmental collaboration as well as data collection on various contaminants, it is necessary to centralise data collected from these groups (EAD, 2010). A number of stakeholders are involved in the data collection- some are private organisations and others are government led initiatives. All three entities need to come together and establish a centralised database that will facilitate a greater degree of collaboration between these entities. Data reporting regulations are needed in order to ensure that these collaborations work effectively. In the research area, many other areas such as environmental model development and environmental health risk analysis need to be developed. Once the health risks of indoor air pollution are fully understood by organisations, then it is likely that the concerned entities will be more inclined to provide adequate levels of research in this area. Certain disciplines need to be inculcated in these analyses such as economics. For example, the need to do a cost – benefit analysis of certain policy options in the indoor environment can go a long way in improving the state of indoor air quality (Samet and Spengler, 2005).

The level of indoor air quality cannot be effectively controlled when the public is not involved in this process. The UAE is faced with an increased need to inform the public about the environmental health risks of bad indoor air quality. Information campaigns are still few and far between. The public may be aware of the risks that emanate from their respective external environments, but may not know that their indoor air environments are also a risk to their health (Bell and Standish, 2005). They need to be warned about the implications of air conditioning systems (as these are adversely used in the UAE owing to the high external temperatures). Employers ought to be sensitised about the need to focus more on employees' health, especially their indoor air quality, rather than the need to cut energy costs. As stated earlier, the need to minimise energy use has taken precedence over occupants' health. Business owners need to know that if their employees work in an environment with poor air quality, then it is likely that their productivity will go down, and this could translate to huge losses for the organisation concerned (Branham, 2004).

When it comes to actual air quality, the UAE has not met the requirements for particulate matter concentrations in the external environment. Air pollution sources are many, and they compromise the quality of air (Moujalled et al., 2008). Particulate matter measurements have illustrated that in a place like Abu Dhabi, air toxins, pollutants, and ozone can exceed set standards for about thirty percent of the days under consideration. Studies on indoor air quality have illustrated that sometimes ozone and other pollutants can enter into a certain indoor environment through the heat ventilation and air conditioning system (Mudari and Fisk, 2007), (Nazarof and Weschler, 2004). Alternatively they may enter through the use of external openings or mechanisms of natural ventilations.

The UAE is a place with extreme weather conditions, this means that many people rely heavily on the use of HVACs. However, numerous researches have shown that poor designs, improper maintenance and selection of the wrong HVAC can be a serious source of bad indoor air (Triantafyllou et al., 2007). It will be imperative to enforce building codes and standards on indoor air quality designs. Unfortunately, many emirates in the UAE are not as vigilant about these things as they ought to be. Few restrictions have been imposed on pollutant generating activities, yet these are highly dangerous.

2.7 Knowledge Gap:

This section will cover the literature review knowledge gap that helped in forming this study framework and highlighted the need to take serious actions to control the causes of poor indoor air quality.

After a detailed review for all the research done in the area of office environment in Dubai, various knowledge gaps were identified , which can be summarized as follows:

- Limited available information about the office environment in Dubai. Some initiatives are found for sustainability and green buildings, but no enough information about the indoor environment.
- Lack of office design standards set by Dubai Municipality.
- Lack of understanding of the sources of indoor air pollution. People need to get a better understanding of the selection criteria for the materials used in the indoor environment. It's much more than matching colours and selecting a theme/design style for the interior. It's about occupants' health, productivity, performance, etc.
- Absence of previous detailed studies about the indoor air quality in Dubai offices. There is no enough research about the office indoor environment in Dubai. The focus is more about saving energy, green buildings, etc.
- Lack of regular assessments to the offices indoor environment.
- Lack of policies and regulations related to offices' health conditions.
- Absence of controlling the import of Toxic building materials, such as paint, coatings, etc.

2.8 Research Question(s):

- What are the IAQ parameters levels in typical office buildings in Dubai?
- What are the possible effects of IAQ condition on office occupants' health and comfort?
- Can IAQ condition affect office occupants' Performance?
- Can IAQ condition affect office workers' absenteeism rates?

2.9 Research Aim and Objectives

Aim:

- To have preliminary understanding of indoor air quality (IAQ) condition in office buildings in Dubai

Research Objectives:

- To examine IAQ parameters levels in typical office buildings in Dubai
- To examine the effects of IAQ condition on office occupants' health and comfort
- To examine the effects of IAQ condition on office occupants' performance
- To examine the effects of Indoor Air Quality condition on office workers' absenteeism

Chapter 3: Methodology

3.1 Analysis of Research Methods

A crucial factor of building a successful research document is the correct selection of the research methodology, as it forms the outcome/conclusion of the study. A large number of research methodologies were identified. As this paper is a clear analysis of the effects of the poor indoor air quality on occupants' health and performance in office buildings in Dubai, it was important to complete a deep investigation of the different research methods, and understand the pros and cons for each of them, in order to decide which technique(s) can be suitable for the selected topic, taking into consideration the possible limitations of the environment of the study including: Time, money, feasibility, rules and regulations, etc.

3.1.1 Literature Review

This research methodology is a reflection of published sources for a specific topic of research. Moreover, it analyzes the different arguments around the research topic, besides, identifying the research gap (Loughborough University, 2011.).

Literature reviews may also be regarded as research methods because they allow one to support one's arguments (Denzin, 2009). A literature review is therefore defined as a comparison and evaluation of the major arguments, theories, controversies and methodologies found in scholarly papers. In certain instances, literature reviews may stand alone as articles or they may be part of a research dissertation, proposal or report. The purpose is to link one's research with the work found in other literary pieces. First, they facilitate the process of determining some research gap in one's line of research (Liu and Fellows, 2008). Literature reviews prevent replication of work because they will allow one to determine an area that has not been covered. The researcher, can find inconsistencies in certain matters, and may try to correct that wrong through a literature review (Randolph, 2009). The process may not necessarily provide thorough support for one's ideas; however, it allows one to take in a particular slant concerning one's area of interest. One may also carry out an evaluation or a review based on a literature review. However, this approach is restrictive because, for the method to be reliable, the information used must come from very reputable sources (Grey, 2011). In academic research, these are usually peer reviewed articles. The challenge with this requirement is that sometimes, one's area of research may be inadequately addressed in previous work in the field. Alternatively, this method is limited by the proficiency and the ability of the previous researcher. Therefore, one must take the time to ensure that the research covered in that primary source was accurately and reliably done. Additionally, such an approach needs to depend upon the most valid, reliable and appropriate materials (Hair and Money, 2006). These criteria may be difficult to meet when the concerned researcher has a wide range of sources to select. Literature reviews contribute tremendously in research processes because they delimit research problems, provide new lines of inquiry and provide support from theory.

3.1.2 Surveys

Survey methods are used when one plans on collecting descriptive information. They may be structured, unstructured, direct, or indirect. Researchers can use the survey method, through questionnaires and interviews, to collect data about various variables. One then uses analytical techniques to make inferences between the variables (McBurney and White, 2009). They are quite helpful because one can collect different types of information. Furthermore, when compared to other techniques such as experiments and observations, surveys are easier to administer, or they take less time (Bryman and Bell, 2009). The information obtained through survey methods is quite easy to generalise to other populations. The researcher under consideration can collect a high volume of data in a short amount of time. This is because it can be done through mail, fax or the internet. However, surveys may result in inaccurate information that emanates out of the participants' reluctance to respond to questions from unknown researchers (Coleman and Briggs, 2007). Alternatively, surveys can lead to distorted results when participants give insincere answers to impress interviewers (Walton, 2006). Some people may be too busy to participate. This method often makes it quite difficult to understand the processes behind certain findings. Surveys should be done when uniqueness is an important quality in the research (Randolph, 2007a). The approach allows one to collect information that would, otherwise, not been found in other sources. When a person needs unbiased representation from the population under analysis, then this method should be used. Surveys can also limit an individual because they are quite costly to administer (Singleton and Straits, 2010).

3.1.3. Case Studies

The case study method of research entails examining a certain occurrence in its natural setting, through several data collection methods, in one group or more (Repko et al. 2011). This method does not allow one to manipulate the occurrence in any way. It is a useful approach because it allows one to analyse the issues under investigation in their natural setting. Furthermore, it gives the researcher flexibility to know the processes involved by responding to questions that deal with 'why' and 'how' (Christensen and Allison, 2008). Besides these qualities, case studies allow one to carry out an investigation in areas where other researchers have not covered. The method is quite appropriate for scenarios where few theories already exist. Additionally, they should be used where no variable manipulation is necessary. In most scenarios, the case study method requires several methods of data collection in order to improve construct validity (Hesse-Biber and Leavy, 2011). These methods include structured and unstructured interviews, indirect and direct observations, documentations, and recordings of technologies used within the research. This method is quite advantageous because it facilitates detailed capture of reality. Furthermore, the number of variables that the researcher can find is much more than one can analyze in other types of research. On the other hand, this kind of research cannot be generalised because it is specific to one group (Wendy et al., 2007). This is true because one may find it difficult to find similar researchers that provided almost equal data for statistical analyses. Additionally, it may be extremely difficult to establish whether the research was interpreted in an accurate way by another researcher. Since the case study method involves a series of data collection methods, then the researcher should possess multiple abilities or experience. If the individual uses outsiders, he may find that they are naive. For scientific purposes, the total lack of control makes such an approach quite problematic. In this community, most researchers recognise the need to make comparisons or contrasts. When one's report contains isolated knowledge, then he or she may appear illusionary.

3.1.4. Field measurement

Instruments are used in order to analyse or measure a certain quality in the subjects (BYU, 2011). The instruments provide a mechanism for obtaining the data that must be used in the study. In research, the instruments can take the form of unstructured or structured interviews. They may be done through questionnaires or observations. Sometimes, diaries can be regarded as instruments. Documents or record reviews may also be plausible instruments. An instrument should measure a certain attribute accurately; otherwise, it will lead to the wrong conclusions (Beverisge and Andersson, 2007).

3.2. Advantages of combining more than one method

Using more than one research method is useful because it facilitates cross checking between research findings (Babbie and Rubin, 2008). For instance, if one was analysing students' perception of a certain assessment process, one may use survey research in order to determine their opinions. Then one might cross-check this information through an analysis of the student record data in order to determine how well those students performed. Their opinions can then be cross-referenced with their actual assessments (Creswell and Clark, 2007).

Using more than one method also provides different ways of looking at the problem. Alternatively, mixed methods allow an investigator to expand upon previously acquired information (Pickard, 2008). This makes the research richer and more applicable to the concerned field. Quantitative research methods such as surveys often focus on general relationships between variables. However, they do not provide answers about the reasons behind those observations. Qualitative methods are useful in such instances because they provide great insight. Therefore, they bring in fresh revelations about a certain phenomenon (Meyers et al., 2006).

The methods provide a basis for triangulation. All research methods have their limitations. In order to increase the validity and reliability of research findings, one must overcome these limitations by using more than one method (Kuhfeld, 2009). Therefore, when selecting the types of research methods to be used, a researcher must look for methods that complement each other. In other words, instances of overlapping weaknesses should not arise in the methods chosen (Oliver, 2010). It is assumed that when many methods are used, then they will strengthen the effects of the research tremendously. If one research method finds a certain relationship between two variables, and a second research method also finds that the same relationship exists, then this second or third research method will act as evidence for the first one. It somehow corroborates the information that was asserted in the previous findings (Randolph, 2007b).

In most researches, the investigator may choose an inductive or deductive approach. In the deductive one, the analyst will normally come up with a hypothesis or theory and will try to test it through a research (Dane, 2011). On the other hand, a researcher may first collect data from the field and then use it to establish hypotheses or come up with theory on the same. This bottom-up approach is called inductive research. Mixed methods allow scientists to do both (Thomas et al., 2010). They can have the flexibility to choose between the inductive or deductive approach. Alternatively, researchers have a choice of applying one in a certain part of a research and another one in another section.

This approach is also quite advantageous because it allows the concerned researcher to analyse behaviour under different conditions. One may choose to control or manipulate the conditions. One may also opt to view the subjects in their natural settings. This provides a multi-lens focus hence an insightful analysis of the same (McNab, 2008).

3.3 Dubai weather conditions

Summer in Dubai is quite hot. This occurs between the months of June to September. Sometimes, temperatures can reach a maximum of 45 ^{o}C. On average, Dubai summers lie in the mid thirties. In the month of August, temperatures are likely to be 35^{o}C. This is the reason why air conditioning is a must in buildings. The months of September and June are relatively high too. Most of them will have an average of 30^{o}C, and may peak at 35^{o}C. During the summer, it is very unlikely to find rain. In fact, hot sunshine may last for 11.5 hours a day. The driest month of the year is June (Holiday Weather, 2011).

During the winter, temperatures may drop a little bit. The months between December and February are the coolest. They may average 20^{o}C, but may sometimes increase to 25^{o}C (Trip advisor, 2011). There is the possibility of rain in the winter, but this is still not a substantial amount. One is likely to find an average of 150 mm of rainfall in that period. Once in while, some heavy rainfall may occur during the month of January as was the case in the year 2008. Humidity averages approximately 60% all year long. However, winters tend to be more humid than summers. Shown is a summary of weather conditions in Dubai.

Table 3.1: Weather Conditions in Dubai

Source: (UAE Interact, 2011)

	Dec	Nov	Oct	Sep	Aug	July	June	May	Apr	Mar	Feb	Jan
Rainfall (mm)	10	4	2	1	3	2	1	1	10	34	38	11
Temp (^{o}C)	26	30	35	39	40	40	39	38	33	29	25	24

The excessively hot temperature in Dubai emanates from its desert terrain. When temperatures reduce in Dubai, then the opposite thing happens to humidity; it increases. For example most nights have a temperature that may be lower than 30 degrees. However, the humidity could increase by 10 or 20% (Visit Dubai, 2011).

It should also be noted that the weather in Dubai depends upon one's geographical locations. If one lives in the mountains, winters may go as low as 7^{o}C. This is substantially lower when compared to the average winter temperature of 22^{o}C. If one lives near coastal areas, then humidity levels average at about 60%. However at the sea, this changes dramatically to approximately 90%.

Dubai also experiences sandstorms every now and then. These conditions arise out of a low pressure and strong winds emanating from the North West. The sandstorms often reduce visibility on certain days as they increase the amount of sand in the air.

3.4 Office Standards

Thermal comfort is understood as the state of feeling neither cold nor hot. This is achieved when three components of the office building have been evenly balanced, and they include: temperature, ventilation rate (air movement), and humidity (Gang et al., 2005). Although temperature preferences depend upon the occupant, it is generally accepted that certain extremes are not comfortable (Stavrakakis et al., 2008). For example, when temperature in an office building is too high, this causes workers to feel tired (Huizenga et al., 2006). Conversely, employees tend to be easily distracted and restless when the temperature of their building is too cold. Stressed-out workers may be overly sensitive to changes in temperature when they occur (Zagreus et al., 2008). During the summer, it is advisable to increase indoor temperatures of buildings with HVACs so as to minimise temperature differentials between the external and the internal environment (Yoshida and Ichiro, 2005). Office standards are therefore imperative in providing a guideline for protecting workers against these unwanted effects.

When it comes to humidity, it is advisable for office environments to have a relative humidity of fifty percent during the cold season. When a place has too much humidity, it tends to heighten the feeling of stuffiness among workers (Sharpe, 2004). This also accelerates the growth of mould and other micro organisms in the environment. However, when humidity levels fall below fifty percent, they tend to increase workers' susceptibility to skin rashes and cause drying out of the mucous membrane (Spengler et al., 2005).

The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) body is internationally recognised for its standards on office building indoor air environments. It covers ventilation rates, temperature and humidity requirements that will cause an acceptable level of comfort. The guideline is a lengthy one that covers different codes. With regard to ventilation, the following requirements have been specified in the 2004 ASHRAE standard 62.1

Minimum ventilation rates for 62.1 2004 ASHRAE in cubic feet per minute per person (cfm/person)

Table 3.2: ASHRAE standards for minimum ventilation rate per occupancy category

Source: ASHRAE (2004a)

Occupancy category	(ASHRAE (cfm/person
Hotel, resort, dormitory lobbies, and motels	10
(Office building (office space	17
Conference room	6
Theatre auditorium or public assembly	5
Educational classroom	15
Correctional facility	19

It should be noted that when smoking is permitted inside a building, then the ventilation rates need to be increased dramatically. The increments depend upon the level of smoking in the building, and may be anywhere between 25 and 125 cubic feet per minute per person. Carbon dioxide guidelines in office buildings have been placed at 1000 parts per million (ASHRAE, 2007).

ASHRAE also has set out the following criteria for temperature and humidity in the office environment

Table 3.3: ASHRAE standards for temperature and humidity in offices

Source: ASHRAE (2004b)

Temperature/Humidity range for Thermal comfort			
Conditions	Temperature values		Relative humidity ((in percentage
	^{0}F	^{0}C	
Winter wear	68-75	20-24	60%
Winter wear	69-78	20.5-25.5	30%
Summer wear	74-78	23-25.5	60%
Summer wear	76-82	24.5-28	30%

3.5 Office Buildings and their sites

In this study, four offices were selected in various locations within Dubai, to make sure that all the exterior environment conditions are considered while completing the measurements and results. Jumeira, Nad AlHamar, Sheikh Zayed Road and DIAC are a number of the locations that were selected for the office study to test the indoor air quality through: walk-through investigation, subjective and objective study phases.

Furthermore, in order to use the results of this study as a strong document that can be included in the research database of the environmental studies of the UAE, it was necessarily to have a clear understanding of the different industries that form UAE market. This study is a comprehensive analysis of the indoor air quality of office environment in the industries below:

- Financial Institutions
- Academic Institutions
- Furniture Suppliers
- Lighting Solutions

One sample was selected from each industry, and a detailed research was completed to get a full picture of the environmental conditions and how it affects the occupants of these spaces. A good start was to investigate about the common sources of indoor pollution in these offices, based on the type of the business. For instance, in the IT solutions industry, computers, printers and scanners are the main sources of indoor air pollution. On the other hand, in the financial institutions, besides the PCs, papers are main source of pollution.

In this study, a group of research methods was used including: Literature review, case-studies, field measurement and surveys.

3.6 Importance of Walk-through Investigation

A walkthrough is an important part of a case study investigation because it provides first hand information of the ventilation system in the building, its floor plan as well as it design. The walkthrough offers enough information to create a hypothesis on the indoor air quality issues under analysis (Health Canada, 2011). It also provides adequate information to make certain recommendations on the office building. In the walkthrough, one may check on a number of factors to determine the problem indicators in the building. Issues such as odours, stained or discoloured ceilings and walls, moulds, dust, overcrowding and unsanitary conditions are important indicators of the problems that may exist in that area.

In the walkthrough, one may check on the nature of the odour in order to relate it to specific indoor air quality problems. For instance, if the investigator smells some diesel fumes, and the workers report cases of nausea, tiredness and headaches, then chances are that there could be carbon monoxide in the office. Alternatively, if the analyst finds a strong body odour, then there are minimal levels of carbon dioxide or low ventilation rates. Such workers are likely to suffer from headaches, stuffiness and exhaustion. If the investigator finds a musty smell, then this could indicate the presence of dump surfaces or microbial materials (Heseltine and Rosen, 2009). Smells of chemicals indicate the presence of volatile organic compounds or pesticides, formaldehyde and other types of chemicals (Aerias, 2011). If the walkthrough reveals a dusty and chalky smell, then the office could have problems with its particulates or the humidification system in general. In other scenarios, if the office has sewage or gas-like odours, then there may be water traps in the drainage or the office's basement.

The walk-through is also quite helpful in determining how effectively the office has used its office space. If the place is overcrowded, it is likely that ventilation rates will be much lower. This investigation allows the analyst to look at the seat arrangements in the case study. If the office has recorded recent complaints, then the walk-through can allow the concerned analyst to look at the arrangements of the equipments such as computers or printers and photocopiers. Furthermore, the walkthrough provides information about room usage.

One can easily identify areas that are undergoing renovations, repairs or replacements as these may be vital sources of pollution. The analysts can also check on the presence of paint fumes or dust in the concerned building. Other contaminants such as moulds may be spotted easily in this first encounter. These may come from water leaks or other dump environments in the office (US Environmental protection agency, 2010).

A walkthrough may also allow the investigator to assess the general indoor air quality. He or she may record the sensations of humidity and temperature that he or she experiences. One will need to determine whether one feels stuffy or hot.

3.7 Subjective Study (Occupancy Survey)

Surveys are quite important because they provide measurements that are standardised (Creswell, 2010). This means that the same information is collected from all respondents. If one has found secondary sources for one's research, then one can use surveys to compliment the data obtained from that research (USAID, 2006).

It is vital to adapt surveys to the local context because sometimes the population size may differ from the standard survey estimates (Zikmund et al., 2010). One must first consider the population size in order to ensure that the research is carried out successfully. Sometimes, the kind of precision needed in one location may be different from another. This may depend on the standards used in that geographical location (Neuman, 2010). A survey needs to consider the homogeneity of the participants. If it requires contributions from certain members more than others, then the questionnaires or interviews should be altered to accommodate this (Smith, 2008). The research media used in the survey should suit local conditions too. If the method involves the use of the internet, and most of the participants have no internet access, then the survey would fail.

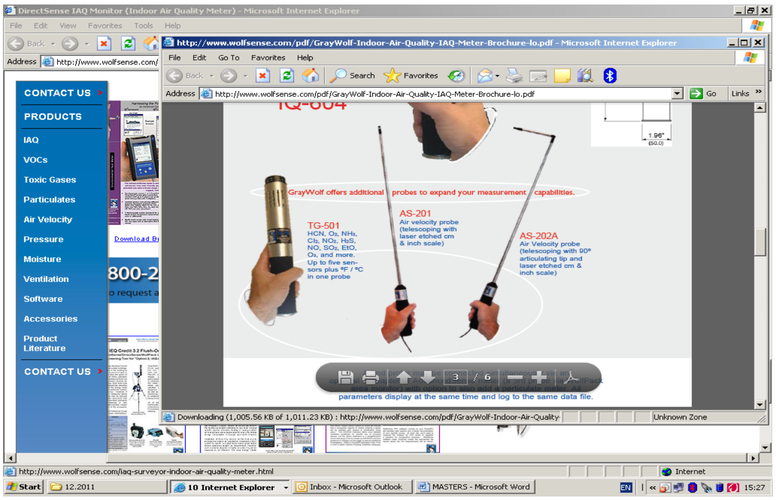
In this research, EPA indoor environmental quality survey was used with some changes to the questions approach in order to adapt to local conditions in the UAE. Hard and soft copies of the survey were available for the participants, based on their preference and the nature of their jobs. It is important to highlight that all the participants were given 5 minutes summary of the requirement, survey structure, study objective and the answering format. All the results of the survey were recorded in an excel sheet in order to generate the needed visuals (graphs and pie charts) to make sure that all the tested parameters are compared evenly, and that any trend in the results is noted and clearly elaborated.

3.8 Objective Study (Measurement with Mobile devices)

3.8.1 Direct Sense by GrayWolf

A. Overview:

Direct Sense-IAQ is a monitoring instrument which allows you to identify and measure any indoor air quality issue that can affect the space users, before it becomes a serious problem that requires an immediate action. This technique is significantly advanced whilst user-friendly. Furthermore, as it’s a portable device, it allows you to do any required measurement for any assigned space easily. This instrument is suitable not only for the walk-though investigation but also continuous long-term measurements (Hours/days), as it classifies the exact percentage/amount of the relevant air components in a way that gives a clear picture of the indoor air quality status. Simply, it combines the sensitive detector and the fast and accurate results, as it’s a very rich source for professional IAQ reports.



Hard Shell Security Case for unattended, long-term trending.

Figure 3.1: Objective measurement Instrument – Direct Sense by GrayWolf

B. Specifications:

- ***Multi-functional Device:*** This instrument measures 6 major indoor air quality indicators: TVOCs, Carbon dioxide, Carbon Monoxide, Ozone, temperature, and relative humidity. Moreover, more parameters could be added, as per the user's study requirements. Furthermore, this device provides optional air velocity probes.
- ***Data Logging***: Snapshots can be taken manually using the device.
- ***Back-lit color display:*** This device provides the user not only with accurate figures, but also the supporting graphics and Visuals (such as detailed graphs).
- ***Intelligent user interface***: *very user-friendly interface with drop down menus.*
- ***Reporting:*** The user can easily download the data and the notes to WolfSense® PC software, and use the results directly for any required reporting.
- ***Accessories***: Hard-shell security case can be used to protect the instrument during transport and long-term measurements Moreover, option camera and various other devices and softwares can be combined with the main device for a wide range of measurements.

The image below shows the user-friendly interface of the device and the different forms of extracting the data from the main device.

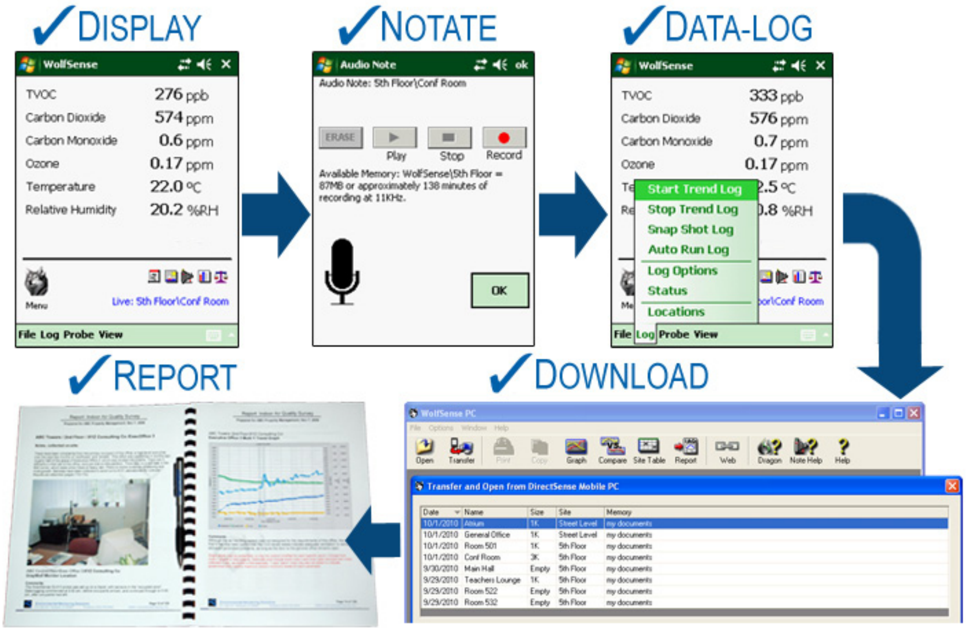


Figure 3.2: Interface of Direct Sense device

3.8.2 HCHO Detector

This portable gas detector is very sensitive device as it uses (photoelectric Photometry method) as a detection principle; in order to measure the formaldehyde (HCHO) level in a specific zone, without any false readings because of other gases interfere. HCHO detector weights 500g. only which allows the user to move it easily from one location to another. The device has a very efficient size of built-in memory as it Stores up-to 99 reading, which can be easily viewed on the digital LCD display screen.

Figure 3.3: HCHO Detector

3.9 Data Analysis

An essential phase in this research was to collect the data from various accredited sources that are as relevant, accurate and up-to date as possible. Literature review, Surveys, Walkthrough investigation, case studies and field measurements were the main research methods used in this paper.

After collecting all the data from the range of sources, the challenge was to put everything together in a scientific context and find a clear path to the indoor air quality condition in the office buildings in Dubai. The literature review was the key reference for the sources of the indoor pollution and their effect on the indoor environment. First of all, during the walkthrough investigation, special attention was given to the building materials and furnishings in order to identify any common sources of pollutants' emission (collected from the literature review) in the selected offices, for instance: stones used for masonry/concrete, wood, coatings, paint, etc. In addition, general observations were documented to highlight people activities, space hygienic condition, ventilation, maintenance, space layout, etc. The observation phase gave a clear first impression about the space indoor condition; however, it was necessary to complete the field measurement phase to have a set of numeric data that reflects the exact condition of the space.

All the results collected using the well-selected instruments for indoor air quality measures were compared to the office standards from ASHRAE, EPA and Dubai Municipality (DM).

Also, interviews were conducted with some maintenance specialists in the office buildings, to get a better understanding of the office maintenance schedule and ventilation system.

The last research method was the survey, which was distributed to the office occupants during their working hours. This Survey was adopted from EPA Indoor environmental Quality survey, and amended to match the environment conditions in Dubai. The results of the survey helped to identify the common illness symptoms for the space users, which were expected based on the walkthrough investigation notes and the instruments readings.

Combining all the research methods has helped to put all the collected data in a scientific context in order to build a strong database for the studies of offices' environment in Dubai.

Chapter 4: Results and Discussion

4.1 Introduction

This research is a deep investigation of the effect of indoor air quality on occupant's health and performance in office buildings in Dubai, which is completed through various research techniques: walk-through investigation to collect data, site visits, surveys and field measurements. Four major businesses in Dubai market were chosen as the case-studies that will not only highlight the key indoor air pollutants, but also identify the wrong practices in the architecture and design technicality.

In this section, all the parameters of the indoor air quality in each case-study will be illustrated separately. It is important to note that for confidentiality reasons, all the offices names are identified with an alphabet – starting from A, as agreed with the office managers. All the phases of this study were completed during week-days to make sure that the collected data and the instruments' readings are a clear reflection of the indoor air quality status during busy hours. It was essential to consider the traffic-flow and the volume of the space users when selecting the study zone(s) within each office. The study was conducted during the months of June, July and August.

The survey structure is described as a combination of opened and closed questions, to give the participants the option of any further elaboration for their answers. Furthermore, the open questions help the researcher short-list the common answers among the participants' population, without the limitation of specific options used in the closed questions. The questions' format is designed to determine the environment quality of the selected offices through referring to occupants regarding: work-place information, information about health and well-being, description of workplace conditions and perception of indoor air quality. In addition, the walk-through investigation was a key phase to take notes about the indoor environment conditions, and anticipate the results of the survey and the instruments. Physical and chemical parameters were measured to support the understanding of the correlation between the various sources of pollution and occupants' health, productivity and performance. All the findings of the different investigation phases, including data, graphs and tables with a detailed analysis are highlighted below

4.2. Findings

A pre-agreement was arranged prior to the visit with the general manager in order to get all the support from the staff and sue the instruments for short and long-term measurements. All the findings are documented in a suitable format that identifies any trend in any of the indoor air indicators. Furthermore, every zone was measured in different timings to compare the outcome and spot the key sources of the air pollution, in order to plan the recommendations list for maximum air pollution control.

4.2 .1. Office (A)

This is an Industrial Trading Company that has its 2 storey offices located in an open area close to a running high way. The premise that was built in 1997 has a big open showroom on the ground floor and a smaller furniture showroom on the 1st floor along with mix of closed partitioning offices and open area working offices. The office holds an excess of 80 employees distributed mostly on the second floor. The observation shows a lot of different factors that can affect the Indoor Air Quality. To start with, employees were seen smoking exactly next to the car parking area located directly at the entrance of the building.

The walls from outside seems to have a poor paint job. Moreover the water is leaking from the roof to the ground omitting some moderate odor. As first entered to the premise the interior of the building has carpet on almost 70% of its floor. However the floor carpet looks clean all over except one room where water leakage from the HVAC has caused stain on the floor. Moving to the workplace, most of the working desks are clean with very minor exceptions where dust was seen on couple.

High VOC solvents as well vacuum machine were used in cleaning the interior of the office that is usually done every morning before the arrival of any employee. The solvents as well as the vacuum machine are stored in closed cabinets inside the office's pantry. The walls around the office are well maintained and don't show any signs of cracks or peeling. Although the power supply and ceiling grills where properly distributed around, molds and dust were observed growing on the ceiling grills and diffusers in some rooms.

Since the office has a very high traffic load, perfume odors were excessive all around the area that will also affect the IAQ. The pantry showed also that the exhaust fan system was missing, which in return will have effect on the moisture increment in the office. Printers, fax machines and scanners are heavily used in the area where the workstations are located. Some of the workstations used by the employees were almost 10 years old and color changing effect was seen. However the major observation pointed out in this office is that all the windows in the office are firmly closed and can't be open. The only source of air ventilation for this office aside from the HVAC was the main door entrance.

4.2.1.1 Plan Overview

Walking through the office, the first impression taken is that a lot of open office working space is found. For instance the office furniture showroom which is located on the first floor has also open office area were staff are seated, the showroom oversees a lot of windows along both end of the walls to allow daylight to enter. Adjacent to the showroom, two washrooms and a small pantry are located which are extremely close to the area of the staff. This might cause discomfort to anyone working in this area especially if no proper ventilation is installed to prevent the bad odor from circulating the area.

Moving forward towards the rest of office, a big reception area is located in the middle to guide the guests towards their destination. The area also holds a lot of open cubicles with low height partition. One can notice the excess usage of upholstery on the partitions and carpet on the floor. Another observation is that the reception and the open office area surrounding it has zero natural light passing through into the middle because of the office cubicles that are located on the windows exactly blocking sunrays from passing through. This is the case happening throughout the remaining space of the whole office.

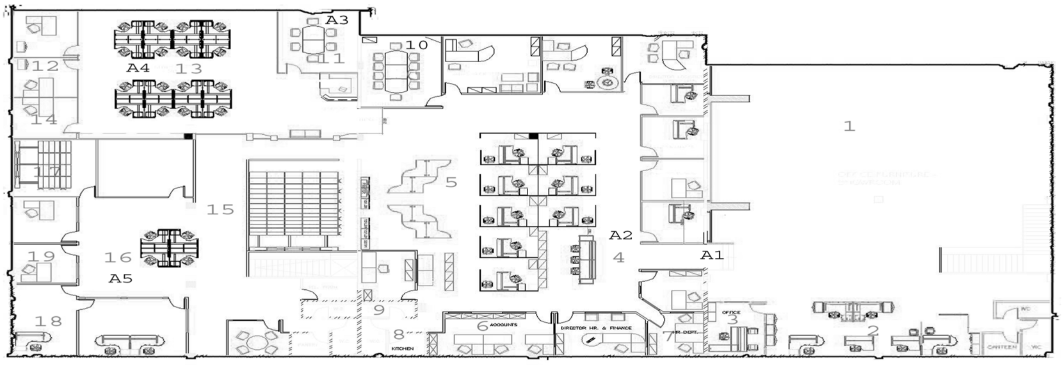


Figure 4.1: Floor plan for Office (A)

4.2.1.2 Spot measurements

Measurements were taken in 20 different locations in the office to check the TVOC; Carbon Dioxide, Ozone, Carbon monoxide, Temperature, Humidity and Toluene and the way they affect the users of the space.

The readings showed that most spaces inside the office had high numbers of IAQ Parameters. This is due to a lot of factors which will be explained briefly in the below.

Table 4.1: Direct Sense Spot measurement readings for office (A)

Parameters	**Zones**										
	Location 1	*Location 2*	*Location 3*	*Location 4*	*Location 5*	*Location 6*	*Location 7*	*Location 8*	*Location 9*	*Location 10*	*Location 11*
TVOC (ppb)	894.8	669.8	571.1	595.8	545.9	476.6	581.3	542.6	528.2	630.3	611
Carbon Dioxide (ppm)	766.2	745.9	720.4	758.3	978.6	753.2	740.7	798.1	782.5	792.2	806.4
Ozone (ppm)	0.02	0.023	0.024	0.029	0.027	0.03	0.03	0.03	0.029	0.026	0.026
Carbon monoxide (ppm)	0.82	0.75	0.61	0.64	0.54	0.57	0.6	0.51	0.54	0.49	0.48
Temperature °C:	24.32	24.99	24.87	25.18	25.44	25.69	25.83	25.19	25.2	25.24	25.43
Relative Humidity %RH	53.21	49.61	48.01	48.35	48.4	44.43	47.35	47.77	48.88	50.47	49.37
Toluene ppb	474.25	354.96	302.6	315.81	289.3	252.6	308.05	287.56	279.97	334.05	323.86

Parameters	**Zones**							
	Location 12	*Location 13*	*Location 14*	*Location 15*	*Location 16*	*Location 17*	*Location 18*	*CM.*
TVOC (ppb)	609.9	658.5	551.5	597	571.9	560.7	890	625.6
Carbon Dioxide (ppm)	828.2	709.4	719.4	847.9	783.8	871.6	504.8	719.9
Ozone (ppm)	0.025	0.025	0.029	0.026	0.028	0.028	0.175	0.04
Carbon monoxide (ppm)	0.66	0.35	0.35	0.39	0.44	0.44	8.28	0.07
Temperature °C:	25.28	25.24	25.32	25.5	25.53	25.79	30.96	26.38
Relative Humidity %RH	51.17	53.31	49.37	51.17	49.85	48.61	96.94	41.48
Toluene ppb	323.24	349.03	292.27	316.4	303.08	297.24	471.7	331.58

The TVOC measurement showed consistency throughout the locations in the office. However in some areas, the readings increased in the showroom as well as the procurement room. This expected increase in the numbers of TVOC is due to several factors. For the showroom a lot of furniture pieces are displayed in a relatively small area thus the increase in the numbers of TVOC (Wolkoff et al 1997, Uhde and Salthammer 2006). Another factor that increases the numbers is the usage of adhesives in cleaning the furniture pieces. The locked windows that was never open since occupying the building also helps in increasing the number of TVOC. As mentioned also, the TVOC number was also high in the procurement room for a clear reason which is the excess number of staff that occupies that small area. Two numbers of printers as well as four computers are fitted in the room; also the area is almost filled with exposed materials such as rubber, wood and some kinds of cartons.

The readings for the Carbon Dioxide showed consistency throughout the office perimeter. Almost all spaces that were examined inside the office have shown similar readings at an average between 750-800 ppm. However there was a difference in two locations. For example, In location 5 the readings jumped to excess of 900 ppm. This is due to the fact that in this location in precise a lot of activity is been done. For instance the reception is located there; a lot of visitors are directed to this area. Another factor that increases the carbon dioxide reading in this particular location is the excess cubicles of staff in a small given area. These cubicles are made of fabric which helps increasing the carbon dioxide readings. There are also a lot of printers, scanners, fax machines and pc that are being used in the area that helps in defining the readings. One more major factor of this increase in the reading is that this area is been placed in the middle of the office where no windows are close to it, hence no fresh air can enter this area.

According to Niosh guidelines, the average exposure for the ozone ppm is considered to be as low as 0.1 ppm. In the case of the study on the office, the reading shows that all location has less than the average desired ppm of ozone in a given space. This means that the ozone gas ppm is considerably low throughout the locations of the office and that the staff is in no danger in regards with the ozone readings.

Location 18 shows that the readings of the carbon monoxide are high according to rest of the office locations. The average reading across the office locations shows a low of almost 0.3 ppm. However location 18 showed a reading high of 8.25 ppm. This increase of the readings in the location 18 is happening because of the heat that can be sensed directly. A small space of almost 12 m2 is accommodating four staff at all times along with their pcs can generate a high amount of heat. Specially that the staffs at this location have almost zero movement away from their desks which means 9 hours a day a minimum of 4 staff are being inside the room can cause high heat emissions.

As discussed earlier in this research paper, the average Temperature given for a certain working room should be between 20-25 degrees Celsius. All the temperature readings in the office locations fall between the average brackets, except for location 18 which the reading showed a 30 degrees Celsius in that room. Location 18 has a lot of staff working in a small area which emit a heat, thus increasing the temperature in the room.

Humidity causes a lot of discomfort to the human being especially in the work space. Humidity was consistent all over the office. However Location 18 seems to have a huge increase in the percentage of the humidity. The readings showed that location 18 has 98% humidity in the room. This usually causes a lot of stress and anxiety to the staff who are exposed for more than 9 hours a day. Aside from the fact that location 18 isn't properly exposed to A/C, it is also not exposed to proper air ventilation, thus the increase in the humidity in the area.

Touline ppb pollutant was found heavily in location 18. The readings in all other locations show almost the same number throughout. However location 18 showed a high number of Touline in a given space. This is always due to the poor ventilation, excess of staff working in a given space and to many different factors.

4.2.1.3 Continuous Measurements

A continuous measurement has been done on one location over the course of twenty four hours. This experiment is done to get the all the readings needed and the variables happening when its exposed to several conditions when the A/c is of or on, when there are staff working or not when the pc are on or not.

The reading was done on location 13 where a lot of traffic, fax machines pc and desks are placed in.

The readings showed that difference between the spot measurements and the continuous measurements were very minimal. All measurements showed that almost all readings gave the same number in both the spot and continuous measurements. After checking the surrounding, the following was discovered on why the readings were the same for both measurements.

Firstly, location 13 doesn't have standard timings for the staff, meaning it would be very normal to find staff working extra hours than the normal. Secondly A/C is kept running 24 hours in the area. Pc are not switched off even after the staff have left the office. Another major fact is that the windows in that certain area are always locked thus no fresh air is entered in the space ever.

All these factor are the reason why the two measurements done have given the exact same results.

4.2.1.4 Airflow measurement

Airflow measurement that shows the air speed and the temperature of given space has been made in five different zones in the office. These zones were:

Zone A1: Open office Area (limited staff)

Zone A2: Open office Area with some cubicles

Zone A3: Meeting Room

Zone A4: IT Area

Zone A5: Engineering Area

Table 4.2: Airflow readings Office A

	Zone A1	Zone A2	Zone A3	Zone A4	Zone A5
Air Speed	0.088	0.027	0.8	0.053	0.12
Temperature	23.2	24.6	24.3	26	25

The reading showed that the air speed measurement varied according to the activity done in each area. For instance zones A1 and A3 showed high air speed measurement than the others. The reason is that these two areas have low foot traffic in their respective areas.

The reading also showed that the temperature in all these zones was consistent at an average of 25 degrees Celsius.

4.2.1.5 HCHO measurement

The formaldehyde measurement was taken in three different areas, the Showroom, IT Department and the Engineering Department. The readings given showed that throughout these three locations is less than 0.01. The reason why all the location showed the same reading is because of the open plan area these location falls under.

4.2.1.7 Survey

A survey was distributed among the staff to get their feedback on the IAQ if their office. The following charts will show the outcome of the survey done. The number of staff working in the whole office is 65.

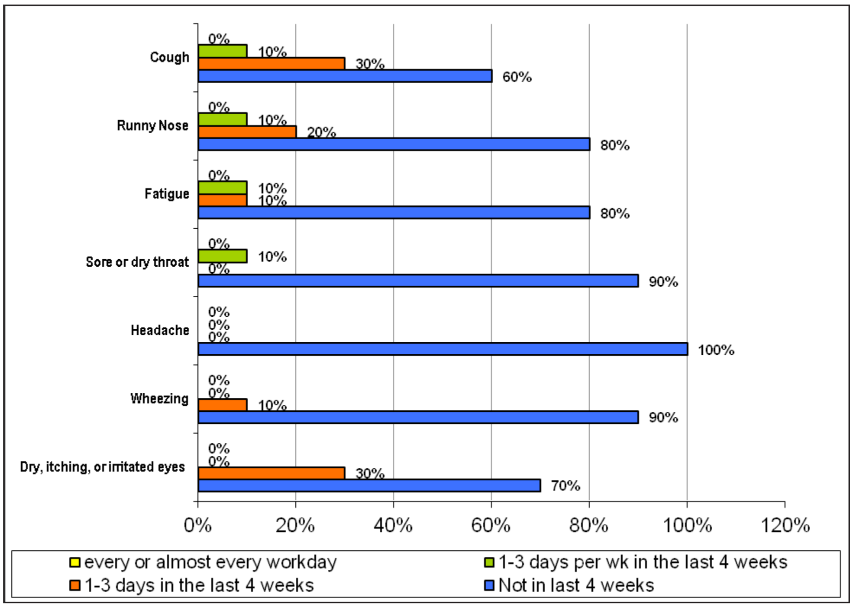


Figure 4.2: Discomfort/Dissatisfaction symptoms (1) in office (A)

The chart above show that most staff didn't any sickness symptoms that kept them away from work for the past 4 weeks. Minority felt sore throat or irritated eyes.

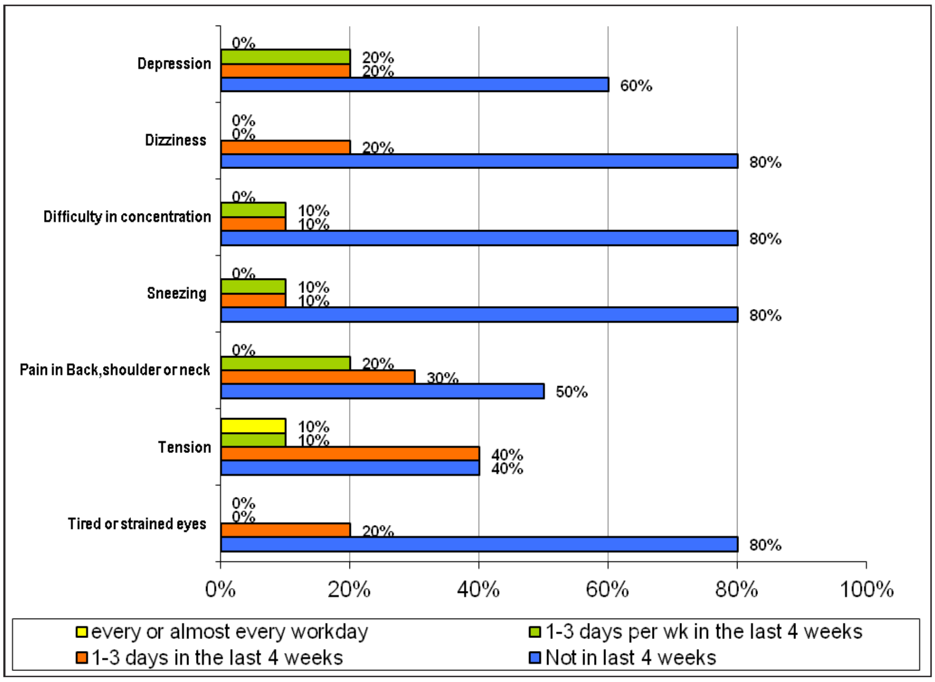


Figure 4.3: Discomfort/Dissatisfaction symptoms (2) in office (A)

This chart clearly shows that majority of the staff are not experiencing any sysmptoms that are shown in the graph. Around 40% feel the tension in their muscles. However no serious threats has been shown.

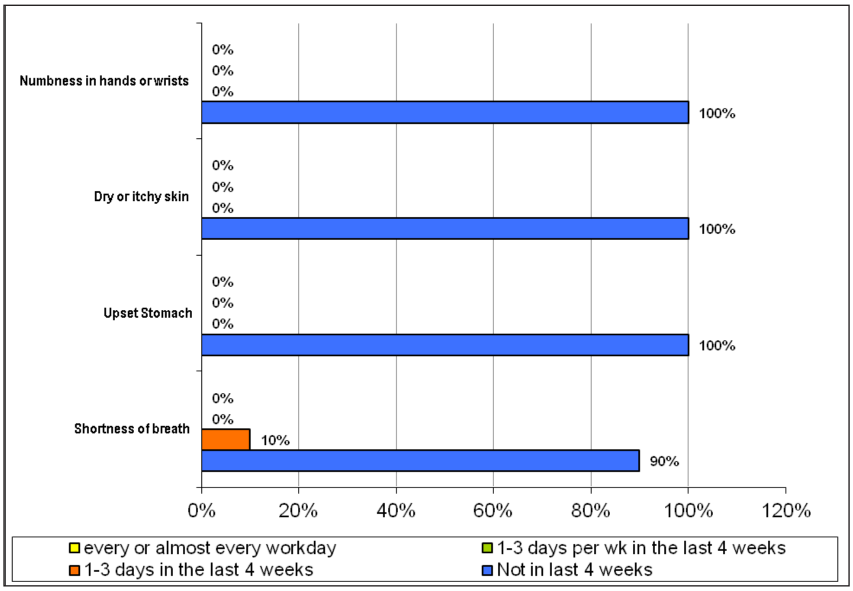


Figure 4.4: Discomfort/Dissatisfaction symptoms (3) in office (A)

Another observation according to the chart is that none of the surveyed staff felt any upset stomach or itchy skin. They didn't feel any numbness in hands or wrists. Very few showed expressed their shortness of breath.

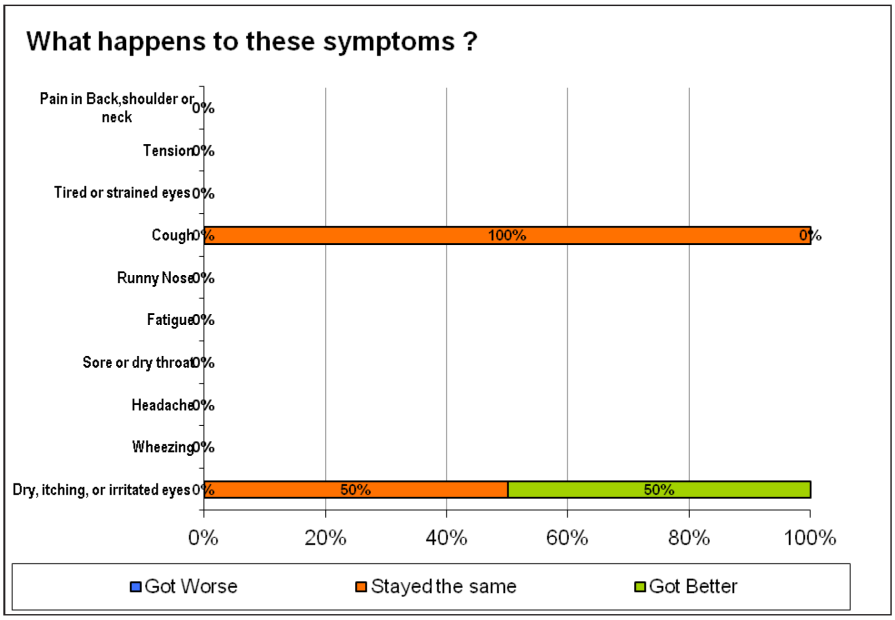


Figure 4.5: What happens to the symptoms (1)

The chart above explaines that after getting hit by any of the symptoms shown earlier, that the majority stayed the same. They didn't get better nor get worse.

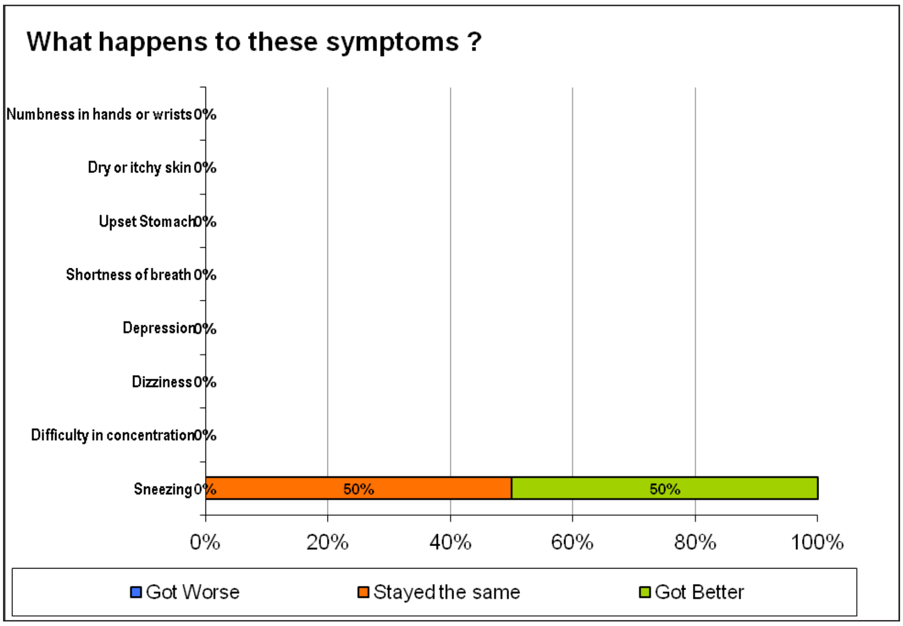


Figure 4.6: What happens to the symptoms (2)

Some have recovered from the sneezing discomfort. While the others didn't.

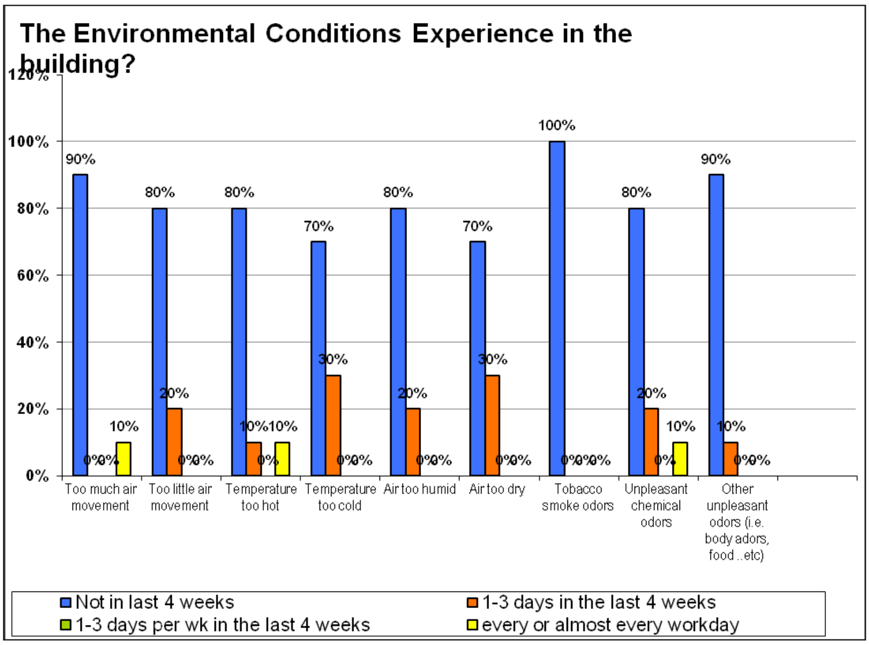


Figure 4.7: Environmental Conditions experience in office (A)

Two main observation can be found in the chair above , one is that 80% of the surveyed staff don't complain about any discomfert from the office's IAQ. However some show a discomfort about the temperature which is too cold.

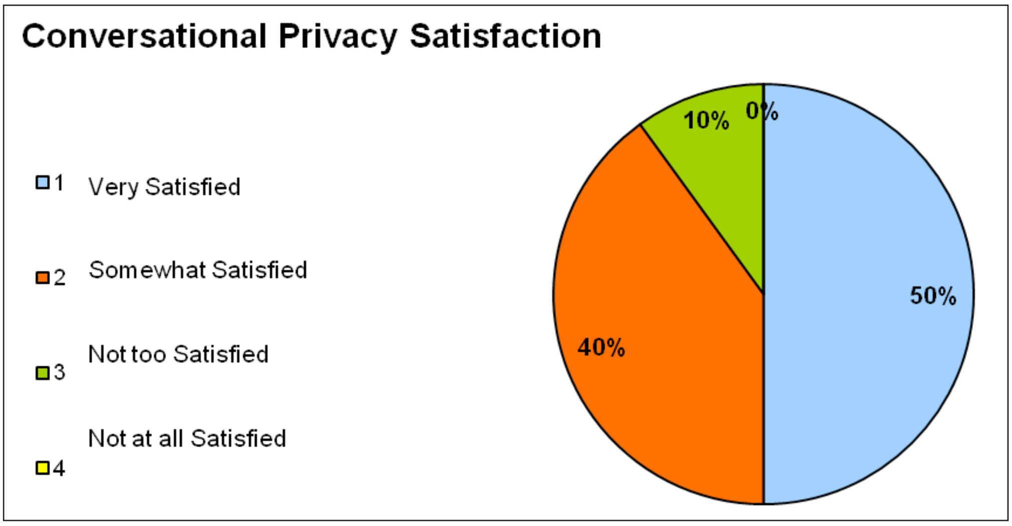


Figure 4.8: Conversational Privacy satistfaction in office (A)

The chart above shows that 50 % of the staff are happy with there privacy settings in the office, only a very few are not all satisfied.

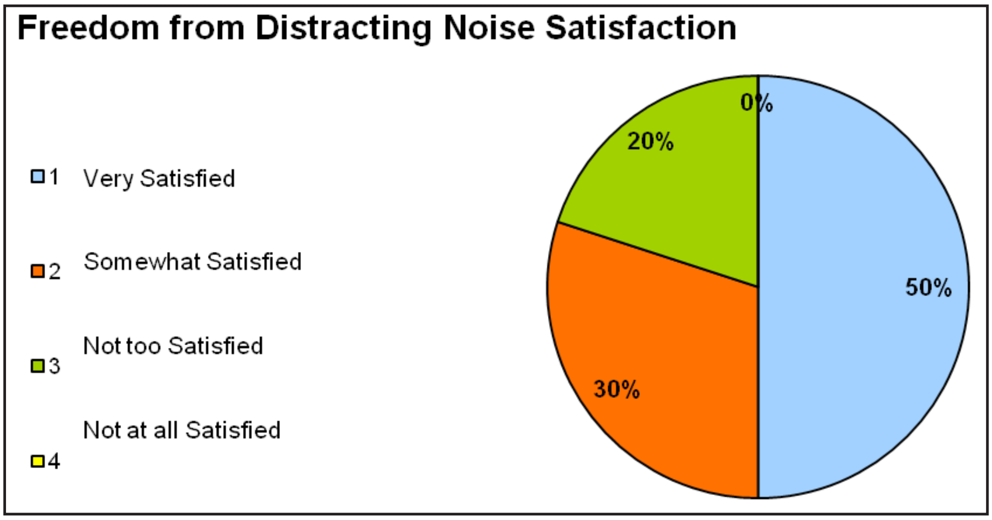


Figure 4.9: Freedom from distracting Noise satisfaction in office (A)

This chart also shows that the majority of the staff are very satisfied in the regards of distracting noise which sems to be very limited in the office.

4.2 .2. Office (B)

This building is located in Dubai Academic City, and it has seven floors including the ground floor. The study was conducted for the second and third floors, which are owned by an educational institute. This building can be described as a 5 years old building which accommodates more than 50 staff. A high traffic flow is noticed in the evening, as most of the classes are scheduled at that time, due to the expected increase in the number of space users (Staff and Students). The site visit was necessarily to get a better understanding of the space conditions, hygiene, layout, users' activities and any other general observations. During the walkthrough, a strong odour (more of chemical smell of paint) was noticed. However, the building looked clean and hygienic in general, with very little dry dust in few obscure locations. As for the other hygienic conditions, high VOC cleaning solvents were used in the cleaning of the office, which is usually done every morning using vacuum cleaners and other cleaning solvents. All the cleaning material is stored in a store room, which is usually locked. To test the indoor air quality level in the space, it was essential to check the finishing of the interior, as any water damage, mold or cracks might be a sign to low air quality level which might lead to serious health issues in the space. Starting with the wall, as this office has been extensively renovated 7 months before this study, it is not surprisingly that there were no evident deterioration of wall peeling and cracks. On the other hand, though this was a new building, there were water stains on the ceiling of some of the rooms. In addition, there was no evidence of any mold growth at the supply diffuser and return grills.

Indoor air quality is directly impacted by human activities. As a result, it was important to spend a full day in the first visit to understand the numerous users' activity patterns and list the most common habits/behaviours. First of all, spraying perfumes and fragrances is a common habit by a large number of space users. The staff meeting rooms is used by BUID employees and students, which increases the traffic flow.

4.2.2.1 Plan Overview

The study was completed for the first and second floors of the building, where the selected office is located. To describe the functions and activities in each floor, the first floor is assigned for all the administration offices, library, auditorium, few labs and English language support classrooms. The reception and administration zones form an open space plan, for easy access and maximum space usage. This design allows the sunlight to permeate throughout the whole space. However, the open space plan does not give the space users enough privacy. In addition, this plan causes a lot of acoustics problems unless thick insulation is carefully installed. Studies have shown there is a strong relationship between privacy level and the employees' productivity. In other words, the distraction caused by the lack of privacy leads to employees' dissatisfaction which drops the productivity level (Tierney 2012). As for the second floor, it depends on the close-plan layout, as it's mainly for classrooms and professors offices. Below are the floor plans for the first and second floors, highlighting the different zones and functions

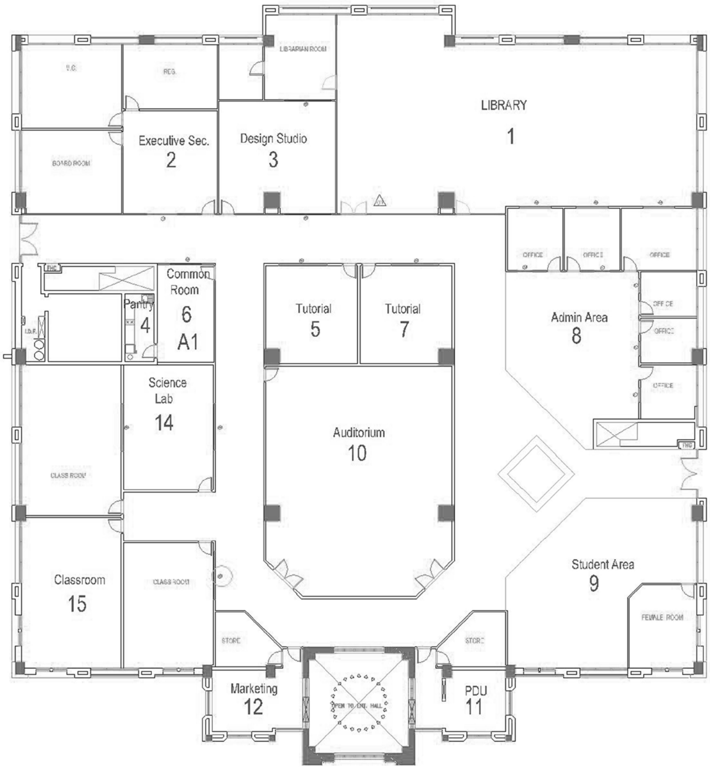


Figure 4.10: First Floor Plan for building (B)

Figure 4.111: Second floor plan for Building (B)

4.2.2.2 Spot measurements

Table 4.3: Direct Sense Spot measurement readings (1) for office (B)

C.N.	Parameters	Zones						
		Location 1	Location 2	Location 5	Location 6	Location 8	Location 9	Location 16
1	TVOC (ppb)	1507.6	1167.4	1148.6	1027	969.6	925	498
2	Carbon Dioxide (ppm)	531.4	542.5	583.1	535.3	560.4	554	480.2
3	Ozone (ppm)	0.471	0.498	0.765	1.145	0.977	0	0.015
4	Carbon monoxide (ppm)							
5	Temperature °C:	24.06	23.52	22.97	22.74	22.48	22.3	20.66
6	Relative Humidity %RH	49.31	47.49	51.97	50.6	51.13	50.9	67.37
7	Toluene ppb	799.03	618.76	608.78	544.33	513.88	490.2	793.92

It was essential to test the key IAQ parameters in almost all the zones/ spaces, in order to understand how the layout, finishes and people activities affect the pollution level. As a start, the first instrument (Direct Sense) was used for the spot measurement, which takes few minutes per room. An average of VOC, CO_2, O_3 and Toluene levels was recorded for each space. Below is a summary of the findings followed by a detailed analysis for the instrument readings for the spot and continuous measurements.

Table 4.4: Direct Sense Spot measurement readings (2) for office (B)

C.N.	Parameters	Zones						
		Location 17	Location 18	Location 20	Location 21	Location 23	Location 24	CM.
1	TVOC (ppb)	1682.1	1330.2	1377.8	1075.7	1115.5	1063.9	988
2	Carbon Dioxide (ppm)	471.8	488.1	570.6	518.3	485.2	484.3	532.3
3	Ozone (ppm)	0.02	0.016	0.015	0.05	0.036	0.045	0.048
4	Carbon monoxide (ppm)							
5	Temperature °C:	20.65	19.85	20.09	20.78	20.3	20.57	20.79
6	Relative Humidity %RH	71.99	66.29	74.31	60.9	69.81	69.09	65.72
7	Toluene ppb	891.54	704.98	730.22	570.1	591.23	563.84	523.61

First of all, the highest TVOC level in the first floor is found in Zone 1 which represents the Library. The high emission rate was expected in this zone specifically because of the type of human activities and the work routine. Papers, office equipment such as scanner, photocopy machine, etc are all clear indicators for high pollution level. If we look closely at the layout and design of the library, it will be noticeable that both factors are the key reasons for the environmental health condition of the space. As s start, below are some observations for the library design and finishes failures that align to the instruments readings:

- Carpet flooring in a very high traffic area, which is direct source of indoor pollution due to the trap of dust, dirt, particles, etc. Carpet is used in most of the libraries as flooring finishing in order to absorb noise. However, for a high traffic zone, the maintenance and hygiene factors should be a priority and the noise control could be achieved by using enough insulation besides various design techniques for acoustics.
- Massive use of wood finishes in the all the storage and display units.

Based on EPA (2012), no specific standards have been published for VOCs level in non industrial settings. However, “OSHA regulates formaldehyde, a specific VOC, as a carcinogen. OSHA has adopted a Permissible Exposure Level (PEL) of .75 ppm, and an action level of 0.5 ppm”.

When testing indoor air quality in offices, the thermal comfort standards should be considered. As the library contains a number of PCs, printers and photocopy machine that emits heat, it was expected that the instruments reading reflect a high temperature level (24.06 º C), compared to the rest of the rooms, especially that a central A/C system is used in each floor. Based on ASHRAE 55-220, the temperature and humidity ranges that meet the thermal comfort needs of 80% of individuals are as follows:

Table 4.7: ASHRAE humidity and temperature standard levels that meets thermal comfort

Temperature / Humidity Ranges for Comfort			
Conditions	**Relative Humidity**	**Acceptable Operating Temperatures**	
		C°	F°
(Summer (light clothing	If 30%, then If 60%, then	28 - 24.5 25.5 - 23	82 - 76 78 - 74
(Winter (warm clothing	If 30%, then If 60%, then	25.5 - 20.5 24 - 20	78 - 69 75 - 68

The ozone level is reasonable in the second floor, but a massive increase is noticed in the first floor due to the high traffic and poor design. The open plan has supported the transition of pollutants to most of the spaces. Locations 6 and 8 represent the common room and administration area are reported for the highest ozone levels in this office. The administration area is an open space

Ozone is produced by the operation of high voltage equipment such as photocopiers

4.2.2.3 Continuous measurement

The continuous measurement process was completed in the staff common room, considering the high readings recorded in the spot measurement phase for this space. The instrument was placed on the main table in the room for 24 hours to get clear records for any changes in the IAQ parameters level during and after the official working hours. It is noticeable that the level of TVOC dropped in the continuous measurement compared to the spot measurement of the same space (difference of 39). People activities explain the high TVOC level during the working hours.

4.2.2.4 Airflow measurement

A handle was placed in front of the air supplier to measure the airflow level of the air conditioning system in key location within the office: Common Study Room. Below is a summary of the air flow readings:

Table 4.8: Airflow readings for office (B)

	Zone A1
Air Speed	0.054
Temperature	24.1

4.2.2.5 HCHO measurement

This exercise was completed in the Library, considering the high traffic flow in this space, and the massive use of the PCs, printers, scanners in a close floor plan. The instrument was placed on the reception counter in the library and the reading was as follow: Average of 0.02.

4.2.2.7Survey

A survey was shared with the institute employees (administration, professors, etc) to get a better understanding of the environment health conditions and the common symptoms of employees' discomfort. All the participants were very supportive and keen to know the study findings and the final recommendations.

The survey questions about the effects of SBS symptoms on occupants' ability to work and leave of absence in the last 4 weeks has shown the results below:

Table 4.9: Effects of SBS symptoms on occupants' ability to work and leave of absence in the last 4 weeks in building (B)

Office	Effects of symptoms	day 0	1-4days	5-to 10 days	More than 10 days
B	In the last 4weeks how often have any of the ***symptoms reduced your ability to work***	50%	50%	0%	0%
	In the last 4weeks how often have any of the ***symptoms caused you to stay home***	75%	25%	0%	0%

Various symptoms were highlighted in the questionnaire to understand the exact health conditions of the space and the frequency of the illness. The graphs below show the different illness symptoms and the response rate of the survey participates.

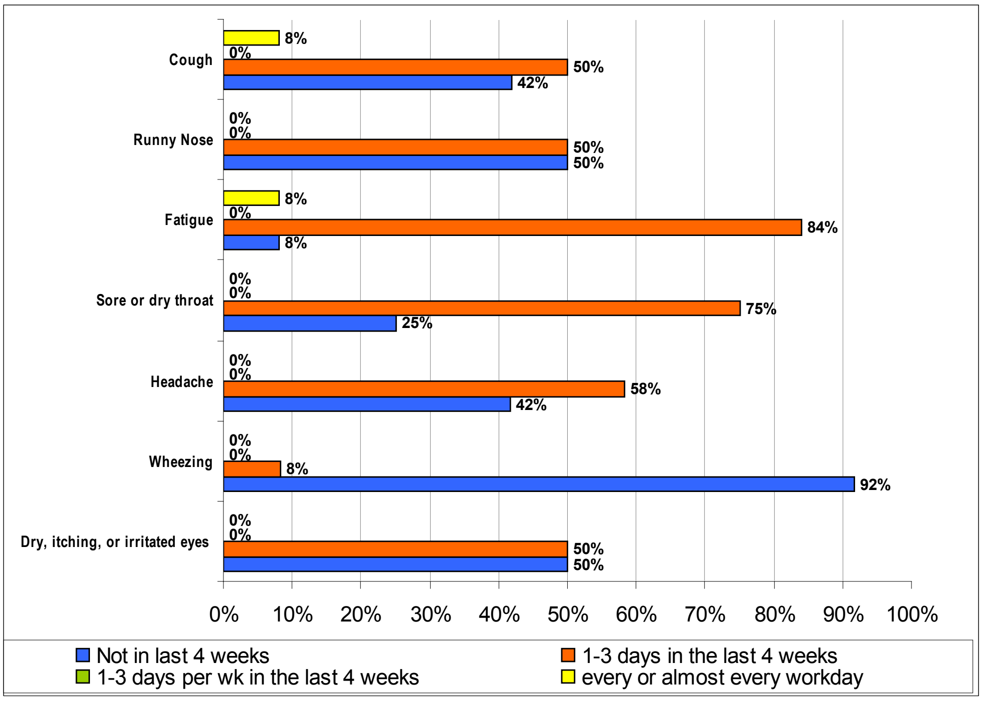


Figure 4.12: Discomfort/ dissatisfaction symptoms (1) in office (B)

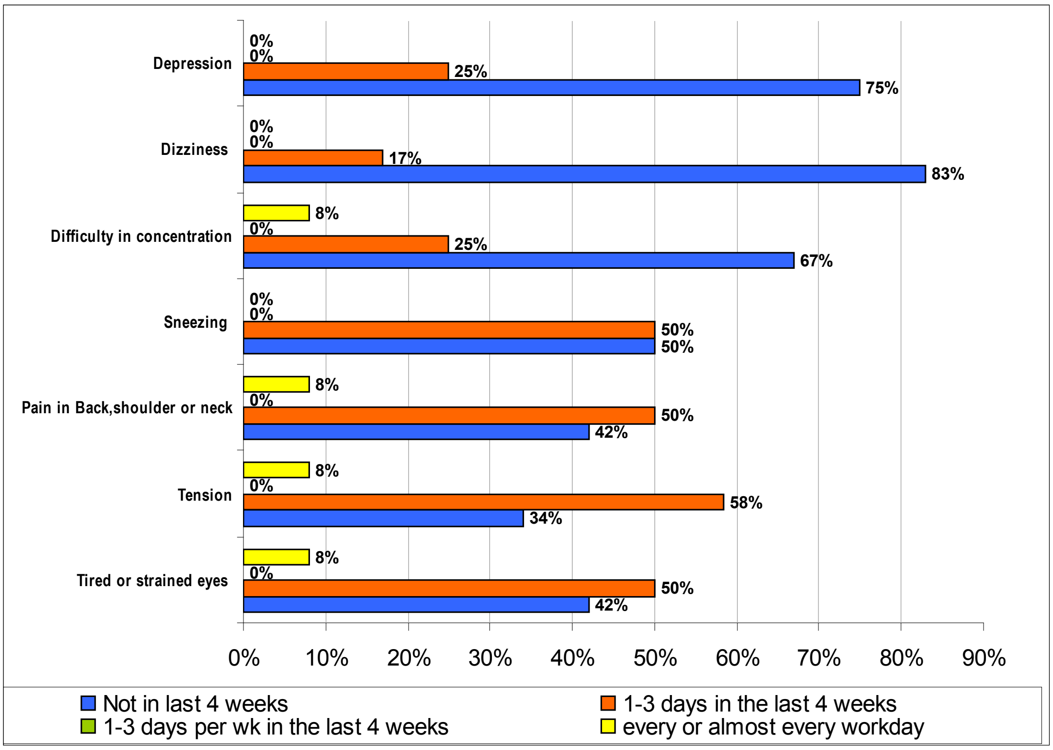


Figure 4.13: Discomfort/ dissatisfaction symptoms (2) in office (B)

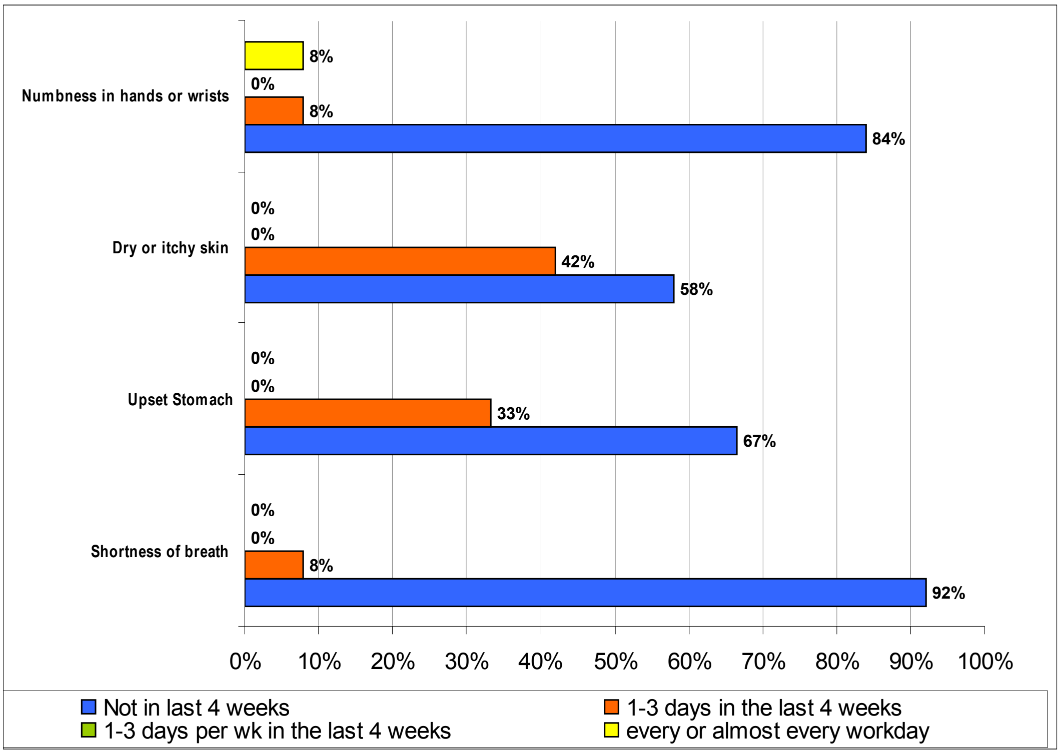


Figure 4.14: Discomfort/ dissatisfaction symptoms (3) in office (B)

The readings show that 84% of the employees suffer from fatigue symptoms, and 75% of the employees got sore or dry throat illness 1-3 days in the last 4 weeks. A small population of an average of 8% suffered from other symptoms such as cough, difficulty in concentration, pain in back and shoulder and tension in every working day. The readings give a clear indication of the health conditions of this office.

Moreover, to get a clear picture of the space health condition, the participants were asked to answer few questions about the environmental conditions experience in the building, and a summary of the responses is demonstrated in the graphs below:

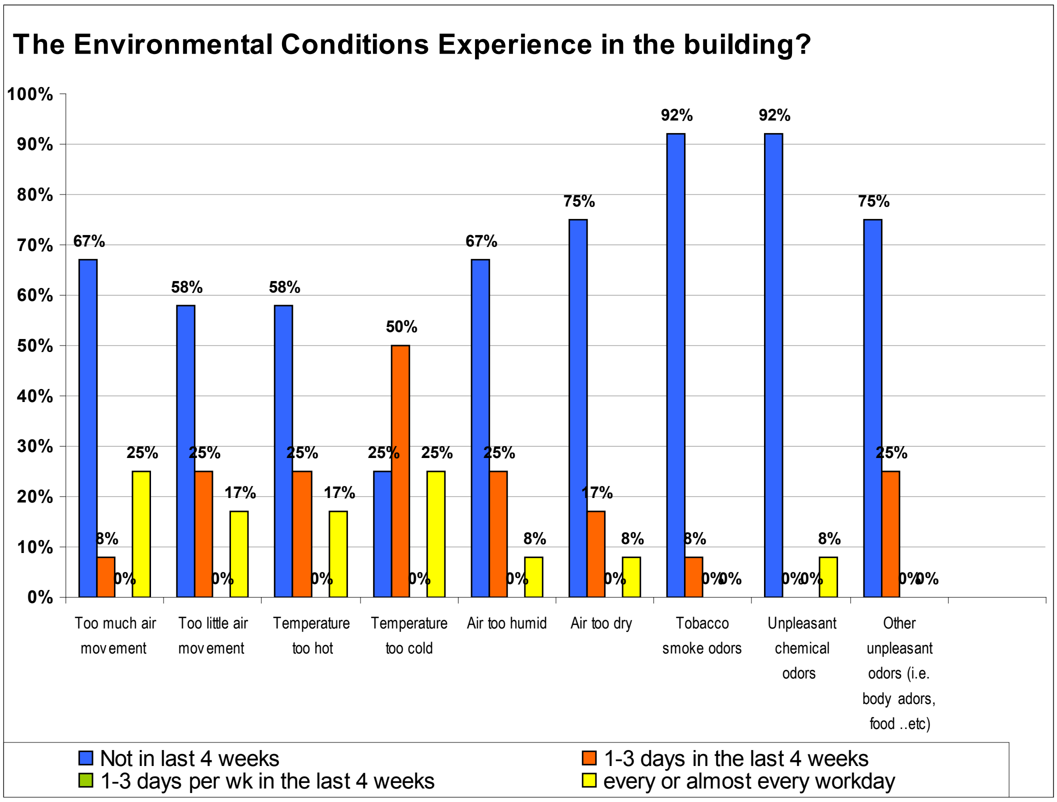


Figure 4.15: Environmental conditions experience in office (B)

92% of the occupants didn't experience tobacco or smoke odor in this space, which was expected considering the fact that the smoking zone is placed outside the office premises, in a totally different direction to the office main entrance (Only source of natural ventilation, as all the windows are closed). As a result, minimal transfer of outdoor pollution (smoking) is expected.

The readings clearly show that there is no consistency in the air distribution in the office spaces. While 25% of the occupants weren't pleased of the hot temperature, 50% complained about the cold temperature in their desks zone. Most of the occupants didn't sense any unpleasant odor, but 25% of the occupants highlighted the fact that body odors and food smell is noticeable.

The acoustics and privacy factors are key design considerations when measuring the occupants' comfort and satisfaction level. Below is a summary of the survey participants' feedback when they were asked how they feel about the privacy level and acoustics control in their office(s).

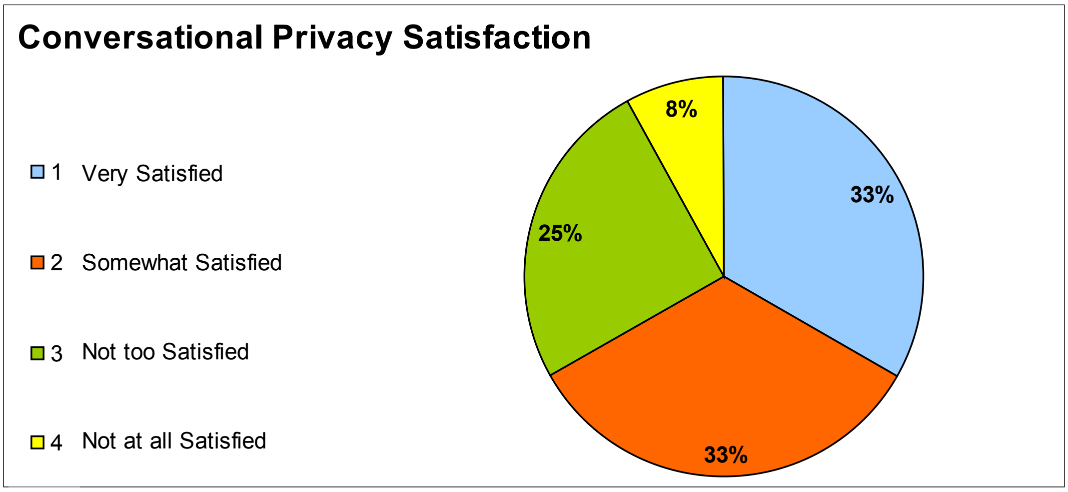


Figure 4.16: Conversational Privacy satisfaction in office (B)

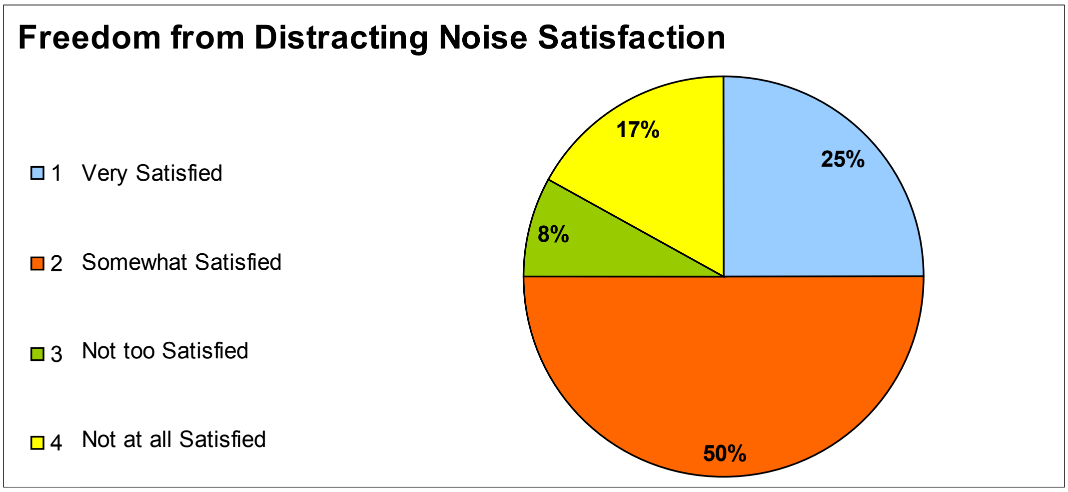


Figure 4.17: Freedom of distracting noise satisfaction in office (B)

As the office design is mostly an office space plan, the majority of employees (58%) were either somewhat satisfied or not too satisfied with the privacy level. 58% of employees were somewhat or not too satisfied by the noise level. Overall, the office acoustics were acceptable but the open floor plan design creates some distraction, especially in the operations zone.

4.2 .3. Office (C)

This office is located in a residential area and accommodates more than 200 staff in a 2-storey building (Ground + First) that is more than 15 years old. The walk-through investigation phase was completed on 28th October 2011. Various observations were noted during the visit. As a start, the building envelope didn't show any evidence of envelope failure such as cracks, leakage, etc. Moreover, there was no any obvious stain and material deterioration. In addition, the windows were generally closed not only during the study but also throughout the day. The location of the building could pose threat to IAQ if adequate actions are not taken, as it faces a major (busy) road.

Regarding the interior, a strong odor and moldy smell is observed in the entire building. The offices are so crowded because of the population of the space users. The scattered papers in a dry environment with the observed dust were all indications for the poor indoor air quality of the space.

HVAC System and natural ventilation were also observed during the walk-through investigation and the meeting with the facilities manager confirmed our expectations, which can be summarized as below:

- The Air is tight completely, no any leakage.
- Aluminum wire-mesh filters are used in the HVAC System, which is removed and cleaned with water on regular-basis.
- Regular maintenance- once every 2 months (*Last time was in two weeks time before the study date*).
- Inducting of fresh air is used – no separate fresh air unit.
- The system conducts Variable air volume (VAV) method
- The HVAC system contains modifiers in the IT room.

- One hour full maintenance is arranged every 15 days, only when necessarily
- The HVAC system depends on the re-circulation of the indoor air rather than typical outdoor air change.
- The only source for the outdoor air is the electrical door by the entrance (front Façade)

4.2.3.1 Plan Overview

The plan below shows the different spaces with the selected color-coding for both ground and first floors. The layout of the ground floor is a combination of an open-space plan with minimal partitions to separate the departments, besides some private meeting rooms to maintain customers' information confidentiality and privacy. Most of the front office desks are placed in a semi-circle shape around the reception desk. Almost the same furniture pieces are used in the different zones in this floor. Storage pieces are used massively in the back-office area to store the papers, envelopes, customers' files and some stationary items. Two interior doors are allocated on both sides of the semi-circle front office shape to allow staff to access any facilities in the back office. The office entrance automatic sliding door was the main source of outdoor air to the interior.

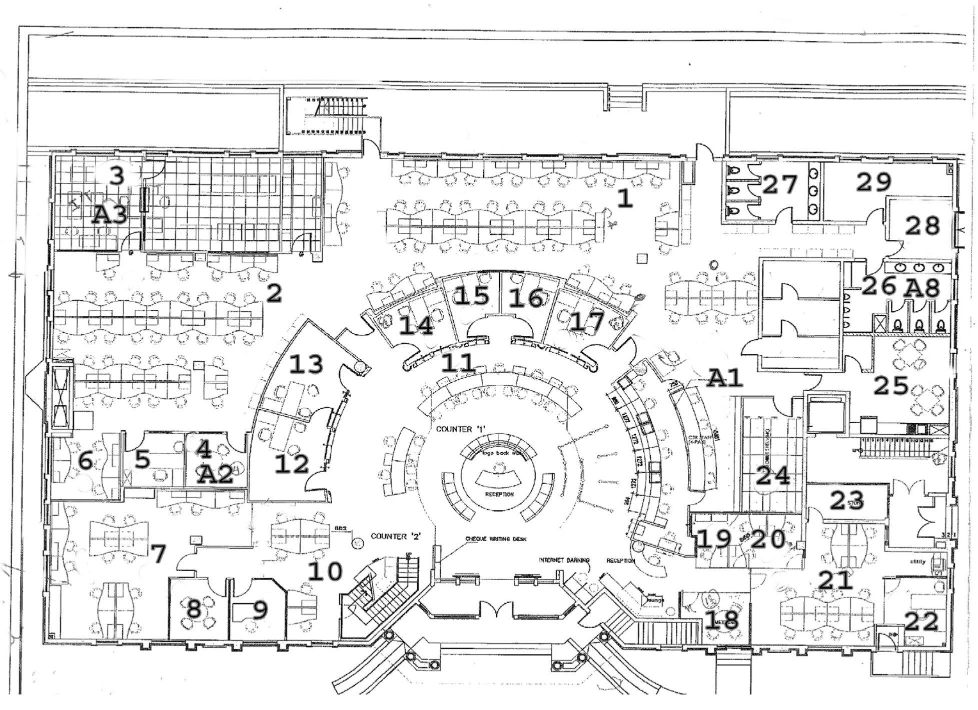


Figure 4.18: Ground floor plan for building (C)

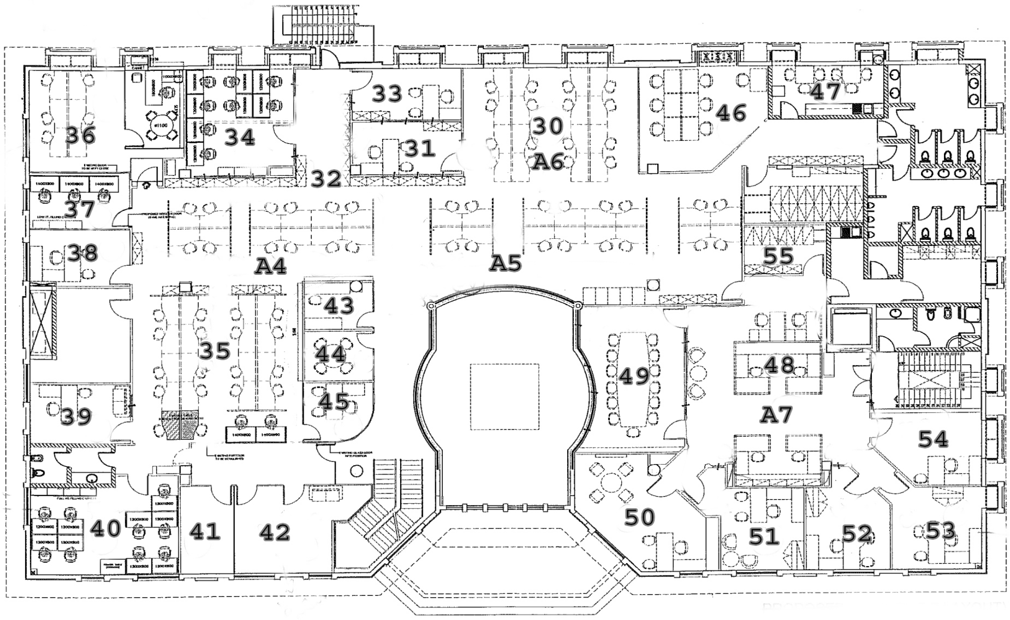


Figure 4.19: First floor plan for building (C)

4.2.3.2 Spot measurements

7 key IAQ parameters, including TVOC, Carbon Dioxide, Ozone, Carbon Monoxide, temperature, relative humidity, and Toluene, were measured in most of the zones using Wolfsense PC, and the table below shows the summary of the spot
measurements.

Table 4.10: Direct Sense spot measurement readings (1) for office (C)

C.N.	Parameters	Zones								
		Location 1	Location 2	Location 3	Location 4	Location 5	Location 6	Location 7	Location 8	Location 9
1	TVOC (ppb)	472	372.6	374	385.9	395.8	392.3	320.3	364.1	324.2
2	Carbon Dioxide (ppm)	1221	1158.6	1096.3	1153.2	1183.1	1170.8	1197.4	1446.6	1231.7
3	Ozone (ppm)	0.003	0.005	0.005	0.003	0.005	0.005	0.005	0.008	0.013
4	Carbon monoxide (ppm)	1.03	1.04	0.96	1	1.03	0.85	0.84	0.79	0.88
5	Temperature °C:	21.32	21.12	21.15	21.65	21.37	21.82	21.4	22.37	22.96
6	Relative Humidity %RH	44.34	42.11	40.68	41.57	40.01	40.47	39.85	42.06	39.82
7	Toluene ppb	250.18	197.49	198.28	204.55	209.77	207.92	169.79	192.92	171.82

Table 4.11: Direct Sense spot measurement readings (2) for office (C)

C.N.	Parameters	Location 10	Location 11	Location 12	Location 13	Location 14	Location 15	Location 16	Location 18	Location 19
1	TVOC (ppb)	325.6	297.1	312.1	935.6	317.8	315.8	318.9	748.2	301.3
2	Carbon Dioxide (ppm)	1247.6	1244.6	1196.2	1314.2	223.7	1260.1	1354.1	1331.7	1317.6
3	Ozone (ppm)	0.017	0.014	0.006	0.022	0.006	0.006	0.004	0.057	0.006
4	Carbon monoxide (ppm)	0.92	0.83	0.74	0.98	0.66	0.6	0.61	2.19	0.75
5	Temperature °C:	23.17	22.85	22.23	24.3	22.09	22.01	21.69	30.55	21.99
6	Relative Humidity %RH	38.67	38.36	38.05	52.59	39.87	40.75	41.44	36.04	42.86
7	Toluene ppb	172.51	157.49	165.38	495.87	168.43	167.36	169.02	396.57	159.66

Table 4.12: Direct Sense spot measurement readings (3) for office (C)

C.N.	Parameters	Location 20	Location 21	Location 23	Location 25	Location 26	Location 27	Location 28	Location 29	CM.
1	TVOC (ppb)	283	291.9	307.1	335.2	1716.4	471.5	541.2	327.5	725.9
2	Carbon Dioxide (ppm)	1352.1	1429.2	1409.7	1325.2	1320.9	1385.4	1610.4	1307.2	1111.3
3	Ozone (ppm)	0.006	0.005	0.006	0.008	0.005	0.022	0.013	0.016	0.052
4	Carbon monoxide (ppm)	0.62	0.64	0.52	0.63	1.02	0.91	0.66	0.69	0.11
5	Temperature °C:	21.28	22.11	21.7	22.83	23.87	23.95	23.38	23.22	25.34
6	Relative Humidity %RH	41.71	41.66	42.74	45.61	49.16	45.45	42.78	39.19	40.57
7	Toluene ppb	150.03	154.71	162.74	177.65	909.66	249.89	286.82	173.55	384.75

Table 4.13: Direct Sense spot measurement readings (4) for office (C)

C.N.	Parameters	Zones									
		Location 30	Location 31	Location 32	Location 33	Location 34	Location 35	Location 36	Location 37	Location 38	Location 39
1	TVOC (ppb)	355	339.3	333.5	292.4	329.4	319.6	279.7	298.6	308.7	288.5
2	Carbon Dioxide (ppm)	1588.6	1510.7	1552.3	1485.9	1589.5	1582.8	1400.3	1423.5	1497.6	1371.4
3	Ozone (ppm)	0.007	0.009	0.011	0.018	0.017	0.01	0.012	0.018	0.012	0.009
4	Carbon monoxide (ppm)	0.62	0.58	0.65	0.66	0.63	0.61	0.52	0.49	0.54	0.5
5	Temperature °C:	22.69	22.98	23.25	22.91	23.18	23.28	23.17	22.99	22.91	22.95
6	Relative Humidity %RH	41.75	41.83	41.31	40.7	41.81	39.52	39.28	39.46	40.01	39.16
7	Toluene ppb	88.18	179.83	176.74	155	174.59	169.36	148.25	158.28	163.64	152.91

Table 4.14: Direct Sense spot measurement readings (5) for office (C)

C.N.	Parameters	Location 40	Location 41	Location 45	Location 46	Location 47	Location 50	Location 52	Location 53	Location 55	Location 56
1	TVOC (ppb)	268.1	238.3	1450.2	798.8	1324	1147.1	1025.2	1008.1	950.6	1028.7
2	Carbon Dioxide (ppm)	1457.7	1630.6	1079.4	1564.7	1632.1	1136.9	1263.1	1254.3	1259.7	552.3
3	Ozone (ppm)	0.013	0.008	0.017	0.016	0.014	0.024	0.025	0.027	0.03	0.103
4	Carbon monoxide (ppm)	0.48	0.49	1.77	1.49	1.4	1.33	1.31	1.27	1.2	1.05
5	Temperature °C:	22.97	20.62	23.57	22.39	23.72	24.58	25.16	25.56	25.46	32.79
6	Relative Humidity %RH	40.03	34.62	68.72	43.45	65.79	58.07	54.87	52.81	51.33	73.38
7	Toluene ppb	142.12	126.31	768.62	423.4	701.72	607.96	543.34	534.32	503.84	545.11

The readings have shown an average of 445 for TVOC in all the zones in the ground floor. It was important to understand the typical office range of TVOC as start point to evaluate the office environment condition. Based on the office standards, an acceptable range of TVOC in an office should be between few micrograms to few milligrams per cubic meter; while in the outdoor environment it shouldn't exceed 0.1 mg/m^3 (Health Canada. 2007).

The summary above states a rapid increase in the HVOC reading in the customers' meeting room, assigned as zone (13), with an average of 935.6 ppb, which is clearly due to the emission of Dichlorobenzene and 4-phenyclohexene (4-PC) from the old carpet used in the room. Moreover, the chairs used are all made of pressed wood and cotton Fabric for upholstery, with a solvent-based wood-coating and glue, which are all sources of formaldehyde and VOC. Although VOC emission rate decreases over time, formaldehyde emits for years. In addition, dust mite is observed by the edges/corners of the furniture pieces. Moreover, no any sources of natural ventilation, which means that the air is re-circulated through the air conditioning system only without any source of fresh air entering the room. Furthermore, the highest VOC emission rate in the ground floor is noted in the Males' toilet, assigned as zone 26. This trend is because of the high moisture level with a low ventilation rate. The first odor to be described upon entering the toilet is the moisture smell. The floor tiles and countertops are always wet which causes mold growth. The walls have no any obvious cracks; however, a clear change in paint color in some corners with some paint peeling is noted. Used toilet paper is scattered in some corners and on the countertop which increases the moisture smell. Moreover, metal cabinets are placed in a corner for storage purpose and all the cleaning solvents are left on the floor. All of the above are major sources of indoor air pollution, which has a crucial effect on the indoor air quality.

Moving to the first floor, the results show a higher average of VOC level with an approximate amount of 590 ppb. This is due to having a full open space plan with fewer partitions. In other words, open spaces are more populated than closed offices, which mean more traffic flow is expected which causes more heat. As a result, a lot of factors need to be considered when selecting this form of design. The Summary shows the highest TVOC average in meeting room, assigned as Zone (45). This reading illustrates the design and maintenance problems of the space. The resins and glues found in the glass curtain wall are major source of indoor pollution. Moreover, the room size does not accommodate a large number of people; however, 5 chairs are placed in the room for medium group meetings. The space is usually used by a larger number of people, which illustrates the poor plan of the design at the first place.

The second highest reading is for the Kitchen, assigned as zone (47). Kitchen appliances emit nitrogen dioxide (NO_2). Electric water kettles, microwave and fridge are all considered as sources of kitchen pollution. As the temperature is an important factor to consider for IAQ office evaluation, due to its direct effect on occupants' comfort which links to their performance and productivity , it was essential to measure the temperature in various zones in the this office. The average temperature for the ground floor is 22.63 ºC, which is within the thermal comfort standards for offices (21- 23 ºC) (CCOH 2011). The readings show constant range of thermal conditions in all the zones in the First floor, except the kitchen (Zone 18) with an average of 30.55 ºC. Any study for the kitchen thermal comfort should consider four main factors: air temperature, radiation, air movement and humidity. As temperature and heat phrases are usually used interchangeably, it is important to focus on the different sources of heat in the kitchen, which led to the shocking instruments' readings. Boling water on a countertop is not only a source of moisture (Parott et al 2003, Pickett et al. 1986), but also heat. Surprisingly, the kitchen didn't have any natural ventilation or exhaust fan, which is the main reason for the heat. Microwave ovens transfer the moisture from food and "vent it into the kitchen space" (Parott et al 2003). With all the activities that take place in the kitchen, such as boiling the water, warming food in the microwave, etc., there is was no any source of natural ventilation to control the heat emission with the presence of the indoor air pollution sources.

Moreover, the number of users of the space is quite high compared to the size of the room. As a seated person gives off an approximate range of sensible heat that equals btuh into the occupied space (Sugarman, 2005), the kitchen didn't meet the design standards.

As for the ground floor, Customers' meeting room (Zone 18) shows the highest temperature rate. The layout, material selection and orientation of the space clearly explain the results. This room is facing the front façade of the building, which means heat is transferred from the sun to the wall through radiation mechanism. Followed by the heat transfer from the wall to the interior and stored in the room, as there's no any source for air leakage except the room door.

Heat transfer cannot be stopped; however, it can be reduced if suitable insulation was used. It is important to mention that the building original design was meant to be occupied by around 150 employees only whereas it's used by more than 250 staff, which means more than 60% increase in the occupants' rate. From design perspective, the massive increase in the number of space users without any building renovation to expand the building space is very crucial. A lot of ventilation, maintenance and indoor air quality limitations and failures will immediately be noticed. Moreover, as the building interior was designed to meet the office requirements of a smaller population, the current status of the building with the large number of users demonstrate that some of the rooms are converted to a different use/purpose than the actual design to meet the new capacity. This can be easily translated to the occupants' health problems, due to the indoor health issues.

4.2.3.3 Continuous measurement

It was essential to keep an eye on the office indoor environment and complete the continuous measurement process to understand the main factors of indoor air pollution with respect to the office working hours and traffic flow of the space. The table below summarizes the results of the continuous measurement which was completed in the Zone () with the highest traffic rate.

Table 4.15: Direct sense continuous measurement reading for office (C)

IAQ Parameters	*Readings*
TVOC ppb:	Min = 538 at 01-Jul-10 06:26:03 AM
	Max = 915 at 30-Jun-10 03:51:03 PM
	Average = 725.9
Carbon Dioxide ppm:	Min = 586 at 01-Jul-10 06:25:33 AM
	Max = 1720 at 30-Jun-10 05:15:33 PM
	Average = 1111.3
Ozone ppm:	Min = 0.00 at 01-Jul-10 01:16:29 PM
	Max = 0.45 at 01-Jul-10 01:14:58 PM
	Average = 0.052
Carbon Monoxide ppm:	Min = 0.0 at 01-Jul-10 01:16:44 PM
	Max = 0.6 at 30-Jun-10 10:08:38 AM
	Average = 0.11
Temperature °C:	Min = 23.6 at 01-Jul-10 06:26:18 AM
	Max = 27.7 at 30-Jun-10 09:03:18 AM
	Average = 25.34
Relative Humidity %RH:	Min = 34.7 at 30-Jun-10 09:02:03 AM
	Max = 42.1 at 30-Jun-10 05:04:18 PM
	Average = 40.57
Toluene ppb:	Min = 286.2 at 01-Jul-10 06:26:08 AM
	Max = 485.0 at 30-Jun-10 03:51:03 PM
	Average = 384.75

4.2.3.4 Airflow measurement

Below is a table that summarizes the air flow results in 8 different zones in Office.

Table 4.16: Airflow readings for office (C)

	Zone A1	Zone A2	Zone A3	Zone A4	Zone A5	Zone A6	Zone A7	Zone A8
Air Speed	0.098	0.036	0.128	0.033	0.468	0.172	0.029	0.038
Temperature	22	22.1	23	21.3	20.8	21	22	27.3

The air speed readings show slight changes from one zone to the other. However, a high increase is shown in Zone 5 readings – open space plan for cubicles.

Massive increase is recorded in the temperature of Zone A8, which represents the Males Toilet, which is due to the lack of ventilation in this space. Poor Air quality is noticed when you enter the space.

4.2.2.5 HCHO measurement

The reception area was selected for the formaldehyde measurement, as it's a space with high traffic and minimal natural ventilation (Automatic double sliding door). The records have shown an average of 0.08 formaldehyde level in the space.

4.2.2.7 Survey

To maintain consistency in the analysis approach, the same survey used in buildings A and B was used in building C.

The readings show that an average of 37% of employees suffered from headache / sore or dry throat 1-3 days in the last 4 weeks. While 31% suffered from neck and back-pain which is associated with most of the people who work or drive for long hours every day.

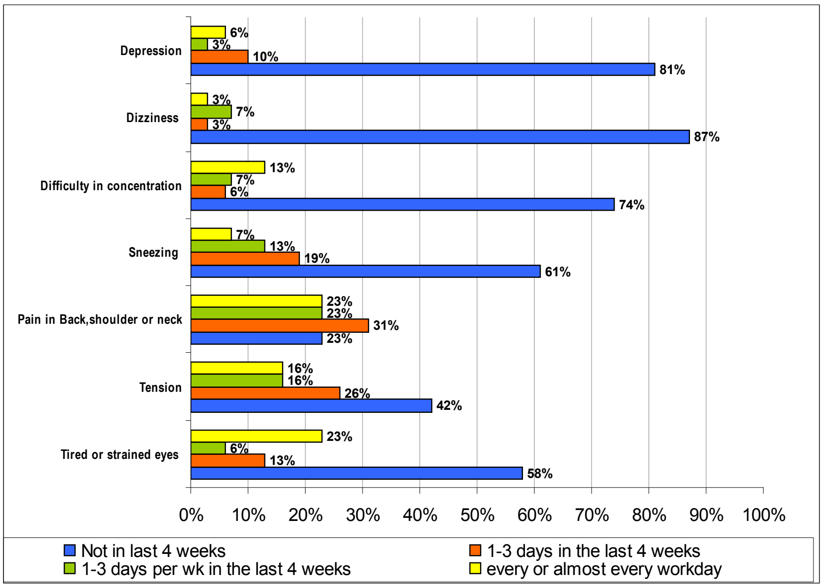


Figure 4.20: Discomfort/dissatisfaction symptoms (1) in office (C)

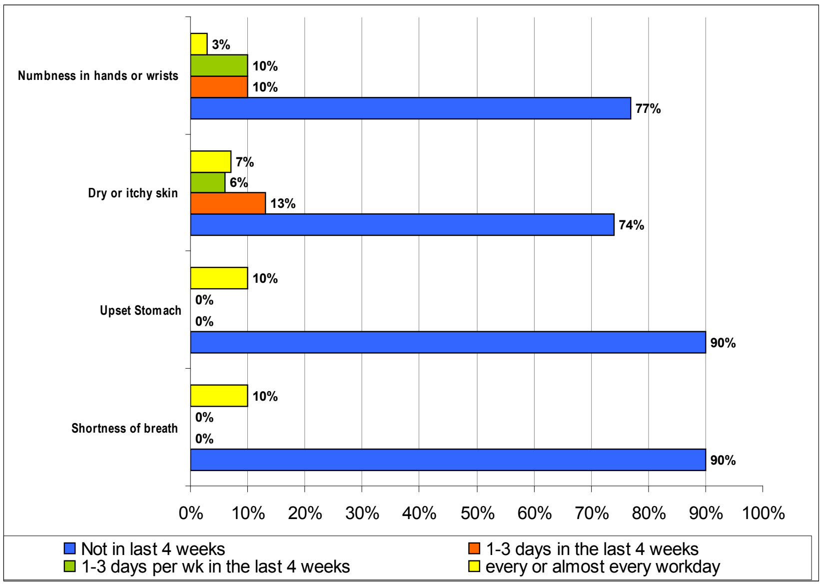


Figure 4.21: Discomfort/dissatisfaction symptoms (2) in office (C)

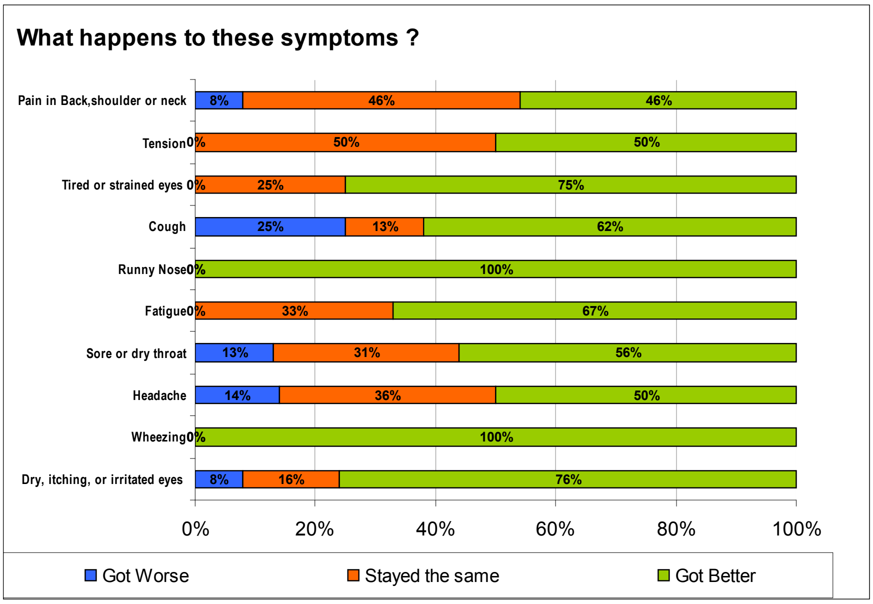


Figure 4.22: Discomfort/dissatisfaction symptoms (3) in office (C)

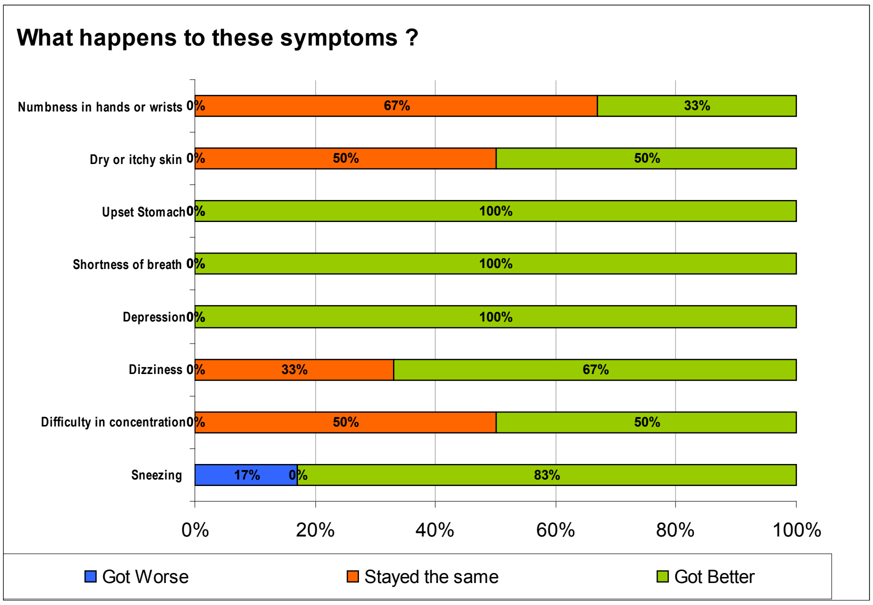


Figure 4.23: Discomfort/dissatisfaction symptoms (4) in office (C)

Most of the employers confirmed that the illness symptoms got better. However, 50% of the participants' difficulty in concentration stayed the same, while the remaining 50% confirmed that the symptoms got better. It is important to highlight that difficulty in concentration can occur due to various reasons: lack of privacy, noise, uncomfortable seating, glare, work habits, etc. As a result, you need to determine the exact cause of the difficulty of concentration in order to analyse the results and solve the problem.

The readings below show that 40% of the employees were not satisfied with the hot temperature in the office, while the rest either didn't face any issues with the temperature or had minor complain about the humidity level (20%).

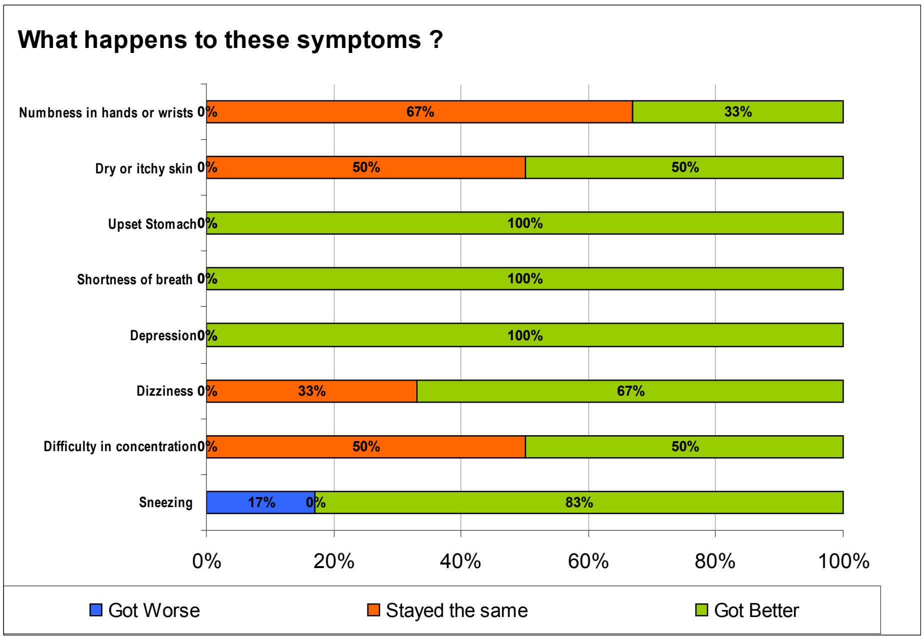


Figure 4.24: what happens to the symptoms (1)

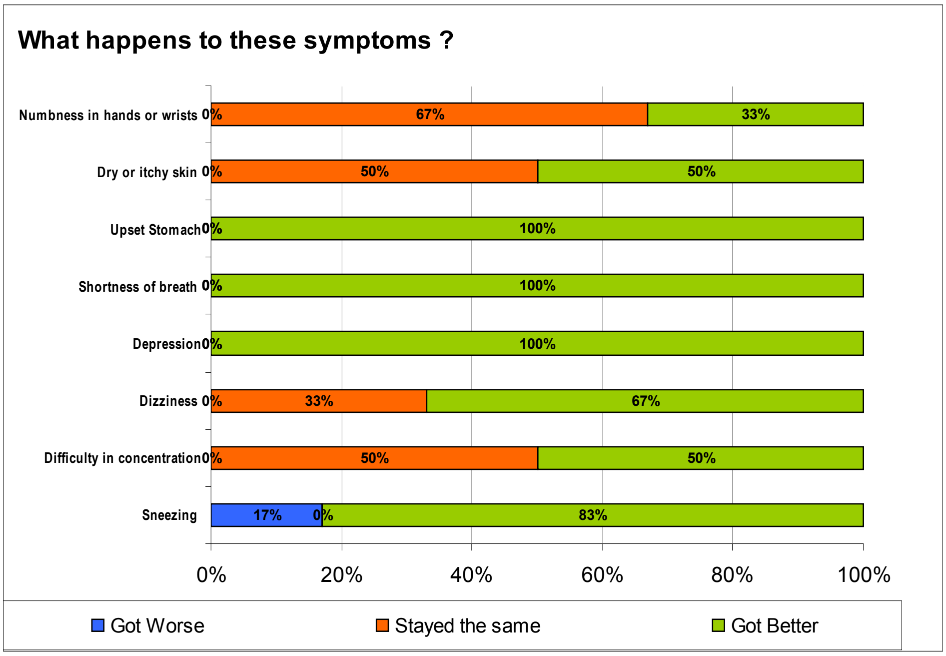


Figure 4.25: what happens to the symptoms (2)

The chart above shows that the majority of the employees (67%) were either somewhat satisfied or not too satisfied about the privacy level in the office. This is due to the open floor plan design of the office, which not only affects the privacy level, but also allows the transition of distracting noise from one space to another, which explains the 66% of dissatisfaction level of noise distraction in the readings below.

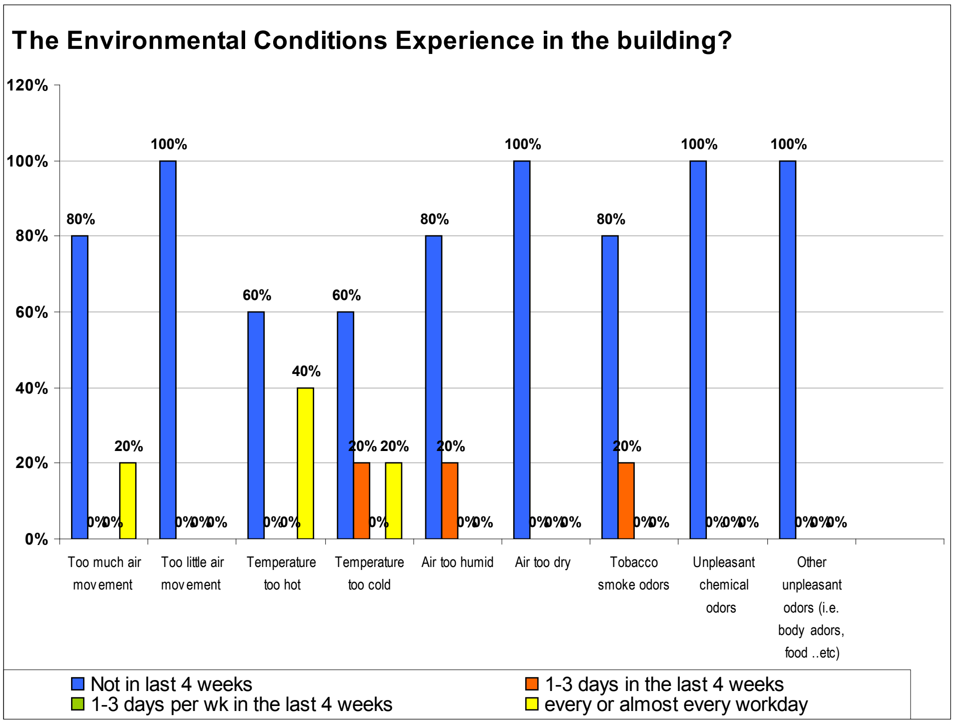


Figure 4.26: Environmental conditions experience in office (C)

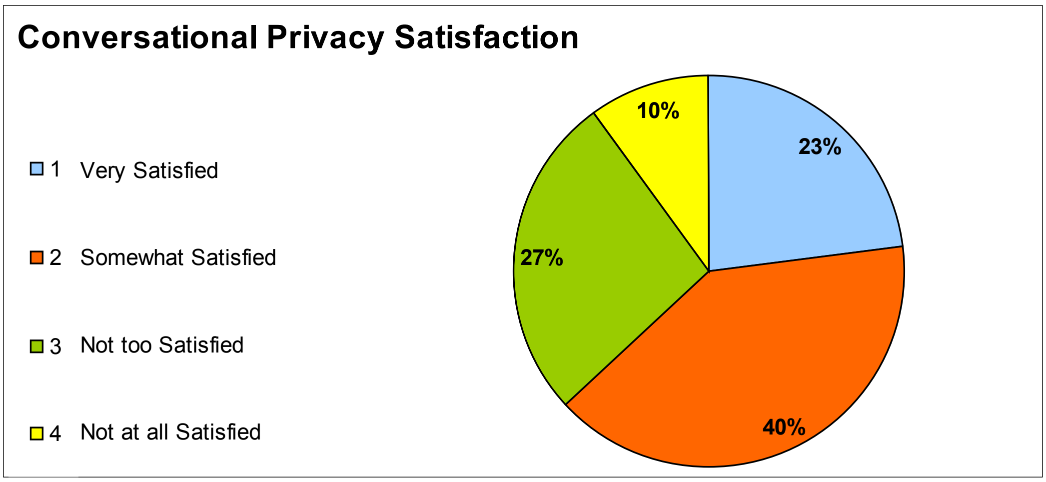


Figure 4.27: Conversational privacy satisfaction in office (C)

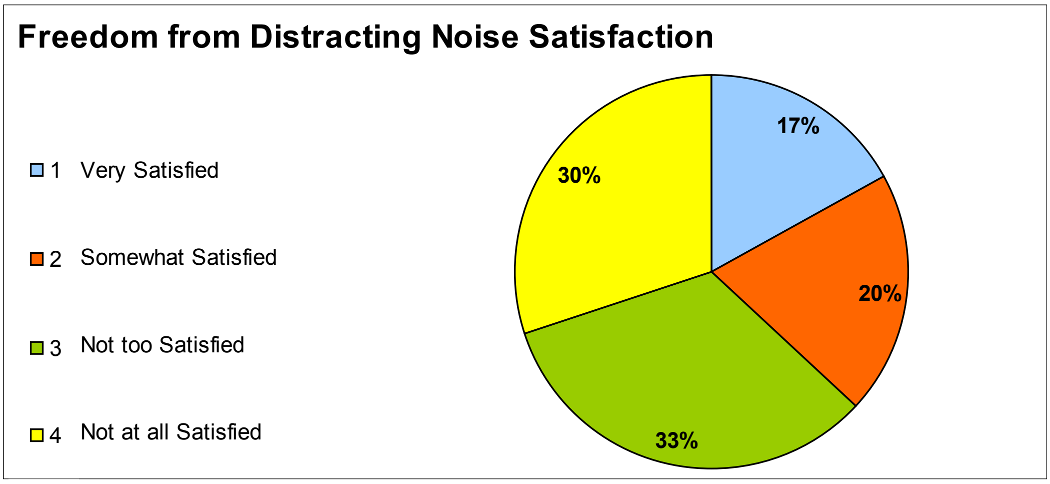


Figure 4.28: Freedom from distracting noise satisfaction in office (C)

4.2.4 Office (D)

The forth case-study is for a ten year old office which accommodates 25 staff. Since this business provides architecture and commercial lighting solutions services, it was expected to see an open-space plan for display units (Galleries), besides the employees' workstation and meeting rooms. This office is in the first floor of a two storey building which faces a service road next to Sheikh Zayed road. It was opened to a neighboring compound, which didn't help us identify any obvious source of pollution from the outdoor environment. The only observation in regards to the effect of the outdoor environment on the indoor air is the office front door which is opened frequently and supports the transport of outdoor air pollution to the indoor space.

As for the building envelope, there were no obvious failures (cracks), and some windows were facing the entrance side, while the office windows are on the opposite side. On both sides, the windows were always closed, either during working hours or after that, which is a normal practice in all the lighting companies to emphasize on the displayed lighting fixtures.

4.2.4.1 Plan Overview

The walkthrough investigation was the first step to have a clear picture of the space layout, building hygiene and maintenance and occupant activities. The first odor impression when entering the space was moderate; more to chemicals smell. Overall, the office looked organised with some partitions to separate the different zones based on the lighting fixtures brands, country of origin (COO) or usage. Below is the office floor plan; highlighting the different zones of the study.

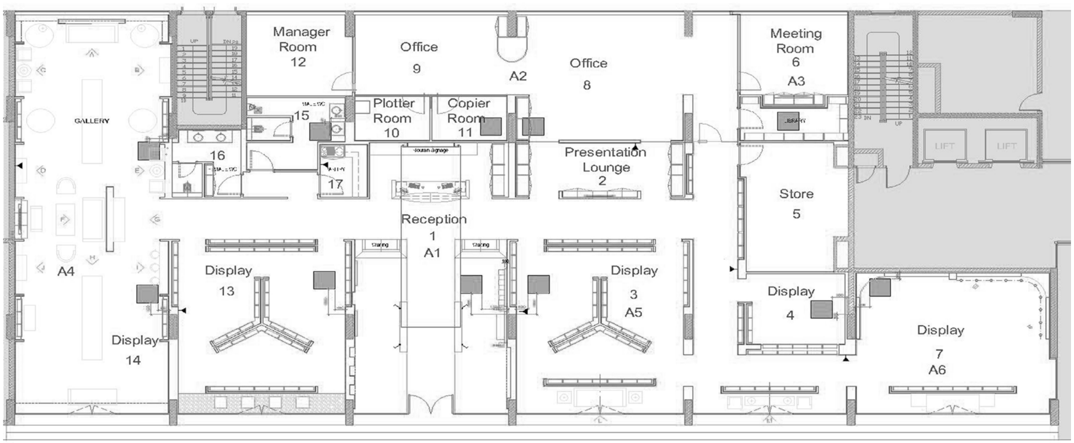


Figure 4.29: Floor Plan for office (D)

The lighting display gallery was very clean, as it was cleaned regularly in the morning and after working hours using cleaning solvents and vacuum cleaner. All the cleaning solvents are then stored in a cabinet inside the office pantry.

During the visit, it was essential to understand key specifications of the HVC system and the outdoor air role in the air circulation inside the office. The HVAC maintenance specialist has answered few questions about the HVAC, filters and maintenance frequency which can be summarized as follows:

- No untilizing outdoor air intake
- The system operated under recirculation of conditioned air mode.
- The system adopts variable air volume (VAV)
- Aluminum mesh filter is used (*based on the information given by the specialist, as we weren't given access to mechanical room*).
- The maintenance schedule of the filter is done once every year, through flushing it with water and placing it back. The filter is only replaced when it is worn out.
- The air diffusers were distributed with little or no potential short circuiting effects.

4.2.4.2 Spot measurements

After completing the walkthrough stage and understanding the exact layout of the space, it was decided to cover the whole office zones when placing the instruments for field measurements phase. Both short and long-term measurements were completed for 11 different zones to understand the full cycle of the air flow and circulation and identify the key air pollutants' level, based on the time, traffic, occupant activities and the context.

As a start, Direct Sense instrument was used to test 6 major indoor air quality indicators: TVOC, Carbon dioxide, Carbon Monoxide, Ozone, temperature and relative humidity, exactly as it was used for the office A, B and C. The instrument has shown the highest TVOC and Toluene readings are for the reception area – 894.8 (ppb). This intensive increase is due to the front office door that faces a car parking, which allows the transfer of air pollution from the outdoor environment to the indoor. The lowest TVOC level is recorded in Zone (7) – Gallery. The space is very clean and there is no any sign of indoor air pollution sources, because of the high hygiene level. As for the Ozone level, all the office zones had average readings between 0.02 and 0.03 (ppm). The Gallery (Zone 7) had the highest temperature readings due to the number of light fixtures displayed in the gallery. Besides that the light consumes more than 40% of the energy use in an office, it emits very high illumination level that is transformed to heat.

The table below summarizes the results of the 6 major parameters of the spot measurement.

Table 4.17: Direct sense Spot measurement readings for office (D)

C.N.	Parameters	Zones										
		Location 1	Location 2	Location 3	Location 4	Location 5	Location 6	Location 7	Location 8	Location 9	Location 10	Location 11
1	TVOC (ppb)	894.8	669.8	571.1	595.8	545.9	476.6	252.6	542.6	528.2	630.3	611
2	Carbon Dioxide (ppm)	766.2	745.9	720.4	758.3	978.6	753.2	740.7	798.1	782.5	792.2	806.4
3	Ozone (ppm)	0.02	0.023	0.024	0.029	0.027	0.03	0.03	0.03	0.029	0.026	0.026
4	Carbon monoxide (ppm)	0.82	0.75	0.61	0.64	0.54	0.57	0.6	0.51	0.54	0.49	0.48
5	Temperature °C:	24.32	24.99	24.87	25.18	25.44	25.69	25.83	25.19	25.2	25.24	25.43
6	Relative Humidity %RH	53.21	49.61	48.01	48.35	48.4	44.43	47.35	47.77	48.88	50.47	49.37
7	Toluene ppb	474.25	354.96	302.6	315.81	289.3	252.6	308.05	287.56	279.97	334.05	323.86

During the walkthrough phase, the CEO was found smoking in his office (Zone 12) and we learnt that is his usual practice. As the office air condition system is operating under 100% air recirculation mode, pollutants generated from the smoking may be redistributed to other rooms in the office.

4.2.4.3 Continuous measurement

It was essential to complete the continuous measurement in a zone with high traffic load to understand the environmental health conditions of the space in a 24 hours period continuously, and track any obvious trends in order to identify the major sources of the pollution. As zones (8) and (9) are open space plans for workstations with all the required technical machinery for printing, scanning, binding , etc, they were the selected zones for this study. The study was between 28/06/2011 and 29/06/2011.

The table below summarizes the Minimum, Maximum and average readings for the continuous measurement.

Table 4.18: Direct sense continuous measurement readings for office (D)

IAQ Parameters	***Readings***
TVOC ppb:	Min = 264 at 29-Jun-10 05:54:49 PM
	Max = 1031 at 29-Jun-10 07:37:59 AM
	Average = 625.6
Carbon Dioxide ppm:	
	Min = 553 at 29-Jun-10 06:53:54 AM
	Max = 938 at 29-Jun-10 02:09:44 PM
	Average = 719.9
Ozone ppm:	
	Min = 0.01 at 28-Jun-10 08:45:44 PM
	Max = 0.06 at 29-Jun-10 08:42:09 AM
	Average = 0.040
Carbon Monoxide ppm:	
	Min = 0.0 at 29-Jun-10 05:55:14 PM
	Max = 0.5 at 28-Jun-10 05:26:59 PM
	Average = 0.07
Temperature °C:	
	Min = 22.6 at 28-Jun-10 08:38:59 PM
	Max = 30.1 at 29-Jun-10 08:17:09 AM
	Average = 26.38
Relative Humidity %RH:	
	Min = 36.1 at 29-Jun-10 08:21:44 AM
	Max = 48.4 at 28-Jun-10 03:23:09 PM
	Average = 41.48
Toluene ppb:	
	Min = 139.9 at 29-Jun-10 05:54:49 PM
	Max = 546.4 at 29-Jun-10 07:37:59 AM
	Average = 331.58

All the readings highlight a very important factor that controls the pollution level in this office: Timing. The readings demonstrate a rapid increase in TVOC, Ozone, temperature, humidity and toluene levels early in the morning, as the office working hours start. The computers, 3 in 1 and scanner are all major sources for ozone emission in this particular space. As the employees start their working day, and they turn on all the computers, the massive emission rate is recorded by the measuring instrument. There is another dedicated room for printers and scanners with no exhaust/extractor fan though, and the room's door was open to adjacent space in the office. Pollutants generated from these equipments may flow into adjacent space, as the reading proof.

4.2.4.4. Air flow Measurement

It was noticed that there was no any thermometers available for the employees to measure the temperature and do any adjustments accordingly. Direct sense combined with an air flow sensor was used to test the airflow level in 5 selected zones (1, 9, 6, 14, and 7). The process was completed by holding the handle close to the air supplier in the room for 2 minutes-approximately. The instrument was saving the readings of the selected zones, and below is a summary of the findings.

Table 4.19 : Airflow readings for office (D)

	Zone A1	Zone A2	Zone A3	Zone A4	Zone A5
Air Speed	0.614	0.486	0.931	0.001	0.133
Temperature	21.6	22.4	16.7	27	24

The readings demonstrate that the highest air speed and the lowest air temperature are found in the meeting room. It is very important to focus on the relation between the air speed/temperature and the term "Thermal Comfort''. The law does not state a specific rate for air speed or temperature in offices, however, the normal is at least 16^{o}C (HSE, 2010).

This office is used less frequently compared to other rooms within the space, which means the door is not opened frequently so the space is saving all the cool air .The temperature of this room specifically is impractical and temporary heating should be available to avoid employee's discomfort.

4.2.4.5 HCHO measurement

Four zones were selected for the formaldehyde testing using HCHO detector and the readings were between 0.015 and 0.040. The highest reading is in the office zones (8 and 9). The tables made of pressed wood and the hardwood plywood paneling used in cabinet are all sources for fomaldehyide emission.

4.2.4.7 Survey

In order to finalize the results of this study, it was essential to get the occupants' opinion and perception of the indoor air quality of the office. Below is a summary of the employee's information about the health and well-being.

As the graph states, 50% of the participants experienced the symptoms of fatigue 1-3 days in the last 4 weeks. Moreover, 67% of the population suffered from headache and17% experienced cough or/and dry, itching or irritated eyes. All the above symptoms are a signs for SBS or BRS.

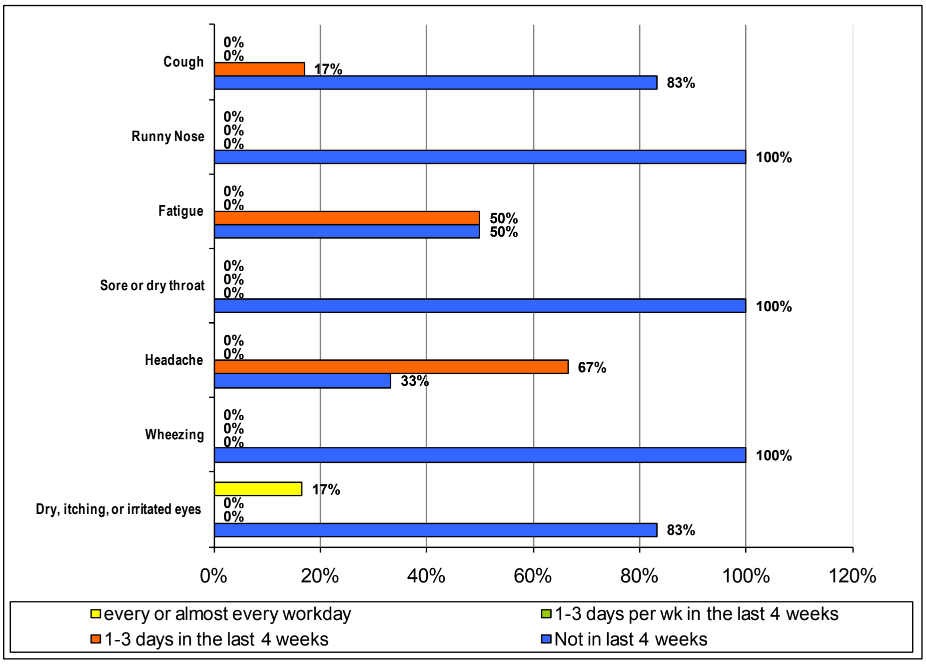


Figure 30: Discomfort/dissatisfaction symptoms (1) in office (D)

33% of the employers confirmed that they suffered from dizziness and/or tension 1-3 days in the last 4 weeks

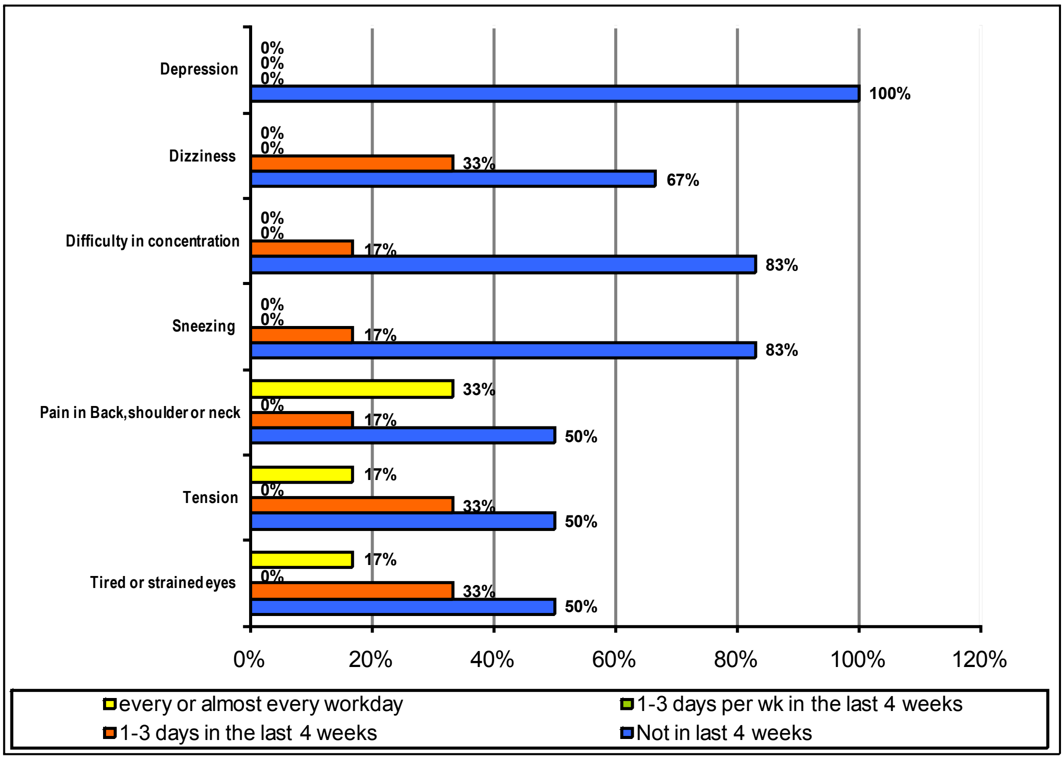


Figure 31: Discomfort/dissatisfaction symptoms (2) in office (D)

As this office has an open floor plan, all of employers were either not too satisfied or not at all satisfied with the privacy level of their space. It was shocking to receive a 0% satisfaction about the privacy factor, although it is an essential element to control to assure employees' productivity and maintain work confidentiality.

On the other hand, the distracting noise satisfaction level was 83% somewhat satisfied. This means that the noise level of this office is acceptable but no enough privacy is provided to the employee's space.

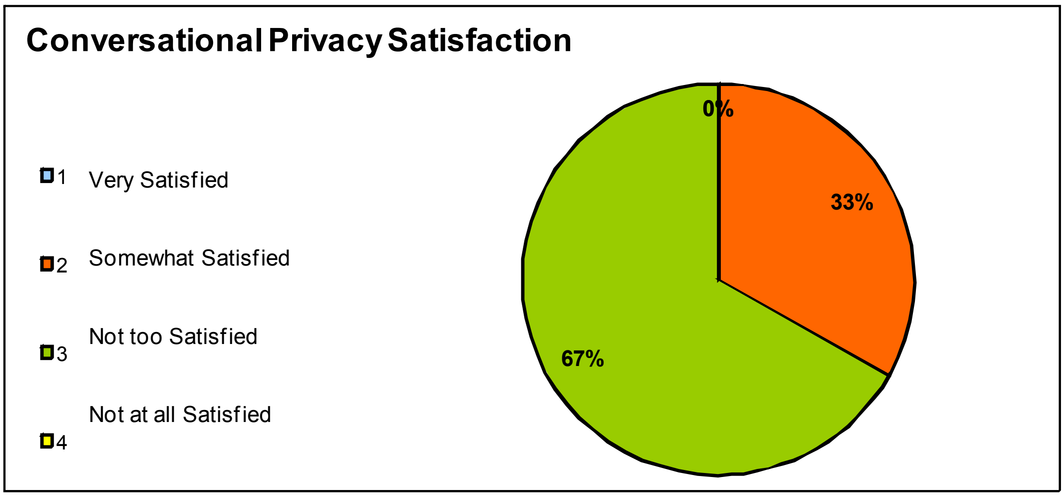


Figure 32: Conversational Privacy satisfaction in office (D)

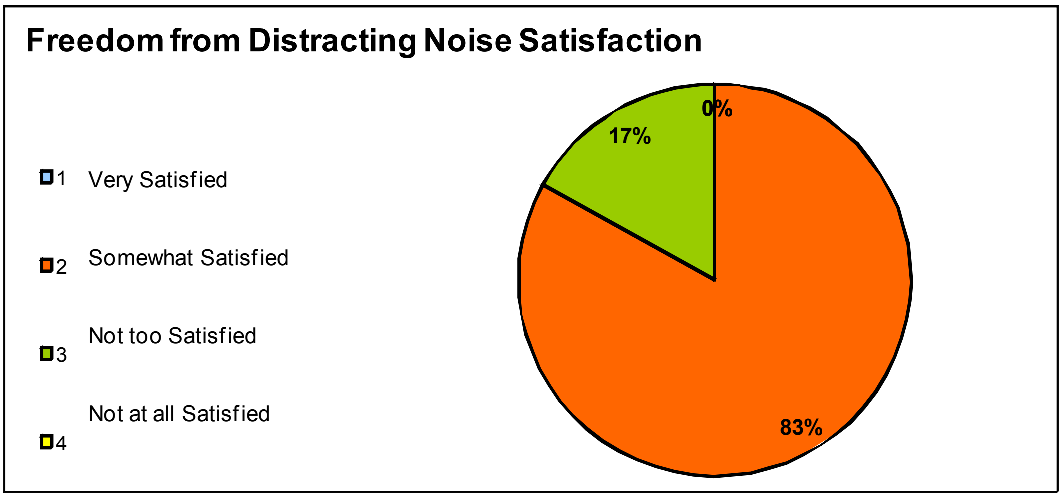


Figure 33: Freedom from distracting noise satisfaction in office (D)

4.3 Discussion: IAQ

Indoor air quality is a key global problem, considering the fact that people spend an average of 90% of their time indoors (EPA 2011). The sources of indoor air pollution are not limited to pollutants available inside the building; however, a lot of pollutants can simply be transferred from the outdoor environment to the indoor space through various mediums due to design or maintenance gap/failure.

The effect of poor indoor air quality is not limited to unhealthy environment for building occupants or users, however, it can be extended to people's performance and productivity. As a result, it is important to study all the factors that are directly linked to indoor air quality. Key parameters were observed separately to get a clear indication of the relationship between the sources of pollution and the indoor air quality parameters.

As this study is focusing on the indoor air quality in offices, key parameters were tested in selected office buildings in Dubai, to get a clear understanding of the health conditions of the building. Below is a summary of the selected parameters standards in indoor air quality, followed by a table that summarizes the actual findings and observations. Covering both aspects will give a clear picture of the indoor air quality problem in offices , which will lead to list of recommendations on both individual and government levels to control the size of the pollutants and design failures, and achieve a healthy and productive work environment in the offices in Dubai.

4.3.1 Carbone Dioxide

There is no clear record of carbon dioxide (CO_2) limits/standards in indoor environment. Various researches state that the typical level of CO_2 in indoor environment vary from few hundreds to above 1000ppm, based on the traffic flow and the ventilation system (MDH 2010). When measuring the concentration of CO_2 in any indoor environment the researcher should consider a lot of factors in regards to: space users and the surroundings, such as: number of space users, natural ventilation and outdoor pollution level.

4.3.2 Ozone

First of all, American Conference of Governmental Industrial Hygienists (ACGIH) has set the below standards for the ozone exposure level:

- 0.2 ppm for no more than 2 hours exposure
- 0.1 ppm for 8 hours per day exposure doing light work
- 0.08 ppm for 8 hours per day exposure doing moderate work
- 0.05 ppm for 8 hours per day exposure doing heavy work

Secondly, detailed analysis was completed by OSHA (2012) to understand the Ozone standards and the expected health symptoms due to the gradual increase in the Ozone concentration level. The results are highlighted below:

Table 4.20: Ozone Standards in the workplace by OSHA

Exposure Limit	Limit Values	HE Codes	Health Factors and Target Organs
OSHA Permissible Exposure Limit (PEL) - General Industry	0.1 ppm (0.2 mg/m^3) TWA	HE7	Headache Target organs: Brain, central nervous system
		HE10	Lung damage, chronic respiratory disease
		HE11	Pulmonary congestion, edema, and hemorrhage
		HE14	Eye, nose, throat, and respiratory irritation
OSHA PEL - Construction Industry	0.1 ppm (0.2 mg/m^3) TWA	HE7	Headache Target organs: Brain, central nervous system
		HE10	Lung damage, chronic respiratory disease
		HE11	Pulmonary congestion, edema, and hemorrhage
		HE14	Eye, nose, throat, and respiratory irritation
OSHA PEL - Shipyard Employment	0.1 ppm (0.2 mg/m^3) TWA	HE7	Headache Target organs: Brain, central nervous system
		HE10	Lung damage, chronic respiratory disease
		HE11	Pulmonary congestion, edema, and hemorrhage
		HE14	Eye, nose, throat, and respiratory irritation

National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limit (REL)	0.1 ppm (0.2 mg/m^3) Ceiling	HE7	Headache Target organs: Brain, central nervous system
		HE10	Lung damage, chronic respiratory disease
		HE11	Pulmonary congestion, edema, and hemorrhage
		HE14	Eye, nose, throat, and respiratory irritation
American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) (2001)	**Heavy work:** 0.05 ppm (0.1 mg/m^3) 8-hour TWA **Moderate work:** 0.08 ppm (0.16 mg/m^3) 8-hour TWA **Light work:** 0.1 ppm (0.2 mg/m^3) 8-hour TWA **All workloads:** 0.2 ppm (0.39 mg/m^3) 2-hour TWA A4	HE7	Headache Target organs: Brain, central nervous system
		HE10	Lung damage, chronic respiratory disease
		HE11	Pulmonary congestion, edema, and hemorrhage
		HE14	Eye, nose, throat, and respiratory irritation
CAL/OSHA PELs	0.1 ppm (0.2 mg/m^3) TWA 0.3 ppm (0.6 mg/m^3) STEL	HE10	Lung damage and decreased lung function

In addition, The NIOSH guidelines were more standardized, as it recommended an average exposure limit for ozone = 0.1 ppm (0.2 mg/m^3). According to NIOSH, any Ozone levels that are equal or higher to 5 ppm are considered very dangerous to life or health for the space users.

4.3.3 Carbon Monoxide

Potential sources of Carbon monoxide emission in office buildings are stoves, hot water heater, smoking, etc. According to IDPH (2011), in office spaces, the average of Carbon monoxide level is between 0 and 5ppm. Any readings which are higher than the average level are clearly an indication of the "presence of exhaust gases". In extreme cases, level of carbon monoxide is detected greater than 100ppm. In these cases, the building occupants must be asked to leave the building immediately until the emission source is identified and the problem is solved.

4.4. Summary of Results

The following table will give a clear summary of the health conditions of the selected case studies, besides the general observations related to building hygiene, biological contaminants, occupant activity, mechanicals observations, etc.

Table 4.21: Walkthrough investigation and interview information for each of the studied office building

Observations/ interview categories	**Walkthrough investigation issues**	**:Observations in office**			
		A	**B**	**C**	**D**
General building information	Age of the building (in which the studied office is (situated	years 5 >	years 5 >	years 15 >	years 10 >
	Number of staffs	staffs 25>	staffs 50 >	staffs 200 >	staffs (with 25> about 15 staffs constantly in (office
	Office type	Furniture Supplier	Education industry	Financial Institution	Lighting Solutions
	Investigation location	Ground floor of a building having 5 upper floors including the GF	1st and 2nd floor of a building having 7 floors including the GF	Entire building (Ground and (Upper floor	1st floor of a building having 2 floors including the GF

Building hygiene and maintenance	First odour impression	Moderate odour	Strong odour-more of chemical smell	Strong odour-more of moldy smell	Moderate odour-more of chemical smell
	Assessment and rating of building hygiene	There were dry i.e. neither oily nor greasy dust (very dusty) on horizontal surfaces in obscure locations like top of shelves and windows, behind computers, cabinets, .furniture, etc Some offices desks were found to be dusty while others looks .clean In general, on a scale of 1 to 10 with 1 being poor and 10 being sterile, the building can be rated as 5	Looked clean with very little dry dust in few obscure .locations In general, on a scale of 1 to 10 with 1 being poor and 10 being sterile, the building can be rated as 6	Crowded office with many scattered papers. The dusts in some of the rooms' obscure areas were greasy and dry in most .of the areas We observed many filled dustbin under .cabinets Furthermore, the carpets in these office's rooms were very dirty. We were told they have not changed the carpets for at .least 6 years In general, on a scale of 1 to 10 with 1 being poor and 10 being sterile, the building can be rated as 4	Looked clean and organised. Even the gallery for lighting fixtures were very clean. We were told they clean them regularly. The board room table was found to be a bit dusty .though In general, on a scale of 1 to 10 with 1 being poor and 10 being sterile, the building can be rated as 7
	Any evidence of rodent	No	No	No	No
	Cleaning solvents used in the building and their frequency of use	High VOC cleaning solvents were used in the cleaning of the office. The cleaning is usually done every morning. Vacuum cleaner is also use in the everyday cleaning	Same as office A	Same as office A and B. However, cleaning is usually done both in the morning and after office hours	Same as office C
	Storage for cleaning solution	The cleaning solvents were stored in cabinet inside the office pantry	The cleaning solvents were stored in store room which is usually locked	The cleaning solvent were stored in toilet area	Same as office A
	Deterioration of finishing on the interior wall	No evident deterioration of wall peeling and cracks	As this office (company) has just been extensively renovated (7 months before this study), it is not surprisingly that there were no evident deterioration of wall peeling and cracks	Yes, there were evidences of paint peeling	Same as office A

Biological contaminants	Evidence of water staining due to condensation or leakage	Generally, there was no water stain observed with the exception of one room having water stain .on its carpet	Though, this was a new building, there were water stains on the ceiling of some of the rooms	There were numerous evidences of water staining due to condensation or leakage on the ceiling and carpets. In fact, stain on carpet was very obvious in some of the rooms	There was no water stain observed
	Evidence of mold growth	There were evidence of mold growth at some of the supply diffusers and return grills	There were no evidence of mold growth at the supply diffuser and return grills	Yes. There were evidences of mold growth on many of the supply diffusers and return grills especially in the open plan workstations	Same as office A
	Any plants or vegetation within the ?space	Plant was found only at the reception area	Plants were found in some of the rooms	Plants were found in some of the rooms	Yes

Occupant Activities	Human activities with the space that may contribute to pollutants. If so, how are ?they vented	Perfume used by office occupants may also contribute to poor IAQ Boiling in the pantry and with no special exhaust/extractor fan in the pantry might be major source of moisture in the .office No smoking was observed in the office but people were found smoking outside the office building. This could posed threat to IAQ	Same as office A	Same as office .A In addition, some of the office occupants were found eating at their workstations during lunch .time	Same as office A In addition, the CEO (owner of the company) was found smoking in his office and we learnt that is his usual practice. As the office air condition system is operating under 100% air recirculation mode, pollutants generated from the smoking may be redistributed to other rooms in . the office
	Any recent renovation or operating changes	No	Yes, 7 months before the study	No	No
	Other contaminant sources such as: Equipment; furnishing and finishes; car pack location	Printers, scanners which were all around the workstations are potential sources of pollutants such as ozone, particulates which office occupants may be exposed .to Car park area was located in front of the building	There were dedicated rooms for the printers with no exhaust/ extractor fan, and these rooms' doors are usually open to adjacent spaces in the office. Pollutants generated from these equipments may flow into adjacent spaces Some printers and scanners were observed at some workstations. The interior finishes seem to be emitting some chemicals as we .could smell it Car park was in the basement. There were some parking lots also adjacent to the .building	Same as office A Car park area was located in front of the building (for visitor) and basement of the building (for (staffs	There is a dedicated room for printers and scanners with no exhaust/ extractor fan though, and the room's door was open to adjacent space in the office. Pollutants generated from these equipments may flow into adjacent space Car were parked in front of the building

Mechanical observations within the space	Locate air diffusers and grilles within the space	The air diffusers were properly distributed with little or no potential short .circuiting effects	Same as office A	The air diffusers were properly distributed with little or no potential short circuiting .effects We were not allowed to remove supply diffusers and grills and shine flashlight to see the condition of the ductwork and/or plenum space as we intended. However, the very dirty nature of the supply diffusers and grills suggest that ductwork and/ or plenum may .be very dirty	Same as office A
	Is there any blockage of the air supply diffusers by books, furniture, plants or other ?obstructions	No	No	No	No
	Any modification of diffusers	No	No	Yes. Due to poor functioning of the supply diffusers that were originally installed at a particular section of the open plan workstation, a new large ceiling cassette split unit was installed. As at the time of this walkthrough investigation, this new unit also looked .dirty	No
	Condition of the grille	Almost all the return grills were very dirty	The return grills were not dirty	Very dirty	Looked clean

Mechanical observations within mechanical room	Assessment of mechanical room and its level of cleanliness	Access was not given to enter the mechanical room. Excuse given was that it was shared by many building . tenants	Same as office A	Air handling unit was placed at the roof top. Stagnant water was found at one part of the roof top under the AHU	Same as office A
	Type of air-conditioning system and filtration	Though there is a dedicated outdoor air inlet, it was not operational. The air system was operated under recirculation of conditioned air mode. According to information given (as we were not given access to the mechanical room), aluminium mesh filter is placed in the system for filtering .supply air	Variable air volume ventilator system was in place. From 9am to 6pm, the air system was operated under recirculation of conditioned and ventilation air mode with larger percentage (the actual percentage could not be ascertained) been recirculation. Between 6pm to 9am, the system worked solely on .recirculation We were told (but could not ascertain it as we were not given access to the mechanical room) that bag filter was in the system to filter .outdoor air However, we were shown aluminium mesh filter used in the fan coil unit (placed at strategic locations) for filtering supply .air	According to the facility manager, though there is a dedicated outdoor air inlet, it is not usually operational. Outdoor air supply is usually done once every 15 days. Reason was not given for this .schedule This means that the air system is usually operated under recirculation of conditioned air mode (true picture of the building air-conditioning system) and this was the case during the walkthrough .investigation Aluminium mesh filter was placed in the system for filtering supply .air	Same as office A
	Maintenance schedule of the filter	Usually 1 to 2 .times a year The filter is usually flush with water and put back into the system. They only replace it when it .is worn out	Usually 2 times a .year Maintenance is same as office A	Usually 3-4 times a year, according to the facility .manager Maintenance is same as office A	It is usually done once a year Maintenance is same as office A

Building envelope	General condition of the building envelope	There was no evidence of envelope failures .like cracks No obvious stain and material deterioration The windows were all closed during the period of study, and we learnt it is usually .like that	Same as office A Same as office A Windows were closed in most of the rooms with the exception of few rooms where windows were opened	Same as office A Same as office A Same as office A	Same as office A Same as office A Same as office A
Air intake location	Is there potential for contamination of the air ?intake	Open to the compound and express road. If the outdoor air intake is operation and adequate filter is not in place. This could be source of outdoor to indoor transport of .pollutants	Open to the office compound and this could be source of outdoor to indoor transport of cigarette smoke, exhaust from outdoor car park areas, and sandy surrounding environment especially if adequate filter is .not in place	Stagnant water at the roof top may be source of biological contaminates and this may be transported from outdoor to indoors. If care is not taken, this may lead to emergence of legionnaire diseases	Open to neighbouring compound. We could not identify any potential source of pollutants
Contextual observation	Type of neighbourhood in which the studied building is located	The office building is located in .industrial area	The office building is located in undeveloped, sandy area with some ongoing construction projects	Residential and office area	Residential and office area
	Activities in the neighbourhood that may pose a threat to IAQ of the studied building	No neighbourhood activities that could pose a threat to IAQ were identified. Traffic pollutants could be source of .pollutants though	Sandy environment (especially during sandstorm) could pose threats to IAQ	The building faces major (busy) road and this could pose threat to IAQ if adequate actions are not taken. Cigarette smoking behind the office building could also pose a .threat	There is very little set back between the building and the busy (because the building is close to a very popular shopping mall) street road. The frequent opening of the office door (located on the ground floor) may be source of outdoor to indoor transport of pollutants

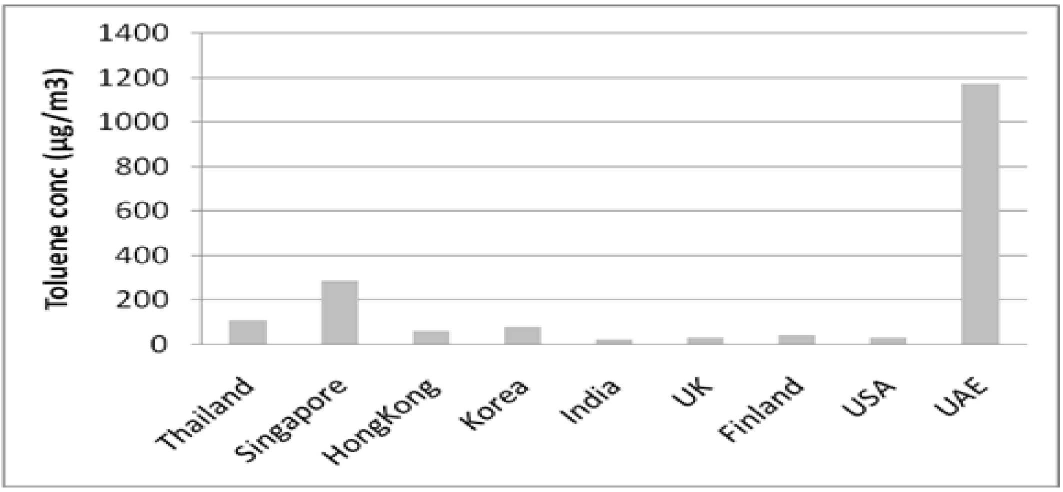


Figure 4.33: Comparison of UAE (based on measured offices) TVOC concentration (µg/m^3) with other countries. Reference: Dubai, UAE (current study); other countries (Ongwandee et al. 2011 and references there in)

The figure above is a comparison of UAE (based on measured offices) TVOC concentration (µg/m^3) with other countries. Reference: Dubai, UAE (current study); other countries (Ongwandee et al. 2011 and references there in). The figure shows a huge difference in the Toluene in UAE compared to other countries. It's amusing that a country like U.A.E with all its development still has high number of Toluene gas being emitted in its offices. Second comes Singapore and Thailand respectively

Table 4.22: Effects of SBS symptoms on occupants' ability to work and leave of absence in the last 4 weeks

Office	**Effects of symptoms**	**day 0**	**1-4 days**	**5-to 10 days**	**More than 10 days**
A	In the last 4weeks how often have any of the ***symptoms reduced your ability*** *to work*	80%	20%	0%	0%
	In the last 4weeks how often have any of the ***symptoms caused you to stay*** *home*	60%	30%	10%	0%
B	In the last 4weeks how often have any of the ***symptoms reduced your ability to work***	50%	50%	0%	0%
	In the last 4weeks how often have any of the ***symptoms caused you to stay home***	75%	25%	0%	0%
C	In the last 4weeks how often have any of the ***symptoms reduced your ability to work***	44%	48%	8%	0%
	In the last 4weeks how often have any of the ***symptoms caused you to stay home***	60%	40%	0%	0%

D	In the last 4weeks how often have any of the ***symptoms reduced your ability to work***	67%	33%	0%	0%
	In the last 4weeks how often have any of the ***symptoms caused you to stay home***	83%	0%	17%	0%
All the offices Com-bined	In the last 4weeks how often have any of the ***symptoms reduced your ability*** *to work*	60%	38%	2%	0%

The figure shows that the SBS (Sickness Building Syndrome) that affected or not the occupants and their ability to work, combined for all offices. The majority had not been affected by the SBS. Some had been affected for couple of day, whereas few just had been affected for more than couple of days.

Average concentrations of measured parameters (objective measurement) in each of the offices

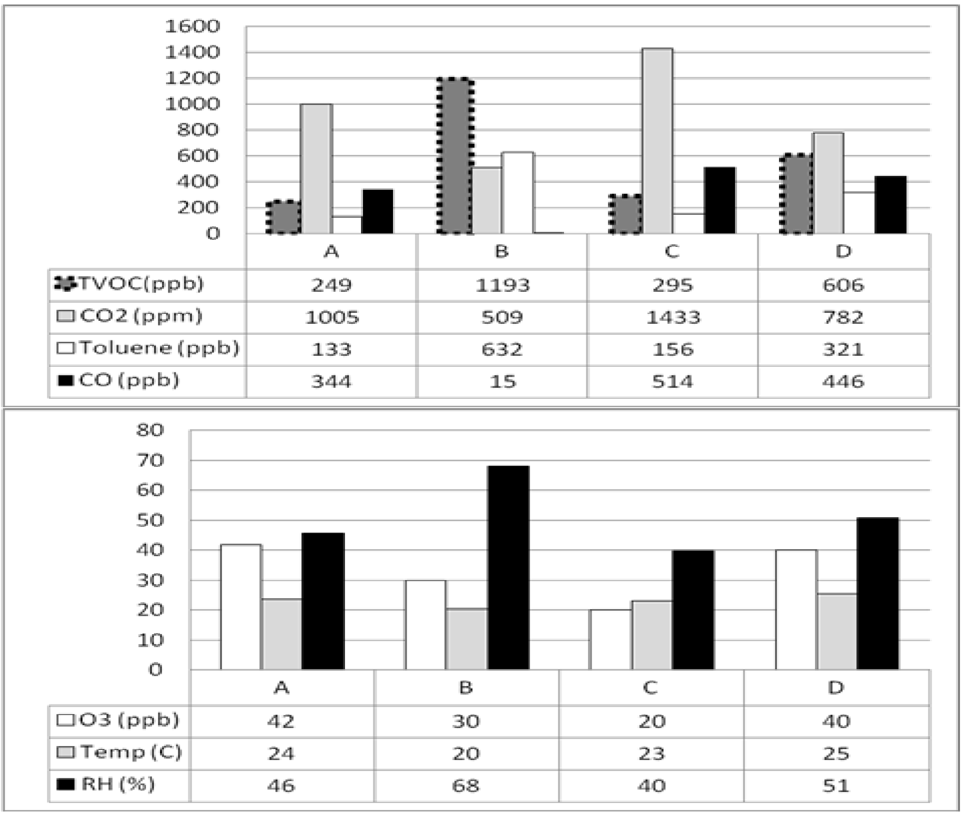
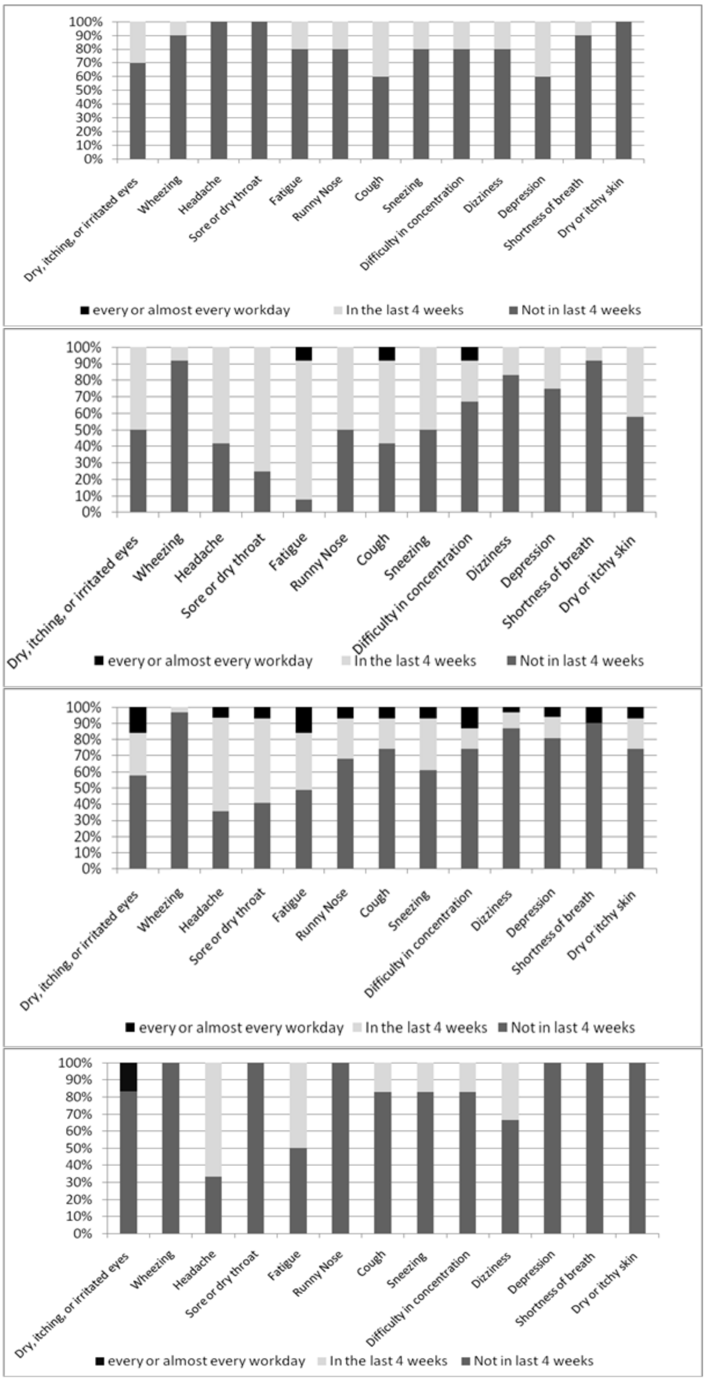


Figure 4.34: Average concentrations of measured parameters in the four offices

The figure above shows the average concentrations of measured parameters (objective measurement) in each of the offices. In office A the highest gas emitted was the CO_2, while the TVOC was the highest in Office B and the CO as the lowest amongst all offices. Office C has also high numbers of CO_2 emitted. The readings in Office D shows that all the gases emitted are almost equal.



A

B

C

D

Figure 4.35: Subjective responses from office occupants working in each of the studied offices

The figure below shows the different symptoms that affected the occupants. Office A IAQ had the least effect on its occupants, as none suffered any symptoms of any every day. While Office C has the most effect on its occupants as almost all have suffered from all kinds of symptoms at least once every day. Office D has a major problem causing its occupants to feel the symptoms of dry, itching and irritated eyes at least once every day, while office B has a problem of fatigue, cough and difficulty in concentrating.

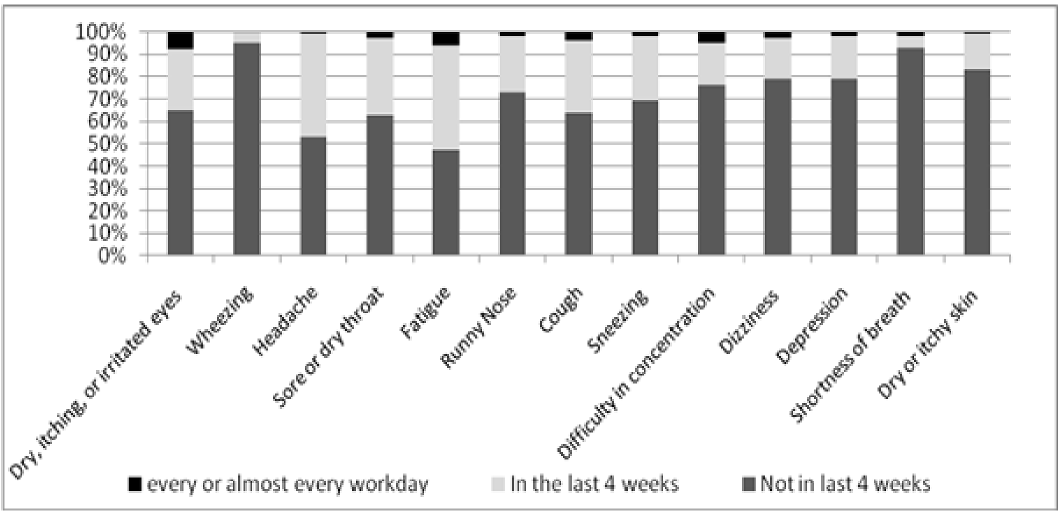


Figure 4.36: Combined Responses from all studied offices.

The figure above Combined responses from all the studied offices shows that the major problem facing most of the occupants from the different offices is the dry itching or irritated eyes, while the wheezing symptoms was almost irrelevant as very few have suffered from this symptom. The rest symptoms that were worthy of mentioning were the fatigue, cough and difficulty of concentrating.

The graph below shows the particles readings in all the offices. It is noticeable that a rapid increase in the particle level is reported in office (B). This unhealthy alert of particles level can cause vital health problems to the building occupants. People exposed to these particles are more likely to suffer from health issues. People with heart or lung problems have a higher risk of hospital visit due to health problems/illness.

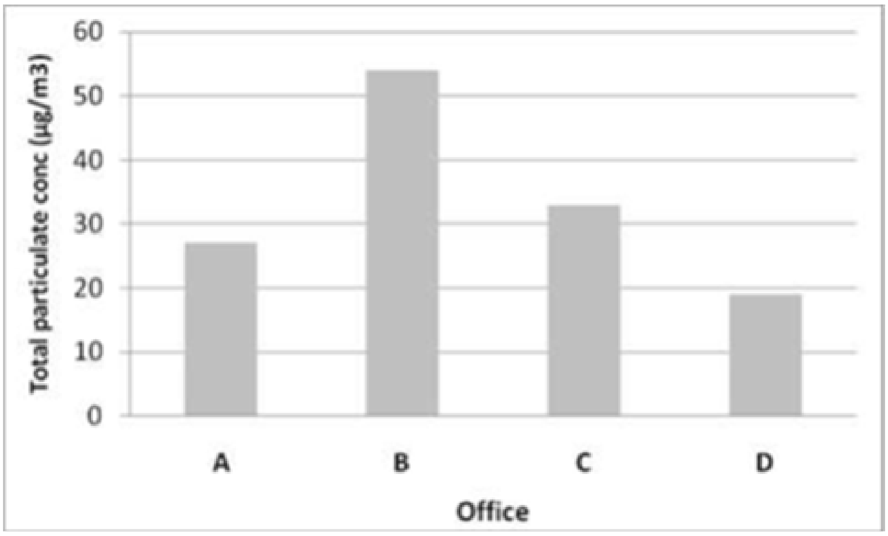


Figure 4.37 :Summary of particles readings in all the offices

Below are some of the key parameters standards that we referred to during the analysis:

Table 4.23 :Summary of IAQ parameters standards

Measured parameters	Standards/guidelines
TVOC	DM- 300µg/m3; Comfort range for TVOC exposure- 200µg/m3 (Mølhave 1990)
CO2	DM- 800 ppm; The Department for Education and Skills (2006): ≤1500ppm
CO	DM and NAAQS: 9ppm
Ozone (O3)	DM: 0.06ppm; NAAQS: 0.075ppm
Formaldehyde	DM: 0.08ppm
TSP	World Bank Group (1998) and European Union:150µg/m3 (annual) and 300µg/m3 (24 hours); WHO: 60-90µg/m3 (annual) and 150-230 µg/m3 (24hours)
Relative Humidity/Temperature	DM:30–60% 22°C to 25.5°C

4.5 Implication of Results

Reviewing the field measurement result that was taken from each office separately have shown that a lot of factors can and will affect the users of this certain office respectively. The list below will further explain how each office has its effects on the users according the results taken.

Office A: Location 1 has shown high level of TVOC emissions in the area. It was observed that this specific area, a lot of old and not well maintained carpet tiles is used. The excess use of carpet will yield according to Sollinger et al. (1994) and Guo et al. (2004) to increase in TVOC in the area as discussed in the literature review earlier. Increase in TVOC leads to Sick Building Syndrome (Kuo-Pin et al., 2006) hence the performance and health of the users in the area will be directly affected (Milton et al., 2000). The affect was clearly recognized on the users as 30% of them have stated in the survey that they have dry, itching or irritated eyes every once in while in the office.

Office B: In location 8, which is the administration area, the readings on the instruments showed that the ozone gas emission level was relatively higher than the normal readings. As per the Dubai Municipality standards the Ozone gas emission shouldn’t exceed the 0.06ppm. The reading showed that the Ozone gas emission was at 0.978ppm. This was due to several factors. Printers, copiers, fax machines and scanners for example that are placed and used in the admin area would cause high ozone gas emissions (Hetes et al., 1995 and Lee et al., 2001). Another factor that causes high indoor air pollutant, such as Ozone gas, is the excess usage of carpet as the study that is widely spread through out the administration area (Guo et al., 2004, Molhave, 1982, Wallace et al., 1987, Levsen and Sollinger, 1993, Sollinger et al., 1993, Sollinger et al., 1994, Black et al., 1993, Kirchner et al., 1993). Since the readings of this area showed high level of Ozone gas emissions and the observation made on the area clearly clarifies why these emissions are high, this will directly yield and according to the previous literature review discussed earlier, these emissions when interacted with other compound will cause Building Related Syndromes to the occupants of this area (Buchanan et al., 2008). These syndromes are but not limited to dizziness, headaches, fatigue, eye irritation and nausea (Brightman et al., 2008). These symptoms were checked in the surveys completed by occupants as the majority of the occupants felt headaches and irritated eyes as shown in the surveys.

Office C: Location 18 which holds a meeting table in the ground floor has a very high level of carbon monoxide gases according to the measuring instruments readings'. The amount of carbon monoxide in this room reached 2.19 ppm where as the rest of the examined offices had an average of below 1 ppm. This room, which is located next to the entrance door, has excessive amount of meetings which are conducted in. A lot of reasons that leads to high carbon monoxide readings are gas stoves, hot water heater and smoking (IDPH, 2011). Although none of these factors were directly found in the mentioned room. However, and since the room is located next to the entrance door, a lot of carbon monoxide gas are permitted to the inside of the building because of the sliding door entrance of the building. According to IDPH (2011) these gases are produced from the passing by cars exhausts that are close to the entrance, as well as from the smoke of the cigarettes of the smokers, either staff or clients, who stay at the entrance also.

In the field observation done on the building, it was found out that there was poor ventilation and non consistent HVAC maintenance schedule to this precise room, thus the increase of SBS (Mendell and Smith, 1990).

In Summary, the field observation done on all offices along with the readings on the instruments were all directly related to the literature review done earlier in the paper. The findings were all supported by materialistic evidences from either the site observations, the survey conducted by the space users of from the readings of the instruments. The selection of the different research methods done in this exercise assisted in achieving the most accurate outcome.

Chapter 5: Conclusion

5.1 Conclusion

Office buildings in Dubai were selected for this study in order to understand the level of awareness of indoor air quality issues in this part of the region. Moreover, it was essential to have records of the common design practices in key locations in Dubai, in order to identify local policies and standards gaps. This study should not only be a study reference or a design guide, but also a solid framework that can be followed by actions and regulations.

Minimal effort was put into indoor air quality researches in the UAE and the focus is mainly of sustainable projects, such as Masdar. As a result, this study is a key elaboration for the importance of indoor air quality control in office buildings, which is part of the sustainability international standards. This study has clearly identified the problems in indoor air quality in the offices in Dubai, which negatively affects the space users' health, performance and productivity. Design improvements and environment considerations can play a key role in changing the indoor environment health conditions, which leads to maximum usage of the space with high satisfaction rate of occupants.

A short term study was conducted in four office buildings (A, B, C and D) in different locations in Dubai in order to test the indoor air quality condition in the office spaces. Various factors were taken into consideration during the selection: Type of business/industry, Age of the building, occupants' population, etc. As this study should be a general guide for Commercial Design in Dubai, the four offices covered the major industries in Dubai market: Financial Institutions, Lighting solutions, IT Solutions and Office Furniture suppliers.

Buildings A and B are less than 5 years old, while C and D were between 10 – 15 years old. Most of the offices were made of the same construction materials and shared the same design failures. Overall, although each office has a different industrial activity, but they have the same internal functions: open plan offices, meeting rooms, washrooms, open-plan display area, etc.

The study was conducted in numerous stages: walkthrough investigation, survey, case-studies and field measurements. The selection of the different research methods is to assure that the study findings and analysis are as accurate as possible. In addition, the study plan is based on the balance of collecting quantitative and qualitative data for the case-studies.

As a start, the walk through investigation was the first phase of the study to get a clear picture of the building/office surroundings and any daily activities that take place in the office during/after working hours. Also, this stage is essential to understand the different parameters that affect the indoor air quality level are the space. All the observations were recorded on a copy of the floor plan, in order to set the expectations of the environmental health condition of each space and compare it to the findings of the next phases. Secondly, instruments were installed to monitor the key physical parameters and chemical pollutants for indoor air quality: ($CO_{2,}$ VOC, O_3, TVOCs and TPM). Some of the instruments were set for short-term measurement (few minutes) while others were used for a long-term measurement to understand how the occupants' activities, habits and traffic during the day affects the monitored parameters. Thirdly, a survey was distributed to the offices' occupants in order to understand the comfort level of the space and any noticeable symptoms for the occupants' health issues.

In conclusion, all the research, observations and findings proof that there is no enough indoor air quality awareness in Dubai. All the case-studies share the same environmental health issues and the occupants suffer from almost the same symptoms but with minor variations in the level and frequency. Below is a summary of the key design failures and negative occupants' habits and activities in the four buildings, selected for the study:

1. No regular maintenance schedule for air-conditioning system. Most of the owners depend on the business requirement for A/C service when any problem occurs. Unfortunately, the common practice is as long as the system is working and the business didn't receive any official complaint about the level of cooling , the owner/manager does not give any attention to the maintenance value.

2. Changes in the office layout and space usage are implemented without any review or consultation from design experts. Part of the business growth plan is to create a proposal of the teams' structure. Unfortunately,

most of the businesses start changing their business units' responsibilities to match the new strategy/vision, which might lead to the need of additional manpower, without any consideration to the floor planning and layout aspect. The initial space design is limited to a maximum number of occupants at the standard level of comfort. This massive increase in the space users creates crucial health problems and overall discomfort.

3. Random usage of printers, fax machines and 3 in 1 units in the space layout. Nowadays, most of the office work depends on the technology with minimal paper work. The office occupants either move an old machine from one room to another, or simply order a new machine and place it next to the old one. No any attention is given to the emission of pollution caused by this change. The machines are scattered in all the offices with no efficient planning or environmental health control.

4. Massive Kitchen/pantry appliances with minimum or no ventilation.

5. Smoking zone next to main entrance. For Safety reasons, all the owners have prohibited smoking in the office premises. Because the owners have no enough knowledge about the control of Indoor air quality, the buildings surroundings were excluded from the controlled factors.

6. Cost driven approach when selecting the materials for interior finishes. Toxic materials are heavily used in Dubai Market as their prices are quite competitive. As these products are for retails sale, any office owner can purchase any product (paint, floor finish, etc) based on the shade, material, design, brand, etc without giving attention to the product testing information or the breakdown of the components. The consequences of the lack of awareness can lead to serious health problems.

7. Lack of efficient use of natural ventilation. Because of the weather conditions in Dubai, all the offices depend on air conditioning systems as major sources of cooling and air circulation. Windows are mainly used for natural lighting and design purposes.

In Summary, the UAE, as a tropical region, has specific challenges when managing indoor air quality such as excessive temperature, high humidity levels, and overreliance on HVACs. Currently few municipalities coordinate their activities, and research capacity is yet to be strengthened. External air quality is wanting and this may spill over into the internal office environment. Few regulations on compliance among building owners exist. However, some progress has been made in terms of risk awareness among stakeholders in environmental health. Abu Dhabi is paving the way for indoor air quality management through air monitoring stations. Despite these accomplishments, there is plenty that can be done to protect the health and well being of workers in office buildings within the UAE.

5.2 Recommendations

Indoor air quality is a shared responsibility. Poor indoor air quality can be caused by building management when a failure occurs in the maintenance quality and frequency. Moreover, toxic products used by the office occupants, besides some unhealthy habits, can be a major source of indoor pollution which affects the office users' health, performance and productivity.

Based on this research project, the selected case studies' findings along with the literature review give a clear picture of the common building issues. Moreover, the analysis of the study findings gives a clear indication of the size of the problem in Dubai offices, and the required immediate actions to control the consequences of the research gap in the area of indoor environment health on the office occupants.

As this study focuses on offices conditions in Dubai, the list of recommendations will be assigned to: Government bodies, Building/Office owners, Building users/occupants, Architects and Interior designers and Arts and Architecture Schools

5.2.1 Dubai Municipality

It is essential to understand Dubai Municipality development plans and key objectives that are aligned to the overall strategy. A lot of effort was put into setting standards for consultants and contractors. Besides, introducing the steps and procedures for building permits. In addition, a lot of e-publishing on building issues is introduced by Dubai Municipality to support the development of any construction, which includes: Green building regulations and specifications, advisory note on building material specifications, code of construction safety practice, etc.

5.2.1.1 Indoor Environmental Health Awareness

Dubai Municipality should be the key driver to raise the indoor environmental health awareness in Dubai. The first step should be by planning the awareness campaigns in strategic locations in Dubai. Large number of residents in the UAE does not understand the consequences of poor IAQ, and this step will encourage them to read more about it and start taking actions and changing the bad/unhealthy habits in their offices.

Raising the awareness could be by posting signs, colourful posters and flyers in local business, shopping malls or places known for the high traffic. Some informative brochures can be distributed to give people some facts about the relationship between the indoor air quality and building occupants' health. In addition, key speakers and researchers can be selected for conferences and workshops about indoor air quality, to ensure that the commercial building owners are providing healthy and productive work environment for the employees.

5.2.1.2 Introducing Sustainability Audit

All commercial building owners should expect an annual audit for the offices to determine any improvement needs. The auditors should be LEED qualified with a clear understanding for Dubai environment, weather conditions, construction requirements, etc. The checklist used needs to include some mandatory requirements that the building needs to meet such as efficient indoor air quality level, in order to pass the audit. The Audit should be completed over a week time in order to complete the site visit, instruments readings and survey phases. Every commercial building will have a file in Dubai Municipality that will include all the records for the completed audits. Agreed action plans will be saved in the records and reviewed in the next scheduled audit to test whether the changes are implemented or not. Any breach to the agreed standards can cause fines.

5.2.1.3 Updated Building Permit Checklist

The current checklist by Dubai Municipality includes checking the building drawings phase, foundation phase and the final approval. A gap is found in the post-opening phase, which includes the site visit and the ongoing review and investigation. More attention should be given to the planning and layout since the initial stage of approval.

5.2.1.4 Introduce IAQ Guide

A collective pack should be issued by Dubai Municipality to include all the required information about indoor air quality. This research finding could be listed as one of the researches completed in this field. The pack should start by giving an overview of the issue (globally) and move to the weather conditions in this region and the UAE specifically. A section should be assigned for the design failures and proposals for design improvements. This pack will be used as a guide for all contractors, architects and even building users. It must be updated with the latest techniques to protect the indoor environment.

5.2.1.5 Ratio: Room size and number of occupants

Dubai Municipality regulations should cover a standard approved ratio between the space size and the maximum number of occupants. This step will not only restrict the unplanned/unnecessarily renovations, but also protect the space users' health. In simple terms, any increase in the number of space users will lead to a direct increase in the level of Carbon Dioxide emission, and a further increase in the Oxygen consumption. The emission level varies based on the occupant's activity level; however, the average carbon dioxide emission from an adult engaged in office work is about 0.0052 L/s (0.011 cfm) (Persily 1997).

The CO_2 level shouldn't exceed 1,800mg/m3 (1000ppm (v)) for a space to (Persily 1997, Persily 1993) or 20 cubic feet per minute (cfm) per occupant (Deily – Swearingen) comply with ASHRAE standards. Considering that the ventilation system and the space layout are agreed based on the initial space users' number, a real problem will occur when this standard is modified. For instance, ASHRAE ventilation standards per unit area and per person for each space: is 5cfm/p + 0.06 cfm/ft2 (Mudarri 2010). The building will not meet the standards if any of the controlling parameters: Occupants, space size is amended.

As a result, a standard ratio should be maintained to prevent discomfort and indoor pollution. California Building Code (1998) determines that a minimum of 100 square foot per occupant is required for office spaces (RCALC 2004)

In summary, any massive change in the occupants' number will require municipality approvals, and must be followed by the office building extension or renovation.

5.2.2 Emirates Authority for Standardization and Metrology (ESMA)

ESMA is a government authority that is responsible for "formulating and issuance of national standards of UAE as well as adopting international standards, in 2009 amounted to more than 5000 standards". Besides, it focuses on consumer, environment and national market protection, which leads to strengthening the national economy.

ESMA should standardize the interior finishing materials components to align it to the global sustainability standards. For instance, plastics and other synthetic products are widely used nowadays: in electronics, textiles, etc ((health building Network 2006). Most of these products need to be modified to meet fire and safety standards to protect the consumer. ESMA should be responsible for the ongoing review for the products available in Dubai market and banning the import of any product that includes any hazardous component that is not aligned to the agreed standards.

5.2.3 Building/Office Owners

With no doubt, the building owners are responsible for the ongoing review of their building standards, design improvements, layout changes, maintenance schedules, etc. As a result, their contribution to the overall sustainability strategy is very critical.

5.2.3.1 Use of Non-Toxic materials

Chemicals emitted from building materials are the main source of indoor pollution. Special attention should be given to the selection of the Interior flooring and finish products. Key hazardous components of some of the products can lead to serious health problems. The building/office owners should screen the purchased products and materials used in the interior not only in the building construction phase, but also in the renovation phase(s). Some of the materials such as polyvinyl chloride (PVC) in vinyl flooring emit chemicals in its full lifecycle: manufacture, disposal and maintenance (health building Network 2006). The standardized and certified products should be used rather than focusing on a cost-driven approach. The building owner should have a good understanding of the serious consequences of any design failure on the long-term. As all the studies proofed that employees' health affects their productivity, numerous factors should be controlled at the first stages of the construction, in order to avoid further design developments at a later stage.

5.2.3.2 Fixed Schedule for Air-conditioning system maintenance

Building owners should plan a fixed maintenance schedule for the ventilation system to assure the cleanness and spare parts replacement, if needed. This process will include a detailed bi-annual checking (especially during the peak cooling seasons) and a routine backwash for the filters to remove any deposits from the surface and avoid the growth of any undesirable biological deposits (Hess et al 2002)

5.2.3.3 Fixed Hours of occupancy

Most of the results for indoor air quality studies and observations are based on the assumption that the occupant spends an average of 40 hours a week in the office. The real problem in Dubai market is that a large number of offices extend their working hours to 10 and 12 hours a day (50 – 60 hours a week), although the labour law in UAE (Article 65) clearly states that the total number of working hours for office work for adult employees should not exceed 8 hours a day/ 40 hours a week, unless there was a necessitate and that's when he/she is entitled for overtime payment. The companies' owners assume that the increase of the number of working hours will definitely increase the people productivity which will lead to more profit. This might be true in a very short term plan; however, the employees' health conditions will affect their performance and productivity.

If the type of business requires working in shifts or extending the working hours to meet any required time zone differences, numerous design considerations should be highlighted at the building/office design phase followed by regular maintenance schedules to assure sustaining a safe and healthy environment for the occupants.

5.2.3.4 Partnership with environmental Organizations and researchers

More encouragement and cooperation is required from building owners to support the researchers with any studies about indoor air quality in UAE. We need to target at least 15% increase in LEED certifications by end of 2015. The building owners should work closely with the environmental organizations such as: Middle East Centre for Sustainable Development (MECSD), Emirates Environmental Group (EEG), Estidama, etc.

5.2.4 Architecture and design schools

The UAE is in adverse need of capacity development in this area. Many universities, besides the British University in Dubai (BUID), need to introduce doctoral or post graduate programs that revolve around environmental health, so as to increase the number indoor air quality research papers. A number of institutions need to focus on increasing undergraduate student enrolments in environmental degrees. However, for this to occur there should be career opportunities in the field (Bluyssen, 2009). Government positions need to be provided for this. Proper training is also lacking in this regard, and needs to be improved. Laboratory capacity for environmental health analysis is not at its peak. If this can be improved, then chances are that better analysis of indoor air quality data will be done. Current research organisations are focusing on other topics in environmental health, but have not prioritized indoor air quality, yet this is fundamental in maximisation of the existing structures (EAD, 2009). Few research priorities revolve around this topic, so they ought to be improved. Overall, all architects and designers should be updated about the tools and standards to control the indoor air quality problem to provide healthy, comfortable and productive environment for all users.

5.2.5 Recommendation for future Research:

This research paper is a detailed analysis of the indoor air quality condition in the office buildings in Dubai. Various parameters were tested in order to determine the common sources for pollution in the indoor environment in Dubai offices. Although big attention was given the environment surroundings, buildings locations, human activities, etc., more research is suggested to understand the health level of the other indoor spaces. Indoor air quality in the residential spaces is a key research area considering the variation in the age of the space users, with different sensitivity levels to the environment conditions and pollutants' concentrations. In additions, other commercial industries should be given more attention to assure a safe, healthy and productive indoor environment for all employees and building occupants.

It is essential to understand that the data collected for this study, either from field measurements, surveys or interviews is all based on the selected space conditions. In other words, the symptoms highlighted in the surveys could be due to the exposure to pollutants in other spaces that were accessed before visiting the office (residence, clinics, hospitals, etc). These symptoms can last with the occupant for some time even after leaving the space. As a result, there is a lot that can be done to study and enhance the indoor environment conditions in Dubai for all the indoor spaces: residential, commercial, industrial, etc.

In addition, further studies could be arranged to focus on the offices in specific areas in Dubai, in order to establish a detailed database for the pollutions level in each commercial area in Dubai, this will be followed by setting clear rules and regulations for establishing any business in this area. Understanding the exact weather condition, influence of external factors are key design elements to assure a sustainable and healthy indoor environment.

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Adopted from

EPA INDOOR ENVIRONMENTAL QUALITY SURVEY

"This survey is being conducted to determine the environmental quality of your building".

ALL OF YOUR ANSWERS WILL BE TREATED IN TH STRICTEST CONFIDENCE

Date:
Building Name:
Floor (G/1st /other):

WORKPLACE INFORMATION

1. How long have you worked in this building, to the nearest year? -- years If less than one year, how many months have you worked in this building? -- months	4a. How many people work in the room in which you workstation is located (including yourself)? - 1 - (2-3) - (4-7) - 8 or more 5. Is there a carpet on most or the entire floor at your workstation? - Yes - No
2. On average, how many hours a week do you work in this building? -- hours per week	6. In general, how clean is your workspace area? - Very Clean - Reasonably Clean - Somewhat dusty or dirty - Very dusty or dirty
3. During THIS WEEK, including today, how many days did you work in this building? -- days	7. Please rate the lighting at your workstation - Much too dim - A little too dim - Just Bright - A little too Bright - Much too bright
4. Which best describes the space in which your current workstation is located? - Single Person Private office - Shared Private Office - Open Space with Partitions - Other (Specify)	8. Do you experience a reflection (Glare) in your field of vision when at your workstation? - Rarely - Occasionally - Sometimes - Fairly - Very Often

9. How comfortable is the chair at your workstation?
- Very Comfortable
- Reasonably Comfortable
- Somewhat uncomfortable
- very uncomfortable
- don’t have one specific chair

10. How comfortable is the current set-up of your desk or work table (i.e.; height, general arrangement, etc)?
- Very Comfortable
- Reasonably Comfortable
- Somewhat uncomfortable
- very uncomfortable
- don’t have one specific desk

11. Do you work with a computer or word processor?

-- Yes -- No (skip to #12)

11a. About how many hours a day do you work with a computer or word processor, to the nearest hour?

-- hours per day

11b. If you use a computer, do you usually wear glasses when using the computer?

-- Yes -- No

11c. Do you use a glare screen on your computer?

-- Yes -- No

12. Which one of the following statements describes the windows in your work area?

- No windows in my personal Workspace and non in the general area visible from my workstation.

- No windows in my personal workspace but I can see one or more windows in the area.

- There are no windows in my personal workspace

13. If there is a window visible from your workspace, how far (in feet) is the closest window from your desk chair?

- feet - No Window

14. During the PAST THREE MONTHS, have the following changes taken place within 15 feet of your current workstation?

	Yes	No
New Carpeting		
Walls painted		
New Furniture		
New Partitions		
New wall Covering		
Water damage		

15. How often do you use the following at work?

A. Photocopier

-- Several Times a day
-- About once a day
-- (3-4) times a week
-- Less than 3 times/week
-- Never

B. Laser Printer

_ _ Several Times a day
_ _ About once a day
_ _ (3-4) times a week
_ _ Less than 3 times/week
_ _ Never

C. Cleanser, glue, correction fluid, or other odorous chemicals

-- Several Times a day
-- About once a day
-- (3-4) times a week
-- Less than 3 times/week
-- Never

Information about health ad well-being

1. Have you ever been told by a doctor that you have or had any of the following?

	Yes	No
Migraine		
Asthma		
Eczema		
Hay Fever		
Allergy to dust		
Allergy to molds		

4. Do you consider yourself especially sensitive to the presence of other chemicals in your workspace?

-Yes -No

5. What type of corrective lenses d you usually wear at work?

- None
- Glasses
- bifocals
- Contact lenses

2. What is your Tobacco smoking status?

-- Never Smoked

-- Former Smoker

-- Current Smoker

6. Ho old were you on your last birthday?

- Under 20
- (20 -29)
- (30 -39)
- (40- 49)
- (50-59)
- over 59 years

3. Do you consider yourself especially sensitive to the presence of tobacco smoke in your workspace?

- Yes - No

7. Are you:

- Male - Female

During the last FOUR WEEKS you were at work, how often have you experienced each of the following symptoms while working in this building? *(If you check "Not in Last 4 weeks", move to the next Symptom. If you check any other column rather than the 1st one, ,move horizontally to the next question followed by the rest of the symptoms)*					What happened to the Symptom at times when you were away from work?			How many days did you experience the symptoms this WEEK?
Symptoms	Not in last 4 weeks	1-3 days in the last 4 weeks		Every or almost every workday	Got Worst	Stayed Same	Got better	No of days this week
Dry itching or irritated eyes								
Wheezing								
Headache								
Sore or dry throat								
Fatigue								
Runny nose								
Cough								
Tired or strained eyes								
Tension								
Pain in back, shoulder or neck								
Sneezing								
Difficulty in concentration								
Dizziness								
Depression								
Shortness of breath								
Upset stomach								
Dry or itchy skin								
Numbness in hands or wrists								

A. In the LAST FOUR WEEK how often have any of the symptoms listed above reduced you ability to work?

- Days

B. In the LAST FOUR WEEK how often have any of the symptoms listed caused you to stay at home or leave work?

- Days

Description of workplace conditions

During the last FOUR WEEKS you were at work, how often have you experienced each of the following environmental conditions while working in this building? *(If you check "Not in Last 4 weeks", move down to the next condition)*				How many days did you experience the condition this WEEK?
Conditions	Not in last 4 weeks	1-3 days in the last 4 weeks	Every or almost every workday	Number of days this week
Too much air movement				
Too little air movement				
Temperature too hot				
Temperature too cold				
Air too humid				
Air too dry				
Tobacco smoke odors				
Unpleasant chemical odors				
Other unpleasant ododrs (food, perfume, etc)				

A. How satisfied are you with the following aspects of your workstation?

1. Conversational Privacy
   - Very Satisfied
   - Somewhat satisfied
   - No too satisfied
   - Not at satisfied at all

2. Freedom from distracting noice
   - Very Satisfied
   - Somewhat satisfied
   - No too satisfied
   - Not satisfied at all

IV. PERCEPTION OF THE INDOOR QUALITY

Sex:	Time of filling this section:
Date:	

PLEASE MARK ON THE SCALES

1. How do you assess the air quality?

   Notice the distinction between acceptable and unacceptable

   Clearly acceptable

   Just acceptable

   Just unacceptable

   Clearly unacceptable

2. How do you assess the odour intensity?

   No odour

   Slight odour

   Moderate odour

   Strong odour

   Very strong odour

   Overpowering odour

3. How do you perceive the air?

Fresh — Stuffy

Not Dusty — Dusty

Not Moldy — Moldy

>> THANKS A LOT FOR YOUR TIME. YOUR EFFORT IS HIGHLY APPRECIATED <<