DETERMINATION OF BACKGROUND INDOOR AIR POLLUTANTS AND THERMAL COMFORT IN FSB NEW BUILDING

by

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DECLARATION

I declare that this thesis entitle "Determination of background of indoor air pollutants and thermal comfort in FSB new building" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidates of any other degree.

Signature :

Name :

Date :

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Determination of Background Indoor Air Pollutants and Thermal Comfort in FSB new building

ABSTRACT

The main focus of this study was to determine the most significant factors that influencing indoor air quality (IAQ) and thermal comfort of a mechanically room in FSB new building. This study measured the concentrations of ozone (O_3), nitrogen dioxide (NO_2), total volatile organic compound (TVOC), carbon dioxide (CO_2), carbon monoxide (CO), particulate matter (PM), temperature and relative humidity using seven set up conditions. The set up condition for laboratory is based on temperatures that have been selected between 22ºC to 26ºC and window of the room being either close or open. The IAQ were analyzed by descriptive analysis, time series plot and diurnal variations. Furthermore, thermal comfort for the room of FSB new building has been determine by the CBE thermal comfort tool based on ASHRAE 55 standards. Next, multiple linear regression (MLR) was utilized to determine the most significant factors that influencing IAQ and thermal comfort. Result suggested that the IAQ of room FSB new building has maximum value during the window was opened. The setup of selected temperature air conditioner was minimizing the concentrations of IAQ because IAQ were increase during high temperature. Among of the selected IAQ parameters, only particulate matter concentration was surpasses the guideline limit set by DOSH for the indoor environment. The increment of particulate matter concentrations was due to the suspended dust in the room and additional movements of the occupants inside the room exaggerate the condition. Besides, results of this study suggested that a good IAQ inside an air conditioning room was achieved when the temperature is set at 26ºC. The result suggested that IAQ parameters such ozone, nitrogen dioxide, total volatile organic compound, carbon dioxide, relative humidity was significant in influencing the room thermal comfort.

Penentuan Pencemar Udara Dalaman Asas dan Keselesaan Terma di Bangunan Baru FSB

ABSTRAK

Fokus kajian ini adalah untuk menentukan parameter yang mempengaruhi Kualiti Udara Dalaman (IAQ) dan Keselesaan Terma di dalam bilik di bangunan baru FSB. Kajian ini mengukur kepekatan ozon (O_3), nitrogen dioksida (NO_2), jumlah bahan organik meruap (TVOC), karbon dioksida (CO_2), karbon monoksida (CO), zarahan terampai (PM), suhu dan kelembapan udara relatif menggunakan tujuh keadaan yang telah ditetapkan. Keadaan yang ditetapkan untuk bilik adalah berdasarkan suhu yang telah dipilih antara 22 ^{o}C hingga 26 ^{o}C dan sama ada tingkap bilik tertutup atau terbuka. Kualiti udara dalaman bilik FSB telah dianalisa dengan analisis diskriptif, plot siri masa dan variasi diurnal. Selain itu, keselesaan terma bagi bilik bangunan baru FSB telah ditentukan dengan menggunakan CBE thermal comfort berdasarkan piawaian ASHRAE 55. Selain itu, regrasi linear berganda (MLR) telah digunakan untuk menentukan faktor yang yang mempengaruhi kualiti udara dalaman (IAQ) dan keselesaan terma. Keputusan mencadangkan bahawa IAQ bilik FSB bangunan baru mempunyai nilai maksimum semasa tingkap dibuka. Penggunaan penghawa dingin meminimumkan kepekatan IAQ kerana IAQ meningkat semasa suhu tinggi. Di antara parameter IAQ yang terpilih, hanya kepekatan zarahan terampai yang melebihi had garis panduan yang ditetapkan oleh DOSH untuk kualiti udara dalaman. Peningkatan kepekatan zarahan terampai disebabkan oleh habuk yang termendap di dalam bilik dan aktiviti pengguna ruang tersabut. Walaubagaimanapun, keputusan kajian ini mencadangkan bahawa IAQ yang baik di dalam bilik penghawa dingin dicapai apabila suhu ditetapkan pada 26 ^{o}C. Seterusnya, keputusan mencadangkan bahawa parameter IAQ seperti kepekatan ozon, nitrogen dioksida kepekatan jumlah organik meruap, karbon dioksida, kelembapan relatif adalah penting dalam mempengaruhi keselesaan terma bilik.

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LIST OF ABBREVIATIONS

CH_2O	Formaldehyde
CO	Carbon monoxide
DOSH	Department of Safety and Health, Malaysia
FSB	Fakulti Sains Bumi
IAP	Indoor Air Pollutant
IAQ	Indoor Air Quality
NO	Nitric oxide
NO_2	Nitrogen doxide
O_3	Ozone
PM	Particulate Matter
$PM_{2.5}$	Fine particles
PM_4	Respirable particulate matter
RH	Relative Humidity
SBS	Sick Building Syndrome
SO_2	Sulphur dioxide
TVOC	Total volatile organic compound
UMK	Universiti Malaysia Kelantan
VOCs	Volatile organic compounds

LIST OF SYMBOLS

^{o}C	Degree Celsius
μ	Micro
g	gram
>	Greater than
<	Less than

CHAPTER 1

INTRODUCTION

1.1 Background of study

Indoor Air Quality (IAQ) in working place and home were engaged the attention of scientist and public. IAQ is a common among human being but not well recognized thus people still not consider as a problems. It considered as apodictic cause many people spend most of their lifetime indoor. There were various aspects of the indoor environment affect their health and performance (Kamaruzzaman, Egbu, Zawawi, Ali, & Che-Ani, 2011). There become the most critical global environmental issues to identify about indoor air pollution. Stated that a human being spends about eighty percent of the life inside the workplace or in the house (Norhidayah, Lee, Azhar, & Nurulwahida, 2013). Besides, some research showed that people spend roughly ninety percent of their time indoors. Furthermore, the health risk cause by the exposure towards indoor pollution is more dangerous than outdoor air pollution (Kamaruzzaman et al., 2011).

Based on Lee & Chang, (2000) stated that the failed to prevent indoor air pollutants from entering the indoor environment enhanced the chances of long term and short term health issues. There are also causes of degraded towards environment and reduced the comfort productivity. There are effects of indoor air pollution which related together with factors of physical, chemical and biological. Besides, the suitable of ventilation into indoor air is one of the causes of indoor air pollution (Lee

& Chang, 2000). Therefore, Indoor Air Pollutant (IAP) is any pollutants from things such as gases and particles contaminate the indoor environment. The effect of smoke's cigarette, store and operational oven, particle board, cement and emissions from other building materials were frequently the most significant determine of IAQ. The common IAQ parameters are carbon dioxide, formaldehyde, particulate matter, total bacteria, nitric oxide and nitrogen dioxide, temperature and relative humidity (Lee & Chang, 2000).

Furthermore, the important factor that pollutes the quality of indoor air is the ways of room to be ventilated. Based on Seppänen & Fisk (2002) stated that ventilation meaning is the supply of ambient air to a room through the ventilation system for example are air flow through open doors, air infiltrate through windows and infiltration through the building cover. Thus shows that the indoor air quality was influenced by exchanged rate of indoor and outdoor air. There are two types of air exchange for indoor environment which natural and mechanical ventilation. The rate exchange influenced the indoor pollutants concentration in two ways. Firstly when at a high rate of air exchange the pollutants inside of the building are removed from the indoor air. This happened when the pollutants concentrations of outdoor air is lower. The rate of exchange air is higher thus helps to lower the level of indoor air pollutants. However, if the concentration of pollutant outdoor air is raised and there are an increase in the rate of exchange air that will bring the materials into the indoor air. Meanwhile, at a lower rate of exchange air, pollutants are removed outside from indoor air. There are sources inside the building can contribute to increasing the level of indoor pollutants (Vallero, 2007).

In this study the room was occupied by mechanical ventilation. Mechanical ventilation is the usage of the air-conditioning system in an indoor air environment

(Persily, 2015). The system of air-conditioning functional as cooling, heating and humidifier to supply air inside rooms as necessary to sustain suitable indoor air conditions (Seppänen & Fisk, 2002). However in previous study the air conditioner states specifically as cooling effects and supplement air supply.

Thermal comfort was an acceptable standard of indoor climates which need to consider every factors related to indoor air environment. Thermal comfort standards act as a guideline for a building systems provide an indoor environment that comfortably towards humans inside the building (Nicol & Humphreys, 2002). The occupants have natural tendency to get used to the changes of indoor air environment. To describe a decent indoor environment, the most important is to the success of a room building while ensuring occupants comfortable. It will indicate the energy consumption thus influence the sustainability. Previously, human being still do not realise it as part of their task to ponder sustainability that lead to the increasing of pollution and climate change (Nicol & Humphreys, 2002). In this study the indoor environment was influenced by climates control which manipulation the technologies of air conditioning.

1.2 Problem statement

Indoor air quality (IAQ) recently received serious discussion and negative perception from the scientific community where is give effect towards health (Jones, 2002). Health issues were related to building disease and sick building syndrome. SBS define as clinical symptom with no acknowledged their causes. The existence of SBS is because there are mucosal in a building. Additionally, that was related to works in that particular building exposed to the age of building, the flow rate of ambient air, issues from waste management, the low of cleaning management of photocopiers or humidifiers. There were SBS symptoms such as headache lead to dizziness, sensory discomfort due to odours, dry skin, fatigue, lethargy, wheezing, sinus, congestion, skin rash, nausea , irritation in the eyes, blocked nose and throat (Gupta, Khare, & Goyal, 2007). Besides, the thermal comfort is a standard of acceptable indoor climates which important to be achieve in a building to give comfortable environment towards occupants (Nicol & Humphreys, 2002).

This study was about determined the best seven selected conditions and the most significant level of thermal comfort inside the room of FSB new building. This will show the importance to maintain the IAQ at good levels so that the health of the occupants that are using the room are in good conditions. It is also, the occupants can be more comfortable in the room, and they will be free from polluted surrounding. The study also to help maintain good health and improved the indoor air environment in ensuring comfortability in the faculty new building.

1.3 Objectives

The objectives of this study were:

1. To determine the concentration of Indoor Air Quality (IAQ) parameters and thermal comfort parameters in FSB new building.
2. To identify the most significant factors that influencing IAQ and thermal comfort in FSB new building.

1.4 Scope of study

This study was focused on the indoor air quality (IAQ) and thermal comfort level of the FSB new building. It is ensured the FSB new building at good level thus give healthy indoor air environment towards students and staff. The monitoring equipment used to obtain the data of IAQ parameters was WolfSense Indoor Air Quality. The data of parameters obtained were ozone, nitrogen dioxide, total volatile organic compound, carbon dioxide, carbon monoxide, relative humidity, temperature and wind speed. Besides, to detect the data of particulate matter the equipment used was Casella Microdust Pro. These parameters were the main element of this study. The parameters were to determine the level of IAQ and thermal comfort level of FSB new building with the changed of the seven selected condition.

The changed conditions for the room temperature as a variable measured. The room temperature changed at 22˚C, 23˚C, 24˚C, 25˚C, and 26˚C along the window conditions either the window close or open. This is because the building was fully ventilated by mechanical ventilation which is the usage of air-condition. This changed variable was important as the factor of increasing the concentration of pollutants that affect human health. The time frame of this study conducted between 8.00 a.m. and 5.00 p.m. for seven days. This time was selected by assumed the operational time of this building which followed the office hour operational time.

After monitored the IAQ and thermal comfort level, the data were analysed using descriptive analysis. Descriptive analysis is an analysis that able to show the different concentration levels for each condition. Thermal comfort level was determined by using CBE Thermal Comfort Tool ASHRAE 55 standard. This standard provides the requirement for suitable and acceptable thermal comfort level in an indoor air environment. Lastly, the most significant thermal comfort at a good level of IAQ was determined by multiple linear regressions. The multiple linear regression come out with a model that determined the relationship between two variables by fitted the multiple linear equations with data monitoring. Thus the data analysis of IAQ and thermal comfort level act as variables and find the relation between both variables.

1.5 Significant of study

This study was about the indoor air quality (IAQ) and thermal comfort level of the FSB new building. Data obtained were ozone, nitrogen dioxide, total volatile organic compound, carbon dioxide, carbon monoxide, particulate matter, relative humidity, temperature and wind speed. Thus, this study gave beneficial values towards students and staffs of FSB building about good IAQ level. The IAQ level was important to maintain the indoor quality at the good level and avoided any contamination pollutant. Besides, the thermal comfort determined to find an acceptable thermal comfort level. The most significant level for both determined to prove the good IAQ level in acceptable thermal comfort. This study helped people to understand the importance of monitoring the IAQ and thermal comfort level at a good level. This is because the effect of bad IAQ level caused them to obtain diseases. The diseases were because of pollutant present in the building. Other than that, this study determined the most significant thermal comfort level, so people felt comfortable in the room as the IAQ also in good level.

CHAPTER 2

LITERATURE REVIEW

2.1 Indoor air pollution

Indoor air pollution is an air contaminant from outdoor to a building penetrates indoor air environment which varying and persistent, which be determined by the ventilation system and pollutant reactivity. Since 1960, indoor air pollution had been a serious public health problem (Jonathan & Bahrami, 2016). Besides, there are abundance of high reactive molecules and radicals inside a room of indoor environment such as ozone, nitrogen oxides, hydroxyl radicals and sulfur dioxide. The pollutants either come from the ambient air or generated inside the building by daily activities of the occupants for example are photocopiers activities, laser printers machine, cooking gas and UV lighting. Human wellbeing will be effected even in small concentrations and lead to sick building syndrome (Champiré, Fabbri, Morel, Wong, & McGregor, 2016).

2.2 Health effects due to IAQ

The air pollution is the main of causes for the respiratory system due to the active tissue biochemically involving mediators that induce the local and systemic effects of exposure. Besides, air pollution also contributes to respiratory diseases, chronic obstructive pulmonary disease, pneumonia, allergic diseases such as asthma and tuberculosis (Khafaie, Yajnik, Salvi, & Ojha, 2016). The indoor air pollutants has become the third leading risk factor that causes global disease burden after high blood pressure and smoking (Barron & Torero, 2017).

2.3 Indoor air quality parameters

Indoor air quality (IAQ) parameters that selected to be monitor are ozone, nitrogen dioxide, total volatile organic compound, carbon monoxide, carbon dioxide, particle matter thermal comfort level. These parameters will be monitors to determine the most significant IAQ and thermal comfort level in the mechanically ventilated new building of UMK.

2.3.1 Ground level ozone

The ground level ozone is an important component of photochemical pollution. The O_3 has been related with negative impacts toward human health, vegetation growth and materials lifetime. The O_3 concentrations considered as one of the greenhouse gas that contributes to global warming (Awang, Elbayoumi, Ramli, & Yahaya, 2016). Based on (Li, Manning, Tong, & Wang, 2015) stated also that O_3 is the most common phytotoxic pollutant threatening the productivity of forest and health in many parts of the world. There are several study findings in the past ago, complemented by the toxicology investigation and prove evidence on the adverse effects of air pollution especially focused on particulate matter and O_3. The O_3 formed in the troposphere which a strong oxidant through reactions of the chemical in the presence of precursor pollutants such as nitrogen dioxide and volatile organic compound and sunlight (Samoli et al., 2017). World Health Organization states there were evidences on the short-term rather than long-term effects of O_3 which specifically effected on the respiratory system (Weschler, 2000).

Ozone can cause many diseases such as asthma, coughing, congestion on chest and headache. Whereas, the concentration of the ozone layer at troposphere also can interfere with the photosynthesis and stunt the growth of plant species. The concentration of ozone in outdoor increase will influence the increase of indoor ozone concentrations. Thus, some case between outdoor ozone and both morbidity and mortality cause due to outdoor ozone transported into the indoor environment such as residential area, workplace, schools, hospital and motor vehicles (Weschler, 2006).

2.3.2 Nitrogen dioxide

Nitrogen dioxide is a significant towards air pollutant that adds in formation of photochemical smog that has substantial impacts on social health. Based on (Awang, Ramli, & Yahaya, 2015) stated that the main sources of NOx are comes when people do activities and additionally with combustion of fuels. The NOx is produced when fuel is burned at high temperature. The main causes of NOx is came from many activities such fossil fuel combustion from either vehicular, burning of biomass, microbe activities in soils or lightning. This occur when NO is generated by photolysis of NO_2 with the presence of sunlight however it will oxidize by O_3 to regenerated NO_2. Next, the O_3 destructed when it was reacted with NO to produce NO_2. The reaction was directly influenced by meteorological changeability such as temperature, UV radiation, wind speed and direction along with the availability of the precursors sources

The nitrogen dioxide will mainly affect the breathing likelihood lead of respiratory problems. Nitrogen dioxide inflames the lining of the lungs, and it can reduce immunity to lung infections. This can cause problems such as wheezing, coughing, colds, flu and bronchitis. In a study stated that the use of gas appliances was became a primary source of NO_2. The exposure towards indoor or outdoor NO_2 have increased the risk of lower respiratory tract symptoms in both general population (Kattan et al., n.d.). Based on study Kattan et al., (n.d.) result suggested the increased of NO_2 concentrations exposure was along with increased of asthma symptoms among nonatopic children.

2.3.3 Total volatile organic compounds

Jokl,(2000) stated that according to World Health Organization, TVOC is as agents which have chemically such as toluene, xylene, pinene, 2-(2 etoxyetoxy), ethanol and etc. Commonly, a human being will sense the TVOC by smell sensors due to the aromatic from TVOC emissions. There is general agreement said that formaldehyde and TVOC are the main indoor pollutant where is the concentrations of formaldehyde and TVOC indoors were 2-10 times than that outdoors. Based on (Tao, Fan, Li, Zhang, & Hou, 2015) stated that the VOCs are not directly associated with health problems. However, the VOCs may act as sensory irritations and their indoor concentrations may indicate indoor air quality of the building. There are effects of long-term exposure to formaldehyde and TVOC which would bring both acute and chronic health such as sensory irritation, drowsiness, and headache to cancer (Tao, Fan, Li, Zhang, & Hou, 2015).

Additionally, based on (Brown, 2002) study that related to the presents of formaldehyde and VOC concentrations in the new dwelling. The results from the study suggested was indoor concentrations were high at construction due to many materials were significant pollutant sources such as water-based paints, adhesives and wood-based panels.

Besides, based on Tao et al., (2015) the study was related about underground mall in investigation of formaldehyde and TVOC. The study stated that the mechanical ventilation which an air conditioning for underground malls were concern on temperature, humidity controlling was gave contributions towards indoor air quality. This is because most of the hazardous substances such as formaldehyde, benzene, radon, VOCs were volatile chemically and the sources were from the various decoration materials and the merchandises sold (Tao et al., 2015).

2.3.4 Carbon monoxide

Carbon monoxide state by WHO is the common and widely known and will distribute air pollution. CO is a colourless, odourless and tasteless gas that poorly soluble in water. The emission of largest sources of CO is a vehicle, especially in urban area. The carbon monoxide can bind reversibly with hemoglobin and inhibit oxygen uptake. Thus an individual can suffer from a headache and nausea and risk of coronary artery disease and exposure to CO also increases the risk of coronary artery disease (Jo & Lee, 2006).

2.3.5 Particulate matter

Particulate matter is a pollutant that spread through the air which is consists of a heterogeneous mixture of solid and liquid particle suspended in air that varies continuously in size and chemical composition in space and time. There is an indicator that been used to explain the PM such as the mass concentration of particles with a diameter of less than 10 µm (PM_{10}) and particles with a diameter of less than 2.5 µm ($PM_{2.5}$). $PM_{2.5}$ often called fine PM and comprised ultrafine particles which have a diameter of less than 0.1 µm (Huboyo, Tohno, & Cao, 2011).

The inhalable particles are PM_{10} and $PM_{2.5}$ which small enough to penetrate the respiratory system. Thus, PM can affect the human being health. The examples of health issues caused by PM are short term and long term. This includes the cardiovascular and respiratory morbidity such asthma and also mortality from cardiovascular respiratory disease such lung cancer (World Health Organization, 2013).

2.4 Thermal comfort

Thermal comfort is defined by ASHRAE as the condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation'. The subjective evaluation of thermal comfort is influenced by the thermal environment and personal factors influencing the heat transfer with this environment, but also by psychological factors influencing the condition of mind directly. All these factors in thermal comfort can be altered by behavioral, physiological or psychological adaptation (Hensen, Loomans, & Boerstra, 2011)

De Dear & Brager (2002) stated that thermal environmental conditions for human occupancy are to specify the combinations of the indoor space environment and personal factors that will produce thermal environmental conditions acceptable to 80% or more of the occupants within a space. Besides, the acceptability is never be defined by the standard, it is commonly agreed within the thermal comfort researches community that acceptable is synonymous with satisfaction and that satisfaction is associated with thermal sensations of slightly warm, neutral, and slightly cool.

Malaysia building received more heat compare other because of its location near to the equator. The heat surplus cause discomfort to a human in tropical climate because of higher solar radiation reaches the building. Thermal comfort is measured by finding the temperature or combination of thermal comfort parameters which is temperature, humidity, and air velocity. The thermal scale is described by American Society of Heating, Refrigerating and Air-Conditioning Engineer (ASHRAE 55) which a global professional association that seeks to advance heating, ventilation, air conditioning and refrigerator system design and construction (Nicol & Humphreys, 2002).

2.4.1 Relative humidity

Relative humidity means the heat and moisture behavior of the building (HolHolm, Künzel, & Sedlbauer, 2004). The impact of RH on immediate effect and longer-term perceived IAQ by VOCs, ozone, and particles are complex. This is because both the thermodynamic condition and the emission characteristics of building materials are influenced. The low RH that indicates by Epidemiological, clinical, and human exposure studies, plays a role in the increase of reporting eye irritation symptoms and alteration of the precorneal tear film (Wolkoff & Kjærgaard, 2007).

2.4.2 Temperature

Based on a study by Kim, Kang, Choi, Yeo, & Kim (2008) temperature is one of the environmental factors that influence the emission rates from building materials and resulting indoor concentrations of VOCs.

2.5 New building

The new building is meaning, several buildings in which new materials were introduced because of renovation, extension or construction and being monitored for periods of weeks to months. New building indoor concentrations of pollutants were high during the construction process which this shows that many materials were significant pollutant sources which probably water-based paints, adhesives and wood-based panels (Brown, 2002). As referred Godwin & Hao (2014) stated that the Volatile organic compounds (VOCs) within new and established buildings findings is new building have higher total volatile organic compound (TVOC) concentrations compared to the established building. Next, It was shown that formaldehyde levels are higher than that of domestic and international recommended thresholds in all units (Kim et al., 2008).

2.6 Mechanically ventilated building

Previous study stated that, the building of tighter dwelling has reduced infiltration of air thus there need to control ventilation to provide acceptable indoor air quality. The mechanical ventilation supply unconditioned warren outside air in a smaller amount necessary to fulfill hygienic ventilation requirements and thereby limits the cooling loads and allow better control of the indoor environment (Tomasi, Krajčík, Simone, & Olesen, 2013). In mechanically ventilated the spaces ranging from small office rooms to large industrial buildings, effective air distribution is generally achievable through good design and operation of air distribution system (Gan, 2000). The air change rates depend on a few categories which are the building, some of occupants and the floor are, assuming complete mixing and not taking others factors such enthalpy of inhaled air or ventilation effectiveness (Ventilation for acceptable indoor air quality, 2010).

2.7 Sick Building Syndrome (SBS)

Sick building syndrome meaning is a set of sub-clinical symptoms without an identified cause. The factors that contribute to the SBS are the age of the building, the outdoor air flow rate, dampness problems, the presence of photocopiers or humidifiers and a low standard of cleaning. There are many symptoms of SBS which include irritation in the eyes, blocked nose, and throat, complaints in upper airways, headache, dizziness, sensory discomfort from odours, dry skin, fatigue, lethargy, wheezing, sinus, congestion, skin rash, irritation and nausea (Rosli & Jalaluddin, 2012).

2.8 CBE thermal comfort ASHRAE 55 standards

The CBE thermal comfort ASHRAE 55 Standards are to determine thermal comfort standards environmental scientists work with models in which the neutral or optimal thermal comfort condition can be achieved, considering mainly the six factors affecting thermal comfort as discussed. The two most popular thermal comfort models that have been developed which are the predictive mean votes (PMV) or heat balance model and the Adaptive Comfort Model

Based on previous study by Efeoma & Uduku, (2012), both models the concept of the predicted mean vote which gives the percentage of people who are satisfied or dissatisfied with their comfort levels is often used as well to determine comfort. PMV developed the heat balance equation which is based on a combination of six factors that will affect the thermal balance between the human body and the environment. These factors include four primary factors are air temperature, mean radiant temperature, air velocity and relative humidity. There have two personal factors which are activity rate and clothing insulation.

2.9 Multiple Linear Regression

Based on Sousa, Martins, Alvim-Ferraz, & Pereira (2007) the linear equations was $\hat{Y} = P_0 + P_1 X_1 + . . . + P_n X_n$. This method was used to determine the most significant level of IAQ and thermal comfort.

$$\hat{Y} = P_0 + P_1 X_1 + . . . + P_n X_n \quad (3.1)$$

where

P_i *(i = 0,.,n)* are the parameters generally estimated by least squares

X_i *(i= 1,.,n)* are the explanatory variables (predictors)

CHAPTER 3

MATERIALS AND METHODS

3.1 Research flow chart

Figure 3.1 shows the flow of research methodology of this study, where from the start of the study, where the study area was selected, to the preparations of the equipment to obtain the data, then the process of data analysis and finally the conclusion.

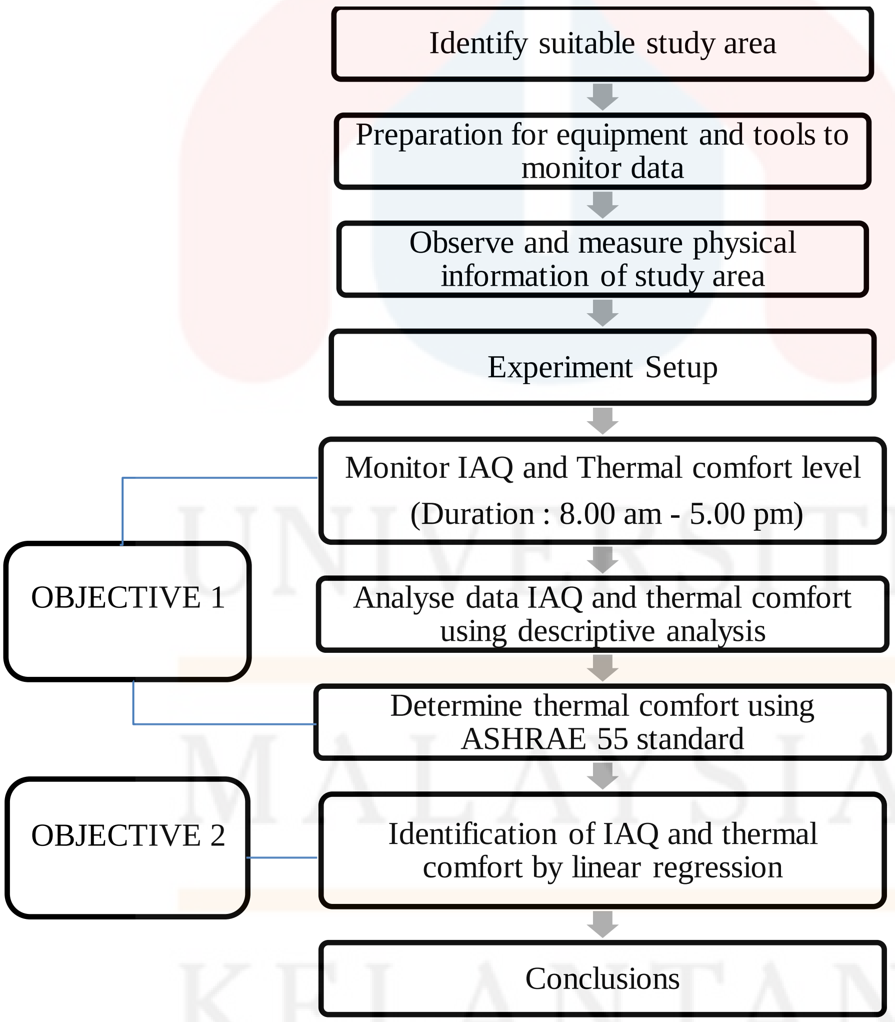
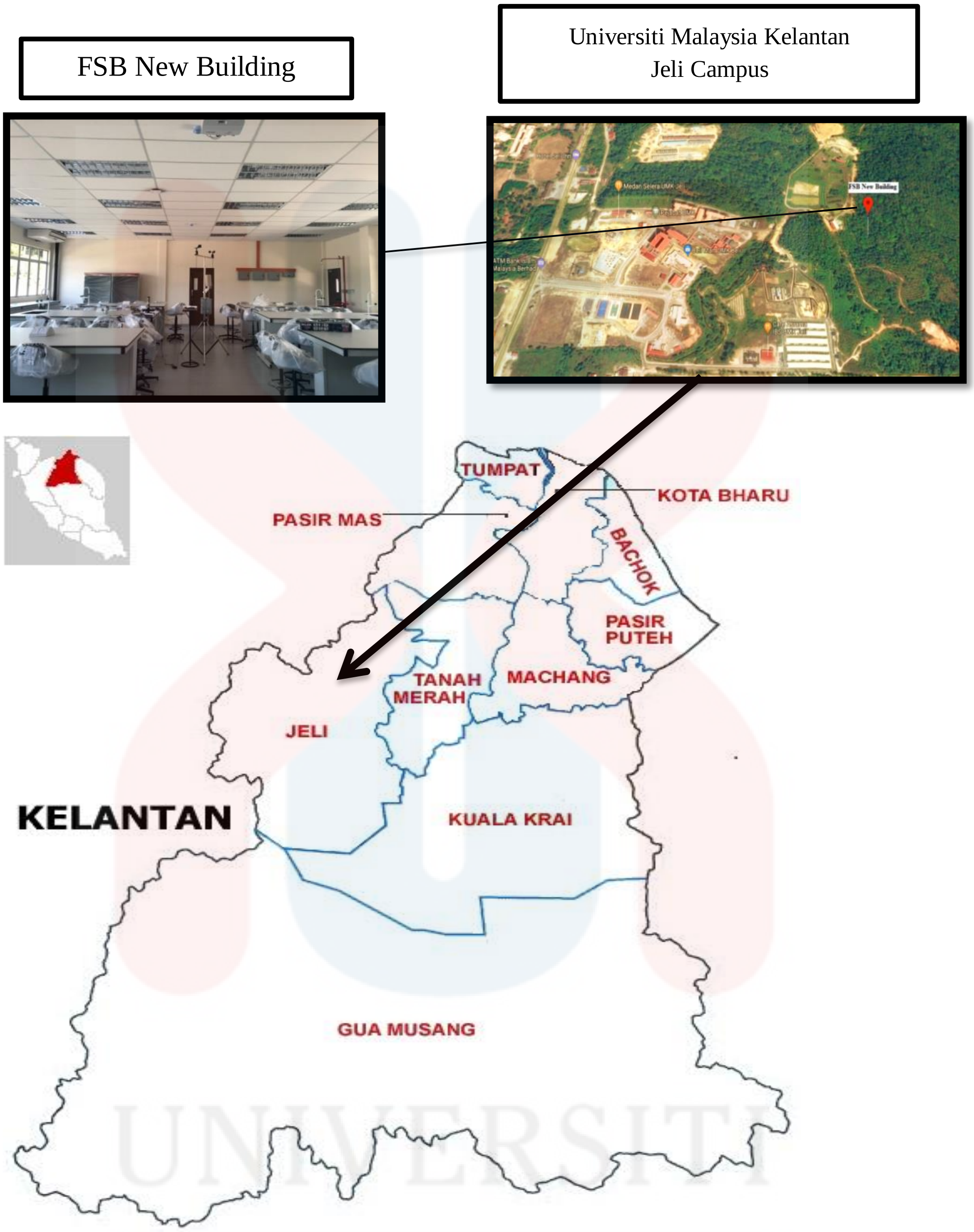


Figure 3.1: The flow chart of methodologies

3.2 Study area

The study area for this study was in the FSB new building in Universiti Malaysia Kelantan Jeli Campus (UMK) as shows in Figure 3.2 with the coordinates of 5°44'44.7"N 101°52'08.1"E on the map. Universiti Malaysia Kelantan Jeli Campus was located at Jeli district in Kelantan. Kelantan state districts have ten districts in total. Data was monitored at the new building of FSB which a new building that been constructed past one year ago. This building was constructed near to UMK Agropark. This building also located near to student’s hostel. This monitoring site is also near to the construction site of the new library. The room has measurement width and length with 9.91 m and 11.74 m respectively whereas high 3.10 m as shown in Figure 3.3. The building fully depends on mechanical ventilation which is an air conditioner system. The monitoring of the room has followed the Department of Occupational, Safety and Health (DOSH) for indoor air quality standard as shown in Table 3.1.



*Note: Sources from google maps (map is not to scale) and google images.

Figure 3.2: Location of the study area in Universiti Malaysia Kelantan Jeli Campus.

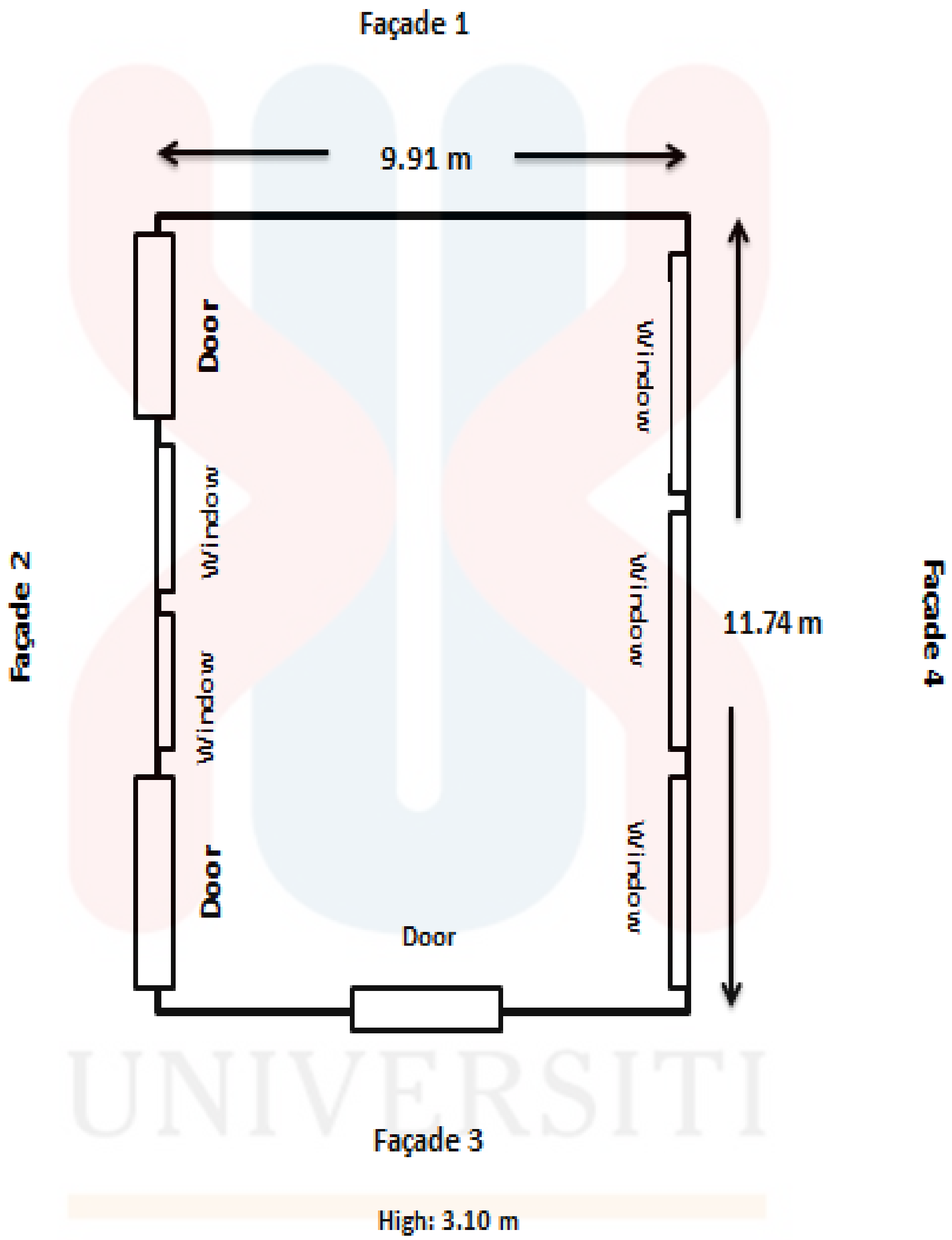


Figure 3.3 shows the measurement of the FSB room

Table 3.1: Guideline indoor air quality monitoring by Department of Occupational, Safety and Health (DOSH).

Total floor area	11.74m × 9.91m = 116.34 m^2
Distance of instrument from mechanical ventilation	5.35 m
Number of sampling points	1 (Area less than 3000 m^2 (DOSH))
Windows	Total = 12
Distance instrument from the ground	1.30 m (Placing inlets of samplers at a height between 75 and 120 cm, preferably 110 cm from the Floor (DOSH))

3.3 Data collection

The study area was located in FSB new building. The study monitored the IAQ and thermal comfort of the new building. The IAQ parameters were ozone, nitrogen dioxide, total volatile organic compound, carbon dioxide, carbon monoxide, temperature, particulate matter, relative humidity. The new building was utilized by mechanical ventilation of air-conditioning.

3.3.1 Experiment setup

In this study, the setup condition of indoor monitoring of FSB new building was regulated based on room temperature. The specific conditions of FSB new building are illustrated in Table 3.1. Five different conditions tested and the ranges of temperature were chosen based on normal temperature setup for indoor spaces in Malaysia. The monitoring period for one day is a day. In this case, the number of the day spent to monitor was about five days.

Table 3.2: Setup conditions per day.

Day	Temperature (˚C)
Day 1	22 ˚C
Day 2	23 ˚C
Day 3	24 ˚C
Day 4	25 ˚C
Day 5	26 ˚C

The monitoring period for the FSB new building was continuously collected from 8.00 a.m. to 5.00 p.m. This period was selected because during the period the FSB building will operate as an academic building for students and staff.

3.3.2 Monitoring equipment

The wolfsense indoor air quality apparatus was used to obtain parameters of ozone, nitrogen dioxide, total volatile organic compound, carbon dioxide, carbon monoxide, temperature and relative humidity. The reading of the particulate matter was used the casella microdust pro. The equipment Specification for wolfsense indoor air quality shows in Table 3.2 and equipment Specification for Casella Microdust Pro shows in Table 3.3.

Table 3.3: Equipment specification for wolfsense indoor air quality

<table>
<tr><th colspan="2">EQUIPMENT SPECIFICATION</th></tr>
<tr><td>Equipment Name</td><td>Woflsense indoor air quality</td></tr>
<tr><td>Manufacture</td><td>Wolfsense</td></tr>
<tr><td>Measurement</td><td>1. Total volatile organic compound
2. Carbon monoxide
3. Carbon dioxide
4. Ozone
5. Temperature
6. Relative humidity</td></tr>
<tr><td>Instrument Range</td><td>
1. Carbon monoxide
<table>
<tr><td>Range</td><td>0 to 500 ppm</td></tr>
<tr><td>Accuracy</td><td>± 2 ppm < 50 ppm, ± 3% rdg > 50 ppm</td></tr>
</table>
2. Carbon dioxide
<table>
<tr><td>Range</td><td>0 to 10,000 ppm</td></tr>
<tr><td>Accuracy</td><td>± 50 ppm, ± 3% rdg</td></tr>
</table>
3. Total volatile organic compounds
<table>
<tr><td>Range</td><td>0 to 50,000 ppb
(user selectable units: ppb, ppm, $\mu g/m^3$, mg/m^3)</td></tr>
<tr><td>Resolution</td><td>1 ppb, L.O.D. < 5 ppb</td></tr>
</table>
4. Relative humidity
<table>
<tr><td>Range</td><td>0 to 100 % RH</td></tr>
<tr><td>Accuracy</td><td>±2 % RH < 80 % RH (±3 % RH >80 % RH)</td></tr>
</table>
5. Temperature
<table>
<tr><td>Range</td><td>-10°F to 160°F (-25°C to +70°C)</td></tr>
<tr><td>Accuracy</td><td>±0.3°C</td></tr>
</table>
</td></tr>
</table>

Table 3.4: Equipment specification for casella microdust pro

<table>
<tr><th colspan="2">EQUIPMENT SPECIFICATION</th></tr>
<tr><td>Equipment Name</td><td>Casella microdust pro</td></tr>
<tr><td>Manufacture</td><td>Casella</td></tr>
<tr><td>Measurement</td><td>1. Particulate matter</td></tr>
<tr><td>Instrument Range</td><td>
<table>
<tr><td>Measuring Range</td><td>0.001 mg/m^3 to 250,000 mg/m^3</td></tr>
<tr><td>Zero stability</td><td>< 2 ug/m^3</td></tr>
<tr><td>Resolution</td><td>0.001 mg/m^3</td></tr>
</table>
</td></tr>
</table>

3.4 Data analysis

The data obtained was analysed by statistical analysis. The data analysis methods were descriptive analysis, time series plot, diurnal variations, CBE Thermal Comfort Tool ASHRAE 55 Standards and multiple linear regressions. Data was obtained about 7 days for 9 hours per day. The data was collected in minutes. Thus the total data obtained was 3780 data.

3.4.1 Descriptive analysis

Descriptive analysis is an analysis that able to identify the minimum, maximum value, mean, standard deviation of IAQ parameters. Other than that, this method analysis showed the different concentration levels for each condition. Thus, this method was used to obtain more details information on each condition.

3.4.2 Time series plot

Time series plot analysis is a statistical analysis which data is in a series of hourly time periods for Indoor Air Quality parameters and Thermal Comfort parameters in selected conditions.

3.4.3 Diurnal variations

Diurnal variability of indoor air quality and thermal comfort parameters concentrations in FSB new building in selected conditions was analyzed using diurnal plot. Diurnal variation was used to see hourly variation of indoor air quality and thermal comfort parameters concentration.

3.4.4 CBE thermal comfort tool ASHRAE 55 standards

The CBE Thermal Comfort ASHRAE 55 Standards are to determine thermal comfort standards environmental scientists work with models in which the neutral or optimal thermal comfort condition can be achieved, considering mainly the six factors affecting thermal comfort as discussed. The two most popular thermal comfort models that have been developed which are the predictive mean votes (PMV) or heat balance model and the Adaptive Comfort Model.

In this study, the method used was predictive mean votes (PMV). The data was obtained from monitoring such as air temperature, mean radiant temperature, air velocity and relative humidity. There was also observation towards a few factors from occupants. These factors include activity rate and clothing insulation

3.4.5 Multiple Linear Regressions

The multiple linear regression (MLR) were used to predict the next day hourly ozone concentration using as predictors air pollutant concentrations and meteorological parameters. Thus MLR were used to determine the relationship between two variable which the IAQ parameters and thermal comfort level by fitted a linear question data. Based on Sousa, Martins, Alvim-Ferraz, & Pereira (2007) the linear equations was $\hat{Y} = P_0 + P_1 X_1 + . . . + P_n X_n$. This method was used to determine the most significant level of IAQ and thermal comfort.

$$\hat{Y} = P_0 + P_1 X_1 + . . . + P_n X_n \tag{3.1}$$

where

P_i *(i = 0,.,n)* are the parameters generally estimated by least squares

X_i *(i= 1,.,n)* are the explanatory variables (predictors)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introductions

This chapter represents the results and discussions of indoor air quality (IAQ) selected parameters that were in room at FSB which was taken under seven selected conditions. The selected condition at the FSB was the temperatures at 22 ˚C, 23 ˚C, 24 ˚C, 25 ˚C and 26 ˚C and either window are opened or closed. A few of statistical analysis were conducted in this study which consists of descriptive statistic, time series plot analysis, diurnal variations, CBE thermal comfort tool ASHRAE 55 standards and multiple linear regressions.

4.2 Descriptive statistic of indoor air quality and thermal comfort parameters

The parameters that take account in IAQ were ozone, nitrogen dioxide, total volatile organic compound, carbon dioxide, carbon monoxide and particulate matter while for thermal comfort were temperature, relative humidity and wind speed. Total days that take account were 7 days. the IAQ monitoring were conducted inside the room of FSB, the IAQ monitoring was conducted according to different temperature each day, which is 22 °C, 23 °C, 24 °C, 25 °C and 26 °C. The overall variations concentrations of parameters IAQ and thermal comfort in studied area were studied using descriptive statistic. Descriptive statistical analysis was used to obtain the minimum, maximum, mean and standard deviation value of continuous data. The descriptive analysis for IAQ and thermal comfort parameters with different conditions are shown in Table 4.1 and meanwhile, for thermal comfort Table 4.2 respectively.

Table 4.1 shows that the concentrations of ozone have minimum value which is 0 ppm when the window was closed. This is because the concentrations of O_3 in window close condition are limited due to confine area and lack of ultraviolet sunlight gets into laboratory unlike outdoor air environment. Based on (Awang, Ramli, & Yahaya, 2015) the productions of O_3 is produced by series of chemical reaction of the main precursors that were anthropogenic emitted in the ambient air with ultraviolet radiation that act as catalyst to the reactions. However, the concentration of O_3 was increase when the window was opened. The concentrations of O_3 have maximum value which 0.027 ppm when the window was opened due to the intrusions into the room which brings the O_3 from ambient air. The concentration of O_3 during the usage of air conditioner was lower compared to usage of window. The usage of air conditioner at temperature of 24˚C shows the O_3 concentrations have the lowest maximum value which is 0.001 ppm while the O_3 concentrations at temperature 25˚C have the highest maximum value which is 0.003 ppm. The concentrations of O_3 will be elevated with intense solar radiation, high temperature, minimal rainfall, low wind speed, and low relative humidity (Awang, Ramli, Yahaya, & Elbayoumi, 2015).

Table 4.1 shows the concentrations of NO_2 have the maximum value on temperature 24 ˚C with 0.066 ppm and minimum value which is 0.032 ppm during window was opened. The execution of NO_2 is related to the formations of O_3. Based on Awang, Ramli, & Yahaya, (2015) the single atom O that created from photolysis of NO_2 will react with molecule of O_2 that exits in atmosphere will produce O_3, thus the destruction of O_3 will happen when it is reacted with NO to produce NO_2. Thus when the O_3 inside the room of FSB new building was lower, the concentrations of NO_2 became higher. These show the inversely proportional relationship between O_3 and NO_2.

Results in Table 4.1 shows that total volatile organic compound concentrations during window closed has maximum value which is 437.200 ppm, where the minimum value of TVOC concentrations is during the set up temperature at 26˚C with 154.370 ppm. Based on Tao et al., (2015) stated that the high temperature of indoor has ability to add indoor exposure to TVOC. Thus show supposedly the value of TVOC among the air conditioner temperature was the highest is temperature 26 ˚C. However, the result shows temperature 22 ˚C have high concentration of TVOC. This is because due to the conditions of outside weather that hot and sunny compare to temperature 26 ˚C the weather outside was cloudy and have rainy. This is because during hot weather the temperature of outdoor was affected the indoor temperature. Based on Nguyen, Schwartz, & Dockery, (2014) stated in the study that outdoor temperature were highly correlated with indoor temperatures during outdoor temperatures were warmer. Meanwhile, there were weak correlations between indoors temperature and outdoors temperature on cooler days. Thus the result based on that study was suggested that outdoor temperature is a poor indicator of indoor temperature on cool weathers. Besides, there was an error caused by the instrument that affected the reading of TVOC during conditions of temperature 22 ˚C.

Table 4.1 shows the concentrations of CO_2 has maximum value of 522.850 ppm while the minimum value is 322.72 ppm. The value was high when the window was opened. This is because due to intrusion of CO_2 from ambient air into indoor air environment. The CO_2 concentrations during windows closed also higher this due to closed space without any ventilation. Additionally, the raised of CO_2 concentrations was due to the process of breathing by the occupants that released CO_2. Based on Lee & Chang, (2000) stated that the indoor level was influenced by human occupancy which the result suggest the carbon dioxide concentrations began to increased when students start occupying the classroom and reached a maximum level. Other than that, based on the same study also stated that CO_2 concentrations increased due to overcrowded classrooms and inadequate ventilation (Lee & Chang, 2000).

Table 4.1 showed that CO has the minimum and maximum concentrations value which is 0.000 ppm and 1.622 ppm respectively. The concentrations of CO are related to incomplete combustion of fuel in vehicles engine thus the exposure of CO into indoor air is minimal. However, the CO concentration is higher when the window opened due to intrusion from outside pollutions. The CO concentrations in the indoor were found to be influenced by concentrations of ambient particles air which were emitted by traffic vehicle (Chithra & Shiva Nagendra, 2012). However, among the conditions set up the minimum concentration of CO was also during the window opened. This is because the opened window was allowed wind to pass through the room thus bring away the CO outside especially during high rate of wind speed. Based on Chithra & Shiva Nagendra, (2012) stated that the CO concentrations with respect to wind speed shows CO concentration pattern has a negative linear relationship with wind speed. The higher wind speed enhances dispersions and dilutes the ambient concentration, which is intern bringing down the indoor pollution levels.

The concentrations of particulate matter have minimum and maximum value which is 18.331 mg/m^3 and 21.185 mg/m^3 respectively. The maximum concentrations were obtained when the window closed without any ventilation. During the conditions the temperature was relatively high compare to other condition and the dust uplifted to from floor into air and suspended in the room. In contrast, the minimum concentrations of particulate matter was observed when the usage of air conditioner that have minimal effect on dust uplifting and keep the indoor environment in healthier conditions with less air pollution concentrations. The movement of occupants in the room contributes to higher rate of indoor dust uplifting. Based on Chithra & Shiva Nagendra, (2012) stated that the indoor PM concentrations were varied significantly with occupants activities. The higher concentrations of particulate matter also cause when delayed of deposition or settlement due to induced turbulence created by occupant's movements. While minimal activity also can have a significant impact on the concentration of air borne particles such as walking into and out of the room can increase the mass of coarse suspended particles (Chithra & Shiva Nagendra, 2012).

For the thermal comfort parameters, the temperatures have minimum and maximum value which is 22.635 ^oC and 33.272 ^oC. The maximum value of temperature is when the window was closed. This because of the space become enclosed room and without any ventilation that brings to the increase of temperature. While that the minimum value of temperature was when the temperature of air conditioner was setup to 24 ^oC. The variations of temperature parameters are relatively small and accordance with the set up temperature. However, there was unexpected trend event happened due to interruption and disturbance from occupants. In the morning, the temperature was relatively higher due to the operations of air conditioner that need time to make the room to set up temperature.

Relative humidity shows in Table 4.2 which a typical trends where the maximum value is when the temperature decrease and relative humidity will increase. Relative humidity has minimum and maximum value which is 44.360 % and 73.873 % respectively. When the window was opened, the relative humidity observed as the highest due to wind-blown into indoor building. During usage of air condition the trends of relative humidity was decrease in the morning during beginning operational hours but then increase due to setup temperature after some period.

Table 4.1 Descriptive analysis of Indoor Air Quality

Parameters	Conditions	Min.	Max.	Mean	S.D
O_3 (ppm)	Window Closed	0.000	0.000	0.000	0.000
	Window Opened	0.002	0.027	0.020	0.009
	Temperature 22 ˚C	0.000	0.004	0.003	0.001
	Temperature 23 ˚C	0.000	0.003	0.001	0.001
	Temperature 24 ˚C	0.000	0.002	0.001	0.001
	Temperature 25 ˚C	0.000	0.004	0.001	0.002
	Temperature 26 ˚C	0.000	0.003	0.001	0.001
NO_2 (ppm)	Window Closed	0.032	0.048	0.042	0.005
	Window Opened	0.038	0.059	0.047	0.007
	Temperature 22 ˚C	0.057	0.063	0.060	0.002
	Temperature 23 ˚C	0.057	0.067	0.062	0.003
	Temperature 24 ˚C	0.059	0.066	0.063	0.002
	Temperature 25 ˚C	0.057	0.064	0.061	0.002
	Temperature 26 ˚C	0.058	0.063	0.061	0.002
TVOC (ppm)	Window Closed	0.334	0.437	0.360	0.033
	Window Opened	0.205	0.289	0.228	0.026
	Temperature 22 ˚C	0.236	0.253	0.248	0.005
	Temperature 23 ˚C	0.179	0.222	0.188	0.014
	Temperature 24 ˚C	0.194	0.225	0.203	0.010
	Temperature 25 ˚C	0.160	0.218	0.188	0.019
	Temperature 26 ˚C	0.154	0.211	0.174	0.020
CO_2 (ppm)	Window Closed	322.720	437.250	355.840	38.686
	Window Opened	466.570	522.850	487.406	19.504
	Temperature 22 ˚C	322.720	437.250	355.840	38.686
	Temperature 23 ˚C	342.150	392.330	356.040	16.752
	Temperature 24 ˚C	329.830	384.700	346.537	18.405
	Temperature 25 ˚C	331.470	376.030	345.664	13.247
	Temperature 26 ˚C	372.380	385.125	378.808	4.595
CO (ppm)	Window Closed	1.197	1.510	1.316	0.096
	Window Opened	0.731	1.622	1.225	0.316
	Temperature 22 ˚C	0.148	0.502	0.312	0.120
	Temperature 23 ˚C	0.000	0.150	0.068	0.066
	Temperature 24 ˚C	0.000	0.147	0.067	0.065
	Temperature 25 ˚C	0.129	0.365	0.235	0.089
	Temperature 26 ˚C	0.127	0.367	0.236	0.085
PM (mg/m^3)	Window Closed	20.591	21.185	20.944	0.240
	Window Opened	18.949	21.186	20.027	0.948
	Temperature 22 ˚C	19.425	19.629	19.567	0.062
	Temperature 23 ˚C	18.518	19.488	18.760	0.288
	Temperature 24 ˚C	18.429	19.389	18.672	0.278
	Temperature 25 ˚C	18.552	19.483	18.857	0.303
	Temperature 26 ˚C	18.331	19.457	18.979	0.402

**Note: S.D is standard deviation*

Table 4.2 Descriptive analysis of thermal comfort parameters

Parameters	Conditions	Min.	Max.	Mean	S.D
T (^{0}C)	Window Closed	28.318	30.878	29.633	0.829
	Window Opened	26.092	33.272	30.449	2.742
	Temperature 22 ˚C	22.743	23.457	23.085	0.228
	Temperature 23 ˚C	23.632	24.872	24.000	0.364
	Temperature 24 ˚C	22.635	24.683	23.034	0.643
	Temperature 25 ˚C	22.697	24.115	23.118	0.481
	Temperature 26 ˚C	24.782	25.420	25.017	0.208
RH (%)	Window Closed	61.78	67.558	64.200	1.833
	Window Opened	48.017	73.873	59.826	9.770
	Temperature 22 ˚C	44.360	50.877	46.302	1.828
	Temperature 23 ˚C	46.428	59.612	48.900	4.163
	Temperature 24 ˚C	47.154	59.165	50.307	3.542
	Temperature 25 ˚C	48.802	57.170	51.795	2.302
	Temperature 26 ˚C	44.672	57.260	50.082	4.337

**Note: S.D is standard deviation*

4.3 Time series of indoor air quality and thermal comfort parameters concentrations

Time series plot analysis is a statistical analysis which data is in a series of hourly time periods for indoor air quality parameters and thermal comfort parameters in selected conditions. The result is showed in Figure 4.1 and Figure 4.2.

Figure 4.1 illustrated the hourly variations of O_3 from 8 a.m. until 5 p.m. for 7 days under selected conditions. The concentration of O_3 varies with time and the concentrations spikes. Result suggested that during window closed the concentration is lower due to enclose space without any ventilations thus no intrusions from outside. In contrast when the window opened the concentrations of O_3 was began increase from morning into evening due to intrusion of O_3 from ambient air through the window. Based on Dueñas, Fernández, Cañete, Carretero, & Liger, (2004) stated that in ambient air the formations of O_3 is with the presence of sunlight while nitrogen dioxide undergoes photochemical reactions to produce free oxygen atom O which later reacts with oxygen to form ozone. Compared to conditions when the air conditioner was used, the O_3 concentration from morning until evening was lower. The O_3 concentration was lower related to the relationship of O_3 disruption and NO_2 formation, showed in Figure 4.1.

The hourly variations of NO_2 showed in Figure 4.1, which seven selected conditions overall showed the same variations which increment of NO_2 concentrations. During the window closed, the NO_2 variation was minimal increased due to no formations of O_3 inside the room of FSB new building. Based on (Abdul-Wahaba, Bakheitb, & Al-Alawia, 2015) the increase of NO_2 influenced by the formation of tropospheric ozone include stratospheric injection and processes (Abdul-Wahaba et al., 2015). In contrast, when the window opened, the concentration of NO_2 was sharply increased in the morning. This cause by the open space that brings outdoor air enter the room, the pollutants consist of fuel burning from human activities. Based on Awang, Ramli, & Yahaya, (2015) stated that NO_2 is produced when fuel is burned at high temperature. However, NO_2 variations slightly declined in the evening due to photolysis of NO_2 that created the single atom O and reacted with molecule O_2 that already existed in the atmosphere to create O_3. Meanwhile, the usage of air-conditioner under set up temperature cause the variations of NO_2 was lower. This might cause by not enough sunlight to undergo photolysis of NO_2 and additionally with enclosed space without intrusions of O_3 from ambient air, the insufficient O_3 concentrations cause the NO that generated by the photolysis of NO_2 cannot be oxidized by O_3 to regenerated NO_2.

The concentration of total volatile organic compound caused by factors such newly paint wall. Generally, the paint walls of FSB room consist of substance that suspended in liquid that might contribute to the emissions of TVOC. The variation of TVOC is showed in Table 4.1. Based on table, TVOC concentration is high when the window closed. The concentration of TVOC is increase due to high temperature inside the enclosed room that cause TVOC particle volatile. Based on An, Kim, Kim, & Seo, (2010), result suggested that during higher temperature shows the higher of TVOC emission concentration. They also conclude that there are relationship was observed between the temperature and formaldehyde and VOC behavior. The rates of formaldehyde and TVOC emission are affected by both ventilation and temperature (An et al., 2010). Meanwhile, when the window was opened, the TVOC concentration was steeply declined. This might cause by wind was blown from outside into inside and brings TVOC away from the room. In contrast, the concentration of TVOC under air-conditioner set up was clearly shows the trend slightly fluctuated. The variations seems have minimal changes varies the time. This might cause of control conditions which lower temperature that would not lead to volatilization of TVOC.

The concentration of carbon dioxide was illustrated in Figure 4.1. Generally, the highest variation of CO_2 observed was during the conditions of window closed. The hourly variations of CO_2 during window closed was suddenly raised at some hour make it was the maximum value observed, this might due to the presence of occupants inside the room. In contrast, during the conditions of window was opened, the CO_2 variations fluctuated was gradually declined in the morning but began raised when comes to evening. This might due to the interference of CO_2 from outdoor air and additionally in high temperature cause the flow rate of wind from outside into inside of the room bring the CO_2 particle away outside. Based on Santamouris et al., (2008) stated that there was relational between indoor temperature and the corresponding air flow rate. The result suggested, the higher the indoor temperature range, the higher the tendency to open windows and increase the air flow rate. However, Figure 4.1 showed there were dramatically changes variations of CO_2 concentration when used air-conditioner. The trends of CO_2 every condition under air conditioner shows lower concentrations compared to the conditions when window was used. The previous study have showed that the conditions of window opened was present a higher average of CO_2 concentration compared than the mechanically ventilated (Santamouris et al., 2008).

Next, the concentration of carbon monoxide was in Figure 4.2, generally the variations of CO when the window was closed and opened was higher compared to when the room was under air-conditioner set up temperature. During the condition window was opened, the variations have minimal declined. In contrast with the condition when the window opened, the variation of CO was sharply increased. The concentrations of CO are related to the combustion of engine of vehicle. When the window of FSB room was opened, the polluted air from outside entered into indoor buildings thus cause the increment of CO. However, the usage of air conditioner at selected set up temperature caused the CO variations was lower. The reason might due to closed room without intrusions from outside and additionally, with no sources contribute to production of carbon monoxide inside the room. It's proven that previous study mention about the CO concentrations is depending to wind speed. The higher wind speed enhances dispersions and dilutes the ambient concentration, which is intern bringing down the indoor pollution levels (Chithra & Shiva Nagendra, 2012)

The concentration of particulate matter was illustrated in Figure 4.2. Generally, the variations of particulate matter show various variations in every set up conditions. The results suggest that during window closed the particulate matter variations was stabile in the morning but began to decline in the evening. This might cause by there was no ventilation into the room, thus the dust just suspended on the floor. In contrast, the result shows that when the condition of window opened, the particulate matter variations was raised in the morning however gradually declined when comes to evening. This result was due to the air flow into the room and brings away the dust outside. Furthermore, the variations of particulate matter when under set up air conditioner shows similar patterns which have small fluctuation from morning until evening. However, this different with the condition set up at 23 ˚C where as the result shows steeply declined. This happened cause by the presents of occupants that move in the room also gave affect to the dust that can easily uplift.

The hourly variation shows the temperature spikes. The result shows that there was small fluctuation of temperature variation pattern during window closed. In contrast, there was high fluctuation of increased temperature when the window opened. Furthermore, the result of temperature when the room temperature set up at 22˚C, 23˚C, 24˚C, 25˚C and 26˚C shows similar pattern which have slightly fluctuation from morning until evening accordance with the set up temperature. However, there was uneven trend event happened due to some error and interruption and disturbance from occupants. Based on observation, in the morning the temperature was relatively higher due to the operations of air conditioner that need time to make the room to set up temperature.

The relative humidity shows the opposite relationship with temperature. Based on Figure 4.2 the relative humidity shows the typical trends where increase when the temperature decreases. The variations of relative humidity varies over time was showed that during conditions of window closed and the set up air conditioner temperature at 22˚C, 23˚C, 24˚C, 25˚C and 26˚C have similar patterns. The patterns were begun at certain point in morning, gradually declined until evening. However, when the conditions of window opened, there was steeply declined of relative humidity which the starting point in the morning was highest compared to others starting point observed. The range of relative humidity observed as the highest was due to wind blown into indoor building.

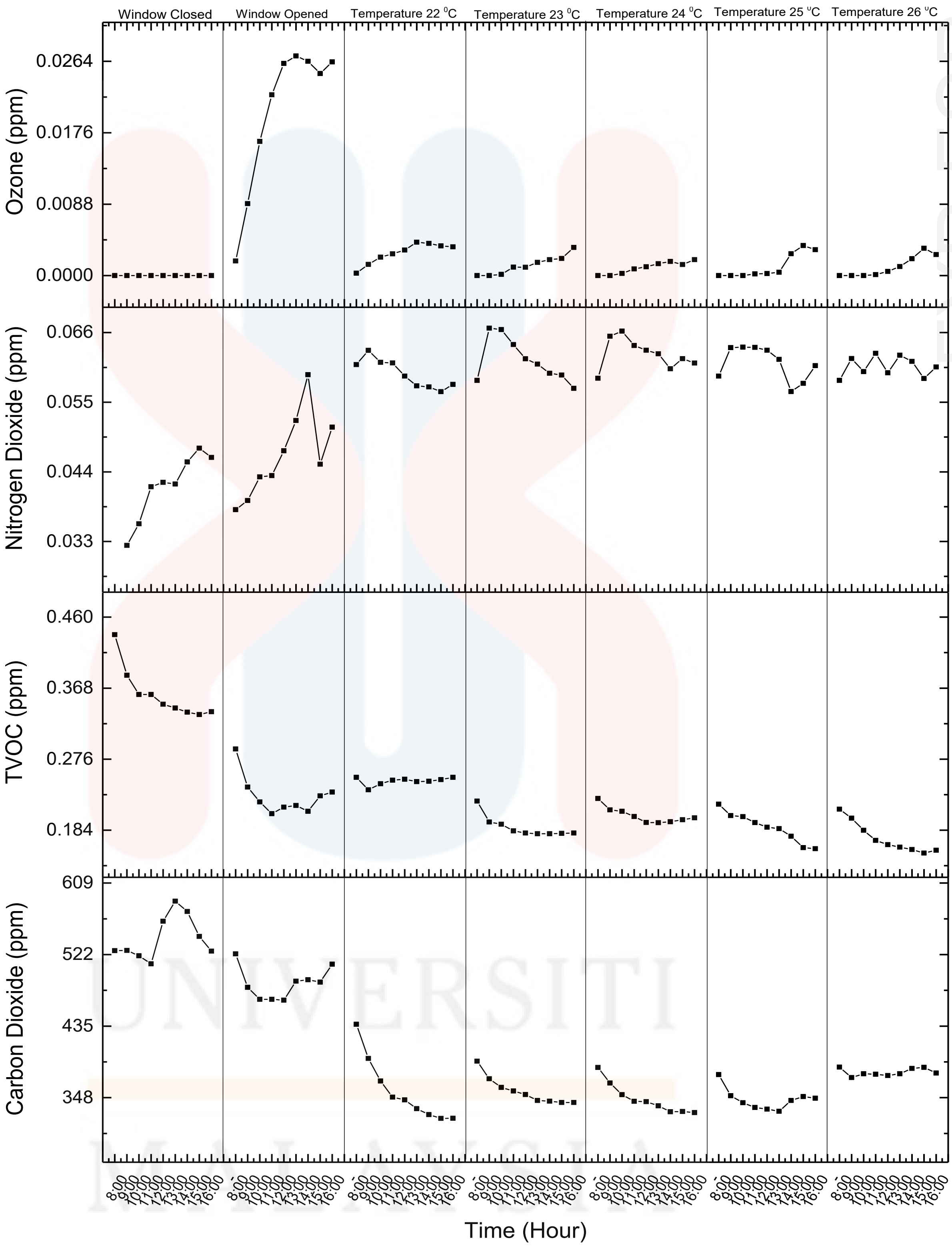


Figure 4.1 Time series plots of indoor air quality parameters

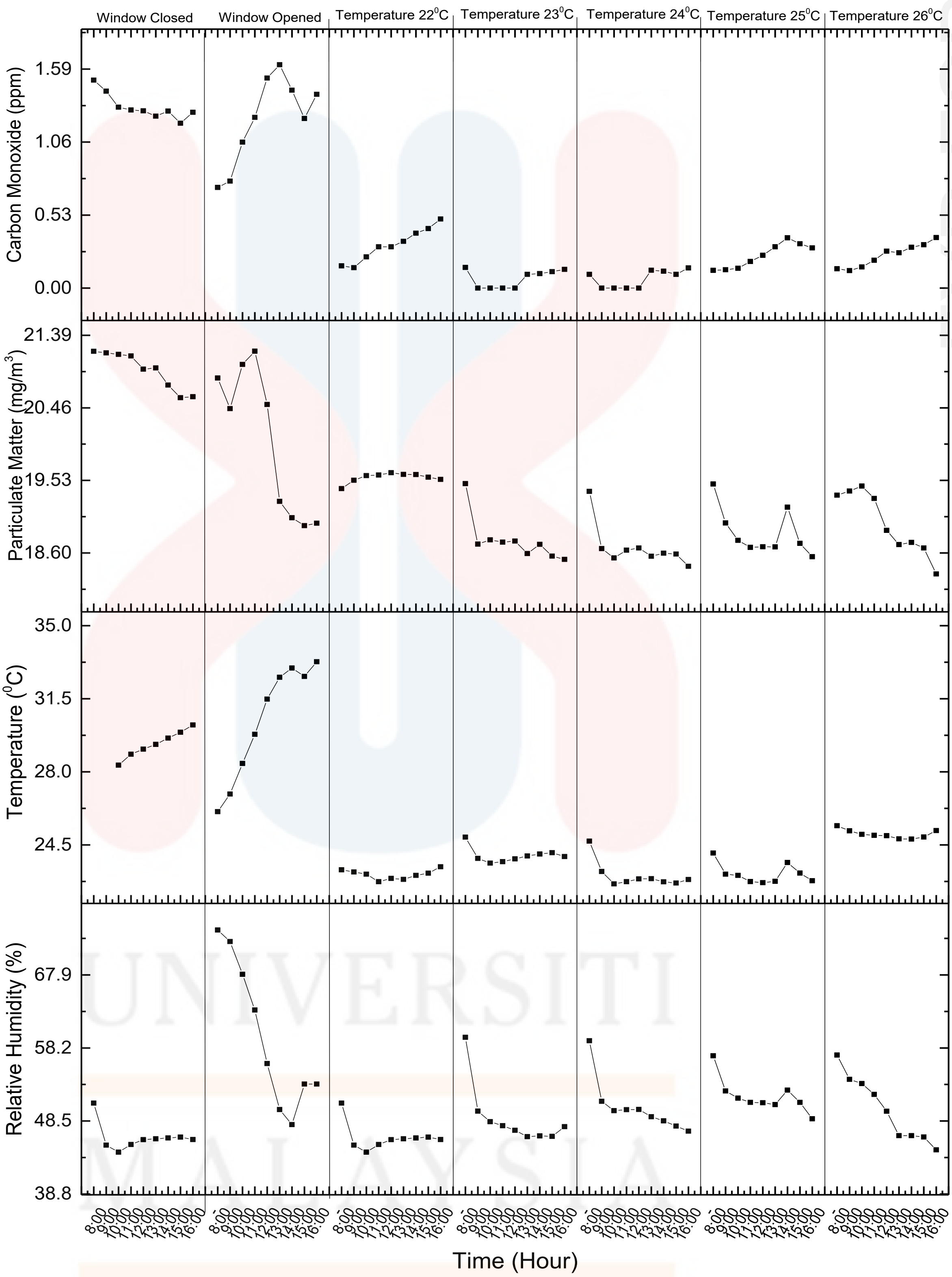


Figure 4.2 Time series plots of thermal comfort parameters

4.4 Diurnal variation of indoor air quality and thermal comfort in FSB new building

Diurnal variability of indoor air quality and thermal comfort parameters concentrations in FSB new building in seven selected conditions was analyzed using diurnal plot. Diurnal variation was used to see hourly variation of indoor air quality and thermal comfort parameters concentration.

4.4.1 The diurnal variations of indoor air quality parameters.

Figure 4.3 (a) showed the diurnal variability pattern of ozone concentration in FSB room. Generally, the diurnal variations of O_3 shows the ranged between 0.000 ppm until 0.005 ppm except the maximum value which until 0.025 ppm. The variation of O_3 during conditions of window opened, was sharply increased began at 8:00 a.m. until 13:00 p.m. and slightly declined at 15:00 p.m. and began raised after that moment. The opened spaces cause the intrusion of O_3 from ambient to indoor. However, the result of O_3 concentrations was not exceeding 0.05 ppm which the limits of DOSH guidelines for indoor air quality. Based on Dueñas et al.,(2004) that the O_3 concentrations abundance in ambient air especially in the morning and decreasing during noon time, thus the opened window cause the O_3 concentration from outdoor enter indoor air. Meanwhile, when the condition was set up into selected air-conditioner temperature, the variations concentration was lower. Furthermore, the diurnal variations of O_3 concentrations showed same diurnal pattern which raise began at 8:00 a.m. until 17:00 p.m. However, there has minimal declination during those durations. While that, the diurnal variations of temperature 22 ˚C have the highest variations among other temperature due to the O_3 concentrations that left in the building due to opened window before.

Figure 4.3 (b) shows the diurnal variations of nitrogen dioxide concentrations. Generally, the NO_2 diurnal patterns have various variations which every conditions design different diurnal pattern. The diurnal pattern of NO_2 during the condition window closed the range was between 0.030 ppm until 0.045 ppm. This shows the diurnal pattern increased from 9:00 a.m. until 17:00 p.m. but it is the lowest range among the others. This might due to the not enough O_3 concentration inside the room to oxidize the NO in forming NO_2, thus NO_2 concentration remain lower. In contrast, when the conditions of window opened the NO_2 concentration was ranged 0.038 ppm until 0.060 ppm which shows the increment from 8:00 a.m. until 14:00 p.m. and slightly decline in the evening. This cause by the destruction of NO_2 pollutants from outside air enters the room. Furthermore, the diurnal pattern of set up air conditioner have almost similar pattern which range between 0.055 ppm until 0.070 ppm which the highest range of NO_2 observed. The diurnal variations of set up air conditioner temperature on Figure 4.3 (b) shows the maximum NO_2 variation was between 9:00 a.m. until 10:00 a.m. However, the diurnal variation of NO_2 concentrations was not above 10 ppm which the limits of DOSH guidelines.

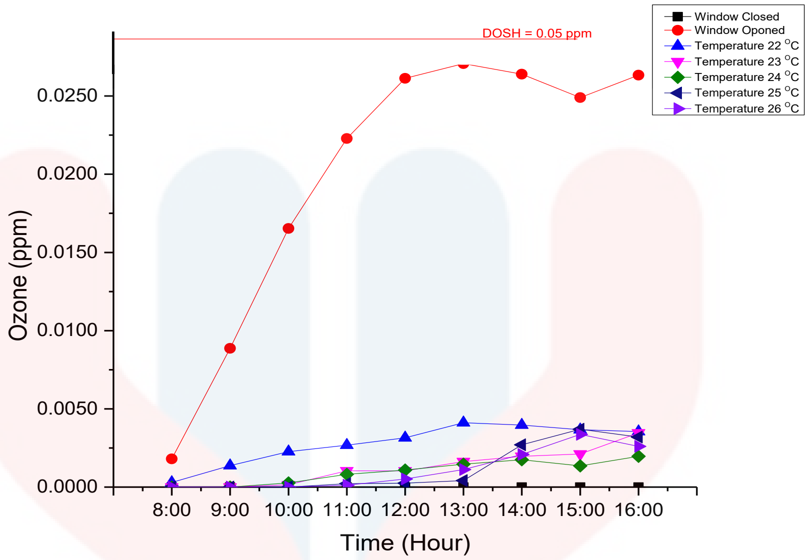


Figure 4.3 (a) Diurnal variation of ozone

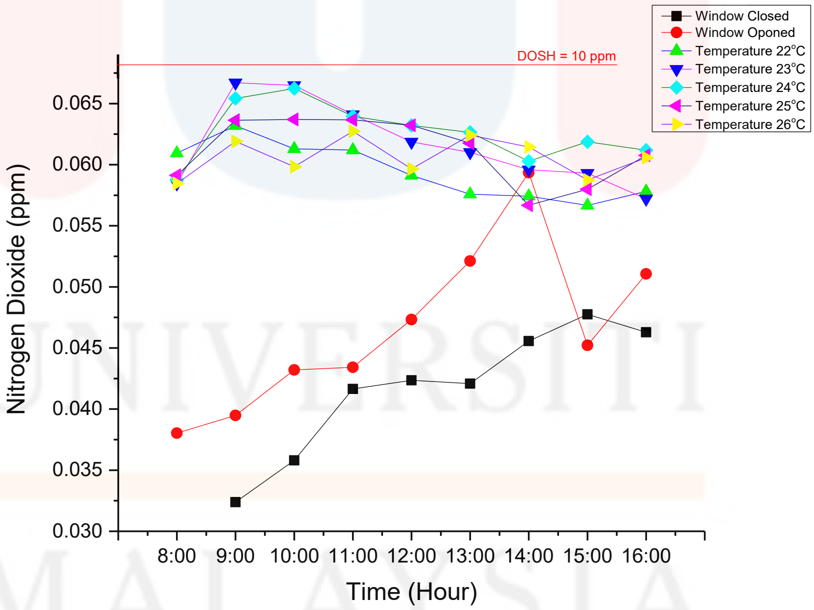


Figure 4.3 (b) Diurnal variation of nitrogen dioxide

Figure 4.3 (c) shows the diurnal variations of total volatile organic compound concentrations. Generally, the diurnal variation of TVOC was ranged between 0.15 ppm until 0.43 ppm. The diurnal variation of TVOC, most of time was range between 0.15 ppm until 0.29 ppm except during the conditions of window closed which showed the highest range of TVOC concentration observed. The closed space without any ventilations cause the temperature inside the room increased, the increased of temperature cause the TVOC particle volatile and the variation was increased. Previous study stated that high temperature environment will increase the release rate of formaldehyde and TVOC. The TVOC particle was emitted from decoration materials and goods (Tao et al., 2015). Therefore, reducing indoor air temperature would not only slow down the release rate, but also may improve the comfort of the room. However, the concentrations of TVOC was not above 3 ppm which the limits of DOSH guidelines for indoor air quality. In contrast, the TVOC diurnal variation of room under set up air conditioner which 23 ˚C, 24 ˚C, 25 ˚C and 26 ˚C have similar diurnal pattern. The result suggests there were only minimal fluctuation of diurnal variations especially in the evening at 13:00 p.m until 17:00 p.m. This was happened due to set up air conditioner at low temperature. As mentioned that TVOC would affected under high temperature.

Figure 4.3 (d) shows the diurnal variations of carbon dioxide. Generally, the diurnal variation was ranged between 300 ppm until 600 ppm. The diurnal variation of CO_2 in condition the window was closed was increased began on 11.00 a.m. until 13:00 p.m. and minimal declined until 17:00 p.m. The range was the highest among others CO_2 pattern. The diurnal variation was highest might due to enclosed space without any ventilation thus when the occupants released CO_2, the CO_2 particle remains in the room without flow outside. As mention based on (Santamouris et al.,

2008) stated that the most contributors to the concentrations of CO_2 are occupants. In contrast with the condition of window opened, which the ranged of CO_2 between 455 ppm until 555 ppm. The variations was not the highest due to air flow from outside that bring away the CO_2 outside the room and along with that the CO_2 particle as not accumulated in the room. Furthermore, the room was under set up air conditioner temperature, the result shows the range of CO_2 variations between 325 ppm until 448 ppm. The air conditioner with set up temperatures have cause the CO_2 concentration shows similar variations with low fluctuations every hour from morning to evening.

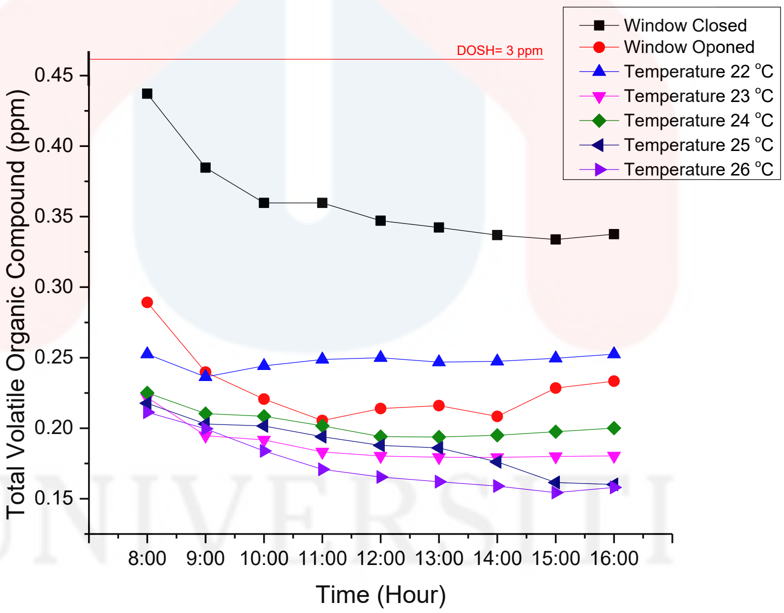


Figure 4.3 (c) Diurnal variations of total volatile organic compound

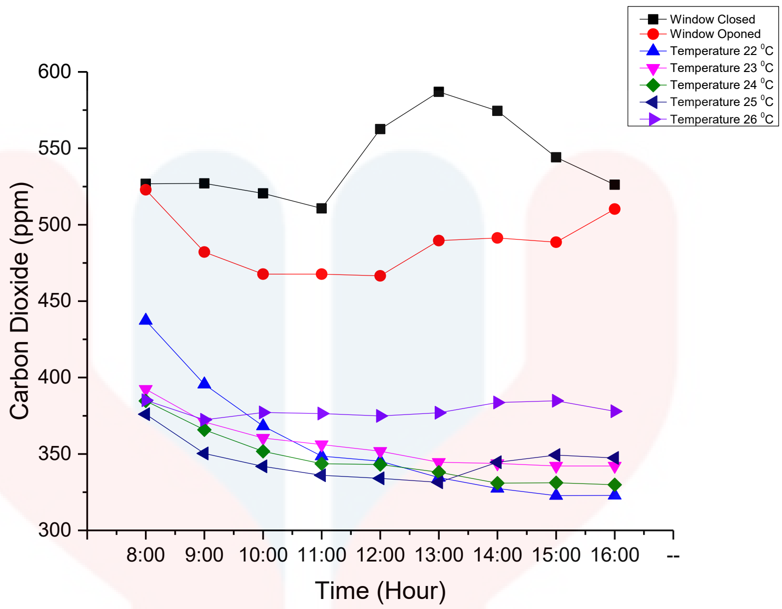


Figure 4.3 (d) Diurnal variation of carbon dioxide

Figure 4.3 (e) shows the diurnal variations of carbon monoxide concentrations. The diurnal variation of CO during window closed shows a slightly declined which the fluctuation is minimal which ranging between 1.2 ppm until 1.5 ppm. In contrast with the condition window opened, the fluctuations was bigger which clearly show the increased began at 8:00 until 13:00 p.m. and steeply declined and raised back to certain point, the range between 0.7 ppm until 1.6 ppm. However, the maximum value was not exceeding the limits by DOSH guideline for indoor air quality. The increase was due to interruption from traffic pollutants from ambient air that enter into FSB room. Based on Chithra & Shiva Nagendra, (2012) stated that the CO concentrations with respect to wind speed shows CO concentration pattern has a negative linear relationship with wind speed. The higher wind speed enhances dispersions and dilutes the ambient concentration, which is intern bringing down the indoor pollution levels. Furthermore, the CO diurnal variation when under air conditioner set up is range between 0 ppm until 0.45 ppm. The diurnal pattern shows almost similar pattern.

Figure 4.3 (f) shows the parameter particulate matter, the concentrations of particulate matter increase and above the acceptance limits by DOSH. This is because the temperature high and the dust uplifted to from floor into air and suspended in the room. Besides, the result related to the new building and new furniture that have suspended dust. The dust suspended on the floor and over the furniture thus when there is movement from occupants the dust uplifted to indoor air.

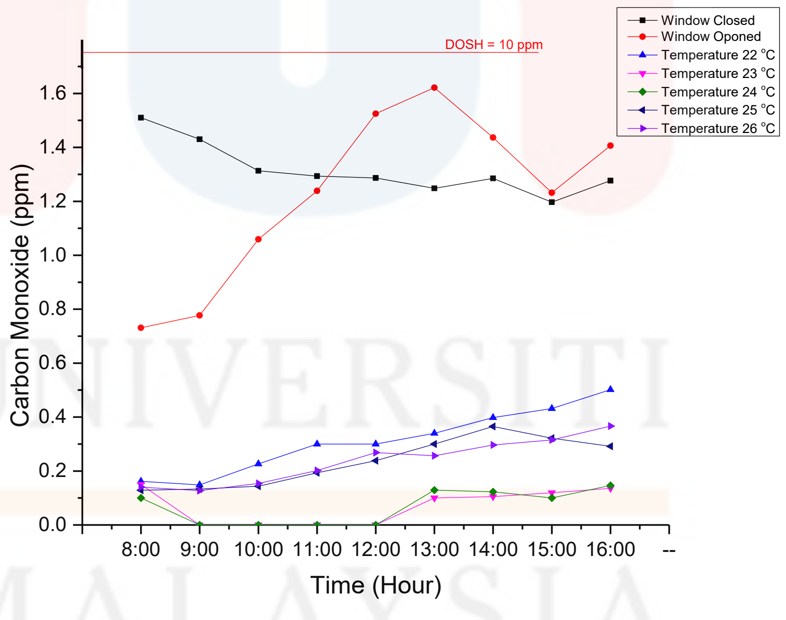


Figure 4.3 (e) Diurnal variation of carbon monoxide

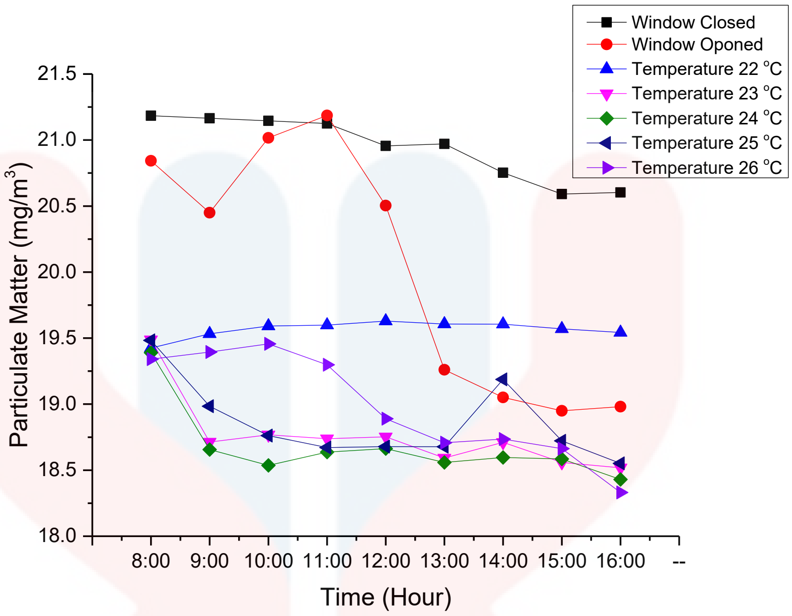


Figure 4.3 (f) Diurnal variation of particulate matter

4.4.2 The diurnal variations of thermal comfort parameters concentrations

Figure 4.3 (g) shows the temperature variations. The result suggested that the range of temperature variation is between 22˚C until 33˚C. The highest range of the temperature observed was during window opened. The diurnal variation was steeply raised from 8:00 a.m. and slightly decline at 15:00 p.m. The highest temperature was due to influences from outdoor temperature. Besides, the range of temperature during window closed also rose. The ranged was beet 28 ˚C until 30 ˚C. The value of temperature increased during the window was closed was due to enclosed space without any ventilation. The variations of temperature parameters are relatively small and accordance with the setup temperature. However, there was uneven trend event happened due to some error and interruption and disturbance from occupants. In the morning, the temperature was relatively higher due to the operations of air conditioner that need time to make the laboratory temperature to setup temperature.

Figure 4.3 (h) shows the relative humidity diurnal pattern of variation is inversely proportional with the temperature. The result shows the relative humidity was spiked which have the typical trends where the maximum value is when the temperature decrease and relative humidity will increase. Based on the Figure 4.3 (h) clearly illustrated that during window closed conditions, the variations pattern was bigger. Began at 8:00 a.m. it was gradually declined and slightly raised in the evening. The range of relative humidity was between 48 % until 74 %. The relative humidity observed as the highest due to windblown that consist of water vapour into the indoor building. In contrast, the condition of window closed was showed a minimal fluctuation varies time. The result shows that there was slightly declined from morning until evening. During the room was under air condition set up temperature, the range of the conditions was between 43% until 60%. This shows that the fluctuation among the temperature set up was minimal. The results of relative humidity have relationship with the temperature observed.

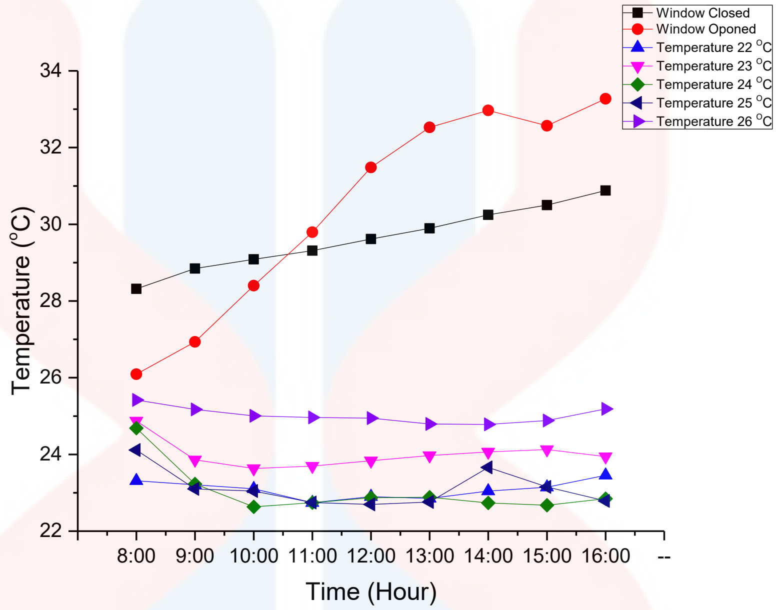


Figure 4.3 (g) diurnal variations of temperature

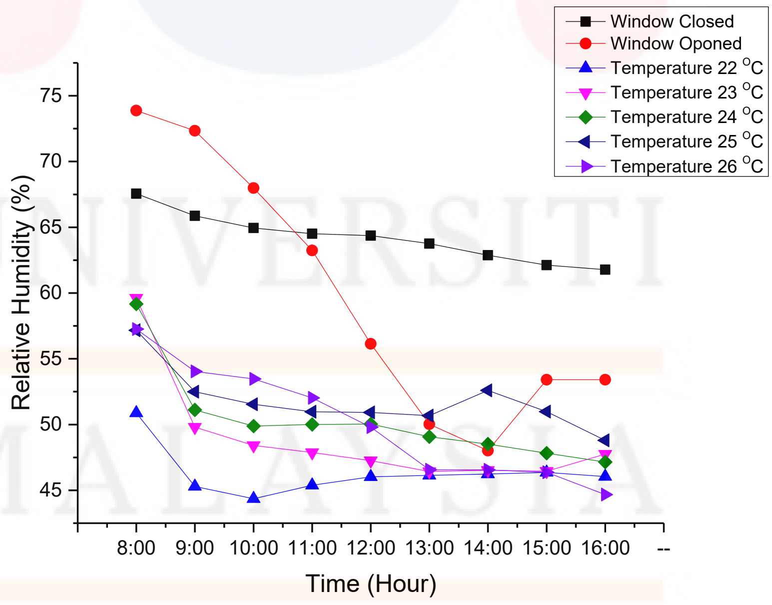


Figure 4.3 (h) diurnal variations of relative humidity

4.5 Thermal Comfort Compliance to ASHRAE 55

The thermal comfort parameters were monitored to FSB new building then the complieness has been determined by using CBE Thermal Comfort Tool. Thermal comfort and air quality compliance results can be as indicator to identify the best conditions of FSB new building.

Table 4.3 shows the summary of thermal comfort compliance in FSB new building. Based on the Table 4.3 the result suggested that the most satisfying condition that complies with the thermal comfort ASHRAE 55standard was setup of temperature 26 ˚C. Meanwhile, the setup of window closed shows the result of not complies with ASHRAE 55 standard from 8:00 a.m. to 17:00 p.m. due to closed space without any ventilations. Furthermore, the setup of opened window shows that on 8:00 am until 10:00 am the condition was complies with ASHRAE 55 standard but after time increment to the noon the conditions become not complies. The condition was slightly warm and to the evening the condition becomes warm. This condition is not satisfying the thermal comfort of ASHRAE 55 standard. The setups of temperature at 22 °C, 23 °C, 24 °C and 26 ˚C have shown similar result which in earlier operational the conditions is complies with ASHRAE 55 standard but when time increment the conditions turn to cool and not complies the ASHRAE 55 standard.

Table 4.3 Summary of thermal comfort compliance in FSB new building

Hour Conditions	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00
Window Closed	NCc	NCc	NCc	NCc	NCc	NCc	NCc	NCc	NCc
Window Opened	C	C	NCc	NCc	NCd	NCd	NCd	NCd	NCd
Temperature 22 °C	Ncb	NCb	NCb	NCb	NCb	NCb	NCb	NCb	NCb
Temperature 23 °C	C	NCb	NCb	NCb	NCb	NCb	NCb	NCb	NCb
Temperature 24 °C	C	NCb	NCb	NCb	NCb	NCb	NCb	NCb	NCb
Temperature 25 °C	NCb	NCb	NCb	NCb	NCb	NCb	NCb	NCb	NCb
Temperature 26 °C	C	C	C	C	C	C	C	C	C

**Note:* C : (Comply) NCa : (Cool) NCb : (Slightly Cool) NCc : (Slightly warm) NCd : (Warm)*

4.6 Multiple Linear Regressions

Multiple linear regression attempts to model the relationship between two or more explanatory variables and a response variable by fitting a linear equation to observed data. Thermal comfort (a) is the relationship between complies and not comply variables. Meanwhile, thermal comfort (b) is the relationship between complies and derivatives of not complies which is cool, slightly cool, slightly warm and warm.

4.6.1 Multiple linear regressions of thermal comfort (a) and thermal comfort (b)

The MLR results of thermal comfort (a) and thermal comfort (b) was illustrated in Table 4.4 that showed both thermal comfort have the p-value is less than 0.05. These conclude that the model is valid for this data. The result suggested for thermal comfort (a) the ozone, total volatile organic compound, carbon dioxide, relative humidity is statistically significant as the p-value is less than value 0.05. Thus, the ozone, total volatile organic compound, carbon dioxide, relative humidity is significant in influencing the thermal comfort. However, the nitrogen dioxide, carbon monoxide and particulate matter is statistically insignificant, which is higher than value 0.05. Thus, it is concluded that the variable do not give a big influence in estimating thermal comfort. In contrast with thermal comfort (b) the result was showed that the ozone, nitrogen dioxide, carbon dioxide, carbon monoxide, relative humidity is statistically significant as the p-value is less than value 0.05. Thus, the ozone, nitrogen dioxide, carbon dioxide, carbon, relative humidity is significant in influencing the thermal comfort. However, temperature and particulate matter is statistically insignificant due to the higher value than 0.05. This showed that the variable do not give a big influence in estimating thermal comfort.

Furthermore, the thermal comfort (a) have the R square and Adjusted R square values are 0.781 and 0.721 respectively. However the thermal comfort (b) showed that the R square and Adjusted R square values are 0.853 and 0.813 respectively. The Adjusted R square of both thermal comfort values is being considers as it is more accurate. Next, thermal comfort (a) have value is 0.721 that showed there was 72.10% of total variation, while, thermal comfort (b) have value is 0.813 shows that about 81.30% of total variation. Both thermal comfort total variations was explained by the ozone, nitrogen dioxide, total volatile organic compound, carbon dioxide, carbon monoxide, particulate matter, temperature and relative humidity.

To compute the strength of relationships between variables, the coefficient of correlation is being observed. Thermal comfort (a) have R value is 0.884 and thermal comfort (b) have R value is 0.924. Thus results showed that there is a strong positive relationship between thermal comfort, ozone, nitrogen dioxide, total volatile organic compound, carbon dioxide, carbon monoxide, particulate matter, temperature and relative humidity.

Table 4.4 regression summary for indoor air quality and thermal comfort

R^2	Models	Range of VIF	Durbin-Watson
0.781	Thermal Comfort (a) = 3.827 + 0.131 O_3 + 21.417 NO_2 + 0.005 TVOC – 0.007 CO_2 – 0.946 CO – 0.069 PM – 0.096 Temp + 0.036 RH	2.577-39.931	1.642
0.853	Thermal Comfort (b) = -4.045 + 0.221 O_3 + 48.446 NO_2 + 0.001 TVOC – 0.007 CO_2 – 1.510 CO – 0.270 PM – 0.127 Temp + 0.062 RH	2.577-39.931	1.531

Based on Table 4.4 the multicollinearity occurs when independent variables used in a multiple regression model are highly correlated. The multicollinearity by checking related statistics such as tolerance value or variation inflation (VIF) and tolerance statistic. VIF measures how much the variance of an estimated regression coefficient is inflated as compared when predictor variables are not linearly related. If the value of VIF is greater than 10, it indicates the presence of multicollinearity. The tolerance statistic is the reciprocal of the VIF. A tolerance value of less than 0.2 indicates multicollinearity. Both thermal comfort have the value of VIF and tolerance value of ozone, carbon dioxide, carbon monoxide, and temperature shows the model have multicollinearity. This is because of VIF value and tolerance value was more than 0.2 and greater than 10 respectively.

CHAPTER 5

CONCLUSIONS

5.1 Conclusion

This study determined the indoor air quality (IAQ) parameters and thermal comfort in FSB new building using different conditions which window closed or opened and temperature set up at 22 ˚C, 23 ˚C, 24 ˚C, 25 ˚C and 26 ˚C. Overall the indoor air quality (IAQ) parameters were not exceeding the limits of DOSH guideline for indoor air quality except the value of particulate matter concentration. The highest concentration of ozone, nitrogen dioxide, TVOC, carbon dioxide, carbon monoxide, temperature and relative humidity which are 0.027 ppm, 0.067 ppm, 0.437 ppm, 522.850 ppm, 1.622 ppm, 21.186 mg/m^3, 33.272 ºC and 73.873 % respectively. Result shows the IAQ in FSB new building was better when used air-conditioner than window as ventilations which set up at 26 ˚C.

Time series and diurnal variations shows the variation hourly of every IAQ parameters from 8:00 a.m. until 17:00 p.m. The ozone, nitrogen dioxide, TVOC, carbon dioxide, carbon monoxide, temperature and relative humidity variation fluctuated throughout the studies with clearly shows the trends variously. The uneven pattern was because of error and disturbance.

The thermal comfort in FSB new building result suggests that thermal comfort parameters have typical trends. During the window either closed or opened, the temperature increases after period of time. Meanwhile, when the room set up temperature at 22 ˚C, 23 ˚C, 24 ˚C, 25 ˚C and 26 ˚C, the temperature was accordance the setup temperature.

Result suggested the best conditions of thermal comfort to satisfy the conditions are using of air condition system at temperature of 26 ˚C. The usage of air condition system at temperature 26 ˚C was compiles thermal comfort ASHRAE 55 standard to factors such temperature, thermal radiation, humidity and two personal factors which are activity and clothing of occupants.

5.2 Recommendations

In this study there are a few recommendations need to be suggested. Firstly, it is recommended that the study also be doing in others room such tutorial class and lecturers room. This is because that the size of room and present of occupants in certain room affects the results differently. Therefore, in future the future researchers have to consider others room too to ensure the validations of data.

Secondly, the instrument used are recommends to be more careful handling and adding precautions step to avoid error such missing data due to loss of batteries. Thus, the researcher can reduce the not available data obtained.

Lastly, the recommendation to the future researcher to ensure they know the limitations of method of data analysis. Thus will help to improve the results of future research.

REFERENCES

Abdul-Wahaba, S. A., Bakheitb, C. S., & Al-Alawia, S. M. (2015). Characterization studies of activated carbon from low cost agricultural waste: Leucaena leucocephala seed shell. *Rasayan Journal of Chemistry*, *8*(3), 330–338.

An, J. Y., Kim, S., Kim, H. J., & Seo, J. (2010). Emission behavior of formaldehyde and TVOC from engineered flooring in under heating and air circulation systems. *Building and Environment*, *45*(8), 1826–1833.

Awang, N. R., Elbayoumi, M., Ramli, N. A., & Yahaya, A. S. (2016). Diurnal variations of ground-level ozone in three port cities in Malaysia. *Air Quality, Atmosphere and Health*, *9*(1), 25–39.

Awang, N. R., Ramli, N. A., & Yahaya, A. S. (2015). Temporal Analysis of Ozone and Nitrogen Oxides Fluctuations at Pasir Gudang, Malaysia. *Applied Mechanics and Materials*, *773–774*(x), 1237–1241.

Awang, N. R., Ramli, N. A., Yahaya, A. S., & Elbayoumi, M. (2015). Multivariate methods to predict ground level ozone during daytime, nighttime, and critical conversion time in urban areas. *Atmospheric Pollution Research*, *6*(5), 726–734.

Barron, M., & Torero, M. (2017). Household electrification and indoor air pollution. *Journal of Environmental Economics and Management*, *86*, 81–92.

Brown, S. K. (2002). Volatile Organic Pollutants in New and Established Buildings in Melbourne, Australia. *Indoor Air*, *12*(1), 55–63.

Champiré, F., Fabbri, A., Morel, J. C., Wong, H., & McGregor, F. (2016). Impact of relative humidity on the mechanical behavior of compacted earth as a building material. *Construction and Building Materials*, *110*, 70–78.

Chithra, V. S., & Shiva Nagendra, S. M. (2012). Indoor air quality investigations in a naturally ventilated school building located close to an urban roadway in Chennai, India. *Building and Environment*, *54*, 159–167.

De Dear, R. J., & Brager, G. S. (2002). Thermal comfort in naturally ventilated buildings: Revisions to ASHRAE Standard 55. *Energy and Buildings*, *34*(6),

Dueñas, C., Fernández, M. C., Cañete, S., Carretero, J., & Liger, E. (2004). Analyses of ozone in urban and rural sites in Málaga (Spain). *Chemosphere*, *56*(6), 631–639.

Efeoma, M. O., & Uduku, O. (2012). Assessing thermal comfort and energy efficiency in tropical African offices using the adaptive approach.

Gan, G. (2000). Effective depth of fresh air distribution in rooms with single-sided natural ventilation. *Energy and Buildings*, *31*(1), 65–73.

Gupta, S., Khare, M., & Goyal, R. (2007). Sick building syndrome-A case study in a multistory centrally air-conditioned building in the Delhi City. *Building and Environment*, *42*(8), 2797–2809.

Hensen, J. L. M., Loomans, M. G. L. C., & Boerstra, A. C. (2011). Adaptive thermal comfort in primary school classrooms : Creating and validating PMV-based comfort charts. *Building and Environment*, *46*(12), 2454–2461.

Holm, A. H., Künzel, H. M., & Sedlbauer, K. (2004). Predicting indoor temperature and humidity conditions including hygrothermal interactions with the building envelope. *ASHRAE Transactions*, *110 PART I*, 820–826.

Huboyo, H. S., Tohno, S., & Cao, R. (2011). Indoor PM 2.5 characteristics and CO concentration related to water-based and oil-based cooking emissions using a gas stove. *Aerosol and Air Quality Research*, *11*(4), 401–411.

Jo, W. K., & Lee, J. Y. (2006). Indoor and outdoor levels of respirable particulates (PM10) and Carbon Monoxide (CO) in high-rise apartment buildings. *Atmospheric Environment*, *40*(32), 6067–6076.

Jokl, M. V. (2000). Evaluation of indoor air quality using the decibel concept based on carbon dioxide and TVOC. *Building and Environment*, *35*(8), 677–697.

Jonathan, S., & Bahrami, H. (n.d.). Indoor Air Pollution and Cardiovascular Disease, 2342–2344. https://doi.org/10.1164/ajrccm/136.6.1486.2.

Jones, A. P. (2002). Chapter 3 Indoor air quality and health. *Air Pollution Science for the 21st Century*, *Volume 1*(1999), 57–115.

Kamaruzzaman, S. N., Egbu, C. O., Zawawi, E. M. A., Ali, A. S., & Che-Ani, A. I. (2011). The effect of indoor environmental quality on occupants' perception of performance: A case study of refurbished historic buildings in Malaysia. *Energy and Buildings*, *43*(2–3), 407–413.

Kattan, M., Gergen, P. J., Eggleston, P., Cynthia, M., Mitchell, H. E., & York, N. (n.d.). Health care education , delivery , and quality Health effects of indoor nitrogen dioxide and passive smoking on urban asthmatic children, (2), 618–

Khafaie, M. A., Yajnik, C. S., Salvi, S. S., & Ojha, A. (2016). Critical Review of Air Pollution Health Effects With Special Concern on Respiratory Health. *Journal of Air Pollution and Health*, *1*(12), 123–136. Retrieved from http://japh.tums.ac.ir

Kim, S. S., Kang, D. H., Choi, D. H., Yeo, M. S., & Kim, K. W. (2008). Comparison of strategies to improve indoor air quality at the pre-occupancy stage in new apartment buildings. *Building and Environment*, *43*(3), 320–328.

Lee, S. ., & Chang, M. (2000). Indoor and outdoor air quality investigation at schools in Hong Kong. *Chemosphere*, *41*(1), 109–113.

Li, L., Manning, W. J., Tong, L., & Wang, X. (2015). Chronic drought stress reduced but not protected Shantung maple (Acer truncatum Bunge) from adverse effects of ozone (O3) on growth and physiology in the suburb of Beijing, China. *Environmental Pollution*, *201*, 34–41.

Nguyen, J. L., Schwartz, J., & Dockery, D. W. (2014). The relationship between indoor and outdoor temperature, apparent temperature, relative humidity, and absolute humidity. *Indoor Air*, *24*(1), 103–112. https://doi.org/10.1111/ina.120

Nicol, J. F., & Humphreys, M. A. (2002). Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy and Buildings*, *34*(6), 563–572.

Norhidayah, A., Lee, C. K., Azhar, M. K., & Nurulwahida, S. (2013). Indoor air quality and sick building syndrome in three selected buildings. *Procedia Engineering*, *53*(2010), 93–98.

Nur Fadilah, & Juliana, J. (2012). Indoor Air Quality (IAQ) and Sick Buildings Syndrome (SBS) among Office Workers in New and Old Building in Universiti. *Health and the Environment Journal*.

Persily, A. (2015). Challenges in developing ventilation and indoor air quality standards: The story of ASHRAE Standard 62. *Building and Environment*.

Samoli, E., Dimakopoulou, K., Evangelopoulos, D., Rodopoulou, S., Karakatsani, A., Veneti, L., … Katsouyanni, K. (2017). *Journal of Exposure Science and Environmental Epidemiology*, *27*(3), 346–351.

Seppänen, O., & Fisk, W. J. (2002). Association of ventilation system type with SBS symptoms in office workers. *Indoor Air*, *12*(2), 98–112.

Sousa, S. I. V., Martins, F. G., Alvim-Ferraz, M. C. M., & Pereira, M. C. (2007). Multiple linear regression and artificial neural networks based on principal components to predict ozone concentrations. *Environmental Modelling and Software*, *22*(1), 97–103.

Tao, H., Fan, Y., Li, X., Zhang, Z., & Hou, W. (2015). Investigation of formaldehyde and TVOC in underground malls in Xi'an, China: Concentrations, sources, and affecting factors. *Building and Environment*, *85*, 85–93.

Tomasi, R., Krajčík, M., Simone, A., & Olesen, B. W. (2013). Experimental evaluation of air distribution in mechanically ventilated residential rooms: Thermal comfort and ventilation effectiveness. *Energy and Buildings*, *60*, 28–37.

Vallero, D. A. (2007). *Fundamentals of Air Pollution*. *Fundamentals of Air Pollution*. https://doi.org/10.1016/B978-0-12-373615-4.X5000-6

Ventilation for acceptable indoor air quality. (2010). *ASHRAE Standard*, (STANDARD 62.1), 1–70.

Weschler, C. J. (2006). Ozone's impact on public health: Contributions from indoor exposures to ozone and products of ozone-initiated chemistry. *Environmental Health Perspectives*, *114*(10), 1489–1496.

Weschler, C. J. (2000). Ozone in Indoor Environments: Concentration and Chemistry. *Indoor Air*, *10*(4), 269–288.

Wolkoff, P., & Kjærgaard, S. K. (2007). The dichotomy of relative humidity on indoor air quality. *Environment International*, *33*(6), 850–857.

World Health Organization. (2013). Health Effects of Particulate Matter: Policy implications for countries in eastern Europe, Caucasus and central Asia. *Journal of the Korean Medical Association*, *50*(2), 20.

APPENDIX A

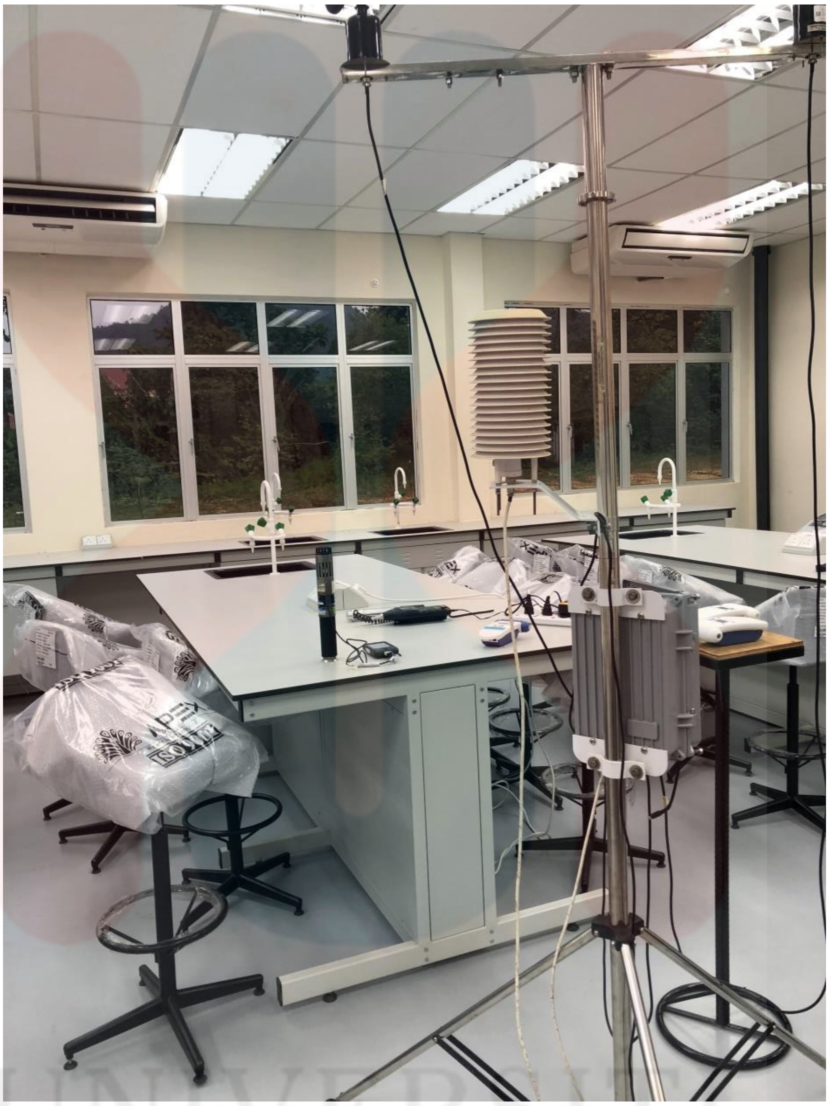


Figure A1 shows the setup of apparatus during monitoring in FSB room