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INDOOR AIR QUALITY OF OFFICE BUILDINGS IN IDUSTRIAL COMPLEX

BY

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ABSTRACT

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Measurement of air quality in the places where people are used to spend a large amount of their time is essential. Hazardous substances emitted by anthropogenic activities, building construction materials, indoor equipment or heating & cooling system may lead to broad range of health problems. Therefore, it is vital to investigate the quality of the indoor workplace environment. Due to extreme environmental conditions in Qatar, people have to spend most of their time inside whether children in schools, adults in offices, malls or at home. These accumulative effects have added a concern that air quality of indoor atmosphere should be monitored, analyzed, and reported properly.

Seventeen parameters including temperature, relative humidity (RH), ozone (O_3), hydrogen sulfide (H_2S), hydrochloride (HCl), ethylene oxide (EtO), hydrogen cyanide (HCN), fluorine (F_2), carbon monoxide (CO), carbon dioxide (CO_2), total volatile organic carbon (TVOC), oxygen (O_2), ammonia (NH_3), nitrogen dioxide (NO_2), nitric oxide (NO), chlorine (Cl_2) and sulfur dioxide (SO_2) were measured at eleven locations inside industrial complex buildings in Mesaieed City, Qatar using GRAYWOLF indoor air quality monitoring pack. Monitoring duration lasted for eight hours during June-August 2017. Keeping the above-mentioned factors in view, all of the eleven locations have been evaluated based on different international standards such as OSHA and ASHRAE

(American Society of Heating, Refrigerating, and Air Conditioning Engineers). Accordingly, the indoor air quality of 11 locations were categorized as acceptable and not acceptable as per permissible limits defined for each parameter.

Eight parameters, RH, temperature, CO_2, SO_2, EtO, H_2S, TVOCs, O_2 were detected.at acceptable levels except two locations i.e. for Room 6 -Control Room Main Building (office 110 CBGF) and Room 8- Laboratory 2 where Mean temperature in Room 6 & 8 is above the upper extreme of the permissible range as recommended by OSHA (CFR 29) i.e.20^oC-27^oC. However, in rest of rooms it was within the prescribed range. CO_2, SO_2, EtO, H_2S, TVOCs and O_2 concentration in all the office rooms is below the lower extreme of the permissible range as recommended by OSHA (CFR 29). However, CO, NO_2, NO, Cl_2, HCH, NH_3, F_2, O_3 and HCl were non-existent in all the rooms because of their concentrations being below the limit of the instrument used.

Overall, this study highlighted that the air quality in most of the rooms is considered to be healthy and the parameters monitored during IAQ survey were within the ASHRAE and OSHA CFR29 limits. This study can be used as a baseline for any future detailed IAQ investigation in Qatar.

DEDICATION

Every challenging work always requires a self-dedication and a certain support and guidance. I would like to dedicate this dissertation to my parents and wife; Sadia whose affection, encouragement, and prayers makes me capable to complete this project. I would also like to dedicate this to my hardworking respected teachers.

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CHAPTER 1: INTRODUCTION

Globally, air pollution is considered as one of the major environmental concerns. Worldwide, air pollution, especially in large cities, is directly related to the increased number of lung and heart disease cases which eventually result in high death rate (Li et al., 2017). Quality of air is meticulously related to the activities of human. Currently, different methods have been used to confirm the impacts of human effects on the natural environment. Few scientists considered CO_2 and SO_2 as indicators for change in climatic conditions as well as air pollution in Britain (Sike Li et al., 2015). Researchers also used temperature matrix for measuring changes in quality of environment to carry out different analysis in parallel (Zhou et al., 2017).

Indoor air quality is considered serious concern for the human health either in isolated or public indoor environments. Risk to health arising from conventional usage has been decreased worldwide but in contrary more health hazards arising from closed buildings and use of different building materials. Air-conditioned building and closed building is constructed because of severe weather conditions in Middle East. Tightly closed buildings can result in worsening of indoor air quality because pollutants gather inside building. This matter becomes vital for health as people spending more than 95% of their time in indoor environments and during hot season 98% because of high temperature 50°C. Irrespective of this fact, there is no sufficient regulatory framework for indoor air pollution and associated health impact in MEA countries. Regardless of this prevailing circumstance currently there is no governing agend for indoor pollutants in Middle East. In Middle East there are insufficient studies addressing indoor air quality health issues. Therefore, inclusive studies are required for Qatar as having fast economic growth. (Dikaia Saraga et al., 2017)

Indoor air quality of office buildings has become a main concern for the public in recent years (Funk et al., 2014). It can affect the wellbeing, health, luxury, happiness, and productivity of residents. The US EPA has listed indoor air quality as one of the top 5 public health risks (USEPA, 2007). In the USA, Center for Disease Control & Prevention (CDC) has given an estimation that normally residents of the country spend 90% of their time indoor which is the major reason for being exposed to indoor air pollutants more than outdoor air pollutants (Al-Horr et al., 2016; Morawska et al., 2013).

There has also been a substantial worldwide change in the economy from the manufacturing sector to the service and knowledge-based sectors which has increased diversity and level of indoor pollution. In urban and industrial environment, a wide use of closed soundproof windows and air-conditioning has decreased ventilation, which had increased probability of high concentration of indoor pollutants (Thomas and Frankenberg, 2002; Banerjee and Dufl, 2007). Therefore, it is vital to study and investigate the quality of the indoor workplace environment.

During the last mid-century with the development of technology, there have been prominent changes in manufacturing of materials used for buildings and everyday items used at homes which have resulted in the formation of various air pollutants inside homes (Zhou et al., 2017).

Recent investigations in this field have raised several questions regarding the indoor air quality and risk to human health (Banerjee et al., 2004; Cunningham et al., 2005;

Steinemann et al., 2017). The use of chemicals, paints, varnishes, and certain cleaning and polishing are agents designed to improve the quality of buildings; however, these substances also caused many health concerns (Banerjee et al., 2004). Air Pollution coming from sources like vehicles, industrial areas and from human activities are typically argued, but indoor pollution generally remains ignored.

Exposure to indoor air pollutants is common but public awareness regarding this issue is very limited when compared to outdoor air pollutants (Cunningham et al., 2005). Since, indoor air pollutants are known to cause significant health problems across the globe, it is important to understand the hazardous nature of these pollutants as well as to take necessary steps to reduce their effects and minimize human exposure. Different age groups have different sensitivity when exposed to these pollutants (WHO, 2005). According to the WHO global air quality guidelines, 1.6 million deaths per year were the result of increased concentrations of particulate matter and gasses in indoor air (WHO, 2005). Similarly, a recent study published by WHO in 2012 highlighted that 4.3 million people died because of indoor air pollutants as compared with 3.7 million due to outdoor air pollutants (WHO, 2012).

Due to extreme environmental conditions in Qatar, people have to spend most of their time inside their houses, schools, or offices. Currently, there is no comprehensive study publicly available where indoor air quality assessments are conducted, and results are shared with the residents. Individual studies have been carried out by different organizations, but the reports are not published. Variety of pollutants, such as volatile organic compounds (VOCs), carbon dioxide (CO_2), carbon monoxide (CO), ozone (O_3), formaldehyde (HCHO), hydrogen sulfide (H_2S), hydrochloride (HCl), ethylene oxide

(EtO) could be potential source of pollution. Their concentrations are evaluated and compared by different international air quality standards, such as OSHA and ASHRAE.

Determinants of Indoor Air Quality (IAQ)

Determinants of indoor air quality (IAQ) include a variety of compounds, such as VOCs), CO2, CO, O3, HCHO, H_2S, HCl, and EtO. Because of improved life style nowadays, people give more importance to interior ornamentation and building structures. Such activities generate indoor air pollution, particularly volatile organic compounds pollution. In case of poor ventilation volatile organic compounds (VOCs) can be five time higher as compared to outdoor environment (Zhou et al., 2017). This increase can have many acute and chronic effects on residents like dizziness, tiredness, irritation and drowsiness (Xu et. al., 2001)

In paragraphs below, each determinant factor is described in detail:

Temperature is a very important factor, directly linked to the comfort of building occupants (Kemp, 2004). The standard 55-2004 of American Society of Heating Refrigeration and Air-Conditioning Engineers (ASHRAE, 2004) stated that this comfort level of occupants can be achieved if the operating temperature is maintained-between 19 to 27°C.

Ozone is another factor, which impacts indoor air quality. Ozone in stratosphere is a protection shield against harmful ultra violet rays. Opposite to this ozone, ozone produced in lower atmosphere through anthropogenic activities is dangerous for human health. Recent issues of urban smog are linked to production of ozone in lower atmosphere by the reaction of direct sunlight, NOx & VOCs (Banerjee and Annesi-Maesano, 2012). The US OSHA (1997) set a permitted exposure level (PEL) for ozone at 0.1 ppm for 8 hours (USOSHA, standard 29 CFR, 2012).

For indoor air quality applications, hydrogen sulfide (H_2S) is usually a nuisance gas, having a "rotten egg" smell that some individuals can detect at a level as low as 5 ppb. Threshold limit values (TLV) and short-term exposure level (STEL) of H_2S were set at 10 and 15 ppm, respectively (Air Quality Guidelines, 2006).

In the list of federal hazardous air pollutants developed in April 1993, hydrochloride was identified as a toxic air contaminant. Hydrochloride in gaseous form is a colorless corrosive gas with a pungent irritating odor. Sources of HCl can be fuel combustion, metal smelting, and pyrolysis of wire insulation. In industrial area, operations of neighboring steel, petrochemical, and chemical industries are big contributor of this pollutant. The USOSHA regulations (Standards-29 CFR) state the limit of HCl in door environment at 5 ppm (OSHA, 1997).

EtO does not have any detectable smell, it is a colorless gas. In the chemical industries, there are multiple uses of EtO, like sterilizing a laboratory. It is used in antifreeze, brake fluids, heat transfer agent. As being a volatile organic compound, it can be a contributor in the formation of lower level ozone. EtO possesses several physical and health hazards that merit special attention. EtO is both flammable and highly reactive (Traynor et al., 1982).

Hydrogen Cyanide (HCN), which is commonly known as hydrocyanic acid, is a chemical asphyxiate. At temperature less than 25.6°C, it is colorless and above this it has pale blue color. There was a time when it was used as a warfare chemical agent as well. It is used in industries for fumigation, synthetic fiber production, pesticides etc. In indoor air, it can be found as gaseous and/or liquid spray aerosol. Based on the USOSHA (1997) Regulation standard 29 CFR, time weighted average (TWA), STEL (write the full name), and immediately dangerous to life and health (IDLH) levels for HC were set at 10 ppm, 4.7 ppm, 50ppm, respectively (Brown et al., 2004).

Fluorine (F_2) is produced because of combustion process and it is 10 to 100 times more toxic than sulfur dioxide. The permissible exposure limit of 0.1 ppm and TWA of 0.2 mg/m^3 were identified for F levels in indoor environment by the USOSHA (1997).

The relative humidity (RH) is one of the most important parameters to measure for providing a comfortable environment for residents. It is an indicator to show moisture levels in the air. It is determined by measuring a ratio of density of water vapors to saturation density of water vapors in the air (Mahyuddin and Awbi, 2001). The standard 55 (2004) of ASHRAE set a ratio less than 0.012 to be best for RH in indoor environment. While calculating this ratio, parameters are kept at standard pressure; RH should be 56% up to maximum 86% and temperature should be maintained between 19-27 °C.

Major source of carbon monoxide (CO) is burning of fossil fuels. High concentration of CO can be captured / trapped in any typical environment due to multiple reasons due to inadequate exhaust in combustion (Hays et al., 1995). The PEL for CO is set at 500 ppm for 8-hours (OSHA, 1997)

It is usually measured as a tracer gas; this is used usually to measure ventilation of outdoor air in a confined or closed space. It is comparatively less toxic in normal environment for human beings (Zhang, 2005). As Per OSHA 1000 ppm should be considered as the maximum ceiling limit for CO_2.

The permitted exposure levels set by USOSHA (1997) for acetone, benzene, ethanol, formaldehyde, and styrene are 1000, 1, 1000, 0.75 and 100 ppm, respectively.

Aeration inside most of buildings in cities is reduced due to usage of windows having sound-proof materials and air conditioners. As soon as ventilation inside the building is reduced, volatile organic compounds are gathered which are known as key indoor air pollutant. The concentration of VOCs that are present inside can be five times higher than the concentrations present outside that can result in acute and chronic effects, such as faintness, vomit like feeling, sensual annoyance and fatigue (Zhou et al., 2017). Zhou et al. (2017) analyzed the collective effects of humidity and temperature on volatile organic compounds collected from residential buildings in Xi'an and Hangzhou during the years 2014 and 2015. The authors determined that the levels of volatile organic compounds for refurbished residential units are ten to fifteen times more than the levels detected in old buildings. They concluded that the concentrations of volatile organic compounds as indoor air pollutants have increased because of combined effects of temperature and humidity, known as sink effect, for the components with high Henry's Law Constant.

Oxygen (O_2) is most important for existence of life on earth. Recently, in some of the most polluted cities the level of O_2 has dropped to 12 to 15% from 35% as reported in earlier studies. When the levels go beyond 7%, life cannot be supported; hence, it is important to measure oxygen levels in indoor environments (Tian et al., 2006). As per OSHA (1997), the PEL for O_2 is set at 19.5% minimum and according to NIOSH (write the full name), the concentration should be between 19.5-25% at 760 mm Hg.

Ammonia (NH_3) is a colorless gas and has pungent smell. In buildings, ammonia is generally produced through construction material. Moreover, industrial manufacturing processes such as production of fertilizers and de-NOx (non-catalytic reformer reactions, heaters and boilers) processes also contribute to ammonia emissions (Norback et al, 1990). Other sources that emit ammonia include refrigeration units, internal chemical storages, and units for cleaning. Common health issue linked to higher ammonia concentration is tiredness. Sick building syndrome is also observed when ammonia concentration is higher than the permissible exposure limits recommended by OSHA. Throat, skin, nose and eye irritation are some common symptoms observed when ammonia concentrations are high (OSHA, 1997). As per OSHA guidelines, limits of ammonia in indoor environment are 50 ppm or 35 µg/m^3.

Nitrogen dioxide is brown reddish gas and the most common source is fossil fuels burning in plant areas like reformers, boilers, heaters, and others (Goyal and Khare, 2010). It is also reactive in the formation of ozone. Nitrogen dioxide does cause irritation in eyes, nose and throat. It has more severe effects on respiratory system and on lung function as well. Some biochemical investigations have been carried out to study sub-chronic and acute effects of nitrogen-dioxide. The values reported in these studies were relatively high, around 2 ppm (Sagai et al.,1984). Based on the findings of these studies, it was evident that a high concentration of 0.4 ppm affected the lipid metabolism of rat's lungs (Sagai et al, 1984). Annual mean outdoor concentrations of nitrogen dioxide in urban areas throughout the world are in the range of 2090 µg/m^3 (~0.01-0.05 ppm) as per WHO (1997). A detailed research carried out by WHO in fifteen countries and eighteen cities reported a concentration mean value between 10-81 µg/m^3. The major source of nitrogen dioxide was the gas stoves used indoors (Levy, 1998). The USOSHA (1997) Regulation (Standards-29 CFR) set the PEL level for NO_2 at 25 ppm.

Sulphur dioxide (SO_2) is a corrosive gas and it is very difficult to smell or see at lower level. The sources of SO_2 are power plants, petrochemical plants, heaters and other sources of burning fossil fuels. Sulfur dioxide has severe health impacts especially on young children, causing heart and lung diseases (Fisk et al., 2009). The USOSHA (1997) says limit should be 5 ppm for duration of 8 hour.

Chlorine, a green colored gas, is considered as irritant and suffocated when inhaled. It is di-atomic and is highly soluble in alkalis, water and alcohol. Exposure to chlorine as an indoor air pollutant could be harmful as it is a strong oxidizer, an electronegative and a highly reactive gas (Merck, 1989). The limits for chlorine are 1 ppm or maximum 3 mg/m^3.

Significance of the Study

The significance of this researched will rely on the data collected and analyzed. The result of this study would be helpful in the upcoming investigation on issues like; correlation between IAQ and designs of the buildings, occupants' health, behavior and productivity and others. This study can support initiative for Qatar Sustainability Assessment System (QSAS) working for green building certification to improve environment of office buildings.

Findings of this study will also be helpful for evaluating the existing pertinent policies and proposing amendments therein to tackle the issue efficiently. Moreover, the significance of the study lies on the knowledge and awareness more and more would have on the issue. After awareness, the public will be able to recognize the harmful effects of indoor air pollutants upon their health. They will be knowing how a short-term exposure of CO can negatively impact their health and can even lead them to death; toxicity of VOCs, NOx, particulates matter (PMs) and others can cause respiratory and cardiovascular problems.

This project will unveil the factors that may affect occupants' productivity in the roomed environment. The findings of the investigation will help to the Qatar National Vision 2030 to promote safe and productive indoor environment.

Research Questions & Hypotheses

Research Questions:

- What are the main indoor air Pollutants available in industrial complex buildings in Qatar?
- What are the key correlations between different indoor air pollutants?

Hypothesis:

- 1- Indoor Air Quality of office buildings can be Polluted due to outdoor pollutants
- 2- Possible Pollutants include VOCs, Chlorine, H_2S from Plant Operations

Research Objectives

The main objective of the study was to investigate the indoor air quality of workplace environment at QAFAC complex in Mesaieed. The sub-objectives of the study were;

1. To investigate key environmental factors that can affect occupants' productivity.
2. To help industry to improve the designs consideration before construction that can sustain acceptable levels of indoor air quality.
3. To support and promote a sustainable building industry in Qatar.
4. To Support Qatar National Vision 2030's call for sustainable development and environmental protection.
5. To supports the priorities of NPRP (National Priorities Research Program) 10's themes (Improve the Environmental Quality).
6. To identify the health risk from indoor air pollution to office buildings by monitoring the quality of air to which occupants are exposed.
7. To Identify main source of indoor air pollution exposure

CHAPTER 2: LITERATURE REVIEW

To investigate deeply into the problem, an extensive review of the relevant literature was carried out on indoor air pollutants, their source materials, their negative impacts on human health and productivity, particularly in residential buildings. A study conducted by National Institute of Occupational Safety and Health (NIOSH, 2014) showed different sources of indoor air pollution. Among the various causative factors of indoor air pollution, inadequate ventilation came out to be the main reason of affecting indoor quality of air (IQA). The causes of indoor air pollution have been summarized in Table 1. Figure 1 shows different sources of indoor pollution. Sources of indoor air pollutants can be from inside building and can be drawn in from outdoor sources. Sources from outside building can be pollen, dust, fungal spores, industrial pollutants, general vehicle exhaust, emissions generating from nearby sources (e.g. odors from dumpsters, loading docks etc.), soil gas (radon, leakage from underground fuel tanks, pesticides etc.), moisture or standing water promoting excess microbial growth (rooftops after rainfall, crawlspace), HVAC equipment (dust or dirt in the duct work or other components, microbiological growth in dripping pans, ductwork, coil, improper use of biocides, sealants and cleaning compounds, improper venting of combustion products, refrigerant leakage, non HVAC equipment (elevator motors and other mechanical systems), human activities (smoking, cooking, cosmetic orders, maintenance activities), building components and furnishings locations that produce or collect dust or fibers, unsanitary conditions and water damage, and chemicals released from building components or furnishings. Other sources include accidental events and redecorating/remodeling/repair activities (USEPA and NIOSH, 2014)

Table 1

Different Sources of Indoor Pollution (NIOSH, 2014)

Pollutants	**Percentage**
Inadequate Ventilation	53%
Inside Contamination	15%
Unknown Causes	13%
Out-side Contamination	10%
Bioaerosol	5%
Building Products	4%

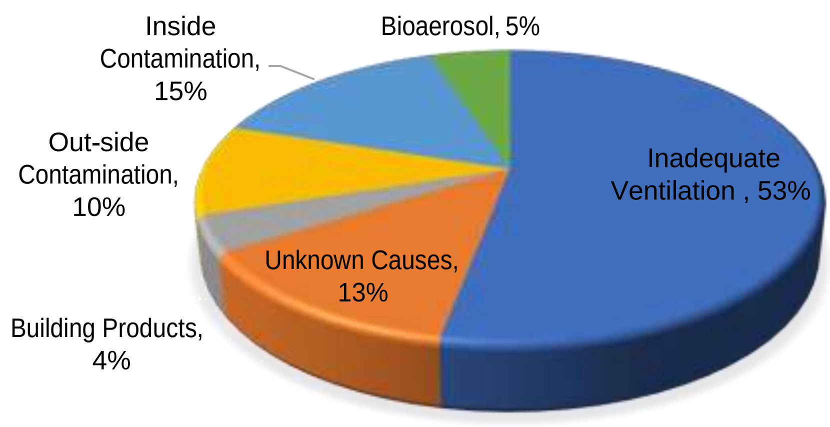


Figure 1. Different sources of indoor pollution (NIOSH, 2014).

Indoor Environment Pollutants

People spend almost 90% of their time in the indoor environment but it is very unfortunate that the least attention is being paid to this facet of congenial work-environment (Nazaroff, 2013). It is rather a height of oblivion that governments are all-out to adopt measures that may address the outdoor airborne pollutants instead of indoor ones. In the following section, however, the origin and producers of several indoor air pollutants, as noted in the previous Chapter, includes the following pollutants like nitrogen oxides, volatile organic compounds, formaldehyde sulfur dioxide, carbon monoxide, ozone, particulate matter and radon, as identified by the United States Environmental Protection Agency (USEPA, 2009) (Table 2).

Table 2

Major Indoor Air Pollutants (Kumar and Kumar, 2007; USEPA, 2009)

Pollutants	Source
By-means of combustion (e.g. CO, CO_2, NOx)	Gas & kerosene heaters and stoves, wood and gas hearths, automobile exhausting in garages, tobacco smoke, leaking furnaces and chimneys
Tobacco smoke	Cigars, cigarette pipes
Formaldehyde	Products of pressed wood (plywood, hardboard, fiberboard, particleboard and wall paneling,) used in furniture and buildings, pressed textiles, foam insulation, glue, tobacco smoke, fireplaces, stoves, vehicle exhaust
Other Volatile Organic Compounds	Aerosol sprays, wood preservatives, paints, dry cleaned clothes, cleaners and disinfectants, solvents, moth repellents, and air fresheners
Radon	Water, soil, rocks
Bioaerosols	Humidifiers, pets, drip pans, ventilation systems, moist surfaces, outside air, plants,

Indoor Air Quality and PAHs

Polycyclic aromatic hydrocarbons (PAHs) are also taken into consideration when studying indoor and outdoor air quality. Chen et al. (2017) studied indoor and outdoor air pollution namely, $PM_{2.5}$ and PAHs seasonally. The correlation analysis of the results showed that both indoor and outdoor air have certain concentrations of PAHs, but the annual mean of indoor PAHs concentrations was lower than 1ppm as compared to outdoor PAHs concentrations (Chen et al., 2017).

Several studies have been carried out to investigate the indoor air pollutants in school environment where school children have long term exposure to pollutants with serious health hazards (Morawska and Salthammer, 2003). Certain indoor air quality conditions like temperature, relative humidity, carbon dioxide, formaldehyde, benzene, trichloroethylene, pinene, limonene, nitrogen dioxide, carbon monoxide, radon and ozone were listed (Morawska and Salthammer, 2003). Increase in temperature results in increase of sub micrometer particles that have emitted during heat treatment of indoor dust and observed even at a temperature of 50–100°C when lamps are used. Changes in relative humidity can affect carpet dust resuspension ability. Detaching of spores for fungi growth is related to changes in relative humidity.

When ozone reacts with potentially irritant unsaturated compounds like formaldehyde, acrolein, glyoxal it can result in production of water soluble compounds. It was concluded benzene did not reveal clear gradient with respect to distance from road but on the other side black smoke and NO_2 demonstrated clear gradient. (Morawska and Salthammer, 2003).

NO_2 concentrations inside housing unit was reported at 8–25 μg m–3 whereas the value outside was found to be 17–51 μg m–3 which shows the effect of vehicle emissions from outside. A higher concertation of ozone in offices has a source of ozone than controlled environment. In these reading a difference was noticed for particles of size range between 0.1–0.2 μ m diameters. Particles of this size range found 20 times more in office with addition of ozone compared to controlled environment (6000 vs. 300 particles cm^{-3}). When ozone was introduced, concentration differences developed successively and produced in 0.2–0.3, 0.3–0.4, 0.4–0.5, and 0.5–0.7 μ m diameter size ranges (Morawska and Salthammer, 2003).

An important aspect of relative humidity is encouraging microbial growth in the carpets and other possible potential sources. ASHRAE standard, 62.1-2016, recommends maintaining RH% between 30-60%. A higher concentration will facilitate growth of mildew, mold, bacterial, fungi and dust mites. Similarly, a relative humidity less than 30% will aggravate discomfort among occupants/residents, and may allow spread of viral infections (ASHRAE, 62.1, 2016).

Carbon monoxide (CO) is odorless, colorless, and tasteless. It is highly toxic gas. Yet, at ordinary conditions, it is un-reactive (HPA, 2007). It causes dearth of oxygen and disrupts its supply to the human body. Under-rate combustion processes like operation of gasoline power tools, fuel-fired appliance, vehicles or closed-devices, etc. usually add carbon monoxide to the atmosphere. The CO is added to the atmosphere through countless sources, such as kerosene and gas stoves and heaters, wood and gas hearths, vehicle exhaust, tobacco smoke, leaking furnaces and chimneys (Christoforou, 2007; American Lung Association, 2008; USEPA, 2009). CO is a source of indoor air pollution produced because of combustion processes. It poses high risk to living organisms leading to poisoning, cardiovascular diseases, and sometimes deaths. The behavior and chemical nature of pollutants and the ventilation processes indoors are important to evaluate the toxicity and the harm it can cause to occupants of the building (Sharma and Crump, 2012). Carbon dioxide (CO_2) is a well-known naturally produced gas by the process of respiration. In evaluation of indoor air quality, it is used as an indicator of whether the ventilation systems are competent in replacing carbon dioxide with fresh air or not. Inefficient removal of carbon dioxide eventually results in its accumulation in microenvironments and hence, increases its concentration. Increased carbon dioxide concentration is not healthy for the occupants in offices or accommodations as it can displace oxygen as well as cause dizziness, suffocation and other such health risks (Neumeister-Kemp et al., 2012).

Oxides of Nitrogen (NO_X) are of different types depending upon the number of constituent oxygen atoms. However, two very commonly found oxides are: nitrogen dioxide (NO_2) and nitric oxide (NO). Nitrogen dioxide (NO_2) is an ill-smelling and irritating odor reddish-brown gas which occurs in the atmosphere abundantly and particularly when there is excessive lightning, thundering and flashing. It irritates lungs and causes bronchitis and asthma if it is inhaled in high concentrations (Christoforou, 2007). Nitrogen dioxide is another lethal pollutant which comes from the sources like boilers, hot water heaters, fireplaces and gas ranges (American Lung Association, 2008).

NO_2 effects on humans studied widely exposure to yet should be reduced in any case (Kajtar, et., 2008). In some studies, higher concentration of indoor NO_2 is linked to increased symptoms of asthma. Other health conditions such as chest tightness, respiratory problems, and cough are also outcomes of exposure to NO_2 (Paulin et al., 2014).

Researches have been done to analyze the concentrations of VOC's both indoor and outdoor. For indoor air quality analysis, stores, photocopy centers, theaters, schools and offices were assessed. In one of the research the most detected volatile organic compounds were hexan-2-one and heptan-2-one (Jares et al., 2012). Similarly, another research measured about fifteen VOC's in many microenvironments including homes, offices, stores, and transport areas. Even though, the presence of VOCs was observed in most of the micro-environments, but the elevated concentrations were observed in transport sector (Kim et al., 2001). Certain studies focus on the effect of seasonal variations on the concentration of VOCs. One of a research concluded the presence of high concentrations of VOCs in indoor environment in winter as compared to summer with about three to four times less concentration (Schlink et al., 2004). VOCs are also mutagenic, carcinogenic, and teratogenic (Vincent et al., 2008). They vaporize rapidly and can easily adopt in the photochemical reactions in the atmosphere to convert into vapor (Stedman, 2007). There are numerous types of VOCs that can be present in indoor air but only aromatics, halocarbons and aldehydes are examples of commonly found ones (Wang et al., 2007).

Presence of VOCs is higher in indoor air than that of outdoor (Meininghaus et al., 2000). It has been proved through a researched conducted by USEPA in six different venues in the United States that VOC's accumulation in indoor was almost 10 times greater than the outdoor (USEPA, 2009). Liquids and solids such as benzene, perchloroethylene, and formaldehyde constantly evaporate and emitted VOCs in gaseous form at room temperature (USEPA, 2009). According to Parra et al. (2008) emission of VOCs in higher concentrations are harmful and lay negative impacts on human health. That is why more and more researchers are prone to conduct their studies upon them.VOCs are released from various organic sources like combustion, cooking, construction materials, tobacco smoke, office equipment, consumer and cleaning products (Wang et al., 2007; Parra et al., 2008). Table 3 presents some specific indoor sources of organic vapors.

Table 3

Some Specific Indoor Sources of Organic Vapors (Source: Wang et al., 2007)

Compound	Source Material (s)	Compound	Source Material (s)
Paradichlorobenzene	Deodorants, Moth crystals	Methylene chloride	Solvent, paint removers
Formaldehyde	Foam, pressed wood products,	Styrene	Plastics, Insulation, paints textiles and disinfectants
Acetaldehyde	Mould growth on stored edibles, glues, preventives deodorants	Acrolein	Oak-wood, cotton, by-product of wood combustions and kerosene oil
Toluene diisocyanate	Aerosols, polyurethane foams	Benzyl chloride	Vinyl tiles plasticized with butyl benzyl phthalate
Benzene	Smoking	Tetrachloroethylene	Storing or wearing of dry-cleaned clothes
Alcohols	Cosmetics, Aerosols, paints, window, thinners adhesives, and cleaners	Ketones	Varnishes, lacquers, adhesives, polish removers
Ethers	Varnishes, Resins paints, dyes, lacquers, cosmetics and soaps	Esters	Resins, Plastics, flavours, plasticizers, perfumes, lacquers solvents
Pentachlorophenol	Preservatives	Lindane	Preservatives of woods

Materials such as paints, carpets, polyvinyl chloride, wallpapers and items of room decoration also emit various types of VOCs (Meininghaus et al., 2000). According to Geng et al. (2008) benzene compounds found in solvents used for ornament painting evaporate into the indoor air. A study conducted by USEPA (2009) on IQA concluded that building materials, personal items, house decors, graphics and art materials, household products, office equipment are the main sources of VOCs. They consist of aromatic compounds, for instance toluene, benzene, dichlorobenzene, xylene and others (Sone et al., 2008). It should be noted here that most of the aromatic compounds are carcinogenetic and their exposure to even low quantity can cause severe health effects. VOCs are found everywhere in the air and humans are all the times exposed to them through smelling, eating and touching them consciously and unconsciously (Sone et al., 2008). VOCs emit in very high concentration usually at the rate of 50 $\mu g/m^3$ (Wang et al., 2007). However, for the household cleaning products, their emission rates fluctuate between 1.7×10^4 to 2.6×10^8 $\mu g/m^2/h$ and for construction coverings it ranges from $10 \mu g/m^2/h$ to $1.7 \times 10^7 \mu g/m^2/h$.

Sulphur dioxide (SO_2), one of the components of a gaseous group of sulfur oxides (SO_x), is a non-combustible, colorless, and non-explosive gas (Christoforou, 2007). Combustion of fossil fuel by power plants and other natural processes such as volcanoes eruptions and industrial processes like extraction of metals from ores and sources like locomotives, ships and heavy equipment that burn fuel with a sulfur content are the chief sources of SO_2 emission (USEPA, 2009). However, combustion of coal in power plants is commonly mentioned sources of SO_2 (Christoforou, 2007).

Ozone (O_3) is another indoor air pollutant if present above threshold concentrations for a specific environment. Out of the total inhaled ozone, 25 to 60% of ozone is inhaled indoors. Indoor ozone exposure is between 45 to 75% of the total exposures (Weschler, 2006). Not only ozone but its oxidation products are inhaled, and they are able to unpleasantly affect the health of living beings. Outdoor ozone concentrations highly affect the concentrations indoors because of its transport from outside sources. Even though, indoor ozone concentrations are usually low, but the exposure is long term hence, affect to human health is more. Similarly, the ozone reactive by-products produced indoors are more than outdoors. Ozone exposure can critically affect depending on the age groups exposed. Indoor ozone concentrations could be controlled by installing charcoal filters or filters with chemical impregnation. These filters can highly be productive in removing ozone from buildings. Similarly, installing efficient ventilation systems can always be helpful in decreasing not only ozone concentrations but also other such harmful compounds that are major players in affecting indoor air quality (Weschler, 2006).

Ozone is a gas that is found both at ground level and on the surface of the earth. In different types of chemical reactions which occur in the atmosphere, when atomic oxygen (O) combines with molecular oxygen (O_2) ozone (O_3) is formed. Ozone in the stratosphere protects the earth from ultraviolet rays (Christoforou, 2007). Ozone is directly produced by ozone generators like electrical powered air cleaning machine produced O_3 indirectly (USEPA, 2009).

Availability of chlorine (Cl_2) and its evaluation does play a role in indoor air quality. It can be present either as hydrogen chloride or chlorine. Presence of high concentrations of chlorine and short or long-term exposure of living beings to it can be problematic. Similarly, it is reactive with metals and hence, can affect the artifacts in an accommodation or indoor environment (Muller et al., 2005).

Relative humidity and temperature also play an important role in maintaining a suitable and healthy environment. Relative humidity is the fracture of water vapor at given temperature in the air. Relative humidity can differ in percentage depending upon the nature of the building. An average of less than or equal to 60% relative humidity per day can prevent or control the growth of mold; however, dust-mites can still grow (Angelon-Gaetz et al., 2015). It is important to have all these air quality parameters to stay within the threshold range to prevent any health complications. In a recent study, the average indoor temperature and relative humidity was resulted to be 22.1 °C and 38.29% (Irulegi et al., 2017). However, no comparisons were mentioned in the research article. Increased percentage of humidity indoors results in the microbial growth as well as discomfort among the occupants leading to sick building syndrome. Provision of efficient ventilation levels and maintaining humidity levels are two contradicting processes and achieving them is challenging specifically in regions with high temperature and humidity (Bayer et al., 2002). Mold growth in indoors is promoted by the damp and moist environment. Ventilation and dehumidification systems can prevent the mold growth by maintaining the humidity levels indoors (Fish, 2005).

Energy conservation and humidity control are two factors that are receiving much attention. Even though, these techniques are effective, they are creating indoor air quality problems posing threat to human health (Fu et al., 2017).

IAQ and Associated Health risks

IAQ is one of the emerging health issues worldwide. The severity of the issue is vivid through the fact that the citizens spend most of their time (almost 90%) in confined indoors such as homes, schools, offices, labs and workshops and others (Joshi, 2008). Such lifestyle increases the human exposure to certain chemicals and compounds found indoors. Various studies unveiled the relationship of cardiovascular and respiratory diseases with particulate matter (Curtis et al., 2006). Recent studies have also proved this correlation (Aizat, et al., 2009). One of the very common ailments associated with indoor air pollution, as named by the World Health Organization (WHO, 1983) is Sick Building Syndrome (SBS). SBS is felt by most of the people working in the offices. Symptoms of SBS include headache, fatigue, and irritation in nose, eye, throat and erythema (Fadilah and Juliana, 2012). With a view to confirm these symptoms a study was conducted upon 1736 office workers. 50% of the workers confirmed common symptoms of sick building syndrome like headache, tiredness and irritation. As per findings of the study 30% workers showed upper respiratory symptoms whereas 20% workers were showing lower respiratory symptoms (Lee et al., 2002). The risks of death increase when outdoor fine particulate particles speedily penetrate the indoor air. This happens in large industrial cities where outdoor air is more contaminated than that of the indoor air (USEPA, 2007).

Design of the buildings laid a significant effect on the indoor air quality. In 1996, US general accounts office stated that in the United State one out of every 5 school buildings faces problems of indoor air quality. The problems of indoor air quality are related with the building designs. The buildings are designed with a view to save energy and by doing so infrastructure is sacrificed (Muhamad-darus et al., 2011).

Carbon monoxide (CO) lays serious effects on human health. Humans' exposure to CO for continuous eight hours can cause death (Christoforou, 2007). Through blood circulation, hemoglobin carries oxygen to all body parts. But hemoglobin is more prone bind with CO than with oxygen (240:1). Human exposure to higher concentrations of CO forms carboxyhemoglobin (COHb) within five minutes may cause death (ALA, 2008). Patients of chronic cardiovascular and pulmonary diseases are more vulnerable to the increased supplies of CO (USEPA, 2009).

Oxides of nitrogen participate in different pathological and physiological processes such as inflammation, vasodilatation, malignant transformation and lung carcinogenesis (Chen et al., 2008). It has been proved through various studies that oxides of nitrogen cause damage to the respiratory tract and continuous exposure to low levels of these oxides leads to the lungs infection and high levels to emphysema (American Lung Association, 2008). Exposure of NO_2 even at minimum levels results into respiratory infections and at extremely high levels lung injury and pulmonary edema may occur (USEPA, 2009).

Hence, these were the primary indoor air pollutant VOCs extensively affect human health and if exposed for several hours VOCs can result into SBS (Geng et al., 2008). Nearly, all the VOCs affect negatively on occupant's health. The effects may include irritation in the throat, nose, and eyes, lowering the liver functions, dyspnea, rhinitis, allergies and in severe cases of central nervous system failure (Sone et al., 2008). Also, most of the VOCs are carcinogens, mutagens and teratogens (Meininghaus et al., 2000).

Another carcinogen is formaldehyde. It is harmful to asthmatics and causes cancer to humans. It also causes irritation to the eyes, nose, and throat, and if exposed even at a level of 1/10,000,000 parts cause dyspnea (USEPA, 2009) and congestion in respiratory tract, allergies and rhinitis (ALA, 2008).

Various pathological studies proved SO_2's harmful effects on different parts of the human body, particularly on the lungs (Christoforou, 2007). If exposed to SO_2 concentrations at a level of 6/1,000,000 mucous membrane severely causing bronchial blockage and for the asthmatics even very small exposures (4/10,000,000) can lead them to beyond the cure complications (USEPA, 2009).

Ozone causes eyes and lungs irritation. It may also cause asthma to younger persons (Christoforou, 2007).

Effects of IAQ on Office Occupants' Performance and Productivity

Apart from number of the health risks to the occupants of nonindustrial and commercial buildings, the impacts of poor IAQ have also affected occupants' performance and productivity. Numerous studies have proved this phenomenon (Antikainen, 2008). Wyon (2004), through an experimental study, justified the correlation between the performance of the workers and indoor air quality. Wyon, 2004 proved that ventilation is of utmost importance in creating a productive indoor environment. Ventilating air takes away the pollutants emitting from different indoor sources. Findings of his comparative study vividly showed that performance of workers in those office buildings where from sources of indoor air pollution such as computers, decoration pieces, floor coverings, equipment and Xerox copiers were removed was better as compared to those whose rooms contained these things (Wyon, 2004). Contrary to the experimental method used by Wyon (2004). Another study was conducted by the Berkeley national laboratory based onsurvey method. A self-administered questionnaire was used as a tool of data collection. The results of correlational analysis showed a strong positive correlation between workers' performance and indoor air quality. Following the same lines, Fisk and Seppanen (2006) proved in their study that improving indoor air quality productivity of the workers enhanced. Similarly, Bakó-Biró and Olesen (2005) concluded through their study that: People's performance is significantly associated with indoor air quality and vice versa. Performance and productivity of the people increase with higher rates of ventilation. Healthcare costs are reduced with improved indoor air quality (Bakó-Biró and Olesen, 2005).

Heating, Ventilation, and Air Conditioning (HVAC) system and Indoor Air Quality

Heating, Ventilating and Air Conditioning (HVAC) systems are used by the people worldwide (Lin and Chen, 2014). In general terms HVAC system consists of those equipment which are installed in apartments and buildings for cooling, heating, filtering the outdoor air as well as for controlling humidity to provide a comfortable environment in the building. But all the buildings are not necessarily provided with these systems, as most of the buildings are not using HVAC systems instead they rely on natural ventilation (CDC, 2014). On the other hand, natural ventilation does not suit to every building. For a ventilation system to work adequately, design of the building matters a lot. Reversal from ventilation to HVAC systems invites lot many issues. Such a conversion also proves to be costly (TSI, 2013). Therefore, the lay-out of the building should be such that it should provide maximum comfort and safety to the occupants. It should also be airy, bright and spacious enough for the occupants' activities (US Department of Energy, 2013). As for the HVAC systems, there are multiple factors or variables that must be considered before installing them. These factors include climate of the area, the time length of the plan, budget, building codes, building's utility plan, HVAC designers' and users' priorities and alterations (CDC, 2014). Installation of HVAC systems at buildings are diversified regarding their complexity. Usually large, well-lit modern office buildings require air conditioners and chillers to curtail the rise in temperature due to profuse lighting, crowded gatherings and equipment operation.

Figure 2 shows acceptable air quality. To make a building acceptable for all residents it should be at least meeting with the expectations of 80% residents. Normally to reduce infiltration of airborne particles from outdoor environment a filtration system is added. (ASHRAE 62.1, 2016)

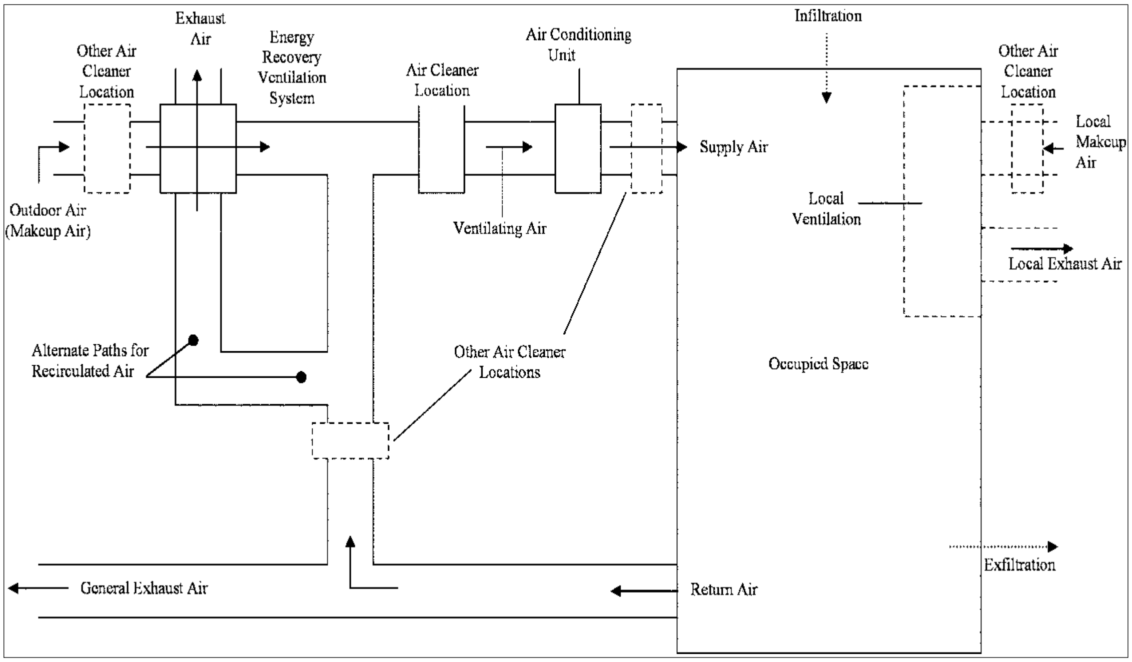


Figure 2. A typical illustration of standard HVAC system (ASHRAE, 2016)

Indoor climate and climate change are two interlinked processes and requires high level of attention from experts in both fields. Controlling indoor climate in highly advanced industrial sectors and in developing countries rely mainly on sustainable energy consumption technologies (Levin. 2008). These technologies might help in sustaining resources but also result in release of greenhouse gases.

Keeping in mind the climate change and related concerns, the influence of cooling systems cannot be overlooked. The energy consumption in buildings is approximately 60% due to ventilation and heating processes. Different experimental and theoretical models have been utilized to assess the indoor air quality and thermal stability. Computational fluid dynamics (CFD) and other experimental processes have been widely used in United

Kingdom (UK) to study indoor air quality (Jomehzadeh et al., 2017). Air flow and change rate, concentration of carbon dioxide, effectiveness of air change and mean air age are some of the parameters that were studied in previous researches to evaluate indoor air quality. These researches concluded that indoor air quality at satisfactory levels could be achieved by using wind catchers. Also, the use of wind catchers to obtain thermal comfort was mainly conducted in the Middle East where the climate is hot. A variety of cooling methods were exploited along with night ventilations (Jomehzadeh et al., 2017; Telejko, 2017).

Pollutant Minimization and Reduction Technologies

Besides conventional approaches (i.e. ventilation, source control and air cleaning) of air pollutant minimization, some modern approaches like air filtration, dehumidification and source isolation are becoming more and more popular. Controlling the source has always been difficult in multistoried buildings of a populous city. Moreover, variety of airborne pollutants rushes into the indoor through ventilation. Therefore, the only option left with occupants of the buildings is air cleaning. Among the conventional approaches, air cleaning has become most effective way to improve indoor air quality (Kumar and Kumar, 2007; Wang et al., 2007).

On the other hand, advanced oxidation has become most effective method of air purification, a modern approach. Advanced oxidation is a process through which air contaminants are oxidized to water and carbon dioxide. Thermal oxidation destruction and photocatalytic oxidation are the commonly used processes of advanced oxidation. (Wang et al., 2007).

Destruction of thermal oxidation occurs at extreme temperature ranging from 200 to 1200 ºC. Thermal oxidation destruction proves very costly and particularly when the concentrations of pollutants is very low. On the other hand, photocatalytic oxidation occurs at ordinary temperature and pressure conditions (Wang et al., 2007).

Moreover, photocatalytic Oxidation is a procedure to cure polluted air caused by bacteria and VOCs (Vincent et al., 2008). This technology, therefore, is more cost-effective technology to get rid of VOCs and bacteria from the environment than other technologies like thermal oxidation destruction (Wang et al., 2007).

Numerous researches have proved photocatalytic oxidation as a promising technology. These investigations have resulted into devising variety of photocatalyst systems (Wang et al., 2007).

Variety of photocatalytic reactors are already out in the market speaking of which are flat plate fluidized bed reactors, fixed layer photocatalytic reactors, annular photocatalytic reactors, photocatalytic reactors with fiber optic bundles, just to name a few (Vincent et al., 2008; Wang et al., 2007; Geng et al. 2008).

Ozone is strong oxidizing agent. Ozonation of the porous material results into the reduction VOCs in indoor air. In a catalytic reaction occurring in the porous structures, the residual ozone is also reduced. VOCs from the indoor air can also be controlled using activated carbons or zeolite solutions on the larger surface area of the porous material. In this way, absorption capacity of the porous materials increases (Kwong et al., 2008). Activated carbon, hence, is the best way of decreasing concentrations of indoor pollutants. On the other hand, under humid condition a mesoporous molecular sieve effectively adsorbs the present number of VOCs, as shown in Figure 3.

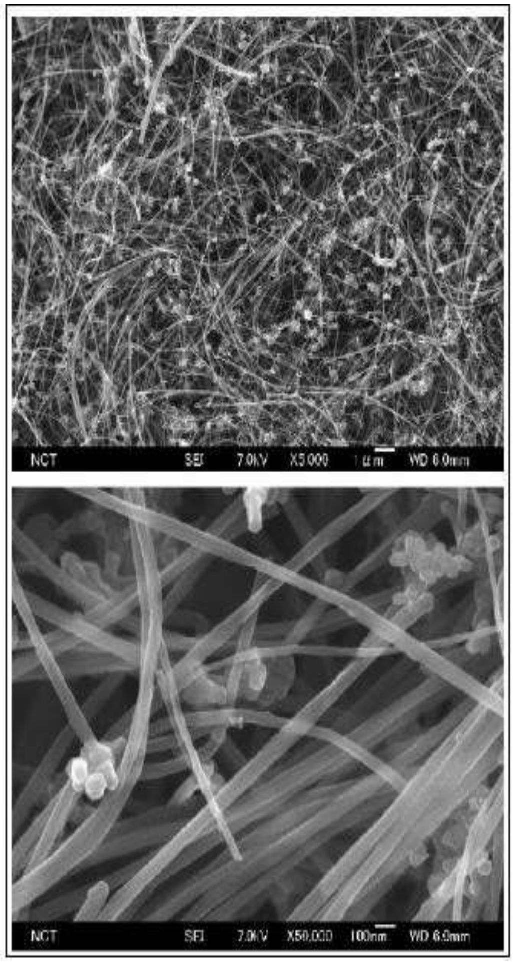


Figure 3. Characteristic of a microscopic image extremely crystallized multi-walled carbon nanotubes at low resolutions (top) and high resolutions (bottom) (Source: Sone et al., 2008)

Additionally, to develop techniques for eliminating VOCs from the indoor air, various efforts have been made during the past 30 years. Because of these efforts, a technique named carbon nanotubes was developed. Since these tubes were made of amorphous and crystalline carbon they have ability to effectively absorb pollutants (Sone et al. 2008). There are two types of carbon nanotubes; single-walled and multi-walled. Multi-walled carbon nanotube was the first one being launch to the market and then followed by single-walled carbon nanotubes. Standard Microscopic images of the multi-walled carbon nanotubes at low resolutions (top) and high resolutions (bottom) were displayed in Figure 3.

CHAPTER 3: MATERIALS AND METHOD

Description of the Study Area

The indoor air sample collection was carried out in Mesaieed city, one of the largest industrial areas in Al Wakrah Municipality in the state of Qatar, about 40 kilometers south of Doha. Mesaieed Industrial City (MIC) was established in 1949 as a tanker terminal by Qatar Petroleum. All the activities concentrated in the area constitute the core of Qatar's industry. Today, about 60% of Qatar's economy flows through Mesaieed city. MIC accommodates main industries like oil refinery, gas and petrochemical industries, fertilizer, vinyl, steel, aluminum lubricants plastic products, shipping, metals coating Formaldehyde Company, melamine, acids and others (Al-Kubaisi, 1984). Figure 4 illustrates the locations of the study in Mesaieed Industrial city (Google Map).

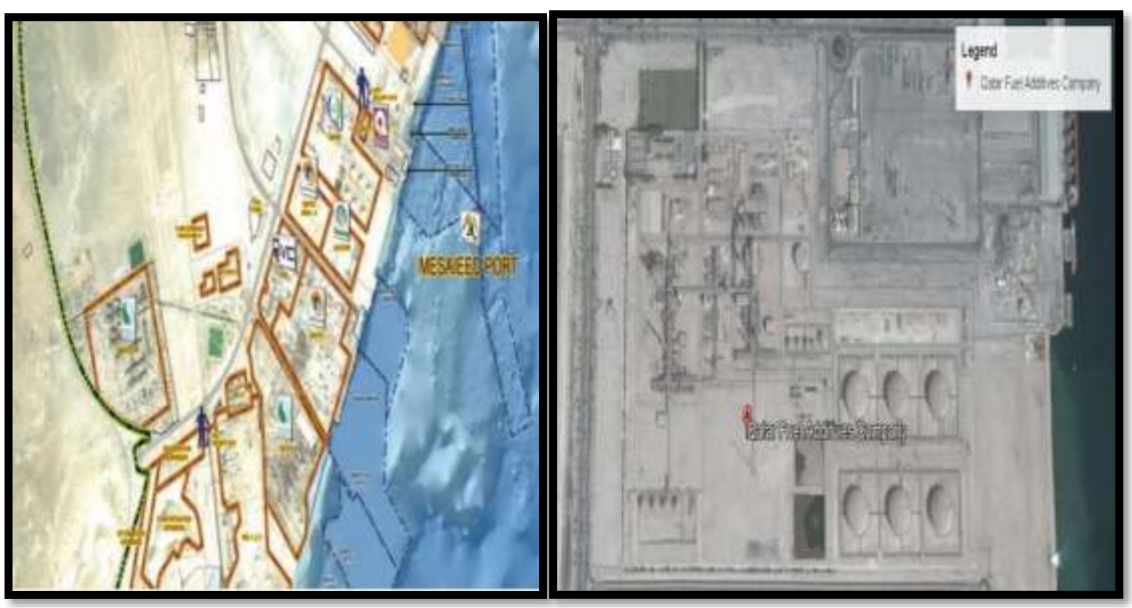


Figure 4. Location map of Mesaieed Industrial City (Google map on left and Google Earth map on right)

Qatar Fuel Additives Company Limited (QAFAC) plant was selected for investigating indoor air quality in this study. This plant is located in MIC on the southeast coast, approximately fifty kilometers south of Qatar's capital, Doha. Mesaieed Industrial city is the main locations for manufacturing industries in Qatar. It is having multiple downstream petrochemical and chemical plants, steel and aluminum plant, a refinery and fertilizers plant as well. (Al-Kubaisi, 1984)

The area of the study includes administration building, control room building, health, safety, security and environment building, chemical storage, laboratory and workshops inside QAFAC plant. QAFAC manufactures Methyl tertiary butyl Ether (MTBE) and Methanol. The current capacity of the plant is 1830 MTPD of MTBE and 3000 MTPD of Methanol (QAFAC, 2017). QAFAC methanol facilities are based on the Jacobs Engineering/ICI Katalco process, which is a well-proven methanol synthesis technology. The process is designed to use sweet gas supplied from QP's North Field gas plant as feedstock. The crude methanol is fed to intermediate storage and then to the distillation section for removal of light and heavy contaminant by-products. The resulting sales specification methanol passes to methanol product tanks and then partially used for the production of MTBE and remaining exported globally. QAFAC MTBE complex consists of the following integrated process units, all of which are licensed by Honeywell UOP. Deisobutanizer (DIB) is used for separation of isobutane, n-butane and heavier hydrocarbons. Butamer isomerisation ("conversion") unit for conversion of n-butane to isobutene, oleflex dehydrogenation for conversion of isobutane to isobutylene, continuous catalyst regeneration of oleflex catalyst, ethermax unit synthesis of MTBE from isobutylene and methanol, pressure swing adsorption (PSA) and hydrogen separation and purification unit.

Buildings inside complex are occupied by staff used to spend average 8 hours in the offices 5 days a week. Figure 5 shows a photograph of QAFAC plant in Mesaieed city.

Figure 5. QAFAC plant in Mesaieed

Measurement of Indoor Air Pollutants

A monitoring instrument called Gray Wolf Direct Sense-IAQ was used to measure the levels of indoor air pollutants. Each Probe (shown in figure 6) is fixed on main IAQ pack. These probes can measure 4-5 parameters. The Sensor installed in these probes requires Factory Calibration after 6-12 months. Details for calibration is mentioned in

Appendix A and B. Uncertainty factor, ranges from 1 to 5.85% for different parameter with operating temperature 0-50C^{o}. Three readings were taken at each location monthly once for three consecutive months. This instrument allows the researcher to determine and recognize any IAQ matter which may cause harm to the occupants. This portable device allows the users to perform any needed analysis for a particular area more easily. It is suitable not just for walk-through investigation but also for consistent long-term measurements, as it determines the accurate ratio/amount of the corresponding air components in such a way that it affords a pure picture of the IAQ status. Keeping reliability check equipment was sent for a factory calibration to the manufacturer facility in Ireland. Calibration certificates are available in Appendix A. Manufacturer has mentioned uncertainty factor, which ranges from 1 to 5.85% for different parameters and detail of each uncertainty factor is mentioned in Appendix B. A detailed IAQ management plan was prepared enlisting all buildings and offices inside plant as per Table 5. Limits mentioned in Table 6 were followed for data analysis.

Figure 6. Monitoring probes

Offices were chosen randomly considering the diversity of Heating, Ventilating and Air-Conditioning (HVAC) system present in buildings. One indoor air quality monitoring equipment (Gray Wolf's modular Wolf Pack Area Monitor interfaces with multiple DirectSense probes/sensors) was placed inside of select offices for 8 hours (shown in Figure 6).

Data logging lapse time was set with five minutes time interval. Data was logged for parameters, such as CO_2, CO, Ozone, temperature, relative humidity, dew point and others. After logging, data was downloaded, and analysis of readings was recorded.
Gray Wolf IAQ kits include an Advanced Sense meter (or mobile computer), plus multi-sensor indoor air quality probe.

Table 4

Details of Building, Number of Locations, Room Details and Duration (hrs.) for Monitoring Indoor Air Quality

Serial Number	Building	Room Details	No. of Locations	Duration	Specific Location
1	Administration Building Ground floor	Guest/Reception room-Room1 Office 118 (Admin GF)- Room 2 Office 209- Room 3	3	8 Hours	One office selected randomly in similar HVAC system
2	Control Room	MTBE Shift Engineer Office- Room 4 Production Engineer Office Room 5 Control Room Office 110 (CB)- Room 6	3	8 Hours	Main Control room
3	Laboratory	Laboratory 1- Room 7 Laboratory 2- Room 8	2	8 Hours	Product analysis lab
4	Fabrication workshop	Workshop 1- Room 9 Workshop 2- Room 10	2	8 Hours	Main welding, fabrication area
5	Chemical storage (warehouse)	Chemical Storage Room 11	1	8 Hours	Main chemical storage area

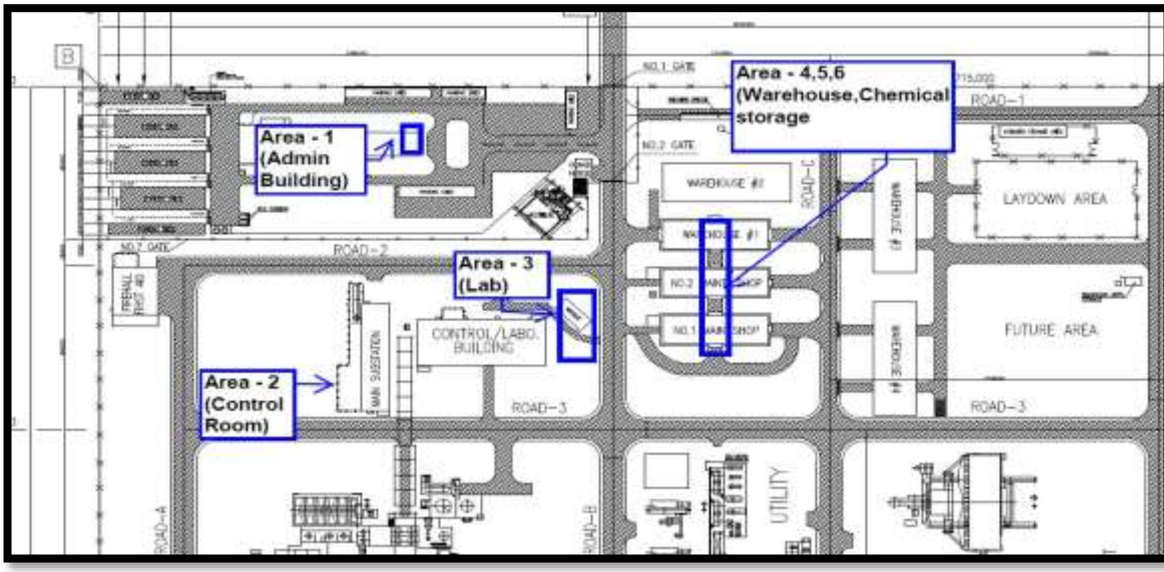


Figure 7. Monitoring locations (11 Locations in 5 Buildings)

Table 5

IAQ Parameters and the Reference Standard Limits

Serial Number	Parameter	Permissible Exposure limits	Reference Standard
1	Temperature	19 – 27oC	ASHRAE
2	Relative Humidity	30 - 60%	ASHRAE
3	Ozone	0.1 ppm	OSHA CFR 29
4	Hydrogen Sulfide	10 ppm	ACGIH
5	Hydrochloride	5 ppm	OSHA CFR 29
6	Ethylene Oxide	1 ppm	OSHA CFR 29
7	Hydrogen Cyanide	10 ppm	OSHA CFR 29
8	Fluorine	0.1 ppm	OSHA CFR 29
9	Carbon monoxide	500 ppm * (8 hrs.)	OSHA CFR 29
10	Carbon dioxide	1000 ppm	OSHA CFR 29
11	TVOC	0.22 mg/ m3	OSHA CFR 29
12	Oxygen	19.5 – 25 %	NIOSH
13	Ammonia	50 mg/m3	OSHA CFR 29
14	Nitrogen Dioxide		WHO
15	Nitric Oxide	25 ppm	OSHA CFR 29
16	Chlorine	1 ppm	OSHA CFR 29
17	Sulfur Dioxide	5 ppm	OSHA

Figure 8. Indoor air quality monitoring equipment installation

Table: 6 shows a general ambience, size and details of each room which includes furniture, type of equipment available in vicinity and average number of occupants. Visitors/occupants used to spend average eight hours in the offices five days a week except reception area where visitor used to spend from few minutes to one hour maximum.

Table 6

Room Description Selected for Monitoring of Indoor Air Quality; Room Size, Number of Occupants, Construction Material, Furniture and Equipment

Serial No.	Room Description	Room Size	No of Occupants (Person)	Construction material	Furniture & Equipment
1	Guest/Reception Room 1	3M x 4M	Average 3	Marble tiles, paint & gypsum flooring	Two sitting Sofa, One LED & CPU
2	Office 118 (Admin GF)-Room 2	3M x 4M	Average 1	Wall-to-wall carpet, paint for walls, and gypsum ceiling	3 Chairs & one work station, two LED
3	Office 209-Room 3	3M x 4M	Average 1	Marble tiles wall-to-wall carpet, paint, gypsum ceiling	3 chairs, one Work Station table, 2 file cabinets.
4	MTBE Shift Engineer Office-Room 4	5Mx4.5M.	2 Persons	Marble tile & gypsum flooring	3 chairs, one work station, One LED & CPU
5	Production Engineer Office-Room 5	4Mx5M	3 Persons	Wall-to-wall carpet, gypsum ceiling	6 Chairs, 3 work station, All in one LED
6	Control Room	3Mx4.5M	1 Person	Wall-to-wall	One LED, One

	Office 110 (CB)- Room 6			carpet, gypsum ceiling	work station, 2 cabinets
7	Laboratory 1 Room 7	6Mx 4M	2-3 Person	Vinyl flooring, Chemical extraction Hood, and gypsum ceiling	Central Work Station table, wall mounted racks for storing
8	Laboratory 2 Room 8	6Mx5M	3 Persons	Marble tiles for flooring, wall-to-wall carpet, painted walls	3 chairs, one Work Station table, 2 file cabinets & analyzers, Two LED & Tower CPU
9	Workshop 1- Room 9	3M x 4M	2 Persons	Marble tiles for flooring,	one LED, one Tower CPU, one printer and scanner
10	Workshop 2- Room 2	4.5Mx2.6M	8-10 Persons	Concrete flooring & metal roof	10 chairs, benches, tool cabinets, Two LED&CPU
11	Chemical Storage -Room 11	15Mx12M	No permanent occupancy	Concrete flooring & fixed metal roof	2 chairs,

Data Analysis

Selected Locations were monitored for average 8 hours and with standard deviation (SD), 95% confidence interval (CI), minimum and maximum of measured data was calculated for entire locations. for 17 parameters selected for indoor air quality monitoring. This data was compared with international standard values mentioned in Table 5. Also, correlation tests performed to check possible correlation between parameters. The statistical software program was used to analyze the collected data. These results were displayed in tabular as well as graphically forms to show the comparison and fluctuations in values in the studied buildings. SPSS (Statistical Package for Social Sciences) Version 22 was used to analyze the collected data. The results were displayed graphically to find the relationships between different data.

CHAPTER 4: RESULTS

The data collected and analyzed relative to the indoor air quality of eleven office buildings in QAFAC building complex are shown in Tables 7-17 for rooms 1-11.

Table 7

Parameters Analysis (Mean, Max & Min) in Room 1 Guest/Reception Room Compared with Permissible Exposure Limit

Sr #	Parameters	Mean Value	At 95%CL		S.D.	Permissible Exposure Limit*	Safe Range?
			Max	Min			
01	RH	45.76	42.7	49.1	3.2	30 - 60%	Yes
02	Temp.	25.83	27.1	23.8	1.8	20 -27^{o}C	Yes
03	CO	ND	ND	ND	ND	<50 ppm (8 hours)	Yes
04	CO_2	450	466	420	25.7	<1000 ppm	Yes
05	SO_2	1.1	1.8	1.5	0.9	<5 ppm (8 hours)	Yes
06	NO_2	0.02	0.03	ND	0.01	<5 ppm (8 hours)	Yes
07	NO	0.07	0.20	ND	ND	<25 ppm	Yes
08	Cl_2	ND	ND	ND	ND	<1 ppm	Yes
09	HCN	ND	ND	ND	ND	<10 ppm	Yes
10	NH_3	ND	ND	ND	ND	<50 ppm	Yes
11	F_2	ND	ND	ND	ND	<0.1 ppm	Yes
12	O_3	ND	ND	ND	ND	<1 ppm	Yes
13	EtO(C_2H_4O)	0.56	1.6	ND	ND	<1 ppm	Yes
14	HCl	ND	ND	ND	ND	<1 ppm	Yes
15	H_2S	0.030	0.09	ND	0.51	<1 ppm	Yes
16	TVOCs	0.174	0.20	0.099	0.010	<0.22 mg/m^3	Yes
17	O_2	20.6	20.7	20.5	0.10	19.5 -23.5%	Yes

ND : Not Detectable

All the parameters of IAQ, as shown in Table 7, are in safe range. The concentrations of CO, Cl_2, HCN, NH_3, F_2, O_3 and HCl were below the detection limit of the instrument; therefore, the readings were not recorded.

Table 8

Parameters Analysis (Mean, Max and Min) in Room 2 Office 118 (Admin GF) Compared with Permissible Exposure Limits.

Sr #	Parameters	Mean Value	At 95%CL		S.D.	Permissible Exposure Limit*	Safe Range?
			Max	Min			
01	RH	53.8	58.7	47.1	5.9	30 - 60%	Yes
02	Temp.	25.8	22.8	22.2	1.8	20 -27^{o}C	Yes
03	CO	ND	ND	ND	ND	<50 ppm (8 hours)	Yes
04	CO_2	432	459	406	26	<1000 ppm	Yes
05	SO_2	1.4	2.5	1.7	1.2	<5 ppm (8 hours)	Yes
06	NO_2	0.027	0.07	ND	0.01	<5 ppm (8 hours)	Yes
07	NO	ND	ND	ND	ND	<25 ppm	Yes
08	Cl_2	ND	ND	ND	ND	<1 ppm	Yes
09	HCN	ND	ND	ND	ND	<10 ppm	Yes
10	NH_3	ND	ND	ND	ND	<50 ppm	Yes
11	F_2	ND	ND	ND	ND	<0.1 ppm	Yes
12	O_3	ND	ND	ND	ND	<1 ppm	Yes
13	EtO(C_2H_4O)	0.20	0.80	ND	0.04	<1 ppm	Yes
14	HCl	ND	ND	ND	ND	<1 ppm	Yes
15	H_2S	0.08	0.10	0.07	0.01	<1 ppm	Yes
16	TVOCs	0.136	0.171	0.112	0.030	<0.22 mg/m^3	Yes
17	O_2	20.6	20.6	20.5	0.05	19 -23.5%	Yes

All the parameters of IAQ, as shown in Table 8, are in safe range. However, CO, Cl_2, HCN, NH_3, F_2, O3 and HCl are non-existent in this room.

Table 9

Parameters Analysis (Mean, Max and Min) in Room 3 Office 209 Compared with Permissible Exposure Limit

Sr #	Parameters	Mean Value	At 95%CL		S.D.	Permissible Exposure Limit*	Safe Range?
			Max	Min			
01	RH	60	64.6	57.6	3.6	30 - 60%	Yes
02	Temp.	22.6	24.2	20.1	0.3	20^o -27^oC	Yes
03	CO	ND	ND	ND	ND	<50 ppm (8 hours)	Yes
04	CO_2	384	421	359	32	<1000 ppm	Yes
05	SO_2	0.9	1.8	0.1	0.09	<5 ppm (8 hours)	Yes
06	NO_2	0.03	0.04	0.01	ND	<5 ppm (8 hours)	Yes
07	NO	ND	ND	ND	ND	<25 ppm	Yes
08	Cl_2	ND	ND	ND	ND	<1 ppm	Yes
09	HCN	ND	ND	ND	ND	<10 ppm	Yes
10	NH_3	ND	ND	ND	ND	<50 ppm	Yes
11	F_2	ND	ND	ND	ND	<0.1 ppm	Yes
12	O_3	ND	ND	ND	ND	<1 ppm	Yes
13	EtO(C_2H_4O)	0.20	0.40	ND	0.02	<1 ppm	Yes
14	HCl	ND	ND	ND	ND	<1 ppm	Yes
15	H_2S	ND	ND	ND	ND	<1 ppm	Yes
16	TVOCs	0.105	0.21	0.097	0.01	<0.22 mg/m^3	Yes
17	O_2	20.6	20.6	20.6	ND	19.5 -23.5%	Yes

All the parameters of Indoor Air Quality (IAQ), as shown in Table 9, are in safe range. However, CO, Cl_2, HCN, NH_3, F_2, O_3, H_2S and HCl are non-existent in this room.

Table 10

Parameters Analysis (Mean, Max and Min) in Room 4 MTBE Shift Engineer Office Compared with Permissible Exposure Limit

Sr #	Parameters	Mean Value	At 95%CL		S.D.	Permissible Exposure Limit*	Safe Range?
			Max	Min			
1	RH	49.4	50.1	46.9	0.6	30 - 60%	Yes
02	Temp.	21.5	24.4	23	2.2	20^o -27^oC	Yes
03	CO	ND	ND	ND	ND	<50 ppm (8 hours)	Yes
04	CO_2	518	533	509	0.76	<1000 ppm	Yes
05	SO_2	0.083	1.70	0.03	0.05	<5 ppm (8 hours)	Yes
06	NO_2	ND	ND	ND	ND	<5 ppm (8 hours)	Yes
07	NO	ND	ND	ND	ND	<25 ppm	Yes
08	Cl_2	ND	ND	ND	ND	<1 ppm	Yes
09	HCN	ND	ND	ND	ND	<10 ppm	Yes
10	NH_3	ND	ND	ND	ND	<50 ppm	Yes
11	F_2	ND	ND	ND	ND	<0.1 ppm	Yes
12	O_3	ND	ND	ND	ND	<1 ppm	Yes
13	EtO(C_2H_4O)	0.03	0.10	ND	0.05	<1 ppm	Yes
14	HCl	ND	ND	ND	ND	<1 ppm	Yes
15	H_2S	0.08	0.15	0.03	0.06	<1 ppm	Yes
16	TVOCs	0.18	0.21	0.167	0.05	<0.22 mg/m³	Yes
17	O_2	20.56	20.6	20.5	.057	19.5 -23.5%	Yes

All the parameters of Indoor Air Quality (IAQ), as shown in Table 10, are in safe range in control room main building (Room4*)* However CO, Cl_2, HCH, NH_3, F_2, O3 and HCl are non-existent in this room.

Table 11

Parameters Analysis (Mean, Max and Min) in Room 5 Production Engineer Office Compared with Permissible Exposure Limit

Sr #	Parameters	Mean Value	At 95%CL Max	At 95%CL Min	S.D.	Permissible Exposure Limit*	Safe Range?
01	RH	50.5	47.7	52.4	2.4	30 - 60%	Yes
02	Temp.	23.9	24.7	22.1	0.8	20^o -27^oC	Yes
03	CO	ND	ND	ND	ND	<50 ppm (8 hours)	Yes
04	CO_2	543	548	529	5	<1000 ppm	Yes
05	SO_2	0.97	1.60	0.40	0.06	<5 ppm (8 hours)	Yes
06	NO_2	0.02	0.14	0.04	ND	<5 ppm (8 hours)	Yes
07	NO	ND	ND	ND	ND	<25 ppm	Yes
08	Cl_2	ND	ND	ND	ND	<1 ppm	Yes
09	HCN	ND	ND	ND	ND	<10 ppm	Yes
10	NH_3	ND	ND	ND	ND	<50 ppm	Yes
11	F_2	ND	ND	ND	ND	<0.1 ppm	Yes
12	O_3	ND	ND	ND	ND	<1 ppm	Yes
13	EtO(C_2H_4O)	0.16	0.50	ND	0.02	<1 ppm	Yes
14	HCl	ND	ND	ND	ND	<1 ppm	Yes
15	H_2S	0.04	0.06	ND	0.03	<1 ppm	Yes
16	TVOCs	0.195	0.20	0.193	0.052	<0.22 mg/m³	Yes
17	O_2	20.60	20.6	20.6	ND	19.5 -23.5%	Yes

All the parameters of IAQ, as shown in Table 11, are in safe range. However, CO), Cl_2, HCH, NH_3, F_2, O_3 and HCl are non-existent in this room.

Table 12

Parameters Analysis (Mean, Max and Min) in Room 6 Control Room Main Building (Office 110 (CB GF) Compared with Permissible Exposure Limit

Sr #	Parameters	Mean Value	At 95%CL		S.D.	Permissible Exposure Limit*	Safe Range?
			Max	Min			
01	RH	54.7	55.0	54.3	0.3	30 - 60%	Yes
02	Temp.	30.5	32.7	20.8	12.3	20 -27^{o}C	No
03	CO	ND	ND	ND	ND	<50 ppm (8 hours)	Yes
04	CO_2	526	567	491	38.35	<1000 ppm	Yes
05	SO_2	1.20	1.70	0.60	0.55	<5 ppm (8 hours)	Yes
06	NO_2	ND	ND	ND	ND	<5 ppm (8 hours)	Yes
07	NO	ND	ND	ND	ND	<25 ppm	Yes
08	Cl_2	ND	ND	ND	ND	<1 ppm	Yes
09	HCN	ND	ND	ND	ND	<10 ppm	Yes
10	NH_3	ND	ND	ND	ND	<50 ppm	Yes
11	F_2	ND	ND	ND	ND	<0.1 ppm	Yes
12	O_3	ND	ND	ND	ND	<1 ppm	Yes
13	EtO(C_2H_4O)	0.10	0.30	ND	0.01	<1 ppm	Yes
14	HCl	ND	ND	ND	ND	<1 ppm	Yes
15	H_2S	0.06	0.09	0.04	0.02	<1 ppm	Yes
16	TVOCs	0.16	0.21	0.07	0.05	<0.22 mg/m^3	Yes
17	O_2	20.53	20.6	20.5	0.05	19.5 -23.5%	Yes

All the parameters of IAQ, as shown in Table 12, are in safe range except temperature which is a bit higher than the upper sealing i.e.27°C. However, CO, Cl2, HCH, NH_3, F_2, O_3 and HCl are as usual non-existent in this room.

Table 13

Parameters Analysis (Mean, Max and Min) in Room 7 Laboratory 1Compared with Permissible Exposure Limit.

Sr #	Parameters	Mean Value	At 95%CL Max	At 95%CL Min	S.D.	Permissible Exposure Limit*	Safe Range?
01	RH	45.9	47.5	45.1	1.3	30 - 60%	Yes
02	Temp.	22.7	27.3	27.0	0.05	20 -27°C	Yes
03	CO	1.20	2	1.6	0.05	<50 ppm (8 hours)	Yes
04	CO_2	413	418	404	8	<1000 ppm	Yes
05	SO_2	1.50	2.30	0.60	0.08	<5 ppm (8 hours)	Yes
06	NO_2	0.55	1.60	ND	0.09	<5 ppm (8 hours)	Yes
07	NO	ND	ND	ND	ND	<25 ppm	Yes
08	Cl_2	ND	ND	ND	ND	<1 ppm	Yes
09	HCN	ND	ND	ND	ND	<10 ppm	Yes
10	NH_3	ND	ND	ND	ND	<50 ppm	Yes
11	F_2	ND	ND	ND	ND	<0.1 ppm	Yes
12	O_3	ND	ND	ND	ND	<1 ppm	Yes
13	EtO(C_2H_4O)	0.06	0.10	ND	0.05	<1 ppm	Yes
14	HCl	0.06	0.02	ND	0.11	<1 ppm	Yes
15	H_2S	0.12	0.17	0.09	0.04	<1 ppm	Yes
16	TVOCs	0.21	0.22	0.20	0.011	<0.22 mg/m³	Yes
17	O_2	20.5	20.6	20.5	.05	19.5 -23.5%	Yes

All the parameters of Indoor Air Quality (IAQ), as shown in Table 13, are safe. However, CO, Cl2, HCH, NH3, F2, O3 and HCl are non-existent in this room.

Table 14

Parameters Analysis (Mean, Max and Min) in Room 8 Laboratory 2 Compared with Permissible Exposure Limit

Sr #	Parameters	Mean Value	At 95%CL		S.D.	Permissible Exposure Limit*	Safe Range?
			Max	Min			
01	RH	48.96	53	43.6	4.8	30 - 60%	Yes
02	Temp.	27.20	27.5	27.2	0.173	20 -27^{o}C	No
03	CO	ND	ND	ND	ND	<50 ppm (8 hours)	Yes
04	CO_2	304	408	100	17	<1000 ppm	Yes
05	SO_2	1.46	2.20	0.4	0.94	<5 ppm (8 hours)	Yes
06	NO_2	0.006	0.02	ND	0.01	<5 ppm (8 hours)	Yes
07	NO	ND	ND	ND	ND	<25 ppm	Yes
08	Cl_2	ND	ND	ND	ND	<1 ppm	Yes
09	HCN	ND	ND	ND	ND	<10 ppm	Yes
10	NH_3	ND	ND	ND	ND	<50 ppm	Yes
11	F_2	ND	ND	ND	ND	<0.1 ppm	Yes
12	O_3	ND	ND	ND	ND	<1 ppm	Yes
13	EtO(C_2H_4O)	0.03	0.1	ND	0.05	<1 ppm	Yes
14	HCl	ND	ND	ND	ND	<1 ppm	Yes
15	H_2S	0.07	0.11	0.03	0.04	<1 ppm	Yes
16	TVOCs	0.22	0.241	0.193	0.025	<0.22 mg/m^3	Yes
17	O_2	20.5	20.6	20.5	0.05	19.5%-23.5%	Yes

All the parameters of IAQ, as shown in Table 14, are in safe range except temperature which is a bit higher than the upper sealing i.e.27°C.However, CO, Cl_2, HCH, NH_3, F_2, O_3 and HCl are non-existent in this room.

Table 15

Parameters Analysis (Mean, Max and Min) in Room 9 Workshop 1 Compared with Permissible Exposure Limit

Sr #	Parameters	Mean Value	At 95%CL		S.D.	Permissible Exposure Limit*	Safe Range?
			Max	Min			
01	RH	56.6	60.1	52.4	3.8	30 - 60%	Yes
02	Temp.	24.06	25.9	22.3	0.057	20 -27°C	Yes
03	CO	ND	ND	ND	ND	<50 ppm (8 hours)	Yes
04	CO_2	485	493	476	8.73	<1000 ppm	Yes
05	SO_2	0.70	1.2	ND	0.06	<5 ppm (8 hours)	Yes
06	NO_2	0.003	0.01	ND	ND	<5 ppm (8 hours)	Yes
07	NO	ND	ND	ND	ND	<25 ppm	Yes
08	Cl_2	ND	ND	ND	ND	<1 ppm	Yes
09	HCN	ND	ND	ND	ND	<10 ppm	Yes
10	NH_3	ND	ND	ND	ND	<50 ppm	Yes
11	F_2	ND	ND	ND	ND	<0.1 ppm	Yes
12	O_3	ND	ND	ND	ND	<1 ppm	Yes
13	EtO(C_2H_4O)	ND	ND	ND	ND	<1 ppm	Yes
14	HCl	ND	ND	ND	ND	<1 ppm	Yes
15	H_2S	0.03	0.06	0.01	0.02	<1 ppm	Yes
16	TVOCs	0.17	0.207	0.147	0.03	<0.22 mg/m³	Yes
17	O_2	20.5	20.6	20.5	0.057	19.5 -23.5%	Yes

All the parameters of IAQ, as shown in Table 15, are in safe range in Workshop 1(Room 9). However, CO), Cl_2, HCH), NH_3, F_2, O_3, and HCl are non-existent in this room.

Table 16

Parameters Analysis (Mean, Max and Min) in Room 10 Workshop 2 Compared with Permissible Exposure Limit

Sr #	Parameters	Mean Value	At 95%CL		S.D.	Permissible Exposure Limit*	Safe Range?
			Max	Min			
01	RH	52.50	55.6	47.4	4.45	30 - 60%	Yes
02	Temp.	24.4333	23.5	22.3	1.89	20 -27°C	Yes
03	CO	ND	ND	ND	ND	<50 ppm (8 hours)	Yes
04	CO_2	500	533	479	29	<1000 ppm	Yes
05	SO_2	1.00	1.90	ND	0.09	<5 ppm (8 hours)	Yes
06	NO_2	0.003	0.01	ND	0.005	<5 ppm (8 hours)	Yes
07	NO	ND	ND	ND	ND	<25 ppm	Yes
08	Cl_2	ND	ND	ND	ND	<1 ppm	Yes
09	HCN	ND	ND	ND	ND	<10 ppm	Yes
10	NH_3	ND	ND	ND	ND	<50 ppm	Yes
11	F_2	ND	ND	ND	ND	<0.1 ppm	Yes
12	O_3	ND	ND	ND	ND	<1 ppm	Yes
13	EtO(C_2H_4O)	ND	ND	ND	ND	<1 ppm	Yes
14	HCl	ND	ND	ND	ND	<1 ppm	Yes
15	H_2S	0.08	0.11	0.04	0.04	<1 ppm	Yes
16	TVOCs	0.127	0.143	0.111	0.16^3	<0.22 mg/m³	Yes
17	O_2	20.53	20.6	20.5	0.06	19.5 -23.5%	Yes

All the parameters of IAQ, as shown in Table 16, are in safe range. However, CO, Cl_2, HCH, NH_3, F_2, O_3, EtO and HCl are non-existent in this room.

Table 17

Parameters Analysis (Mean, Max and Min) in Room 11 Chemical Storage 1 compared with Permissible Exposure Limit

Sr #	Parameters	Mean Value	At 95%CL Max	At 95%CL Min	S.D.	Permissible Exposure Limit*	Safe Range?
01	RH	52.5	47.2	38.2	4.4	30 - 60%	Yes
02	Temp.	24.4	25.5	22.6	1.5	20 -27^{o}C	Yes
03	CO	ND	ND	ND	ND	<50 ppm (8 hours)	Yes
04	CO_2	459	531	411	6.3	<1000 ppm	Yes
05	SO_2	0.96	1.6	ND	0.08	<5 ppm (8 hours)	Yes
06	NO_2	ND	ND	ND	ND	<5 ppm (8 hours)	Yes
07	NO	ND	ND	ND	ND	<25 ppm	Yes
08	Cl_2	ND	ND	ND	ND	<1 ppm	Yes
09	HCN	ND	ND	ND	ND	<10 ppm	Yes
10	NH_3	ND	ND	ND	ND	<50 ppm	Yes
11	F_2	ND	ND	ND	ND	<0.1 ppm	Yes
12	O_3	ND	ND	ND	ND	<1 ppm	Yes
13	EtO(C_2H_4O)	0.06	0.2	ND	0.11	<1 ppm	Yes
14	HCl	ND	ND	ND	ND	<1 ppm	Yes
15	H_2S	0.07	0.09	0.06	0.01	<1 ppm	Yes
16	TVOCs	0.165	0.188	0.14	0.025m^3	<0.22 mg/m^3	Yes
17	O_2	20.5	20.6	20.5	0.05	19.5 -23.5%	Yes

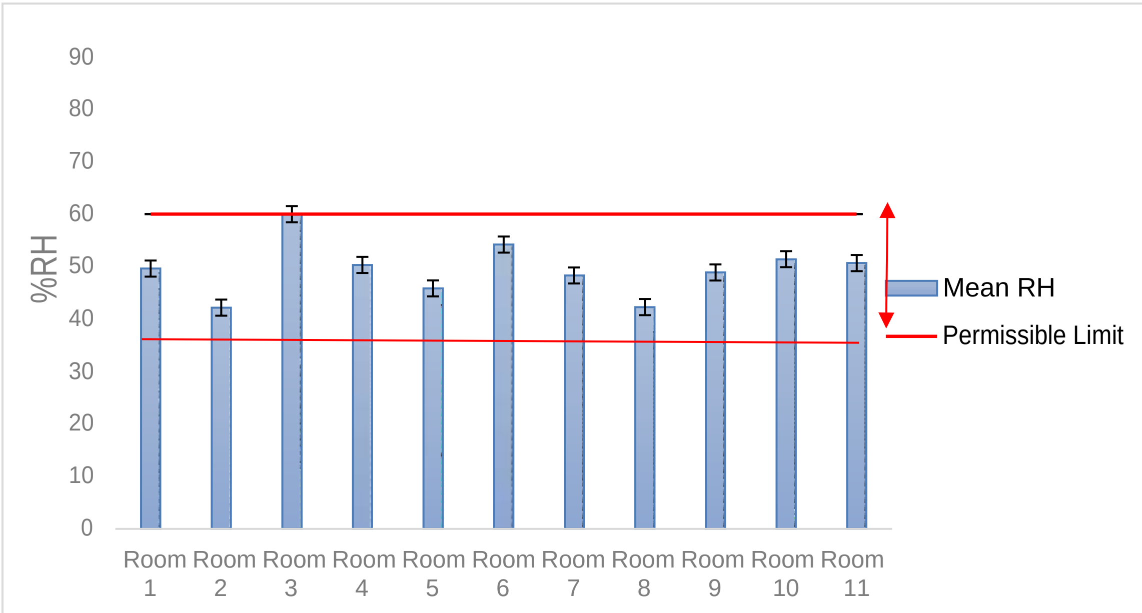
All the parameters of Indoor Air Quality (IAQ), as shown in Table 17, are safe. However, CO, Cl_2, HCH, NH_3, F_2, O_3 and HCl are non-existent in this room.

CHAPTER: 5 DISCUSSIONS

Following eight parameters were found to be active in the sampling sites.

1. Relative Humidity
2. Temperature
3. Carbon Dioxide (CO_2)
4. Sulphur Dioxide (SO_2)
5. Ethylene Oxide (EtO)
6. Hydrogen Sulfide (H_2S)
7. Total Volatile Organic Compounds(TVOCs)
8. Oxygen (O_2)

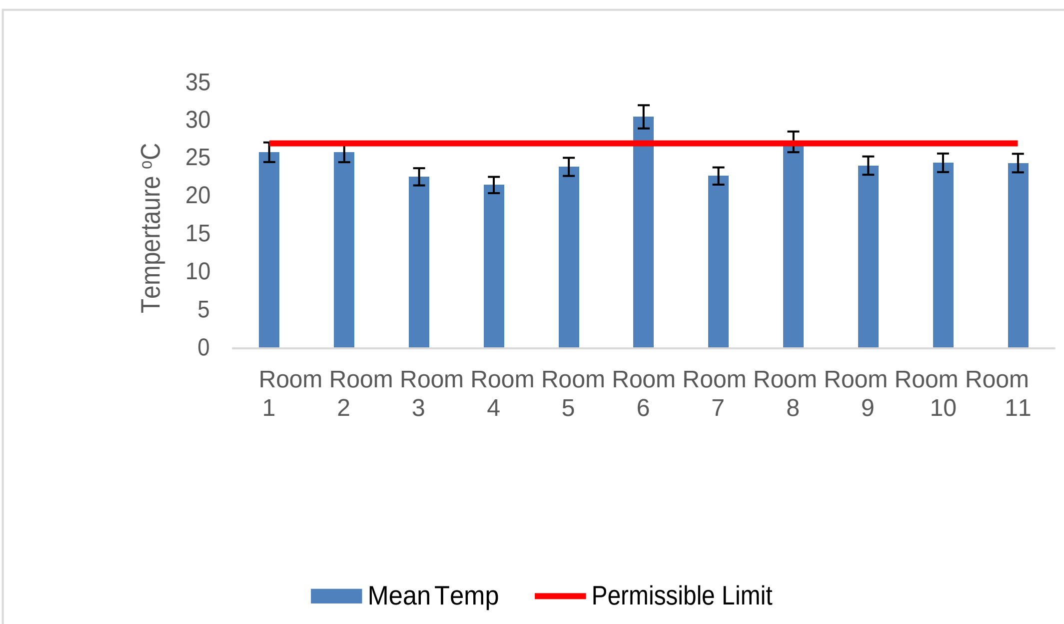
However, the remaining nine parameters were not detected by the equipment most probably because of their least concentrations:



Graph 1. Mean RH on 11 monitoring locations compared with permissible limits (red)

The mean relative humidity (RH) in the offices, as shown in Graph 1, was below the upper permissible range as recommended by ASHRAE (2016) that is 30 to 60%. Another experiment conducted by Stankevica and Lesinkis (2011) in laboratory rooms showed the relative humidity levels below 40%, but during the classes a considerable rise in relative humidity was recorded. These values, however, did not exceed the maximum allowable levels for thermal comfort recommended by the International Organization for Standardization in 2015 (Telejko, 2017). Similarly, an experiment performed to monitor the indoor air pollution inside office buildings of China in 2013 illustrated relative humidity ranging from 62% to 78% (Rong et al., 2013). Therefore, this humidity range is also within the permissible range recommended by USOSHA (CFR 29) but they are higher as per recommendation given by ASHRAE (2016). In a study by Stankevica and Lesinkis (2011) showed that average relative humidity of six daycare centers was 40 ± 5% and the levels did not vary to a great extent during the day. All the facilities had relative humidity within the range of 30 to 60%, as recommended by ASHRAE standard (Stankevica and Lesinkis, 2011).

Indoor Air Quality and Temperature

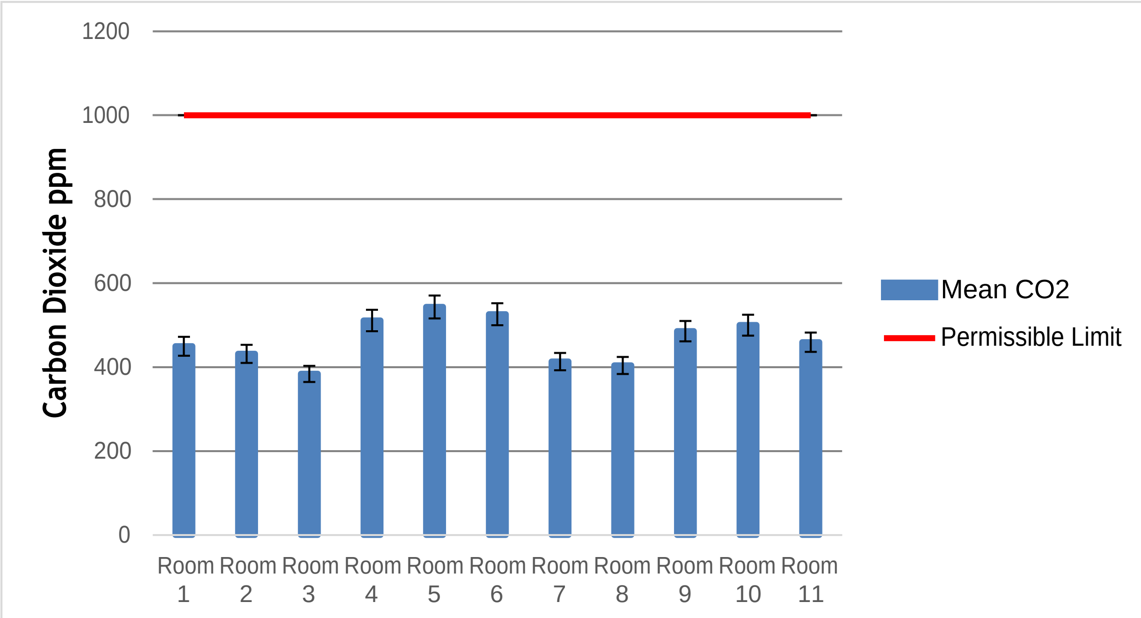


Graph 2. Mean Temperature readings on 11 monitoring locations compared with permissible limit (red)

The mean temperatures in Room 6 and 8, as shown in Graph, are above the upper extreme of the permissible range as recommended by OSHA (CFR 29) i.e.20 -27^{o}C. When investigated it was found that increase in temperature in control room is due to operations of certain equipment's that can operate only on recommended temperature levels, so it cannot be reduced to bring at permissible levels. While in Lab room a slight variation found above the upper limit because of chemical use. It is recommended to improve ventilation system of lab by installation of local ventilation device that is designed to reduce the exposure of fumes and vapors those are possibly increasing the VOCs and temperature in the lab. The installation of engineering control prescribed in OSHA's laboratory standards 29CFR, 1910.1450.

However, in other rooms it is within the prescribed range (Also see Table 5). A recently published report stated that the temperature of laboratory rooms in a school fluctuated between 20 and 29.6^{o}C, which are all within the range recommended by International Organization for Standardization (Telejko, 2017).

The temperature of offices in China was recorded at 23 C^{o}- 29.5 C^{o} (Rong et al., 2013). Therefore, in this experiment, the maximum temperature exceeded the permissible range recommended by OSHA (CFR 29). In another study conducted the temperatures recorded in all rooms exceeded the optimal values for thermal comfort. The maximum temperature, 29.6°C, was recorded on a sunny day in laboratory HS1 which has windows facing south. Maximum temperatures recorded in the other rooms ranged from 26,8 to 29,5°C. During teaching hours, temperatures lower than 20°C were recorded only after intense and long period of window opening. The lowest indoor temperatures, from 19.8°C to 21.2°C, were recorded at night and early in the morning (Telejko, 2017)

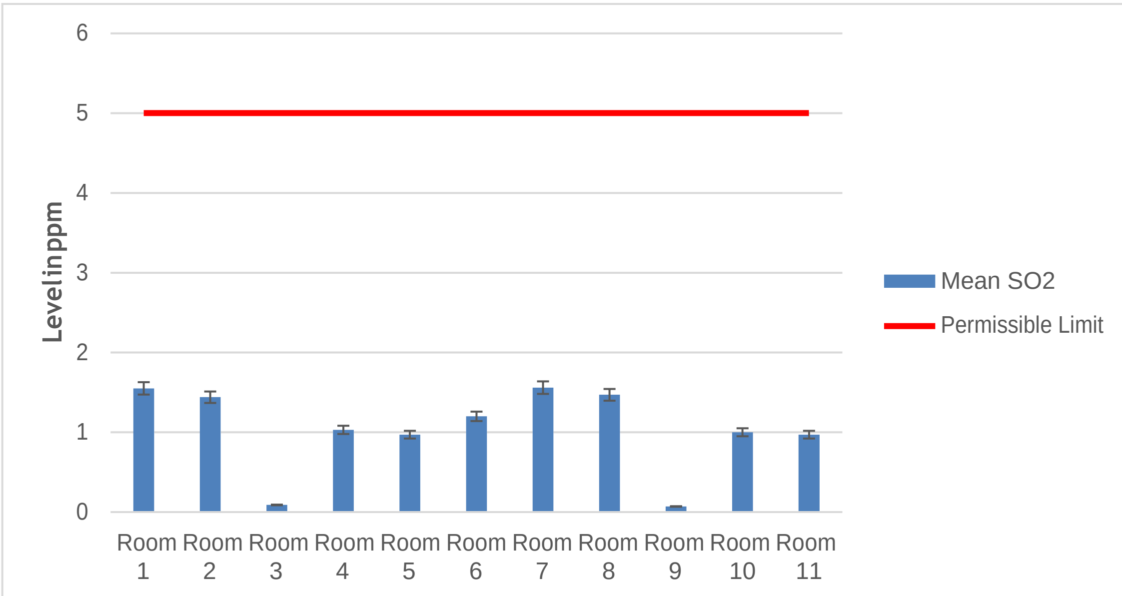


Graph 3. Mean Carbon Dioxide readings on 11 monitoring locations compared with permissible limit (red)

Carbon dioxide (CO_2) in all office rooms, as shown in Graph 3, is below the lower extreme of the permissible range as recommended by USOSHA (CFR 29) i.e. <1000ppm. (Also see Table 5). In a recent study, the indoor air quality showed that Carbon dioxide had a relatively high concentration (32600 ppm) in a computer laboratory but by increasing the incoming air flow in the room, the concentration dropped to a lower level within the range recommended by the International Organization for Standardization (Telejko, 2017).

Alves et al. (2016) conducted an experiment in classrooms of a school in Europe to monitor indoor quality. It was concluded that the CO_2 concentrations exceeded the limit of 1000 ppm, indicating inadequate ventilation provided into the area.

Further studies show that lowest CO_2 concentrations, from 419 ppm to 517 ppm, were recorded at night or at early hours (CFR29). During the day, the values rose quickly exceeding 3200 ppm in some cases. Characteristic minor drops during the day result from short periods of ventilation by opening the windows and from breaks during which IAQ improves for a very short time (Telejko, 2016). The CO_2 concentrations exceeded 1000 ppm in 75% of the studied daycare centers, with the highest level (1356 ppm) measured in 2 renovated daycare facilities with the natural ventilation system (Stankevica and Lesinkis, 2011).

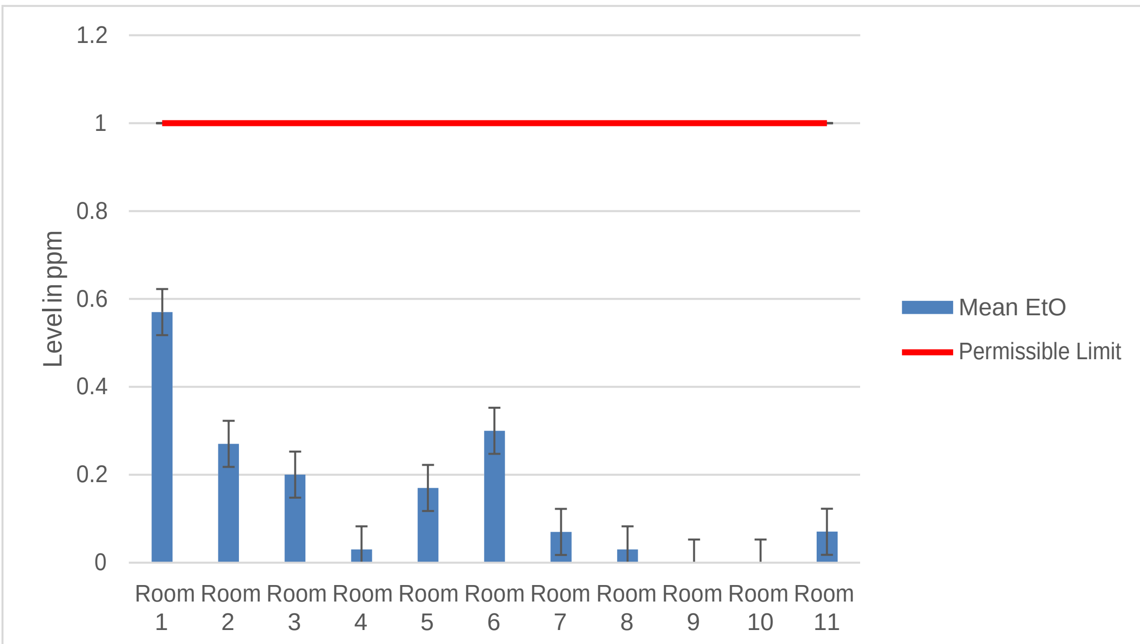


Graph 4 . Mean Sulphur Dioxide (SO_2) reading on 11 monitoring locations

Sulphur Dioxide (SO_2) in all office rooms, as shown in Graph 4, is below the lower extreme of the permissible range as recommended by OSHA (CFR 29) i.e. <5ppm. (Also see Table 5) Another experiment conducted in 2009 to monitor the indoor air pollution displayed the indoor ranges for Sulfur Dioxide between 0.092 and 0.32 ppm (Assimakopoulos et al., 2009). Therefore, it is also in the lower extreme of the permissible range. Indoor concentrations of SO_2 were monitored in an experiment performed in Canada in 2002. SO_2 concentrations ranged from 0.5µg/m^3 (0.0005ppm) to 32 µg/m^3 (0.032ppm)

(Brauer et al., 2002). Therefore, this is also within the lower extreme of the permissible limit.

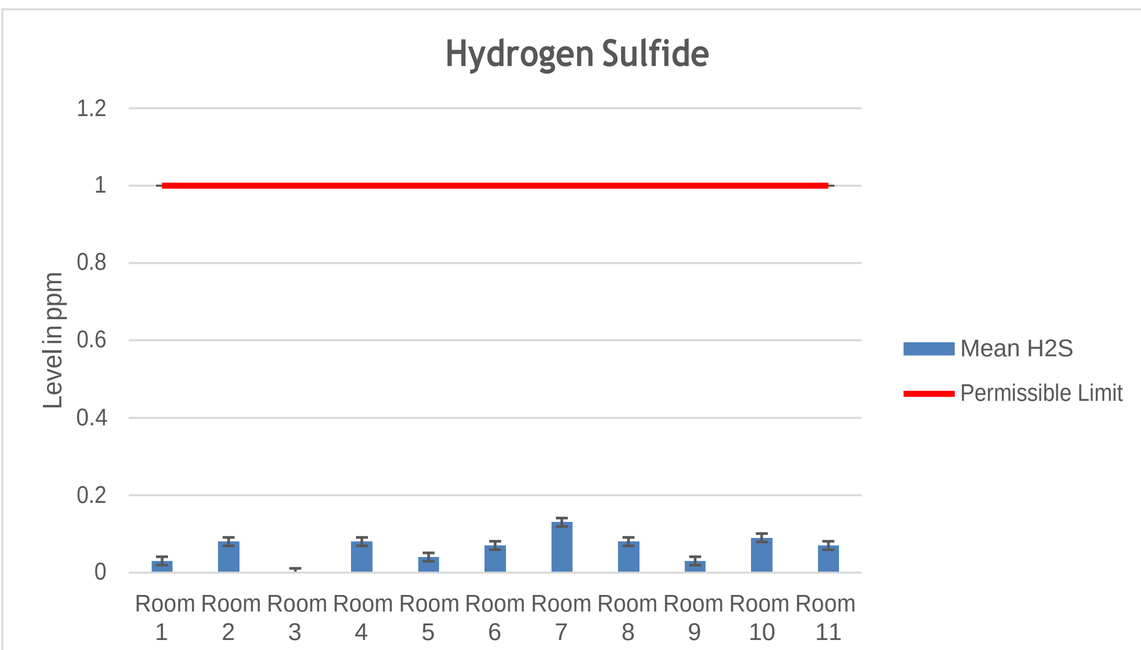
Indoor Air Quality and Ethylene Oxide



Graph 5. Mean Ethylene Oxide (EtO) readings on 11 monitoring locations

Mean Ethylene Oxide (EtO) concentration in all office rooms, as shown in Graph 5, is below the lower extreme of the permissible range as recommended by OSHA (CFR 29) i.e. <1ppm (Also see Table 5). Another experiment conducted in Greece in 2007 (Argyro et al., 2007) to monitor the indoor air quality of hospital rooms displayed the concentration of EtO from 0.5ppm-1ppm (Argyro et al., 2007). Therefore, this is also within the permissible range by OSHA (CFR 29). An experiment conducted in Canada 2008 to measure pollutants in indoor air showed the concentration of EtO as 0.062 ppm (Amanda et al., 2008) which is also within the permissible lower range. The results from some studies reveal that the indoor/outdoor ratio for Ethylene oxide generally ranges from 1.5 to 3.9 ppb under most circumstances (Morgott, 2015).

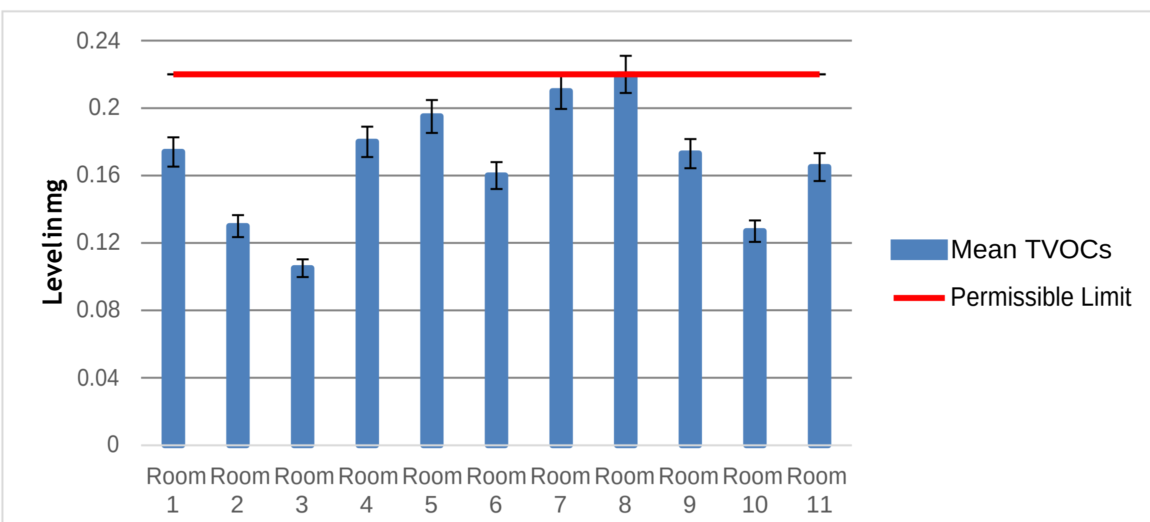
Indoor Air Quality and Hydrogen Sulfide



Graph 6. Mean Hydrogen Sulfide (H_2S) reading on 11 monitoring locations

Mean Hydrogen Sulfide (H_2S) concentration in all the office rooms, as shown in Graph 6, is below the lower extreme of the permissible range as recommended by OSHA (CFR 29) i.e. <1ppm (Also see Table) In one report (WHO,1981), the average ambient air hydrogen sulfide level was estimated to be 0.3ppm (WHO, 2000). In north-west London indoor air levels of hydrogen sulfide were generally almost 0.0001 ppm. Therefore, these experiments displayed H_2S concentration within the lower extreme of the permissible range. Another experiment conducted to monitor indoor air quality in Netherlands showed that Hydrogen Sulfide concentration ranged from 0.4µg/m^3 (0.0004ppm) to 0.5 µg/m^3 (0.0005ppm) (Frans et al, 1995). Hence, these results are also within the permissible range recommended by OSHA (CFR 29).

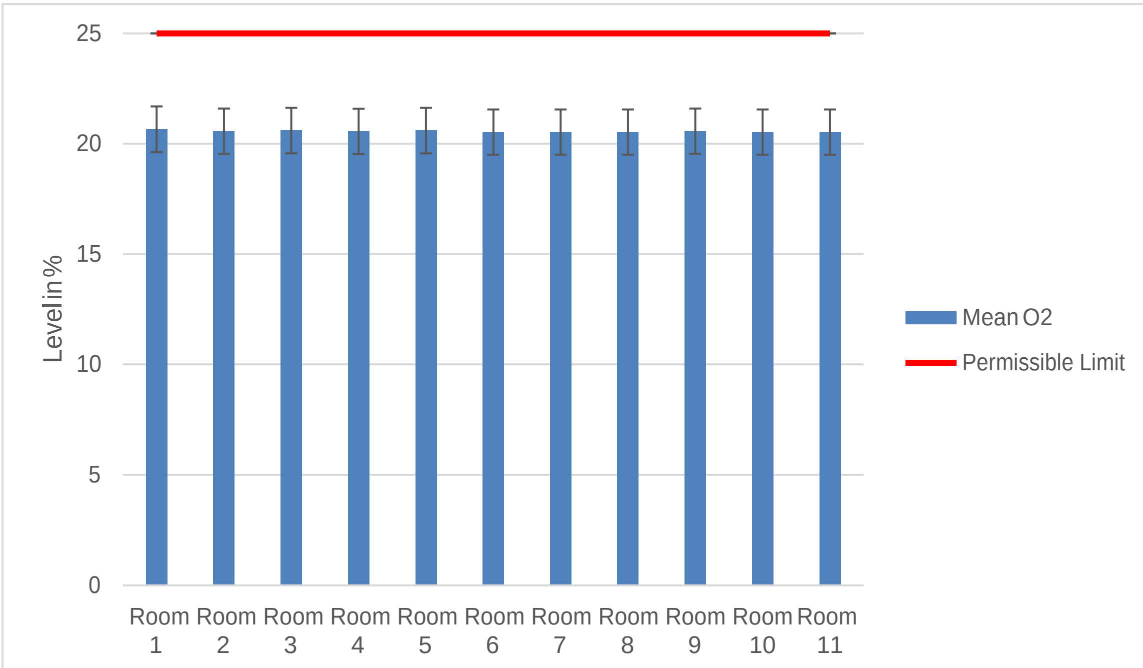
Indoor Air Quality and Total Volatile Organic Compounds (TVOCs)



Graph 7 . Mean TVOCs concentration on 11monitoring locations compared with

permissible limit (red)

Mean TVOCs concentration in all the office rooms, as shown in Graph 7, is below the lower extreme of the permissible range as recommended by OSHA (CFR 29) i.e. <0.22 mg/m³ (Also see Table 5). TVOC values found very near to permissible limit in Room 7 and 8 because of use chemicals in Lab. An experiment conducted in China to detect indoor air quality displayed the concentration of TVOCs ranging between from 0.040 to 0.090 mg/m^3 whereas the concentration of toluene was $0.34mg/m^3$ and *m,o*-xylene was $0.32mg/m^3$ (LIU et al., 2009). Therefore, majority of the TVOCs were within the lower extreme of the permissible range whereas toluene and *m,o*-oxylene surpassed the permissible range. Another experiment conducted in Australia in 2007 to monitor the indoor air quality showed that the mean concentration of each TVOC in established buildings is generally below 50 $\mu g/m^3$ ($0.05mg/m^3$), but higher than 5 $\mu g/m^3$ (0.005). In a study conducted the total VOC (TVOC) concentration was generally above the S3-class limit of 600 g/m^3 in the newly finished buildings but the concentration usually decreased below the S3-level and in some apartments below the S1-level of 200 g/m^3 in six months. The concentrations of the major VOCs decreased most strongly during the first six months of occupancy, reaching mean concentration levels of 5-15 g/m^3 (Jarnstrom, 2008) mg/m^3) (H.M et al., 2007).



Graph 8. Mean Oxygen (O_2) readings on 11 monitoring locations

The indoor oxygen concentration was recorded as 19.8 to 20.8 respectively in an experiment conducted to monitor indoor air quality in USA (Andrew et al., 1996). Hence, this is recorded indoor oxygen concentration is also within the permissible range recommended by OSHA (CFR 29).

Correlations of Parameters

Table 19 shows inter-parametric correlations of different parameters. The relative humidity (RH) and temperature are negatively correlated with each other at <0.05 significance level. The RH at the same level of significance is also negatively correlated with TVOCs. The correlations are stronger in both cases. The significant negative correlations at the same significance level were observed between carbon dioxide and ethylene oxide. Similarly, negative correlation of carbon dioxide with oxygen was also observed. However, no significant correlations are found among rest of the parameters.

Table 18

Correlation Between Different Parameters of IAQ (*Sig.<0.05)

	RH	Temp	CO_2	SO_2	EtO	TVOCs	O_2
RH	1.000	*-0.6312	0.4125	-0.1403	0.3956	-*0.5943	-0.2391
Temp	*-0.6312	1.000	0.5932	0.1173	-0.4820	-0.1483	0.5490
CO_2	0.4125	0.5932	1.000	0.4306	*-0.7321	-0.321	*-0.7104
SO_2	-0.1403	0.1173	0.4306	1.000	0.0138	-0.1119	-0.1960
EtO	0.3956	-0.4820	*-0.7321	0.0138	1.000	0.4104	-0.2012
TVOCs	*-0.5943	0.1483	-0.321	-0.1119	0.4104	1.000	0.4531
O_2	-0.2391	0.5490	*-0.7104	-0.1960	-0.2012	0.4531	1.000

Inter-Cameral Comparisons

The mean relative humidity (RH) in all offices, as shown in Figure 7, is below the lower extreme of the permissible range as recommended by OSHA (CFR 29) i.e. 30-60%. However, in Room 3 it is within the prescribed range. Mean temperature in Room 3, 4, 5 and 6, as shown in Figure 8, is below the lower extreme of the permissible range as recommended by OSHA (CFR 29) i.e.$20^{o}C$-$27^{o}C$. However, in rest of rooms it is within the prescribed range. CO_2 in all the office rooms, as shown in Figure 9, is below the lower extreme of the permissible range as recommended by OSHA (CFR 29) i.e. <1000ppm., SO_2 in all the office rooms, as shown in Figure 10, is below the lower extreme of the permissible range as recommended by OSHA (CFR 29) i.e. <5ppm. Mean Ethylene Oxide (EtO) concentration in all the office rooms, as shown in Figure 11, is below the lower extreme of the permissible range as recommended by OSHA (CFR 29) i.e. <1ppm. Mean Hydrogen Sulfide (H_2S) concentration in all the office rooms, as shown in Figure 12, is below the lower extreme of the permissible range as recommended by OSHA (CFR 29) i.e. <1ppm. Mean TVOCs concentration in all the office rooms, as shown in Figure 13, is below the lower extreme of the permissible range as recommended by OSHA (CFR 29) i.e. <0.22 mg/m^3. Mean Oxygen (O_2) concentration in all the office rooms, as shown in Figure 14, is within the permissible range as recommended by OSHA (CFR 29) i.e. 19.5%-23.5%.

CHAPTER 6: CONCLUSION

This study is about investigation of indoor air quality of workplace at QAFAC complex in Mesaieed. Overall it was fund that almost all the rooms found with acceptable indoor air quality as complying with the ASHRAE and OSHA CFR29 limits. Different parameters were used to assess the indoor air quality; however; relative humidity and temperature are two key factors which influence the presence of indoor air pollutants significantly. Both parameters are interdependent. Their percentage varies from summer to winter. A relative humidity of more than 60% allows significant enhancement in growth of dust mites, bacteria, fungi and other microbial organisms. Simultaneously a decrease in RH% less than 30% aggravate discomfort among occupants. But overall HVAC systems must be able to maintain a humidity ratio of at or below 0.012. Keeping these factors in mind, all the 11 locations were categorized as acceptable and not acceptable as per permissible limits defined for each parameter. Eight parameters, RH, temperature, CO_2, SO_2, EtO, H_2S, TVOCs, O_2 were detected.at acceptable levels except two locations i.e. for Room 6 -Control Room Main Building (office 110 CBGF) and Room 8- Laboratory 2 where Mean temperature in Room 6 & 8 is above the upper extreme of the permissible range as recommended by OSHA (CFR 29) i.e.20^{o}C-27^{o}C. When investigated it was found that increase in temperature in control room (Room 6) was due to operations of certain equipment's those can operate only on recommended temperature levels, so it cannot be reduced to bring at permissible levels. While in Lab room8 room a slight variation found above the upper limit was because of use of different simultaneous operating equipment and use continuous execution of different chemical experiments. This conjugative operation aggravates indoor temperature. However, in all other rooms it is found within the permissible range. CO_2, SO_2, EtO, H_2S, TVOCs and O_2 concentration in all the office rooms is below the lower extreme of the permissible range as recommended by OSHA (CFR 29). TVOC values found in Room 7 and 8 were very near to permissible limits. Because of use chemicals in the Lab. However, CO, NO_2, NO, Cl_2, HCH, NH_3, F_2, O_3 and HCl were non-existent in all the rooms. No critical parameter found above Threshold Limit Value (TLV) that's why no outdoor Air Quality comparison was performed. It is recommended to improve ventilation system of lab room 7 and 8 by installation of local ventilation devices those should be designed to reduce the exposure of fumes and vapors Use of chemicals are possibly increasing the VOCs and temperature in the lab. It is recommended to install engineering control prescribed in OSHA's laboratory standards 29CFR, 1910.1450. It was identified that Indoor Air Quality of office buildings is not polluted due to outdoor pollutants because values of 8 detected parameters were complying with permissible limits and other 9 parameters were not detected. Therefore, it can be concluded that there is no ingress of pollutant from outdoor environment. Possible pollutants from Plant Operations include VOCs, Chlorine, H_2S were not detected.

A detailed comprehensive study is proposed to investigate cumulative impacts. MIC (Mesaieed Industrial City) has already initiated an Air Capacity Modeling Study. A long-term project can be initiated to monitor seasonal variations. More parameters can be added as per industrial Processes. Such as Formaldehyde, Radon, PM 1, 2.5, Biological, microbial pollutants like molds and others.

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APPENDIX

Appendix A: Calibration Certificates of Probe

1. Probe – Serial Number 03-0737

Gray Wolf Sensing Solutions
Calibration Certificate

Certificate # 36982

Qatar Fuel Additives Company (QAFAC)
Qatar Fuel Additives Company (QAFAC)
Mesaieed Industrial Area (QAFAC Plant),
Mesaieed, State of Qatar

Order Details
Invoice # E14890
Contact: Mr. Khurram Babur Mukhtar

Model # TG501
Serial # 03-0737

Probe Details
Date: 10-Jul-17
ID: 31347

Calibration Details

Sensor	Bar Code/ID	Set Point	Verified	Error	Uncertainty
Chlorine	70570009105	0.00ppm	0.00ppm	0.00ppm	0.34 %
		6.60ppm	6.66ppm	0.06ppm	2.03 %
Nitric Oxide	60840044110	0.0ppm	0.0ppm	0.0ppm	0.87 %
		23.6ppm	23.7ppm	0.1ppm	2.18 %
Sulfur Dioxide	51200163066	0.0ppm	0.0ppm	0.0ppm	1.40 %
		10.2ppm	10.2ppm	0.0ppm	2.44 %
PT100	Pt001	20.0C	20.0C	0.0C	1.42 %
		40.0C	40.0C	0.0C	0.80 %
Nitrogen Dioxide	85320227011	0.00ppm	-0.08ppm	-0.08ppm	0.34 %
		6.60ppm	6.57ppm	-0.03ppm	2.03 %
Ammonia 100PPM	026025	0.0ppm	0.0ppm	0.0ppm	3.51 %
		23.5ppm	23.5ppm	0.0ppm	4.04 %

Temperature calibration performed in moving air at 1m/sec.
All test equipment and/or reference materials used in calibration are fully traceable to recognized national standards.
The uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%.

Lab Ambient Conditions

Temperature 22.0C

Humidity 47.7%RH

Pressure 1005.00mbar

Calibrated By: Gary Le Gear

Date: 10-Jul-17

Facility: Annacotty
GrayWolf Sensing Solutions LTD
Annacotty Buisness Park
Unit 1C
Annacotty,Co Limerick
IRELAND

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2. Probe – Serial Number 03-0741

Gray Wolf Sensing Solutions
Calibration Certificate

Certificate # 36994

Qatar Fuel Additives Company (QAFAC)
Qatar Fuel Additives Company (QAFAC)
Mesaieed Industrial Area (QAFAC Plant),
Mesaieed, State of Qatar

Order Details

Invoice # E14890
Contact: Mr. Khurram Babur Mukhtar

Model # TG501
Serial # 03-0741

Probe Details

Date: 10-Jul-17
ID: 20739

Calibration Details

Sensor	Bar Code/ID	Set Point	Verified	Error	Uncertainty
Hydrogen Fluoride	11956133336	0.0ppm	0.0ppm	0.0ppm	0.1 ppm
		7.0ppm	7.0ppm	0.0ppm	0.1 ppm
Hydrogen Chloride	119679981336	0.0ppm	0.0ppm	0.0ppm	5.50 %
		10.6ppm	10.5ppm	-0.1ppm	5.85 %
Hydrogen	0217275482011	0ppm	1ppm	1ppm	0.30 %
		494ppm	495ppm	1ppm	2.02 %
Hydrogen Sulfide	24320201120	0.00ppm	0.01ppm	0.01ppm	0.24 %
		15.00ppm	15.01ppm	0.01ppm	2.01 %
PT100	Pt001	20.0C	20.0C	0.0C	1.42 %
		40.0C	40.0C	0.0C	0.80 %
Ozone	010012764071067	0.00ppm	0.00ppm	0.00ppm	2.35 %
		0.84ppm	0.84ppm	0.00ppm	3.09 %

Temperature calibration performed in moving air at 1m/sec.
All test equipment and/or reference materials used in calibration are fully traceable to recognized national standards.
The uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%.

Lab Ambient Conditions

Temperature 22.0C

Humidity 47.7%RH

Pressure 1005.00mbar

Calibrated By: Gary Le Gear

Date: 10-Jul-17

Facility: Annacotty
GrayWolf Sensing Solutions LTD
Annacotty Buisness Park
Unit 1C
Annacotty,Co Limerick
IRELAND

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3. Probe – Serial Number 03-0743

Gray Wolf Sensing Solutions
Calibration Certificate

Certificate # 36983

Qatar Fuel Additives Company (QAFAC)
Qatar Fuel Additives Company (QAFAC)
Mesaieed Industrial Area (QAFAC Plant),
Mesaieed, State of Qatar

Order Details
Invoice # E14890
Contact: Mr. Khurram Babur Mukhtar

Model # TG501
Serial # 03-0743

Probe Details
Date: 10-Jul-17
ID: 20737

Calibration Details

Sensor	Bar Code/ID	Set Point	Verified	Error	Uncertainty
Ethylene Oxide	119679981336	0.0ppm	0.0ppm	0.0ppm	0.1 ppm
		10.0ppm	10.0ppm	0.0ppm	0.3 ppm
Hydrogen Cyanide	0217275482011	0.0ppm	0.0ppm	0.0ppm	2.01 %
		10.0ppm	10.1ppm	0.1ppm	4.55 %
PT100	PI001	20.0C	20.0C	0.0C	1.42 %
		40.0C	40.0C	0.0C	0.80 %
Fluorine	010012744626057	0.00ppm	-0.01ppm	-0.01ppm	0.76 %
		2.66ppm	2.67ppm	0.01ppm	20.01 %
Arsine	010012712159027	0.00ppm	0.00ppm	0.00ppm	1.50 ppm
		0.80ppm	0.80ppm	0.00ppm	1.50 ppm

Temperature calibration performed in moving air at 1m/sec.
All test equipment and/or reference materials used in calibration are fully traceable to recognized national standards.
The uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%.

Lab Ambient Conditions

Temperature 22.0C   Humidity 47.7%RH   Pressure 1005.00mbar

Calibrated By: Gary Le Gear

Date: 10-Jul-17

Facility: Annacotty
GrayWolf Sensing Solutions LTD
Annacotty Buisness Park
Unit 1C
Annacotty,Co Limerick
IRELAND

1 / 1

4. Probe – Serial Number 03-1165

Gray Wolf Sensing Solutions
Calibration Certificate

Certificate # 36986

Order Details

Qatar Fuel Additives Company (QAFAC)
Qatar Fuel Additives Company (QAFAC)
Mesaieed Industrial Area (QAFAC Plant),
Mesaieed, State of Qatar

Invoice # E14890
Contact: Mr. Khurram Babur Mukhtar

Probe Details

Model # TG501
Serial # 03-1165

Date: 10-Jul-17
ID: 31349

Calibration Details

Sensor	Bar Code/ID	Set Point	Verified	Error	Uncertainty
Phosphine	0125632142103	0.00ppm	-0.01ppm	-0.01ppm	0.02 ppm
		5.00ppm	5.00ppm	0.00ppm	0.21 ppm
Ozone	12564225076	0.00ppm	0.00ppm	0.00ppm	2.35 %
		0.84ppm	0.84ppm	0.00ppm	3.09 %
PT100	Pt001	20.0C	20.0C	0.0C	1.42 %
		40.0C	40.0C	0.0C	0.80 %
Phosgene	010012768915057	0.00ppm	0.00ppm	0.00ppm	2.60 %
		0.76ppm	0.76ppm	0.00ppm	20.17 %

Temperature calibration performed in moving air at 1m/sec.
All test equipment and/or reference materials used in calibration are fully traceable to recognized national standards.
The uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%.

Lab Ambient Conditions

Temperature 22.0C | Humidity 47.7%RH | Pressure 1005.00mbar

Calibrated By: Gary Le Gear

Date: 10-Jul-17

Facility: Annacotty
GrayWolf Sensing Solutions LTD
Annacotty Buisness Park
Unit 1C
Annacotty,Co Limerick
IRELAND

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5. Probe – Serial Number 05-0816

Gray Wolf Sensing Solutions
Calibration Certificate

Certificate # 36985

Order Details
Invoice # E14890
Contact: Mr. Khurram Babur Mukhtar

Qatar Fuel Additives Company (QAFAC)
Qatar Fuel Additives Company (QAFAC)
Mesaieed Industrial Area (QAFAC Plant),
Mesaieed, State of Qatar

Probe Details
Date: 10-Jul-17
ID: 20742

Model # IQ610
Serial # 05-0816

Calibration Details

Sensor	Bar Code/ID	Set Point	Verified	Error	Uncertainty
Carbon Dioxide	MQ 003296	345ppm	350ppm	5ppm	1.97 %
		1,251ppm	1,257ppm	6ppm	0.70 %
Carbon Monoxide	15363239120	0.0ppm	0.1ppm	0.1ppm	0.47 %
		96.6ppm	96.8ppm	0.2ppm	0.69 %
PT100	Pt001	20.0C	20.0C	0.0C	1.42 %
		40.0C	40.1C	0.1C	0.80 %
Relative Humidity	Rh001	10.0%RH	9.9%RH	-0.1%RH	1.40 %
		75.0%RH	74.7%RH	-0.3%RH	1.41 %
TVOC	141390068	10ppb	10ppb	0ppb	0.19 %
		8,100ppb	8,133ppb	33ppb	0.30 %
Oxygen	59317344057	0.0%	0.0%	0.0%	1.00 %
		20.9%	20.9%	0.0%	1.01 %

Temperature calibration performed in moving air at 1m/sec.
All test equipment and/or reference materials used in calibration are fully traceable to recognized national standards.
The uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%.

Lab Ambient Conditions

Temperature 22.0C
Humidity 47.7%RH
Pressure 1005.00mbar

Calibrated By: Gary Le Gear

Date: 10-Jul-17

Facility: Annacotty
GrayWolf Sensing Solutions LTD
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Annacotty,Co Limerick
IRELAND

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Appendix B: Equipment Measuring Ranges

May 2016

GRAYWOLF SPECIFICATIONS

AdvancedSense Pro®/AdvancedSense BE®/WolfPack®/DirectSense® Gas Sensor Specs Summary

Note: any sensor(s) used for life safety critical situations, such as OSHA TWAs or STELs, must be user calibrated or, at minimum, exposed to a target gas (bump tested) to assure sensor response *each day of use* with a reference gas close to the critical level. Failure to carry out such tests may jeopardize the safety of people and property.
Refer to the endnotes at the bottom of this document for additional information.

SENSOR	INSTR RES (ppm)	RANGE (ppm)	SENSOR LOD (ppm)	SENSOR DRIFT	T_{90} RESPONSE	RECO'D CALIBRATION FREQUENCY[i]	EXPECTED LIFE
NDIR							
Carbon Dioxide (CO_2)	1	0 to 10,000[ii]	1	<80ppm/year[iii]	≤20s	≤12 months	>10 years
Electrochemical							
Ammonia (NH_3) Standard Range	0.1	0.0 to 100.0	<1	5%/6 months	<60s	≤12 months	>24 months
Ammonia (NH_3) High Range	1	0 to 1000	12	10%/6 months	<90s	≤6 months	24 months
Arsine (AsH_3)	0.01	0.00 to 1.00	0.03	5%/6 months	<30s	≤12 months[iv]	>18 months
Carbon monoxide (CO combo w/H_2S sensor)	1	0 to 1000	1	4%/year	<35s	≤12 months	24 months
Carbon monoxide (CO solo)	0.1	0.0 to 750.0[ii]	<0.3[v]	<5%/year	<25s	≤12 months	36-60 months[v]
Chlorine (Cl_2)	0.01	0.00 to 20.00	<0.02	<10%/year	<60S	≤12 months[vi]	>24 months
Chlorine dioxide (ClO_2)	0.01	0.00 to 1.00	0.03	10%/6 months	<120s	≤6 months[iv]	12 months
Diborane (B_2H_6)	0.01	0.00 to 1.00	0.03	5%/6 months	<30s	≤6 months[iv]	>18 months
Ethylene oxide (EtO)	0.1	0.0 to 100.0	0.3	5%/year	<150s	≤12 months	>24 months
Fluorine (F_2)	0.01	0.00 to 1.00	0.02	5%/month	<80s	≤4 months[iv]	>18 months
Hydrogen (H_2)	1	0 to 2000	1	3%/year	<90s	≤12 months	>24 months
Hydrogen chloride (HCl)	0.1	0.0 to 30.0	0.7	3%/month	<70s	≤6 months	>24 months
Hydrogen cyanide (HCN)	0.1	0.0 to 30.0	0.2	5%/month	<50s	≤4 months	>18 months
Hydrogen fluoride (HF)	0.01	0.00 to 10.00	<0.1	<10%/6 months	<90s	≤6 months[iv]	>18 months
Hydrogen sulfide (H_2S combo w/CO sensor)	0.1	0.0 to 200.0	0.5	2%/year	<30s	≤12 months	24 months
Hydrogen sulfide (H_2S solo)	0.01	0.00 to 50.0	0.03	2%/year	<30s	≤12 months	36-60 months[v]
Nitric oxide (NO)	0.1	0.0 to 250.0	0.2	<5%/year	<45s	≤12 months	36-60 months[v]
Nitrogen dioxide (NO_2)	0.01	0.00 to 20.00	0.02	10%/year	<50s	≤12 months	36-60 months[v]

GRAYWOLF SENSING SOLUTIONS

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GRAYWOLF SPECIFICATIONS

SENSOR	INSTR RES (ppm)	RANGE (ppm)	SENSOR LOD (ppm)	SENSOR DRIFT	T_{90} RESPONSE	RECO'D CALIBRATION FREQUENCY	EXPECTED LIFE
Ozone (O_3)	0.01	0.00 to 1.0	0.02	10%/6 months	<60s	≤12 months[vi]	12-18 months[vii]
Phosgene ($COCl_2$)	0.01	0.00 to 1.00	0.02	5%/6 months	<120s	≤12 months[iv]	>12 months
Phosphine (PH_3)	0.01	0.00 to 10.00	0.05	<10%/year	<25s	≤6 months	>24 months
Silane (SiH_4)	0.1	0.0 to 50.0	<1	5%/6 months	<60s	≤12 months	24 months
Sulfur dioxide (SO_2)	0.01	0.00 to 50.00	<0.1	<4%/year	<35s	≤12 months	36-60 months[v]
	RES %	Range %	LOD %	Full Scale			
Oxygen (O_2)	0.1%	0.0 to 25.0%	0.2%	<1%/3 months	<15s	≤12 months	24-36 months[v]
PID (VOCs)							
Low Range	0.001	0.000 to 20.000[ii]	0.005	<10ppb/day (zero drift)[iv]	<5s	≤2weeks User, 12 months Factory	>5 years (except lamp & detector)[viii-ix]
Mid/Low Range	0.01	0.00 to 200.00[ii]	0.025	TBD	<5s	Daily User, 12 months Factory	>5 years (except lamp & detector)[viii]
Mid Range	0.1	0.0 to 2000.0	0.050	TBD	<5s	Daily User, 12 months Factory	>5 years (except lamp & detector)[viii]
High Range	0.1	0.0 to 10,000.0	0.1	<0.1ppm/day (zero drift)	<5s	Daily User, 12 months Factory	>5 years (except lamp & detector)[viii]

All specifications are subject to change without further notice.

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[i] Calibration cycles are based on Indoor Air Quality (IAQ) applications. Calibration may be User or Factory. However, annual factory calibration is also recommended, even if user calibrations are being performed.
Any sensor(s) used for safety critical situations, such as OSHA TWAs or STELs, must be user calibrated or, at minimum, exposed to a target gas (bump tested) to assure sensor response each day of use with a reference gas close to the critical level. Failure to carry out such tests may jeopardize the safety of people and property.
For optimum accuracy, it is advised to perform more frequent user calibrations of zero and/or span (dependent on application). GrayWolf makes the user calibration procedure simple and reliable. The software walks users through the calibration process. Calibration kits and appropriate reference gasses are available for shipment to most locations.

[ii] Higher range (to 2x that listed) available with this sensor, but requires special calibration (and at reduced accuracy). Higher overall range available with alternative sensor.

[iii] Over the "IAQ critical range" (350ppm to 1500ppm), based on GrayWolf data and long-term experience.

[iv] For User calibrations, a surrogate reference gas is recommended. Contact GrayWolf for details.

[v] This specification is enhanced vs. the sensor mfg. spec based on GrayWolf data & long-term experience.

[vi] For User calibrations, NO2 surrogate ref. gas is recommended as it is easier to work with than Cl2 or O3 gas.

[vii] This specification is reduced vs. the sensor mfg. lifetime spec based on GrayWolf data & long-term experience.

[viii] Lamps, which carry a 1 year warranty, are rated >5000 hours lit and usually perform far better. Unless clients are running 24/7, GrayWolf's experience is that it is rare to replace lamps or detectors before 4 years.

[ix] PID up to 95% RH can be specified for high humidity environments.

Appendix C: Equipment Manual

✓MEASURE SMART ✓REPORT EFFICIENTLY

WOLFPACK®

Modular Area Monitor

SPECIFICATIONS:
(for additional sensor/probe specifications please refer to GrayWolf's probe brochures)

Dimensions:

Without handle:	9.84in. (25cm) w. x 10in. (25.5cm) h. x 5.1in. (13cm) d.
With handle:	11in. (28cm) w. x 16in. (40.9cm) h. x 5.1in. (13cm) d.
Overall Height with probe(s) fitted:	18.1in. (46cm)
Weight (without probes):	11lb. 5 oz. (5kg)
Probe Weight (without probe handle):	~8 oz.
PCC-16 Hardshell Case:	19.7in. (50cm) w. x 24.6in. (62.5cm) h. x 11.7in. (30.0cm) d.

Power:

Battery:	Lead Acid (rechargeable)
Battery Life: (new bat. powering PID, NDIR & multi EC sensors)	15 hours typical with backlight off, fan on 21 hours typical with backlight off, fan off
Recharge time (100/250VAC, 50-60Hz internal charger):	5 hours

Connectors:

3 x Lemo 8 pin for GrayWolf probes
1 x Lemo 7 pin for optional USB key download cable, formaldehyde meter or camera
1 x Lemo 6 pin for particulate, 3rd party meters
1 x mini USB socket - 1m USB B to USB A download cable supplied as standard
1 x IEC 320 universal socket for power. 1.5m cable with local plug supplied

Miscellaneous:

Operating Range: -10ºC to 50ºC (15ºF to 122ºF), 0 to 98% RH (non-condensing)
Screen Size: 3.5" HVGA 320 x 480 color touch screen with backlight
Memory: 32GB for data-logging (1million+ readings), audio notes, program, help videos, documents and auto data backup
Adjustable handle - adjust to any angle from 180º to 30º
Wireless Network: WiFi 802.11 a/b/g with integrated antenna and Bluetooth 4.0 standard (may optionally be ordered with wireless hardware removed)
Wall-mountable if required
GrayWolf Software is 21 CFR Part 11 Compliant
All specifications are subject to change without further notice

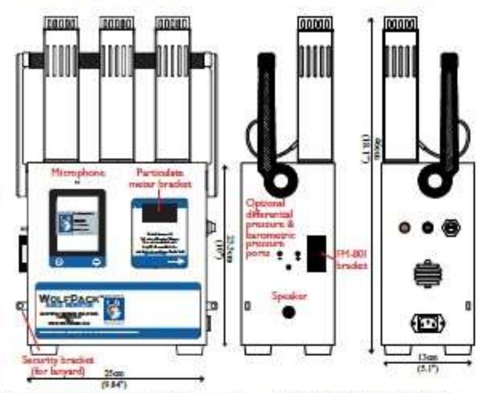
Optional Built-in Sensors:

	Differential Pressure (**DP-702LH**)	Barometric Pressure (**BP-101**)*
Range	±10,000Pa, ±40 inH₂O, ±1000 mmH₂O, ±100 mbar, ±70 mmHg	600 to 825 mmHg, 800 to 1100mBar, 23.50 to 32.50 inHg, 0.80 to 1.10atm
Resolution	0.1 Pa, 0.001 inH₂O, 0.01 mmH₂O, 0.001 mbar, 0.001 mmHg	0.1mmHg, 0.1mBar, 0.01 inHg, 0.01atm
Accuracy (auto-zeroing enabled)	±1% of rdg ±0.1Pa up to 250Pa, ±1%rdg ±4Pa >250Pa (±1% of rdg ±0.001 inH₂O to 1.000 inH₂O, ±1%rdg ±0.015 inH₂O>1.000 inH₂O)	±0.1% rdg

Differential Pressure is auto-zeroing (every 2 minutes by default but zeroing frequency is user adjustable to 5 min. or OFF)

*The barometric pressure sensor will, when installed, compensate mass concentration readings (µg/m³) for pressure changes.

Refer to the GrayWolfLive brochure for specifications on remote access and alerts.



▲ WolfPack shown with **PC-3016A** 6-channel Particle Counter and **PM-801** Formaldehyde meter interfaced

Probes are inter-changeable with **AdvancedSense** meters and tablet/laptop PCs ▼

WolfPack shown with **PM-205** Particulate Monitor (Thermo pDR-1500) ▼

PCC-16 Hardshell Carrying Case with handle, wheels and storage for WolfPack, probes, mobile PC and accessories.
Dimensions: 62.5cm x 50.0cm x 30.0cm (24.6" x 19.7" x11.7") ▼

◄ **WolfSense PC** data transfer and analysis software supplied as standard

Calibration kits, Advanced Reporting Software, tablet PCs and other accessories are available from GrayWolf. View them online at accessories.graywolfsensing.com

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