

**DEVELOPING A CORRELATION BETWEEN INDOOR  
AIR QUALITY AND SICK BUILDING SYNDROME IN  
APARTMENT BUILDINGS**

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Thesis submitted in partial fulfillment of the requirements for the degree  
Master of Science in Construction Project Management

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Sri Lanka

March 2022

## **DECLARATION**

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## **ABSTRACT**

Sick Building Syndrome (SBS) is currently a widely discussed topic all around the world since most of the population spend majority of their time indoors. However in Sri Lanka, there is less discussion on SBS. Among the contributory factors for SBS, polluted air plays a leading role while aggravating the situation with poor ventilation. In order to assess the magnitude of SBS prevail in Apartment buildings in Sri Lanka, a field study was carried out placing the focus on Total Volatile Organic Compounds (TVOC) and Carbon Dioxide (CO<sub>2</sub>) concentrations. A series of measurements were taken on selected Indoor Air Quality (IAQ) parameters in a sample of apartment buildings located close to a main highway. The IAQ monitoring was coupled with a questionnaire survey on SBS symptoms, building operational practices and other related parameters. The results of the study revealed that IAQ parameters could correlate with SBS symptoms at different significant levels. Moreover, poor ventilation had been identified as a prominent contributory factor for substandard air quality which in turn would result several SBS symptoms. The results of this research will be benefited to Engineers, Architects, Developers, and general public.

**Key words:** SBS, IAQ, CO<sub>2</sub>, TVOC, Symptoms

## **ACKNOWLEDGEMENTS**

Firstly, I would like to express my sincere gratitude to my research supervisor Prof. (Mrs.) Chinthia Jayasinghe, for the guidance and support provided throughout the research. The immense knowledge and determination that have given by her to make awareness on this research area has inspired me to perform at the best where without the continuous support offered, the completion of this research would not have been possible.

Secondly, my thank goes to Mr. Nipun Kumarage, an undergraduate of the Department of Civil Engineering, University of Moratuwa for the assistance he provided during data collection. Furthermore, I would like to extend my thanks to Mr. Kasun Zoysa, Analytical Chemist of the Department of Civil Engineering, University of Moratuwa for the support provided in finding a good and reliable measuring instrument.

My parents were always there for me in my ups and downs. Even though I could not spend much time with them due to my busy schedule during the programme, they never complained but gave all the support they could in every possible way.

Also, I am grateful to my Employer, NCD Consultants (Pvt) Ltd. for providing a positive and encouraging working environment to continue my studies where Eng. Nandana Abeysuriya, Eng. Kaveesh Abeysuriya and Eng. Vinod Asanka should be specially mentioned for the flexibility they have provided to manage my workload.

Finally, special thanks should go to all the building occupants who have given their feedback for the questionnaire for providing their honest responses and allowing us inside their apartments freely to take air quality measurements.

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## LIST OF ABBREVIATIONS

Abbreviation	Description
SBS	Sick Building Syndrome
VOC	Volatile Organic Compounds
TVOC	Total Volatile Organic Compounds
CO <sub>2</sub>	Carbon Dioxide
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
WHO	World Health Organization
BRI	Building Related Illness
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
GBCSL	Green Building Council of Sri Lanka
ppm	Parts per Million
ppb	Parts per Billion

# **1. INTRODUCTION**

## **1.1 Background**

In the 21st century, people live indoors more often. (Mentese, et al., 2020) With the Covid-19 pandemic situation people are resorted to live indoors mostly in their residents. When people tend to live most of their time in indoors, Indoor Air Quality (IAQ) becomes a significant factor to consider.

Although it is difficult to provide an exact definition for IAQ, it can be described as the air quality within and around the building as per United States Environmental Protection Agency. (Steinemann, Wargocki, & Rismanchi, 2017) IAQ is related to the pollutants within indoor environments and can be demonstrated as a sub-set of Indoor Environmental Quality (IEQ). When these indoor air pollutants combined with other factors such as poor ventilation, can cause the phenomenon called Sick Building Syndrome (SBS).

As per World Health Organization (WHO), SBS is defined as a medical condition where people in a building suffer from symptoms of illness or feel unwell for no apparent reason. Several authors have used several definitions to describe the nature of SBS. Sundell J. (1996) defines SBS as a set of sub-clinical symptoms with no identified cause (Sun, et al., 2019). Some of those identified symptoms can be mentioned as irritation of the eyes, nose and throat, headache, cough, wheezing, cognitive disturbances, depression, etc. (Al horr, et al., 2016)

Among the many Indoor air pollutants which could cause SBS, CO<sub>2</sub> can be identified as one of the critical pollutants when it is compared with the ventilation of the building. If there is an Air Conditioner available inside the building, the situation could get more critical. (Ai, Mak, Cui, & Xue, 2016). Another critical Indoor air pollutant identified is Total Volatile Organic Compounds (TVOC). Some of the potential sources of TVOC are adhesives for carpet and flooring, furniture and wood products, paints and coatings for walls and floors, etc. (Spengler, Samet, & McCarthy, 2001)

Discussions about SBS were started around the 1970s in western countries and it is still being discussed all around the world (Kishi, Norbäck, & Araki, 2020). Even in Sri Lanka, there is a considerable amount of research which had been done related to

SBS. However, very less number of research had been focused on residential apartments.

## **1.2 Objectives**

The main objective of this research is to find out the relationship among SBS symptoms, building performance, and practices with IAQ.

The sub-objectives are

- to analyse the SBS related factors vs indoor CO<sub>2</sub> levels
- to analyse the SBS related factors with indoor TVOC levels, and
- to determine the level of SBS related symptoms

## **1.3 Scope and Limitations**

This research is focused on residential apartments in urban areas located on a major highway in Sri Lanka. The IAQ parameters considered were TVOC and CO<sub>2</sub>. The selected sample size was 30 residential apartments.

## **1.4 Research Methodology**

This research is based on data collected by a questionnaire survey and measurements were taken on field study. The literature review was carried out to find out on the uses of questionnaire (Carpino, Mora, & De Simone, 2019), the SBS related symptoms and causes for SBS (Gupta, Khare, & Goyal, 2007). Among many indoor air pollutants, TVOC and CO<sub>2</sub> were identified to carry out the research. The questionnaire was developed to collect the data from the building occupants and a pilot study was carried out to measure the effectiveness of that questionnaire. Finally, the Actual survey was carried out and the required data was collected.

The measuring equipment selected for TVOC measurements was OMEGA HHAQ-107 data logging VOC meter which is used to detect the measurements of TVOC concentration, temperature, and relative humidity. The measurement range and resolution were 0 to 50 ppm and 0.01 ppm respectively. For CO<sub>2</sub> measurements, EXTECH CO240 Handheld Indoor Air Quality CO<sub>2</sub> Meter was selected and it had a range of 0 to 9999 ppm with 1 ppm resolution. The questionnaire was developed to assess the factors related to SBS. It was categorized according to General information,

Building materials, Building occupants' information, Residence condition information, Building performance information, Health and symptoms related information, and Occupants' overall rating. It was decided to measure IAQ parameters with TVOC and CO<sub>2</sub> meters namely TVOC concentration, CO<sub>2</sub> concentration, temperature, and humidity. Also it was decided to observe Outdoor TVOC and CO<sub>2</sub> concentrations. During the field measurement taking for indoor areas, readings were taken from six to eight places depending on the area and the type of the apartment unit and averaged it for the final analysis.

A pilot survey was carried out for 6 apartments and the effectiveness of the questionnaire was verified. Then the actual survey was conducted for 30 numbers of apartments and the required data was gathered. During the analysis, all the parameters were compared against the observed TVOC and CO<sub>2</sub> Levels.

### **1.5 Main Findings**

According to the analysed results, followings are the main findings

- Air conditioners and the nature of using it affects the indoor CO<sub>2</sub> level
- Type of Air fresheners used, wall paints and new furniture affects the indoor TVOC level.
- When the indoor CO<sub>2</sub> level and TVOC level get high, the tendency of observing SBS related symptoms in building occupants increases.

### **1.6 Chapter Breakdown**

#### **Chapter 1**

Chapter one contains the research background, objectives, scope and limitations of the study, research methodology, main findings, and chapter breakdown.

#### **Chapter 2**

Chapter two is the literature review. It provides the knowledge available in the relevant research area. Descriptions about Sick Building Syndrome, Indoor Air Quality, indoor

air pollutants and sources, indoor CO<sub>2</sub> and indoor TVOC are included in detail in this chapter.

### **Chapter 3**

Chapter 3 consists of the research methodology. It elaborates how the questionnaire survey was developed and carried out, specifications of the equipment used, and data collection and analysis method.

### **Chapter 4**

Chapter 4 presents the results obtained from the collected data. A statistical analysis has been done separately for CO<sub>2</sub> related factors and TVOC related factors and the results are graphically represented. Further, SBS related factors are analysed in order to find a relationship between SBS and IAQ.

### **Chapter 5**

Chapter 5 contains the conclusions and recommendations.

## **2. LITERATURE REVIEW**

### **2.1 General**

Sick Building Syndrome (SBS) can be described as a medical condition where building occupants feel symptoms of illness or unwell due to building related factors. These factors can correspond to the indoor environment of the building. It is used to describe situations where building occupants start to feel discomfort and acute health conditions.

Indoor Air Quality (IAQ) is one of the governing factors that could affect SBS. Out of many indoor air pollutants, Carbon Dioxide (CO<sub>2</sub>) and Volatile Organic Compounds (VOC) is selected for the study. The categories of pollutants, sources, and threshold values were identified to develop the research methodology.

### **2.2 Sick Building Syndrome**

SBS can be described in many ways and several authors have provided different definitions for SBS with similar contexts.

“Sick building syndrome is a condition affecting occupants of a building from which they may experience a series of non-specific symptoms from being in that building.” (Thach, et al., 2019)

“Sick building syndrome is the term commonly used to describe a constellation of symptoms that have no clear etiology and are attributed to exposure to a particular building environment.” (Wang, et al., 2008)

“Sick building syndrome (SBS) is usually defined as an increased occurrence of non-specific symptoms among populations in determined buildings” (Thorn, 1998)

Similarly, most of the definitions and descriptions are based on the symptoms developed in the human bodies of the occupants. Also, it has been observed that when the building occupants leave the building, these symptoms may eventually disappear. Because of that the idea of sick building and the related symptoms have been established.

### 2.2.1 Symptoms

Following symptoms can be pointed out based on the literature

- Irritation in eyes
- Irritation in skin
- Irritation in ears
- Runny nose
- Blocked nose
- Dry throat
- Lethargy
- Drowsy
- Tiredness
- Fatigue
- Dry face
- Dry hands
- Headache
- Nausea
- Cough
- Poor concentration
- Dizziness
- Difficulty in breathing
- Lack of concentration
- Tightness of the chest

These symptoms may not be very dangerous initially but eventually will lead to loss of work productivity of humans inside the building. (Sun, et al., 2019)

However, having long term exposure to these symptoms may lead to Building Related Illness (BRI) and it may lead to personal health problems. (Crook & Burton, 20210)

### **2.2.2 Causes**

In general, it can be specified that poor Indoor Environmental Quality (IEQ) can lead to SBS. Some of the factors affecting IEQ can be listed down as,

- Quality of air for breathing
- Thermal comfort
- Ventilation
- Visual comfort and lighting
- Acoustic comfort
- Cleanliness of the living environment (Ravindu, Rameezdeen, Zuo, Zhou, & Chandratilake, 2015)

At the time when these factors tend to become inconvenient or not comfortable for building occupants the phenomenon called SBS can be expected. Researchers have justified the fact that having good IEQ can reduce SBS. (Al horr, et al., 2016)

### **2.3 Indoor Air Quality**

Indoor Air Quality (IAQ) is a sub-set of Indoor Environmental Quality (IEQ).

Although it is difficult to provide an exact definition for IAQ, it can be noted that it corresponds to the indoor air pollutants which can be categorized into chemical, physical and biological aspects, etc. The term quality is also subjective here since it depends on the people and also the standards related to IAQ have different figures with respect to countries and regions.

However, the United States Environmental Protection Agency describes IAQ as follows,

“IAQ refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants” (Steinemann, Wargocki, & Rismanchi, 2017)

Among the factors listed in section 2.1.3, ventilation plays a huge role in determining the IAQ. In addition to that, temperature and humidity can also contribute to the IAQ.

Several Green building standards and specifications mention the importance of IAQ and they have given a significant place for IAQ related factors in their point systems.

In addition to that, it has been found that outdoor air quality also contributes to the level of indoor air quality. (Jeong, et al., 2019)

### **2.3.1 Indoor Air Pollutants**

Although there are a lot of indoor air pollutants divided into categories and sub-categories, the following can be mentioned in general.

- Carbon Dioxide (CO<sub>2</sub>)
- Carbon Monoxide (CO)
- Volatile Organic Compounds (VOC)
- Sulfur Dioxide (SO<sub>2</sub>)
- Nitrogen Dioxide (NO<sub>2</sub>)
- Particulate Matter (PM)

The sources of these indoor air pollutants can be listed as;

- Combustion (wood, kerosene, etc.)
- Tobacco smoke
- Building materials (Paints, wood based products, ceilings, gypsum boards, etc.)
- Heating of oils and fats
- Household cleaners
- Cosmetics
- Pesticides
- Adhesive resins and carpets (Paleologos, Selim, & Mohamed, 2020)

### **2.3.2 Standards and Certification Systems related to IAQ**

Several international bodies and standards have provided threshold values for these indoor air pollutants. Some of the commonly referred institutions and documents by the researchers are,

- World Health Organization (WHO)
- National Ambient Air Quality Standards (NAAQS) developed by the United States Environmental Protection Agency (USEPA)
- Indoor Air Quality Guide by The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
- Indoor Air Quality Guidelines by Illinois Department of Public Health (IDPH)
- Technical Manual of Occupational Safety and Health Administration (OSHA)
- Leadership in Energy and Environmental Design (LEED) Guidelines
- Building Research Establishment's Environmental Assessment Method (BREEAM) Guidelines
- Green Star Guidelines
- Rating System for Built Environment by Green Building Council of Sri Lanka (GBCSL)
- Green Building Guidelines for Sri Lanka by Urban Development Council Sri Lanka (UDA-SL)

These standards and their threshold values can be varied widely depending on the climatic conditions of the countries, living standards, etc. Abdul-Wahab (2015) has provided a comprehensive study of how several guidelines have defined its threshold values for indoor air pollutants. (Abdul-Wahab, Fah En, Elkamel, Ahmadi, & Yetilmezsoy, 2015)

### **2.4 The main indoor pollutants considered in the study**

Out of the mentioned indoor air pollutants in section 2.3.1, Carbon Dioxide and Volatile Organic Compounds were selected for the study considering the availability of time and resources (measuring equipment, human resources, etc.)

### **2.4.1 Indoor Carbon Dioxide**

Carbon Dioxide (CO<sub>2</sub>) is a colourless and smell-less gas. According to Chemistry, a CO<sub>2</sub> molecule consists of one Carbon atom and two numbers of Oxygen atoms. It is an inflammable gas as well.

One of the main sources of indoor CO<sub>2</sub> is through building occupants' body respiration and having a poor ventilation system can increase the indoor CO<sub>2</sub> level as well. The other main source of indoor CO<sub>2</sub> is the combustion of Carbon based products. (Shen, et al., 2020)

Another factor that could be decisive in indoor CO<sub>2</sub> level is the air conditioner usage. It has been found that indoor CO<sub>2</sub> levels are high in buildings with non-centralized air conditioning and ventilation systems. (Asif, Zeeshan, & Jahanzaib, 2018)

If the building occupants are not using an air conditioner, a decisive factor that will determine the ventilation rate and indoor CO<sub>2</sub> level will be the window opening frequency and opening time. It has been found that when the window opening time increases, the indoor CO<sub>2</sub> level gradually decreases. (Huang, et al., 2018)

Another factor that could be impacting indoor CO<sub>2</sub> is the number of building occupants at a given time. If building ventilation is designed for a particular number of occupants and when that number of occupants increases, the existing ventilation system may not be capable of handling the indoor air. That could increase the indoor CO<sub>2</sub> level as well.

A less discussed but important indicator related to indoor CO<sub>2</sub> level is the indoor to outdoor concentration ratio. Ventilation systems designed for the buildings are always exchanging indoor air with outdoor air. So arguably the outdoor CO<sub>2</sub> level has an impact on the indoor CO<sub>2</sub> level as well. The statistical models have also been developed to predict the indoor CO<sub>2</sub> levels based on outdoor CO<sub>2</sub> levels claiming that there is a relationship. (Lee, Ryu, Kim, & Bae, 2016)

In Sri Lankan context, the effect of outdoor air pollution has impacted indoor air pollution as well. The general ventilation system design is done by maintaining the indoor CO<sub>2</sub> level below 1000 ppm and assuming the outdoor CO<sub>2</sub> level is around 400 ppm as per ASHRAE guidelines. However, if the outdoor CO<sub>2</sub> level in the urban areas

gets increased up to around 650 ppm, the ventilation system might not work properly increasing the indoor CO<sub>2</sub> level.

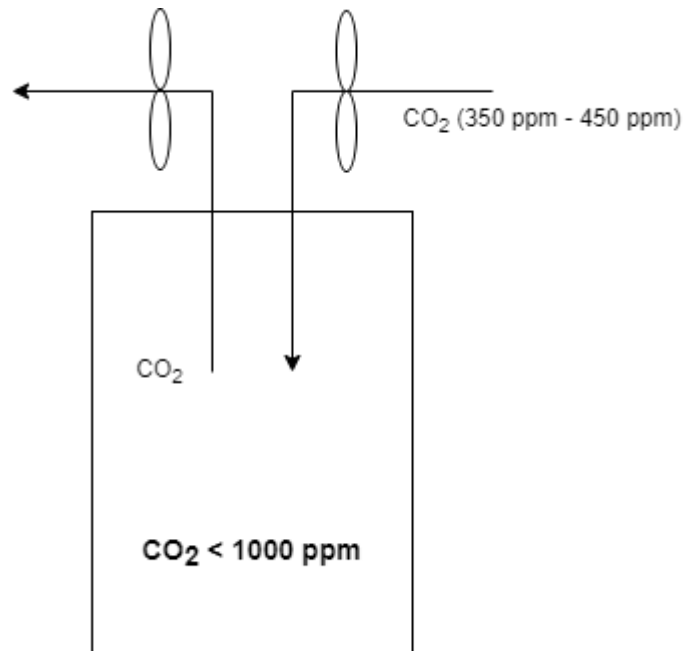


Figure 2.1: Schematic diagram of building mechanical ventilation system

Table 2.1 provides the threshold values specified by several standards and guidelines for indoor CO<sub>2</sub> levels.

Table 2.1: Threshold values of CO<sub>2</sub>

Standard/Guideline	Threshold Value
WHO	1000 ppm
ASHRAE	1000 ppm
IDPH	1000 ppm
OSHA	5000 ppm
UDA-SL	1000 ppm

It is evident that most of the guidelines have decided that the threshold value for indoor CO<sub>2</sub> is 1000 ppm.

Although CO<sub>2</sub> is not considered as a toxic compound, researchers have found that having high CO<sub>2</sub> levels can prevail SBS. (Seppanen, Fisk, & Mendell, 1999)

### **2.4.2 Indoor Volatile Organic Compounds**

Volatile Organic Compound (VOC) is a carbon based gaseous chemical compound. There are many gaseous chemical compounds which can be categorized as VOCs. For measuring and analysis purposes these set of chemicals is labeled as “Total Volatile Organic Compounds (TVOC)”.

Some of the chemical compounds that fall into the VOC category in domestic use are,

- Acetaldehyde
- Benzene
- Carbon Tetrachloride
- Chloroform
- Ethylbenzene
- Formaldehyde
- Hexane
- Methyl chloride
- Naphthalene
- Paradichlorobenzene
- Styrene
- Tetrachloroethylene
- Toluene
- Trichloroethylene
- Xylenes

The sources and the factors affecting these chemical compounds are categorized in Table 2.2 (Tucker, 2004)

Table 1.2: Sources of domestic indoor TVOC

Source	Examples	Factors Affecting
Paints, coatings, sealants, and caulks	<ul style="list-style-type: none"> <li>• Solvent, oil, and water based paints</li> <li>• Varnish</li> <li>• Wax</li> <li>• Waterproofing coatings and sealants</li> <li>• Caulks</li> </ul>	<ul style="list-style-type: none"> <li>• Amount of material used</li> <li>• The volatility of the chemical compound</li> <li>• Time/Duration/Age</li> <li>• Surface area per volume and surface condition of the material</li> <li>• Temperature</li> <li>• Humidity</li> <li>• Ventilation</li> <li>• Chemical reactions of the materials</li> </ul>
Furniture, wood, and timber based products	<ul style="list-style-type: none"> <li>• General residential furniture</li> <li>• Cabinets and pantry cupboards</li> <li>• Plywood</li> <li>• Partition boards</li> <li>• Timber decks</li> </ul>	
Floor, wall, and ceiling materials	<ul style="list-style-type: none"> <li>• Carpets</li> <li>• Vinyl</li> <li>• Gypsum boards</li> <li>• Ceiling tiles</li> <li>• Wall panels</li> <li>• Wallpaper and coverings</li> </ul>	
Adhesives and insulation materials	<ul style="list-style-type: none"> <li>• Carpet, flooring, and other general adhesives</li> <li>• Fibrous and foam materials</li> </ul>	
Cleaning agents	<ul style="list-style-type: none"> <li>• Air fresheners</li> <li>• Detergents</li> <li>• Disinfectors</li> <li>• Other solvent based cleaning products</li> </ul>	
Pesticides	<ul style="list-style-type: none"> <li>• Insect repellents and other general pesticides</li> </ul>	

Out of these categories, building materials and furniture have a lot of impact on emitting VOCs into the indoor air and this phenomenon is severe in newly decorated residential buildings. (Lv & Yang, 2019)

The presence of VOCs in indoor air may be in very little amounts unlikely in CO<sub>2</sub>. Although Parts per million (ppm) can be used as a measuring unit, parts per billion (ppb) may be a more convenient unit of measure due to its little presence in indoor air.

But that little presence also can create a risk to building occupants' health. (Woolley, 2017)

It has been found that the TVOC concentrations in the indoor air due to these sources are gradually decreased with time depending on the use of those sources. A study has been carried out to evaluate the diminishing nature of TVOC based on their sources and Table 2.3 provides a summary of the maximum concentrations observed. (Yu & Crump, 1998) That particular study also reveals that the indoor TVOC concentration is typically ten times higher than the outdoor TVOC concentration.

Table 2.3: Maximum TVOC concentrations and measured periods

<b>Period</b>	<b>Maximum TVOC Concentration</b>
During the first month	9700 $\mu\text{g}/\text{m}^3$
After 6 months	800 $\mu\text{g}/\text{m}^3$
After 12 months	600 $\mu\text{g}/\text{m}^3$
After 18 months	200 $\mu\text{g}/\text{m}^3$

If any TVOC generating source is renewed or reused, again an increment in indoor TVOC level can be expected.

The rating system for the built environment by Green Building Council of Sri Lanka (GBCSL) has provided limitations for some VOC emitting categories in detail. Table 2.4 provides the ranges of VOC limits given under those categories for individual components.

Table 2.4: VOC threshold values by GBCSL

<b>Category</b>	<b>VOC limit or Range</b>
Architectural Applications	50 – 100 (g/L)
Substrate Specific Application	30 – 80 (g/L less water)
Specialty Application	80 – 510 (g/L less water)
Sealants	250 – 450 (g/L less water)
Sealant Primers	250 – 750 (g/L less water)
Paints	50 – 250 (g/L less water)
Coatings	100 – 550 (g/L less water)
Carpet Adhesives	50 (g/L)

## 2.5 Summary

Poor Indoor Air Quality (IAQ) can lead to the phenomenon called Sick Building Syndrome (SBS). Among many indoor air pollutants, Carbon Dioxide (CO<sub>2</sub>) and Volatile Organic Compounds (VOC) have been identified and being researched by many researchers all around the world.

Many standards and guidelines have provided threshold values and limitations for the said indoor air pollutants. For CO<sub>2</sub>, it is 1000 ppm most of the time and for Total Volatile Organic Compounds (TVOC) the values depend on the source and the type of chemical compound.

Exceeding these limitations can prevail the symptoms which are related to SBS such as asthma, irritation in face, drowsy, dizziness, dry face, etc.

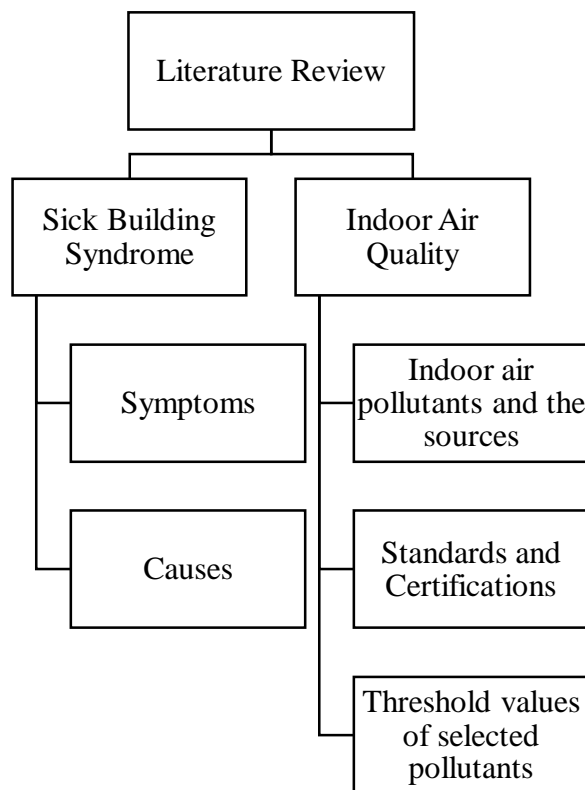


Figure 2.2: Summary of the Literature Review

Based on a detailed literature review it has been identified the knowledge gap as to build the relationship between the sick building syndrome and indoor air quality.

### **3. Field Study**

#### **3.1 General**

This research is based on data collected by a Questionnaire Survey and measurements taken on field study. Literature Review was carried out to find out on the uses of questionnaire and the SBS related symptoms and causes for SBS. Among many Indoor air pollutants, TVOC and CO<sub>2</sub> were identified to carry out the research. The questionnaire was developed to collect the data from the building occupants and a pilot study was carried out to measure the effectiveness of that questionnaire. Finally, the Actual survey was carried out and the required data was collected.

Measuring Equipment were selected after doing a comparison between equipment specifications to obtain TVOC measurements and CO<sub>2</sub> measurements. It could detect the measurements of temperature and relative humidity as well. A questionnaire was developed to assess the factors related to SBS. It was categorized according to General information, Building materials, Building occupants' information, Residence condition information, Building performance information, Health and symptoms related information, and Occupants' overall rating.

It was decided to measure IAQ parameters with TVOC and CO<sub>2</sub> meters namely TVOC concentration, CO<sub>2</sub> concentration, temperature, and humidity. Moreover, it was decided to observe Outdoor TVOC and CO<sub>2</sub> concentrations. During the field measurement taking for indoor areas, readings were taken from six to eight places depending on the area and the type of the apartment unit and averaged it for the final analysis. Pilot survey was carried out for 6 apartments and the effectiveness of the questionnaire was verified. Then the actual survey was conducted for 30 apartments and the required data was gathered. During the analysis, all the parameters were compared against the observed TVOC and CO<sub>2</sub> Levels.

#### **3.2 Questionnaire Survey**

A study was done first to find on the effective ways of carrying out a questionnaire for residential buildings (Carpino, Mora, & De Simone, 2019) as the same should be a task that is required to carry out carefully and cautiously. So following elements were decided accordingly.

- Apartments were selected randomly based on the availability and willingness to help of the occupants.
- Paper based questionnaire (printed) were distributed to the occupants in person.
- Building occupants were encouraged to fill out the questionnaire on their own as much as possible. The data collectors' interference was kept to a minimum when the building occupant was filling the questionnaire.
- The duration to fill the questionnaire was kept to a maximum of 20 minutes

Prior approval had to be obtained from relevant authorities to enter the privately owned apartments. The approvals were obtained from property developers, building management committees, and building occupants. The request for approval letter is attached in the Appendix.

When developing the questionnaire survey which is to be filled by building occupants, based on literature, the following information was finalized. (Gupta, Khare, & Goyal, 2007)

- General building and apartment information
- Building occupants' information
- Building performance
- Factors related to indoor CO<sub>2</sub> concentration
- Factors related to indoor TVOC concentration
- SBS related symptoms experienced
- Overall rating

In order to get a reasonably effective response from each respondent, five point Likert scale was used. (Harpe, 2015)

Before carrying out the actual survey, a pilot survey was performed for 6 apartments in order to verify the procedure and its effectiveness. Then, the data was collected from 30 numbers of apartments for the final analysis.

The used questionnaire is attached in the Appendix.

### 3.3 Equipment Used and Specifications

When selecting a measuring equipment, the factors considered were accuracy, reliability, speed, and robustness.

So the measuring equipment selected for TVOC measurements was OMEGA HHAQ-107 Data logging VOC meter. It could detect the measurements of TVOC concentration, temperature, and relative humidity. The measurement range and resolution were 0 to 50 ppm and 0.01 ppm respectively. The instrument data and the specifications are included in the Appendix.

For CO<sub>2</sub> measurements, EXTECH CO240 Handheld Indoor Air Quality CO<sub>2</sub> Meter was selected and it had a range of 0 to 9999 ppm with 1 ppm resolution. It also could measure the temperature and relative humidity. The instrument data and the specifications are attached in the appendix.

During the field measurement taking for indoor areas, readings were taken from six to eight places depending on the area and the type of the apartment unit and averaged for the final analysis. Then it was decided to observe Outdoor TVOC and CO<sub>2</sub> concentrations. Figure 3.1 shows how the indoor and outdoor air measurements were taken using the measuring instruments.

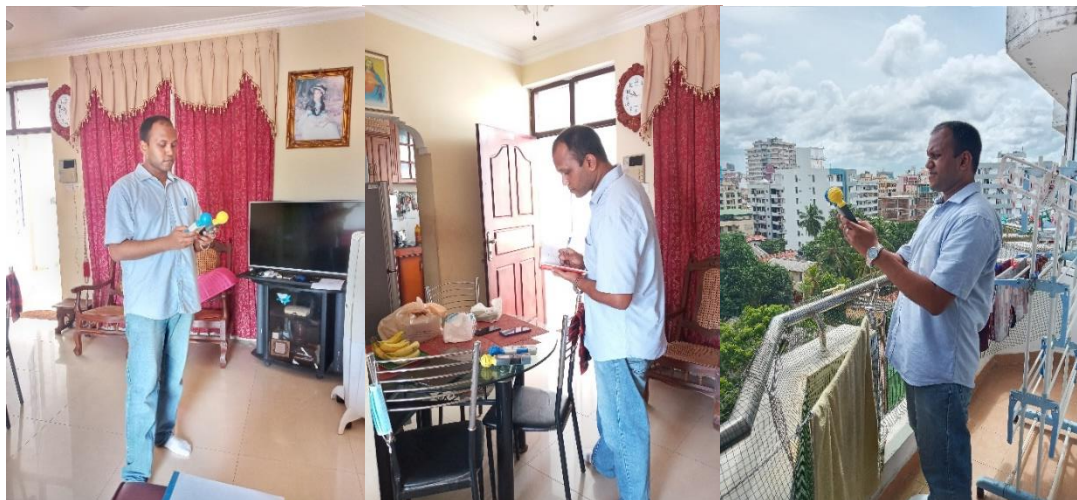


Figure 3.1: Taking the air quality measurements during the questionnaire survey

After carrying out the pilot survey, an actual survey was conducted for 30 apartments and the required data was gathered. During the analysis, all the SBS related parameters were compared against the observed TVOC and CO<sub>2</sub> Levels.

### 3.4 Data Analysis Method

A simple and convenient computer application, Microsoft Excel 2016 was used to analyse the data as it had the ability to do basic statistical operations like averaging, sorting, regression analysis, etc.

For a single apartment unit, all the CO<sub>2</sub> and TVOC values obtained from several locations were averaged to get a single CO<sub>2</sub> and a TVOC value per apartment.

Accordingly, depending on the related factors and symptoms, the values were categorized in a way that a comparison would be more sensible and effective.

Symptoms were analysed according to a points system, which will be described in Chapter 4.

### 3.5 Summary

The entire research methodology can be represented as a summary by Figure 3.2

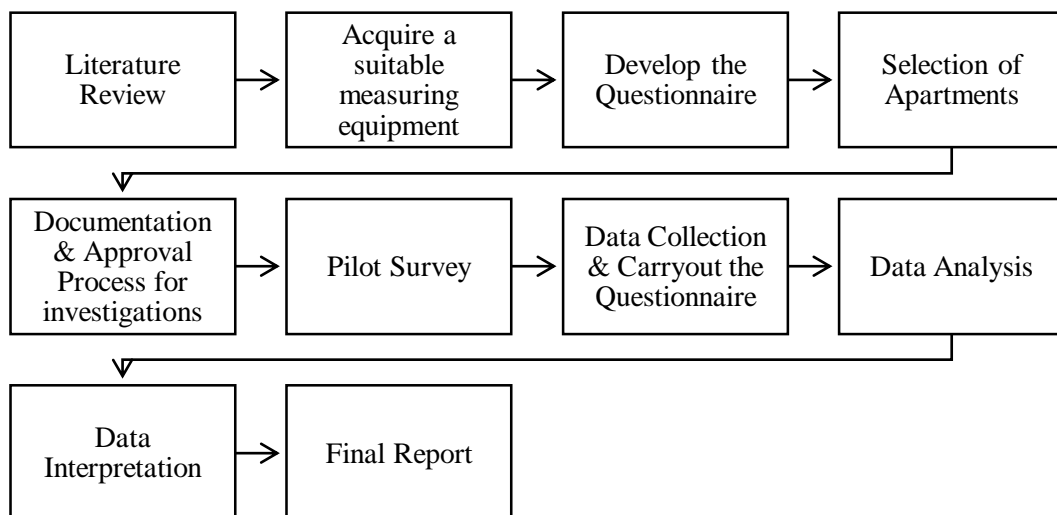


Figure 3.2: Summarized representation of the research methodology

## **4. RESULTS AND ANALYSIS**

### **4.1 General**

The data obtained from the questionnaire was analysed aiming to find relationships between indoor air quality related parameters and the symptoms experienced by the building occupants.

Indoor CO<sub>2</sub> level was compared against the factors of air conditioner usage, window opening frequency, and the frequency of servicing the air conditioner.

Indoor TVOC level was compared against the factors of air freshener type used, time since the walls are painted, and time since new furniture was brought.

Finally, the observed symptoms were analysed by introducing a scoring system. With the help of that scoring system, a comparison was done separately for observed indoor CO<sub>2</sub> levels and indoor TVOC levels in order to find a correlation with the experienced symptoms by the building occupants.

### **4.2 Variation of indoor CO<sub>2</sub> concentrations**

Factors related to air conditioner usage, air conditioner maintenance, and window opening frequency were identified as reasons affecting the indoor CO<sub>2</sub> level.

#### **4.2.1 Variation of indoor CO<sub>2</sub> concentration with Air conditioner usage**

It was identified that the apartments which did not have air conditioners had 528 ppm indoor CO<sub>2</sub> levels on average and the apartments which had air conditioners had 548 ppm indoor CO<sub>2</sub> level on average.

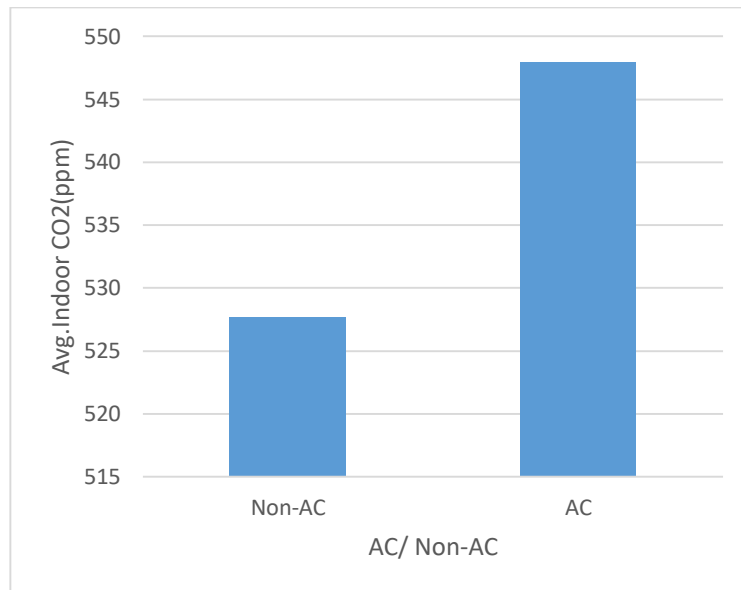


Figure 4.1: Air Conditioner Usage Vs Average Indoor CO<sub>2</sub> level

According to Figure 4.1, it can be clearly observed that the indoor CO<sub>2</sub> level was higher in the apartments which had an air conditioner than the apartments which did not have an air conditioners.

#### 4.2.2 Variation of indoor CO<sub>2</sub> concentration with operational practices of openings

This parameter was analysed separately for air conditioned apartments and non-air conditioned apartments.

For the air conditioned apartments, no responses were received for the option of “Never”. The responses for the options of “Very Often” and “Rarely” were negated as only one response was received for each. So out of the other two options, the average indoor CO<sub>2</sub> level corresponded to “Always” was 524 ppm, and the average indoor CO<sub>2</sub> level corresponded to “Sometimes” was 573 ppm.

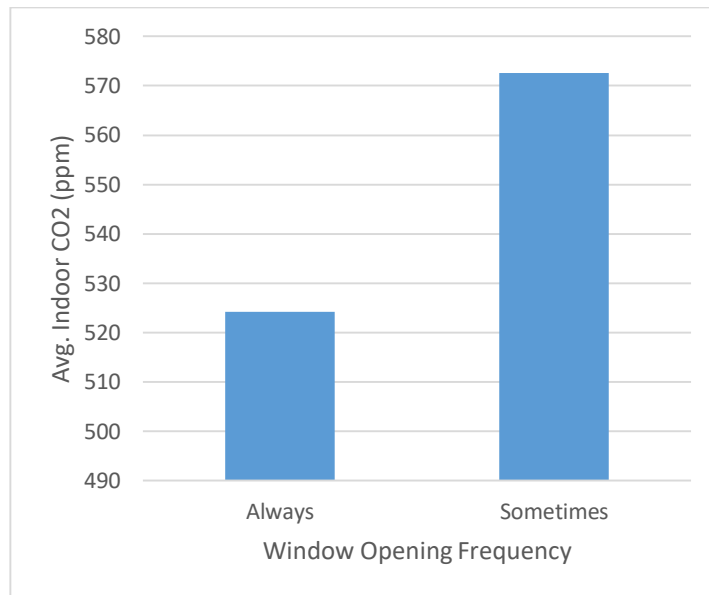


Figure 4.2: Window opening frequency (air conditioned apartments) Vs Average indoor CO<sub>2</sub> level

According to Figure 4.2, it can be seen that the occupants who open the windows sometimes in the apartment are experiencing more indoor CO<sub>2</sub> level than the occupants who open the windows always in the apartment.

The responses were received only for the options of “Always”, “Very Often”, and “Sometimes” from samples comprising non air conditioned apartments. Observed average indoor CO<sub>2</sub> levels were 507 ppm, 552 ppm, 578 ppm respectively.

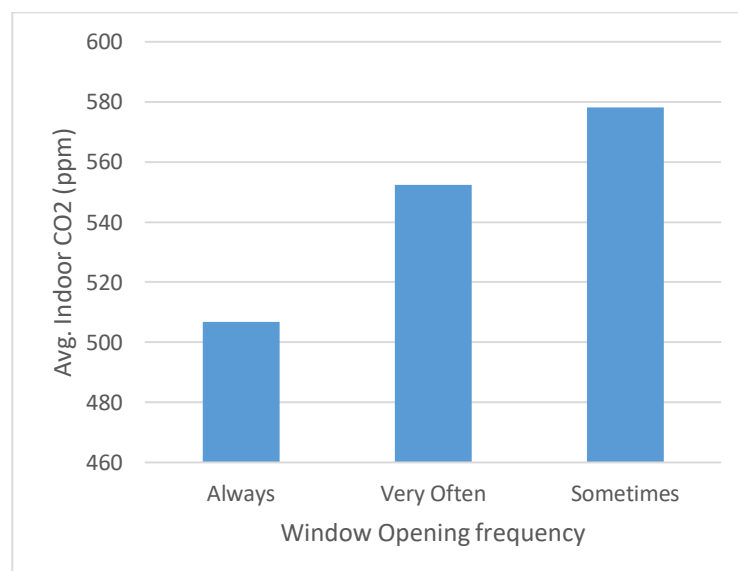


Figure 4.3: Window opening frequency (non-air conditioned apartments) Vs Average indoor CO<sub>2</sub> level

According to Figure 4.3, it can be seen that when the window opening frequency decreased in the apartments, the indoor CO<sub>2</sub> level gets increases.

#### 4.2.3 Variation of indoor CO<sub>2</sub> concentration with the maintenance of Air conditioner

Out of the apartments in which air conditioners were used, this parameter was checked in two different ways.

When analysing the frequency of the air conditioner is serviced, it was identified that if it is less than 6 months, the average indoor CO<sub>2</sub> level is 544 ppm and if it is more than 6 months, the average indoor CO<sub>2</sub> level is 555 ppm.

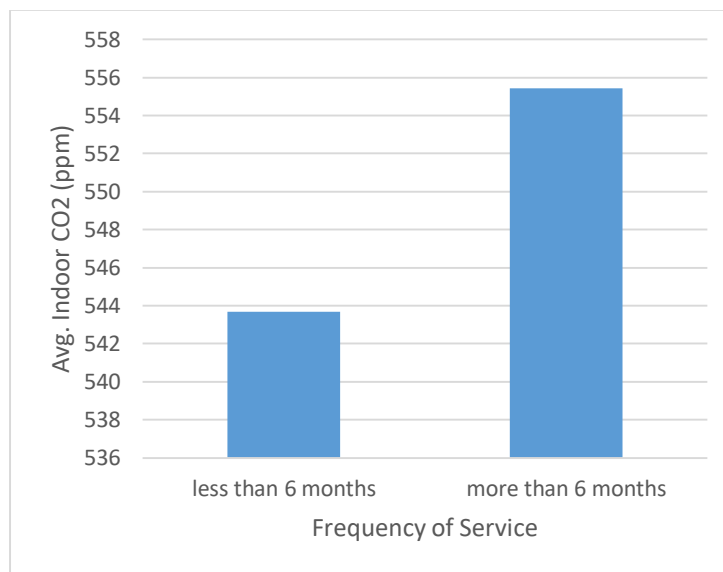


Figure 4.4: Air conditioner service frequency Vs Average indoor CO<sub>2</sub> level

According to Figure 4.4, occupants who service their air conditioner in less than 6 months intervals experience less indoor CO<sub>2</sub> level than the occupants who service their air conditioners in more than 6 months intervals.

When analyzed concerning the time since the last service, it was observed that if the last service was done less than 6 months ago, the average indoor CO<sub>2</sub> level was 537 ppm and if the last service was done more than 6 years ago, the average indoor CO<sub>2</sub> level was 567 ppm.

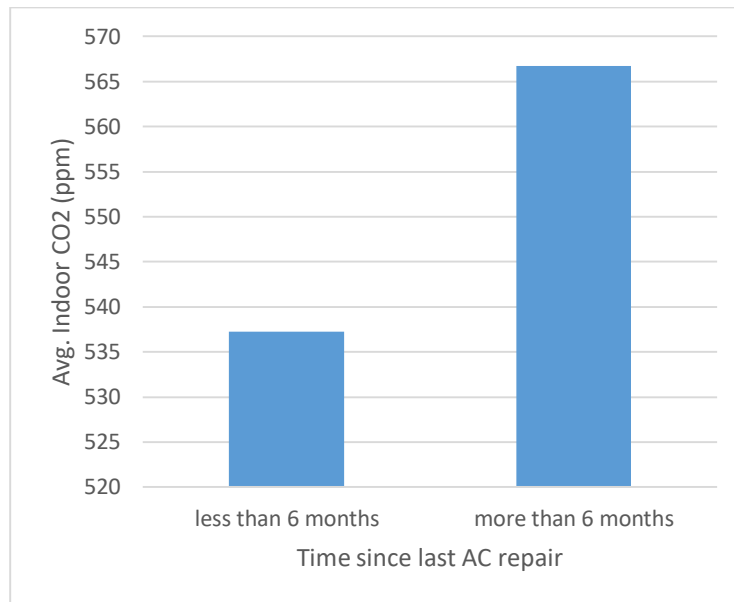


Figure 4.5: Time since last repair to the air conditioner Vs Average indoor CO<sub>2</sub> level

According to Figure 4.5, the indoor CO<sub>2</sub> levels are higher in the apartments in which the air conditioner was last serviced more than 6 months ago compared to the apartments in which the air conditioner was last serviced more than 6 months ago.

### 4.3 Variation of Indoor TVOC related factors

Factors related to types of air fresheners used, application of new paint, time since new furniture brought were identified as reasons affecting the indoor TVOC level.

#### 4.3.1 Variation of indoor TVOC concentration with the type of air fresheners used

Among the obtained options only the “Incense sticks” and “Spray Type” had a sufficient number of responses to carry out a comparative analysis. The obtained average indoor TVOC levels for those were 0.060 ppm and 0.142 ppm respectively.

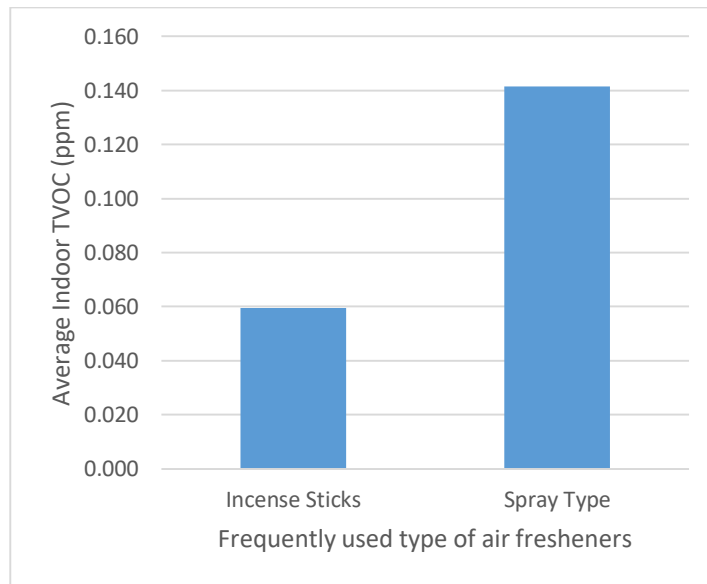


Figure 4.6: Type of air fresheners used Vs Average indoor TVOC level

According to Figure 4.6, it is evident that the apartments which are using spray type air fresheners are having more than two times the indoor TVOC content than the apartments which are using incense sticks.

#### 4.3.2 Variation of TVOC concentration with the application of new paint

The received responses were categorized as less than 6 months and more than 6 months. The observed average indoor TVOC levels were 0.252 ppm and 0.162 ppm respectively.

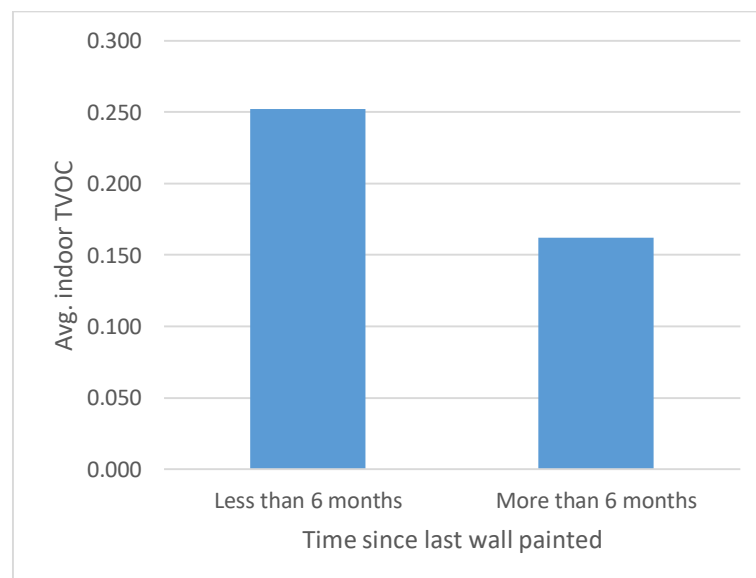


Figure 4.7: Time since the last wall painted Vs Average indoor TVOC level

According to Figure 4.7, the apartments in which the walls were painted within the last 6 months were having more indoor TVOC content than the apartments which had painted the walls more than 6 months ago.

### 4.3.3 Variation of indoor TVOC concentration with the time since new wooden and fabric furniture brought

The responses were received for the options of 3 months, 6 months, 12 months and more than 12 months. Observed average indoor TVOC levels were 0.461 ppm, 0.232 ppm, 0.216 ppm, 0.148 ppm respectively.

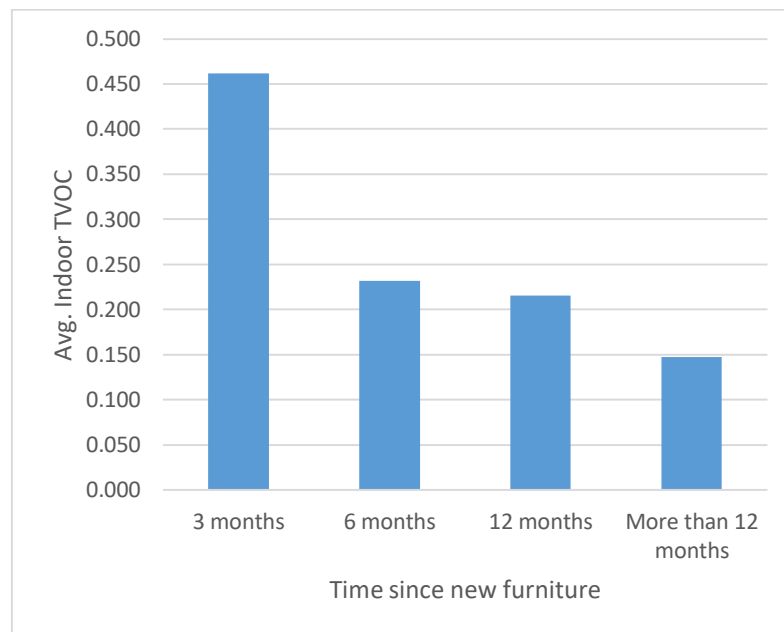


Figure 4.8: Time since last new furniture Vs Average indoor TVOC level

According to Figure 4.8, it is evident that when the time period since new wooden and fabric furniture is brought extends, the observed indoor TVOC level gets decreased.

### 4.4 SBS related Symptoms Analysis

A point system was adopted as per Table 4.1 to analyse the observed symptoms and the frequency of the same. The purpose of this value assignment is to analyse the effect of all the symptoms at once.

Table 4.1: Point system adopted for SBS symptom frequency

<b>Frequency</b>	<b>Assigned Value</b>
Never	0
Rarely	1
Sometimes	2
Very Often	3
Always	4

#### 4.4.1 Scores for each symptoms

Out of the SBS related symptoms inquired through the questionnaire, Table 4.2 provides the individual score for each symptom considered for the analysis.

Table 4.2: Scores obtained for each symptom inquired

<b>Symptom</b>	<b>Total Points</b>
Irritation in eyes	36
Runny nose	32
Dry throat	27
Lethargy/ Drowsy/ Tiredness	34
Dry face/ Dry hands	21
Headache	41
Cough	18

It can be seen that, out of the inquired SBS related symptoms, Headache has the highest points and Cough has the lowest points. Alternatively, it can be said that the tendency of experiencing the SBS related symptoms by the building occupants are in the following order.

- Headache
- Irritation in eyes
- Lethargy/ Drowsy/ Tiredness
- Runny nose
- Dry throat
- Dry face/ Dry hands
- Cough

#### 4.4.2 Correlation of SBS with the indoor pollutants

The symptoms scores obtained with respect to each apartment unit were analysed against the measured indoor TVOC and CO<sub>2</sub> levels in order to find whether there is a relationship between said parameters.

So a regression analysis was performed using Microsoft Excel software.

Figure 4.9 and Figure 4.10 show the analysis results generated by the stated software.

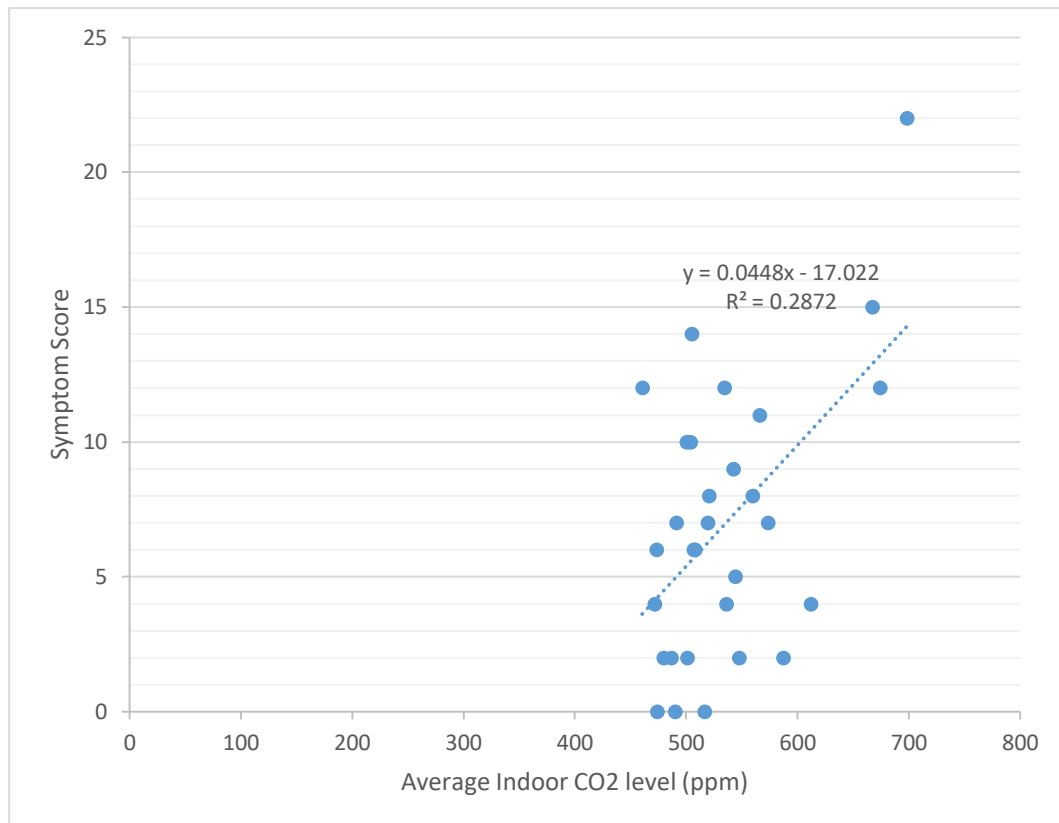


Figure 4.9: Relationship between average indoor CO<sub>2</sub> level and Symptom score

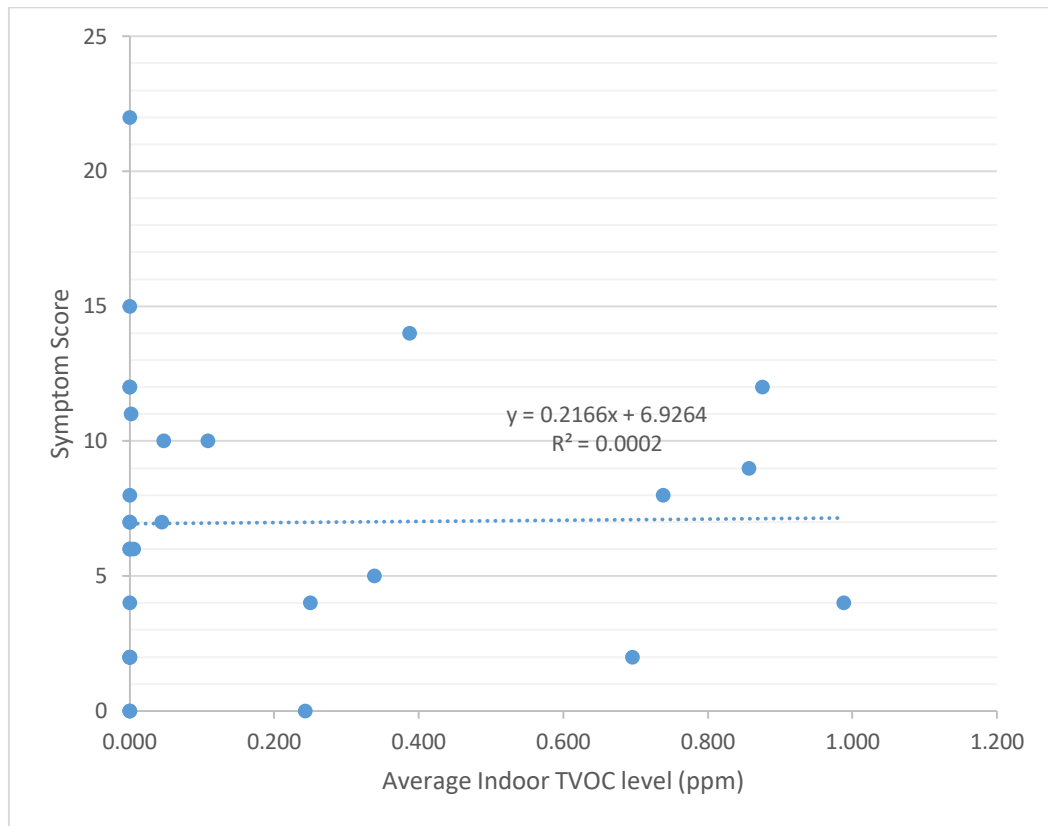


Figure 4.10: Relationship between average indoor TVOC level and Symptom score

According to the analysis, it can be observed that there is a positive correlation between the considered parameters. The correlation coefficients are 0.536 and 0.014 for indoor CO<sub>2</sub> and indoor TVOC respectively.

So it can be said that when the average indoor CO<sub>2</sub> level increases, the symptom score also increases. That implies when the indoor CO<sub>2</sub> and TVOC level increases, the occupants tends to feel several SBS related symptoms. However, although there is a positive relationship between average indoor TVOC level and Symptom score, a reasonable conclusion cannot be derived as the correlation coefficient is very low.

#### 4.5 Summary

To summarize the results with respect to the indoor air quality related parameters, Table 4.3 is used.

Table 4.3: Results summary of indoor air quality related parameters

<b>Related parameter</b>	<b>Analyzed Parameter</b>	<b>Indication</b>
Indoor CO <sub>2</sub>	Usage of air conditioner	Indoor CO <sub>2</sub> levels were higher in the apartments which had air conditioners than the apartments which did not have air conditioners
	Window opening Frequency	Higher the frequency, lower the indoor CO <sub>2</sub> level in both air conditioned and non-air conditioned apartments
	Air conditioner service and maintenance	If it takes longer than six months to service the air conditioner the indoor CO <sub>2</sub> level increases in the apartments
Indoor TVOC	Type of air freshener used	Indoor TVOC levels were higher in the apartments which used spray type air fresheners than the apartments which used incense sticks
	Time since wall painted last	Indoor TVOC levels were higher in the apartments which the painting had done within the last 6 months than the apartments which had done painting more than 6 months ago
	Time since new furniture brought	Longer the time since new furniture brought, lower the indoor TVOC level

Regarding the symptoms of SBS, it was found that the most frequently experienced symptom by the building occupants is headache and least experienced symptom is cough. Other symptoms were ordered according to the symptom score introduced in Table 4.1 in Section 4.4.

Then the relationship between the selected two indoor air pollutants and the symptoms experienced by the building occupants were analysed. Indoor air pollutant level in ppm and symptom score were the parameters selected for the regression analysis. Table 4.4 summarizes the results of the same.

Table 4.4: Summary of regression analysis carried out between indoor air pollutants Vs SBS related symptoms

<b>Parameters</b>	<b>Relationship</b>	<b>Correlation Coefficient (r)</b>
Average indoor CO <sub>2</sub> level Vs Symptom score	Positive	0.536
Average indoor TVOC level Vs Symptom score	Positive	0.014

Further to this, the observed indoor air quality readings were compared with some of the national data sets and it was found that there is no significant deviations in obtained results. Hence these results can be generalized.

## **5. CONCLUSIONS AND RECOMMENDATIONS**

### **5.1 Conclusions**

There is a clear indication that having an air conditioner creates a significant impact on indoor CO<sub>2</sub> levels. The apartments which used air conditioners had more indoor CO<sub>2</sub> content than the apartments which had not used air conditioners. So it can be implied that using an air conditioner increases the indoor CO<sub>2</sub> level.

When analysing the window opening frequency, apartments were categorized as non-Air conditioned and air conditioned depending on the availability of having an air conditioner since there is a natural tendency of the occupants to not open the windows when air conditioners are used. So the options given were analysed separately to identify a pattern that gives more clarity. However, in both cases, it has indicated that higher the window opening frequency, lower the indoor CO<sub>2</sub> content.

With regard to air conditioner repairing, it was identified that when more time is taken to repair the air Conditioner, the indoor CO<sub>2</sub> level gets higher. That means there is a possibility of observing high indoor CO<sub>2</sub> levels when the air conditioner repairing gets delayed.

Among the given options for the type of air fresheners used, the only conclusive options observed were for the usage of incense sticks and spray type air fresheners. Out of those two types of air fresheners, the apartments which used spray type air fresheners had indoor TVOC levels more than two times the apartments which used incense sticks. Therefore it can be concluded that the usage of spray type air fresheners can increase the indoor TVOC level.

With regard to wall paints, it was evident that the apartments which had done the wall painting within the last 6 months, had shown more indoor TVOC levels than the apartments which had done wall painting beyond the last 6 months. Therefore, there's a tendency of emitting more TVOC in recently painted apartments. Alternatively, it can be concluded that the effect of emitting TVOC is reduced when time passes.

In apartments where the occupants bought new furniture recently indicated higher Indoor TVOC levels. Especially the apartments which had new furniture which was

brought 3 months back had almost twice the indoor TVOC amount than the apartments which had 3 to 6 months old furniture. However, it can be concluded that the effect of emitting TVOC due to new furniture depletes with the time.

When it comes to SBS related symptoms, it can be seen that both indoor CO<sub>2</sub> and indoor TVOC levels had a positive relationship with the symptoms score which means there is a tendency of getting frequent SBS related symptoms when the indoor CO<sub>2</sub> level and indoor TVOC level gets higher. However, with respect to the R value which is the correlation coefficient, the graph related to CO<sub>2</sub> had a better value than the graph related to TVOC. A value of R=0.54 means the model fits well with the observations made.

Since the observed indoor air quality readings were compared with some of the national data sets and there were no significant deviations in obtained results, data set could be generalized in order to reach acceptable conclusions.

Therefore, all the conclusions made can be summarized as follows,

- The use of air conditioners can increase the indoor CO<sub>2</sub> level.
- Opening the windows frequently can reduce the indoor CO<sub>2</sub> level.
- When it takes a long time to service the air conditioner or if it is not done frequently, the indoor CO<sub>2</sub> level can get increased.
- Spray type air fresheners emits more TVOC than incense sticks
- The TVOC emittance is higher when the walls are newly painted and with time it reduces.
- The TVOC emittance is higher when the new furniture is placed inside the apartment and with time it reduces.
- An increase in indoor CO<sub>2</sub> and TVOC levels can increase the SBS related symptoms

One of the limitations of this study was the size of the sample selected. The number of the sample was 30 because according to the central limit theorem, the minimum number of a sample which is used to predict the population should be 30 (Groebner, Shannon, Fry, & Smith, 2011). It had to be kept to the minimum due to the prevailed

Covid-19 pandemic situation as data collection was challenging with social distancing guidelines implemented by the government and respective building management committees. So due to building occupants' protection, it was assumed that the 30 numbers could be sufficient as it is justified by statistic theorems. Results are expected to be smoother and more reliable if the sample size could have been increased. So it can be recommended for future research work to extend the sample size and check the relationship between SBS symptoms and other related parameters which have not been included in Chapter 4.

## **5.2 Recommendations**

The results of this study are useful to engineers, architects, developers and the general public. It raises awareness regarding Sick Building Syndrome, Indoor air Quality and related parameters. So the following can be recommended based on this research.

In order to reduce the indoor CO<sub>2</sub> level, windows shall be opened frequently, so that proper ventilation will be there inside the apartment. If an air conditioner is used, proper maintenance and servicing it accordingly will help to increase its performance and eventually will help in maintaining a suitable indoor CO<sub>2</sub> level.

Since the use of spray type air fresheners affects the indoor TVOC level, it is recommended to avoid spray type air fresheners as much as possible. After a paint application inside the apartment or when new furniture is brought, the indoor TVOC level gets increased and with time it will gradually reduce. So it is recommended to building occupants manage the time spend during inside the apartment in the initial stages of paint application done or new furniture is brought. When spending inside the apartment, allowing good ventilation can let the polluted indoor air flow outside the apartment.

Finally, in general, it can be recommended to use suitable building construction materials, adjust the living conditions in apartments to prevent or mitigate SBS, and take care of proper ventilation in the design and operation stages.

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# **APPENDICES**

## Appendix - A

Dear Sir/Madam,

### **Requesting support for an Academic Research**

I am Pamodh Alwis. B.Sc. (Eng). Hons, currently a post graduate student of Department of Civil Engineering, University of Moratuwa. My Master's degree is specialized on Construction Project Management. As a partial fulfillment of the M.Sc. degree programme, I need to carry out a research project in the below mentioned study area.

**Title – Indoor Air Quality and Sick Building Syndrome (SBS) in High rise Apartments**

**Aim – To identify the relationship between SBS & Indoor Air Quality with respect to CO<sub>2</sub> & VOC levels**

**To monitor the SBS related symptoms of the occupants of high rise apartments**

This study area consists of,

1. Measuring indoor Air Quality by collecting Volatile Organic Compound (VOC) levels and Carbon Dioxide (CO<sub>2</sub>) levels within high rise apartments.
2. Carrying out a questionnaire to investigate recent health related symptoms faced by the residents in high rise apartments

I kindly request you to provide access to your apartments & carryout the required field measurements. I assure that the survey would be carried out in a way that no inconvenience happen to the residents or their day to day activities.

Also I assure that the personal information collected in this survey will be kept in confidential and only the summarized outputs will be included in the publications. No references will be made on the participants.

Finally, the results of this research will be used to,

1. Improve the planning process of the apartment developments
2. Add a business value for new ventures
3. Provide an assistance for existing building maintenance
4. Improve the public health, specifically on high rise apartment residents.

Therefore, please be kind enough to give your support for the above mentioned research work.

Thank you.

Faithfully,

Pamodh Alwis B.Sc. (Eng). Hons, AMIE(SL)

+94 716 732 792

pamodhhasanka@gmail.com

**Appendix - B****Research Questionnaire**

*(To be filled by the researcher through the information collected by the Building Management)*

- Name of the Apartment Building** :
- Address/Location** :
- Data Date** :
- Date of Building Construction Started** :
- Date of Building Construction completed** :
- Date of Building Start functioning** :

**Section A – General Information** *(To be filled by the researcher)*

1. Apartment No/ Unit No:
2. Floor:
3. Average Height from the Ground Floor:
4. Floor area of the Apartment/ Unit:
5. AC/ Non AC :
6. If AC, Type and Total capacity of the entire apartment unit:
7. AC capacity of the study area:

**Section B – General Information** *(To be filled by the researcher)*

1. Flooring Material:
2. Walling Material:
3. Roofing Material:

**Section C – Residence Information** *(To be filled by the resident)*

1. How long have you been in this apartment to the nearest years/months?
2. How much time (in hours) do you spend in this apartment per day/week averagely?
3. How many occupants live in this apartment including you?
4. In general how often you open the windows for natural air? (Always / Very Often / Sometimes / Rarely / Never)
5. What is the temperature you usually set in the Air Conditioner?
6. How often the Air Conditioner is serviced (in months)?

**Section D – Residence Condition Information** (To be filled by the resident)

1. During your occupancy, have the following changes made in your apartment?  
Please tick in the appropriate box

	Past 3 months		Past 6 months		Past 12 months	
	Yes	No	Yes	No	Yes	No
AC repair						
New Carpeting						
Walls painted						
New furniture						
New Partitions						

2. What type of air fresheners / kitchen cleaners do you use?
3. What type of cleaners do you use for furniture & carpeting?
4. How often do you feel following conditions when you are at home?  
Please tick in the appropriate box

Condition	Always	Very Often	Sometimes	Rarely	Never
Too much air movement					
Too little air movement					
Temperature too hot					
Temperature too cold					
Air too humid					
Air too dry					
Tobacco smoke odors					
Unpleasant chemical odors					
Other unpleasant odors (body odor, food odor, perfume etc)					

**Section E – Health** (To be filled by the resident)

*\*Please note that the information provided by you will be kept confidential and only used for research purposes anonymously without revealing any of the personal information*

1. Have you ever been told by a doctor that you have or had any of the following?  
Please tick in the appropriate box

	Yes	No
Sinus infection		
Asthma		
Migraine		
Eczema		
Hay fever		
Allergy to dust		

2. Do you feel following symptoms while when you spend some time inside the apartment?  
Please tick in the appropriate box

Symptom	Always	Very Often	Sometimes	Rarely	Never
Irritation in the Eyes					
Irritation in the Nose					
Dryness in mucous membrane (throat etc.)					
Lethargy/Drowsy/Tired					
Dryness on the face/hands					
Headache					
Any other?					
-					
-					
-					

3. Do you find that any of the symptoms mentioned above are experienced when you are outside the apartment as well?

Almost always / Often / Sometimes / Seldom / Never

**Section F – Overall Rating** *(To be filled by the resident)*

- To what extent do you like the internal environment? Please rate from the scale of 1 to 5. (1 is the lowest and 5 is the highest)
- What is your feeling towards the Living area? (Very Comfortable / Comfortable / Acceptable / Uncomfortable / Very Uncomfortable)
- Do you have any other comments on the internal environment?

.....  
 .....  
 .....  
 .....

**Equipment Readings Summary**

VOC Level (Indoor)	
VOC Level (Outdoor)	
CO <sub>2</sub> Level (Indoor)	
CO <sub>2</sub> Level (Outdoor)	
Temperature	
Humidity	

## Appendix - C

Where Do I Find Everything I Need for  
Process Measurement and Control?

**OMEGA...Of Course!**

Shop online at [omega.com](http://omega.com)<sup>SM</sup>

### TEMPERATURE

- Thermocouple, RTD & Thermistor Probes, Connectors, Panels & Assemblies
- Wire: Thermocouple, RTD & Thermistor
- Calibrators & Ice Point References
- Recorders, Controllers & Process Monitors
- Infrared Pyrometers

### PRESSURE, STRAIN AND FORCE

- Transducers & Strain Gages
- Load Cells & Pressure Gages
- Displacement Transducers
- Instrumentation & Accessories

### FLOW/LEVEL

- Gas Mass Flowmeters & Flow Computers
- Air Velocity Indicators
- Turbine/Paddlewheel Systems
- Totalizers & Batch Controllers

### pH/CONDUCTIVITY

- pH Electrodes, Testers & Accessories
- Benchtop/Laboratory Meters
- Controllers, Calibrators, Simulators & Pumps
- Industrial pH & Conductivity Equipment

### DATA ACQUISITION

- Data Acquisition & Engineering Software
- Communications-Based Acquisition Systems
- Plug-in Cards for Apple, IBM & Compatibles
- Data Logging Systems
- Recorders, Printers & Plotters

### HEATERS

- Heating Cable
- Cartridge & Strip Heaters
- Immersion & Band Heaters
- Flexible Heaters
- Laboratory Heaters

### ENVIRONMENTAL MONITORING AND CONTROL

- Metering & Control Instrumentation
- Refractometers
- Pumps & Tubing
- Air, Soil & Water Monitors
- Industrial Water & Wastewater Treatment
- pH, Conductivity & Dissolved Oxygen Instruments

1 YEAR  
WARRANTY



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**User's Guide**

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M5496/0915

**HHAQ-107**  
**Data Logging VOC Meter**



omega.com info@omega.com

**Servicing North America:**

U.S.A.: Omega Engineering, Inc., One Omega Drive, P.O. Box 4047  
Stamford, CT 06907-0047 USA  
Toll-Free: 1-800-826-6342 (USA & Canada only)  
Customer Service: 1-800-622-2378 (USA & Canada only)  
Engineering Service: 1-800-872-9436 (USA & Canada only)  
Tel: (203) 359-1660 Fax: (203) 359-7700  
e-mail: info@omega.com

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## INTRODUCTION

Thank you for purchasing OMEGA's HHAQ-107 Data Logging VOC Meter. Please read this user's manual carefully and thoroughly before using the product.

The HHAQ-107 is an easy-to-use handheld instrument for making ballpark measurements of mixed-gas volatile organic compound (VOC) levels as part of an indoor air quality (IAQ) maintenance program. Examples of VOCs include cigarette smoke, ammonia, ethanol, and the low levels of toluene produced during wood finishing and construction products.

Why does the HHAQ-107 lack a VOC accuracy specification? Because it can only measure the *total* concentration of VOCs contributed by multiple gases, rather than the concentration of a single gas. VOC meters that use photo-ionization detection (PID) technology and ultraviolet lamps to break down single-gas VOCs into ions are faster and more accurate than the HHAQ-107 but they cost at least 10 times more. The HHAQ-107 is therefore a much more suitable solution for home inspectors and facilities managers who only need to spot-check concentrations of mixed-gas VOCs.

---

## KEY FEATURES

- Metal-oxide semiconductor sensor within vented ball housing detects ammonia, toluene, ethanol, hydrogen sulfide (H<sub>2</sub>S) and cigarette smoke
- Makes ballpark measurements of total VOC concentration as well as accurate measurements of ambient temperature, relative humidity (RH), dew point and wet bulb temperatures

- Logs up to 32,000 data points. The entire capacity can be devoted to VOC readings, or devoted one-third each to VOC, ambient temperature and RH readings.
- Powerful data logging software that downloads readings to a PC for display/printing as table or graph. Software supports four data logging modes—including starting and stopping recording without a PC.
- Adjustable high VOC concentration audible alarm
- Min/Max memory (for all measured parameters) and data hold
- Automated VOC zero adjustment procedure
- Manually offsettable temperature and RH sensor drift
- Large backlit dual-readout LCD
- 15-minute Auto Power Off (can be disabled)
- Low battery indication
- Tripod mount
- Powered by (6) "AAA" batteries (not included) or AC adaptor (included)
- CE and RoHS approved
- 2-year limited warranty

---

## WHAT'S IN THE PACKAGE

The HHAQ-107 instrument, a PC-compatible data logging program on disc, a USB cable, an AC adaptor and this hardware user's manual come in a soft pouch inside a white box.

Both hardware and software manuals are also available for download at [omega.com](http://omega.com).

## PRODUCT OVERVIEW

Fig. 1 shows all controls, indicators and physical structures of the HHAQ-107 Fig. 2 shows all possible indications on the LCD. Familiarize yourself with the locations and functions of the control buttons and the meanings of the display icons before moving on to the Setup and Operating Instructions.

1. VOC and temp-RH sensors inside vented ball housing
2. LCD with upper and lower readouts
3. Control buttons

- **HOLD.** Pressed briefly, freezes both readouts. Also used to raise VOC high alarm threshold. Pressed at same time as **PWR** button with meter off, disables 15-minute APO function. **Pressed and held**, clears stored Min and Max session values.

- **MODE.** Pressed briefly, selects value(s) shown on lower readout: Ambient temperature alternating with RH; Dew Point (DP) temperature; or Wet Bulb (WB) temperature. Also shifts flashing digit one position to the left in VOC high alarm threshold setting mode.

- **PWR.** Pressed briefly with meter off, powers meter on. **Pressed and held with meter on**, powers meter off.

**Pressed briefly with meter on**, arms/disarms high VOC concentration alarm.

- **MAX/MIN.** Pressed briefly, displays on the upper readout the highest or lowest concentration detected since the



Fig. 1.  
The controls,  
indicators  
and physical  
structures  
of the  
HHAQ-107

meter was last powered on. Also shifts flashing digit one position to the right in VOC high alarm threshold setting mode.

- **SET.** Pressed and held, enters VOC high alarm threshold mode; also saves changed VOC alarm threshold settings and temperature/RH offset values.

- **UNIT.** Selects °F or °C unit for ambient, DP and WB temperatures.

- **BKLT.** Pressed briefly, turns backlight on and off. Also used to lower VOC high alarm threshold. **Pressed and held in Key Start or Rollover** mode (see Software Manual), starts/stops data logging without a USB connection to a PC.

4. Battery compartment (on back)
5. Threaded tripod mounting screw hole (on bottom)
6. Jack for AC adaptor (on side)
7. Micro USB jack

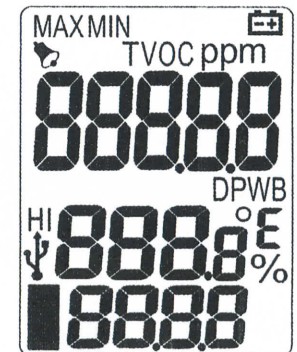


Fig. 2. All possible  
display indications

## SETUP INSTRUCTIONS

### INSTALL BATTERIES

The HHAQ-107 battery compartment (Fig. 1, Callout 4) is located on the lower back of the meter.

Obtain six “AAA” batteries. **To install them:**

1. Open the battery compartment by using your thumb to slide its cover down and away from the meter.

2. Install the batteries in series in the compartment, observing the polarity markings inside.
3. Close the battery compartment by sliding the cover back up on its track until it snaps shut.

---

## OPERATING INSTRUCTIONS

### STANDALONE MODE

To power on the HHAQ-107 press the **PWR** button. The LCD will illuminate and immediately begin scrolling "0s" across the five positions on the upper readout to indicate that it is warming up. During the warmup period, the meter will burn off any dust on the VOC sensor inside the vented ball. If this is the first use of the meter or if it has not been powered on in a long while, the warmup period may last as long as several hours. Normally, it takes 1 to 15 minutes until the scrolling stops and the upper readout stabilizes.

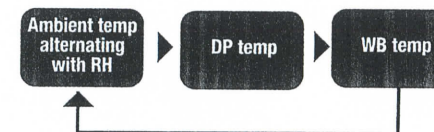
If you need to make ballpark measurements of mixed-gas VOC levels over a period longer than 15 minutes (the meter's Auto Power Off triggering time), you must disable the APO function.

To power on the HHAQ-107 and simultaneously disable the APO function while running on battery power, with the meter off first press and hold the **HOLD** button, and then (without releasing **HOLD**) press and hold the **PWR** button. Doing this will cause a small **n** to briefly appear on the LCD before the meter powers up with both readouts visible. There is no permanent on-screen indication that the APO function has been disabled. So if you disable APO, realize that the batteries will discharge within an hour or two if you forget to manually power off the meter after a measurement session.

Once the meter has been powered on and the values on both readouts have stabilized, the HHAQ-107 automatically begins operating in real-time measurement mode. In this mode you can:

- 1) Turn the display backlight on and off by briefly pressing the **BKLT** button.
- 2) Freeze both readouts by pressing the **HOLD** button.
- 3) Change the temperature unit to/from °F and °C by briefly pressing the **UNIT** button. The HHAQ-107 will "remember" the unit in use when the meter powers off and will resume using that unit for ambient, DP and WB temperatures when it is powered on again.
- 4) Change the values shown on the lower readout by pressing the **MODE** button. The options available by pressing the button repeatedly are (in order): Ambient temperature alternating with RH; Dew Point (DP) temperature; or Wet Bulb (WB) temperature.



Using the **MODE** button to change the value(s) shown on the lower readout



- 5) Adjust the high VOC concentration audible alarm threshold. To enter threshold adjustment mode, press and hold the **SET** button. This will produce a display showing **35.00 ppm** (the default alarm threshold) on the upper readout, with the "5" flashing. Using the **MODE** and **MAX/MIN** buttons to shift the flashing digit to the left and right, respectively, press the **HOLD** and **BKLT** buttons as many times as necessary to increment and decrement the value of each digit until the desired concentration threshold

is displayed. Then, press and hold the **SET** button to save the setting and return to real-time measurement mode.

#### 6) Arm and disarm the high VOC concentration alarm.

- a. To arm the alarm, briefly press the **PWR** button until the  icon appears in the upper left corner of the LCD.
- b. To disarm the alarm (turn off the beeper), briefly press the **PWR** button until the  icon disappears.
- c. To cancel the alarm when it sounds, briefly press the **PWR** button.

#### 7) Display maximum and minimum session values of all measured parameters by using the **MAX/MIN** button. A measurement session is the period of time during which you measure VOC levels at multiple locations. The session begins when you power on the HHAQ-107; it typically ends 15 minutes after you finish making measurements with the activation of the APO function. Max and Min readings are automatically and continuously updated.

You can extend a measurement session beyond 15 minutes by pressing any front-panel button or by disabling the APO function (see page 7) by powering the HHAQ-107 through the included AC adaptor.

The value of being able to quickly determine where the level of VOCs is highest and lowest in a facility should be obvious.

**To display the highest VOC** concentration recorded during a measurement session, press the **MAX/MIN** button once with the meter operating in real-time measurement mode. The maximum reading will appear on the upper readout, with the term **MAX** above it on the top line of the LCD.

**To display the lowest VOC** concentration recorded during a measurement session, press the **MAX/MIN** button twice. The minimum reading will appear on the upper readout, with the term **MIN** above it on the top line.

The figure at right shows both session parameters in their selection sequence relative to real-time measurement mode.



To clear the stored (and continually updated) values of Min and Max from the instrument's short-term (volatile) memory, press and hold the **HOLD** button with the meter operating in Max/Min mode. The letters **Clr** on the bottom line of the LCD will confirm the clearing.

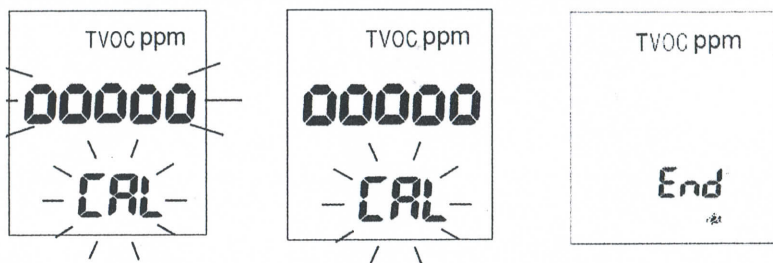
## CALIBRATION PROCEDURE

### VOC ZERO ADJUSTMENT

To make this temporary calibration procedure worthwhile, be sure the ambient environment is well-ventilated and shows no sign of VOC gases, as evidenced by a **0.00** reading on the meter's upper **TVOC ppm** readout.

To initiate the process, press and hold the **MODE** button for at least five seconds. Initially, five zeroes and the term **CAL** will appear and flash for about 20 seconds (left image on next page). Then the zeroes will stop flashing, with **CAL** continuing to flash (middle image). When calibration has finished, the display will confirm that result by displaying **End** (right image). The meter will respond by resuming operation in real-time measurement mode with the calibration point back at the factory default setting.

Alternatively, you can recalibrate the meter using a standard VOC gas. But be aware that attempting to recalibrate the meter without a standard gas may actually lower the meter's accuracy. For best results, send the meter out for calibration to a qualified laboratory recommended by your distributor.



## SPECIFICATIONS

VOC Measurement Range / Resolution: 0 to 50 ppm / 0.01 ppm

VOC Warmup Time: 10 minutes first use, 2 minutes thereafter

VOC Sensor Type / Longevity: Metal-oxide semiconductor / 5 years (typical)

Temperature Measurement Range: 14° to 122°F  
(-10° to 50°C)

Temperature Measurement Accuracy / Resolution: ±1.2°F  
(0.6°C) / 0.1°

RH Measurement Range: 10 to 90%RH

RH Measurement Accuracy / Resolution: ±5% of reading  
@77°F (25°C); ±7% of reading elsewhere in range /  
0.1%RH

Dew Point Measurement Range: -99.22° to 118°F  
(-72.9° to 47°C)

Wet Bulb Measurement Range: 12.2° to 118.8°F  
(-11° to 48.2°C)

Data Logging Capacity: 32,000 points

Display Type / Size: Dual readout LCD / 2 in. (51mm) diagonal

Auto Power Off Trigger: 15 minutes of front-panel inactivity  
(can be disabled)

Operating Temperature: 32° to 122°F (0° to 50°C)  
@ 0 to 95%RH, non-condensing

Dimensions: 8.3 x 2.4 x 1.0 in. (210 x 60 x 25mm)

Weight: 7.2 oz. (204g), including batteries

Power Source: (6) "AAA" batteries (not included) or included  
110VAC adaptor

## OPERATING & MAINTENANCE TIPS

When the low battery indicator appears in the upper left corner of the LCD, install fresh batteries immediately, following the instructions on pages 6 and 7 of this manual.

The metal-oxide semiconductor VOC sensor is as power-hungry as it is sensitive. Omega recommends using the included AC adaptor if you expect to routinely conduct measurement sessions lasting more than 15 minutes.

Remove the batteries if you don't expect to use the HHAQ-107 or an extended period of time (months or years).

Abrupt temperature changes will cause condensation and possible vapor penetration. Clean the LCD after the vapor evaporates. Blow off loose particles with compressed air.

Gently brush remaining debris away with a lens hair brush.

Never use a solvent or an abrasive cleaner on the HHAQ-107. To clean the housing, use a soft, damp cloth.

Do not drop or disassemble the meter or immerse it in water. The HHAQ-107 may display the following two sensor error messages on its bottom readout:

- E- 1:** The VOC, temperature or RH sensor is damaged, or communication with any of the sensors has failed.
- E- 2:** The VOC, temperature or RH level is beyond the range of its sensor.

If the LCD persistently shows a value of **00000** for VOC, that usually means that a logging session was initiated before the VOC sensor was fully warmed up.

### **OFFSETTING SENSOR DRIFT**

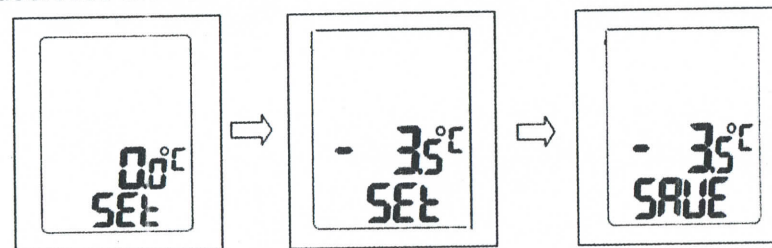
The meter uses a capacitive RH sensor and a thermistor temperature sensor whose accuracy may drift over the long term. Following is a procedure that you can perform to offset these drifts and maximize the meter's measurement accuracy.

- 1) **With the meter powered off**, press and hold the **MODE** and **BKLT** buttons with fingers of your left hand while pressing and holding the **MAX/MIN** and **PWR** buttons with fingers of your right hand.
- 2) When the LCD shows **0.0°C** and **SET**, release all four buttons.
- 3) To select **°C** or **°F** as the temperature offset unit, press the **UNIT** button.
- 4) Press the **HOLD** button once for each 0.1° of temperature offset you wish to add, or the **BKLT** button once for each 0.1° of temperature offset you wish to subtract.
- 5) To offset RH drift instead of, or in addition to, temperature drift, briefly press the **SET** button. This will change the

displayed unit **°C** or **°F** to **%**. Then repeat Step 4. Each press of the **HOLD** or **BKLT** button increases or decreases the amount of RH offset by 0.1%.

- 6) When you are satisfied with the offset value(s) you have entered, press and hold the **SET** button to save the settings. After the bottom line of the LCD shows **SAVE** for two seconds, press and hold the **PWR** button to power off the meter with the offsets in place.

**NOTE:** To apply the maximum amount of temperature offset (+9.9° or -9.9°) or RH offset (+9.9% or -9.9%), press and hold the **HOLD** and/or **BKLT** buttons to quickly increase or decrease the values.



## NOTES:

### WARRANTY/DISCLAIMER

OMEGA ENGINEERING, INC. warrants this unit to be free of defects in materials and workmanship for a period of **13 months** from date of purchase. OMEGA's Warranty adds an additional one (1) month grace period to the normal **one (1) year product warranty** to cover handling and shipping time. This ensures that OMEGA's customers receive maximum coverage on each product.

If the unit malfunctions, it must be returned to the factory for evaluation. OMEGA's Customer Service Department will issue an Authorized Return (AR) number immediately upon phone or written request. Upon examination by OMEGA, if the unit is found to be defective, it will be repaired or replaced at no charge. OMEGA's WARRANTY does not apply to defects resulting from any action of the purchaser, including but not limited to mishandling, improper interfacing, operation outside of design limits, improper repair, or unauthorized modification. This WARRANTY is VOID if the unit shows evidence of having been tampered with or shows evidence of having been damaged as a result of excessive corrosion; or current, heat, moisture or vibration; improper specification; misapplication; misuse or other operating conditions outside of OMEGA's control. Components in which wear is not warranted, include but are not limited to contact points, fuses, and triacs.

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### RETURN REQUESTS/INQUIRIES

Direct all warranty and repair requests/inquiries to the OMEGA Customer Service Department. BEFORE RETURNING ANY PRODUCT(S) TO OMEGA, PURCHASER MUST OBTAIN AN AUTHORIZED RETURN (AR) NUMBER FROM OMEGA'S CUSTOMER SERVICE DEPARTMENT (IN ORDER TO AVOID PROCESSING DELAYS). The assigned AR number should then be marked on the outside of the return package and on any correspondence. The purchaser is responsible for shipping charges, freight, insurance and proper packaging to prevent breakage in transit.

FOR **WARRANTY** RETURNS, please have the following information available BEFORE contacting OMEGA:

1. Purchase Order number under which the product was PURCHASED,
2. Model and serial number of the product under warranty, and
3. Repair instructions and/or specific problems relative to the product.

FOR **NON-WARRANTY** REPAIRS, consult OMEGA for current repair charges. Have the following information available BEFORE contacting OMEGA:

1. Purchase Order number to cover the COST of the repair,
2. Model and serial number of the product, and
3. Repair instructions and/or specific problems relative to the product.

OMEGA's policy is to make running changes, not model changes, whenever an improvement is possible. This affords our customers the latest in technology and engineering.

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# CO240 Handheld Indoor Air Quality CO<sub>2</sub> Meter



Easy-to-use Extech CO240 Air Quality Meter measures Carbon Dioxide (CO<sub>2</sub>), Air Temperature, and Humidity. It also calculates Dew Point and Wet Bulb. User settable high alarm with audible beeper is perfect for conducting a quick check of CO<sub>2</sub> level to help adjust the environmental conditions in an enclosed area, such as a greenhouse or nursery, to ensure optimal plant growth. It's also convenient for testing the air quality in buildings such as factories, hospitals, conference rooms, schools, and anywhere that high levels of carbon dioxide are generated, to ensure proper air ventilation.



## Features

- Dual display of Carbon Dioxide (CO<sub>2</sub>) concentrations and Relative Humidity, Temperature, Dew Point, or Wet Bulb
- Maintenance free NDIR (non-dispersive infrared) CO<sub>2</sub> sensor
- Audible CO<sub>2</sub> warning alarm when concentration level exceeds high user set point
- Min/Max CO<sub>2</sub> value recall function
- Software for on-line (real-time) data streaming to a PC
- Automatic Baseline Calibration function
- Data hold and Auto Power Off (with disable) function
- Low battery indicator
- Tripod mount (tripod sold separately)
- Complete with six AAA batteries, USB cable, PC software, Universal AC adaptor (with 4 plugs US, EU, UK, AUS), and soft case

Specifications	Range	Resolution	Basic Accuracy
Carbon Dioxide (CO <sub>2</sub> )	0 to 9,999ppm	1ppm	±75ppm+5% of reading
Temperature	14 to 122°F (-10 to 50°C)	0.1°F/°C	±2.0°F/1.0°C
Humidity	10 to 90%RH	0.1%RH	±5%RH (@ 25°C)
Dew Point	-99.22 to 118°F (-72.9 to 47°C)	0.1°F/°C	
Wet Bulb	12.2 to 118.8°F (-11 to 48.2°C)	0.1°F/°C	
Dimensions/Weight	8.3x2.4x1.6" (211x60x40mm)/ 6.4oz (181.4g)		

## Ordering

- CO240 ..... Handheld Indoor Air Quality CO<sub>2</sub> Meter
- TR100 ..... Tripod
- SW200-S ..... Replacement Data Streaming Software with Cable



UPC Code: 793950502402