SUPERVISOR DECLARATION

"I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (with Honours)"

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IMPROVEMENT OF AN INDOOR ENVIRONMETNAL QUALITY (IEQ) IN ENGINEERING LABORATORIES

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A report submitted
in fulfilment of the requirements for the degree of
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DECLARATION

"I hereby declare that this project report entitled "Improvement of an Indoor Environmental Quality of Engineering Laboratories" is my own work except as cited in the references."

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DEDICATION

For my beloved Dad and Mum

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First, I would like to express my special thanks of gratitude to my supervisor Dr. Tee Boon Tuan for his patient guidance along this project. I am highly benefited by this project and gained a lot of knowledge about the various analysis conducted to evaluate indoor environment quality.

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ABSTRACT

Indoor environment conditions of a building are one of the concerned issues as people usually spend most of their time inside the buildings. Poor indoor environmental conditions can influence human health in terms of physiological, perceptual and emotional as well. The main objective of this study is to determine the indoor environment condition of engineering laboratories in Mechanical Engineering Laboratories Complex. Thermal comfort analysis and indoor air quality analysis were conducted to evaluate the indoor environment quality of the laboratories. Analysis consists of physical measurement and subjective measurement. Physical measurements were conducted with occupancy and no occupancy condition while subjective measurement was carried out through questionnaire. Results show that air-conditioned machine workshop has temperature of 20.8℃ which is not within the MS 1525:2014 standard but still acceptable by occupants. Meanwhile, the thermal condition of non-air conditioned welding workshop is not complied with ASHRAE Standard 55:2010 in terms of air temperature, PMV and PPD index. In addition, result from occupant's air odor perception indicates that air odor problem occurred in both case study areas. Based on the findings, indoor environment quality improvement measures are proposed to enhance the IEQ level of the laboratory.

ABSTRAK

Keadaan persekitaran dalaman bangunan merupakan salah satu isu yang diberi perhatian kerana orang biasanya menghabiskan sebahagian besar masa mereka di dalam bangunan. Keadaan persekitaran dalaman yang teruk boleh mempengaruhi kesihatan manusia dari segi fisiologi, persepsi dan juga emosi. Objektif utama kajian ini adalah untuk menentukan keadaan persekitaran dalaman makmal kejuruteraan Kompleks Makmal Kejuruteraan Mekanikal. Analisis keselesaan termal dan analisis kualiti udara dalaman dijalankan untuk menilai kualiti alam sekitar dalaman di makmal. Analisis terdiri daripada pengukuran fizikal dan ukuran subjektif. Pengukuran fizikal dijalankan dengan penghuni dan tiada keadaan penghuni manakala pengukuran subjektif dilakukan melalui soal selidik. Hasil kajian menunjukkan bahawa bengkel mesin berhawa dingin mempunyai suhu 20.8 °C yang tidak mencapai Piawaian MS 1525:2014 tetapi masih dapat diterima oleh penghuni. Sementara itu, keadaan termal bagi bengkel kimpalan yang tidak berhawa dingin tidak mematuhi Piawaian ASHRAE 55:2010 dari segi suhu udara, indeks PMV dan PPD. Selain itu, hasil daripada persepsi bau udara penghuni menunjukkan bahawa masalah udara berbau berlaku di kedua-dua tempat kajian kes. Berdasarkan penemuan ini, langkah-langkah untuk memperbaiki kualiti alam sekitar dalaman dicadangkan untuk meningkatkan kualiti alam sekitar dalaman makmal.

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LIST OF SYMBOLS

SYMBOLS	DESCRIPTION
°C	Degree Celsius
°F	Fahrenheit
K	Kelvin
m	Metre
mm	Millimetre
s	Seconds
%	Percent
W	Watt
m/s	Velocity
ppm	Parts-per-million
cfm	Cubic feet per minute
R^2	Coefficient of determination
L/s	Litre per second

LIST OF ABBREVIATIONS

ABBREVIATION	DESCRIPTION
A	Afternoon Session
AV	Air Velocity
AOV	Air Odor Vote
ACMV	Air-Conditioning and Mechanical Ventilation
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
CLO	Clothing Insulation Value
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DOSH	Department of Occupational Safety and Healthy
EEL	Engineer Education Laboratories
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
ISO	International Organization of Standardization
M	Morning Session
MS	Malaysia Standard
PM	Particular Matter
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
RH	Relative Humidity

ABBREVIATION	DESCRIPTION
SBS	Sick Building Syndrome
TSV	Thermal Sensation Vote
UTeM	Universiti Teknikal Malaysia Melaka
WHO	World Health Organization

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

Indoor environment conditions of a building are one of the concerned issues as people usually spend most of their time inside the buildings. The World Health Organization (WHO) mentioned that the indoor environmental conditions have significant impact on human health. Poor indoor environmental conditions strongly influence human health in terms of physiological, perceptual and emotional as well. Human work performance and productivity will also be affected and this can gives negative impact to the country economic development (WHO, 1990). Other researchers emphasize that bad indoor environment conditions will increase the risk of sick building syndrome (SBS) symptoms, poor comfort satisfaction level and health issues (Amin et al., 2015).

Indoor environment quality basically defined through four factors such as thermal comfort, air quality, lighting quality and acoustical quality. These factors are important to be considered in environmental design for a new building (Blyussen, 2009). However, indoor air quality and thermal comfort are major factors to be considered and addressed by building designers (Huizenga et al., 2006). The indoor air quality is evaluated by parameters which included carbon dioxide concentration, temperature and relative humidity (Telejko, 2017) while thermal comfort parameters include air temperature, air velocity and relative humidity (Amin et al., 2015). In this research, the indoor air quality and thermal comfort will be the two main focuses in analysing the indoor environmental quality (IEQ) for mechanical engineering laboratories. Based on the findings, effective ways will be recommended to improve the IEQ for the laboratories.

1.1 PROBLEM STATEMENTS

Laboratory is a building that consists of experimentation and testing activities. Safety, comfort and energy efficiency are considered as the most important criteria for a laboratory (TSI, 2014). In UTeM mechanical engineering laboratories, there are different types of workshops and laboratories that enable students to undergo engineering practices. Thus, the ideal indoor environmental quality in every workshop and laboratory are different due to the thermal environment, machines and equipment, and chemical usage. Based on previous observations, it is indicated that some of the students who have practical sessions in laboratories feel either too hot or too cold. Some of them are also feeling dizziness and tiredness when doing workshop practices due to uncomfortable indoor conditions. These problems should be further investigated in order to find the suitable solution in improving the current indoor conditions. This research will be conducted based on the following questions:

i. Do the thermal comfort and indoor air quality level in the engineering laboratories comply with the current standards?

ii. Do air-conditioned laboratories have better indoor environment quality compared to non-air-conditioned laboratories?

iii. What are the recommended measures that can be taken in order to improve the current indoor environmental conditions of the laboratories?

1.2 OBJECTIVES

The main objectives of this research are:

I. To conduct a thermal comfort and indoor air quality analysis for mechanical engineering laboratory complex.

II. To propose an effective IEQ improvement measures for the laboratory building.

1.3 SCOPES

In this research, only thermal comfort and indoor air quality analysis are conducted in UTeM mechanical engineering laboratories. The thermal comfort parameters such as air temperature, air velocity and relative humidity will be measured by using thermal comfort meter. Indoor air quality parameters such as carbon dioxide concentration and dust concentration will be measured by using IAQ meter and Dust Track meter. Subjective measurements are conducted through questionnaire survey in order to obtain occupant perception towards the current indoor condition.

1.4 SIGNIFICANCE OF THE STUDY

Throughout this research, the quality of indoor thermal environment and indoor air in mechanical engineering laboratories can be evaluated and determine whether it meets with the standard. The data can assist the lab management to propose necessary improvement measures. The project activities will also help in spreading awareness of the importance in maintaining good indoor environmental condition for engineering laboratories. The respective data for thermal comfort and indoor air quality parameters can also be used as a benchmark for future research on indoor environmental conditions among university buildings.

CHAPTER 2

THEORY

This chapter includes all the theories and principles that are related with the indoor environmental quality (IEQ) of a building. Important terms and parameters of indoor environmental quality, thermal comfort, indoor air quality, and ventilation system are thoroughly explained in order to have a good understanding on the overall project.

2.1 INDOOR ENVIRONMENTAL QUALITY

Indoor environmental quality is a term that describes the conditions inside a building such as the air quality, lighting, thermal conditions, acoustics, ergonomics and their effects on occupants. Indoor environmental quality goals basically focus on providing comfortable environments and reduce the risk of building-related health problems (USGBC, 2014). Indoor environment quality is important as it has strong impact on occupants' productivity. A good working environment can help to increase productivity by up to 20% (Al Horr et al., 2016).

The indoor environment of a building can be defined by four basic environmental factors such as indoor air quality, thermal comfort, acoustical quality and lighting quality. These indoor environmental factors basically identified with quantitative indicators and expressed according to acceptable numbers or ranges (Blyussen, 2009).

Indoor environment quality (IEQ) is considered as one of the main categories in Leadership in Energy and Environmental Design (LEED) green building rating system. Moreover, in BRE Environmental Assessment Method (BREAAM), factors such as visual comfort, acoustic performance, indoor air quality and thermal comfort are outlined in 'Health and Wellbeing' category.

2.2 THERMAL COMFORT

Thermal comfort can be defined as the state of mind that expresses satisfaction with the thermal environment (ASHRAE 55, 2010). Thermal comfort is one of the critical components that directly influence the perception of that indoor environment through the senses. It also easily affects the physical and mental state of human inside the building. (Blyussen, 2009). The recommended standards for thermal comfort in building design are ASHRAE Standard 55 and ISO 7730.

Overall thermal comfort in a building is complex to be achieved as thermal comfort is an outcome of different physical parameters, creating a thermal state and understanding a collection of subjective human responses to that thermal state. Thermal comfort varies individually and geographically due to factors including age, sex, metabolism rate, time of the year, among many others (Cena & de Dear, 2001).

Six important factors that used to define thermal comfort of occupants are air temperature, metabolic rate, clothing insulation, radiant temperature, air speed and humidity (ASHRAE 55, 2010). Thermal preference is the ideal thermal state in terms of the environment (Langevin et al., 2013). Preferred thermal state of an environment is different from everyone based on their age, gender and Body Mass Index (Tuomaala et al., 2013).

Thermal comfort also plays an important role in occupant productivity. Productivity loss when thermal comfort is not achieved. Studies show that temperature in range of 21℃ to 25℃ is the appropriate temperature range for office productivity (Seppänen & Fisk, 2006).

2.2.1 Thermal Comfort Environmental Factors

i. Air temperature

The air temperature can be known as a measure of how hot or cold the air surrounding human body. Air temperature can also be defined as dry-bulb temperature as it usually measured with dry-bulb thermometer. Temperature basically expressed in degrees Fahrenheit (°F) and Celsius (°C). The standard unit for temperature is Kelvin. Temperature can describe the kinetic energy of the gas molecules that make up air. Air temperature increases when the gas molecules move faster. Air temperature is important as it affects all weather parameters (Staff, 2010).

ii. Mean radiant temperature

Mean radiant temperature can be easily described as the average temperature of all the objects or surfaces that undergo thermal radiation transfer around the occupant. According to ASHRAE (2010), mean radiant temperature is defined as the uniform surface temperature of an imaginary black enclosure in which an occupant would have same radiation exchange as in the real environment. Assumed the environment is comprised of i black surfaces with temperature T_i, mean radiation temperature can be determined as below:

$T_{mrt} = (\Sigma F_{si} T_i^4)^{1/4}$ [°C]

where F_{si} is the fraction of radiation leaving the black sphere, which reaches the i^{th} surfaces directly (Blyussen, 2009).

iii. Air velocity

Air velocity can be defined as the speed of air moving across human. Air velocity plays an important role in hot and dry conditions as it affect the convection heat transfer between human skin and local air. Most of the people remain comfortable at high relative humidity conditions as the air velocity increases. Control the air velocity is the only solution to achieve physiological comfort at high temperatures environment because it affects both evaporative and convective heat losses from the human body (Indraganti et al., 2012). The acceptable range of indoor air speeds for the comfort zone is from 0.2 to 1.5m/s (ASHRAE 55, 2010).

iv. Humidity

Humidity can be known as the general reference to the moisture content of the air. Basically, it is expressed in several thermodynamics variables such as vapour pressure, dew-point temperature and humidity ratio (ASHRAE 55, 2010). There are two terms used to express the water content in a parcel of air. The first term would be absolute humidity. Absolute humidity is defined as the quantity of water vapour in a particular volume of air, expressed in grams per cubic metre. Absolute humidity easily changes with air pressure. The equation to calculate absolute humidity is shown as below:

$$\text{Absolute Humidity} = \frac{mass\ of\ water\ vapour}{particular\ volume\ of\ air}\ (\text{g/m}^3)$$

The second term is relative humidity. It can be defined as the ratio of the partial pressure of water vapour in a gaseous mixture of air and water vapour to the saturated vapour pressure of water at a given temperature. It is usually expressed in percentage that indicates the maximum amount of water vapour the air can hold at the specific temperature (Blyussen, 2009). According to ASHRAE Standard 62.1 (2016), it is recommended that the relative humidity in an occupied space should be controlled less than 65 percent in order to prevent the growth of microorganism.

2.2.2 Thermal Comfort Personal Factors

i. Clothing Insulation

Clothing is important to protect human body against the hot and cold conditions. The amount of thermal insulation provided by clothing strongly influenced the thermal comfort of a person inside a building as it prevents heat exchange between human body and environment. Clothing thermal insulation of an ensemble can be expressed in clo value (I_{cl}) where 1 clo is equal to 0.155m^2.°C/W. High insulation value of clothing means that lower heat exchange with the surroundings. Clo value can be determined through the methods and tables given in this standard (ASHRAE 55, 2010).

ii. Metabolic rate

Metabolic rate can be defined as the rate at which human body burns calories to produce the energy it needs to function. There are some important parameters to be considered when determine the metabolic rates such as body size, body weight, sex, working intensity, age and gender. Metabolic rate of men is usually higher than elderly, children and women. Human with various physical characteristics have different thermal sensation and thus different desired thermal comfort level inside a building. High thermal sensation requires cooler indoor conditions to achieve comfort (Goto et al., 2002). Metabolic rate is expressed in met units. 1 met is equal to 58.2 W/m^2 which means that the energy produced per unit surface area of an average person seated quietly. Different activities will have different value of met units. It can be determined by referring this standard (ASHRAE 55, 2010).

2.3 PREDICTED MEAN VOTE

Predicted mean vote is basically a thermal scale which used to quantify people's thermal sensation level in a specific place. The six key factors for thermal comfort are related in PMV model by using heat balance principles. ASHRAE seven-point thermal sensation scales are shown as table below:

Table 2.1: ASHRAE Thermal Comfort Scale (ASHRAE Standard 55, 2010)

+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

Another term known as predicted percentage of dissatisfied, PPD is related to PMV. It is used to predict the amount of occupants that will dissatisfied the thermal conditions. Figure 2.1 shows the relationship between PPD and PMV based on the people that vote +2, +3, -2 or -3 on the scale are dissatisfied. The recommended PMV range for general thermal comfort is between +0.5 and -0.5 while the PPD value should less than 10% (ASHRAE 55, 2010).

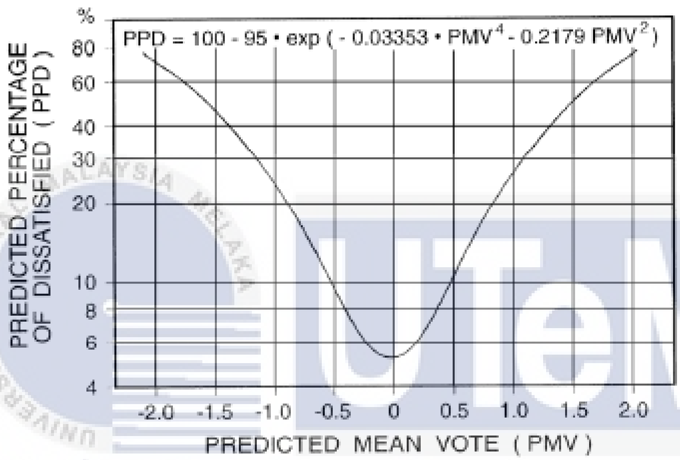


Figure 2.1: Predicted percentage dissatisfied (PPD) as a function of predicted mean vote (PMV) (ASHRAE 55, 2010)

2.4 INDOOR AIR QUALITY

Indoor air quality (IAQ) is a measure of how clean the air that we breathe inside the buildings. The indoor air can easily put building occupants at risk for health problems as it may contain air pollutants. These air pollutants can be in chemical form, gases form such as carbon monoxide, carbon dioxide, nitrogen dioxide and volatile organic compounds and even living organisms like molds and pests. High amount of pollutants in air increase the risk of respiratory infections, allergies, headaches, dizziness, asthma attacks, cancer and even cause death. (EPA, 2008).

The concentration of indoor air pollutant is strongly influenced by the ventilation rate of air changes. Good control of indoor pollution sources as well as providing adequate amounts of uncontaminated fresh air is important to achieve healthy indoor air quality. Contaminants of indoor air can be classified into 3 types of matter shown as table below:

Table 2.2: Types of indoor air contaminants (WHO, 1991)

Gaseous matter	Non-radioactive gases: CO, CO_2, NO_2, SO_2 Radioactive gases: Radon Vapours: CFC's, solvents
Liquid matter	Droplets from man such as sneezing Other sources: from cooking, washing etc
Particulate matter	Non-biological: dusts, smoke, fibres Biological: Pollens, moulds and slimes, algae bacteria and epithelia, insect scales and components.

Acceptable indoor air quality is meant by the air in which there are no harmful concentrations of air contaminants and a majority 80% or more of the people feel satisfy with it (ASHRAE 62.1, 2010). ASHRAE indoor air quality guide mentioned that indoor air quality is important to be taken as a part of the design at the beginning of the project as it directly affects occupant health, comfort and their work productivity. Common causes of indoor air quality problems are shown as below:

i. Indoor air quality not being concerned as a key issue at the beginning of the design process.
ii. Lack of commissioning the designed ventilation system
iii. High level of moisture in building assemblies,
iv. Poor outdoor air quality,
v. Inadequate ventilation rates and indoor contaminant sources

There are many issues have to be considered to design a good indoor air quality system including the outdoor contaminant sources, the activities inside the building, the characteristics of the building occupants and the approaches used to heat, cool and ventilate the building. Good indoor air quality can be achieved by concerning both indoor air pollution levels and thermal environmental parameters.

2.4.1 Indoor Air Quality Parameters

i. Carbon dioxide, CO_2 level

Carbon dioxide acts as a significant indicator of indoor air quality as it exhaled by people inside a building. Indoor carbon dioxide level is a common used criterion to indicate the ventilation rate of a building. Carbon dioxide in indoor usually comes from living organisms. Its emission highly depends on the activity level and the characteristics of a given organism. Table 2.3 shows the emissions of CO_2 for different levels of activity.

Table 2.3: Emissions of CO_2 for various levels of activity (Telejko, 2017)

Type of activity	CO_2 generated per person	
	$[dm^3/s \cdot person]$	$[m^3/s \cdot person]$
At rest	0.04	$4 \cdot 10^{-6}$
Doing light work	0.006 ÷ 0.012	$(6 \div 12) \cdot 10^{-6}$
Doing moderate-hard work	0.012 ÷ 0.020	$(12 \div 20) \cdot 10^{-6}$
Doing hard work	0.020 ÷ 0.026	$(20 \div 26) \cdot 10^{-6}$
Doing very hard work	0.026 ÷ 0.032	$(26 \div 32) \cdot 10^{-6}$

According to ASHRAE standard, the maximum CO_2 level is about 1000 ppm. Ventilation rates have to maintain carbon dioxide level below 1000 ppm in order to create acceptable indoor air quality conditions for most of the people. When the CO_2 level is greater than 5000 ppm, it can have adverse health effects on human.

ii. Carbon monoxide, CO

Carbon monoxide is a colourless, odourless and toxic gas. CO is important to be measured and control as it cannot detect by human senses. It can interfere the oxygen delivery throughout the human body. Carbon monoxides in indoor is mainly from combustion sources such as cooking and heating. High amount of CO will lead to headaches, dizziness, weakness, nausea, and even death (EPA, 2008). The maximum indoor CO level is 9 ppm. The main carbon monoxide sources are leaking vented combustion appliances, unvented combustion appliances, parking garages and outdoor air. High amount of CO will highly influence the people who have heart or circulatory problems (ASHRAE 62.1, 2010).

iii. Dust particles

Aerosol is known as a system of particles that suspended in air. It can exist in form of airborne dusts, sprays, mists, smokes and fumes. Airborne dust concentrations have to be concerned as it relates to wide range of human diseases. Particle sizes of dust are usually determined because different sizes of dust particles have different ability in penetrate and deposit at different sites of respiratory tract. Dusts are generated by work processes and also naturally such as pollens, volcanic ashes, and sandstorms. Table 2.4 shows the types of dust exist in work environment (WHO, n.d.).

Table 2.4: Types of dust in work environment (WHO, n.d.)

Mineral dusts	Those containing free crystalline silica (such as quartz), coal and cement dusts
Metallic dusts	Lead, cadmium, nickel, and beryllium dusts
Other chemical dusts	Many bulk chemicals and pesticides
Organic and vegetable dusts	Flour, woof, cotton and tea dusts, pollens
Biohazards	Viable particles, moulds and spores

Dust particles can be classified into particular matter, PM. PM is the term that represents the mixture of solid particles and liquid droplets found in the air. EPA classified PM into two categories which are PM_{10} and $PM_{2.5}$. PM_{10} refers to the coarse inhalable particles with diameters about 10 micrometres while $PM_{2.5}$ refers to the fine inhalable particles with diameters about 2.5 micrometres. These particles usually emitted from construction sites, unpaved roads, cars and trucks, fields, smokestacks or fires (EPA, n.d.).

Particles $PM_{2.5}$ is mainly from combustion products, cooking, candles, incense, resuspension, and outdoor air. The maximum amount of indoor particles $PM_{2.5}$ is about 15μg/m^3. Particles PM_{10} is mainly from dust, smoke, deteriorating materials and outdoor air. The recommended maximum amount of indoor particles PM_{10} is 50μg/m^3 (ASHRAE 62.1, 2010).

2.5 VENTILATION

ASHRAE Standard 62.1 defined ventilation as the process of supplying air to or removing the air from a space in order to control the air contaminants levels, humidity, or temperature within the space. Ventilation requirements are highly related with the chemical, physical, and biological contaminants that will affect the air quality. Good ventilation system can avoid indoor air quality problems and improve the indoor building environment quality.

Good ventilation design has higher potential in improving the indoor air quality, indoor thermal environment and even the energy efficiency of the building. (Jin et al., 2015). Different indoor conditions require different types of ventilation system to achieve best performances. The main types of ventilation methods for general room ventilation included mixing ventilation, displacement ventilation, personalized ventilation and hybrid air distribution (Awbi, 2017).

2.6 AIR-CONDITIONING AND MECHANICAL VENTILATION (ACMV) SYSTEMS

ACMV basically related to the systems that used to adjust the air conditions within the buildings such as provide fresh filtered air, control the desired temperature and also maintain the best humidity level.

Air-conditioning system is used to control indoor environmental parameters of a specific space based on the occupant requirement. It basically consists of components and equipment that arranged in sequence to condition the indoor air. Air conditioning system condition the indoor air such as heat or cool, humidify or dehumidify, clean and purify. Good air conditioning system can control and maintain the indoor environmental parameters within desired limits such as the indoor temperature, humidity level, air movement, cleanliness, sound level and the pressure difference with outdoor surroundings. Air conditioning systems are classified into few types such as air, water, refrigeration and control systems (S. K. Wang, 2001).

Mechanical ventilation system basically uses ducts and fans to circulate the fresh air. Mechanical ventilation can provide a better indoor air quality by removing air pollutants and moisture that can cause mold problems. It also can provide proper fresh air flow along with appropriate locations for intake and exhaust. Occupant comfort can also be improved as mechanical ventilation system provide a constant flow of outdoor air into the building, filtrate and dehumidify the incoming outside air. Mechanical ventilation system is selected by referring to the local climate and the building's heating and cooling system. Three types of mechanical ventilation systems are listed as below (Energy Star, n.d.).

i. Supply Ventilation System

This system is suitable for hot or mixed climates. It basically draws the fresh air through intake vent and distributes it to rooms by fan and duct system. Supply system keep on introduce outdoor air into the building and cause the indoor pressure increase. This system not suitable for cold climates as the heated indoor air will be pushed through holes and cracks in the construction assembly and cause moisture problems when contact with cold exterior surfaces.

ii. Exhaust Ventilation System

This system is suitable for cold climates. Indoor air is exhausted to the outdoors and thus the indoor pressure will be reduced. This system not suitable to hot and humid climates as the hot outdoor air will draw into holes and cracks in the construction assembly and cause moisture problems when contact with cool interior surfaces.

iii. Balanced Ventilation System

This system is suitable for all climates as the equal amount of air are draw in and out of the building. It is usually achieved by using a fan brings fresh air in and another fan sends indoor air out. Heat recovery ventilation can reduce heating and cooling load and enhance the indoor comfort level by transferring heat in and out in different seasons. Energy recovery ventilation transfer heat and moisture between exhaust air and incoming air.

2.7 STANDARD

Standards are important to specify and recommend the thermal conditions and indoor air quality that can satisfy most of the building occupants. There are three standards are used in this study such as:

i. Malaysia Standard 1525: 2014
ii. ASHRAE Standard 55- 2010
iii. ASHRAE Standard 62.1- 2010

2.7.1 Malaysia Standard MS 1525: 2014

MS 1525 is a code of practice related to the energy efficiency and use of renewable energy for non-residential buildings. It was developed by the Technical Committee on Energy Efficiency in Buildings under the authority of the Building, Construction and Civil Engineering Industry Standards Committee.

MS 1525 mentioned that the comfort condition inside a building is dependent on various factors such as air temperature, mean radiant temperature, humidity, clothing insulation, metabolic rate and air movement. In engineering design, three main factors that need to be concerned for room comfort condition are dry bulb temperature, relative humidity and air movement.

MS 1525 recommended the indoor design conditions of an air-conditioned space for comfort cooling as below:

i.	Recommended design dry bulb temperature	24℃ - 26℃
ii.	Minimum dry bulb temperature	23℃
iii.	Recommended design relative humidity	50% - 70%
iv.	Recommended air movement	0.15m/s – 0.50m/s
v.	Maximum air movement	0.70m/s

2.7.2 ASHRAE Standard 55 – 2010, Thermal Environmental Conditions for Human Occupancy

ASHRAE 55 is intended for purposes in design, commissioning, and testing of buildings and others occupied spaces and their HVAC systems and for the evaluation of thermal environments. It comprises the conditions in which a specified fraction of the occupants will find the environment thermally acceptable.

ASHRAE 55 mentioned that conditions for thermal comfort are defined by environmental factors and personal factors. Environmental factors stated in this standard are air temperature, radiant temperature, relative humidity and air velocity while the individual factors are the metabolic rate and clothing insulation.

Thermal comfort means that the occupant feels satisfy with the thermal environment inside a building. It is hard to achieve an acceptable thermal environment for all occupants in a space due to individual differences. Hence, there are seven standard thermal sensation scales shown in Table 2.1 above which were developed by ASHRAE in order to quantify people's thermal sensation. Personal factors such as metabolic rates for typical tasks and clothing insulation values for typical ensembles were provided in ASHRAE 55.

2.7.3 ASHRAE Standard 62.1 – 2010, Ventilation for Acceptable Indoor Air Quality

ASHRAE 62.1 is used to specify minimum ventilation rates and other measures such as indoor air contaminants in order to provide indoor air quality that is acceptable to occupants and that minimizes adverse health effects.

Indoor air usually contains complex mixtures of contaminants which might badly affect comfort, odors and health. ASHRAE 62.1 mentioned that the indoor air quality is considered acceptable if there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which 80% or more of the people exposed do not express dissatisfaction. Besides indoor contamination levels, the acceptability of indoor air also affected by the thermal conditions, indoor moisture levels as they enhance microbial growth, and other indoor environmental factors.

It is important to measure and control the amount of indoor air contaminants. Table 2.5 below shows the concentration of interest for several common air contaminants recommended by ASHRAE 62.1.

Table 2.5: Concentration of interest for several air contaminants (ASHRAE 62.1, 2010)

Types of contaminant	**Concentrations of Interests**
Carbon monoxide, CO	9 ppm
Nitrogen Dioxide, NO_2	$100\mu g/m^3$
Particles $PM_{2.5}$	$15\mu g/m^3$
Particles PM_{10}	$50\mu g/m^3$
Radon, Rn	4 pCi/L[a]
Sulphur Dioxide, SO_2	$80\mu g/m^3$, $50\mu g/m^3$ if with PM

CHAPTER 3

LITERATURE REVIEW

In this chapter, journal papers which are related to this field of study are reviewed and summarized. The relevant journals are selected based on the scope of this study which covers two of the important indoor environment quality factors such as thermal comfort and indoor air quality. Effective ventilation systems to improve indoor environmental quality are also being reviewed. At the end of this chapter, the building condition and measurement data are then extracted and tabulated.

3.1 INVESTIGATION OF INDOOR ENVIRONMENT QUALITY IN CLASSROOM BY VILCEKOVA ET AL. (2017)

This study was focusing on the indoor environment quality of the selected classroom. The second phase of this study is carried out during summer semester. Thermal comfort and indoor air quality parameters measurements were carried out and subjective evaluation was conducted through questionnaire. The results from subjective assessment and objective measurement were compared and studied. Several solutions were proposed to reduce carbon dioxide concentration and thermal load.

3.1.1 Methodology

This study was conducted in a classroom during summer semester. The dimensions of the classroom are 11m x 5.8m and located in the attic of the building. The classroom's equipment was remained as it will also affect the indoor condition. All the windows and doors were opened for 5 minutes before the lesson and closed during the lesson. There was no any forced ventilation or air-conditioning system used in the classroom.

Measurement parameters such as indoor air temperature, relative humidity and CO_2 concentrations were evaluated by using a multifunctional measuring device TESTO 435-4 with carbon dioxide sensor Testo 0632. The measuring device was placed in the center of the classroom at the height 1.1m above the ground level. The measurements were taken during lectures, breaks and seminars with a total time of 140 minutes.

For subjective assessment, the questionnaire was prepared and distributed to students at the beginning and at the end of each lesson to evaluate the effect of indoor environmental parameters on students' performance. The questionnaire was focused on the perception of air temperature, air draught and odor as well as overall perception of indoor air quality. The scales used in questionnaire are shown as table below.

Table 3.1: Scales used in questionnaire (Vilcekova et al., 2017)

	The perception	The sensational evaluation
Air temperature	3 hot	0 comfort
	2 warm	1 slight discomfort
	1 slightly warm	2 discomfort
	0 neutral	3 very discomfort
	-1 slightly cool	
	-2 cool	
	-3 cold	
Air draught	0 no air draught	0 comfort
	1 slight air draught	1 slight discomfort
	2 mild air draught	2 discomfort
	3 strong air draught	3 very discomfort
	4 very strong air draught	
	5 sublime air draught	
Indoor air quality	0 no odor	0 comfort
	1 weak odor	1 slight discomfort
	2 moderate odor	2 discomfort
	3 strong odor	3 very discomfort
	4 very strong odor	
	5 overpowering odor	

3.1.2 Results

For objective measurements, the indoor air temperature, relative humidity and carbon dioxide concentration were measured for 8 times and the average data were determined. Table 3.2 shows the measured values of each parameter during summer semester. From the table, the average value of air temperature was 24.8℃, relative humidity 36.28% and carbon dioxide concentration 1094.62ppm during the lesson in summer semester. The highest values of carbon dioxide concentrations were determined during the fifth measurement and it exceeded the limit value according to STN EN 15251 and to Pettenkofer criteria.

Table 3.2: Average value of each parameter in summer season (Vilcekova et al., 2017)

Measurement number	1	2	3	4	5	6	7	8	Average
Air temperature [°C]	24.6	24.6	25	24.5	24.9	24.5	25.1	25.2	24.8
Relative humidity [%]	37.35	37.35	36.55	32.84	30.80	31.88	40.52	42.92	36.28
CO_2 concentration [ppm]	1218	1086	1056	1150	1241	968	1149	889	1094.62

For subjective assessment, the results were tabulated in Table 3.3. Based on each parameter, it can be seen that students evaluated IEQ worse at the end of the lesson than at the beginning. In average, students evaluated air temperature as slight warm, no air draught, no odor or slight odor. The results were compared with objective measurements of carbon dioxide concentrations.

Table 3.3: Results of subjective evaluation of IEQ parameters in summer (Vilcekova et al., 2017)

Parameter		1	2	3	4	5	6	7	8
Air temperature	beginning	0.9	0.7	1.1	0.5	0.89	0.8	1.2	1
	end	1.75	1.4	1.3	1.1	1.22	1.2	1	1
Air draught	beginning	0.63	0.5	0.14	0.25	0.44	0.8	0.44	0.56
	end	0.88	0.7	0.57	0.88	0.89	0.4	0.89	1
IAQ	beginning	1	1	1	1	1	1	1	1
	end	1	1	1	1	1	1	1	1

3.1.3 Conclusion

From this study, objective measurements showed that carbon dioxide concentrations exceeded limit value according to STN EN 15251 and Pettenkofer criteria. Subjective assessment showed that students generally marked the indoor environment as more acceptable than unacceptable. It was recommended that intensity of natural ventilation should be increased during lessons, installation of mechanical ventilation and carbon dioxide sensors in order to enhance the indoor environmental quality.

3.2 STUDY TO IMPROVE INDOOR AIR QUALITY IN COMPUTER LABORATORIES BY TELEJKO (2017)

This study investigates the indoor air quality of computer laboratories in different high schools. It is important as low indoor air quality will have bad impact on occupants' health and lead to low academic performance in school. The IAQ parameters such as temperature, relative humidity and carbon dioxide level were measured and compared with standards. Certain modifications for IAQ improvement were proposed and analysed in this study.

3.2.1 Methodology

The investigations were conducted in total six computer laboratories selected from different high schools that built between 1975 and 1991. The laboratories consist of 15 computer stations and 15 to 18 users were assigned to each of them. In this study, carbon dioxide level is chosen for indicator of indoor air quality as it is a common used criterion for air quality assessment. The measurement of IAQ parameters were conducted for 3 months in 2 week periods at 5 minutes intervals. 3 measurement series were conducted for each room.

3.2.2 Results

All the investigated laboratories showed similar plots of microclimate parameters based on the collected measurement data. Figure 3.1 showed the plot of indoor air parameters. Based on the graph, CO_2 concentrations and relative humidity increase and reach maximum rapidly in the beginning of each class. The values then drop during a break and rise quickly again when a new class starts. After teaching hours, the values go down slowly and reach minimum levels. Lowest CO_2 concentrations from 419 ppm to 517 ppm were recorded at night. However, CO_2 concentrations can exceed 3200 ppm during the day which over the allowable level 1000 ppm recommended by WHO and ASHRAE 62. The graph also showed that short periods of ventilation by opening the windows and from breaks cause the minor drops of indoor air parameters values.

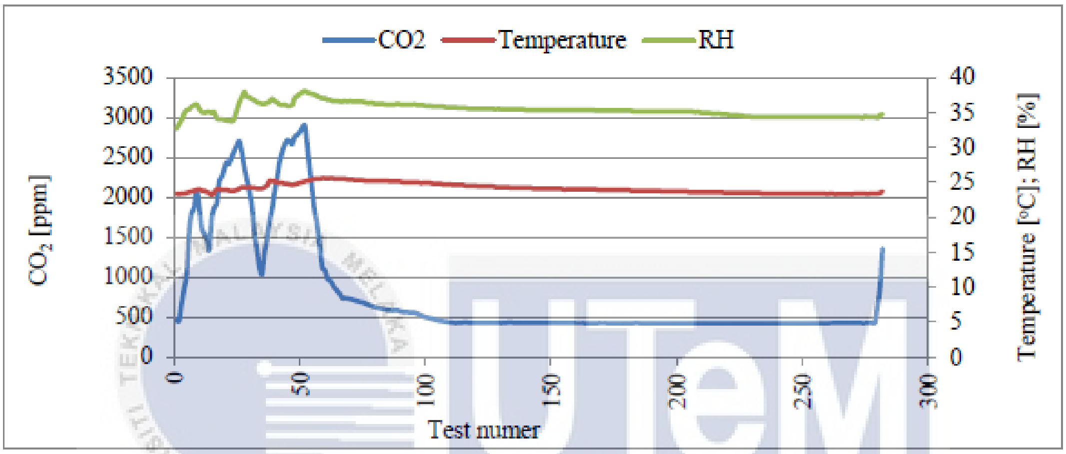


Figure 3.1: Indoor air parameters for a selected laboratory (Telejko, 2017)

Table 3.4 showed the maximum and minimum values of the indoor air parameters for six labs. According to ASHRAE, the range of indoor air temperature for thermal comfort is 20°C to 27°C. Based on the table, the temperatures recorded in all rooms were ranged from 26.8°C to 29.6°C which exceeded optimal values of thermal comfort due to additional heat sources from computers. During teaching hours, temperature lower than 20°C were recorded when window open for 30 minutes. Relative humidity rise rapidly during the classes and fell below 40% when no classes. However, the values did not exceed maximum allowable levels for thermal comfort recommended by ISO 7730.

Table 3.4: Maximum and minimum values of indoor air parameters for six labs (Telejko, 2017)

	Maximum values						Minimum values					
Laboratory	HS1	HS2	HS3	HS4	HS5	HS6	HS1	HS2	HS3	HS4	HS5	HS6
CO_2 concentration [ppm]												
Series 1	2873	2927	2898	2854	2912	3120	434	430	437	441	458	471
Series 2	3010	3079	3024	3151	3138	3260	419	435	430	438	442	463
Series 3	3198	3263	3212	3217	3189	3248	491	517	475	511	492	507
Temperature [°C]												
Series 1	28,1	28,3	26,8	27,2	28,0	27,5	20,6	20,5	20,9	21,0	20,2	21,3
Series 2	29,5	28,2	27,4	27,9	27,6	26,9	21,2	19,8	20,7	20,6	19,9	20,7
Series 3	29,6	28,9	28,1	27,1	28,3	27,2	20,8	20,4	19,5	21,1	20,3	20,7
RH [%]												
Series 1	51,4	49,7	51,7	49,5	50,3	54,0	33,4	33,1	32,5	33,2	31,8	31,2
Series 2	55,1	51,9	51,6	50,1	52,8	53,6	32,6	32,3	32,2	32,7	32,6	33,1
Series 3	49,2	50,6	50,9	50,6	51,5	54,8	31,7	31,6	31,4	33,6	31,4	32,9

Installation of 3 additional air vents was then proposed. The capacity of each vent was $30m^3/h$ which doubled the outside air supplied. Table 3.5 showed the results of the modification. After the modification, the average CO_2 concentration dropped about 800 ppm to 1000 ppm on average and the indoor temperature reduced about 1.0℃ to 1.5℃. The relative humidity level remains unchanged.

Table 3.5: Maximum and minimum values of indoor air parameters for six labs after installation of window vents (Telejko, 2017)

	Maximum values						Minimum values					
Laboratory	HS1	HS2	HS3	HS4	HS5	HS6	HS1	HS2	HS3	HS4	HS5	HS6
CO_2 concentration [ppm]												
Series 1	1873	1952	1957	1864	1757	1921	428	430	417	421	419	438
Series 2	1792	1998	2008	1971	1912	2089	422	435	430	440	424	438
Series 3	1983	2027	2184	1896	1990	2111	491	517	475	443	464	501
Temperature [°C]												
Series 1	26,9	27,1	26,1	26,1	26,8	27,1	20,2	19,8	21,3	20,5	20,0	20,3
Series 2	28,3	27,5	26,7	25,9	27,2	26,4	20,8	20,1	20,4	20,8	19,8	19,9
Series 3	28,6	27,5	26,2	26,1	27,4	26,9	21,0	19,6	19,8	20,7	19,9	19,9
RH [%]												
Series 1	52,1	51,2	49,9	49,2	50,6	53,3	32,9	34,1	35,2	33,3	30,6	30,9
Series 2	54,7	48,9	52,9	50,4	51,3	52,8	33,4	33,2	35,9	31,5	32,1	32,8
Series 3	50,1	53,1	52,6	49,5	51,7	53,8	32,1	36,4	34,7	32,7	31,0	33,2

3.2.3 Conclusion

The investigations show that low quality of indoor air in computer laboratories was due to improper management of air exchange. The proposed attempt to enhance indoor air quality by double up the incoming airflow shows effective result. The initial maximum CO_2 concentration level up to 3260 ppm was reduced to 2184 ppm after additional vents installed. Improvement of indoor air quality can be done by introducing proper volume of outside air. However, inflow of outside air increases will affect the indoor temperature drop and additional amount of energy is needed to heat the increased volume of airflow.

3.3 STUDY OF CONCENTRATION OF PARTICULAR MATTER, CO AND CO_2 IN SELECTED SCHOOLS IN MALAYSIA BY RAZALI ET AL. (2015)

This study investigates the influence of the local surroundings on the IAQ in school classrooms. The selected schools are located in semi urban areas. Concentrations of gas pollutants and particular matter were measured and the results were compared with standards. The main objectives in this study are:

i. To determine the concentration of pollutants (CO, CO_2, PM_{10}, $PM_{2.5}$ and PM_1) in classrooms and compared with concentrations in ambient air.
ii. To investigate the correlation between indoor air pollutants.
iii. To evaluate the influence of the local surroundings towards IAQ in the selected schools.

3.3.1 Methodology

This study was conducted in three different schools located in Bandar Baru Bangi and Putrajaya with different local surrounding activities and traffic conditions. The schools chosen for this study were:

i. Precinct 14 Secondary School, Putrajaya (S1)
ii. Jalan Reko Secondary School (S2)
iii. Section Four Secondary School, Bandar Baru Bangi (S3)

The description of the local surroundings, sampling date, classroom information and type of each school were identified. The study of IAQ at the schools was conducted in one classroom for each school. The instrument for each parameter measurement was shown as below:

i. GrayWolf Sensing Solution IQ-410 IAQ Probe

   It is used for measuring gas pollutants levels and meteorological variables such as air temperature and relative humidity.

ii. Portable aerosol spectrometer model 1.108 with flow rate 1.2L/min

   It is used for measuring the concentrations of particle matters by size from 0.3µm to 20µm.

The measurements were conducted for 8 hours for 2 days. The instruments for indoor measurements were placed in middle of classroom at height of 1m from the floor. For outdoor air quality measurements, the instruments were placed near the main entrance gate of school at height 1m from the floor. All measuring instruments were recorded for 1 minute interval readings in 8 hours. The data is then summarised and statistically analysed using IBM Statistical Package for Social Sciences (SPSS Version 19.0, USA) and MS Excel 2007.

3.3.2 Results

i. Evaluation on concentrations of particular matters and gas pollutants

The data for particular matters, gas pollutants and meteorological variables at outdoor and in the classrooms were recorded in Table 3.6. Based on the results, average concentration of PM_{10} was the highest at S1. The factors contributed to the concentration of PM within the classrooms were the location of classroom, number of students moving in the classroom, classroom conditions and classroom cleanliness. The outdoor average concentrations of PM were also highest at S1. Outdoor concentrations of PM were related to sources like motor vehicle emissions, dust from construction activities, resuspension of road dust and biomass burning. Compared to Malaysian DOSH and Singaporean NEA guide value (150µg/m^3), concentration of PM_{10} in this study was considered good.

CO_2 concentration in the buildings was higher compared to outdoor air while CO concentration is lower in the buildings. Results for CO_2 and CO from this study were considered as excellent as it were below 800 and 1.7ppm respectively, as suggested by EMSD, Hong Kong.

ii. Evaluation on meteorological variables

From this study, indoor temperature in all three schools exceeded the maximum comfort range value recommended by Malaysia Dosh (23℃ to 26℃) and Singaporean NEA (22.5℃ to 25.5℃). However, only the indoor relative humidity for S1 and S2 was in range recommended by DOSH (40% to 70%) and NEA (less than or equal70%).

Table 3.6: Summary of indoor and outdoor air pollutants concentrations (Razali et al., 2015)

Station	Statistics	Indoor air						
		PM_{10}	$PM_{2.5}$	PM_1	CO_2	CO	T	RH
		($\mu g\ m^{-3}$)			(ppm)		(°C)	(%)
Precinct 14 Secondary School, Putrajaya (S1)	Min	16	13	12	462	0.0	26	54
	Max	69	36	32	645	1.3	35	89
	Avg	35	22	20	502	0.2	32	67
	SD	11	6	5	36	0.2	2	8
Jalan Reko Secondary School (S2)	Min	14	8	6	462	0.0	26	51
	Max	72	16	11	684	4.3	35	90
	Avg	28	11	9	507	0.3	32	64
	SD	11	1	1	35	0.6	3	11
Section Four Secondary School (S3)	Min	16	14	13	439	0.0	25	59
	Max	62	34	30	684	3.8	34	90
	Avg	30	22	20	498	0.5	30	72
	SD	8	5	5	53	0.5	2	7
Average (Overall)		31	18	16	502	0.3	31	68
DOSH Malaysia [35].		150	N/A	N/A	1000	10.0	23–26	40–70
NEA Singapore [36].		150	N/A	N/A	1000	9.0	22.5–25.5	≤70

Station	Statistics	Outdoor Air						
		PM_{10}	$PM_{2.5}$	PM_1	CO_2	CO	T	RH
		($\mu g\ m^{-3}$)			(ppm)		(°C)	(%)
Precinct 14 Secondary School, Putrajaya (S1)	Min	33	29	27	461	0.1	25	56
	Max	77	68	61	639	4.2	35	93
	Avg	46	38	35	486	0.8	32	67
	SD	11	10	9	29	1.0	3	11
Jalan Reko Secondary School (S2)	Min	20	17	16	448	0.1	26	68
	Max	71	55	51	645	8.1	34	93
	Avg	34	23	21	494	2.3	30	77
	SD	11	5	4	35	2.0	2	7
Section Four Secondary School(S3)	Min	14	12	10	455	0.0	25	58
	Max	51	32	29	643	2.2	34	89
	Avg	22	17	15	495	0.5	30	70
	SD	7	5	4	33	0.5	3	10
Average (Overall)		34	26	23	491	1.2	31	71

3.3.3 Conclusion

From this study, the concentration of pollutants particularly PM were highly influenced by the location of classroom and the movement of students. Indoor temperature and relative humidity have large impact on the concentration of air pollutants measured in classrooms. High temperatures reduced the concentration of pollutants while high relative humidity increased the concentration of air pollutants in classrooms. This study recommended IAQ assessment should be implemented in other schools as it is important to manage the health hazard and risk associated with indoor air pollutants among the students.

3.4 ARCHITECTURAL EVALUATION OF THERMAL COMFORT: SICK BUILDING SYNDROME SYMPTOMS IN ENGINEERING EDUCATION LABORATORIES BY AMIN ET AL. (2014)

This study was carried out to evaluate the thermal conditions and sick building syndrome (SBS) symptoms in engineering education laboratories. Building-related factors of the lab were also evaluated. Thermal variables were measured and questionnaire was conducted to investigate the SBS symptoms and thermal sensation votes. The obtained results were then compared with standards.

3.4.1 Methodology

This study was conducted in three new engineering education laboratories in Universiti Tun Hussein Onn Malaysia (UTHM). These labs are used to assist students in research, experimentation, teaching and learning activities. Room's dimension, surface reflectance factor, lighting system and windows were identified from architectural drawings during the measurements. The selected labs were shown as below:

i. AutoCAD lab with 15 student occupants, low physical activity level and centralized air-conditioning system.

ii. Electronic lab with 34 student occupants, medium physical activity level and centralized air-conditioning system.

iii. Traffic and Highway Engineering lab with 22 student occupants, high physical activity level and centralized air-conditioning system.

For objective measurements, occupied and unoccupied zones, and measurement points for thermal variables were firstly identified. Thermal parameters such as mean radiant temperature, relative humidity and air velocity were then measured using thermal comfort station (BABUCA). The instrument was located at 1.1m from floor level. InfoGap software was used to analyse the indoor environmental data including estimated clothing characteristics and metabolic heat production. ASHRAE 55 was used to identify metabolic rate for various activities. The measurements were conducted within 3 hours of each lab sessions for 2 months. Subjective measurements were conducted through questionnaire. Questionnaire was developed by 3 sections which are demographic data, architectural evaluation and thermal sensation scales.

3.4.2 Results

i. Analysis on physical measurements

The data collected were compared with ASHRAE, WHO and NEA Standards. The measurement data for three laboratories is shown as Table 3.7 below:

Table 3.7: Measured parameters in three EELs (Amin et al., 2014)

Parameters	EEL 1	EEL 2	EEL 3
Mean radian temperature (℃)	21.46 – 22.42	17.8 – 20.7	18.5 – 21.4
Relative humidity (%)	68.0 – 71.1	55.7 – 60.9	69.3 – 78.3
Air velocity (m/s)	0.0 – 0.17	0.0 – 0.15	0.05 – 0.49

ASHRAE and WHO recommended ranges for the parameters in air-conditioned buildings were shown as Table 3.8 below:

Table 3.8: Recommended ranges for thermal parameters by ASHRAE, WHO, NEA (Amin et al., 2014)

Parameters	ASHRAE	WHO	NEA
Mean radian temperature (℃)	22.5 – 26.0	24.0 – 28.0	-
Relative humidity (%)	Maximum 50	-	Maximum 70
Air velocity (m/s)	Maximum 0.25	-	-

In this study, the mean radian temperature for three labs was not in the suggested range. The relative humidity in EEL 3 (78.3%) was exceeded the maximum limit of NEA. The mean air velocity in EEL 3 also exceeded the recommended range.

ii. Analysis on Sick Building Syndrome (SBS) symptoms

SBS symptoms experienced by all participants were investigated by using questionnaire survey. The result showed that SBS symptoms were found in all EELs were related to respiratory system especially in EEL 3.

iii. Analysis on architectural features

Architectural features in all EELs were rated by students. Result showed that three EELs had adequate to good quality of architectural features. EEL 1 has the highest overall quality rating followed by EEL 2 and EEL 3.

iv. Analysis on thermal comfort

Thermal Sensation Vote on the ASHRAE scale was analysed to determine the thermal conditions of the labs. The subjective judgement on the seven points thermal sensation were divided into three intervals which are (-3, -2), (+2, +3) and (-1, +1). According to Fanger's theory, value of thermal sensation vote in first and second of these intervals show that the microclimate is not acceptable. Votes of -1, 0 and +1 represent acceptable thermal environment. Based on the result, mean radian temperature was not acceptable for all EELs.

According to ASHRAE Standard-55, acceptable environment should have 80% of occupants voted for interval (-1, 0, 1). Based on Figure 3.2, all EELs were not in acceptable thermal conditions as most of the students voted interval (-3, -2) for temperature. Based on Figure 3.3, less than 80% of the students voted for interval (-1, 0, 1) which means that all EELs were not in acceptable relative humidity conditions. However, the sensation vote for air velocity was within acceptable condition in all EELS based on Figure 3.4.

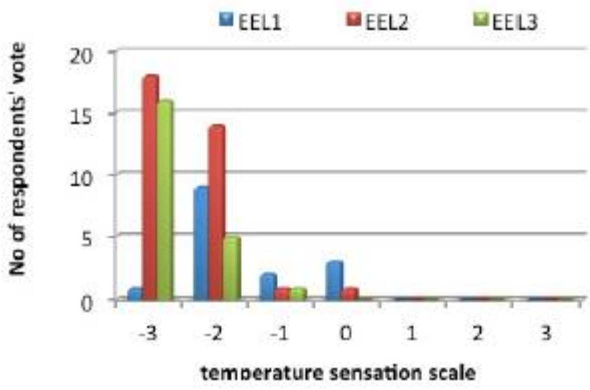


Figure 3.2: Thermal sensation votes in three EELs (Amin et al., 2014)

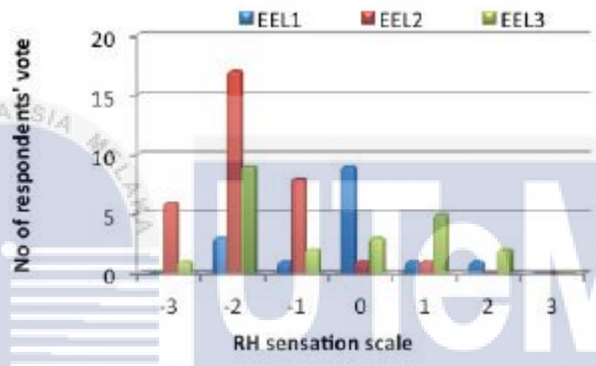


Figure 3.3: Relative humidity sensation votes in three EELs (Amin et al., 2014)

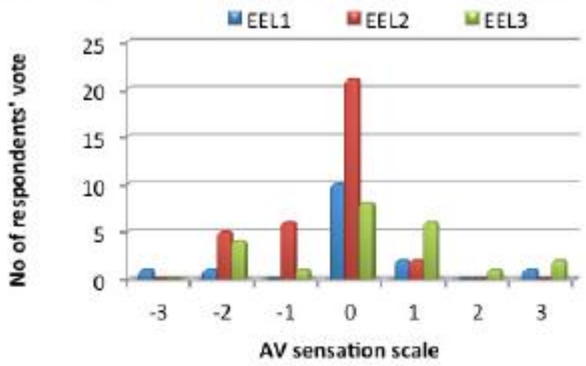


Figure 3.4: Air velocity sensation votes in three EELs (Amin et al., 2014)

3.4.3 Conclusion

From this study, the thermal conditions for all EELs were considered unacceptable as the results show that the temperatures not within recommended range. Subjective measurement also shows that student occupants were not in thermal acceptable condition. Hence, the centralized air conditioned in the labs should adequately be designed. Poor ventilation system of air conditioned EELs will lead to SBS symptoms and affect students' health.

3.5 STUDY OF THE INDOOR AIR QUALITY IN THREE NON-RESIDENTIAL ENVIRONMENTS OF DIFFERENT USE: A MUSEUM, A PRINTERY INDUSTRY AND AN OFFICE BY SARAGA ET.AL (2011)

This study was focusing on identify the main sources contributing to the air pollution of three different indoor environments which are a museum, a printer industry and an office. Particular matter (TSP, PM_{10}, $PM_{2.5}$), inorganic pollutants (NO_2, SO_2, O_3) and organic compounds (BTX, formaldehyde) were measured. Factors such as the indoor activities, the emission from existing equipment, 3number of occupants, the types of ventilation system and the outdoor background were varied among the three selected sites. The results were obtained and analysed throughout the study.

3.5.1 Methodology

Three different buildings located in center and suburbs of Athens that selected for measurements in this study were a museum, a printery industry and two office rooms. Particular matters (PM_{10} and $PM_{2.5}$) measurements were conducted according to European standard methods EN 12341 and EN 14907. Particle number measurements in the two offices and the museum hall were conducted using an automatic portable aerosol spectrometer (GRIMM 1.108). The unit is based on principle of light scattering and can give size distribution (0.23-20µm) of dust particles in µg/l or in number of particles/l.

3.5.2 Results

i. Evaluation of particular matter in museum

24-h gravimetric $PM_{2.5}$ measurements were conducted during the first seven days of the sampling period. The data was recorded in Table 3.9. It can be seen that the average daily value was ranged between 17.4 and 25.5µg/m^3. The daily recorded variations were quite small due to the museum remained closed for public. In the absence of significant indoor emissions, resuspension from the wall to wall carpet was expected to be the main source of producing fine and coarse particles with higher diameter.

Table 3.9: $PM_{2.5}$ concentration values in museum, µg/m^3 (Saraga et al., 2011)

Pollutant	Max	Min	Average	St. dev
$PM_{2.5}$	25.5	17.4	20.3	2.69

ii. Evaluation on printery industry

24-h gravimetric measurements of $PM_{2.5}$ and PM_{10} concentrations were conducted at three different sites of the industry. The data was recorded in Table

3.10. PM_{10} and $PM_{2.5}$ presented the maximum value at bookbindery section while minimum value at presser section. High level of $PM_{2.5}$ and PM_{10} concentrations were due to the large number of occupants, the emissions from the equipment and the outdoor environment which is urban area with intense vehicular circulation.

Table 3.10: $PM_{2.5}$ and PM_{10} concentration values in printer, µg/m^3 (Saraga et al., 2011)

Pollutant	Site 1 Presses section	Site 2 Bookbindery section	Site 3 Dispatch section
	Average	Average	Average
$PM_{2.5}$	65	151	104
PM_{10}	96	205	165

iii. Evaluation on smokers' and non-smokers' offices

24-h sampling for indoor $PM_{2.5}$ and PM_1 concentrations were conducted daily for both offices. The data was recorded in Table 3.11.Based on the results, $PM_{2.5}$ and PM_1 concentrations were higher in smokers' office compared to non-smokers' office.

Table 3.11: $PM_{2.5}$ and PM_1 concentration values in offices, µg/m^3 (Saraga et al., 2011)

Pollutant	Smokers' Office				Non Smokers' Office			
	Max	Min	Average	St. dev	Max	Min	Average	St. dev
$PM_{2.5}$	94.3	17.3	37.6	27.3	40.5	25.3	30.7	6.7
PM_1	66.4	13.2	30.4	18.2	35.7	23.3	26.8	5.3

3.5.3 Conclusion

From this study, printery industry showed the highest concentrations of air pollutants. The main sources included the large number of occupants, the emission from the old building's materials, the resuspension of accumulated dust, the emission from machinery and the special materials (inks, glues etc) used. Regarding the museum, the resuspension from wall to wall carpet and the emission from exhibited items are the main indoor sources. Finally, the main indoor sources in offices were the smoking activity, the resuspension from visitors and occupants' movement and the emission from equipment.

3.6 STUDY OF THERMAL COMFORT IN LECTURE HALLS IN THE TROPICS BY YAU, CHEW, AND SAIFULLAH (2011)

This study investigates the thermal conditions of lecture halls in University of Malaya, Kuala Lumpur. Thermal parameters were measured and analysed the acceptability of the thermal comfort. Subjective measurement such as thermal sensation vote (TSV) analysis was conducted using questionnaire. The obtained results in this study were compared with ASHRAE 55. The objectives for this study are:

i. To determine the thermal conditions in the lecture halls and compared with ASHRAE Standard 55 (2004).
ii. To investigate the satisfaction level of occupants in the lecture halls by using ASHRAE thermal sensation scales.
iii. To investigate the neutral temperature in lecture halls.
iv. To investigate an innovative AC design technique.

3.6.1 Methodology

In this study, 6 lecture halls (DK1, DK2, DK3, DK4, DK5 and DK6) were selected to investigate the thermal conditions. Objective measurement and subjective assessment were conducted simultaneously. Air temperature, mean radiant temperature, relative humidity and air velocity were measured. The measurement instruments used were classified as below:

i. IAQ Monitor (KANOMAX-model 22111)

   It is used for measuring the dry bulb temperature, relative humidity of indoor and outdoor environment.

ii. TSI VELOCICALC (Anemometer)

   It is used for measuring air movement.

iii. Vernon's Globe Thermometer

   It is used for measuring mean radian temperature.

IAQ Monitor and Anemometer were placed at three different heights of 0.1m, 0.6m and 1.1m just above each point on the floor while Vernon's Globe Thermometer was used to measure at about 0.6m above each point. For subjective assessment, personal factors such as metabolism rate and clothing insulation were investigated using questionnaire.

3.6.2 Results

i. Evaluation on PMV

PMD and PPD value for each lecture hall were determined by using ASHRAE TC Tool and recorded in Table 3.12. Based on results, only DK6 was within ASHRAE 55 (2004) recommended range for PPD and PMV which were (PPD ≤ 10%) and (-0.5≤ PMV≤ 0.5). The regression of PMV and operative temperature was done and the neutral temperature based on PMV regression is 24.6°C.

Table 3.12: PMV and PPD in lecture halls (Yau, Chew, and Saifullah, 2011)

Location	Input Parameters						Outputs	
	Clothing (clo)	Air temp. (°C)	Mean radiant temp. (°C)	Activity (met)	Air speed (m/s)	Relative humidity (%)	PMV	PPD
DK1	0.64	20.84	23.4	1.12	0.20	47.67	-1.10	30.50
DK2	0.61	21.1	22.56	1.03	0.10	62.6	-1.20	35.20
DK3	0.57	22.16	22.65	1.08	0.12	69.31	-0.70	15.30
DK4	0.59	22.27	22.13	1.02	0.12	48.2	-1.30	40.30
DK5	0.64	21.38	22.32	1.05	0.14	48.96	-1.00	26.10
DK6	0.60	24.86	25.38	1.10	0.08	62.4	0.20	5.80

ii. Evaluation on TSV

Thermal Sensation Vote by respondents was recorded in Table 3.13. Based on the results, DK6 with a value of -0.05 which is closer to zero indicated that it will provide a more comfortable thermal environment compared to other 5 lecture halls. From Table 3.13, it can be seen that majority of occupants preferred operative temperature which is 25.1°C in DK6. The regression of TSV and operative temperature was done and the neutral temperature based on TSV regression is 25.3°C.

Table 3.13: AMV and TSV in lecture halls (Yau, Chew, and Saifullah, 2011)

Location	Operative temperature °C)	AMV	Votes on ASHRAE Thermal Sensation Scale							
			-3	-2	-1	0	1	2	3	Total
DK1	21.84	-1.77	7	12	3	2	2	0	0	26
DK2	21.85	-1.23	0	13	13	3	0	1	0	30
DK3	22.45	-1.04	2	6	13	3	1	0	1	26
DK4	22.20	-1.19	0	8	15	3	0	0	0	26
DK5	21.85	-0.93	1	5	15	5	2	0	0	28
DK6	25.10	-0.05	0	2	16	10	10	4	0	42
Total			10	46	75	26	15	5	1	178

3.6.3 Conclusion

From this study, DK6 thermal condition was acceptable after compared with ASHRAE 55 (2004). This study recommended that increase the air speed is better than decrease the air temperature and humidity for AC design.

3.7 CARBON DIOXIDE CONCENTRATIONS ANALYSIS INSIDE LECTURE ROOMS BY DADAN ET AL. (2006)

This study was conducted in educational building located in main campus of KUTKM at Durian Tunggal. This study investigates the relationship between CO_2 concentration and air flow rate, and also the relationships between CO_2 concentration and indoor air temperature. Physical parameters were measured and questionnaires were distributed in this study. Pilot tests were conducted to determine the suitable room for measurement. SPSS software was used to analyse the data obtained. The results were compared with ASHRAE Standard 62 (2004). Objectives of this study were successfully obtained

3.7.1 Methodology

This study was conducted by involving information searching, pilot test, physical measurement, questionnaire distribution and lastly data analysis. Physical parameters were measured using 3 instruments in a selected room, which are:

i. Air Velocity Meter and Thermal Comfort Meter used to measure indoor air temperature, relative humidity and air velocity.
ii. IAQ Meter used to measure carbon dioxide level.
iii. AccuBalance used to measure air flow rate.

Before the actual physical measurement begun, several pilot tests were conducted and Room BK2 was selected for this study. Measurement was conducted during 2 hour lecture period with full occupancy.

Questionnaires were prepared based on ASHRAE Standard 62 (2004) and distributed to students to vote for Perceived Thermal Votes (PTVc), Perceived Airflow (PAF) and Skin Dryness (SD). The results were analysed to obtain students' perception towards the indoor environmental conditions of the lecture room.

3.7.2 Results

i. Analysis on parameters

CO_2 concentration was varied over the time while the indoor temperature and relative humidity were nearly constant based on the graph obtained. The obtained range for CO_2 level in the lecture room was from 769ppm to 2001ppm. The average value was about 1395.7 ppm. Indoor temperature was ranging from

21.9℃ to 23.5℃ and showed an average value of 22.3℃. Meanwhile, relative humidity was ranging from 54.4% to 65.7% and showed an average value of 61.1%. According to ASHRAE Standard 62 (2004), the maximum CO_2 level for summer is about 1000ppm. The indoor temperature was recommended in range 22.5℃ to 26℃ while the relative humidity should in range 40% to 60%. Based on the results, the CO_2 concentration exceeded the maximum recommended value. Indoor temperature and relative humidity were close to the recommended range.

ii. Analysis on Statistical Model

Linear regression for statistical model showed that CO_2 concentration and ventilation rate has a high correlation. Based on the linear regression equation, high CO_2 level showed that the ventilation rate is low.

iii. Analysis on questionnaire

Subjective measurement showed 37.5% of the students has medium level of overall satisfactory with their indoor environment.

3.7.3 Conclusion

Based on this study, the relationship between CO_2 concentration and indoor temperature is obtained. The indoor temperature and relative humidity were close to range recommended by ASHRAE Standard 62. Meanwhile for the CO_2 concentration with average value of 1395.7 ppm exceeded the maximum recommended value from the standard. CO_2 concentration has relationship between indoor temperature and ventilation rate based on the statistical model.

3.8 OVERALL COMPARISON OF PREVIOUS STUDIES

Comparison between the studies by researchers in various locations is summarized in Table 3.16. Thermal comfort parameters such as air temperature, air velocity and relative humidity from the studies are compared with ASHRAE Standard 55 (2010), Malaysia Standard MS1525 (2014), and DOSH Malaysia (2010). Indoor air quality parameters such as carbon dioxide concentration and particular matter $PM_{2.5}$ and PM_{10} concentrations are compared with ASHRAE Standard 62.1 (2010) and DOSH Malaysia (2010). Recommended range for thermal comfort parameters is shown in Table 3.14 while indoor air quality parameters in Table 3.15.

Table 3.14: Recommended range for thermal comfort parameters (ASHRAE 55, 2010; DOSH Malaysia, 2010; MS 1525, 2014)

Parameters	**Recommended range**		
	ASHRAE 55	MS 1525	DOSH Malaysia
Air Temperature	20°C to 27°C	24°C to 26°C	23°C to 26°C
Air Velocity	0.1m/s to 1.2m/s	0.15m/s to 0.50m/s	0.15m/s to 0.50m/s
Relative Humidity	40% to 60%	50% to 70%	40% to 70%

Table 3.15: Recommended concentration for indoor air quality parameters (ASHRAE 62.1, 2010; DOSH Malaysia, 2010)

Indoor Air Quality Parameters	**Concentration of interest**	
	ASHRAE 62.1	DOSH Malaysia
Carbon Dioxide Concentration	Not more than 700ppm above outdoor air levels	1000ppm (max)
$PM_{2.5}$ Concentration	15 $\mu g/m^3$ (max)	-
PM_{10} Concentration	50 $\mu g/m^3$ (max)	150$\mu g/m^3$ (max)

Table 3.16: Comparison of results from previous studies

Researchers (year)	Type of study	Building type	Results	Compliance of standards			
				ASHRAE 55	MS1525	DOSH Malaysia	ASHRAE 62.1
Vilcekova et al. (2017)	IEQ investigation	Classroom	Air temperature= 24.8℃	Yes	Yes	Yes	-
			Relative humidity= 36.28%	No	No	No	-
			CO_2 concentrations= 1094.62ppm	-	-	No	Yes
Telejko (2017)	Attempt to improve IAQ	Computer laboratories in high schools	**(before modified)**				
			Air temperature= 26.8℃ to 29.6℃	No	No	No	-
			Relative humidity= 49.2% to 55.1%	Yes	Yes	Yes	-
			CO_2 level= 2854ppm to 3263ppm	-	-	No	No
			(after modified)				
			Air temperature= 26.1℃ to 28.6℃	No	No	No	-
			Relative humidity= 49.2% to 54.7%	Yes	Yes	Yes	-
			CO_2 level= 1757ppm to 2184ppm	-	-	No	No

Dadan et al. (2006)	Carbon dioxide concentrations analysis	KUTKM lecture rooms	Air temperature= 22.3℃ Relative humidity= 61.1% CO_2 concentrations= 1395.7ppm	Yes Yes -	No Yes -	No Yes No	- - No
Amin et al. (2014)	Architectural evaluation of thermal comfort: Sick Building Syndrome symptoms	Engineering education laboratories in UTHM	EEL 1: T_{mrt} =21.46℃ to 22.42℃ RH=68% to 71.1% AV= 0.0m/s to 0.17m/s	 - No Yes	 - No Yes	 - No Yes	 - - -
			EEL 2: T_{mrt} =17.8℃ to 20.7℃ RH=55.7% to 60.9% AV= 0.0m/s to 0.15m/s	 - Yes Yes	 - Yes Yes	 - Yes Yes	 - - -
			EEL 3: T_{mrt} =18.5℃ to 21.4℃ RH=69.3% to 78.3% AV= 0.05m/s to 0.49m/s	 - No Yes	 - No Yes	 - No Yes	 - - -

Saraga et al. (2011)	IAQ study in three non-residential environments	Museum, printery industry and office in Athens	Museum: $PM_{2.5}$= 20.3µg/m^3	-	-	-	No
			Printery industry (Site 1 to 3): $PM_{2.5}$=65, 151,104µg/m^3 respectively PM_{10}= 96,205,165µg/m^3 respectively	- -	- -	- Yes, No, No	No No
			Office (Smokers' and Non-smokers'): $PM_{2.5}$=37.6, 30.7µg/m^3 respectively PM_1= 30.4, 26.8µg/m^3 respectively	- -	- -	- -	No -
Razali et al. (2015)	Investigation of particular matter, CO and CO_2 concentrations	Schools located in Bandar Baru Bangi and Putrajaya	School 1: $PM_{2.5}$= 22µg/m^3 PM_{10}= 35µg/m^3 CO_2= 502ppm T= 32℃ RH= 67%	- - - No No	- - - No Yes	- Yes Yes No Yes	No Yes Yes - -
			School 2: $PM_{2.5}$= 11µg/m^3 PM_{10}= 28µg/m^3 CO_2= 507ppm T= 32℃ RH= 64%	- - - No No	- - - No Yes	- Yes Yes No Yes	Yes Yes Yes - -

			School 3: $PM_{2.5}$= 22µg/m^3 PM_{10}= 30µg/m^3 CO_2= 498ppm T= 30℃ RH= 72%	- - - No No	- - - No Yes	- Yes Yes No No	No Yes Yes - -
Yau, Chew, Saifullah (2011)	Thermal comfort analysis in the tropics	Lecture halls (DK6) in UM, Kuala Lumpur	Operative temperature= 25.10℃ Air speed= 0.08m/s Relative humidity= 62.4%	Yes No No	Yes No Yes	Yes No Yes	- - -

CHAPTER 4

METHODOLOGY

This chapter comprises the methods used on thermal comfort and indoor air quality analysis. The steps for physical measurements, list of instruments, and subjective measurement through questionnaire are explained in this section. The overall steps for this study are presented in a flow chart.

4.1 MECHANICAL ENGINEERING LABORATORIES COMPLEX OF UTEM

Mechanical Engineering Laboratories Complex as shown in Figure 4.1 consists of several workshops, lecture rooms and laboratories. These rooms are either natural ventilated or air-conditioned. It is a single storey building. The purpose of this building is to provide comfortable and healthy learning environment for students to conduct research, experiment, workshop practices and learning activities. The attire for student who has session in workshop and laboratory is lab coat, long pant and safety boot. The plan for this building is shown in APPENDIX D.

Figure 4.1: Mechanical Engineering Laboratories Complex of UTeM

4.2 SELECTION OF MECHANICAL ENGINEERING LABORATORIES

Based on the scope of this study, thermal comfort and indoor air quality analysis is conducted in order to investigate the indoor environmental quality of mechanical engineering laboratories in the complex. In this study, a non-air conditioned welding workshop and an air conditioned machine workshop shown in Figure 4.2 and 4.3 respectively are selected as the case study for physical measurement and survey.

Figure 4.2: Welding workshop (non-air conditioned)

Figure 4.3: Machine workshop (air conditioned)

4.3 PHYSICAL MEASUREMENT

Physical measurement is essential to be conducted in order to determine the environmental conditions of the selected area. The physical parameters that will be measured in this study are classified in Table 4.1. The data for each physical parameter is different in every period of time. Thus, physical measurements in this study will be divided into two sessions in a day which are morning session (10am to 12 pm) and afternoon session (2pm to 5pm).

Physical measurements will involve two sets of conditions which are with occupants and without occupant. Before the actual measurements begin, pilot test will be conducted to observe the preliminary condition of the laboratories. The data obtained from pilot test will be a good indicator in selecting the suitable laboratories for real parameter measurement in this study.

Table 4.1: Physical Parameters involved in this study

Parameters	**Unit**
Indoor air temperature, T_a	Celsius
Air velocity, V_a	m/s
Relative humidity, RH	%
CO_2 concentration	Ppm
$PM_{2.5}$ concentration	µg/m^3
PM_{10} concentration	µg/m^3
Predicted Mean Vote, PMV	-
Predicted Dissatisfied Percentage, PPD	%

4.3.1 Thermal Comfort Parameters Measurement

In this study, the instrument used to measure the thermal comfort parameters is Delta Ohm Thermal Microclimate HD 32.1 as shown in Figure 4.4. The operative temperature range and relative humidity range for this instrument are -5℃ to 50℃ and 0% to 90% respectively. This instrument consists of eight inputs for probes with SICRAM module. The labelled probes are shown in Table 4.2. The probes are all fitted with an electronic circuit and the calibration settings are memorized by the instrument. (Delta Ohm SRL, 2009).

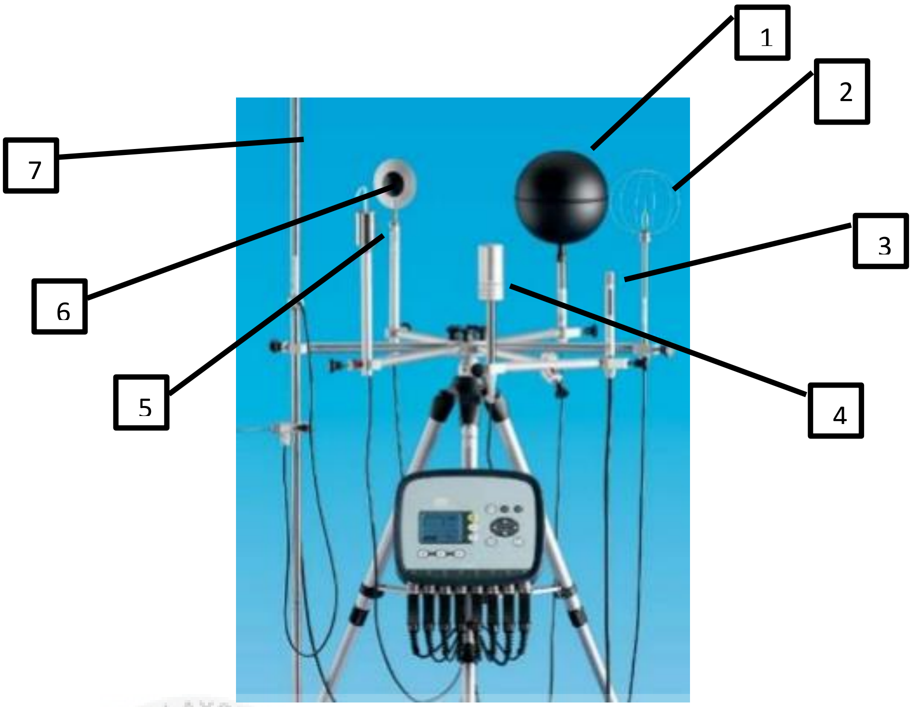


Figure 4.4: Thermal Microclimate HD32.1 (Delta Ohm SRL, 2009)

Table 4.2: Probes in Thermal Microclimate HD32.1

Probes	**Descriptions**
1	Measure mean radian temperature
2	Measure air velocity
3	Measure relative humidity
4	Measure carbon dioxide
5	Measure natural ventilated wet bulb temperature
6	Measure radiant temperature
7	Measure local thermal discomfort

In this study, the operating programs for the instrument are Program A: HD32.1 Microclimate Analysis and Program B: HD32.1 Discomfort Analysis. The probes that used to measure the thermal parameters for the indoor environment are shown in Table 4.3.

Table 4.3: Probes used in this study

Thermal parameters	**Probes**
Sensors for wet bulb and dry bulb temperature	HP3217DM
Relative humidity	HP3217
Globe temperature probe (150mm dia.)	TP3275
Air velocity (Omni directional hot-wire probe)	AP3203

The general steps to conduct thermal comfort analysis are:

i. Selected workshops are divided into few measurement zones.
ii. Thermal Microclimate HD32.1 is configured and placed in the centre of each zone as shown in Figure 4.5 and 4.6 below. The probes that used to conduct measurements are located at 1.1m from the floor level.
iii. Pilot measurement is conducted first by setting minimum interval of time to collect the data. The result is observed to determine how frequent and quick the data changes within an hour. Then, real measurement is conducted by setting 15 seconds time interval to collect data for around 10 minutes in each zone.
iv. Physical measurement is conducted at morning session (10am to 12pm) and afternoon session (2pm to 5pm) for both cases with occupants and without occupants as shown in Figure 4.7 and 4.8 below.

v. The collected data is analysed with Delta Log 10 software.

Figure 4.5: Instrument is placed in the centre of each zone in machine workshop

Figure 4.6: Instrument is placed in the centre of each zone in welding workshop

Figure 4.7: Measurement conducted for non-occupancy condition (left) and occupancy condition (right) in machine workshop

Figure 4.8: Measurement conducted for non-occupancy condition (left) and occupancy condition (right) in welding workshop

4.3.2 Indoor Air Quality Parameters Measurement

In this study, the instruments used to measure indoor air quality parameters are TSI IAQ-Calc Indoor Air Quality Meter 7545 and DustTrak II Aerosol Monitor as shown in Figure 4.9 and 4.10 respectively.

IAQ-Calc Indoor Air Quality Meter 7545 is used to measure CO, CO_2, temperature and humidity while DustTrak II Aerosol Monitor is used to measure aerosol concentrations corresponding to $PM_{2.5}$ and PM_{10} size fractions.

Figure 4.9: IAQ-Calc Indoor Air Quality Meter 7545

Figure 4.10: DustTrak II Aerosol Monitor

In this study, IAQ-Calc Indoor Air Quality Meter 7545 is used to measure CO and CO_2 concentrations. The measurement is conducted at the same zones as divided for thermal comfort analysis as shown in Figure 4.11. The CO_2 concentrations sensor is placed at 1.1m from the floor level. Pilot measurement is conducted by setting 10 seconds time interval to collect the data for 10 minutes. Interval of time will be adjusted if the data shows negligible changes. After that, the real measurement is conducted by setting 10 seconds time interval to collect data for around 10 minutes in each zone. The measurement is conducted at the same time with the thermal parameters measurement during morning session (10am to 12pm) and afternoon session (2pm to 5pm) for both cases with occupants and without occupants. The collected data is then being analysed.

DustTrak II Aerosol Monitor is used to measure $PM_{2.5}$ and PM_{10} concentrations. The measurement is conducted at the same zones as divided in thermal comfort analysis as shown in Figure 4.12. Before measurement starts, zero calibration has to be done in order to get accurate result. Pilot measurement is conducted by setting 1 second time interval to collect the data for 1 minute. Interval of time will be adjusted if the data shows negligible changes. After that, the real measurement is conducted for 5 minutes each to collect $PM_{2.5}$ and PM_{10} concentrations data. 1 second time interval is set for the real measurement. The measurement is conducted at the same time with the thermal parameters measurement during morning session (10am to 12pm) and afternoon session (2pm to 5pm) for both cases with occupants and without occupants. The collected data is then being analysed.

Figure 4.11: Measurement of CO_2 concentrations conducted in same zones as divided in thermal comfort analysis

Figure 4.12: Measurement of $PM_{2.5}$ and PM_{10} concentrations conducted in same zones as divided in thermal comfort analysis

4.4 SURVEY

In this study, subjective measurement is conducted through questionnaire as shown in APPENDIX E and F. It provides an overall view of how the occupants feel with the indoor conditions and the results is correlated with the physical measurements. The variables included in the questionnaire are referring to occupant's perception on thermal comfort (physical activity in the workshop, occupants' clothing types, room air temperature, air velocity) and indoor air quality (air odour).

Questionnaire for the survey is constructed according to the ASHRAE scale and categorized into four sections as described below:

i. Occupant's personal information

It includes occupant's age, sex, health condition and their location inside the workshop.

ii. Current environment conditions

It includes the environment conditions of the workshops such as sunny, windy, cloudy or rainy.

iii. Occupant's psychological parameters

It includes occupant's clothing types and physical activity in the workshop.

iv. Occupant's indoor air and thermal sensation vote

It includes occupant's sensation to the air temperature, air movement and air odour inside the workshop. The sensation voting scales is a seven-point scale recommended in ASHRAE standard (from -3 to +3). Occupant's satisfaction on indoor air temperature and overall comfort perception are also included in this section.

4.4.1 Selection of Respondents

The questionnaire forms were distributed to the occupants who are having class session in the selected workshops during morning (10am to 12pm) and afternoon (2pm to 5pm). Figure 4.13 shows the occupants filled the questionnaires during class session in both workshops. In the workshops, the respondents will do different physical activities and stay in different locations such as standing near the machines, near the door, in the corner and so on. The main purpose of distributing the questionnaires to those occupants is to obtain their perception towards the indoor environment while having session in the workshops.

Figure 4.13: Occupants filled questionnaires in machine workshop (left) and welding workshop (right)

4.5 RESULTS ANALYSIS

Software is used to analyse the physical measurement data as well as the survey's results. In this study, the thermal parameters data are analysed with Delta Log 10 Software and Minitab Statistical Software. However, the indoor air quality parameters data are analysed with Microsoft Excel and Minitab Statistical Software. Meanwhile, results obtained from the surveys are analysed using Minitab Statistical Software. In this study, analysis of results is divided into few sections as below.

4.5.1 Results comparison between physical measurements with standards

Thermal comfort parameters such as air temperature, relative humidity, air velocity, PMV index and PPD index will be compared with Malaysia Standard (MS 1525), ASHRAE 55 or DOSH Malaysia. Indoor air quality measurements such as carbon dioxide concentration, $PM_{2.5}$ concentration and PM_{10} concentration will then compared with ASHRAE 62.1 and DOSH Malaysia. It is essential to know whether the indoor conditions comply with the standards. Furthermore, the results will also compare with condition of no occupants and full occupants in order to know the influence of occupants on each parameter changes.

4.5.2 Analysis of occupant's sensation votes based on questionnaire

Occupant's sensation vote is analysed to investigate their perception on the indoor condition of both workshops. Linear regression analysis is conducted for occupant's thermal sensation vote and operative temperature. Besides, neutral temperature that most of the occupants satisfied is obtained through regression of TSV and operative temperature.

4.5.3 Results comparison between questionnaire and physical measurements

The results from questionnaires are essential to compare with physical measurements. Explanations can be made through the comparison. For thermal comfort analysis, occupant's personal factor and thermal sensation vote determined through questionnaire can be compared with physical measurements. For indoor air quality analysis, occupant's perception towards air odour can compared with physical measurements. Furthermore, linear regression analysis between occupant's sensation vote and physical parameters is done in order to determine the strength of the relationship.

4.6 RECOMMENDATION ON INDOOR ENVIRONMENT QUALITY IMPROVEMENT MEASURES

The condition of the indoor environment in machine workshop and welding workshop is determined through thermal comfort analysis and indoor air quality analysis. Measurement parameters as well as occupant's perception able to determine which parameters have to be concerned in order to achieve better indoor environment. Based on the current condition of the workshops, appropriate measures to improve the indoor environment quality are suggested.

4.7 GENERAL METHODOLOGY IN THIS STUDY

Overall, the general methods to achieve the objectives in this study are presented in a flowchart as shown in Figure 4.7 below.

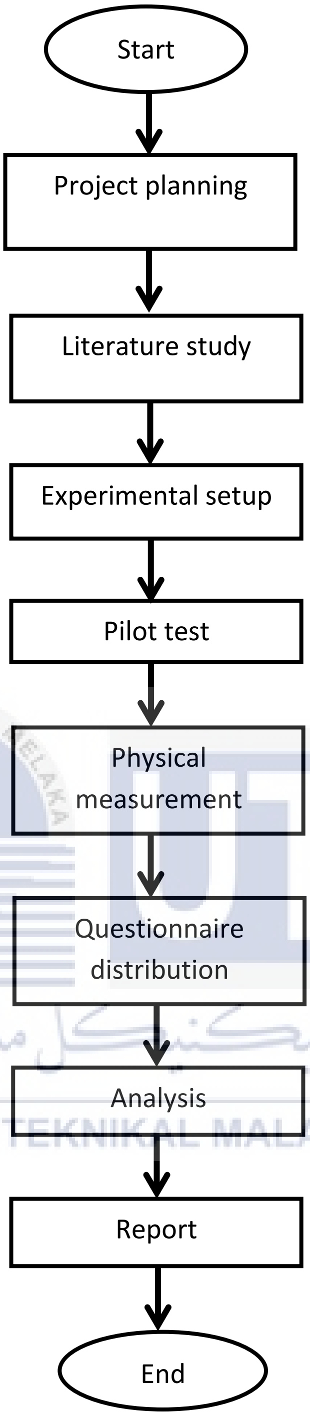


Figure 4.14: Flow chart of methodology

CHAPTER 5

RESULTS AND ANALYSIS

This chapter comprises the measurement data of laboratories for no occupancy and occupancy conditions. The data are analysed and compared with the current relevant standards. Besides that, results from the survey are also analysed and compared with physical measurements. Lastly, effective measure to improve IEQ is proposed in this chapter.

5.1 PHYSICAL MEASUREMENT RESULTS

Physical measurements were conducted for the selected laboratories in Mechanical Engineering Laboratories Complex of UTeM. The measurements consist of two conditions with occupants and without occupants.

Measurements for condition without occupants were carried out for two sessions which are 10am to 12 pm and 2pm to 5pm during semester break. The measurements conducted in welding workshop were on 26th January 2018 and 30th January 2018. Meanwhile, the measurement conducted in machine workshop was on 29th January 2018. However, the measurements for condition with occupants were carried out for two sessions after semester break. The measurements were conducted on 8th March 2018 in machine workshop and 5th April 2018 in welding workshop.

In this study, two main factors which are thermal comfort and indoor air quality are focused in order to determine the indoor environment quality of the laboratories. The physical parameters used to measure human thermal comfort level and indoor air quality are air temperature (Ta), relative humidity (RH), air velocity (Va), carbon dioxide level, concentrations of particulate matter 2.5 and 10. Besides that, personal factors such as metabolic rate (met) and clothing insulation (clo) are also considered in this study. In thermal comfort analysis, Predicted Mean Vote (PMV) index and Predicted Percentage of Dissatisfied (PPD) index are important. These indexes are analysed through Deltalog10 software from the Thermal Microclimate HD32.1 instrument.

5.1.1 Machine Workshop (With Occupants and Without Occupants)

There are total 3 measurement zones in machine workshop. In this study, the obtained results for both conditions are analysed and compared in order to know how good the indoor environment quality is when there are no occupant or occupants in the workshop.

The thermal variables used to analyse human thermal comfort included air temperature (Ta), relative humidity (RH) and air velocity (Va). The data for the thermal parameters are recorded every 15 seconds for around 10 minutes in each zone. The parameters used to analyse indoor air quality included carbon dioxide level and concentrations of PM 2.5 and 10. The data for carbon dioxide level are recorded every 10 seconds for around 10 minutes in each zone while the data for concentrations of PM 2.5 and 10 are each recorded 5 minutes in each zone.

The air temperature results obtained from each zone in morning session and afternoon session are shown in Figure 5.1 and 5.2 respectively. Based on Figure 5.1, the average minimum, maximum and overall indoor air temperature among the zones for no occupancy condition are 19.4°C, 19.6°C and 19.5°C respectively. When there are occupants inside the workshop, the indoor air temperature obviously increased about 1°C to 2°C in each zones. The average minimum, maximum and overall air temperature increased to 20.7°C, 21°C and 20.9°C respectively.

According to MS1525, the recommended range for indoor air temperature in air-conditioned building is 24°C to 26°C. Compared with this study, it is found that the overall indoor air temperature obtained for both conditions are not complying with the standard range. The indoor air temperature is lower than the minimum recommended temperature by 4.5°C and 19% for no occupancy condition while the indoor air temperature is lower by 3.1°C and 12.9% for occupancy condition.

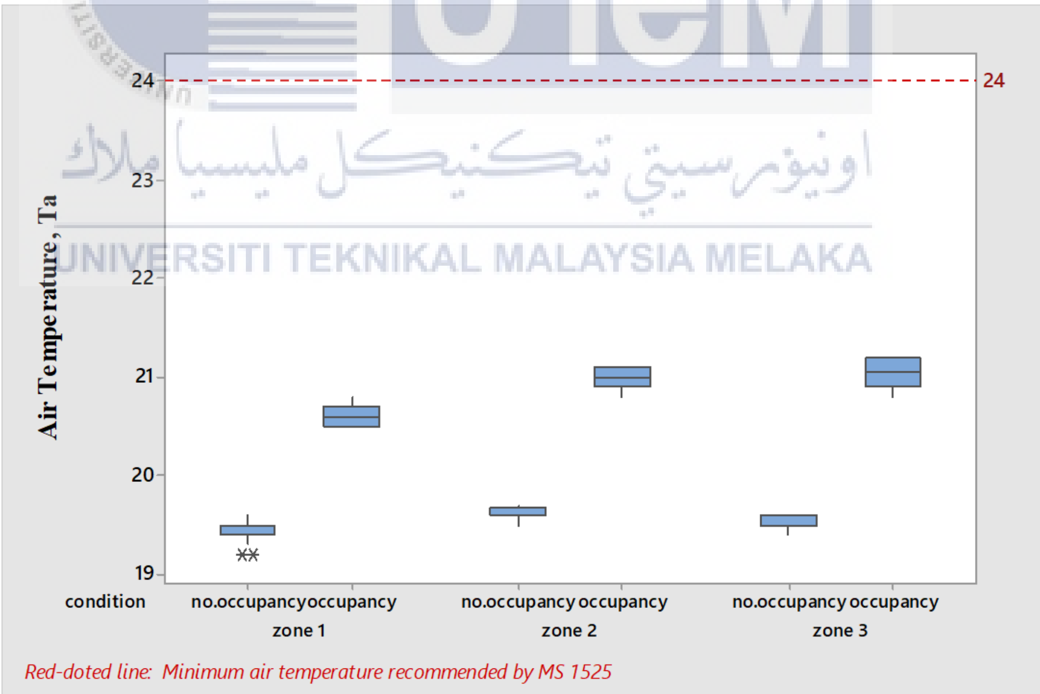


Figure 5.1: Indoor air temperature in machine workshop during morning

According to Figure 5.2, the average minimum, maximum and overall indoor air temperatures in the afternoon are 18.7°C, 19.0°C and 18.8°C respectively when no occupancy in the workshop. However, the indoor air temperature for occupancy condition increased about 2°C in each zones. The average minimum, maximum and overall indoor air temperatures increased to 20.6°C, 20.9°C and 20.8°C respectively.

Compared with MS1525, it resulted that the overall indoor air temperature obtained for both conditions are not complying with the standard range. The indoor air temperature is lower than the minimum recommended range by 5.2°C and 21.7% for no occupancy condition while the indoor air temperature is lower by 3.2°C and 13.3% for occupancy condition.

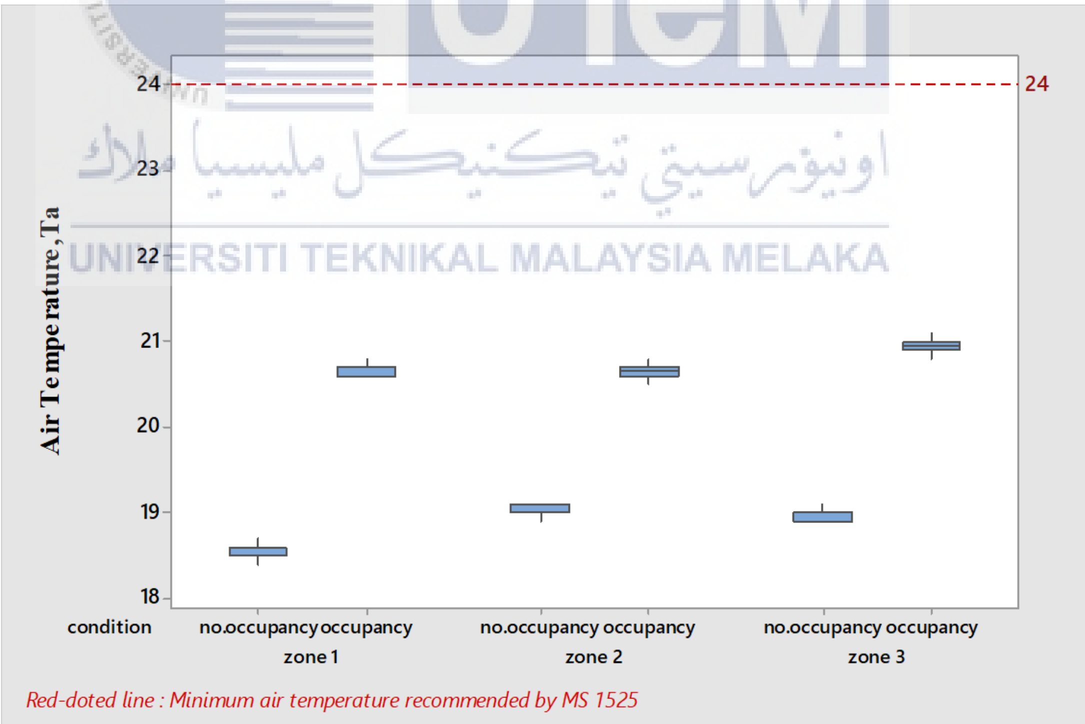


Figure 5.2: Indoor air temperature in machine workshop during afternoon

The relative humidity level recommended by MS1525 is in range 50% to 70%. Based on Figure 5.3, the average minimum, maximum and overall relative humidity among the zones for no occupancy condition during morning session are 52.2%, 53.6% and 52.8% respectively. When occupants are inside the workshop, the relative humidity is obviously increased among the zones. The average minimum, maximum and overall relative humidity increased to 57.5%, 59.7% and 58.6% respectively. Compared with standard, the relative humidity inside the workshop is within the recommended range by standard.

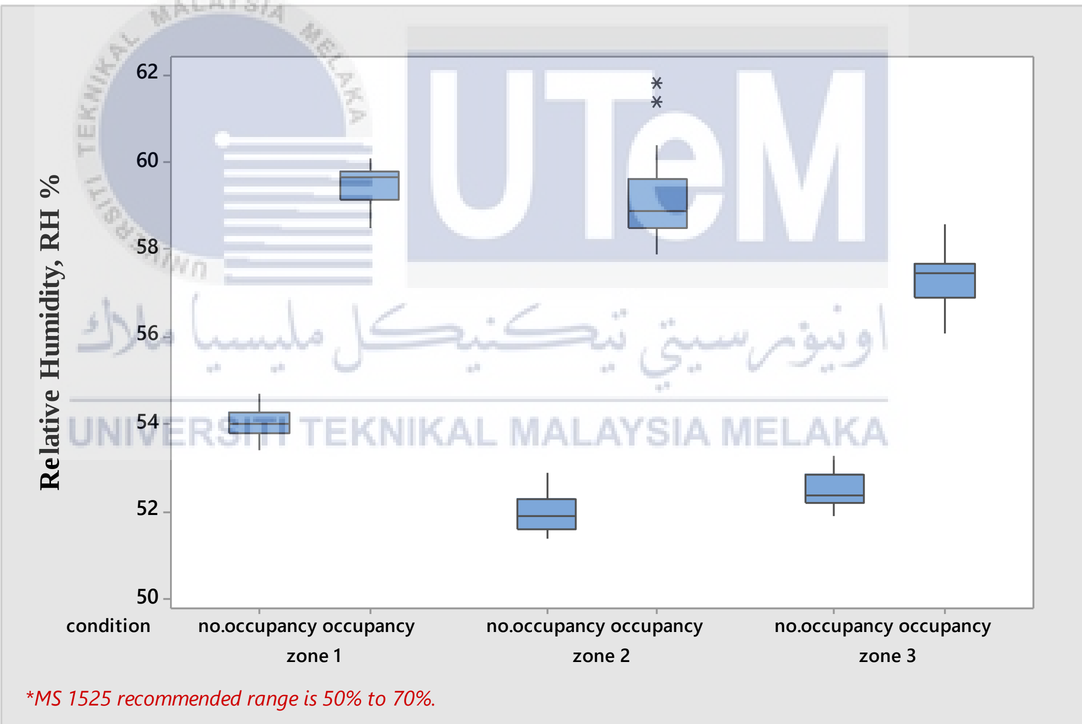


Figure 5.3: Relative humidity in machine workshop during morning

Relative humidity during afternoon session is shown in Figure 5.4. Based on Figure 5.4, the average minimum, maximum and overall relative humidity for no occupancy condition are 56.8%, 58.0% and 57.4% respectively. However, the average minimum, maximum and overall values of the relative humidity for occupancy condition are 55.8%, 57.5% and 56.7% respectively. Overall, the relative humidity for afternoon session is also complying with the recommended range by Malaysia Standard.

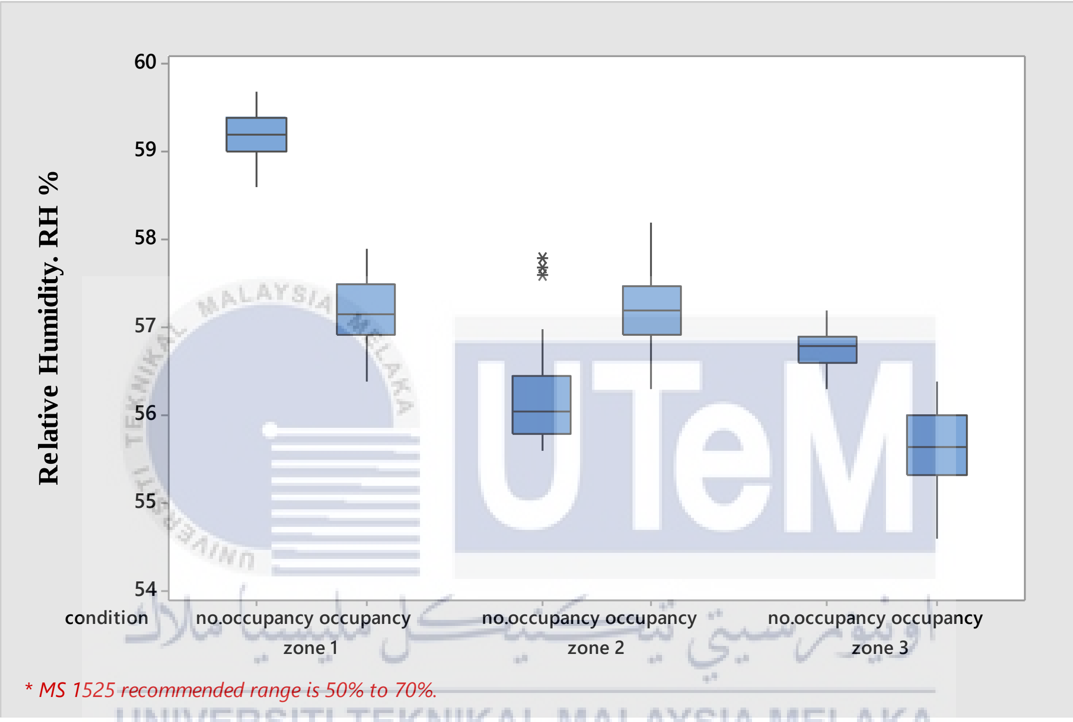


Figure 5.4: Relative humidity in machine workshop during afternoon

According to Malaysia Standard, the acceptable indoor air velocity range is between 0.15m/s to 0.50m/s. In this study, the indoor air velocity for morning session and afternoon session are shown in Figure 5.5 and 5.6 respectively. Based on Figure 5.5, the average minimum, maximum and overall air velocity for no occupancy condition are 0.09m/s, 0.38m/s and 0.20m/s respectively. Meanwhile, the average minimum, maximum and overall air velocity for occupancy condition is 0.017m/s, 0.18m/s and 0.10m/s respectively.

Referring to Figure 5.5, it can be seen that most of the air velocity recorded for occupancy condition is lower than the minimum recommended air velocity by Malaysia Standard. The air velocity for occupancy condition is lower than the minimum recommended air velocity by 0.05m/s and 33.3%. Meanwhile, the air velocity for no occupancy condition is within the recommended range by standard.

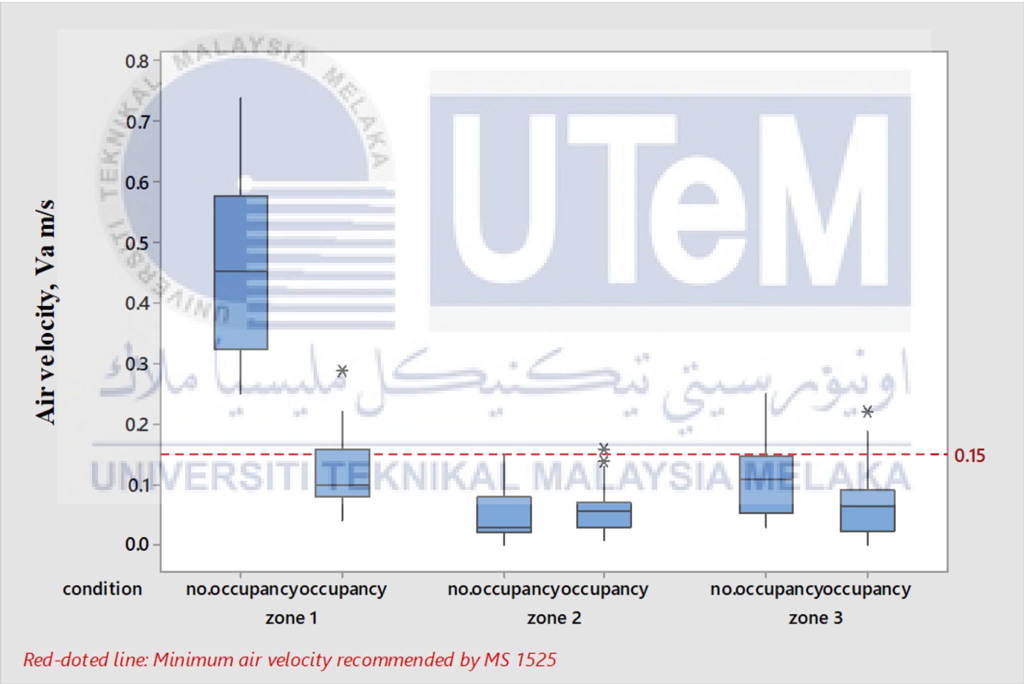


Figure 5.5: Indoor air velocity in machine workshop during morning

Based on Figure 5.6, the average minimum, maximum and overall indoor air velocity in afternoon session for no occupancy condition are around 0.04m/s, 0.31m/s and 0.16m/s respectively. However, the average minimum, maximum and overall indoor air velocity among the zones for occupancy condition are 0.01m/s, 0.31m/s and 0.12m/s respectively.

Compared with the standard, the indoor air velocity for no occupancy condition merely achieves the minimum recommended air velocity by standard. The overall air velocity for occupancy condition is lower than the minimum recommended air velocity by 0.03m/s and 20%.

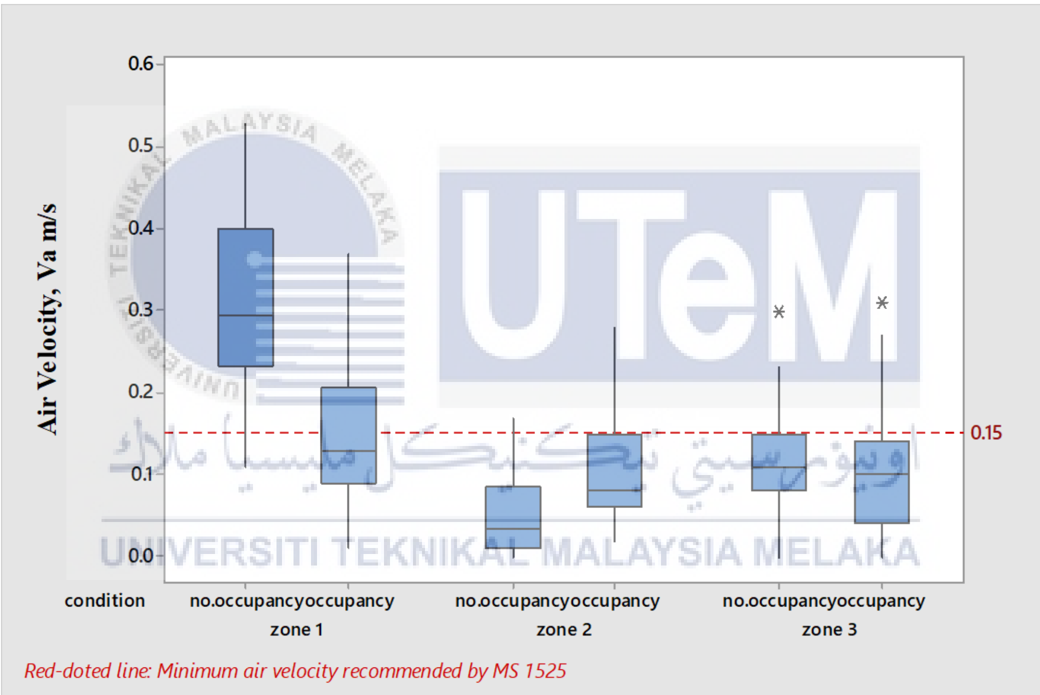


Figure 5.6: Indoor air velocity in machine workshop during afternoon

The average carbon dioxide level for morning session and afternoon session are shown in Figure 5.7 and 5.8 respectively. Based on Figure 5.7, the average carbon dioxide level among the zones for no occupancy condition is 404.7ppm. Moreover, it can be seen that the carbon dioxide level increased when occupants are inside the workshop. The average carbon dioxide level for occupancy condition is 533.8ppm.

According to ASHRAE Standard 62.1, the carbon dioxide level inside a building should not more than 700ppm above outdoor air levels. The carbon dioxide level in outdoor environment is usually around 300ppm to 400ppm. Hence, the maximum carbon dioxide level inside the building should not exceed the range between 1000ppm to 1100ppm. Compared with the obtained results, the carbon dioxide level for both conditions is much lower than the maximum carbon dioxide level allowed by the standard.

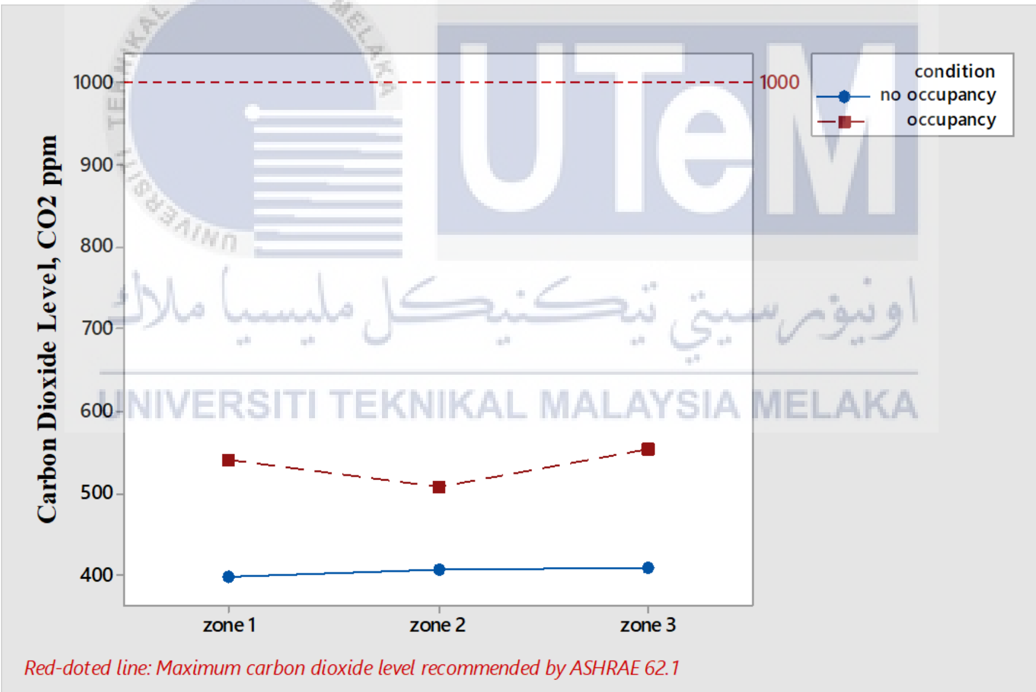


Figure 5.7: Carbon dioxide level in machine workshop during morning

Based on Figure 5.8, the average carbon dioxide level among the zones for no occupancy condition is 381.1ppm. It can be seen that the carbon dioxide level increased when occupants are inside the workshop. The average carbon dioxide level for occupancy condition is 546ppm. Compared the results with standard, it can be seen that the carbon dioxide level for both conditions is much lower than the maximum carbon dioxide level allowed by the standard.

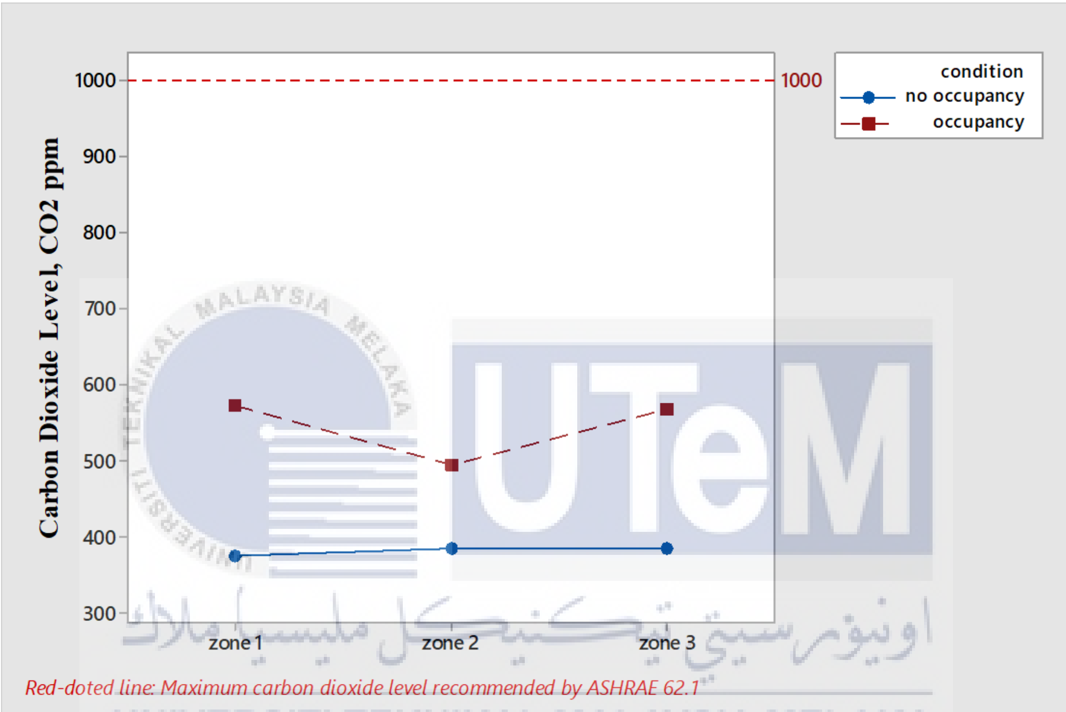


Figure 5.8: Carbon dioxide level in machine workshop during afternoon

The average concentration of particulate matter 2.5 for morning session and afternoon session are shown in Figure 5.9 and 5.10. Based on Figure 5.9, the average concentration of PM2.5 for no occupancy condition is 3.88x 10^{-5}µg/m^3. Meanwhile, the average concentration of PM2.5 for occupancy condition is 4.5x 10^{-5}µg/m^3.

According to ASHRAE Standard 62.1, the concentration of PM2.5 inside a building should not more than 15µg/m^3. Compared the obtained results with standard, it can be seen that the average concentration of PM2.5 for both conditions is far lower than maximum concentration allowed by the standard.

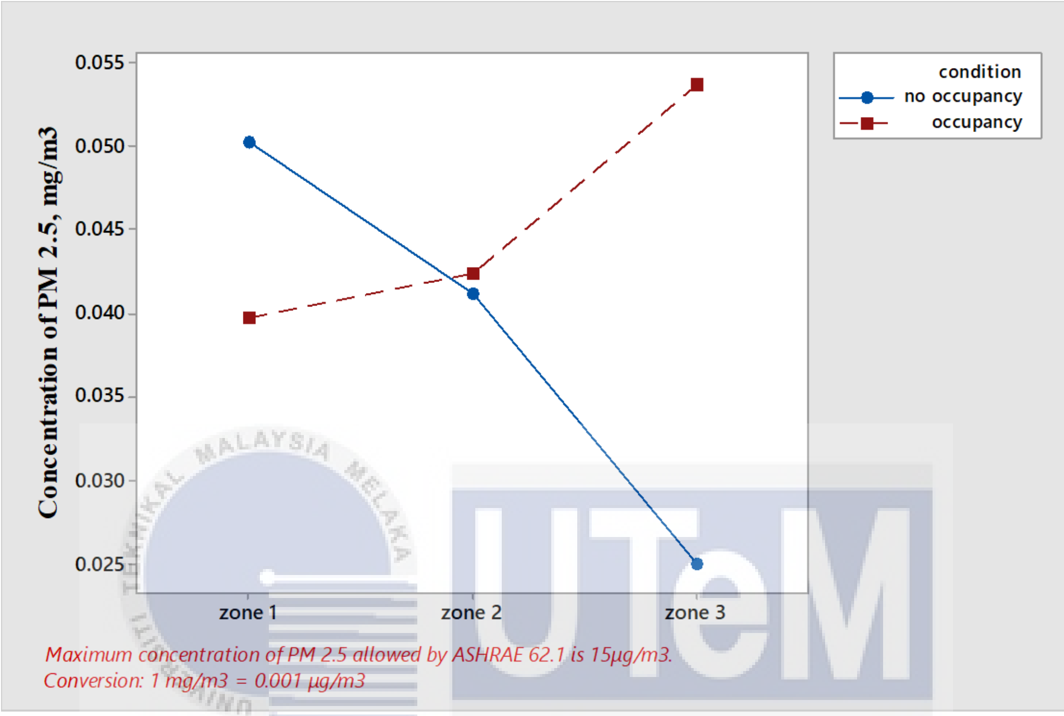


Figure 5.9: PM 2.5 concentration in machine workshop during morning

Based on Figure 5.10, the average concentration of PM2.5 for no occupancy condition is 5.83x 10^{-5}µg/m^3. Meanwhile, the average concentration of PM2.5 for occupancy condition is 4.04x 10^{-5}µg/m^3. Compared with standard, the average concentration of PM2.5 for both conditions is far lower than maximum concentration allowed by the standard.

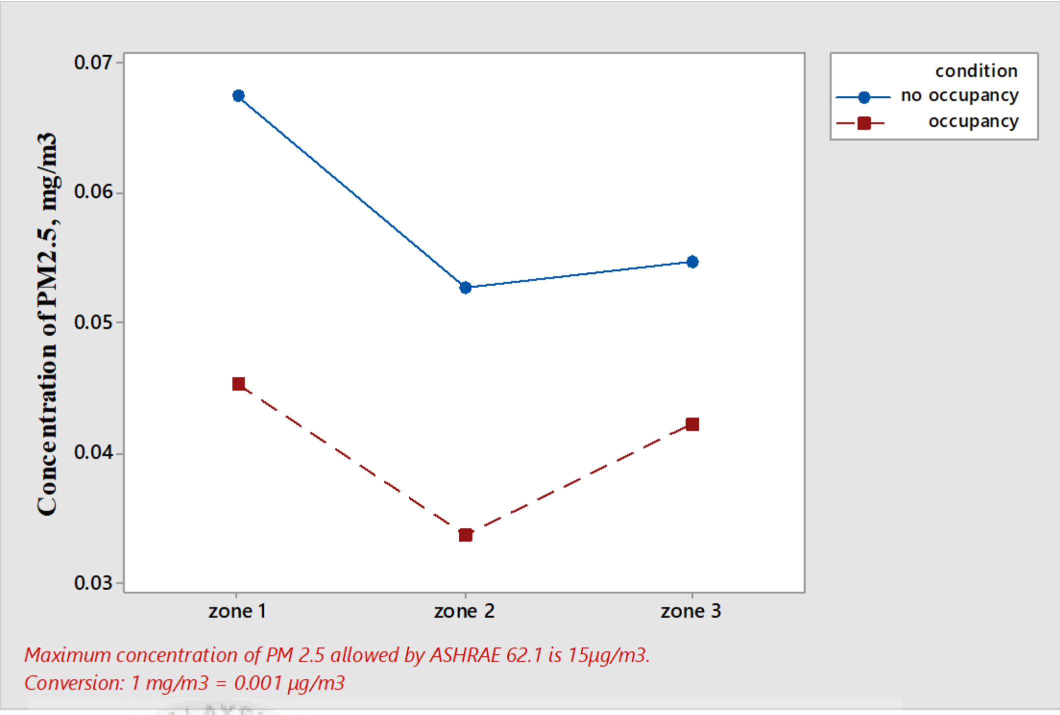


Figure 5.10: PM2.5 concentration in machine workshop during afternoon

The average concentration of PM10 for morning session and afternoon session are shown in Figure 5.11 and 5.12. Based on Figure 5.11, the average concentration of particulate matter 10 for no occupancy condition is 2.90x 10^{-5}µg/m^3. Meanwhile, the average concentration of PM10 for occupancy condition is 5.22x 10^{-5}µg/m^3.

According to ASHRAE Standard 62.1, the concentration of PM10 for indoor should not more than 50µg/m^3. Compared the obtained results with standard, it can be seen that the average concentration of PM10 for both conditions are lower than maximum concentration allowed by the standard.

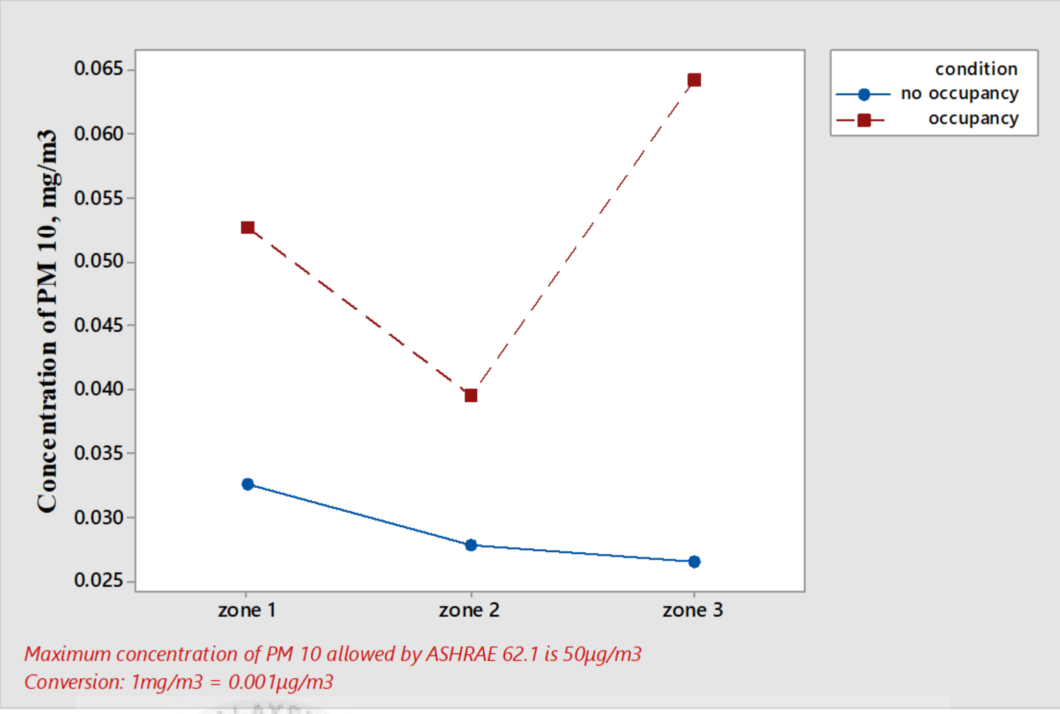


Figure 5.11: PM 10 concentration in machine workshop during morning

Based on Figure 5.12, the average concentration of PM10 for no occupancy condition is 5.26x 10^{-5}µg/m^3. Meanwhile, the average concentration of PM10 for occupancy condition is 4.04x 10^{-5}µg/m^3. Compared with standard, the average concentration of PM10 for both conditions are lower than maximum concentration allowed by the standard.

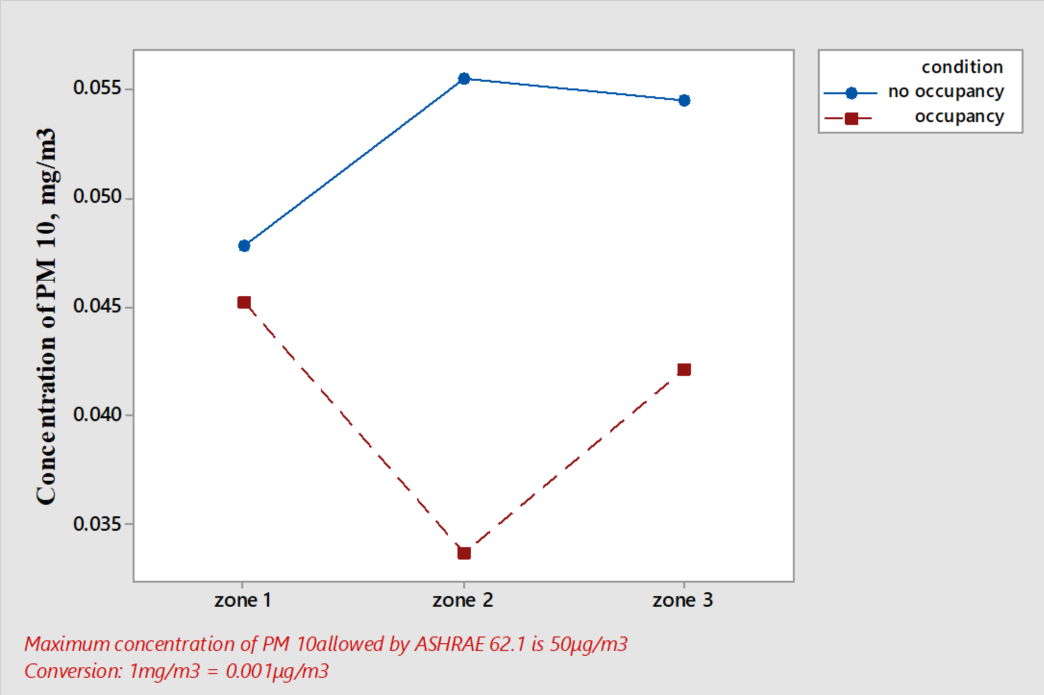


Figure 5.12: PM 10 concentration in machine workshop during afternoon

5.1.2 Welding Workshop (With Occupants and Without Occupants)

In this study, there are total 5 measurement zones in welding workshop. The measurement parameters are same as the parameters measured in machine workshop.

The air temperature in welding workshop during morning and afternoon sessions are shown in Figure 5.13and 5.14 respectively. Based on Figure 5.13, the average minimum, maximum and overall indoor air temperature among the zones for no occupancy condition are 28.0°C, 28.2°C and 28.11°C respectively. When there are occupants inside the workshop, the indoor air temperature obviously increased in each zones. The average minimum, maximum and overall air temperature increased to 31.16°C, 31.6°C and 31.37°C respectively.

According to ASHRAE Standard 55, the recommended indoor air temperature ranges from 20°C to 27°C. Compared with the results obtained, it found out that the overall indoor air temperature for no occupancy condition is slightly exceeded the maximum recommended temperature by 1.11°C and 4.1%. Meanwhile, the indoor air temperature for occupancy condition is exceeded the maximum recommended air temperature by 4.37°C and 16.2%.

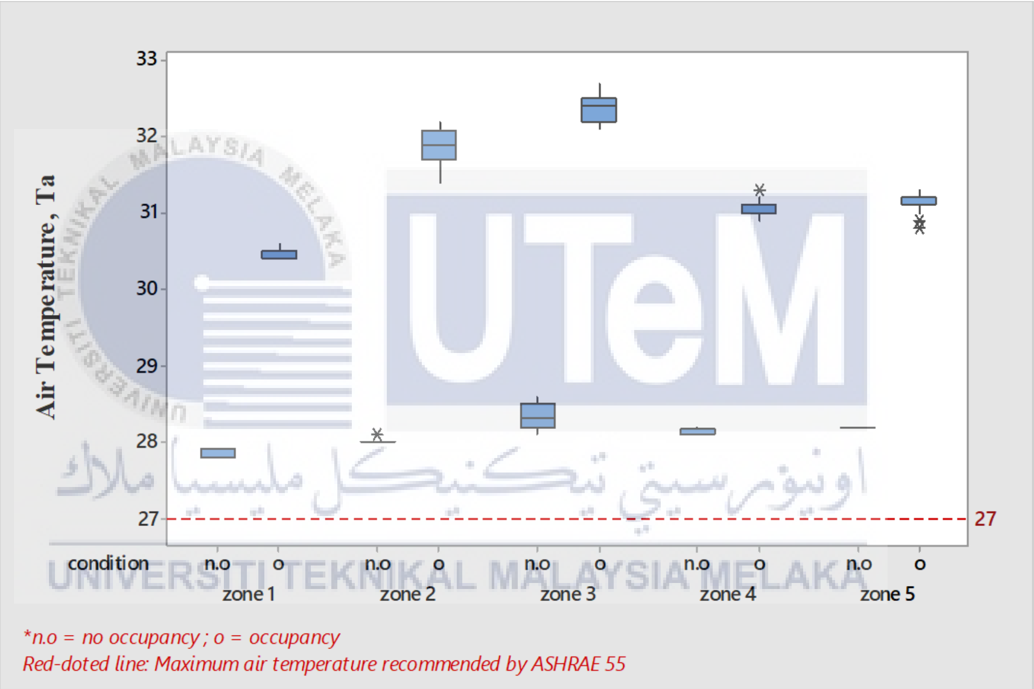


Figure 5.13: Indoor air temperature in welding workshop during morning

According to Figure 5.14, the average minimum, maximum and overall indoor air temperatures in the afternoon are 30.8°C, 31.0°C and 30.9°C respectively when no occupancy in the workshop. However, the indoor air temperature for occupancy condition increased about 2°C in each zones. The average minimum, maximum and overall indoor air temperatures increased to 32.7°C, 33.3°C and 33.0°C respectively.

Compared with recommended range by ASHRAE, it resulted that the overall indoor air temperature obtained for no occupancy condition is exceeded the maximum recommended temperature by 3.9°C and 14.4%. The indoor air temperature for occupancy condition is exceeded the maximum recommended temperature by 6°C and 22.22%.

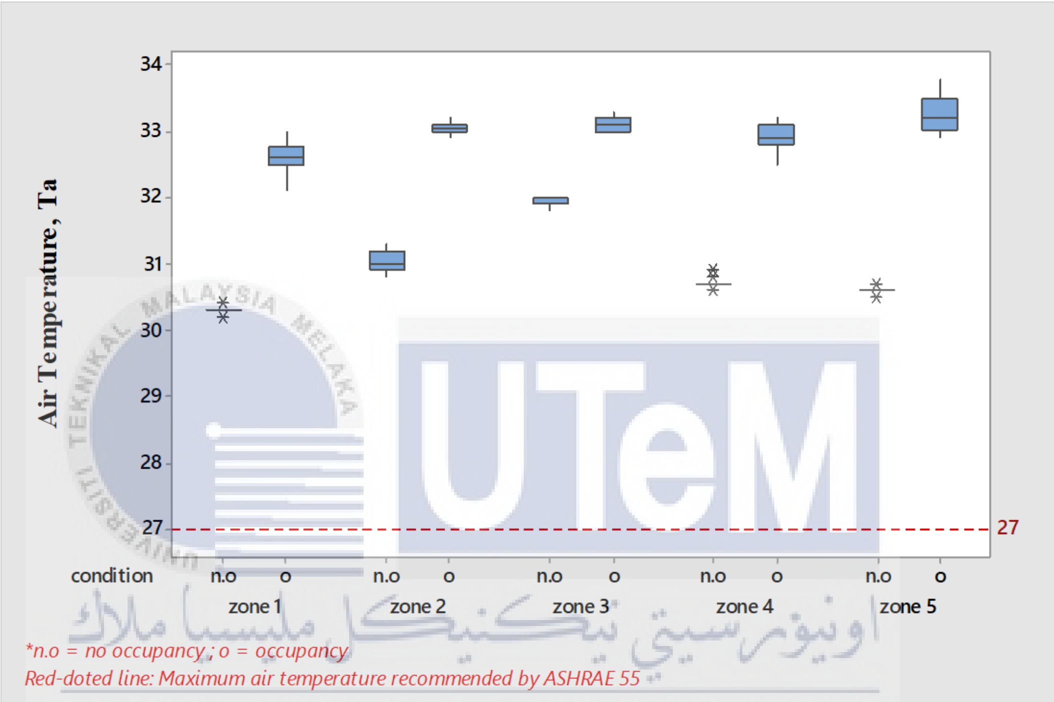


Figure 5.14: Indoor air temperature in welding workshop during afternoon

The indoor relative humidity level recommended by DOSH Standard is in range 40% to 70%. Based on Figure 5.15, the average minimum, maximum and overall relative humidity among the zones for no occupancy condition during morning session are 77.92%, 78.9% and 78.4% respectively. When occupants are inside the workshop, the average minimum, maximum and overall relative humidity decreased to 61.5%, 63.4% and 62.26% respectively. Compared with standard, the relative humidity inside the workshop for no occupancy condition is slightly higher than the maximum recommended relative humidity by 8.4%. Meanwhile, the relative humidity for occupancy condition is within the recommended range.

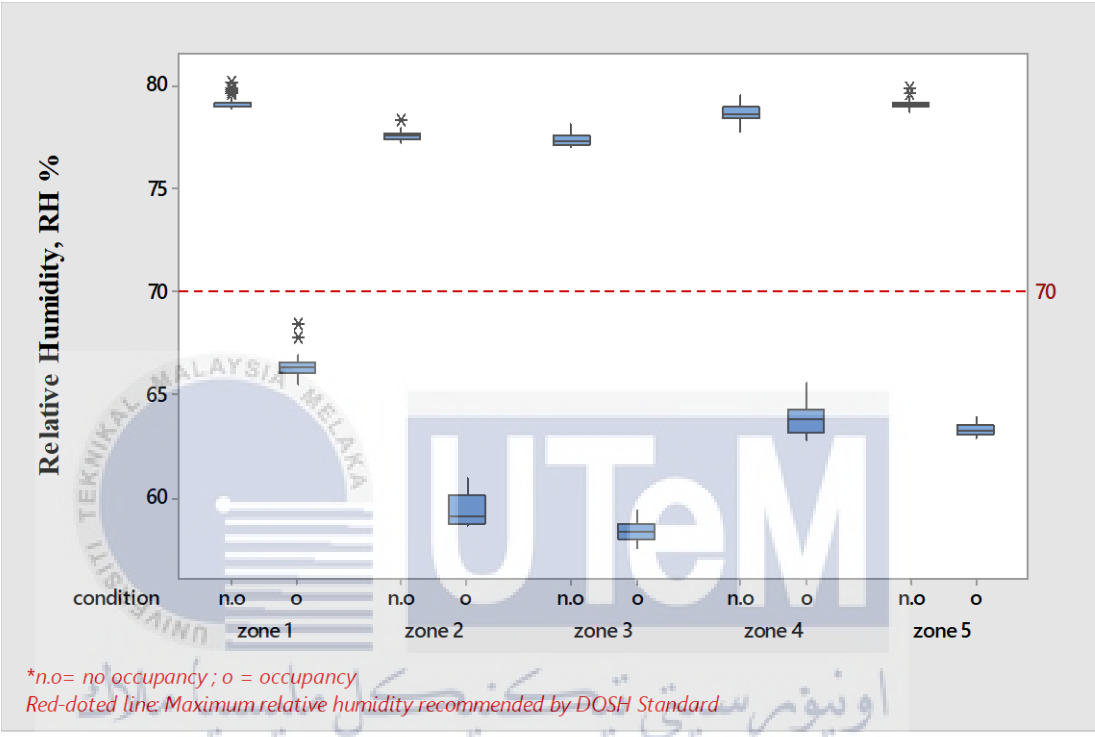


Figure 5.15: Relative humidity in welding workshop during morning

Relative humidity during afternoon session is shown in Figure 5.16. Based on Figure 5.16, the average minimum, maximum and overall relative humidity for no occupancy condition are 66.8%, 68.56% and 67.63% respectively. However, the average minimum, maximum and overall values of the relative humidity for occupancy condition are 54.86%, 57.74% and 56.3% respectively. In overall, the relative humidity in afternoon session for both conditions is within the recommended range by standard.

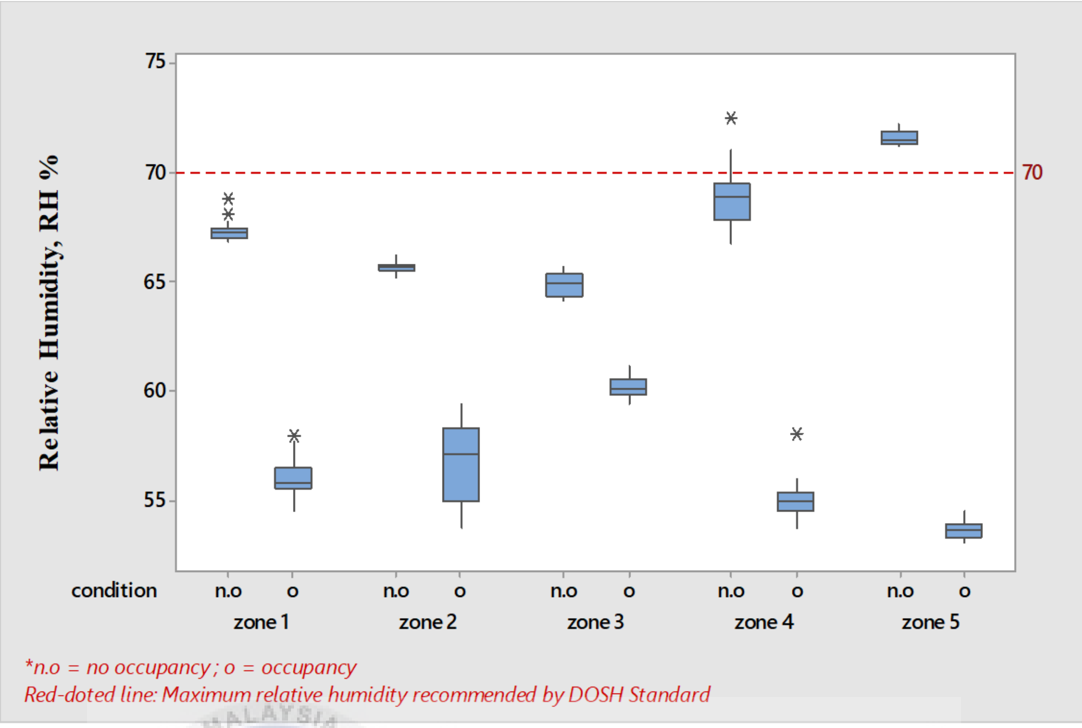


Figure 5.16: Relative humidity in welding workshop during afternoon

According to ASHRAE Standard 55, the recommended range for indoor air velocity is from 0.1m/s to 1.2m/s. In this study, the indoor air velocity for morning session and afternoon session are shown in Figure 5.17 and 5.18 respectively. Based on Figure 5.17, the average minimum, maximum and overall air velocity for no occupancy condition are 0.07m/s, 0.45m/s and 0.23m/s respectively. Meanwhile, the average minimum, maximum and overall air velocity for occupancy condition is 0.04m/s, 0.53m/s and 0.24m/s respectively. Compared with standard, the indoor air velocity for both conditions is within the recommended range.

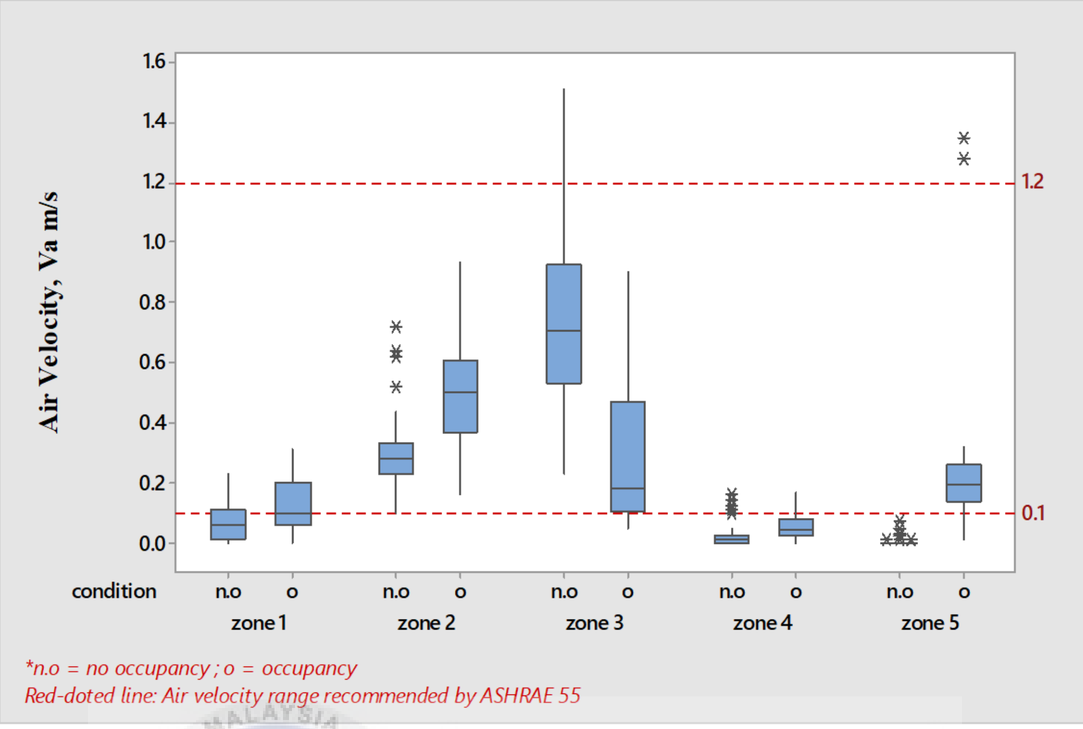


Figure 5.17: Indoor air velocity in welding workshop during morning

Based on Figure 5.18, the average minimum, maximum and overall indoor air velocity in afternoon session for no occupancy condition are around 0.06m/s, 0.25m/s and 0.14m/s respectively. However, the average minimum, maximum and overall indoor air velocity among the zones for occupancy condition are 0.0m/s, 0.28m/s and 0.13m/s respectively.

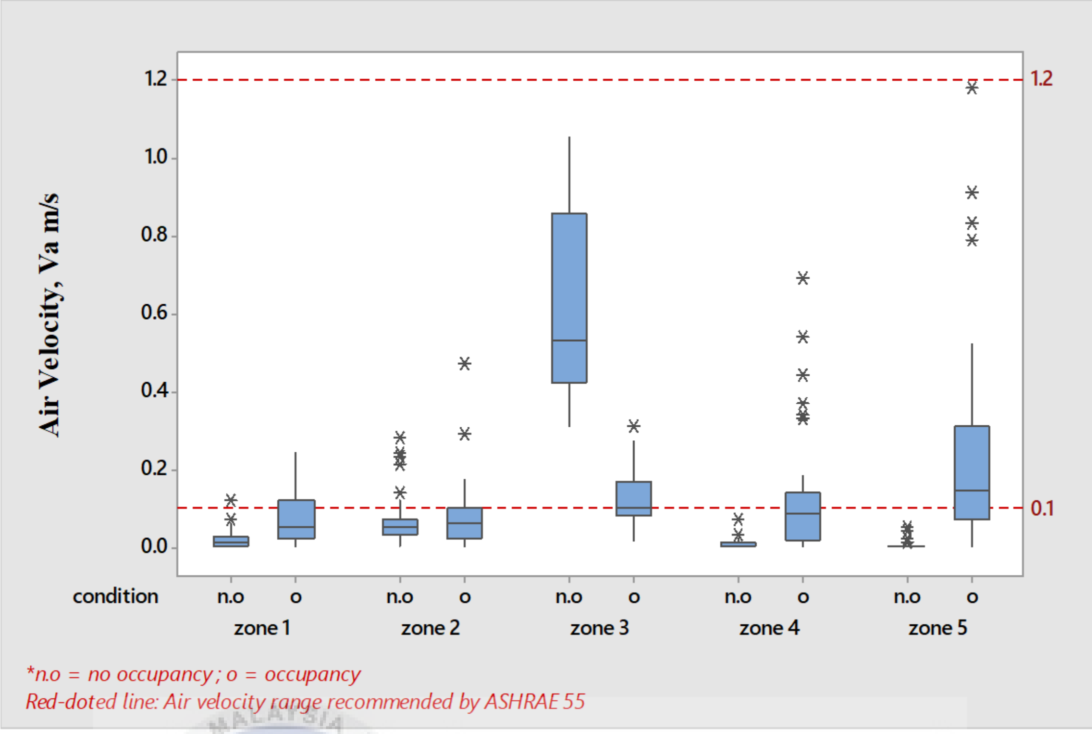


Figure 5.18: Indoor air velocity in welding workshop during afternoon

The average carbon dioxide level for morning session and afternoon session are shown in Figure 5.19 and 5.20 respectively. Based on Figure 5.19, the average carbon dioxide level among the zones for no occupancy condition is 346.7ppm. Moreover, it can be seen that the carbon dioxide level increased slightly when occupants are inside the workshop. The average carbon dioxide level for occupancy condition is 357.3ppm.

According to ASHRAE Standard 62.1, the indoor carbon dioxide level should not exceed the range between 1000ppm to 1100ppm. Compared with the obtained results, the carbon dioxide level for both conditions is much lower than the maximum carbon dioxide level allowed by the standard.

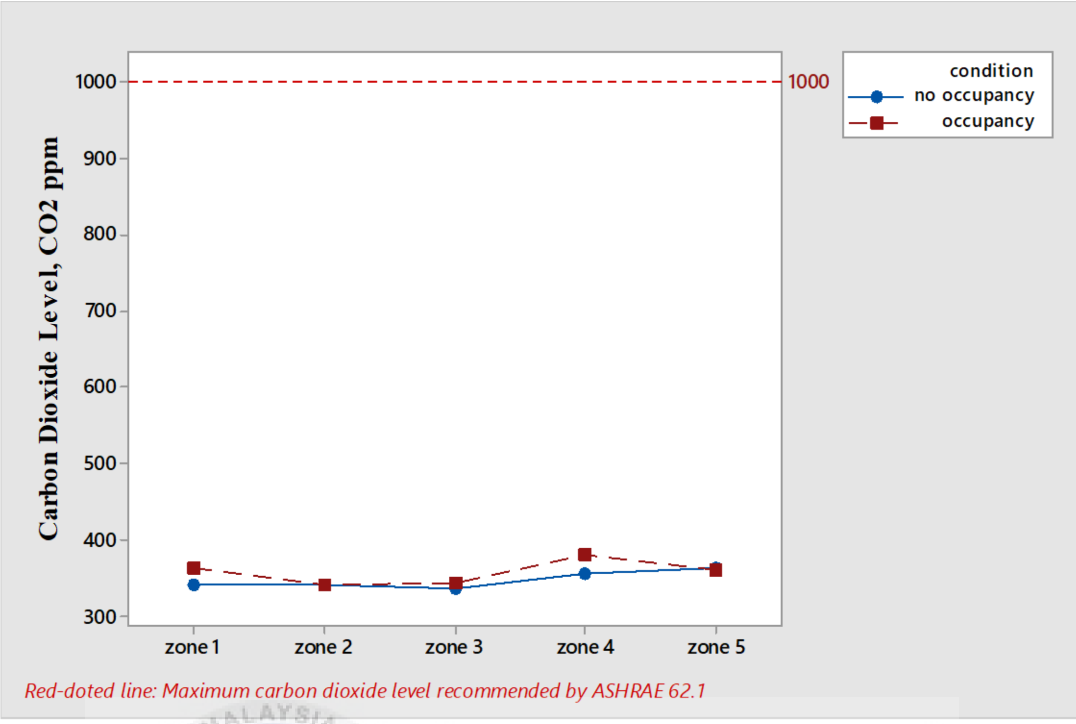


Figure 5.19: Carbon dioxide level in welding workshop during morning

Based on Figure 5.20, the average carbon dioxide level among the zones for no occupancy condition is 362.5ppm. It can be seen that the carbon dioxide level increased among the zones when occupants are inside the workshop. The average carbon dioxide level for occupancy condition is 390.7ppm. Compared the results with standard, it can be seen that the carbon dioxide level for both conditions is much lower than the maximum carbon dioxide level allowed by the standard.

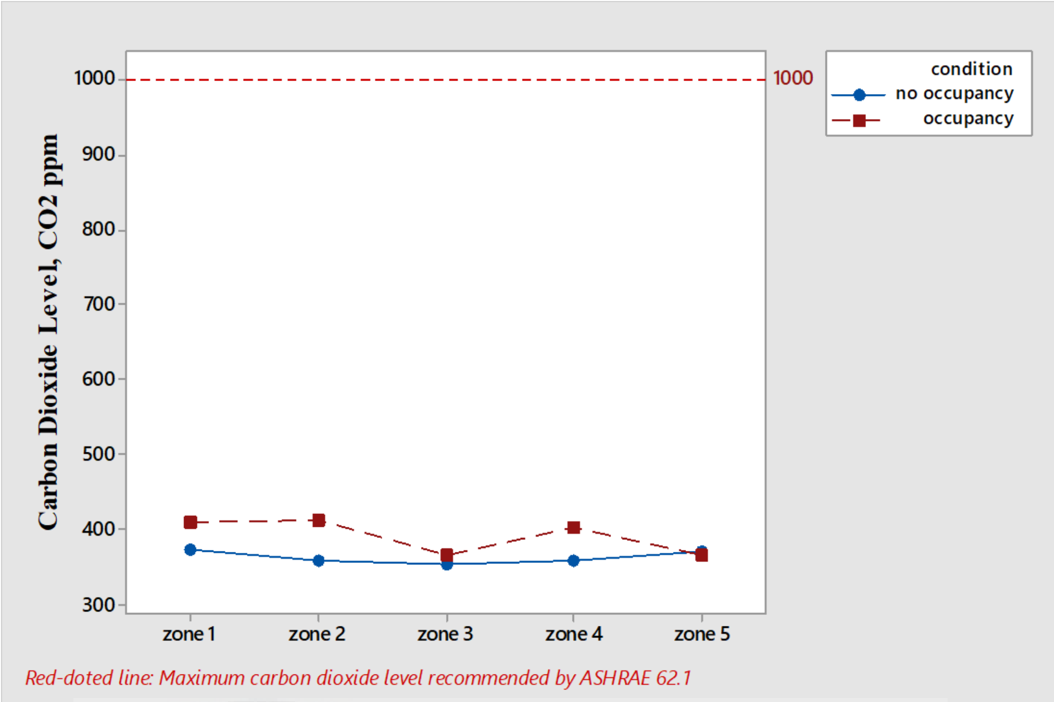


Figure 5.20: Carbon dioxide level in welding workshop during afternoon

The average concentration of PM2.5 for morning session and afternoon session are shown in Figure 5.21 and 5.22. Based on Figure 5.21, the average concentration of PM 2.5 for no occupancy condition is 5.62x 10^{-5}µg/m^3. Meanwhile, the average concentration of PM 2.5 for occupancy condition is obviously increased and showed a value of 1.8x 10^{-4}µg/m^3.

According to ASHRAE Standard 62.1, the concentration of PM 2.5 inside a building should not more than 15µg/m^3. Compared the obtained results with standard, it can be seen that the average concentration of PM 2.5 for both conditions is far much lower than maximum concentration allowed by the standard.

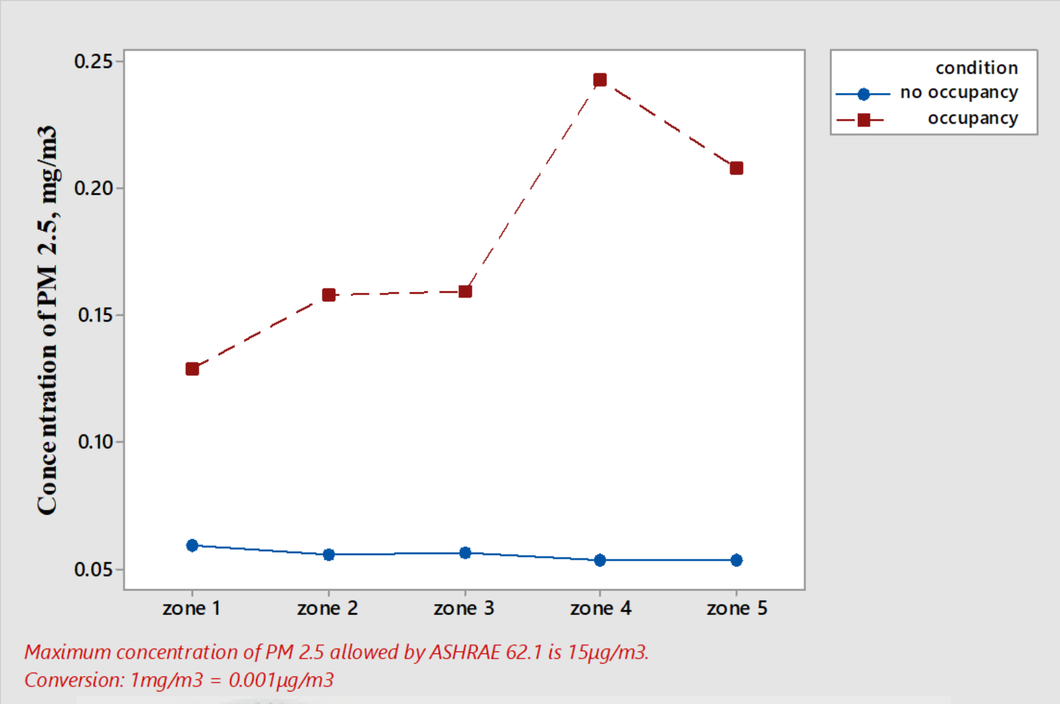


Figure 5.21: PM 2.5 concentration in welding workshop during morning

Based on Figure 5.22, the average concentration of PM 2.5 for no occupancy condition is 5.93x 10^{-5}µg/m^3. Meanwhile, the average concentration of PM 2.5 for occupancy condition is increased to 1.27x 10^{-4}µg/m^3. Compared with standard, the average concentration of PM 2.5 for both conditions is far lower than maximum concentration allowed by the standard.

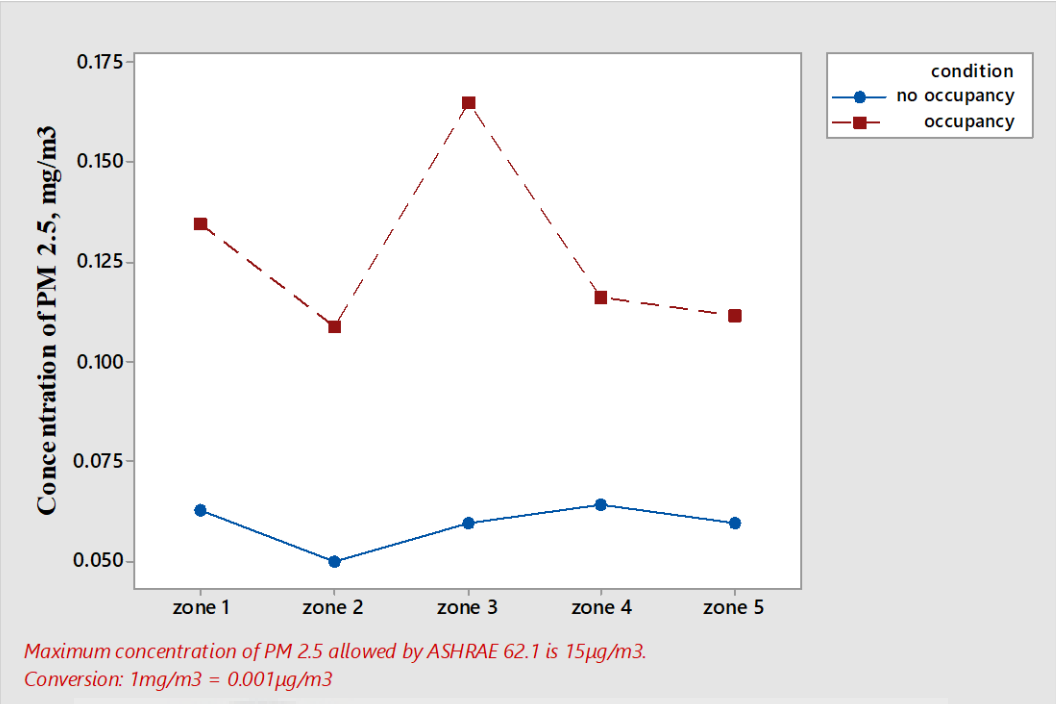


Figure 5.22: PM2.5 concentration in welding workshop during afternoon

The average concentration of PM 10 for morning session and afternoon session are shown in Figure 5.23 and 5.24. Based on Figure 5.23, the average concentration of PM 10 for no occupancy condition is 5.93x 10^{-5}µg/m^3. Meanwhile, the average concentration of PM 10 increased to 1.76x 10^{-4}µg/m^3 when occupants inside the workshop.

According to ASHRAE Standard 62.1, the concentration of PM 10 for indoor should not more than 50µg/m^3. Compared the obtained results with standard, it can be seen that the average concentration of PM 10 for both conditions is far lower than maximum concentration allowed by the standard.

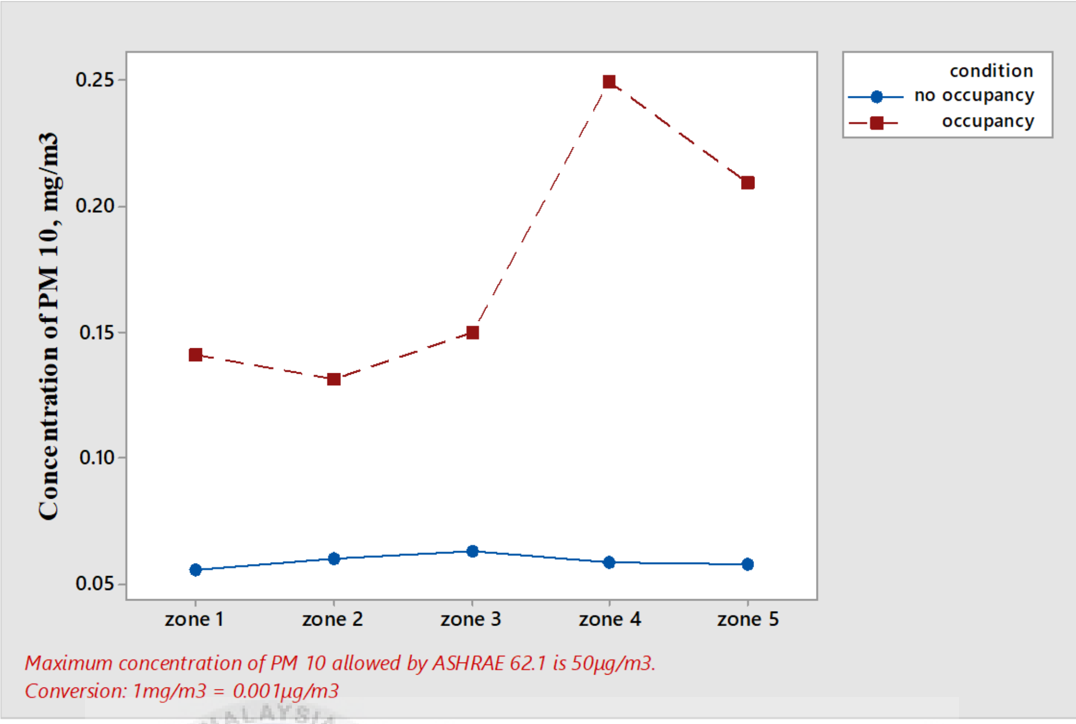


Figure 5.23: PM 10 concentration in welding workshop during morning

Based on Figure 5.24, the average concentration of PM 10 for no occupancy condition is 6.25x 10^{-5}µg/m^3. Meanwhile, the average concentration of PM 10 for occupancy condition is 1.57x 10^{-4}µg/m^3. Compared with standard, the average concentration of PM 10 for both conditions is far lower than maximum concentration allowed by the standard.

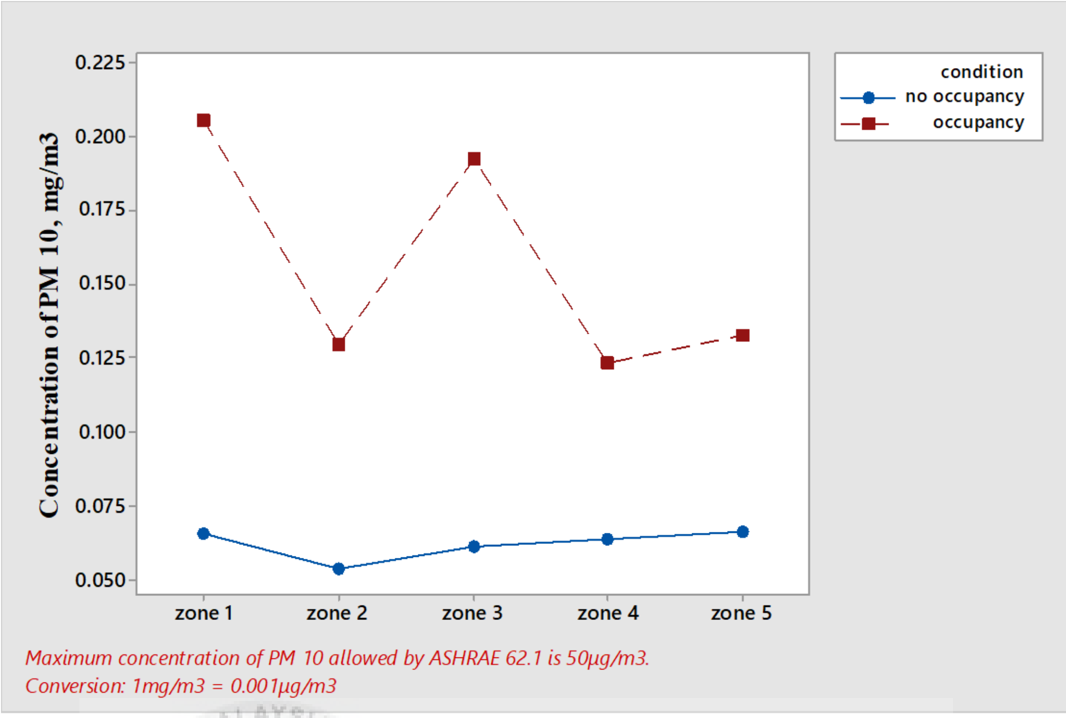


Figure 5.24: PM 10 concentration in welding workshop during afternoon

5.1.3 Overall Physical Measurement Results

Overall, the average readings for each of the parameters for both conditions in machine workshop and welding workshop are tabulated in Table 5.1 and 5.2 respectively.

Table 5.1: Physical measurement results in machine workshop

Parameters	Machine Workshop			
	Without occupants	Comment	With occupants	Comment
Indoor Air Temperature, Ta (°C)	M: 19.5°C A: 18.8°C	Not comply with MS	M: 20.9°C A: 20.8°C	Not comply with MS

Relative Humidity, RH (%)	M: 52.8% A: 57.4%	Comply with MS	M: 58.6% A: 56.7%	Comply with MS
Air Velocity, Va (m/s)	M: 0.20m/s A: 0.16m/s	Comply with MS	M: 0.10m/s A: 0.12m/s	Not comply with MS but acceptable
Predicted Mean Vote (PMV)	M: 0.42 A: 0.32	Comply	M: 0.65 A: 0.64	Not comply but acceptable
Predicted Percentage of Dissatisfied (PPD)	M: 8.98% A: 7.54%	Comply	M: 13.89% A: 13.61%	Not comply but acceptable
Carbon Dioxide Level (ppm)	M: 404.7ppm A: 381.1ppm	Comply with ASHRAE62.1	M: 533.8ppm A: 546.0ppm	Comply with ASHRAE62.1
Concentration of PM2.5 (µg/m3)	M: 3.88x 10^{-5}µg/m^3 A: 5.83x 10^{-5}µg/m^3	Comply with ASHRAE62.1	M: 4.5x 10^{-5}µg/m^3 A: 4.04x 10^{-5}µg/m^3	Comply with ASHRAE62.1
Concentration of PM10 (µg/m3)	M: 2.90x 10^{-5}µg/m^3 A: 5.26x 10^{-5}µg/m^3	Comply with ASHRAE62.1	M: 5.22x 10^{-5}µg/m^3 A: 4.04x 10^{-5}µg/m^3	Comply with ASHRAE62.1

*M= Morning session, A= Afternoon Session, MS= Malaysia Standard 1525: 2014

Table 5.2: Physical measurement results in welding workshop

Parameters	Welding Workshop			
	Without occupants	Comment	With occupants	Comment
Indoor Air Temperature, Ta (°C)	M: 28.11°C A: 30.9°C	Not comply with ASHRAE 55 but acceptable in tropics	M: 31.37°C A: 33.0°C	Not comply with ASHRAE 55
Relative Humidity, RH (%)	M: 78.4% A: 67.63%	Morning condition not comply with ASHRAE 55	M: 62.26% A: 56.3%	Comply with ASHRAE 55
Air Velocity, Va (m/s)	M: 0.23m/s A: 0.14m/s	Comply with ASHRAE 55	M: 0.24m/s A: 0.13m/s	Comply with ASHRAE 55
Predicted Mean Vote (PMV)	M: 1.67 A: 2.17	Not comply	M: 2.16 A: 2.43	Not comply
Predicted Percentage of Dissatisfied (PPD)	M: 60.08% A: 83.81%	Not comply	M: 83.02% A: 91.65%	Not comply
Carbon Dioxide Level (ppm)	M: 346.7ppm A: 362.5ppm	Comply with ASHRAE62.1	M: 357.3ppm A: 390.7ppm	Comply with ASHRAE62.1

Concentration of PM2.5 (µg/m3)	M: 5.62x 10^{-5}µg/m^3 A: 5.93x 10^{-5}µg/m^3	Comply with ASHRAE62.1	M: 1.8x 10^{-4}µg/m^3 A: 1.27x 10^{-4}µg/m^3	Comply with ASHRAE62.1
Concentration of PM10 (µg/m3)	M: 5.93x 10^{-5}µg/m^3 A: 6.25x 10^{-5}µg/m^3	Comply with ASHRAE62.1	M: 1.76x 10^{-4}µg/m^3 A: 1.57x 10^{-4}µg/m^3	Comply with ASHRAE62.1

*M= Morning session, A= Afternoon Session

Based on Table 5.1, the indoor air temperature for both conditions in machine workshop are lower than the minimum recommended air temperature and hence not comply with the Malaysia Standard. The indoor air temperature in morning and afternoon do not vary much due to the existence of air conditioners in the workshop. Air conditioners maintain the indoor temperature in cool condition by removing the heat to outdoor. However, the increment of air temperature when occupants are present is because of additional heat gains from occupants and machines.

The thermal comfort parameters recommended range by MS1525 are mainly for air conditioned building. In this study, welding workshop is non-air conditioned workshop. It considered as a natural ventilated workshop because it highly depend on air movement through openings such as door and roller shutter. Hence, ASHRAE Standard 55 is used to compare the measurement results obtained in welding workshop. Several studies on natural ventilated buildings used to compare their parameters results with ASHRAE Standard 55 (Mishra & Ramgopal, 2014), (Wong & Khoo, 2003) and (Liping & Hien, 2007). Based on Table 5.2, the indoor air temperature for both conditions in welding workshop is slightly higher than the maximum recommended air temperature and hence not complying with the standard.

As we all know, Malaysia is a tropical country with hot and humid climate. The annual average mean temperature is around 26.4℃ while the average daily maximum and minimum temperature is 34℃ and 23℃ respectively (Ahmad & Abdul-Ghani, 2011). There are many studies proved that the occupants were still in comfortable conditions even though the indoor air temperature in tropics natural ventilated buildings were outside of the comfort zone specified by ASHRAE 55. The neutral operative temperature for natural ventilated buildings in tropical countries is range from 27℃ to 31℃ (Kwong et al., 2014). Therefore, the indoor air temperature for no occupancy condition is still considered acceptable. The increment of air temperature when occupants are present can be explained by the heat released by the occupants and the heat released by the welding process inside the workshop. The indoor air temperature for occupancy condition is considered higher than the acceptable indoor air temperature in tropical regions.

Relative humidity can be defined as the ratio of amount of moisture present to the maximum amount of moisture that the air able to hold at its current temperature. Indoor humidity is important to be concerned as it highly affects human health. High humidity enhances the fungal growth and influences the amount of indoor allergens which could lead to Sick Building Syndrome (J. Wang et al., 2013). Table 5.1 shows that the relative humidity in machine workshop for both conditions is within the recommended range by Malaysia Standard. This implies that the humidity condition inside the machine workshop is good and will not affect occupants' health.

Based on Table 5.2, the relative humidity in welding workshop for both conditions are within the recommended range by ASHRAE 55 except the morning session for no occupancy condition.78.4% of relative humidity is higher than the maximum allowable relative humidity by standard. However, most of the natural ventilated buildings in tropics have relative humidity higher than 70% due to the hot and humid climates. The indoor condition of natural ventilated building is highly influenced by outdoor weather conditions as it relies on air movement through openings. Study showed that there is a strong correlation between air temperatures with relative humidity. As air temperature increases, the relative humidity decreases. Relative humidity increases when air temperature decreases (Nguyen & Schwartz, 2014). The outdoor weather condition was cloudy and going to be rain while the measurement was conducting in welding workshop. Hence, the high relative humidity during morning can be explained by the air temperature decreases and cause the relative humidity increases.

Based on Table 5.1, the air velocity for no occupancy condition is within the recommended range by Malaysia Standard. Meanwhile, the air velocity when occupants are present in the machine workshop is not within the recommended range by Malaysia Standard. However, it can still consider acceptable as the ASHRAE Standard 55 (2010) recommended range for air velocity is from 0.1m/s to 1.2m/s. Moreover, study mentioned that 0.1m/s to 1.5m/s of air velocity is considered acceptable for residents in tropical countries (Kwong et al., 2014). From this analysis, it can be seen that the indoor air velocity is lower when occupants are present. Research found that amount of heat dissipation from the occupant decreases as higher number of occupant present in a closed space with constant ventilation rate. This is because the number of occupants affect the changed in air-flow field and wind speed decreases (Fang et al., 2015). Hence, this can explained why the air velocity is lower for occupancy condition in machine workshop. Based on Table 5.2, the air velocity in welding workshop for both conditions is within the recommended range by ASHRAE 55.

ASHRAE Standard 55 recommended that the acceptable thermal environment for general comfort should have PMV index between range from -0.5 to 0.5 and PPD index less than 10%. In this study, the graphs of PPD as a function of PMV for both conditions during morning session and afternoon session are shown in APPENDIX.

Based on Table 5.1, the PMV and PPD indexes for morning session and afternoon session when no occupants around the machine workshop are 0.42; 8.98% and 0.32; 7.54% respectively. Compare with ASHRAE 55, the PMV and PPD indexes are within the recommended range. However, the PMV and PPD indexes for occupancy condition are 0.65; 13.89% and 0.64; 13.61% which slightly over the recommended range. This indicated that the machine workshop is observed closed to 'slightly warm' condition and approximate 14% of the occupants are expected to express dissatisfaction with the machine workshop environment. However, based on subjective assessment in this study, 95% of the occupants in the machine workshop are comfort with the environment condition and 100% of the occupants are satisfied with the temperature in the workshop. Moreover, there are findings stated that PMV index between -1 to 1 are compatible with ASHRAE standards and considered as comfort zone. PPD value that is more than 20% of the respondents is expected to express dissatisfaction. Besides, this study shows that the calculated thermal state of an indoor environment is not necessarily correlated to the occupant's desired thermal state (Ismail et al., 2012). Hence, the PMV and PPD index in machine workshop is considered acceptable indoor environment of the machine workshop is considered as a comfort zone when occupants are present.

Based on Table 5.2, the PMV and PPD indexes for both conditions in welding workshop are not satisfied with the recommended range by ASHRAE 55. This is due to the indoor air temperature is considered high when compared with standard and other studies.

Most of the studies mentioned that carbon dioxide level commonly used as a parameter to determine the indoor air quality of a building. Carbon dioxide level can used to evaluate the adequacy of the room ventilation (Telejko, 2017). Based on Table 5.1, the carbon dioxide level for both conditions in machine workshop are within the maximum allowable level recommended by ASHRAE 62.1. Based on Table 5.2, the carbon dioxide level for both conditions in welding workshop are also within the recommended level by ASHRAE 62.1. The carbon dioxide level increases when occupants are present. This is because occupants act as internal sources to produce carbon dioxide through exhaled air. Most of the studies showed that the carbon dioxide level increases when the rooms start to be occupied.

Concentrations of carbon dioxide as well as particulate matter (PM) are commonly used parameters in indoor air quality analysis. Particular matters are concerned as it can lead to occupants respiratory problems such as asthma and lung disease. Based on Table 5.1 and 5.2, the concentration of PM 2.5 and PM 10 for both conditions in machine workshop and welding workshop is far below the maximum value allowed by ASHRAE 62.1. Several studies mentioned that the factors that influence the concentrations of air contaminants in a closed room included occupants' activities inside the room, emissions from existing equipment, number of occupants, ventilation systems and the outdoor environment (Saraga et al., 2011). Concentration of particulate matter is depend on number of occupants as particulate matter can directly be released from occupants' clothes and shoes as well as hair (Razali et al., 2015). Besides, study mentioned that the increased fraction at particles sizes more than 1µm was highly related with the number of occupants and their activities that causing the particles resuspension(Chatoutsidou et al., 2015). Low concentration of particulate matters in this study can be explained by the number of occupants in both workshops are considered less and hence their movement around the workshop not much influence to the resuspension of dust particles.

In summary, the results in Table 5.1 indicated that the overall environment condition in machine workshop is considered acceptable. The indoor air temperature can be increased in order to achieve a better thermal comfort and enhance the indoor environment quality. Based on Table 5.2, the high value in PMV and PPD indexes are due to the high temperature in welding workshop. The indoor air temperature has to be decreased in order to achieve better indoor environment quality.

5.2 SUBJECTIVE ASSESSMENT

In this study, questionnaire surveys are conducted during the objective measurement session in the workshop. The subjective assessment is carried out during 8th March 2018 in machine workshop and 5th April 2018 in welding workshop. There are total 20 respondents in machine workshop and 20 respondents in welding workshop. The survey results are shown in tables below. Thermal sensation votes in both workshops are shown in Table 5.3.

Table 5.3: Occupant's thermal sensation vote for both workshops

ASHRAE Scale		Machine Workshop			Welding Workshop		
		Morning	Afternoon	Total	Morning	Afternoon	Total
Hot	+3	0	0	0	2	7	9

Warm	+2	0	0	0	2	4	6
Slightly warm	+1	0	0	0	3	0	3
Neutral	0	0	0	0	2	0	2
Slightly cool	-1	5	7	12	0	0	0
Cool	-2	2	2	4	0	0	0
Cold	-3	1	3	4	0	0	0
Total				20			20

In this study, ASHRAE seven point scales are used to investigate occupants' perception towards the indoor environment of the workshops. According to ASHRAE Standard 55, the indoor environment is considered acceptable if 80% of the occupants voted for interval (-1, +1). Moreover, Fanger's theory mentioned that votes for interval (-1, +1) means that the thermal environment is acceptable while votes for intervals (-3,-2) and (+2, +3) describe the environment is not acceptable. Based on the results in Table 5.3, the frequency distribution of occupant's perception on the thermal environment of both workshops is shown in Figure 5.25.

Based on Figure 5.25, it can be seen that results were obviously skewed towards the left in machine workshop. 60% of the respondents voted for slightly cool while 20% of the respondents voted for cool and cold respectively. There is no respondent voted for slightly warm, warm and hot in machine workshop. On the other hand, results were obviously skewed towards the right in welding workshop. 45% of respondents voted for hot in welding workshop and 30% of the respondents voted for warm. There are only 15% of the respondents voted for slightly warm and 10% of the respondents voted for neutral.

Results in Figure 5.25 indicates that less than 80% of the respondents in both workshops voted for the central three categories (slightly cool, neutral, and slightly warm). This finding shows that both workshops were not in thermal acceptable conditions.

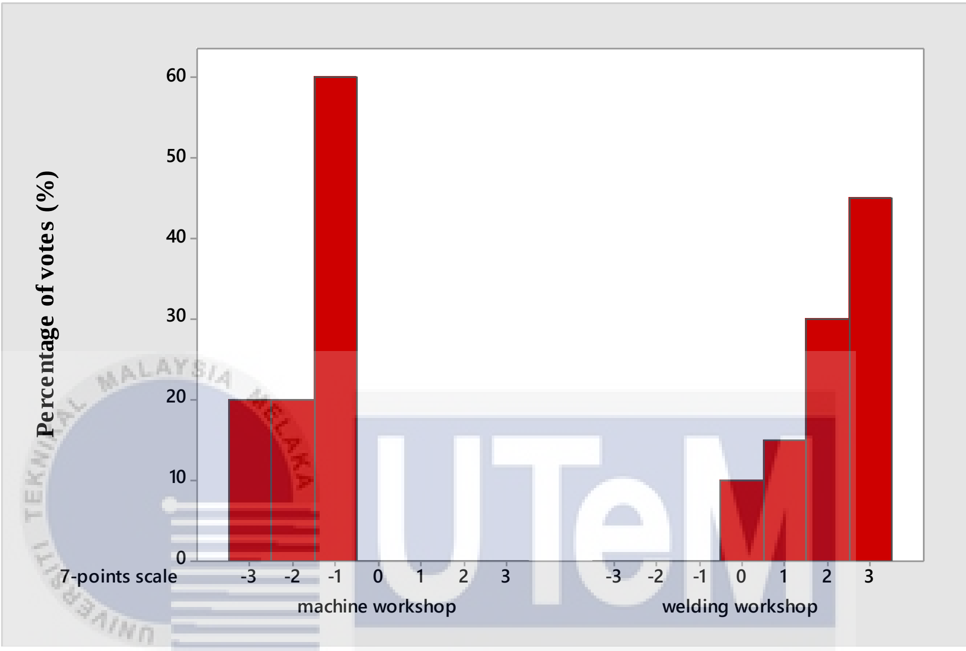


Figure 5.25: Frequency distribution of occupant’s thermal sensation based on ASHRAE 7-points scale

Table 5.4 shows the relative humidity sensation scale in both workshops. Based on the results in Table 5.4, the frequency distribution of occupants’ perception on the humidity level in both workshops is shown in Figure 5.26.

Table 5.4: Occupant's relative humidity sensation vote for both workshops

ASHRAE Scale		Machine Workshop			Welding Workshop		
		Morning	Afternoon	Total	Morning	Afternoon	Total
Very dry	+3	0	0	0	0	1	1
Dry	+2	0	2	2	2	3	5
Slightly dry	+1	3	0	3	3	4	7
Neutral	0	4	5	9	3	0	3
Slightly humid	-1	1	2	3	1	1	2
Moderately humid	-2	0	2	2	0	1	1
Humid	-3	0	1	1	0	1	1
Total				20			20

Based on Figure 5.26, 45% of the respondents voted for neutral and same amount of 15% respondents voted for slightly humid and slightly dry in machine workshop. There are only 5% of the respondents voted for humid while 10% of respondents voted for moderately humid and dry respectively. On the other hand, 15% of respondents voted for neutral and 35% of respondents voted for slightly dry in welding workshop. 25% of the respondents voted for dry condition. 10% of the respondents voted for slightly humid while 5% of the respondents voted for humid, moderately humid and very dry respectively.

Results in Figure 5.26 indicates that majority of the respondents expressed their votes (-1, 0 and +1) in machine workshop (75%) and welding workshop (60%) respectively.

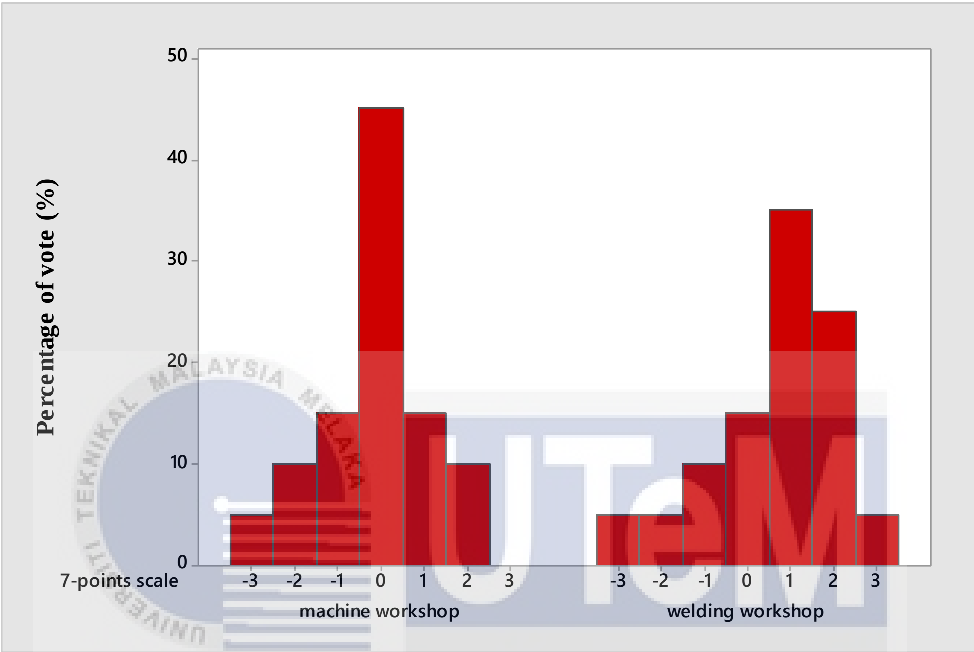


Figure 5.26: Frequency distribution of occupant's relative humidity sensation based on ASHRAE 7-points scale

Table 5.5 shows the air velocity sensation scale in both workshops. Based on the results in Table 5.5, the frequency distribution of occupants' perception on the air flow in both workshops is shown in Figure 5.27.

Table 5.5: Occupant's air velocity sensation vote for both workshops

ASHRAE Scale		Machine Workshop			Welding Workshop		
		Morning	Afternoon	Total	Morning	Afternoon	Total
Very still	+3	0	0	0	0	0	0
Moderately still	+2	0	0	0	6	0	6
Slightly still	+1	2	6	8	1	6	7
Neutral	0	4	6	10	0	3	3
Slightly draughty	-1	2	0	2	2	1	3
Moderately draughty	-2	0	0	0	0	1	1
Very draughty	-3	0	0	0	0	0	0
Total				20			20

Based on Figure 5.27, 50% of the respondents voted for neutral and 40% of the respondents voted for slightly still in machine workshop. There are only 10% of the respondents voted for slightly draughty in machine workshop. On the other hand, 35% of respondents voted for slightly still and 30% of respondents voted for moderately still in welding workshop. 15% of the respondents voted for neutral and slightly draughty respectively. There are only 5% of the respondents voted for moderately draughty in welding workshop.

Results in Figure 5.27 indicates that all of the respondents expressed their votes (-1, 0 and +1) in machine workshop. This implies that the air velocity in machine workshop is within acceptable condition. Meanwhile, majority 65% of the respondents voted interval (-1, 0, +1) in welding workshop and this shows that the overall air velocity condition in both workshops is considered acceptable.

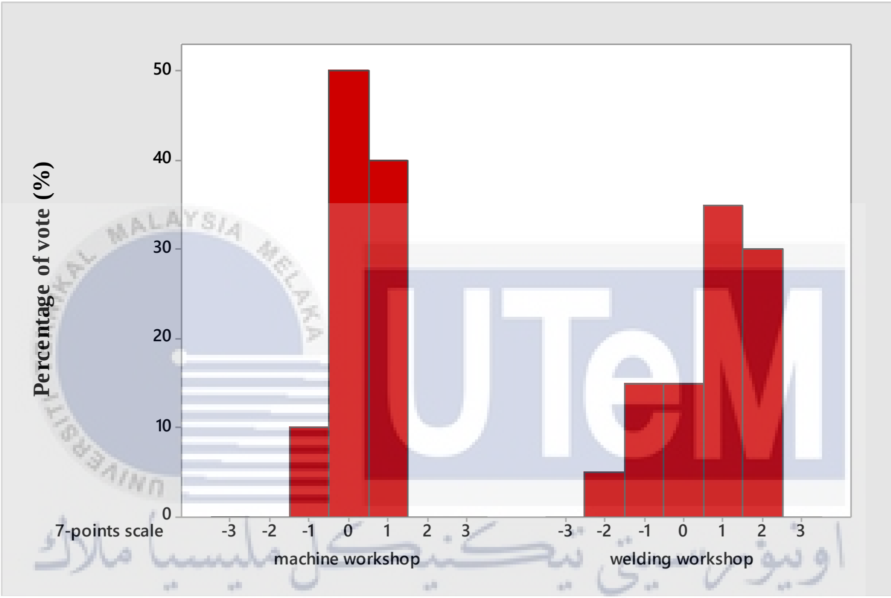


Figure 5.27: Frequency distribution of occupant's air velocity sensation based on ASHRAE 7-points scale

Table 5.6 shows the occupant's perception votes for odor in both workshops. Based on the results in Table 5.6, the frequency distribution of occupants' perception on the odor in both workshops is shown in Figure 5.28.

Table 5.6: Occupant's odor perception votes for both workshops

Scale		Machine Workshop			Welding Workshop		
		Morning	Afternoon	Total	Morning	Afternoon	Total
No odor	0	0	0	0	2	1	3
Weak odor	1	1	0	1	1	2	3
Moderate odor	2	7	12	19	5	8	13
Strong odor	3	0	0	0	1	0	1
Very strong odor	4	0	0	0	0	0	0
Overpowering odor	5	0	0	0	0	0	0
Total				20			20

Based on Figure 5.28, 95% of the respondents voted for moderate odor and only 5 % of respondents voted for weak odor. On the other hand, 15% of respondents voted for no odor and weak odor in welding workshop. 65% of respondents voted for moderately odor and only 5 % of respondents voted for strong odor.

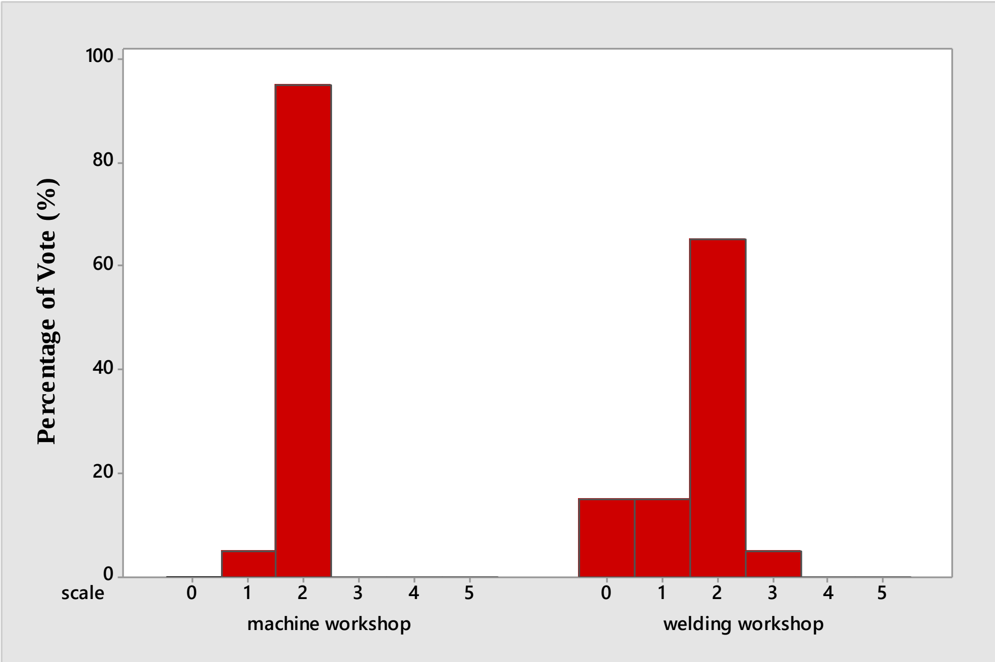


Figure 5.28: Frequency distribution of occupant's odor perception

Table 5.7 shows the respondents' satisfaction with the indoor air temperature of the workshops. Based on Figure 5.29, all of the respondents are satisfied with the indoor air temperature of the machine workshop. Meanwhile, 85% of the respondents are not satisfied with the indoor air temperature of welding workshop and only 15% are satisfied with the air temperature.

Table 5.7: Occupant's satisfaction on air temperature in both workshops

Satisfaction	Machine Workshop			Welding Workshop		
	Morning	Afternoon	Total	Morning	Afternoon	Total
Yes	8	12	20	1	2	3
No	0	0	0	8	9	17
Total			20			20

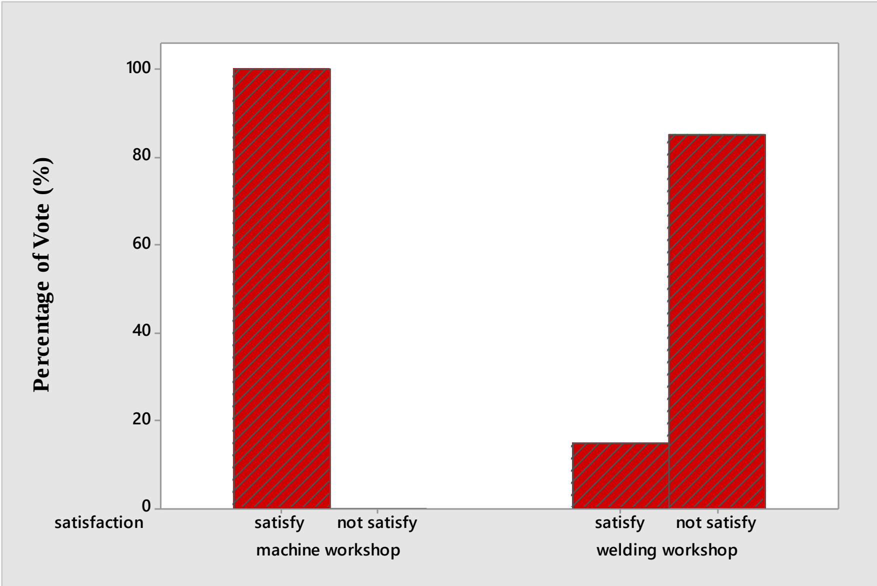


Figure 5.29: Frequency distribution of occupant's satisfaction on air temperature in both workshops

Table 5.8 shows the respondents' overall comfort perception on the indoor environment of the workshops. Based on Figure 5.30, 95% of the respondents are comfort with the environment in machine workshop and only 5% of the respondents are slight discomfort. Meanwhile, only 15% of the respondents are comfort with the environment in welding workshop and 65% of the respondents are slightly discomfort. 15% of the respondents are discomfort and 5% of respondents are very discomfort with the environment.

Table 5.8: Occupant's overall comfort perception on both workshops

Comfort Level	Scale	Machine Workshop			Welding Workshop		
		Morning	Afternoon	Total	Morning	Afternoon	Total
Comfort	0	8	11	19	2	1	3

Slightly discomfort	1	0	1	1	5	8	13
Discomfort	2	0	0	0	2	1	3
Very discomfort	3	0	0	0	0	1	1
Total				20			20

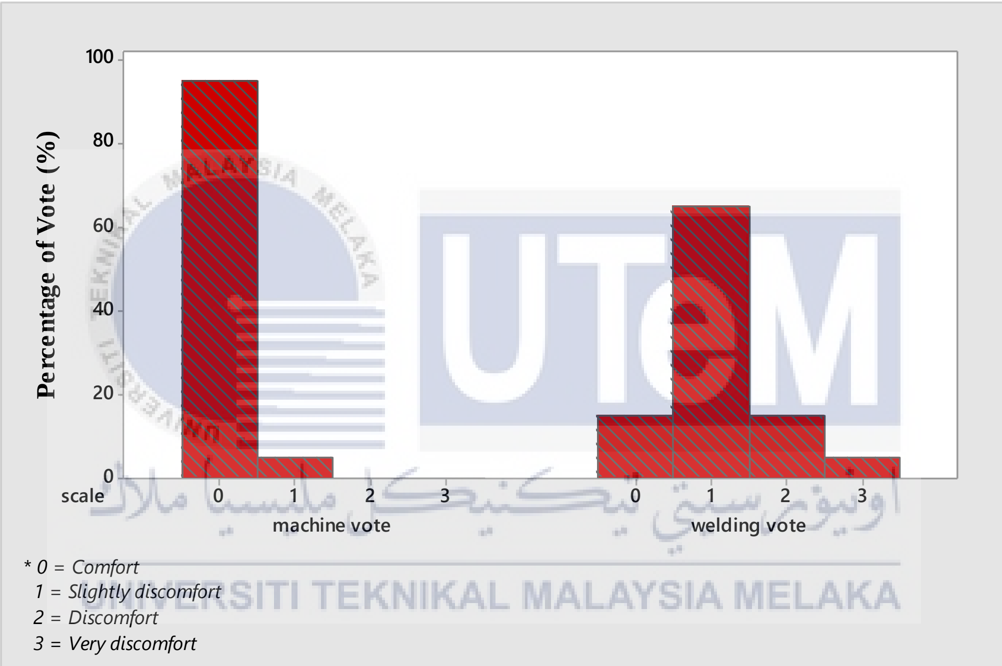


Figure 5.30: Frequency distribution of occupant's overall comfort perception on both workshops

5.2.1 Comparison between objective measurement and questionnaire

Based on measurement results shown in Table 5.1, the air temperature in machine workshop is around 20.8°C when occupants are present. From the subjective measurement results shown in Figure 5.25, the thermal condition in machine workshop is not acceptable due to less than 80% of the respondents voted for the central three categories (slightly cool, neutral, and slightly warm). However, results in Figure 5.29 showed that 100% of the respondents satisfied with the temperature in machine workshop. Based on the overall comfort perception, 95% of the respondents comfort with the environment condition in machine workshop. This situation show that the occupants are still in comfort condition even though the indoor temperature is not within the recommended range by Malaysia Standard. Research noted that the thermal comfort for occupants in tropics usually not depend on theoretical neutrality. Occupants in tropical regions are more satisfied with slightly colder thermal environment. Moreover, thermal requirements depend on the occupants' personal factors such as their age, gender, metabolic rates and clothing types (Sattayakorn et al., 2017). In this study, the clo value and metabolic rate for both workshops are estimated in Deltalog10 software as shown in Table 5.9 below. From Table 5.9, total clo value is 0.87 and the metabolic rate as a milling machine operator is 1.89 met or 110 W/m^2. The age of occupants in machine workshop is range from 20 to 22. Hence, this can explained that the indoor temperature of 20.8°C in machine workshop is considered comfort condition for the occupants that require lower temperature due to their personal factors.

Table 5.9: Occupant's clo value and metabolic rates in both workshops

	Machine Workshop	Welding Workshop
Clo	0.87	0.83
Met	1.89	1.72

Based on measurement results in Table 5.2, the indoor air temperature in welding workshop during morning session and afternoon session is 31.37℃ and 33.0℃ respectively. After comparison, the indoor air temperature is considered high and not within the recommended range. Based on Figure 5.25, less than 80% of the respondents voted for interval (-1, 0, +1). Results in Figure 5.29 also showed that 85% of the respondents are not satisfied with the air temperature in welding workshop. Moreover, results in Figure 5.30 show that most of the respondents are feeling discomfort with the environment in welding workshop. Hence, the hot thermal condition in welding workshop has to be improved to provide a more comfort environment for occupants.

Based on the measurement results in Table 5.1, the relative humidity in machine workshop for occupancy condition is within the recommended range by standard. From subjective assessment, 75% of the respondents voted for neutral, slightly humid and slightly dry as their humidity perception in machine workshop. 100% of the respondents are comfort with the environment condition in machine workshop. This indicated that the occupants accept the current humidity condition in machine workshop.

Based on measurement results in Table 5.2, the relative humidity in welding workshop for occupancy condition is within recommended range by standard. From subjective assessment, 60% of the respondents voted for neutral, slightly humid and slightly dry as their humidity perception in welding workshop. This indicated that majority of the occupants accept the humidity condition in welding workshop.

Based on measurement results in Table 5.1, the air velocity in machine workshop is around 0.1m/s. The air velocity is considered acceptable when compared with ASHRAE 55. From the subjective assessment, all of the respondents voted for neutral, slightly still and slightly draughty. This indicated that the air velocity in machine workshop is within acceptable condition. On the other hand, measurement results in Table 5.2 showed that the air velocity in welding workshop is comply with ASHRAE 55. From the subjective assessment, majority 65% of the respondents voted for neutral, slightly still and slightly draughty. This implies that the overall air velocity condition is considered acceptable.

Based on measurement results in Table 5.1, the indoor air quality parameters such as carbon dioxide level, concentration of PM 2.5 and PM 10 in machine workshop is far below the maximum allowable level by ASHRAE 62.1. From subjective assessment, 95% of the respondents voted for moderate odor in machine workshop while only 5 % of the respondents voted for weak odor. Since the indoor air quality parameters are satisfied with the standard, occupants in machine workshop felt moderate odor is due to the indoor air circulated around the workshop. Research found that most of the rooms with split air-conditioner do not have mechanical ventilation system and outdoor air exchange only depend on infiltration process. Insufficient of ventilation requirement caused the bad dispose of the current air in a room (Putra et al., 2017). In this study, six split air-conditioners are used in machine workshop and the outside air exchange occurs only through process of infiltration. This can explained that the air change rate in machine workshop is not good and hence the odor produced from existing machines and workshop activities keep on circulate in the workshop.

Based on Table 5.2, the indoor air quality parameters such as carbon dioxide level, concentration of PM 2.5 and PM 10 in welding workshop is also far below the maximum allowable level by ASHRAE 62.1. From subjective assessment, majority 65% of the respondents voted for moderately odor. Since the indoor air quality parameters are satisfied with the standard, occupants in machine workshop felt moderate odor is due to the insufficient air change rate and hence the odor produced from existing machines and workshop activities trapped inside the workshop.

5.3 REGRESSION ANALYSIS

Many of the studies on thermal comfort analysis used regression method to investigate the relationship between operative temperature and TSV/PMV as the air temperature is considered the deterministic factor of thermal sensation. Regression analysis is applied to determine the neutral temperature from the thermal sensation data. Based on previous studies, it proved that a strong linear relationship between TSV/PMV and operative temperature. The results from studies showed that most of R^2 exceeded 0.7 (Fang et al., 2018). The classification of R-squared value to interpret the strength of relationship between dependent variable and independent variable is shown in Table 5.10.

Table 5.10: Classification of R-squared value (Moore et al., 2013)

Range of R-squared value	**Strength of relationship**
$R^2 < 0.3$	Very weak
$0.3 < R^2 < 0.5$	Weak
$0.5 < R^2 < 0.7$	Moderate
$R^2 > 0.7$	Strong

5.3.1 Regression analysis on machine workshop

In this study, the regression of TSV and operative temperature for the air-conditioned machine workshop showed that the coefficient of determination, R^2 is only 1.7% or 0.017. This means that the relationship is very weak and only 1.7% of the variation data can be explained by the linear relationship between TSV and operative temperature. Based on the TSV regression line, the neutral temperature obtained is 23.5°C.

According to ASHRAE 55, PMV index relates the thermal comfort factors and predicts the mean value of votes from occupants on the seven point scale. The regression of PMV and operative temperature in machine workshop is shown in Figure 5.31. Based on the figure, the R^2 is 82.4% or 0.824. This indicated that the relationship between PMV and operative temperature is strong. The predicted neutral temperature from PMV regression is 17.14°C. It is lower than the operative temperature obtained from measurement by approximately 3.7°C.

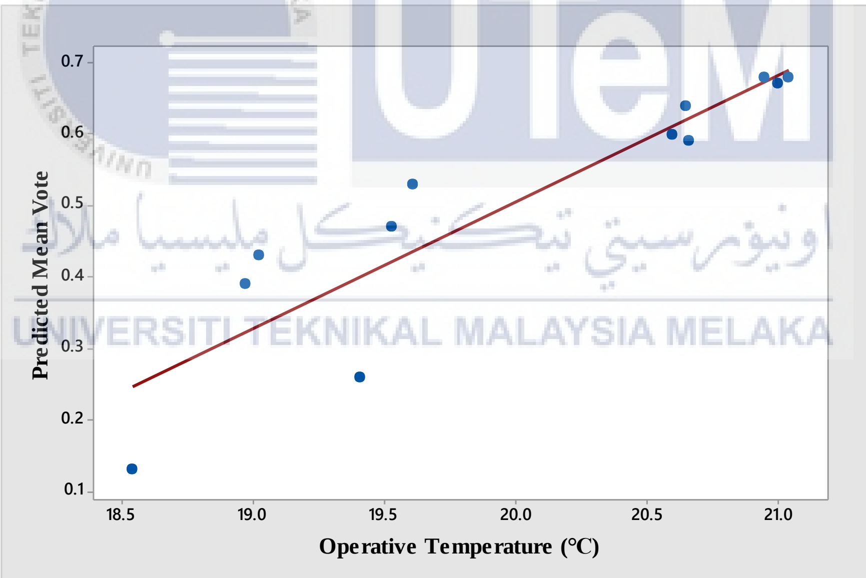


Figure 5.31: Graph of PMV versus operative temperature in machine workshop

Based on the regression of PMV and relative humidity in machine workshop, the coefficient of determination, R^2 is 0.9% or 0.009. This indicated that the relationship between PMV and relative humidity is very weak. Only 1 % of the variation data can be explained by the relationship.

Based on Figure 5.32, the regression of PMV and air velocity in machine workshop showed R^2 = 53.2% or 0.532. This indicated that more than half of the variations can be explained by this relationship. The relationship between PMV and air velocity is a negative relationship. Higher air velocity will reduce the PMV value.

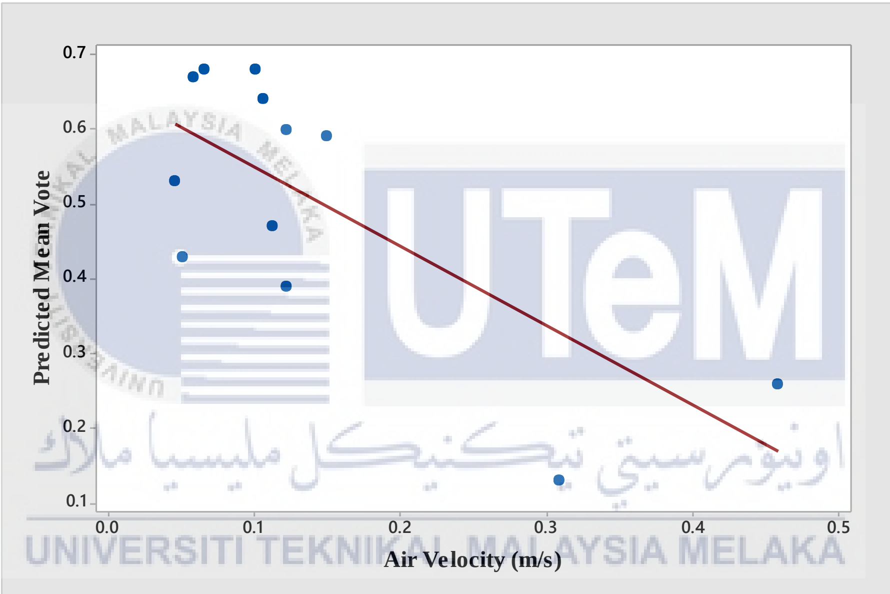


Figure5.32: Graph of PMV versus air velocity in machine workshop

Moreover, investigation on the relationship between air odor vote and indoor air quality parameters are done in this study. Based on Figure 5.33, the regression of air odor sensation and carbon dioxide level in machine workshop showed R^2 = 1.9% or 0.019 only. This indicated that the relationship is very weak. As well as the relationship between air odor vote with concentration of PM 2.5 and PM 10 shown in Figure 5.34 and 5.35

respectively. The calculated R^2 value is only 0% and 1.6% respectively and hence the relationship is too weak.

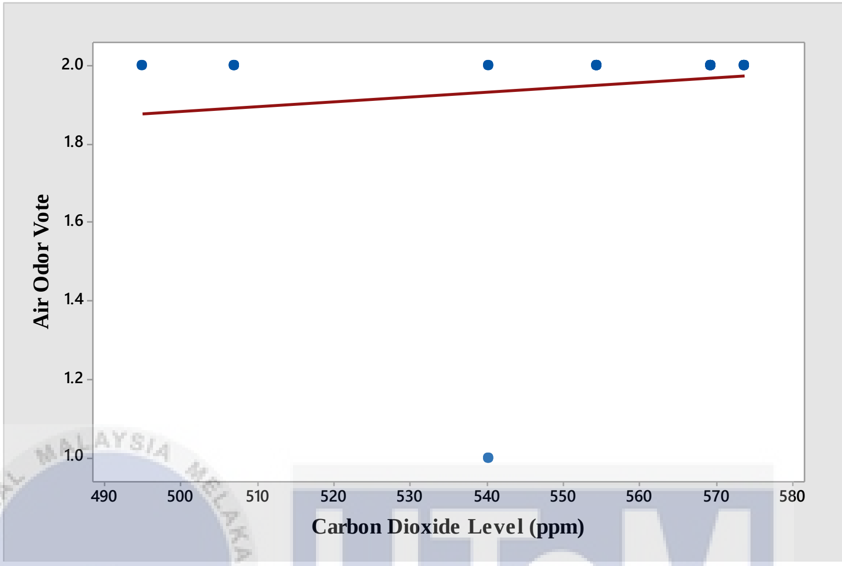


Figure 5.33: Graph of air odor vote versus carbon dioxide level in machine workshop

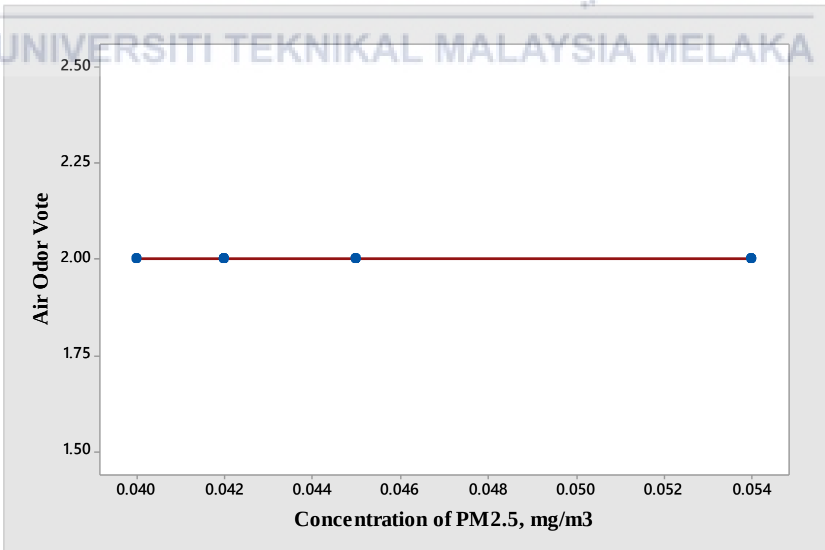


Figure 5.34: Graph of air odor vote versus PM2.5 concentration in machine workshop

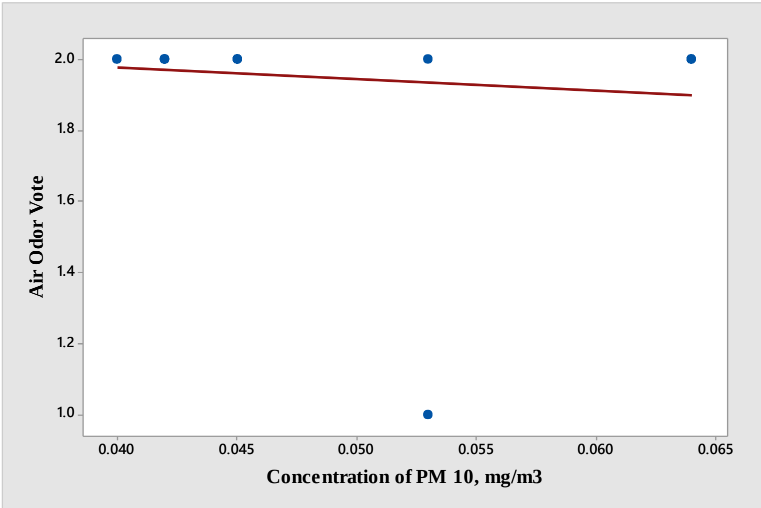


Figure 5.35: Graph of air odor vote versus PM10 concentration in machine workshop

5.3.2 Regression analysis on welding workshop

The linear regression between TSV and operative temperature in welding workshop resulted that the R^2 is 43.6% or 0.436. This linear relationship can only explained 43.6% of the variation in the data. Based on the TSV regression line, the neutral temperature is 29.16°C.

Besides, the regression of PMV and operative temperature in welding workshop is shown in Figure 5.36. Based on the figure, the R^2 is 94.9% or 0.949. This indicated that the relationship between PMV and operative temperature is strong. The predicted neutral temperature from PMV regression is 17.08°C.

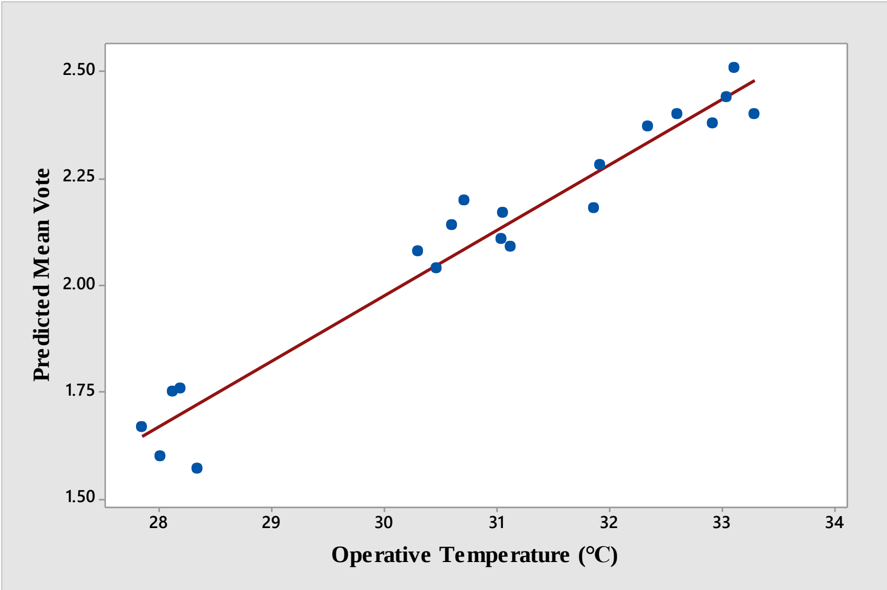


Figure 5.36: Graph of PMV versus operative temperature in welding workshop

Based on Figure 5.37, the regression of PMV and relative humidity in welding workshop showed R^2 = 84.2% or 0.842. This indicated that the relationship between PMV and relative humidity is strong. Besides, the relationship between PMV and relative humidity is a negative relationship. Lower humidity will increase the PMV value.

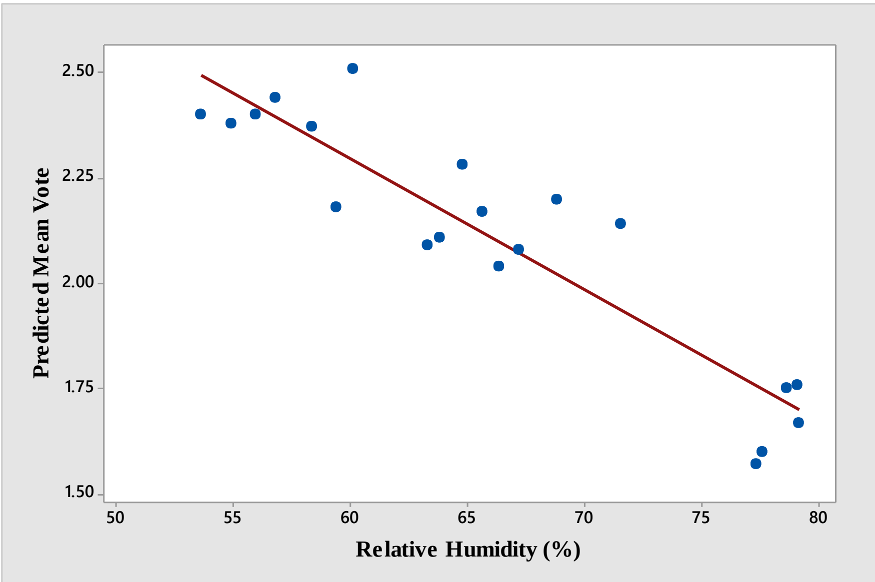


Figure 5.37: Graph of PMV versus relative humidity in welding workshop

Based on Figure 5.38, the regression of PMV and air velocity in welding workshop showed R^2 = 2.4% or 0.024. This indicated that the relationship is too weak.

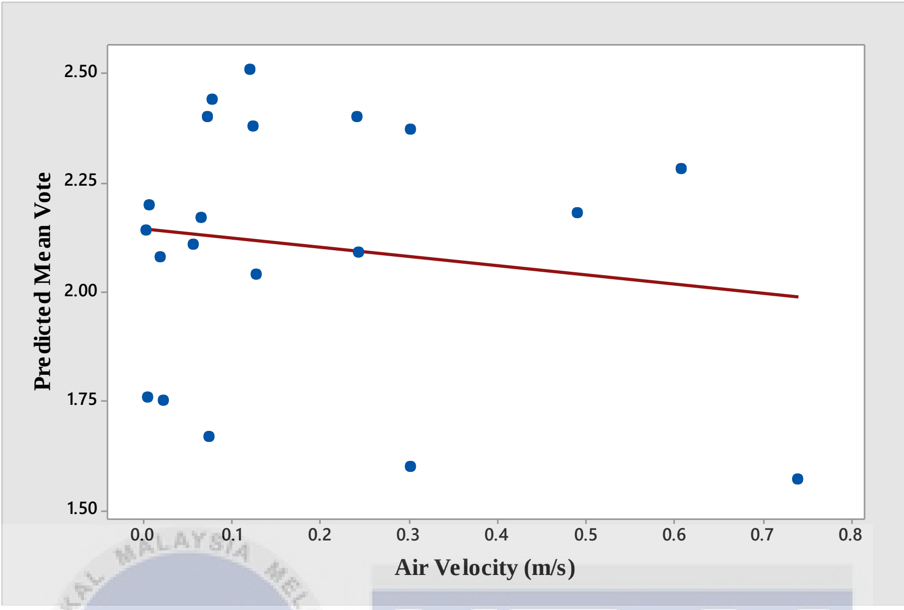


Figure 5.38: Graph of PMV versus air velocity in welding workshop

Based on Figure 5.39, the regression of air odor sensation and carbon dioxide level in welding workshop showed R^2 = 0.1% or 0.001 only. This indicated that the relationship is too weak. As well as the relationship between air odor vote with concentration of PM 2.5 and PM 10 shown in Figure 5.40 and 5.41 respectively. The calculated R^2 value is only 2.4% and 1.3% respectively and hence the relationship is too weak.

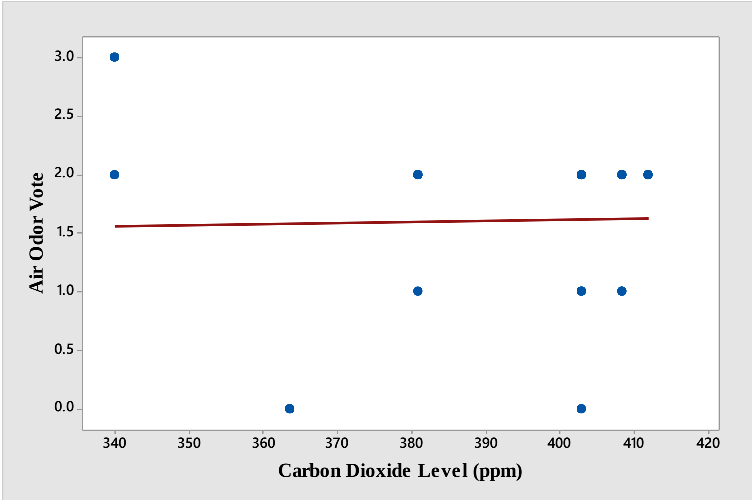


Figure 5.39: Graph of air odor vote versus carbon dioxide level in welding workshop

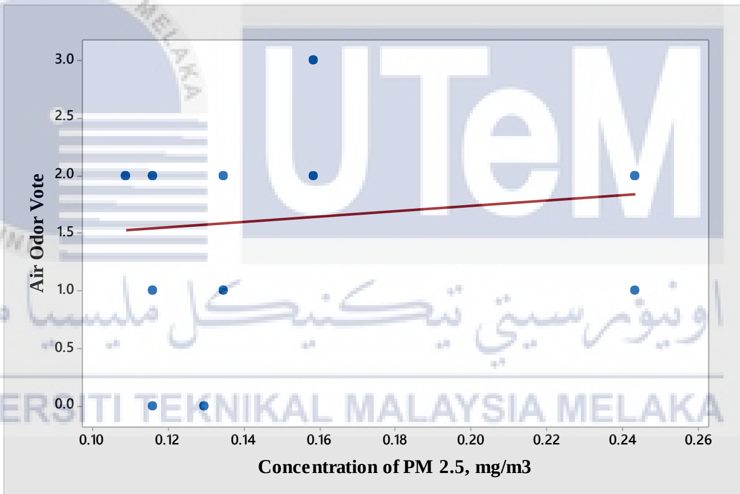


Figure 5.40: Graph of air odor vote versus PM2.5 concentration in welding workshop

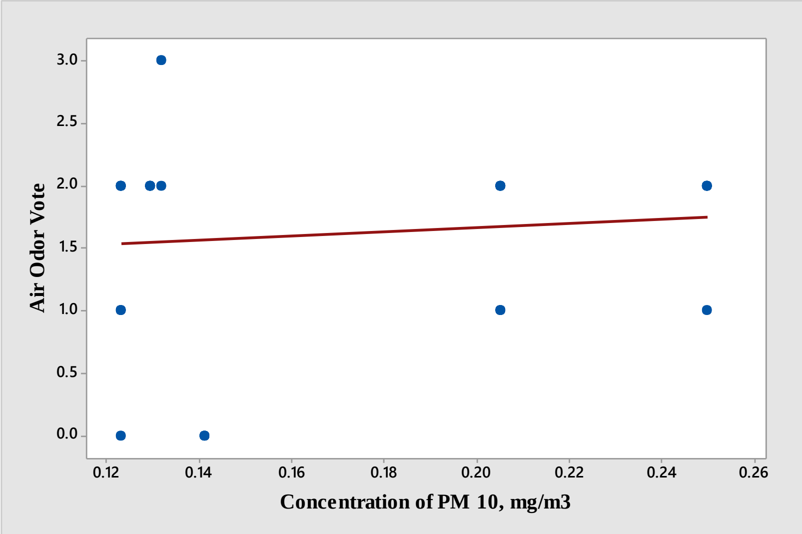


Figure 5.41: Graph of air odor vote versus PM10 concentration in welding workshop

5.3.3 Summary of Result

Overall, the regression analysis results for both workshops are shown in Table 5.11. The strength of relationship is interpreted by referring to Table 5.10. Based on Table 5.11, the regression of PMV and operative temperature showed a higher relationship when compared to regression of TSV and operative temperature. Compare with other studies, the R^2 in TSV regression for both workshops is considered low. The number of occupancy factor might be one of the reasons that contribute to this outcome. In this study, the subjective assessment was done using random subjects and the number of occupants is hard to be controlled. There was around 10 subjects in each session that able to do the subjective assessment while the measurement was conducting. Hence, the outcome might due to the limited thermal sensation data provided by the subjects.

The neutral temperature determined from TSV regression for machine workshop and welding workshop is 23.5°C and 29.16°C respectively. However, the neutral temperature estimated by PMV regression for machine workshop and welding workshop is 17.14℃ and 17.08℃ respectively.

In this study, the neutral temperature of 23.5℃ derived from TSV regression in air-conditioned machine workshop is compatible with the results from other studies in tropics. The neutral temperature found in air-conditioned buildings in tropical countries such as Thailand, Singapore, Indonesia, Hong Kong and Taiwan are 24.8℃, 24.2℃, 26.7℃, 23.7℃ and 25.6℃ respectively (Yang & Zhang, 2008). However, the neutral temperature of 17.14℃ derived from PMV model is 6.37℃ lower than that given by TSV. The underestimation of neutral temperature is due to the PMV models predict mild warm discomfort while the occupants were actually felt slightly cool at the air temperature of 20.8℃ in the machine workshop.

However, the neutral temperature derived from TSV regression for natural ventilated welding workshop is 29.16℃. It found that the neutral temperature of 29.16℃ is compatible with previous findings on natural ventilated buildings. The neutral temperature found in natural-ventilated buildings in tropical countries is range from 28℃ to 31℃ (Kwong et al., 2014). Based on the analysis of PMV regression, the neutral temperature of 17.08℃ is much more lower than neutral temperature predicted from TSV regression. This can be explained by the people in hot-humid region are more adapted to warm weather and hence they can tolerate higher temperature condition than people in other climate. Other studies also found that the comfort temperature in tropical region is higher due to the humans' ability on acclimatization (Li et al., 2010). Hence, the neutral temperature based on occupants sensation vote is higher compared to what PMV had predicted.

Besides, the relationship between PMV and relative humidity is stronger in welding workshop compare to machine workshop. Meanwhile, machine workshop showed a stronger relationship between PMV and air velocity when compared to welding workshop. In this study, the relationship between air odor sensation and indoor air quality parameters are considered weak for both workshops.

Table 5.11: Overall regression results for both workshops

D/I Variables	Machine workshop		Welding workshop	
	R^2 value	Comment on relationship	R^2 value	Comment on relationship
TSV/ T_{op}	0.017	Too Weak	0.436	Weak
PMV/ T_{op}	0.824	Strong	0.949	Strong
PMV/RH	0.009	Too Weak	0.842	Strong
PMV/ AV	0.532	Moderate	0.024	Too Weak
AOV/ CO^2	0.019	Too Weak	0.001	Too Weak
AOV/PM2.5	0	None	0.024	Too Weak
AOV/ PM10	0.016	Too Weak	0.013	Too Weak

*D/I = Dependent/ Independent

5.4 SUGGESTION ON IEQ IMPROVEMENT MEASURES

Thermal comfort and indoor air quality are important factors of the indoor environment quality. Good indoor environment quality should be achieved as it can avoid energy wasted and more sustainable. In this study, further improvement measures are suggested after thermal comfort analysis and indoor air quality analysis are done in both workshops.

5.4.1 Improvement Measures in Machine Workshop

After the thermal comfort analysis and indoor air quality analysis are conducted, it resulted that the indoor air temperature in machine workshop is not within the recommended range by Malaysia Standard. However, all the occupants were satisfied with the air temperature. Further improvement on thermal comfort level can be done by increasing the air temperature around 2℃ to achieve neutral temperature predicted through regression of TSV and operative temperature.

Based on observation, single split air conditioners are used in machine workshop and the indoor air temperature can be adjusted by the air conditioner remote. Hence, the first suggestion is increase the indoor air temperature around 2℃ by using air conditioner remote in order to achieve better thermal comfort level.

From the subjective assessment, it is found that 40% of the occupants felt the air inside the machine workshop is slightly still. Furthermore, 95% of the occupants felt the air inside the machine workshop is moderately odor. This is because the air exchange rate in air conditioned machine workshop highly depends on the infiltration. Hence, the ventilation system should be improved to increase the ventilation rate in machine workshop.

Firstly, the volume for machine workshop is determined as shown as below:

$$\text{Machine Workshop Volume} = \text{Total Area x Height}$$

$$= (300 \text{ x } 3)$$

$$= 900 \text{ m}^3$$

According to ASHRAE 62.1, the breathing zone outdoor airflow, V_{bz} should not less than the value determined in equation 1 below.

$V_{bz} = (R_p \times P_z) + (R_a \times A_z)$ ----- (1)

where

A_z= zone floor area

P_z= number of people in the area

R_p= Outdoor air flow rate from Table 6-1

R_a= Outdoor air flow rate required per unit area from Table 6-1

Lab assistant mentioned that maximum occupants can be reached to 30 students in machine workshop. Refer to Table 6-1 in ASHRAE 62.1, the minimum ventilation rate per person and per area in university laboratories are 5L/s per person and 0.9 L/s per unit area respectively. Substitute the determined values into equation 1. The breathing zone outdoor airflow, V_{bz} is $0.42m^3/s$.

Based on others recommendation, the air change rate for machine workshop should around 6ach. The recommended ventilation rate for machine workshop is determined as below by using the air change rate equation.

Ventilation rate, q = (Air change rate x Volume of space)/ 3600 -------- (2)

The calculated ventilation rate is $1.5m^3/s$. The ventilation rate is considered better as it larger than the breathing zone outdoor airflow, V_{bz} mentioned by ASHRAE 62.1.

Convert to cubic feet per minute, the ventilation rate is 3178.3cfm. Based on calculated ventilation rate, the suitable types of mechanical ventilation system can be selected and implement in machine workshop as shown as below:

a) Installation of exhaust fan in machine workshop

Due to the usage of air conditioners in machine workshop, the smaller capacity of exhaust fan is suggested to install so that the cooling load will not affected. Although the exhaust capacity is not satisfy with the recommended ventilation rate of 3178.3cfm, it still considered acceptable as it higher than the breathing zone outdoor airflow, V_{bz} of 890 cfm.

The location of exhaust fan in machine workshop is designed at wall beside the roller shutter as shown in Figure 5.42. The exhaust fans can remove unpleasant and stale air out from the workshop. This measure will improve the indoor air quality as the air odor in machine workshop can be eliminated. The specifications of exhaust fans are shown in Table 5.12.

Table 5.12: Specifications of exhaust fan ("Industrial Fans Direct," n.d.)

Type/ Model	Shutter Exhaust Fan Direct Drive 

Brand	J&D ES
Fan size	12 inch (diameter)
Opening size	12.5 inch (width) x 12.5 inch (height)
Capacity	970 CFM

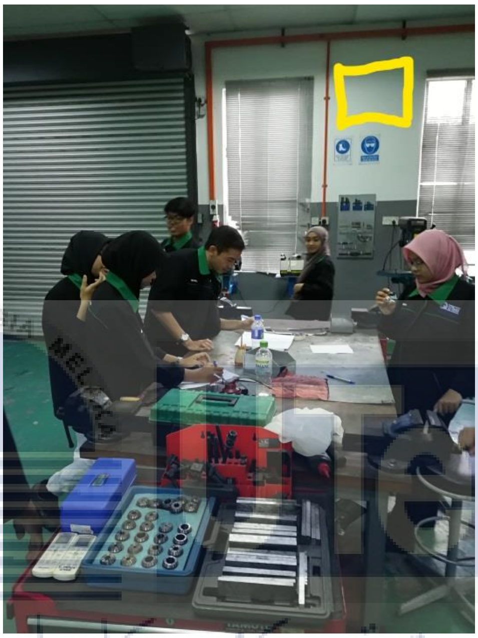


Figure 5.42: Design location for exhaust fan in machine workshop

b) Installation of air grilles in machine workshop

Air grille is able to promote air circulation by continuously supplying and returning the air. It can provide required air flow with suitable size in an occupied zone. Study mentioned that air grille increase the air change effectiveness as well as the pollutant removal efficiency (Fisk et al., 1997). In this study, the purpose of installing transfer air grilles is to provide proper circulation for machine workshop.

Hot air can also be transferred out from air grilles. The specifications of transfer grille are shown in Table 5.13.

Due to the limited space in machine workshop, the air grilles are designed at top of the entrance door and at the entrance door as shown in Figure 5.43 and 5.44. The total volume flow rate is $0.52 m^3/s$ or 1102cfm. Although it is not fulfil the recommended ventilation rate of 3178.3 cfm, it is still considered higher than the breathing zone outdoor airflow, V_{bz}.

Table 5.13: Specifications of transfer air grille ("TROX ", n.d.)

Air grille type	Transfer air grille 
Air grille size	For wall grille: 2 x 625mm (width) x 325mm (height) For door grille: 2 x 325mm (width) x 225mm (height)
Maximum volume flow rate	For wall grille: $2 \times 0.2m^3/s = 0.4m^3/s$ For door grille: $2 \times 0.06m^3/s = 0.12m^3/s$

Figure 5.43: Design location for wall grille in machine workshop

Figure 5.44: Design location for door grille in machine workshop

In overall, the recommended measures for the improvement of environment quality in machine workshop included increasing the indoor air temperature around 2℃ for better thermal comfort environment, installing exhaust fan to eliminate odor and additional air grilles to circulate the air in machine workshop. Figure 5.45 below showed the overall design locations for ventilation system in machine workshop.

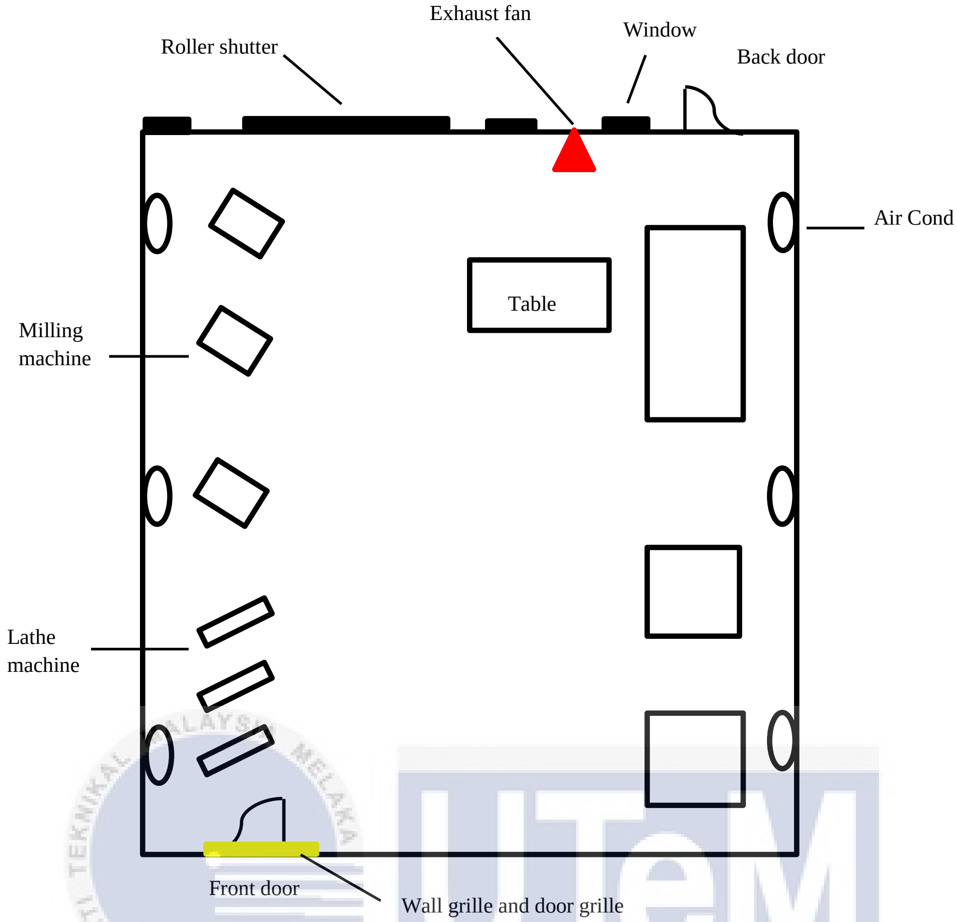


Figure 5.45: Design location in machine workshop

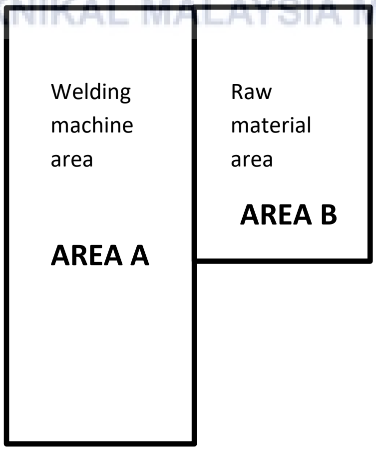
5.4.2 Improvement Measures in Welding Workshop

After the thermal comfort analysis and indoor air quality analysis are conducted, it resulted that the indoor air temperature in welding workshop is not within the comfort condition recommend by ASHRAE 55 and other studies in tropics. From the subjective assessment, a total 90% of the respondents voted for categories (slightly warm, warm and hot). This means that improvement measure should be done to reduce the indoor air temperature.

Besides, air velocity condition in welding workshop is within standard requirement. However, a total 65% of the respondents sensed the air movement in welding workshop is slightly still and moderately still. Moreover, a total of 70% of the respondents sensed that the air in welding workshop is moderately odor and strong odor. Based on findings, indoor air movement and odor problems can be solved by appropriate ventilation system. Ventilation is important as it provide healthy fresh air from outdoor to indoor, removes air pollutants and heat from the building.

In this study, mechanical ventilation system is suggested to be implemented as it has lower energy consumption when compared to air conditioning system. When mechanical ventilation is implemented, the ventilation system in welding workshop is known as mixed-mode ventilation. Mixed mode ventilation system relies on natural driving forces as well as mechanical driving forces to improve the ventilation rate in a building. This study mentioned that mixed-mode buildings can save up to 75% of HVAC energy by alternating natural and mechanical ventilation (Salcido et al., 2016).

In this study, some calculations are done to estimate a better ventilation rate for welding workshop. Firstly, volume for welding workshop is determined as shown as below:



Total Area= Area A + Area B

= $(80.625m^2) + (38.5m^2)$

= $119.13m^2$

Welding Workshop Volume= Total Area x Height

= $(119.13m^2 \times 6m)$

= $714.78m^3$

According to ASHRAE 62.1, the breathing zone outdoor airflow, V_{bz} should not less than the value determined in equation 1 below.

$V_{bz} = (R_p \times P_z) + (R_a \times A_z)$ ------ (1)

where

A_z= zone floor area

P_z= number of people in the area

R_p= Outdoor air flow rate from Table 6-1

R_a= Outdoor air flow rate required per unit area from Table 6-1

Lab assistant mentioned that maximum occupants can be reached to 20 students in welding workshop. Refer to Table 6-1 in ASHRAE 62.1, the minimum ventilation rate per person and per area in university laboratories are 5L/s per person and 0.9 L/s per unit area respectively. Substitute all the determined values into equation 1. The breathing zone outdoor airflow,V_{bz} is 0.207m^3/s.

Based on others recommendation, the air change rate for welding workshop is 8ach. Based on air change rate equation shown as below, the recommended ventilation rate can be determined.

Ventilation rate, q = (Air change rate x Volume of space)/ 3600 -------- (2)

The calculated ventilation rate is 1.59m^3/s. The ventilation rate is considered better as it larger than the breathing zone outdoor airflow, V_{bz} mentioned by ASHRAE 62.1. Convert to cubic feet per minute, the ventilation rate is 3365.6cfm. Based on calculated ventilation rate, the suitable types of mechanical ventilation system can be selected and implement in welding workshop.

a) Installation of supply fan in welding workshop

Cross ventilation system in welding workshop strongly depend on wind forces. Sometimes, the ventilation rate is bad due to no wind flow through the workshop. In this study, supply fan is suggested to install so that it not highly rely on natural ventilation system to supply sufficient fresh air into the workshop. The specifications of the supply fan are shown in Table 5.14 below.

Since the calculated ventilation rate for welding workshop is 3365.6 cfm, a wall mounted supply fan with capacity 3250 cfm is appropriate to be installed in welding workshop as the roller shutter is half-opened where fresh air can also be natural ventilated into the workshop. The suggested location is at the wall location beside the roller shutter as shown in Figure 5.46.

Table 5.14: Specifications of supply fan ("Industrial Fans Direct," n.d.)

Type/ Model	Wall Mounted Supply Fan Direct Drive/ P20-1R 
Brand	Canarm
Blade size	20 inch
Overall fan size	25.25 inch (width), 24 inch (height)
Capacity	3250 CFM

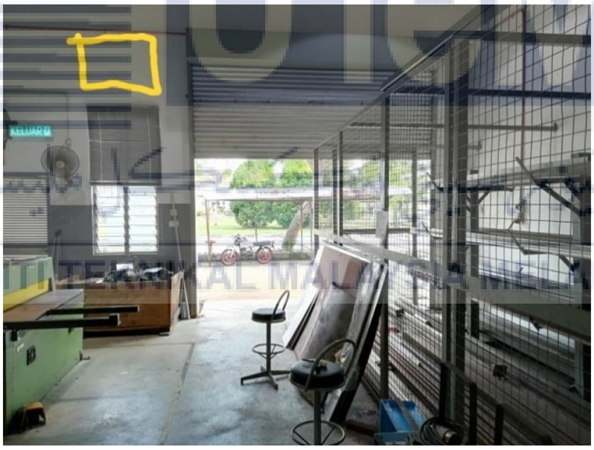


Figure 5.46: Design location for supply air fan in welding workshop

b) Installation of exhaust fan in welding workshop

Exhaust fan is important in welding workshop as it can remove air odor, contaminants and heat from the workshop. An exhaust duct is existed in welding machine area to remove heat produced during welding process. However, the exhaust duct has not much contribution to the thermal condition in welding workshop. Hence, additional exhaust fan is suggested to install in order to improve the ventilation rate of welding workshop. Adequate ventilation rate able to decrease the air temperature in welding workshop as the heat continuously eliminated out. The specifications of the exhaust fan are shown in Table 5.15 below.

Two of the selected exhaust fan should be installed in welding workshop as the speed can be controlled to highest capacity of 1950 CFM each. A balanced ventilation rate will be achieved as the supply air rate and exhaust air rate are approximately the same. The exhaust fan is suggested to be installed at higher location at the wall as shown in Figure 5.47.This is because warm air has lower density and hence go upwards. The warm air can easily exhausted out through the exhaust fan.

Table 5.15: Specifications of exhaust fan ("Industrial Fans Direct," n.d.)

Type/ Model	3 Speed Shutter Exhaust Fan Direct Drive/ SF16110C3 
Brand	VES Enviro Solutions
Blade size	16 inch (diameter)
Overall fan size	17.5 inch (width), 17.5 inch (height)
Capacity	1170 CFM (low), 1890 CFM (medium), 1950 CFM (high)

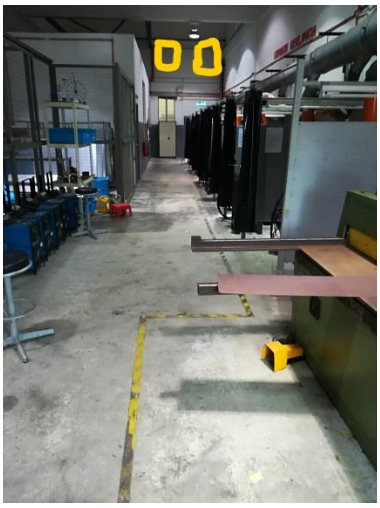


Figure 5.47: Design location for exhaust fans in welding workshop

c) Installation of wall mounted air circulator fans

Wall mounted air circulator fan is also suggested to install in welding workshop to increase the air movement at each zones. Although three functioned wall fans exist in welding workshop, the ventilation in welding workshop is not much affected due to the limited capacity of the fan and the bad location of the fans. The existed wall fans should be removed and three wall circulator fans are suggested to install in welding workshop as shown in Figure 5.48. The specifications of wall circulator fans are shown in Table 5.16.

According to ASHRAE 55, thermal comfort zone can be extended with elevated air speed to 0.8m/s if without personal control and 1.2m/s if have personal control. Besides, study mentioned that fans used in high indoor air temperature room can expand the occupant's acceptable temperature range by cooling them convectively. For natural ventilated building, fans can increase convective cooling when air flow through openings is not strong. Thermal comfort votes were obviously better when fans are used in high indoor air temperature condition. Most of the subjects at indoor temperature above 30℃ required air speeds range from 1.2m/s to 1.8m/s which is higher than the standard recommended value. (Zhai et al., 2015). Hence, installation of air circulator fans at welding machine area can improve occupant’s thermal comfort level.

Table 5.16: Specifications of wall mounted air circulator fan ("Industrial Fans Direct," n.d.)

Type/ Model	3 Speed Wall Circulator Fan/ WMKD24-3SP 
Brand	Canarm
Fan size	24 inch (diameter)
Capacity	4900 CFM (low), 5900 CFM (medium), 6600 CFM (high)

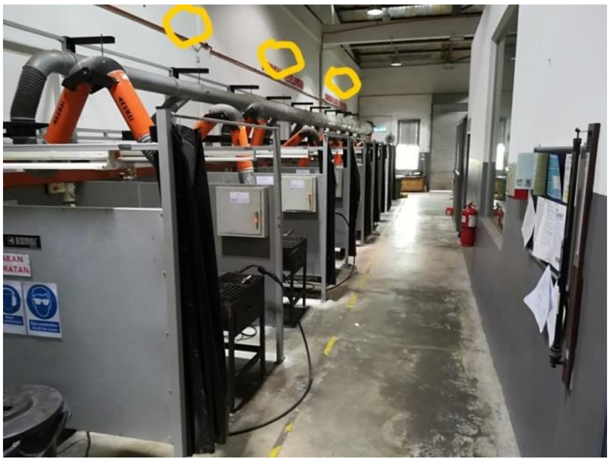


Figure 5.48: Design location for air circulator fans in welding workshop

d) Installation of windows

Window is important for a natural ventilated building as the air is allowed to flow in and out through the window openings and ventilate the indoor space. Additional windows able to increase the air change rate of the room and improve the indoor air quality. Based on observation, welding workshop has limited space to install additional windows. Hence, the appropriate suggestion is to install awning window at the top of the entrance door and exit door as shown in Figure 5.49 and 5.50 respectively. The specifications of the awning window are shown in Table 5.17 below.

Table 5.17: Specifications of awning window ("Stanek Windows," n.d.)

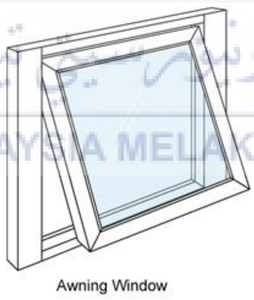
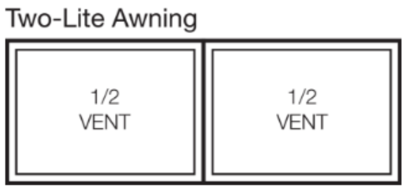
Window type	Awning window 
Window configuration	
Window Size (Each)	24 inch (width), 11 inch (height)

Figure 5.49: Design location for awning window in welding workshop

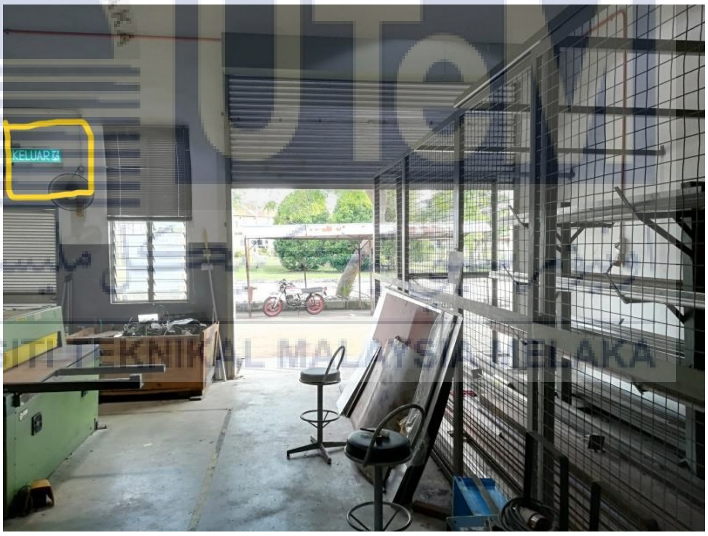


Figure 5.50: Design location for awning window in welding workshop

Besides, the previous window type can also be changed to others window type. The window beside entrance door as shown in Figure 5.51 should change to awning window type that has wider opening as shown in Table 5.18 to increase the air change rate. However, the window beside the exit door should change to casement window type as shown in Figure 5.52. The specifications of casement window are shown in Table 5.19. Figure 5.53 below showed the overall design locations for ventilation system in welding workshop.

Table 5.18: Specifications of awning window ("Stanek Windows," n.d.)

Window configuration	
Window Size (Each)	20 inch (width), 15 inch (height)

Figure 5.51: Design location for awning window in welding workshop

Table 5.19: Specifications of casement window ("Stanek Windows," n.d.)

Window type	Casement window 
Window Size	28 inch (width), 44 inch (height)

Figure 5.52: Design location for casement window in welding workshop

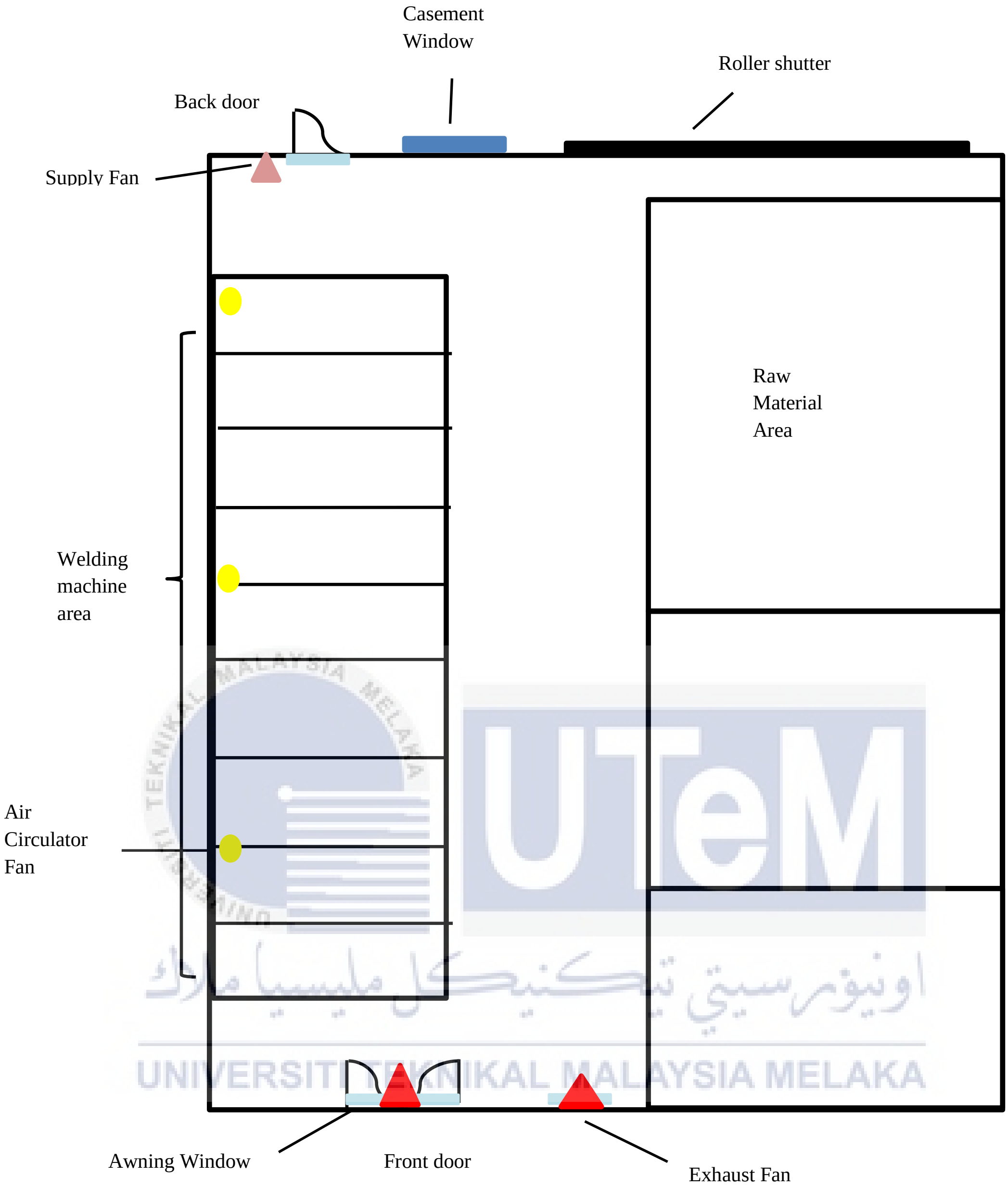


Figure 5.53: Design location in welding workshop

In overall, the recommended measures for the improvement of environment quality in welding workshop included installing supply air fan to provide sufficient fresh air, installing exhaust fans to eliminate odor and heat, installing air circulator fans to improve occupant's thermal comfort level and installing window to provide adequate ventilation rate.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

As a conclusion, thermal comfort analysis and indoor air quality analysis are conducted in this study to evaluate the indoor environment quality of workshops in Mechanical Engineering Laboratories Complex. Results obtained from thermal comfort analysis showed that the indoor air temperature in machine workshop is not within the comfort zone range recommended by Malaysia Standard 1525:2014. Meanwhile, thermal condition of welding workshop is not satisfied with ASHRAE Standard 55 in terms of air temperature, PMV and PPD index. Moreover, results obtained from indoor air quality analysis showed that the concentration of gas pollutant (CO_2) and particulate matter ($PM_{2.5}$ and PM_{10}) in both workshops are far below the maximum concentration allowed by ASHRAE Standard 62.1.

Subjective assessment through questionnaire showed that both workshops were not in thermal acceptable conditions. Majority of the occupants are satisfied with the relative humidity and air velocity condition in both workshops. However, most of them felt that the air has moderate odor in both workshops. Regression analysis between TSV and operative temperature showed that neutral temperature in machine workshop and welding workshop is 23.5°C and 29.16°C respectively. The neutral temperature based on occupants sensation vote is higher compared to what PMV had predicted.

After analysis, measures are vital to be done to improve the indoor environment condition for both workshops. Based on the current condition for both workshops, the measures are more focused on ventillation rate as good ventilation system can enhance air movement and remove air odor. Good indoor environment quality for both workshops able to increase occupant's performance during workshop practice.

6.2 RECOMMENDATION

In this study, regression analysis between occupant's sensation vote with measurement parameters showed very weak relationship. The occupancy factor maybe one of the reasons contributing to this outcome as subjective assessment was conducted using random subjects and do not have direct control on the number. The number of students in both workshops is not much during the workshop practice. Hence, it is recommended to target more number of subjects for future research so that the impact of occupants is more significant and better regression analysis can be done.

This study found that better indoor environment quality of both workshops can be achieved with sufficient ventilation rate. Hence, measures related to ventilation system design are suggested in this study. The results will be better when the suggestion measures come with simulation. Unfortunately, simulation analysis has not sufficient time to be conducted. Therefore, it is recommended that future works can focus on airflow simulation in both workshops so that a more detailed effect of ventilation system design can be observed.

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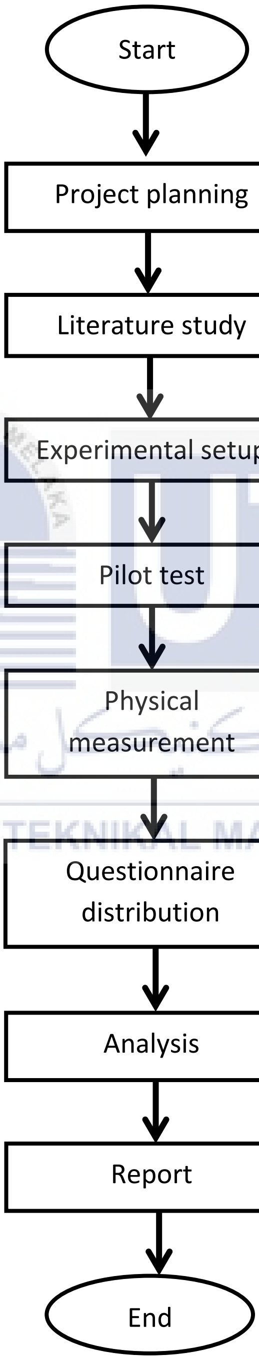
APPENDIX A

Flow Chart of Final Year Project



APPENDIX B

Project Gantt Chart for PSM 1

No	Task	Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Topic selection	■							**Mid-Sem Break**							
2	Project planning		■	■												
3	Preparation of Chapter 1 Introduction			■	■	■										
4	Literature study						■	■		■	■					
5	Preparation of Chapter 2 Theory									■	■					
6	Preparation of Chapter 3 Literature review											■	■			
7	Methodology planning												■	■		
8	Preparation of Chapter 4 Methodology													■	■	
9	PSM 1 draft report submission														■	
10	PSM 1 presentation															■

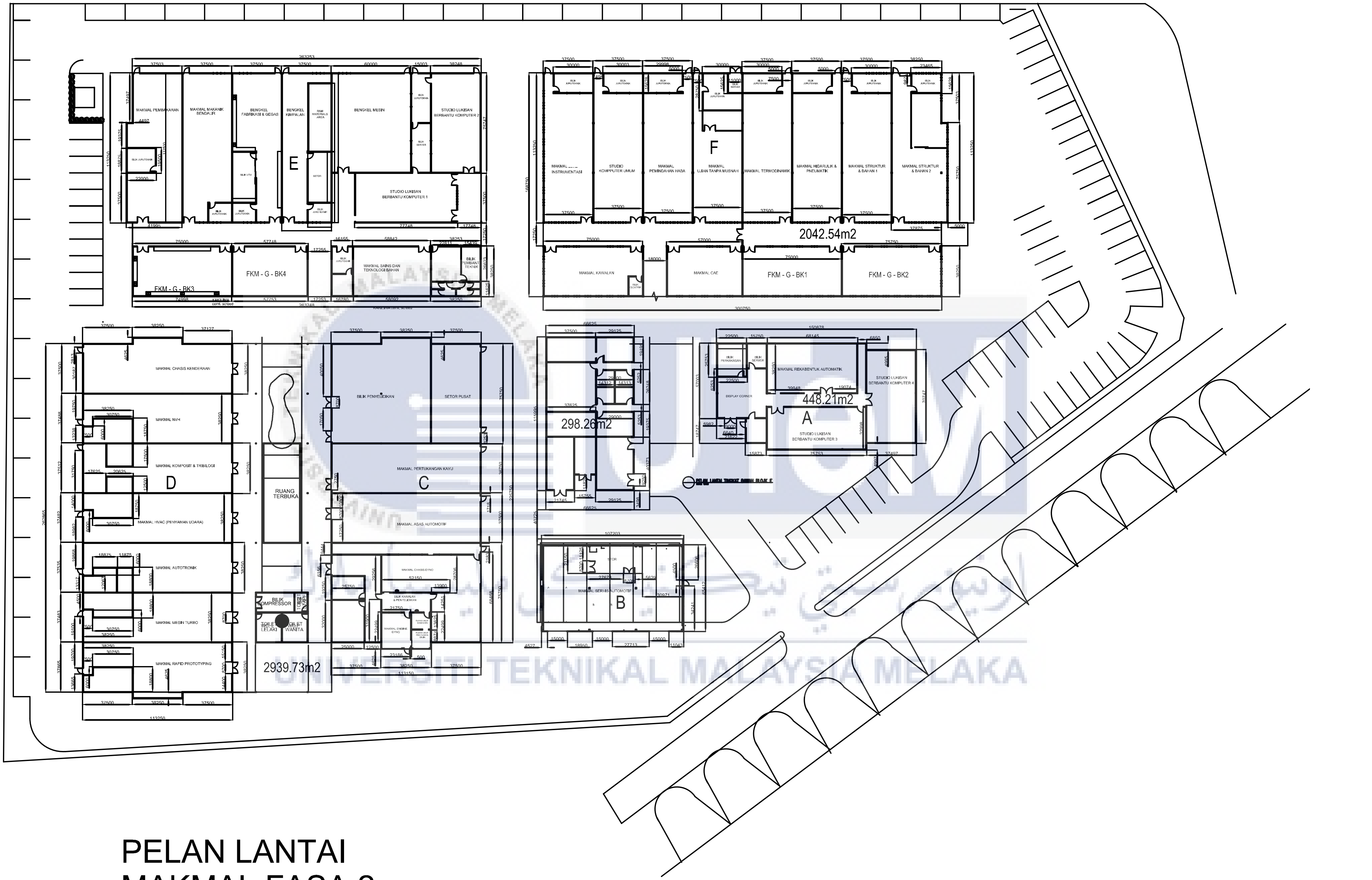
APPENDIX C

Project Gantt Chart for PSM 2

No	Task	Week														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Data Measurement								Mid-Sem Break							
2	Questionnaire Distribution															
3	Analysis of Objective Measurement															
4	Analysis of Subjective Measurement															
5	Suggest IEQ Improvement Measures															
6	PSM 2 Report Submission															
7	PSM 2 Presentation															

APPENDIX D

Floor Plan of UTeM Mechanical Engineering Laboratories Complex



PELAN LANTAI
MAKMAL FASA 2
Jumlah Keluasan Keseluruhan = 8243.49m2

APPENDIX E

Questionnaire for Machine Workshop

QUESTIONNAIRE FORM

Indoor Air Quality and Thermal Comfort Analysis for Mechanical Engineering Laboratories Complex of UTeM

***Please tick your answer provided carefully. Thanks for your cooperation.**

Date: ________________________ Time: _____________________ (a.m. / p.m.)

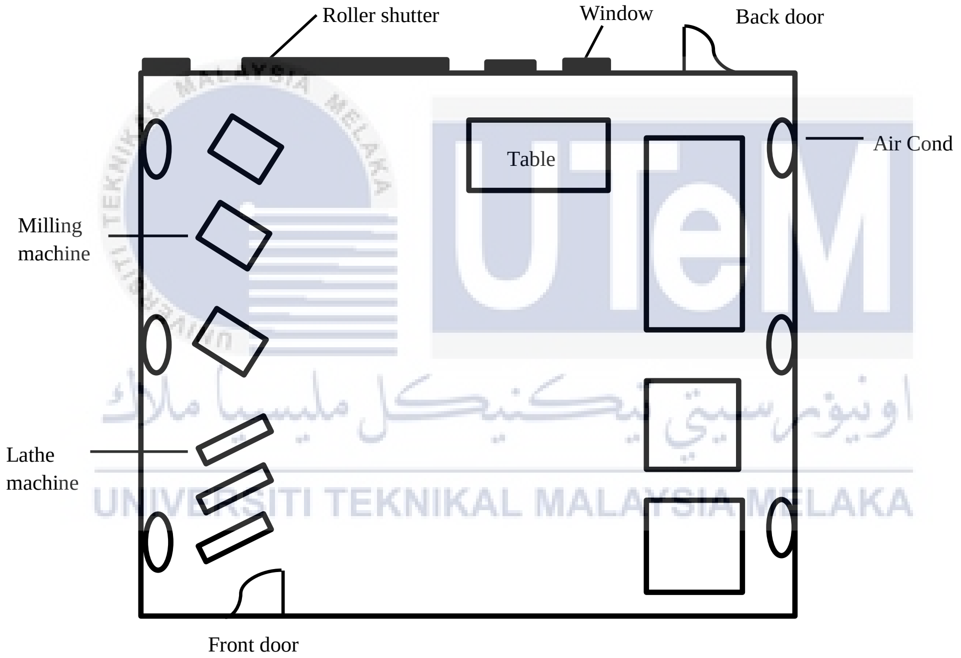
Age: _______ Sex: ☐ Male ☐ Female

Health Condition: ☐ Good ☐ Normal ☐ Not well ☐ Sick

1. How is the outdoor condition?

   ☐ Sunny ☐ Cloudy ☐ Overcast ☐ Rainy ☐ Windy

2. Place "**X**" for your current location in machine lab.



3. Select only **ONE** of your clothing today. If not in the list below, please write down.

   ☐ Trousers, long-sleeve shirt, socks and boots
   ☐ Trousers, short-sleeve shirt, socks and boots
   ☐ Trousers, long-sleeve shirt, lab coat, socks and boots
   ☐ Trousers, short-sleeve shirt, lab coat, socks and boots
   Others: __________________________

4. What is your activity level right now?

   ☐ Seated
   ☐ Standing relaxed
   ☐ Standing and doing lab work activity

5. How do you feel about the laboratory temperature?

- ☐ Hot
- ☐ Slightly warm
- ☐ Slightly cool
- ☐ Cold
- ☐ Warm
- ☐ Neutral
- ☐ Cool

6. Are you satisfied with the temperature inside the laboratory?

- ☐ Yes
- ☐ No

7. How do you feel about the humidity level inside the laboratory?

- ☐ Very dry
- ☐ Slightly dry
- ☐ Slightly humid
- ☐ Humid
- ☐ Dry
- ☐ Neutral
- ☐ Moderately humid

8. How do you feel about the air odor inside the laboratory?

- ☐ No odor
- ☐ Moderate odor
- ☐ Very strong odor
- ☐ Weak odor
- ☐ Strong odor
- ☐ Overpowering odor

9. How do you feel about the air movement inside the laboratory?

- ☐ Very still
- ☐ Slightly still
- ☐ Slightly draughty
- ☐ Very draughty
- ☐ Moderately still
- ☐ Neutral
- ☐ Moderately draughty

10. In overall, how do you feel while inside the laboratory?

- ☐ Comfort
- ☐ Discomfort
- ☐ Slightly discomfort
- ☐ Very discomfort

General Environment Comments: ____

APPENDIX F

Questionnaire for Welding Workshop

QUESTIONNAIRE FORM

Indoor Air Quality and Thermal Comfort Analysis for Mechanical Engineering Laboratories Complex of UTeM

***Please tick your answer provided carefully. Thanks for your cooperation.**

Date: ________________________ Time: _____________________ (a.m. / p.m.)

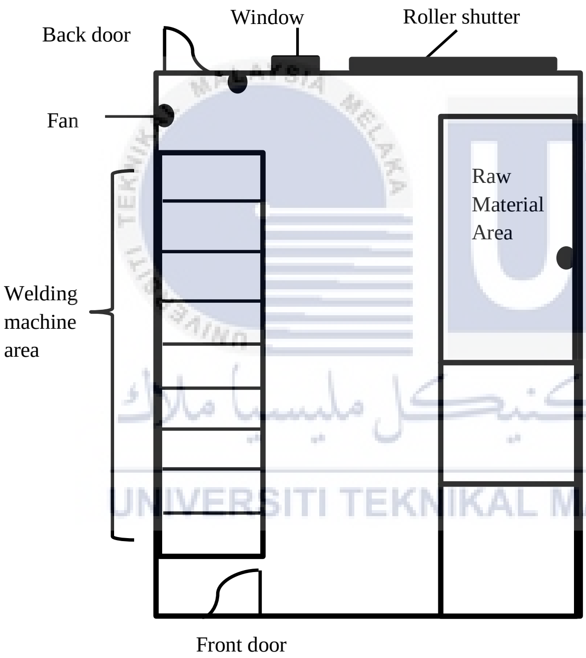
Age: _______ Sex: ☐ Male ☐ Female

Health Condition: ☐ Good ☐ Normal ☐ Not well ☐ Sick

1. How is the outdoor condition?

   ☐ Sunny ☐ Cloudy ☐ Overcast ☐ Rainy ☐ Windy

2. Place "**X**" for your current location in the welding lab.



3. Select only **ONE** of your clothing today. If not in the list below, please write down.

   ☐ Trousers, long-sleeve shirt, socks and boots
   ☐ Trousers, short-sleeve shirt, socks and boots
   ☐ Trousers, long-sleeve shirt, lab coat, socks and boots
   ☐ Trousers, short-sleeve shirt, lab coat, socks and boots
   Others: __________________________

4. What is your activity level right now?

   ☐ Seated
   ☐ Standing relaxed
   ☐ Standing and doing lab work activity

5. How do you feel about the laboratory temperature?

- ☐ Hot ☐ Slightly warm ☐ Slightly cool ☐ Cold
- ☐ Warm ☐ Neutral ☐ Cool

6. Are you satisfied with the temperature inside the laboratory?

- ☐ Yes ☐ No

7. How do you feel about the humidity level inside the laboratory?

- ☐ Very dry ☐ Slightly dry ☐ Slightly humid ☐ Humid
- ☐ Dry ☐ Neutral ☐ Moderately humid

8. How do you feel about the air odor inside the laboratory?

- ☐ No odor ☐ Moderate odor ☐ Very strong odor
- ☐ Weak odor ☐ Strong odor ☐ Overpowering odor

9. How do you feel about the air movement inside the laboratory?

- ☐ Very still ☐ Slightly still ☐ Slightly draughty ☐ Very draughty
- ☐ Moderately still ☐ Neutral ☐ Moderately draughty

10. In overall, how do you feel while inside the laboratory?

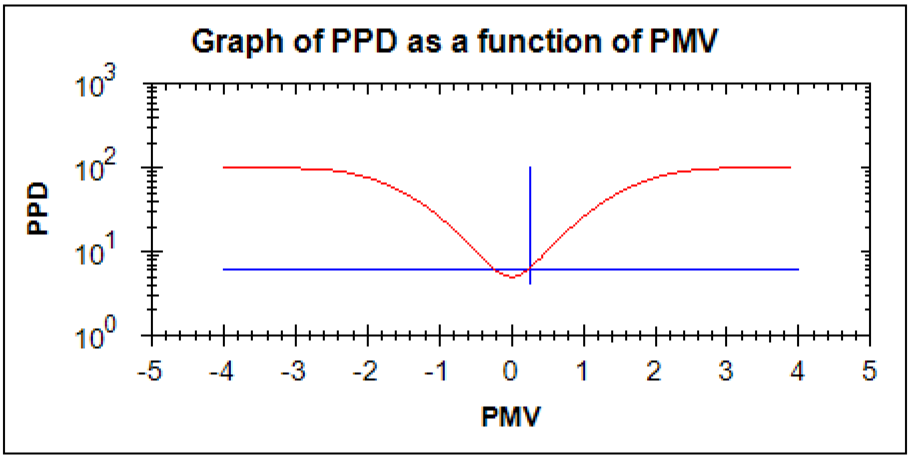
- ☐ Comfort ☐ Discomfort
- ☐ Slightly discomfort ☐ Very discomfort

General Environment Comments: ____

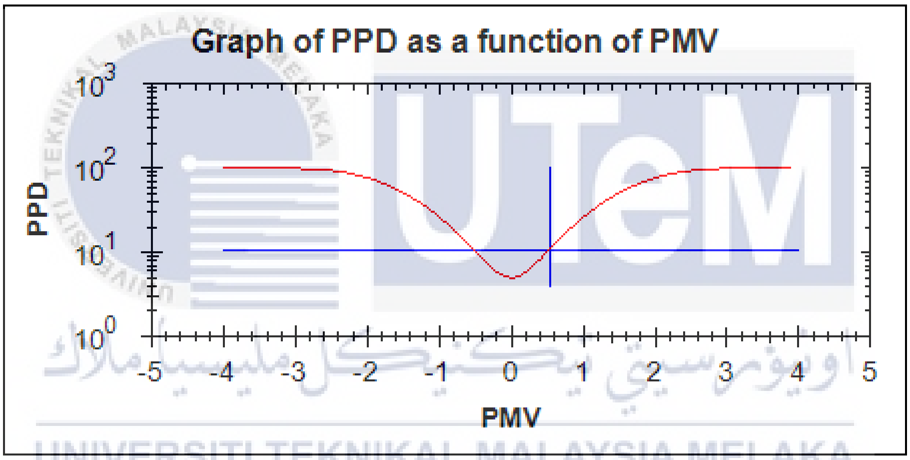
APPENDIX G

Graphs of PPD as a function of PMV for Machine Workshop (No Occupants)

Morning Session (10am to 12pm)



ZONE 1



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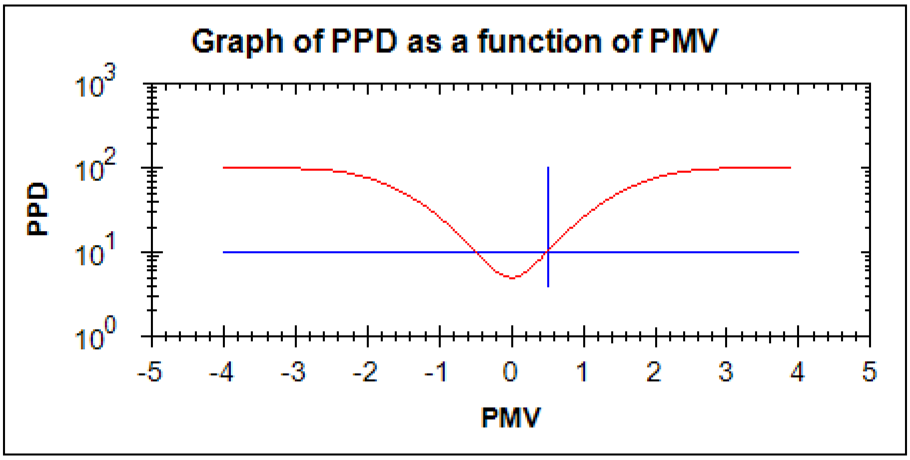
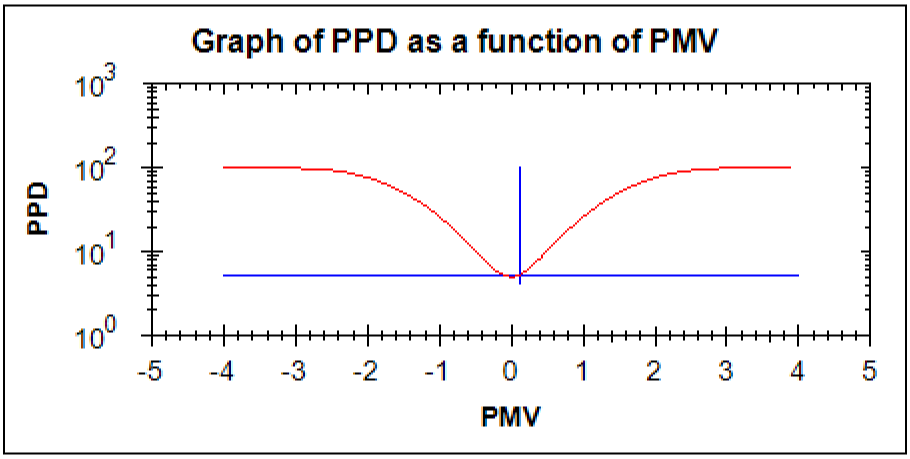


ZONE 3

Afternoon Session (2pm to 4pm)



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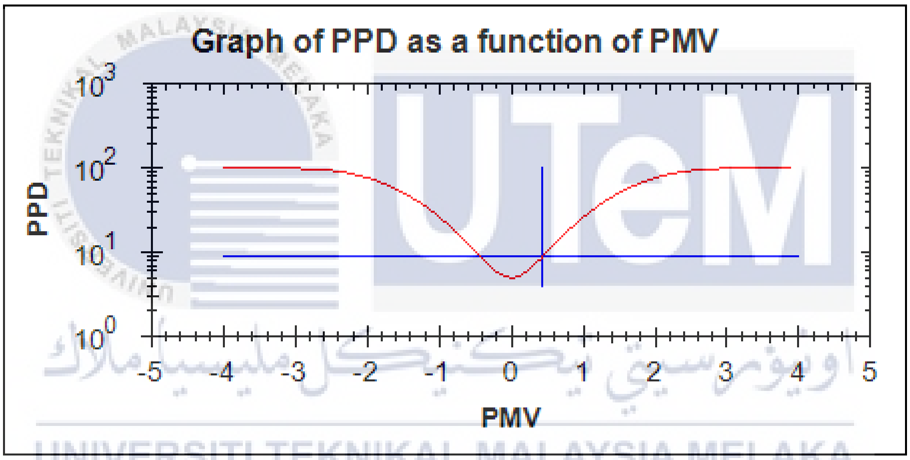

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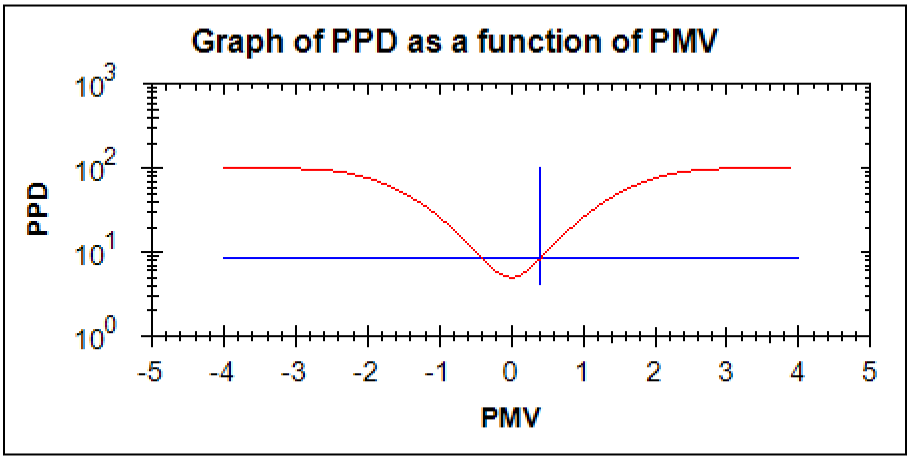
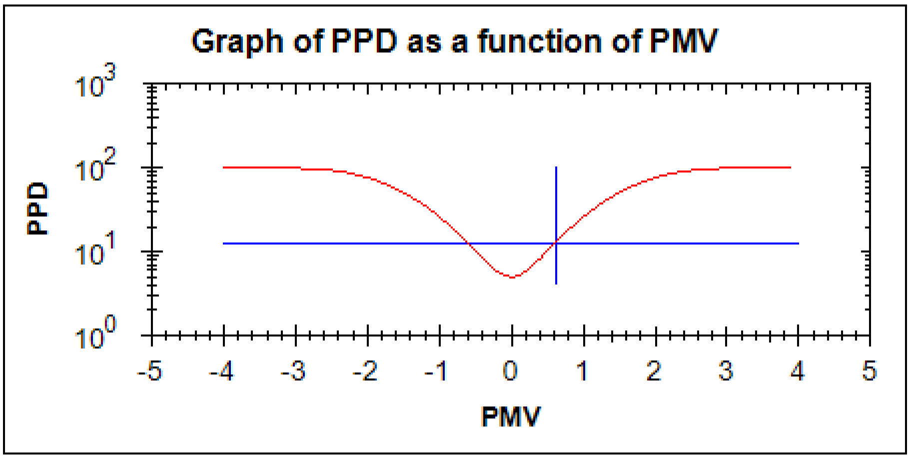


ZONE 3

APPENDIX H

Graphs of PPD as a function of PMV for Machine Workshop (Occupants)

Morning Session (10am to 12pm)



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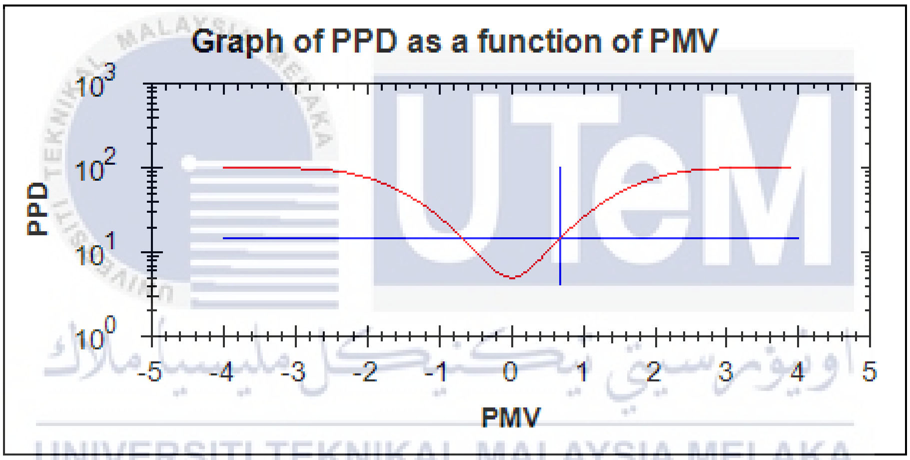

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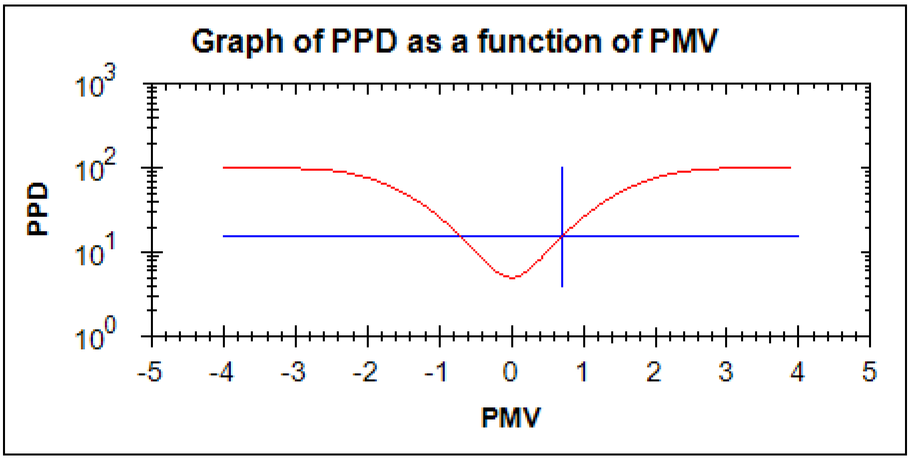
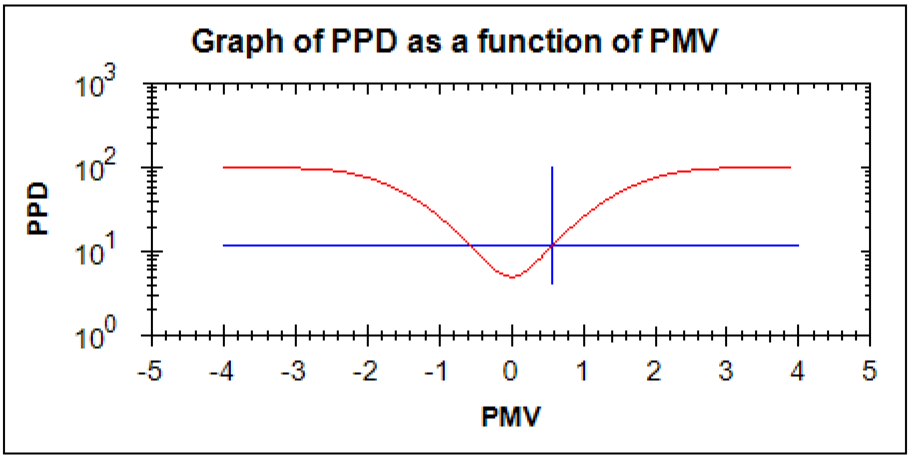


ZONE 3

Afternoon Session (2pm to 4pm)



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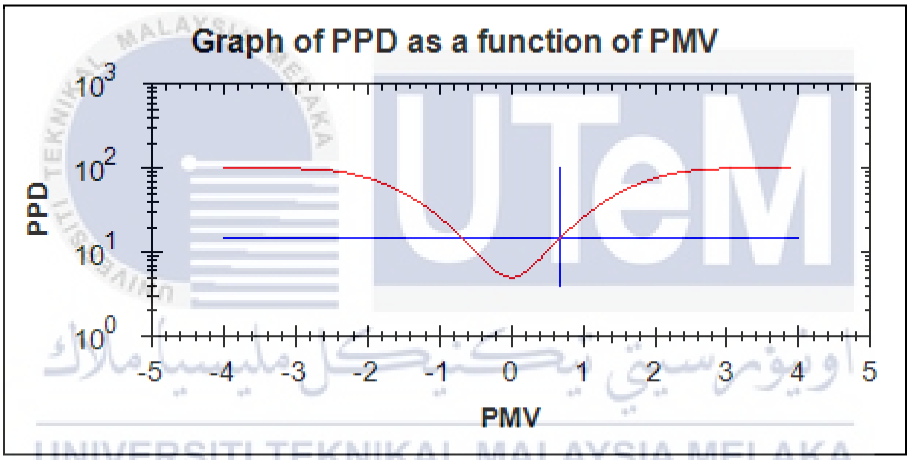
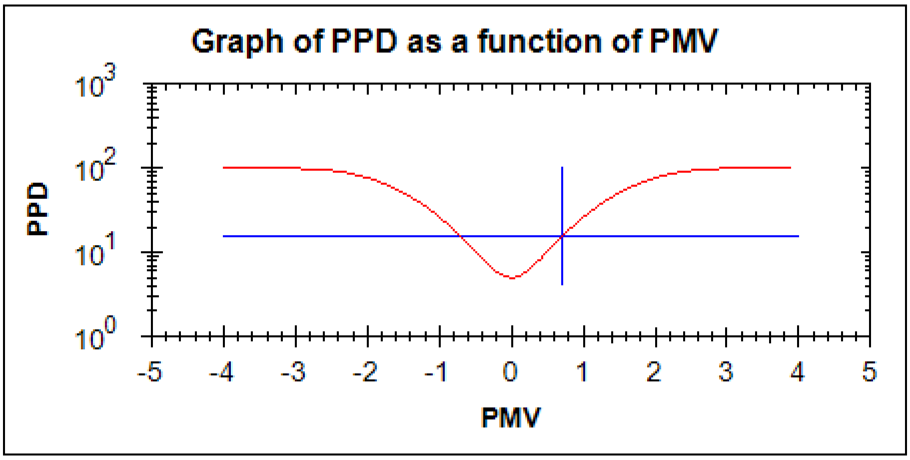


ZONE 2

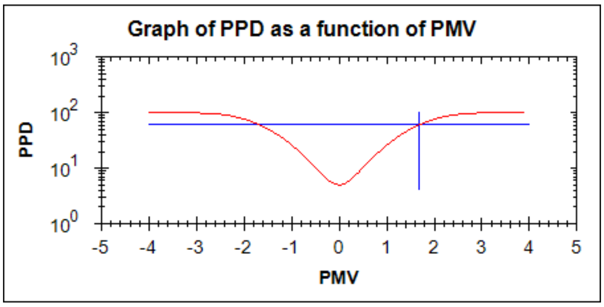


ZONE 3

APPENDIX I

Graphs of PPD as a function of PMV for Machine Workshop (No Occupants)

Morning Session (10am to 12pm)



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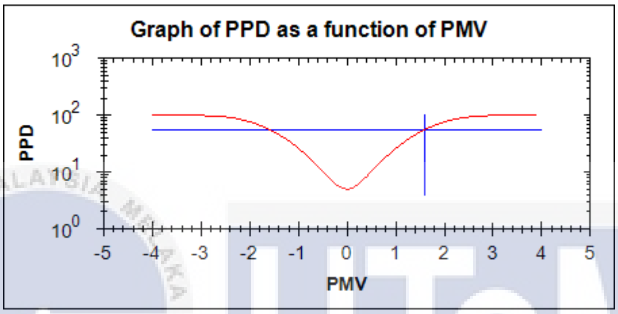

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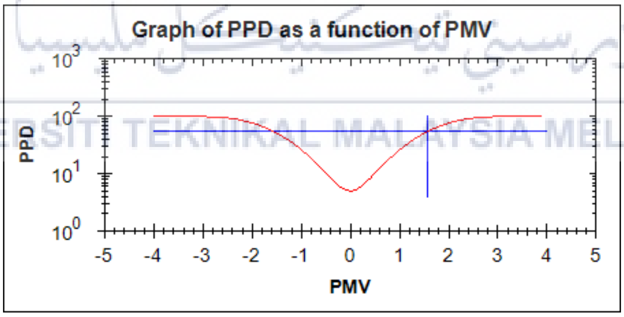

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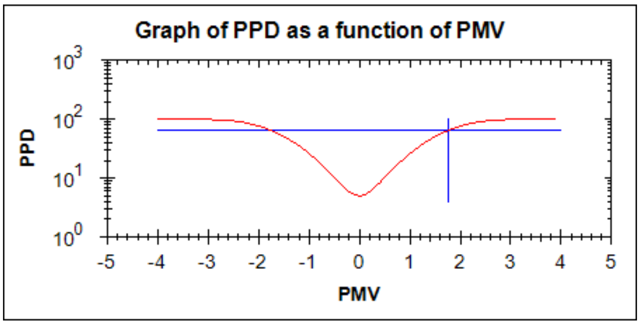

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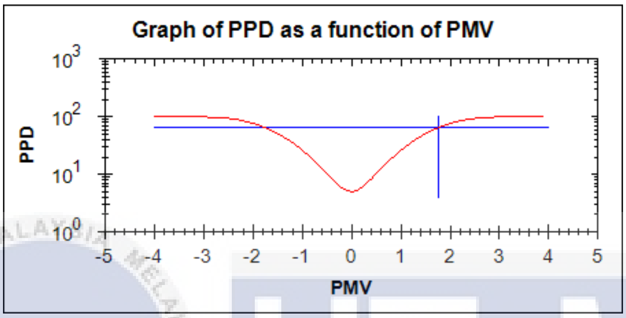
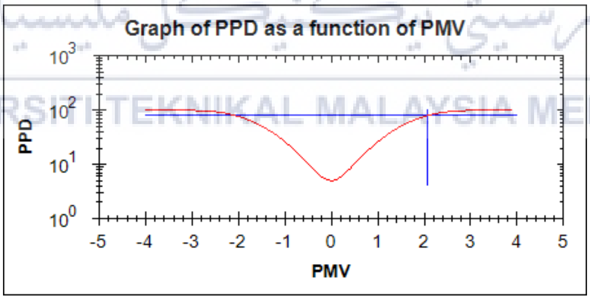


ZONE 5

Afternoon Session (2pm to 4pm)



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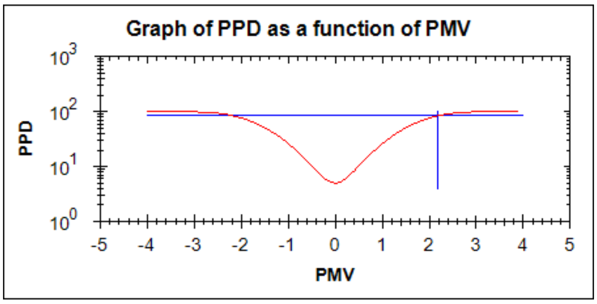

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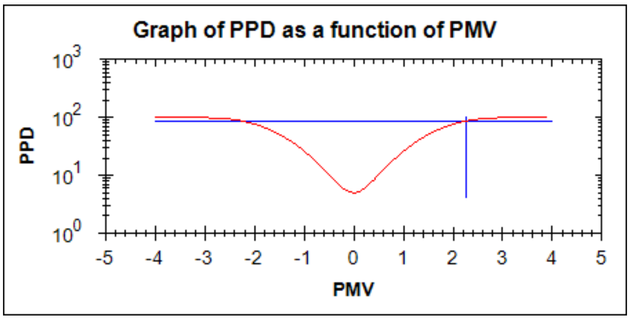

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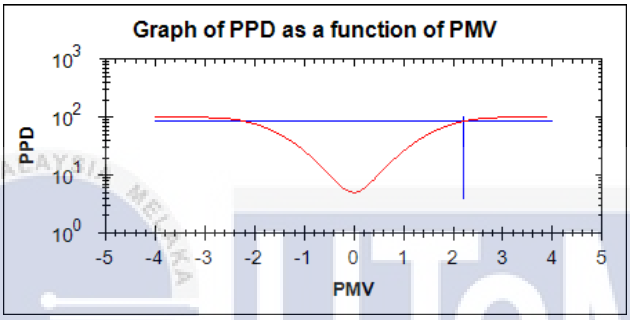

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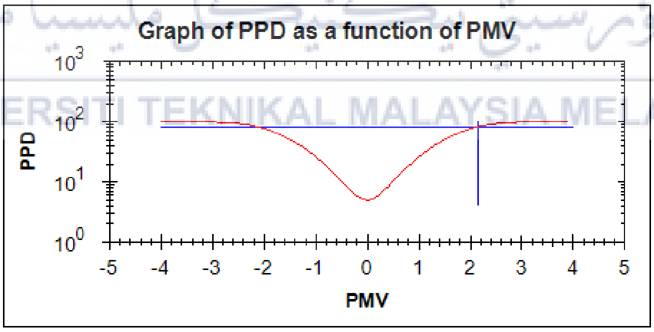
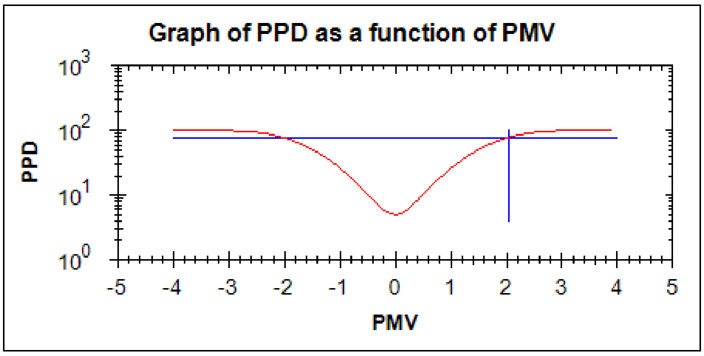


ZONE 5

APPENDIX J

Graphs of PPD as a function of PMV for Machine Workshop (Occupants)

Morning Session (10am to 12pm)



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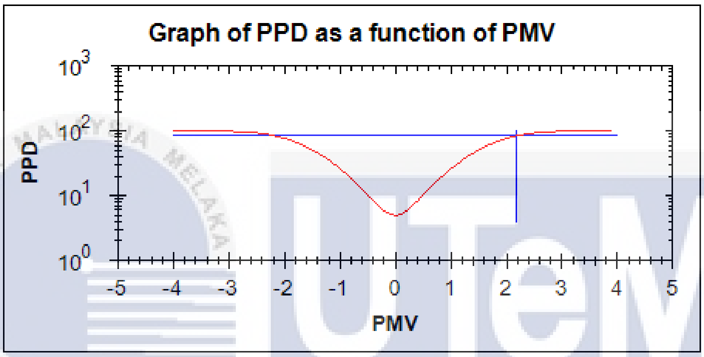
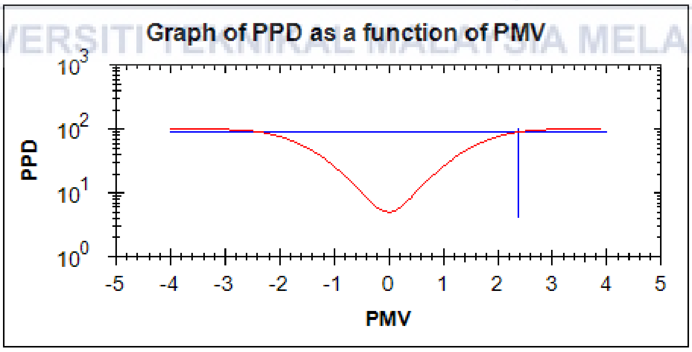
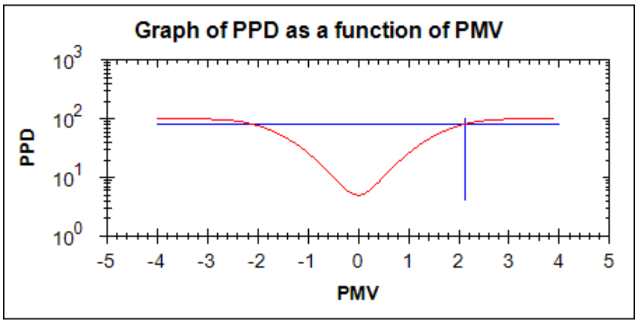


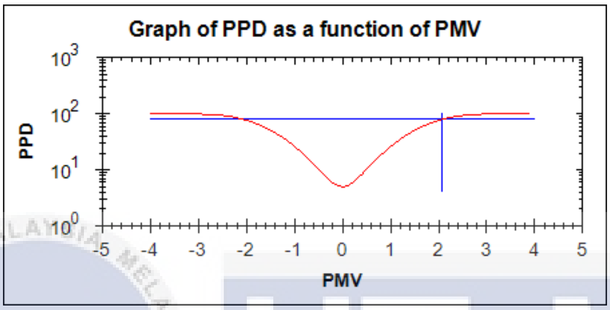
ZONE 2



ZONE 3

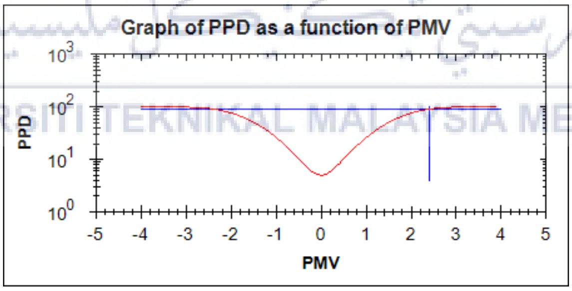


ZONE 4



ZONE 5

Afternoon Session (2pm to 4pm)



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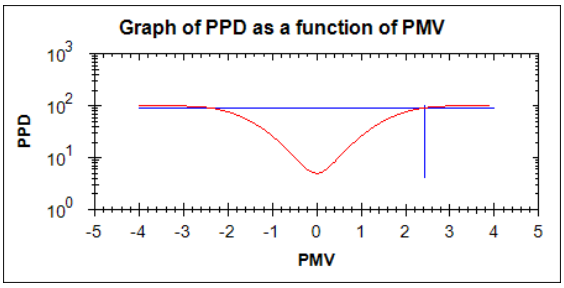
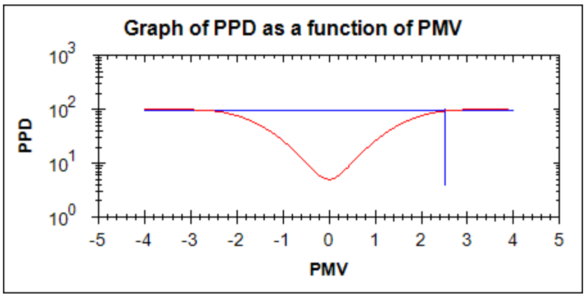


ZONE 2



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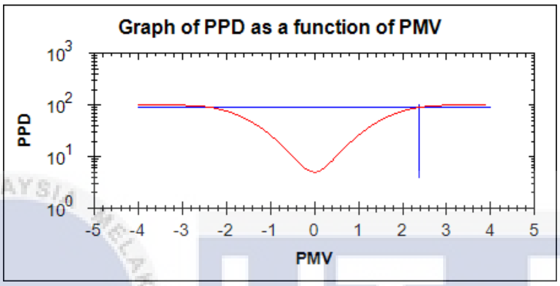

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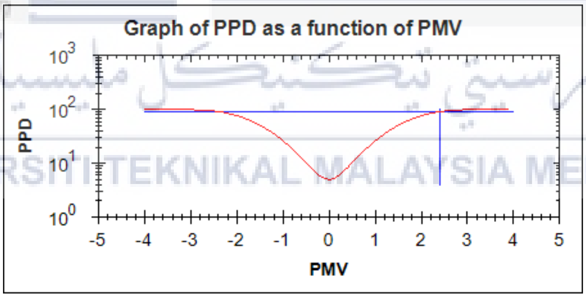
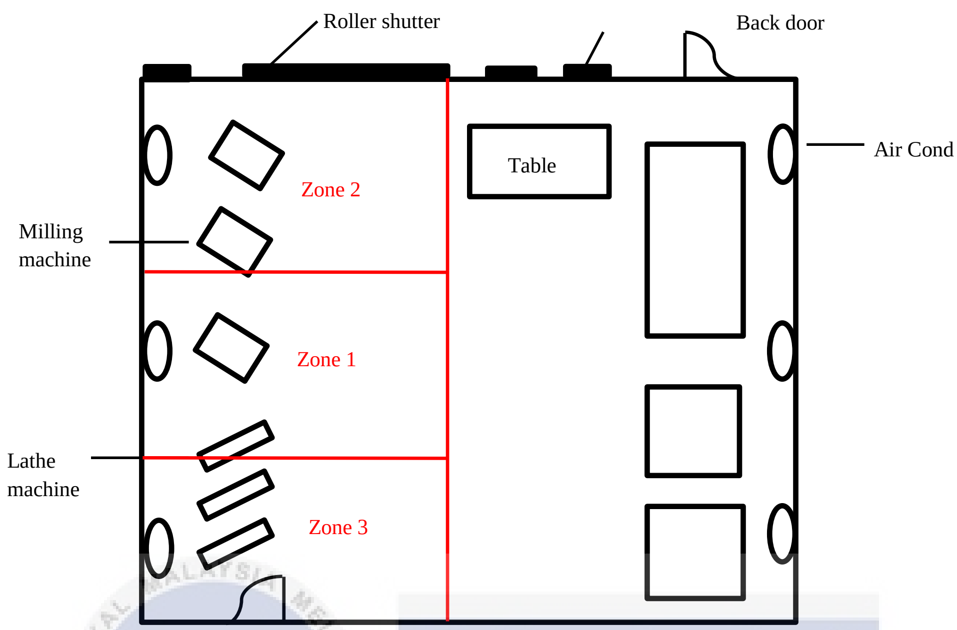


ZONE 5

APPENDIX K

Zone Separation for Machine Workshop and Welding Workshop

Zone Separation for Machine Workshop



Zone Separation for Welding Workshop