THERMAL COMFORT ASSESMENT USING PREDICTED MEAN VOTE (PMV) AND PREDICTED PRECENTAGE DISSATISIFIED (PPD): A CASE STUDY AT SK DURIAN TUNGGAL

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**A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering Technology (Air Conditioning and Refrigeration Systems) with Honors**

Faculty of Mechanical Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DECLARATION

I declare that this Choose an item. entitled "Thermal Comfort Assessment Using Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD): A Case Study at SK Durian Tunggal" is the result of my own research except as cited in the references. Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date : 16/1/2025

APPROVAL

I hereby declare that I have checked this thesis, and, in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Air Conditioning and Refrigeration Systems) with Honors.

Signature :

Supervisor Name : Ts. Dr. Amir Abdullah Bin Muhammad Damanhuri

Date : 16/1/2025

DEDICATION

I would like to dedicate this report with the sincerest appreciation and gratitude to my supervisor, Ts. Dr. Amir Abdullah Bin Muhamad Damanhuri, for his invaluable guidance and encouragement throughout this journey. Above all, thank you to my parents for encouraging me and having greater faith in me than myself to be always persistent. My real appreciation also goes to all friends for their cooperation throughout this report's completion and during data collection at school. Your help and support have been invaluable in the success of this work.

ABSTRACT

In Malaysia, students can spend as long as a third of the day in a classroom; hence, providing thermal comfort to the learning environments is important. Previous research had shown that by establishing a conducive learning environment, it is possible to raise student and teacher productivity, reduce absences, and improve examination results because children will be able to concentrate well in class and they will constantly be allowing new information and developing their thinking systematically. This study aims to investigate indoor data on thermal comfort in the classroom. Data collected was conducted at SK Durian Tunggal, Melaka. All the data were collected for 6 days, and physical measurement were taken using thermal comfort equipment, TSI Velocicalc for outdoor measurement (air temperature, air velocity, and relative humidity). The thermal comfort questionnaire was distributed to 176 students in the classrooms. Based on analysis correlation, as the time increases, PMV and PPD show increased discomfort due to higher temperature and humidity. Correlation analysis showed that sun-facing classrooms, particularly in IBS blocks, experienced increased temperatures, and inconsistent airflow throughout the day. Psychological responses show that inappropriate thermal conditions have a negative impact on students' well-being and concentration during learning sessions. This study successfully assessed the thermal comfort in SK Durian Tunggal classrooms using PMV and PPD index, revealing better comfort levels in the morning with PMV approaching 0 and PPD below 10%, while the afternoon showed higher discomfort with PMV exceeding +1 and PPD reaching 20-30%. Environmental parameters often above DOSH and ASHRAE 55 standards, especially in sun-facing classrooms with inadequate ventilation. Recommendations include exploring adaptive strategies, redesigning school uniforms for heat stress reduction, and implementing advanced hybrid ventilation systems to improve air circulation and indoor air quality for an enhanced learning environment.

ABSTRAK

Di Malaysia, pelajar boleh menghabiskan sehingga satu pertiga daripada hari mereka di dalam bilik darjah; oleh itu, menyediakan keselesaan termal kepada persekitaran pembelajaran adalah penting. Penyelidikan terdahulu telah menunjukkan bahawa dengan mewujudkan persekitaran pembelajaran yang kondusif, adalah mungkin untuk meningkatkan produktiviti pelajar dan guru, mengurangkan ketidakhadiran, dan memperbaiki keputusan peperiksaan kerana kanak-kanak akan dapat menumpukan perhatian dengan baik di dalam kelas dan mereka akan sentiasa menerima maklumat baru dan mengembangkan pemikiran mereka secara sistematik. Kajian ini bertujuan untuk menyiasat data dalaman mengenai keselesaan termal di dalam bilik darjah. Data yang dikumpul dijalankan di SK Durian Tunggal, Melaka. Semua data dikumpul selama 6 hari, dan pengukuran fizikal diambil menggunakan peralatan keselesaan termal, TSI Velocicalc untuk pengukuran luar (suhu udara, kelajuan udara, dan kelembapan relatif). Soal selidik keselesaan termal diedarkan kepada 176 pelajar di dalam bilik darjah. Berdasarkan analisis korelasi, apabila masa meningkat, PMV dan PPD menunjukkan ketidakselesaan yang meningkat disebabkan oleh suhu dan kelembapan yang lebih tinggi. Analisis korelasi menunjukkan bahawa bilik darjah yang menghadap matahari, terutamanya di blok IBS, mengalami peningkatan suhu dan aliran udara yang tidak konsisten sepanjang hari. Tindak balas psikologi menunjukkan bahawa keadaan termal yang tidak sesuai mempunyai kesan negatif terhadap kesejahteraan dan tumpuan pelajar semasa sesi pembelajaran. Kajian ini berjaya menilai keselesaan termal di bilik darjah SK Durian Tunggal menggunakan indeks PMV dan PPD, mendedahkan tahap keselesaan yang lebih baik pada waktu pagi dengan PMV menghampiri 0 dan PPD di bawah 10%, manakala waktu petang menunjukkan ketidakselesaan yang lebih tinggi dengan PMV melebihi +1 dan PPD mencapai 20-30%. Parameter persekitaran sering melebihi piawaian DOSH dan ASHRAE 55, terutamanya di bilik darjah yang menghadap matahari dengan pengudaraan yang tidak mencukupi. Cadangan termasuk meneroka strategi adaptif, mereka bentuk semula pakaian seragam sekolah untuk pengurangan tekanan haba, dan melaksanakan sistem pengudaraan hibrid maju untuk meningkatkan peredaran udara dan kualiti udara dalaman untuk persekitaran pembelajaran yang lebih baik.

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In the Name of Allah, the Most Gracious, the Most Merciful

First and foremost, I would like to express my gratitude to Allah S.W.T the Almighty, Most Gracious, my Sustainer for His blessing that enabled me to finish this thesis and my studies. May Allah S.W.T be gracious to the final Prophet Muhammad, his family, and his companions.

First and foremost, I would like to extend my deep sense of gratitude to my project supervisor, Ts. Dr. Amir Abdullah Bin Muhamad Damanhuri, for this opportunity to work on this. His guidance and advice meant so much to me throughout my thesis writing. I would also like to thank all my committee members for giving my defense an enjoyable moment and your brilliant comments and suggestions; thank you.

Finally, I would like to give my special thanks to my family, who have continuously supported and put up with me during the pursuit of undertaking my research and the writing of this thesis. Your prayer for me has been what carried me thus far. Finally, to all who have helped, supported, and inspired me to proceed with my study.

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LIST OF SYMBOLS AND ABBREVIATIONS

Clo	-	Clothing insulation (m^2/K. W)
Ta	-	Air temperature (℃)
V	-	Air velocity (m/s)
RH	-	Relative humidity (%)
Tmrt	-	Mean radiant temperature
Met	-	Metabolic rate
PMV	-	Predicted Mean Vote
PPD	-	Predicted of Percentage Dissatisfied
SET	-	Standard Effective Temperature (℃)
DOSH	-	Department of Occupational Safety and Health
ASHRAE	-	American Society of Heating, Refrigeration and Air-conditioning
CBE	-	Centre for The Built Environment

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CHAPTER 1

INTRODUCTION

1.1 Background

Thermal comfort can be defined as that state of mind which expresses satisfaction with the surrounding thermal environment. It is a subjective experience and is related to many environmental and personal influences, which include air temperature, humidity, air velocity, and mean radiant temperature in the environment. Personal factors include clothing selection and activity level, which can be combined and is referred to as metabolic rate. Contributing factors include food and drink, acclimatization, age and sex, body shape, subcutaneous fat, and health status (P.O Fanger, 1970).

Students can spend as long as a third of the day in a classroom; hence, providing thermal comfort to the learning environments is important. On the other hand, by creating a suitable learning environment it can improve scores, reduce absent days, and elevate the productivity level among both the children and teachers since a child will focus intensively inside the classroom in that they will always be assimilating new concepts and developing thinking systematically (Wargocki & Wyon, 2013). From primary school to high school, it is common for students to be made to adopt uniforms. Typically, those who do not wear them and who have a cursory understanding of activity-related metabolic rates and experiences specify and design these uniforms.

Thermal comfort is one of the most important aspects of environmental design, which has a significant impact on the well-being and productivity of individuals in a variety of settings. (PMV) Predicted Mean Vote and (PPD) Predicted Percentage Dissatisfied are among the key metrics for thermal comfort assessment. The widely used PMV allows for the effective prediction of the average thermal sensation for a large group of people, ranging from -3 (representing cold) to +3 representing heat and 0 as thermal neutrality. It considers variables such as air temperature, humidity, air velocity, radiant temperature, clothing insulation, and metabolic rate. In contrast, PPD augments the PMV index by considering the percentage of people who may be dissatisfied due to the thermal environment.

It provides an estimate of the proportion of occupants who may feel uncomfortable even if conditions are optimized for most people. Therefore, PMV and PPD can be considered together as key facilitators needed in the design and assessment process of interiors that will facilitate comfort environments that ensure thermal comfort to the majority and thus assist both engineers and architects. This is a presentation widely used in standards such as ISO 7730 and ASHRAE 55 to support thermal comfort assessments.

1.2 Problem Statement

A building's thermal comfort levels promote students' productivity throughout class. Extreme temperatures affect students' and learning performance in classroom, which reduces student's participation and enjoyment. Comfort levels are impacted by temperatures in classrooms that are frequently higher than what is recommended (Wan Muhammad Aidil Wan Azali, 2019). Teachers and students complained that they felt uncomfortable in the classroom building during the teaching and learning session.

This study aims to utilize the CBE Thermal comfort Tools to evaluate the comfortable during learning hours. By take the advantage of these tools, this study can accurately measure key parameter such as air temperature, air velocity, relative humidity and mean radiant temperature. PMV and PPD was a key component of the study's approach. According to the study, PMV and PPD can help address the issue statement when paired with other variables (Sahimi et al., 2024).

1.3 Research Objective

The main aim of this research is to expose the results of a field study based on thermal comfort using PMV (predicted mean vote). Specifically, the objectives are as follows:

a) To investigate indoor data on thermal comfort of classroom at SK Durian Tunggal.

b) To examine the (PMV) predicted mean vote and (PPD) predicted percentage dissatisfied of classroom using CBE tools at SK Durian Tunggal.

1.4 Scope of Research

The scope of this research is as follows:

a) The parameters that will be measured in this study based on thermal comfort are air temperature (Ta), mean radiant temperature (Tmrt), air velocity (v), and relative humidity (RH).

b) The scope of the study focused on students aged 9 - 12 years (SK Durian Tunggal) by collecting information about thermal comfort and heat tolerance level in naturally ventilated classrooms. The scope is focused on 6 classes according to grades 3 to 6.

c) Examine potential variables such as age group differences, gender differences, or clothing practices that may affect school children's thermal comfort. Take into consideration the potential interactions between a building's architectural elements and its surroundings and how each person experiences comfort.

d) The predicted mean vote and predicted percentage dissatisfied index will be calculated using CBE thermal comfort tools version 2.5.6.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Extreme heat waves that have hit our society in recent years are dangerous for both our health and the environment. Every building, including schools, has unique microclimatic needs. How well students can learn and engage with one another is directly correlated to the temperature of the classroom. These days, creating a suitable thermal environment in a building remains one of the most important aspects to consider. Along with other factors like air quality, light, and acoustics, the thermal environment is evaluated.

If occupant's daily environment is uncomfortable, it is expected that their performance would suffer and this will affect their work (Nur Farzana Ku Adzman et al., 2020). Maintaining thermal comfort in classrooms is important for the well-being of students and their ability to learn, the expectations of thermal comfort during the schooling stage vary (Torriani et al., 2023). The structure in which the residents reside is important for creating a pleasant atmosphere. For example, they must have comfortable temperatures in the building area. This chapter will provide an overview of previous studies and data about thermal comfort and (P.O Fanger, 1970) model.

2.2 School in Malacca

According to the Malaysia Education Ministry (2020), there are 238 schools in Malacca, including both urban and suburban areas, out of the 7,780 primary schools in the country of Malaysia. According to Malaysia's national education system, the goal of elementary school is to give children a solid foundation in fundamental literacy and numeracy, as well as to encourage critical thinking and a sense of unity and national identity. Figure *2.1* below show the percentage of children (under 18 years), by state in Malaysia, 2022.

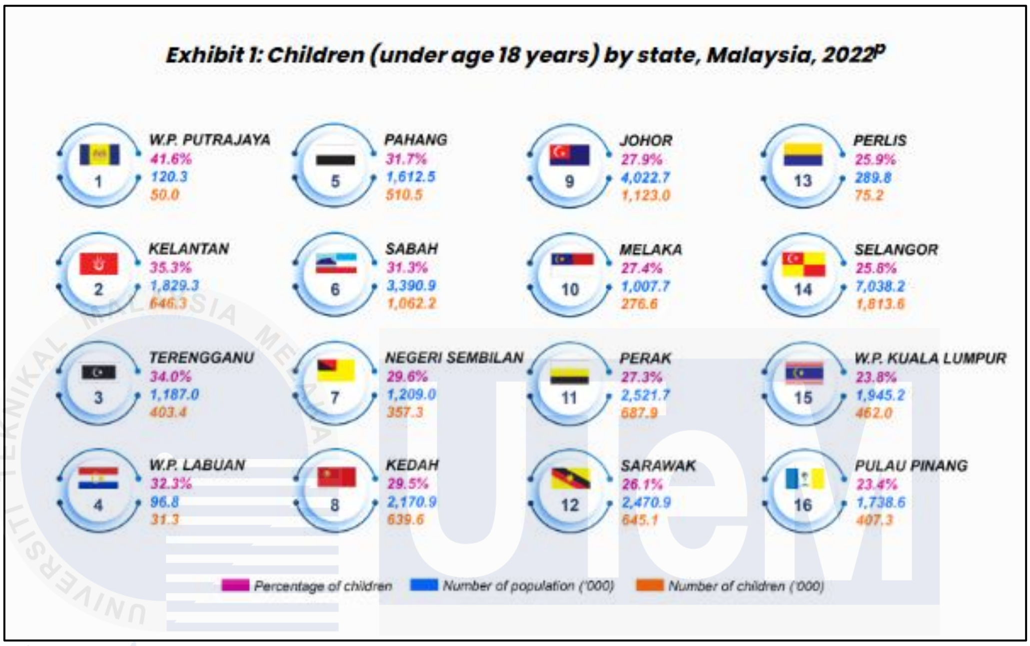

Figure 2.1 Percentage of children (under age 18 years), by state in Malaysia, 2022

(Department of Statistical Malaysia, 2020)

The location of the primary school at roadside, residential area, or even in school area. Not just that, the other parents will send their children to private primary school rather than government school. Smaller class sizes for more individualized attention, a more comprehensive and frequently flexible curriculum, access to better facilities and resources, a strong emphasis on academic excellence.

The climate and comfort of a classroom are important aspects of the teaching and learning process when it comes to education. Furthermore, a lot of outdoor learning opportunities are made practical with the tropical climate, which encourages environmental awareness and good health. In Malaysia, there were about 98.64 thousand children registered in private secondary schools in 2021—a little drop from the year before. In Malaysia, there are three types of private secondary schools which is Chinese-language schools, academic schools, and religious schools. Figure *2.2* shows the number of children registered in Malaysian private schools between 2012 to 2021.

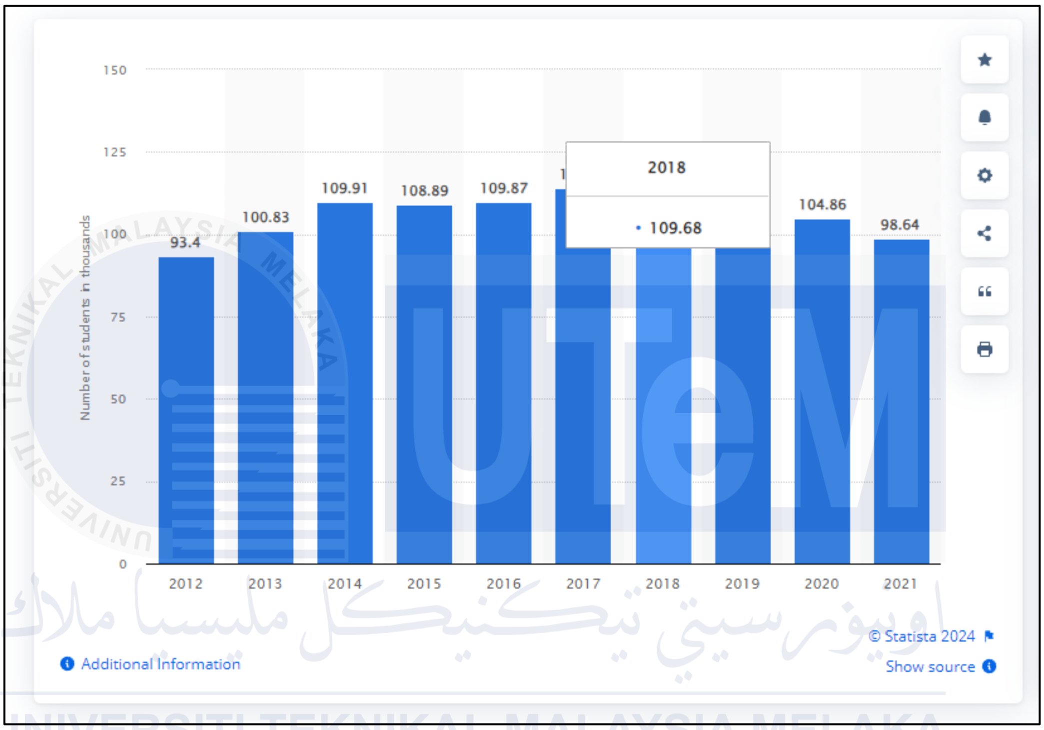

Figure 2.2 Number of children registered in Malaysian private school between 2012 to 2021 (Malaysia: Private Secondary School Students Numbers, 2023)

2.3 Overview of Thermal Comfort

Thermal comfort is described as "the condition of mind that expresses satisfaction with thermal environment and is determined by subjective evaluation – ASHRAE 55" by the American Society of Heating, Refrigerating, and Air-Conditioning (ASHRAE). Due to Malaysia's tropical environment, which is humid and hot all year round, ASHRAE 55's suggested indoor design temperature and relative humidity are not entirely correct. The recommended indoor design temperature and relative humidity are, according with the

Department of Standards Malaysia (DOSM), 23°C to 26°C and 60% to 70%, respectively.

A state of mind that expresses satisfaction with the thermal surroundings is called thermal comfort. It has played an important part in improving everyone's quality of life, including for children who spend a lot of time in the classroom (Hamzah et al., 2020).

To talk about thermal comfort, it is mostly about how comfortable people feel in warmed spaces, particularly in classrooms and schools (Aparicio-Ruiz et al., 2021). To ensure wellness, it is imperative to conduct research on adaptable thermal comfort, cooling and ventilation systems, and variations in comfort levels between adults and children in learning environments.

When someone is content with the temperature around them, they have reached it (Yang et al., 2018). With typical daily temperatures ranging from 24 to 34°C, maintaining thermal comfort is essential for productivity and well-being in Malaysia's hot and humid tropical climate. Thermal comfort is hard to achieve naturally because of the high humidity (on average more than 80% for most of the year), which is compounded by the absence of wind flow (Aziah & Ariffin, 2015).

In Malaysia, students usually adjust the air conditioning (AC) system's temperature to preserve thermal comfort in university classes and classrooms are built for either free running (FR) or mechanical cooling (CL) modes, and students frequently adjust the AC temperature to stay comfortable (Zaki et al., 2017).

Moreover, to improve thermal comfort, most buildings in Malaysia use mechanical fans and natural ventilation to supply fresh air. For the upcoming academic year, the Ministry of Education (KPM) will continue to enforce the current policy requiring students to wear uniforms two days a week (Noor Atiqah Sulaiman, 2024). Research shows that enhanced performance in school has to do with a comfortable temperature environment. Children who are not disturbed by heat discomfort are more likely to participate fully in class activities and score highly on tests.

2.4 Thermal Comfort Among School Children

Children comfort levels and temperature sensitivity are higher during the summer months (Korsavi & Montazami, 2020). Thus, the ages of the elderly should be considered in the development of the building to guarantee that they can achieve their optimal degree of thermal comfort. Schools must create a cozy environment for the benefit of children's health as well as their academic performance.

Since no significant complaints have been made regarding it in Nepalese schools, the current level of children's thermal comfort in school buildings in the country's temperature climate (Shrestha & Rijal, 2023). A mid-autumn 2017 poll focused on the indoor temperature environment and associated thermal perception. The survey was completed by 818 children in total.

The inside globe's temperature was almost the same as the outside air when sufficient natural light was coming in. Nearly 75% of the children found the average temperature of 27 ℃ to be comfortable. Because they wore better insulation clothing, it is probable that children will experience a lower estimated comfort temperature. Children dress less, even despite the clothing regulation, to better suit the outside thermal environment where the air temperature is above 30 ℃. The variables that influenced the thermal comfort temperature range were the age of the study participants, building type, ventilation, and climate.

Older children have a different temperature tolerance than younger children. The most frequent adaptive activities were opening windows, utilizing fans or air conditioning, and adjusting clothing (Arsad et al., 2023). In Nepalese school buildings, building age, ventilation methods, and environmental elements affect behavioral adjustment while ignoring the importance of thermal temperature for children's health and academic performance. The advantage of using simulation to implement passive design measures, which may be done either after the fact or during the planning stages to determine the structure's thermal comfort characteristics (Shrestha & Rijal, 2023).

The previous study examined all educational stages in one place to reduce the potential bias related to operating mode, climatic zone, and cultural adaptability. (Torriani et al., 2023). It is reasonable to conclude from this study that the only factor influencing any variance in people's perceptions of the thermal environment was their educational background. The findings showed that a decrease in adaptation capacities, such as the capacity to open windows and wear clothes with insulation, is linked to lower levels of education.

The ideal, neutral, and comfortable temperatures tend to increase with increasing school levels. For example, 20.6 °C is appropriate for primary school, middle school, high school and university. Furthermore, a linear relationship was found between children's age and neutral body temperature. The different predictive abilities of the predicted mean vote reflect these differences in thermal comfort expectations, which had the largest deviation between predicted and actual thermal sensations in primary school. In summary, the results of this study support the idea that thermal comfort models are needed.

This study aims to discuss thermal comfort and school architecture in Brazil using paradigm of the Anthropocene (Rocha & Nachez, 2023). The Anthropocene is defined as a period in which local and global daily life is affected by climate change at a biopolitical level. The importance of this environmental emergency is recognized.

In the study, the researchers argue that in an Anthropocene scenario, biosecurity requirements can best be met through curricular aspects combined with school architecture. Brazilian laws regulations regarding school design, climate management and public funding are investigated.

A study by (Mba et al., 2022) investigated how different classroom orientations with respect to wind and wind direction affect the ideal amount of natural ventilation for children's comfort in hot weather. The study found a relationship between classroom building orientation and effective natural ventilation coefficient. The average natural ventilation efficiency was 80%, which is significantly higher than the 60% ventilation efficiency requirement worldwide.

Positioning the classroom building's intake window areas facing the prevailing wind direction had a statistically significant positive effect on the efficiency of natural ventilation, which in turn influenced the thermal comfort conditions of the classrooms studied.

For most children, their daily lives revolve around their primary school grounds. The educational environment has a significant impact on children's health and wellbeing. Currently primary school campuses are often built in accordance with current regulations, but that does not mean they are not exposed to potentially dangerous temperatures. To find out more about these, researchers conducted a temperature perception survey in a typical outdoor area of a primary school campus in Guangzhou, China (Guo et al., 2024).

According to the study, the most important meteorological factors influencing children's perception of heat are air temperature and radiant temperature. When it comes to landscaping, children are attracted to large trees and evergreens planted in communities or individually. Architects and landscapes planners can use the recommendations of this study to their advantage when designing elementary school campuses.

2.5 Factors that Affect Thermal Comfort

To estimate PMV and PPD, six factors affecting an individual's thermal comfort must be computed. The four environmental factors are humidity (RH), air velocity (V), mean radiant temperature (Tmrt), and air temperature (Ta); the two personal aspects are the occupants' metabolic rate (met) and the clothing insulation (clo value). The factors that will be covered below will help the person present feel comfortable in the weather.

Figure 2.3 Factor that effect thermal comfort

Source: https://images.app.goo.gl/5BpcpwfYG3HWLLgg7

The selected parameter is relative humidity (RH). The ratio of the saturation vapor pressure of water at a given temperature to the partial pressure of water vapor in the air, represented as a percentage, is known as relative humidity (Reda et al., 2022). A study that created an adapted model for Southeast Asia's hot, humid climate found that naturally ventilated structures had a comfort equation that was comparable to the ASHRAE adaptive model (Amaripadath et al., 2023). While some standards, like ASHRAE 55, do not include any relative humidity criteria, many others, including EN 16798, ISO 7730, and BIS NBC provide both an upper and lower threshold value. While the humidity signal is absent in the equations for adaptive models, the relationship between humidity and thermal comfort models is more obvious in PMV/PPD models.

Occupational Health and Safety Management suggest that the percentage in office building is 40% to 60% (Amaripadath et al., 2023). As comfort is achieved, it can prevent the evaporation of sweat from the skin from evaporating. Low humidity can make your nose, eyes, and throat dry, while high humidity above 80% can make you feel tired and give you a "stuffy" feeling.

Second parameter was air velocity. Air velocity affects rapid loss of heat for the average parts of the tropical region. Evaporation is boosted, and the body is cooled. Ensuring indoor air quality, energy efficiency, and comfort all depend on accurate air velocity monitoring. In HVAC systems, increasing air velocity can result in energy savings and better system performance. In a heated, humid environment, computer-controlled streams that are colder than the ambient air temperature can produce a welcome breeze (Kim Perron, 2022). According to (ASHRAE standard 55-2010, 2013), the optimal air speed range for interior areas is 30–40 fpm. High-performance demand control mechanical ventilation can be achieved by an ERV with controls, guaranteeing ideal ventilation and thermal comfort.

Thirdly, mean radiant temperature (Tmrt). The radiant temperature is a function of the quantity of heat radiated off a surface and is determined by the emissivity, or capacity, of the material to absorb or release heat. The view factor, the temperatures of the neighbouring surfaces, and the emissivity all affect the mean radiant temperature. People, windows, floors, walls, radiators, and even other objects can release and absorb heat or cold, particularly if the building envelope or insulation are inadequate (Kim Perron, 2022).

The impact of environmental elements, building age, and ventilation systems on behavioural adjustment in Nepalese school buildings is noteworthy. However, the importance of thermal temperature for children's health and academic performance is often overlooked.

Air temperature is an important parameter in thermal comfort. The average temperature of the air around an occupant, considering time and location, is called the air temperature. The spatial average, as per the ASHRAE 55 standard, accounts for the head, waist, and ankle levels of occupants, which differ depending on whether they are seated or standing.

The temperature in Celsius (°C) is utilized, and the value for each occupant will vary. In Malaysia, the office building's air conditioning system was set to maintain a comfortable temperature between 20 and 26 °C (Malaysia. Kementerian Sumber Manusia. Jabatan Keselamatan dan Kesihatan Pekerjaan., 1996).

Metabolic rates explain that individuals differ in their rates of metabolism, which might change depending on their level of activity and the surroundings. According to (ASHRAE standard 55-2010, 2013), metabolic rate is the rate at which an individual's metabolic activities convert chemical energy into heat and mechanical work per unit of skin surface area. The metabolic rate of an individual is expressed as 1 met, or 18.4 Btu/hr-ft2, and fluctuates with activity. For example, using heavy machinery or sitting in an office can indicate different amounts of metabolic activity. Table *2.1* below shows metabolic rate for typical tasks (ASHRAE standard 55-2010, 2013).

Table 2.1 Metabolic rate for typical tasks (ASHRAE standard 55-2010, 2013)

Activity	**Met units**	**Metabolic rate (W/m2)**
Sleeping	0.7	40
Seated, reading, writing	1.0	60
Typing	1.1	65
Standing, relaxed	1.2	70
Walking level surface (3.2 km/h)	2.0	115
Driving automobile	1.0-2.0	60-115
House cleaning	2.0-3.4	115-200
Dancing, social	2.4-4.4	140-225

Although the main goal of clothes is to keep one warm, some occupations, like smelting or firefighting, also require protective clothing to keep one cool. In terms of thermal comfort, just the initial scenario is taken into consideration. Clothing insulation is a measurement of how well an item of clothing blocks the transfer of heat. For comfort and safety in a variety of climatic circumstances, clothing insulation effectiveness is important.

When the body loses heat more quickly than it can generate it, the core body temperature falls below normal, leading to hypothermia. Hypothermia, which is characterized by shivering, delayed breathing, and cognitive impairment, can result from prolonged exposure to cold temperatures with inadequate clothing insulation. It is possible for severe hypothermia to be harmful.

Clo units are a way to express clothing insulation. Insulation used in both residential and commercial buildings is referred to by this code, with higher values indicating superior thermal resistance. One Clo = 0.155 $K \cdot m^2 \cdot W^{-1}$. Based on Figure *2.4* below show the insulation of clothing in clo unit based on type of insulation although Table *2.2* and Table *2.3* is the checklist for clothing insulation and underwear in clo units.

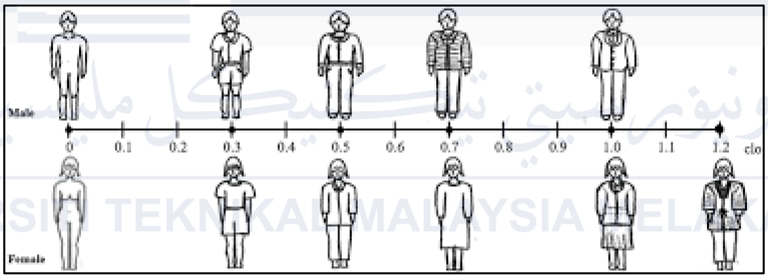

Figure 2.4 Insulation of clothing in clo unit

Source: (Rijal et al., 2019)

Table 2.2 Underwear in clo values (ASHRAE standard 55-2010, 2013)

Clothing	**Clo**
Bra	0.01
Panties	0.03
Men’s briefs	0.04

Table 2.3 Clothing checklist and insulation (clo) values (ASHRAE standard 55-2010, 2013)

Clothing	Light weight	Medium weight	Heavy weight	Description
Footwear	0.02	0.03	0.60	Knee socks (thick), calf – length socks
Shirts and blouses	0.12	0.19	0.34	Sleeveless- short sleeves, Long sleeves
Trousers and coveralls	0.06	0.24	0.49	Shorts, straight pants thin and thick, sweatpants, coveralls
Dress and skirts	0.14	0.23	0.47	Skirt thin and thick, scoop neck thin and thick, short-long sleeve think and thick
Sweaters	0.13	0.25	0.36	Sleeveless vest thin and thick, long sleeve thin and thick
Suit Jacket and Vest	0.1	0.36	0..42	Sleeveless vest thin and thick, single -breasted
Sleepwear	0.18	0.31	0.69	Sleeveless short and long, short sleeve pyjamas thin, long sleeves thin and thick, long sleeve pyjamas thick

Clothing changes are the most effective way for occupants to adjust to a heated environment and plays an important part in achieving thermal comfort. In Malaysia, students who were female tended to have less clothing insulation than students who were male, whereas in Japan, both male and female students had less clothing insulation than those in Malaysia (Zaki et al., 2017). In another study, when chair insulation is added to ensemble insulation as compared to ensemble insulation alone, a greater impact of clothing insulation (clo) on students has been observed (Rupp et al., 2021). The Table *2.4* shows the summary of study and sample size (Zaki et al., 2017).

Table 2.4 Summary of study and sample size

Author	N	Insulation issue with cloth
(Yang et al., 2018)	150	Overheating issue
(Wu & Wagner, 2024)	450	Behavioural adaptation
(Zaki et al., 2017)	1428	Behavioural adaptation
(Wan Muhammad Aidil Wan Azali, 2019)	56	School attire toward female student
(Hamzah et al., 2018)	1594	Different type of uniforms

2.1 Indoor Air Quality (IAQ

Indoor air quality is an important aspect of public health and comfort; it affects peoples' productivity and well-being. The paper provides an in-depth analysis of IAQ, including its importance, contributing variables, health effects, and options for improvement. A clean and it requires clear air quality as 80 % to 90% populations. Its aim is to educate interested parties on the value of preserving high IAQ in a range of indoor settings, including homes, offices, and schools. Bahrain residents' health impacted by indoor air quality (Reda et al., 2022).

According to the (DOSH) Department of Occupational Safety and Health, in the workplace, poor indoor air quality can lead to reduced productivity and absenteeism as well as discomfort and health problems. Good indoor air quality can maintain health and well-being. In general, students are more satisfied with their thermal comfort when they feel that they have control over it, regardless of the actual temperature they are exposed to, as explained in a study by (Torriani et al., 2023). In addition, students who feel more in control of their learning also give more positive personal assessments of indoor air quality. Table *2.5* below shows the acceptable ranges for certain physical parameters according to the Department of Occupational Safety and Health.

Table 2.5 Acceptable range for specific physical parameter (DOSH, 2010)

Parameter	Acceptable range
Air temperature	23 ℃ - 26 ℃
Relative humidity	40% – 70%
Air movement	0.15 m/s – 0.5 m/s

2.6 Thermal Comfort model

The comfort determination can be empirically done, namely through the method of measuring temperature at the study sampling station, comfort zone given by the researchers and through a theoretical method, namely by looking at the perceptions of the public in determining the degree of comfort in their homes. By the theoretical method, the comfort scale is given to determine the conditions of comfort in the environment.

Regarding the assessment of thermal comfort in an occupied space, there are two well-established and widely used indices within the scientific community: the Predicted Mean Vote and the Predicted Percentage of Dissatisfied. The PMV and PPD as defined in ISO 7730 and (ASHRAE standard 55-2010, 2013) were developed by (P.O Fanger, 1970) by taking responses from thermally comfortable occupants under controlled conditions.

PMV is the predicted mean vote of thermal comfort by a large group of occupants under the same thermal conditions. PMV is classified on a 7-level scale: -3 (cold), -2 (cold), -1 (slightly cold), 0 (neutral), +1 (slightly warm), +2 (warm), and +3 (hot). It involves four physical variables of air velocity, air temperature, mean radiant temperature, and relative humidity, with two other parameters related to the occupant, namely, clothing insulation, and activity. The other index is PPD, representing the percentage of people dissatisfied with the indoor climate. These indices have been applied in the past in analyzing thermal comfort in occupied spaces (Shi et al., 2022). Table *2.6* shows the index values and comfort conditions.

Table 2.6 The index values and comfort conditions (Sahimi et al., 2024)

PMV	Comfort conditions
+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral (comfort)
-1	Slightly cool
-2	Cool
-3	Cold

The model proposed by ISO organization to determine of PMV index as follows (Pourshaghaghy & Omidvari, 2012) :

$$\begin{aligned} PMV = {} & (0.303\exp - 0.0336M + 0.028)\ \times \{(M - W) - 3.5\ \times 10 \\ & - 3\,[5733 - 6.99\,(M - W) - pa] - 0.42\,(M - 58.5) \\ & - 1.7\ \times 10^{-5}\ \times M(5867 - pa) - 0.0014M(34 - ta) \\ & - 3.96\ \times 10 - 8\,fcl\,[(tcl + 273\,)4 - (tr + 273)4] \\ & - fcl\ \times hc\,(tcl - ta)] \end{aligned} \tag{2.1}$$

The thermal comfort equation takes into consideration the most important parameters affecting the heat exchange between the human body and its environment. The metabolic rate (M) is the energy produced by the body; mechanical power (W), which is usually negligible, represents physical work. The clothing area factor (fcl) corrects for the insulation effect of clothing in heat transfer. The environmental factors affecting thermal comfort are air temperature (ta), mean radiant temperature (tr), and partial pressure of water vapour (Pa), since heat gain or loss occurs by convection, radiation, and evaporation. Convective heat transfer coefficient (hc) refers to the heat exchange with the surrounding air and depends on air movement. The clothing surface temperature (tcl) is the thermal barrier due to clothing, while thermal load (L), is the balance between internal heat production and heat dissipation, including skin temperature and sweating. These parameters together give a comprehensive assessment of thermal comfort under varying conditions.

The following relationship calculates the PMV value from the Predicted Percentage Dissatisfied (PPD) index, which estimates the amount of people who feel unsatisfied with thermal conditions.

$$PPD = 100 - 95 \times e^{(-0.3353 \times PMV^4 - 0.2179 \times PMV^2)} \quad (2.2)$$

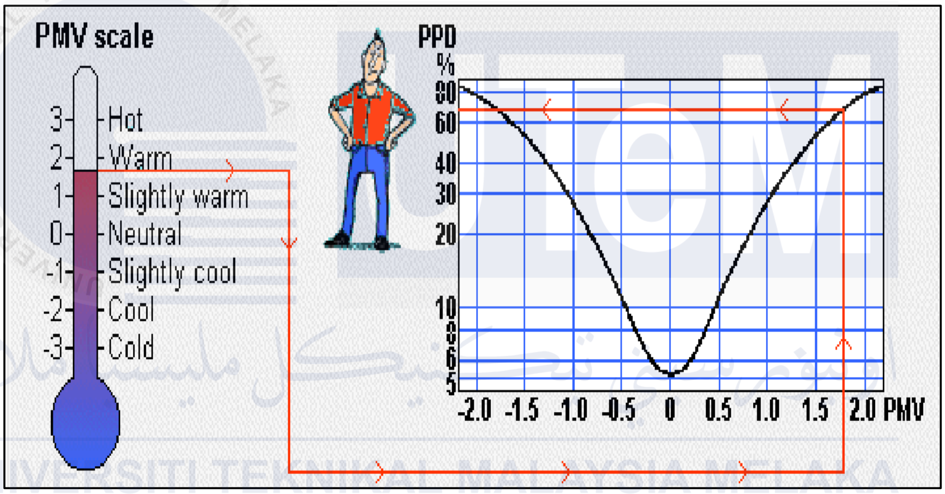

Figure 2.5 PPD as a function of PMV

Source: https://www.semanticscholar.org/paper/SPREADSHEETS-FOR-THE-CALCULATION-OF-THERMAL-COMFORT-Silva/429e233228a61823ad1cbfd2a174a4b4d3b79676

Figure *2.5* above represents an empirical relation between the PPD as percentage of people who are dissatisfied with thermal environment as the function of PMV. The PPD can range between 5% to 100%, depending on the calculation of the PMV; this value could change depending on where the occupant may be in that building and at what time in the building. For general comfort, according to (ASHRAE standard 55-2010, 2013), acceptable thermal environments fall within the range of PMV from -0.5 to +0.5 and a PPD of less than 20%.

2.7 CBE Thermal Comfort Tools

A popular free web-based tool for calculating and visualizing thermal comfort indices is the CBE Thermal Comfort Tool with the ASHRAE 55-2017, ISO 7730:2005 and EN 16798-1:2019 standards. It meets with the main thermal comfort standards and offers practical applications for educators, researchers, engineers, architects, facility managers and lawmaker, as stated by (Tartarini et al., 2020) . The latest version of the program has better models and features, making it more useful for a range of building-related applications. The latest version 2.5.6 of CBE Thermal Comfort Tool via following URL: https://comfort.cbe.berkeley.edu/

For thermal comfort estimates, the CBE Thermal Comfort Tool makes use of variables such air temperature, relative humidity, air speed, and operating temperature. It can be used to compute discomfort models, Standard Effective Temperature (SET), Predicted Mean Vote (PMV), and other thermal comfort models. By choosing PMV method, six parameter that must be filled. At the top, the computations' outcomes are presented in this section. the compliance data and the unprocessed results of the comfort model computations (such as PMV, PPD, etc. for the PMV approach).

The input values that users can change, and update are located on the left side of every page (except from Upload and Other CBE tools). The findings are shown on the right, which also typically has an interactive chart. As users alter the input values, the chart and the outcomes are updated instantly. On the bottom right, an illustration of the input's thermal comfort levels can be found in this section. The thermal comfort zone is now represented by the following three types of charts: plotted using the operating temperature or the dry-bulb air temperature, the method is known as psychometry.

Temperature of the dry bulb temperature compared to relative humidity. Operational temperature versus airspeed. Temperature of dry bulb air vs thermal heat losses. The PMV method's total heat losses latent, sensible, and cumulative values of the human body. Furthermore, certain graphs exhibit psychrometric characteristics when the mouse is moved across the plot region (Tartarini et al., 2020).

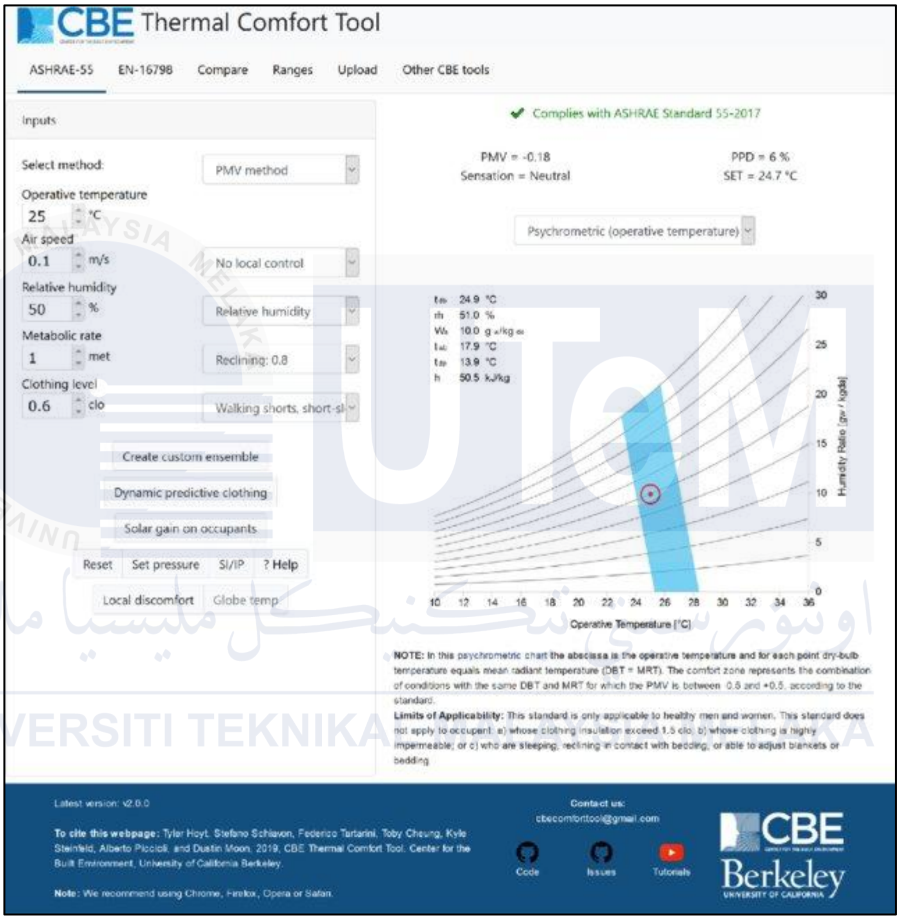

Figure 2.6 CBE Thermal Comfort Tool home page

2.8 Previous Study

In India, the naturally ventilated office had temperature range of 22.60 °C to 25.47 °C for thermal comfort (Aidil & Hariri, 2021). In comparison, the United Kingdom's naturally ventilated offices had a more comfortable temperature range of 17.47 °C to 24.38°C. In India, temperature range for mechanically ventilated offices was 20.63 °C to 24.94 °C. Temperature of the air in naturally ventilated offices in India was considered higher than that of the UK. In

India, naturally ventilated offices had greater relative humidity levels than in the UK. The high humidity in India made people feel hotter since sweat evaporated less effectively, leaving them feeling sticky and steamy. India's air velocity in mechanically ventilated offices was higher than that UK. the mechanically ventilated offices in India felt hotter than those in the UK because of the higher air velocity there. In naturally ventilated offices, there was more clothing insulation in the UK than in India. Even in lower air temperatures, residents in the United Kingdom were able to feel more comfortable thanks to enhanced clothing insulation.

Classroom temperatures in Makassar, Indonesia, typically go from 30.0 °C to 32.6 °C. These classrooms have relative humidity levels ranging from 64.11% to 71.35% (Hamzah et al., 2020). The range of the recorded air velocity is 0.06 to 0.13 m/s. Students' thermal comfort is influenced by their adaptive behaviour and clothing insulation; majority of them use books and handheld fans to stay cool in hot weather.

Thermal comfort in university classrooms is affected by air temperature, relative humidity, air velocity, and clothing insulation (Niza et al., 2023). Studies have indicated that the thermal comfort range in classrooms for females was determined to be 20.39–22.19°C, but the range for males was 19.47–22.56°C. The amount of time individuals spends in buildings, particularly classrooms, has also led to an increase in the evaluation of the thermal environment since it affects overall well-being, academic performance, and student satisfaction. Thermal comfort also influenced by the layout and features of the classroom, including its natural ventilation and size.

For thermal comfort in building spaces, Malaysia and Japan have different air temperature, relative humidity, air velocity, and clothing insulation values (Zaki et al., 2017). For example, it was discovered that Malaysia had higher mean ambient temperatures than Japan under different ventilation modes. Furthermore, respondents' views of thermal comfort may be impacted by the fact that respondents in Malaysia had on average, higher levels of clothing insulation than respondents in Japan.

Thermal comfort in dorm rooms influenced by elements such as clothing insulation, air velocity, relative humidity, and air temperature(Wu et al., 2019). According to a study conducted in Changsha, China, the highest limit for 80% acceptability was determined to be 28.5 °C, whereas the neutral operative temperature (T_o) found to be 26.2 °C. Over eighty percent of passengers found comfort in the temperature range of twenty-five to twenty-seven degrees Celsius, with 26.6 °C being the most acceptable operating temperature (Wu et al., 2019).

The significance of adaptive thermal behaviours in preserving thermal comfort was demonstrated by the strong correlation between indoor (T_o) and behaviours like adjusting air velocity and apparel. According to ASHRAE Standard 55, clothing insulation was estimated using specified types, and the total amount of clothing insulation was determined by adding the insulation values of all the used chairs and the individual items of clothing.

2.9 Summary

Heat waves have adverse effects on human health, the environment, and children's engagement and learning in school. There are 238 private schools in Melaka that emphasize critical thinking, reading, math skills, and national identity. Malaysia has a humid and humid climate, making it challenging to provide thermal comfort in schools. Clothing insulation, air velocity, radiant temperature, humidity, and metabolic rate are some of the factors that can significantly improve students' learning and general health.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The purpose of this study is to evaluate and improve students' thermal comfort by applying the (PMV) Predicted Mean Vote and (PPD) Predicted Percentage Dissatisfied method. To evaluate and improve the indoor temperature in classrooms settings, the PMV and PPD model, a known metric for assessing thermal environments will be used. Our approach includes applying innovative instruments and methods created by the Centre for the Built Environment (CBE) to thoroughly examine the selection factors impacting thermal comfort and to create a detailed flow chart that directs the study procedure.

The objective of this study, which was to determine the thermal comfort of students during learning, involves six (6) classrooms at SK Durian Tunggal. Following this, a set of TSI Velocicalc was set up inside the classroom and the thermal comfort questionnaire was distributed to achieve first objective. However, the questionnaire uses adaptations (ASHRAE standard 55-2010, 2013). The second objective was therefore achieved by utilizing indoor data along with student feedback on thermal comfort using PMV and PPD scale. The collected data was then setup into the CBE tool, allowing for the calculation of PMV and PPD values. By combining objective environmental measurements and subjective assessments, this study provides a holistic understanding of the level thermal comfort experienced by students.

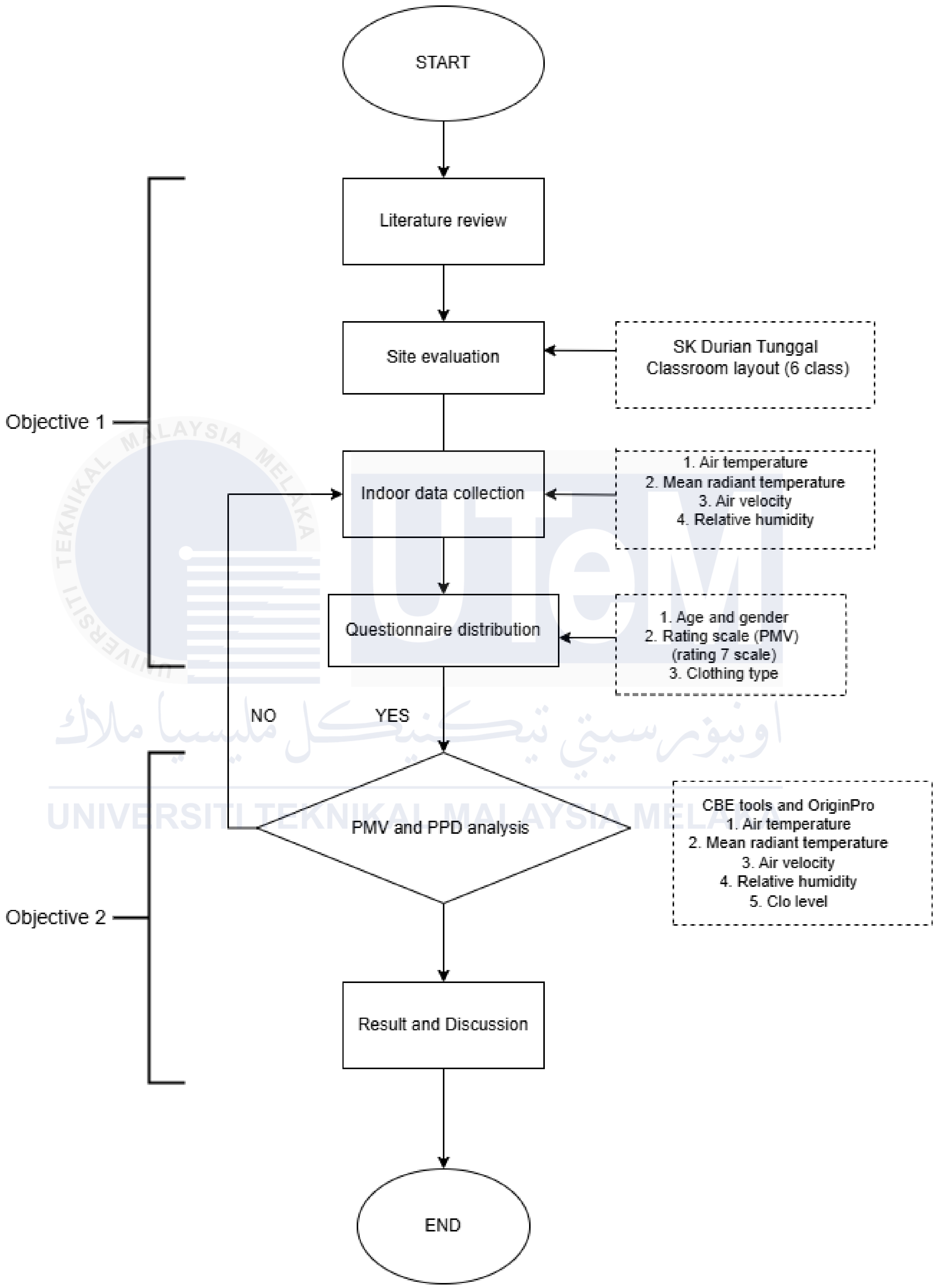

Figure 3.1 Research of flowchart

3.2 Site Evaluation

The school in Durian Tunggal, Malacca, was the subject of this investigation. Most of the classroom buildings are two or three floors tall. Throughout the learning process, these schools are exposed to heat sources because they are by the side of the road. Students will also be exposed to noise pollution. Students who are exposed to this type of pollution may experience heat discomfort and become distracted when learning. Figure *3.2* shows SK Durian Tunggal, Figure *3.3* shows the location of the school.

Figure 3.2 SK Durian Tunggal

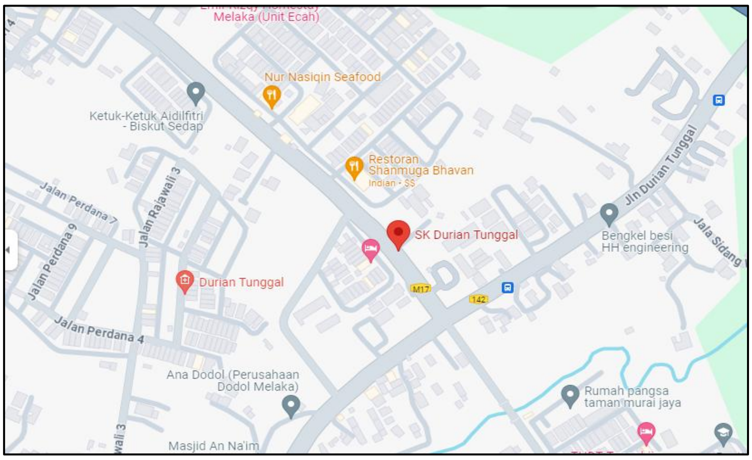

Figure 3.3 Location of SK Durian Tunggal

Classroom setup and dimensions served as one of the important parameters for conducting a survey about thermal comfort. This, plus other classrooms function between 7.00 a.m. and 2.00 p.m. with areas of 64.72m², along with a general class setting with dimensions equal to 8.25 meters for the length and 7.24 meters in width, also has a 3-meter-high ceiling. Class A and C use a fully natural ventilation system consisting of openings from space and the class are not facing the sunlight. It has two wooden doors, each 190 cm high and 60 cm wide, and three windows, adding up to twenty panels, each 200 cm high and 66 cm wide. The furniture consists of 40 chairs 78 cm in height, 40 desks, which are also rectangular, and measure 70 cm high by 60 cm wide, while the teacher's desk is 150 cm long and 70 cm wide. These specifications were important in understanding the physical layout of the classroom and its contribution to ventilation, airflow, and overall thermal comfort. The measurements provided the basis for analyzing how furniture arrangement, structural elements, and dimensions impact the environmental quality and comfort of students during instructional hours. Figure *3.4* and Figure *3.5* show a picture of class A and class C respectively.

Figure 3.4 Class A of SK Durian Tunggal

Figure 3.5 Class C of SK Durian Tunggal

Table 3.1 Specification of layout class A and C of SK Durian Tunggal

No	Part	Quantity	Dimension
1	Operation hours (7.00 a.m. – 2.00 p.m.)	-	-
2	Area	-	L =8.25 m, W=7.24 m Area = 64.72 m^2
3	Ceiling height	-	H = 3 m
4	Wooden door (2 door)	2	H=190 cm, W=60 cm
5	Window (3 door)	20	H = 200 cm, W= 66cm
6	Chair	40	H=78 cm
7	Rectangular Desk	40	H=70cm, W=60cm
8	Teacher desk	1	L= 150cm W=70cm

Class B was selected for study because of its suitability for obtaining data since its weather condition is hot and close to the other side of the road during the data collection. This classroom has an area of 66.06 m², with dimensions of 9 m in length and 7.34 m in width. The ceiling height is 4 m. It contains two wooden doors, which are 208 cm high and 94 cm wide, and two sets of windows consisting of a total of 16 panels, each panel measuring 127 cm high and 87 cm wide. The classroom is equipped with 30 plastic chairs, each 78 cm high, and 30 rectangular desks, each 70 cm high and 60 cm wide. Besides, a teacher's desk, 150 cm long and 70 cm wide, is part of the equipment. Figure *3.6* shows class B of SK Durian Tunggal.

Figure 3.6 Class B of SK Durian Tunggal

Table 3.2 Specification of layout class B of SK Durian Tunggal

No	Part	Quantity	Dimension
1	Operation hours (7.00 a.m. – 2.00 p.m.)	-	-
2	Area	-	L =9 m, W=7.34 m Area = 66.06 m^2
3	Ceiling height	-	H = 4 m
4	Wooden door (2 door)	2	H=208 cm, W=94 cm
5	Window (2 door)	16	H =127 cm, W=87cm
6	Chair (plastic)	30	H=78 cm
7	Rectangular Desk	30	H=70cm, W=60cm
8	Teacher desk	1	L= 150cm W=70cm

Next, Figure *3.7* shows class D, E and F where these sections of the Industrialized Building System (IBS) blocks. IBS blocks are prefabricated structures made of components such as concrete panels, steel frames and modular materials designed for efficiency, durability, and faster construction. With total area of 61.42 m², dimensions of 8.3 m long, 7.4 m wide, and a ceiling height of 3.2 m, the room has two wooden doors, each measuring 190 cm high and 60 cm wide, along with three sets of windows, totaling 16 panels, each measuring 133.4 cm high and 60 cm wide. The furniture consists of 30 plastic chairs with a height of 50 cm, 30 rectangular tables measuring 121 cm long and 60 cm wide, and a teacher's desk with dimensions of 150 cm x 70 cm.

The building orientation facing the sun, which has a significant impact on the interior thermal conditions. These buildings typically offer consistent structural quality, improved thermal performance and reduced construction waste. Prolonged exposure to direct sunlight can increase interior temperatures, especially in the morning and early afternoon when solar radiation is intense. This effect is particularly pronounced if shading elements, such as canopies or blinds, are absent. Although IBS blocks often include features to minimize heat gain, such as insulation or reflective surfaces, direct sunlight exposure can still be challenging to maintain thermal comfort.

Understanding the orientation and criteria of IBS blocks is important in assessing ventilation, airflow, and how sunlight affects the thermal comfort of classrooms during operating hours. Collectively, these factors affect student comfort and productivity during learning.

Figure 3.7 Class D, E and F (block IBS)

Table 3.3 Specification of layout class D, E, and F (block IBS) of SK Durian Tunggal

No	Part	Quantity	Dimension
1	Operation hours (7.00 a.m. – 1.30 p.m.)	-	-
2	Area	-	L =8.3 m, W=7.4m Area = 61.42 m^2
3	Ceiling height	-	H = 3.2 m
4	Wooden door (2 door)	2	H=190cm, W=60cm
5	Window (3 door)	16	H =133.4cm, W= 60cm
6	Chair (plastic)	30	H= 50 cm
7	Rectangular Desk	30	L= 121 cm W=60 cm
8	Teacher desk	1	L= 150cm W=70cm

- Class A: 4 USM
- Class B: 5 UTeM
- Class C: 6 UTeM
- Class D: 3UPM
- Class E: 3 UTeM
- Class F: 3 UKM

3.3 Indoor sampling

Data was collected over 6 days for on 6 August 2024 until 14 August during school hours. In this study, the students will take part as respondents. Each class has about 40 students, and there were 176 responders in all. Based on (ASHRAE standard 55-2010, 2013) TSI Velocicalc is placed in the middle of the room in the location where occupants spend their time at a height of 1.1 meters from floor level to sitting occupants. Because of this location, measurement of indoor environment that students experienced are known to be accurate. Figure *3.8* shows the location of TSI Velocicalc in the classrooms. The data that will be gathered from the school will be between 7 a.m. and 2.00 p.m.

Figure 3.8 Location of TSI Velocicalc in the classroom

First, air velocity (V)was measured to ensure that the airflow in the classroom does not contribute to thermal discomfort or exceed the operating requirements for the device. Air velocity also aids in the dissipation of heat, which directly impacts thermal comfort. Second, it would be the mean radiant temperature (Tmrt). It is to measure the average temperature of the surface. Next parameter is air temperature (Ta). The air temperature is important in this research because it may affect the student's thermal comfort whether the situation in the classroom is cold or hot. Lastly, relative humidity (RH) measured to control humidity levels in classrooms, relative humidity directly impacts the sensation of warmth or coolness and helps maintain overall thermal comfort.

Eight (8) questions about the thermal environment requirements for human occupancy were taken from the 2010 ASHRAE Standard and (Hamzah et al., 2018) used in this study's questionnaires. The Level of Thermal Comfort Questionnaire (Appendix A) will be divided into two sections. The first section will have a name, age, and gender, among other general information. In the meantime, section 2 will assess the children's level of thermal comfort in the classroom. The instructor in charge of the school provided the details on height and weight. It is possible to say that a person's degree of comfort is impacted by weariness, headaches, a lot of sweat, or fatigue. Following the completion of the last environmental measures, the questionnaires were distributed. The survey took 20 minutes to complete, and by 12:30 p.m., students had finished it.

Once all measurements and questionnaires were collected, the data was then arranged in a tabulated form. The environmental data was obtained objectively by TSI Velocicalc, while questionnaires showed subjective responses by the students. This indeed constituted quantitative and qualitative data and formed the basis for PMV and PPD analyses.

Sampling points followed the guidelines by (DOSH, 2010). Table *3.4* shows the minimal number of sampling points that should be used for an indoor air quality assessment of a structure. Additional sampling points were added where necessary to ensure comprehensive data collection across all classrooms.

Table 3.4 Minimal number of sampling points used in indoor air quality (DOSH, 2010)

Total floor area (served by MVAC system) (m^2)	**Minimum number of samplings**
<3,000	1 per $500m^2$
3,000<5,000	8
5,000<10,000	12
10,000<15,000	15
15,000<20,000	18
20,000<30,000	21
≥30,000	1 per $1,200m^2$

3.4 PMV and PPD evaluation

The PMV method was then used to interpret the PMV and PPD results using the "CBE Thermal Comfort Tool" software, and the adaptive method was used to evaluate the acceptable operating parameter range.

3.4.1 CBE tools setup

The data collected from six (6) classrooms at SK Durian Tunggal were analyzed using the CBE Thermal Comfort Tool to evaluate the thermal comfort conditions during morning and afternoon sessions. This tool allows researchers to assess comfort parameters based on environmental measurements and occupant responses, following the guidelines of ASHRAE Standard 55. By inputting key environmental data and comparing results between the two timeframes, a comprehensive understanding of classroom thermal conditions was achieved.

The input parameters for each classroom were derived from measurements taken using the Velocicalc device. These included air temperature (Ta), air velocity (V), and relative humidity (RH). Additional parameters required by the tool were standardized: the mean radiant temperature (MRT) was set equal to the air temperature as no significant radiant heat sources were present, the metabolic rate (M) was set to 1.0 met to represent light activity typical of classroom scenarios, and the clothing level (Clo) was assigned a value of 0.61 clo, reflecting the typical attire worn by students in the Malaysian climate. Data for each classroom during the morning and afternoon sessions were input separately for analysis.

Using the CBE tool, the thermal conditions of the classrooms were evaluated based on two critical metrics: the Predicted Mean Vote (PMV) and the Predicted Percentage Dissatisfied (PPD). The PMV quantifies thermal sensation on a scale ranging from cold (-3) to hot (+3), while the PPD estimates the percentage of occupants likely to feel thermally uncomfortable. In addition to these indices, the tool also assessed compliance with acceptable thermal comfort ranges and visualized the results through psychrometric charts, enabling a detailed examination of the classroom environment.

The comparison revealed noticeable variations in thermal comfort between the morning and afternoon sessions. Morning measurements generally indicated better comfort conditions, with PMV values closer to 0 (neutral sensation) and PPD percentages below 10%, signifying high occupant satisfaction. However, afternoon data showed a shift towards warmer conditions, with PMV values rising closer to +1 (slightly warm) and PPD percentages increasing to around 20%-25%, indicating a higher likelihood of thermal dissatisfaction. These changes were attributed to increased air temperature and relative humidity during the afternoon, as well as potential heat accumulation from classroom activities. Figure *3.9* shows the CBE tools setup parameters.

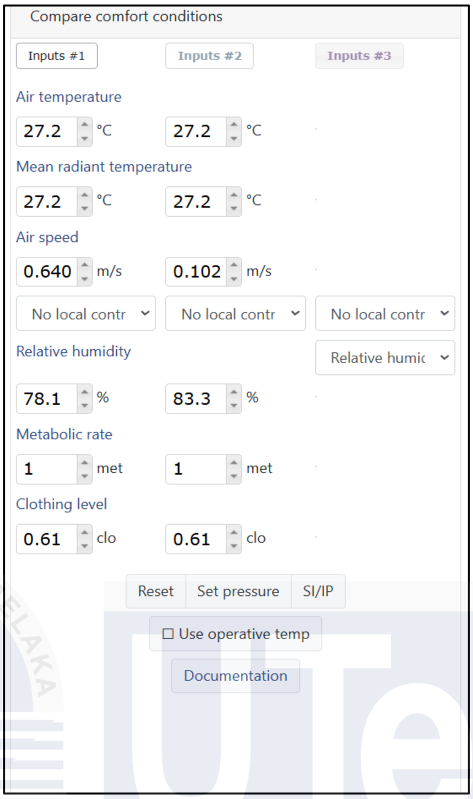

Figure 3.9 CBE tools setup parameters

3.5 Building orientation

The building's orientation is one of the most important factors influencing the internal temperature conditions of classrooms. This directly affects solar heat gain, natural ventilation, and radiant temperature. The building orientation facing the sun, which has a significant impact on the interior thermal conditions. These buildings typically offer consistent structural quality, improved thermal performance and reduced construction waste. Long term exposure to direct sunlight can increase interior temperatures, especially in the morning and early afternoon.

The temperatures and air velocities in each classroom were measured once an hour from 8:00 AM to 2:00 PM. Later, during analysis, recorded data in graph form have been plotted to present the variations in air temperature and air velocity over a day to draw a comparison among the three classrooms with respect to the variations of thermal condition and airflow. It was designed to pinpoint inconsistencies in airflow patterns and relate those to temperature fluctuations that may have occurred due to sun exposure. The methodology therefore provided a complete understanding of how the design and orientation of the IBS block influenced indoor environmental quality, thus enabling recommendations for improved shading, insulation, and ventilation systems for comfort optimization in classrooms.

3.6 Psychological evaluation

This psychological assessment was conducted to examine the impact of classroom environment conditions on students' comfort and well-being during school hours. Accordingly, a structured questionnaire was prepared based on five feelings Dizzy, Drowsy, Hungry, Tired and Hot, which students may experience. The feelings mentioned above were considered as they can be commonly experienced due to thermal discomfort and are relevant to classroom conditions. The questions were uncomplicated and in a form that is most appropriate for the age group of 9 to 12 years. Students were asked to select one or more feelings that they experienced during a class session; this allowed for multiple entries as these feelings may overlap.

The questionnaire was administered during classroom observations and environmental data collection. Responses were collected towards the end of the school day to provide a full picture of how the classroom environment affected students throughout the day. This process was closely monitored to ensure that responses were as accurate as possible, and bias was reduced.

There are 176 children in total who responded, representing 6 classes of respondents. These children range in age from 9 to 12 years old, with 81 male and 95 female. About 53.85% of respondents were 9 years old, while 18.75% were 10 years old, compared to 13.46% of students who were 11 years old and 13.9% who were 12 years old. Body mass index (BMI). The research respondent's backgrounds in Table *3.5* (Zaki et al., 2017).

Table 3.5 Respondent's description

Variables	Percentage (%)	Frequency
Age		
9	46%	81
10	22.2%	39
11	16%	28
12	16.5%	29
Body Mass Index (BMI)		
(Underweight) <18.5	16.5%	29
(Normal) 18.5 - 24.9	75.6%	133
(Overweight) 25 – 29.9	7.95%	14
Gender		
Male	46%	81
female	54%	95

N=176

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This study includes systematic data collecting on indoor thermal environment environments using the Velocicalc device and a structured questionnaire. The thermal comfort parameters stated were based on the 2010 ASHRAE Standard, which means they are based on acknowledged standards for human occupancy. The data collected was then evaluated using the CBE Thermal Comfort Tool Version 2.5.6 and OriginPro software, allowing for a thorough study of thermal comfort across multiple classes. This approach aims to find the classroom location that provides the best indoor thermal comfort for students.

4.2 Walkthrough Observation

From the walkthrough observation of the school, the building uses both natural and mechanical ventilation systems. Fresh air and heat circulate in and out through doors and windows. Fans are also placed in the building to help reduce heat during teaching and learning sessions. The names of classes can be identified as A, B, C, D, E and F for 4USM, 5UTEM, 6UTEM, 3 UPM, 3UTeM, 3UKM. Figure *4.1* layout of class A and C, Figure *4.2* Layout of class B, and Figure *4.3* Layout of class D, E and F.

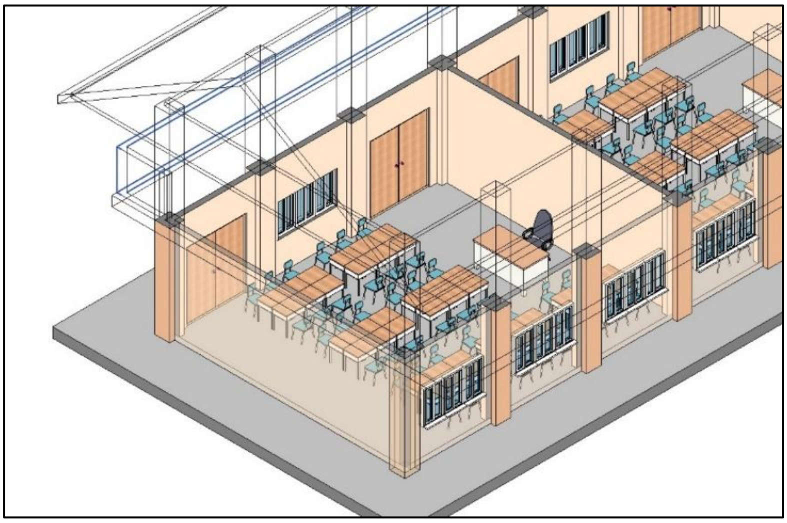

Figure 4.1 Layout of class A and C

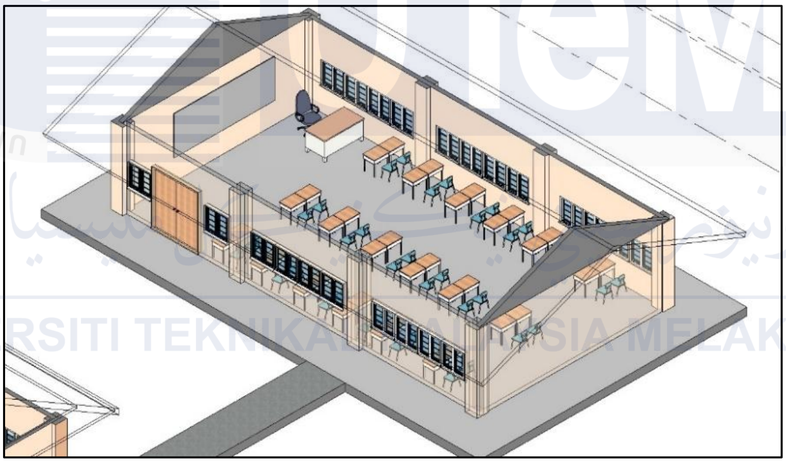

Figure 4.2 Layout of class B

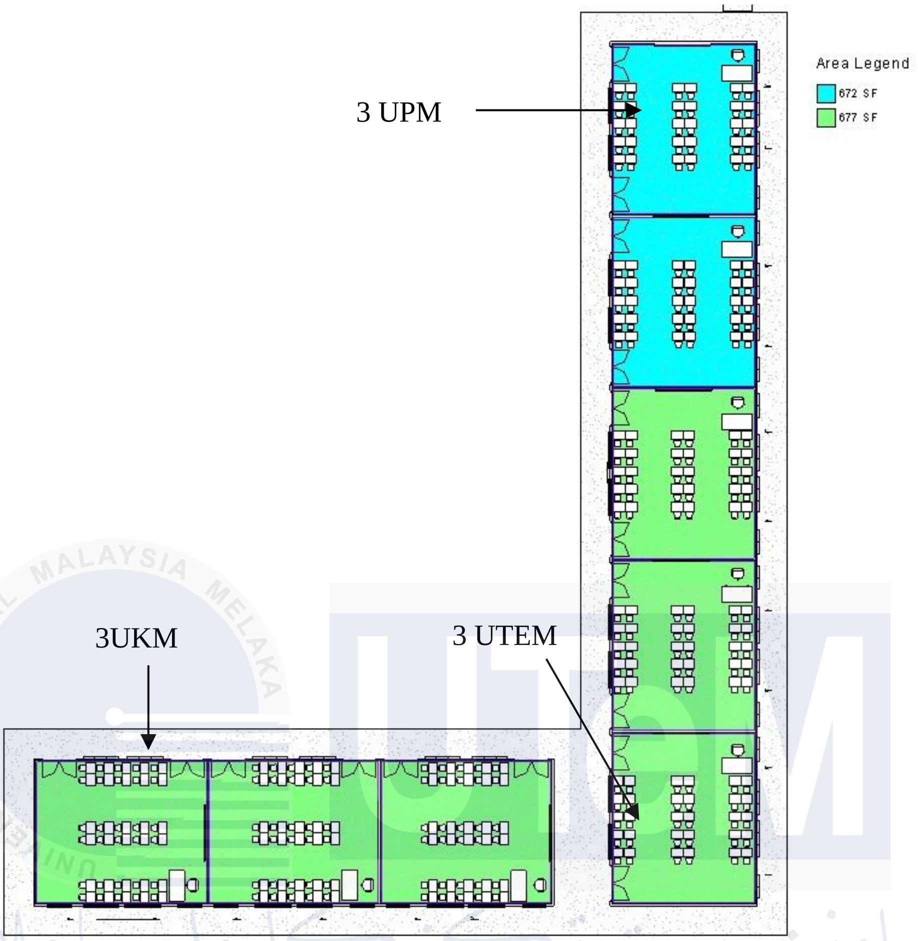

Figure 4.3 Layout of class D, E and F (block IBS)

4.3 Air Temperature, Relative humidity and Air velocity

4.3.1 Air Temperature

Figure *4.4* shows the air temperature at six classes of SK Durian Tunggal. The data shows a consistent rise in temperature all through the day. Starting at approximately 25 -27 ℃ in the early morning and reaching 30 – 32 ℃ by the afternoon. According to the Department of Occupational Safety and Health (DOSH, 2010) Malaysia, the acceptable indoor temperature range for thermal comfort is between 23 ℃ and 26 ℃. However, by 10 a.m., all classrooms are above this range, and by 2.00 p.m. class D, E and F are above this range.

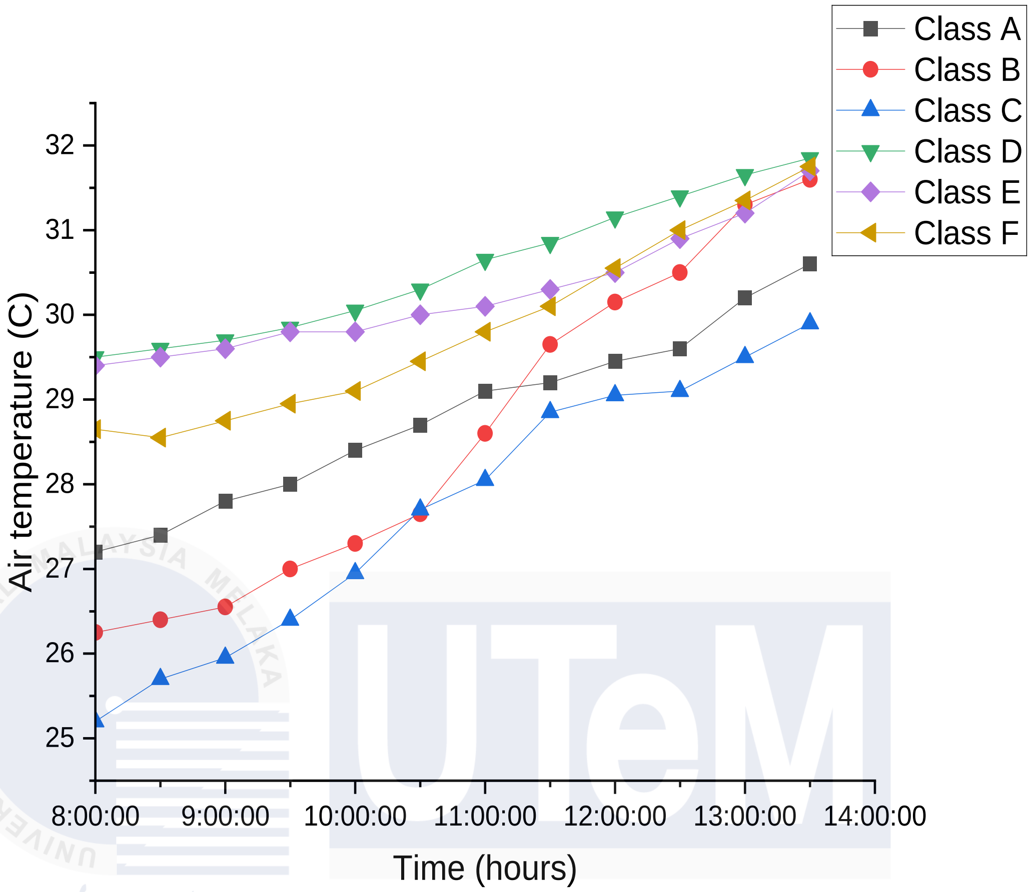

Figure 4.4 Air temperature at six (6) classes of SK Durian Tunggal

Table 4.1 The maximum, minimum, mean and standard deviation of temperature °C

Class	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
A	28.80	1.03	27.20	30.60
B	28.58	1.98	26.25	31.60
C	27.70	1.62	25.20	29.90
D	30.55	0.83	29.50	31.85
E	30.23	0.72	29.40	31.70
F	29.80	1.11	28.55	31.75

4.3.2 Relative humidity

Figure *4.5* shows the relative humidity (%) in six (6) classrooms. According to the (DOSH, 2010) the recommended range for indoor relative humidity to maintain thermal comfort is 40% to 70%. All through the day the relative humidity was around 60% and 90%. All classes experience constant decreases in humidity level at 2.00 p.m. humidity levels slowly drop throughout the day, and after 10 a.m., some classes (class D, E and F) are within the acceptable range of 40% to 70%. Class A, B and C on the other hand, keep falling within or a bit above the above 70% upper limit, particularly in the middle morning.

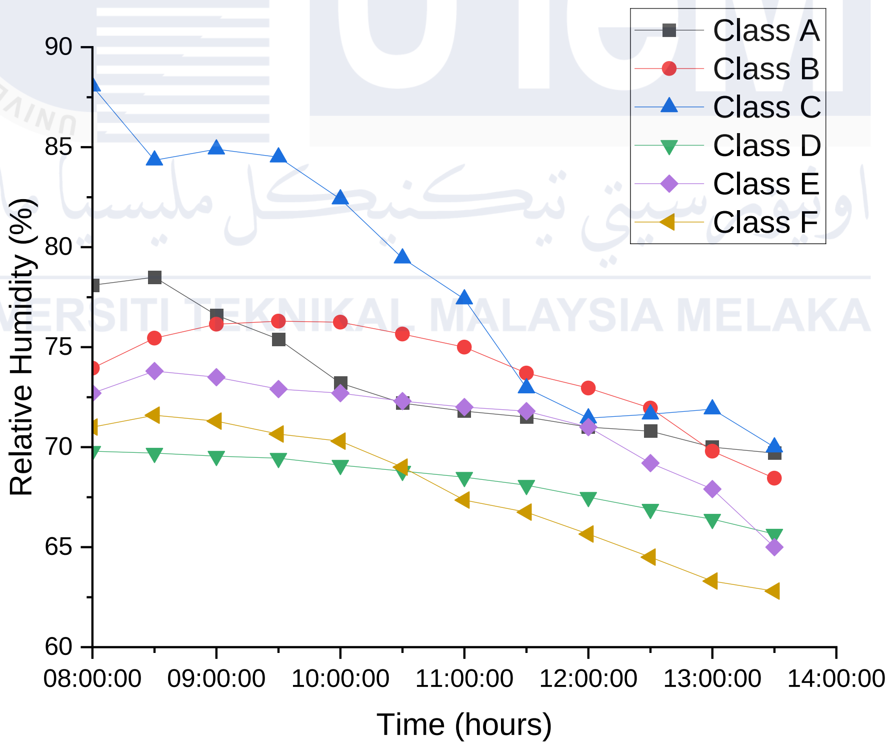

Figure 4.5 Relative humidity (%) at six classess of SK Durian Tunggal

Table 4.2 The maximum, minimum, mean and standard deviation of relative humidity (%)

Class	Mean	Standard Deviation	Minimum	Maximum
A	72.23	3.13	69.70	78.50
B	73.80	2.60	68.45	76.30
C	78.25	6.48	70.00	88.05
D	68.29	1.39	65.65	69.80
E	71.23	2.61	65.00	73.80
F	67.85	3.23	62.80	71.60

4.3.3 Air velocity

Figure *4.6* shows the air velocity in six (6) classes at SK Durian Tunggal. The Department of Occupational Safety and Health (DOSH, 2010) Malaysia states that to ensure proper ventilation and thermal comfort, indoor air velocity should be between 0.15 and 0.50 m/s. The only class that continuously maintains an acceptable air velocity is Class C. While class A has an excessively high velocity that may cause discomfort for students. The remaining experience poor air circulation, which probably makes heat discomfort worse.

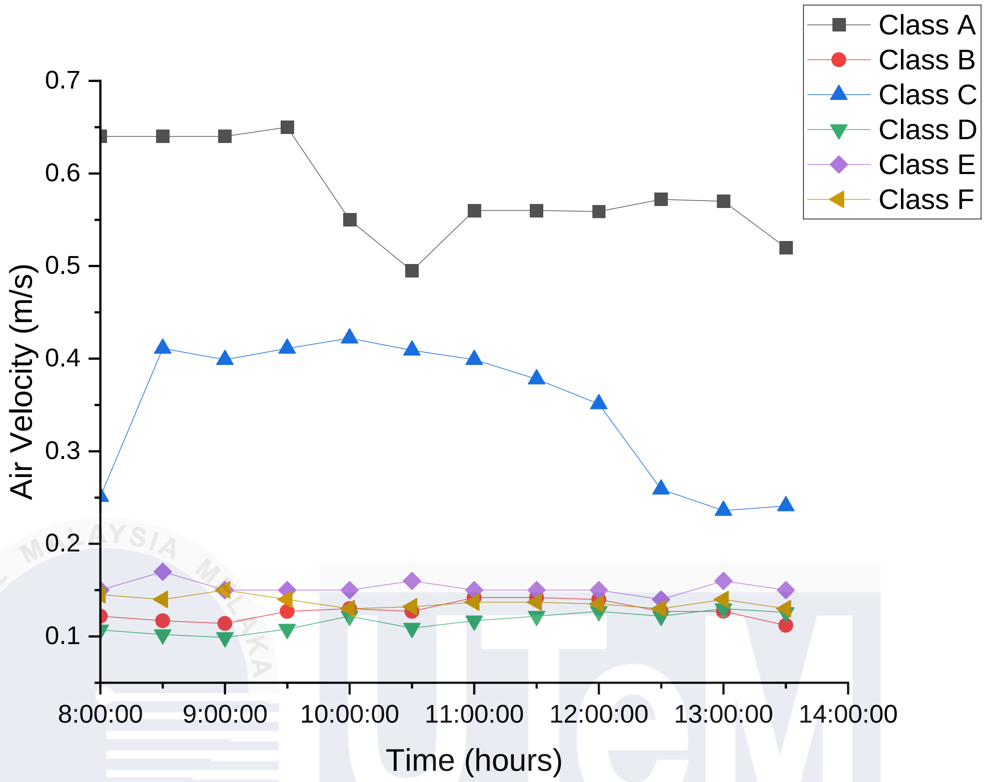

Figure 4.6 Air velocity (m/s) at six classrooms of SK Durian Tunggal

Table 4.3 The maximum, minimum, mean and standard deviation of air velocity (m/s)

Class	Mean	Standard Deviation	Minimum	Maximum
A	0.58	0.05	0.50	0.65
B	0.13	0.01	0.11	0.14
C	0.35	0.08	0.24	0.42
D	0.12	0.01	0.10	0.13
E	0.15	0.01	0.14	0.17
F	0.14	0.01	0.13	0.15

4.4 Relationship between PMV and PPD using CBE Tool

Based on ASHRAE 55 standard, it is stated that thermal comfort can be achieved based on an 80% occupant satisfaction rate or more 10 % of occupants will experience dissatisfaction based on whole body discomfort and the remaining percentage will be based on partially body discomfort. The Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) are key metrics in evaluating thermal comfort, particularly in indoor environments, and can be analyzed effectively using CBE (Center for the Built Environment) Thermal Comfort Tool.

The PMV index predicts the mean thermal sensation of a large group of people on a seven-point scale, ranging from cold (-3) to hot (+3), based on factors such as air temperature, humidity, velocity, mean radiant temperature, clothing insulation, and metabolic rate. In contrast, the PPD index estimates the percentage of people likely to feel uncomfortably warm to cool. As PMV moves away from neutral comfort range (approximately -0.5 to + 0.5), PPD increases shows that more occupants are likely to feel discomfort.

In Malaysia's tropical climate, characterized by high temperatures and humidity, managing indoor thermal comfort becomes challenging. The PMV value indices are difficult to reduce within the range of -0.5 to 0.5 due to conditions. The CBE Thermal Comfort Tool was used to assess thermal comfort for PMV and PPD. The input data were collected using TSI Velocicalc, taking into consideration ambient and personal thermal comfort parameters.

Figure *4.7* shows comfort condition for class A during morning and afternoon readings that also represent as input 1 and 2. Morning reading meets the requirement, as the PMV of -0.01 and PPD of 5% fall within the acceptable range, require thermal neutrality and a low level of discomfort. Meanwhile afternoon reading exceeds the acceptable PMV range, with a PMV of 1.25 and PPD of 38%, reflecting a "slightly warm" sensation and a higher dissatisfaction rate. Occupants may experience a higher possibility of discomfort.

Figure 4.7 shows the value of PMV and PPD on the PPD curve based on the line. The blue lines mean the value of PMV which is for morning reading and the black line for afternoon reading. Next, Table *4.4* reveals the data of environmental parameters, PMV and PPD for every 30 minutes starting from 7.30 am to 1.30 pm in class.

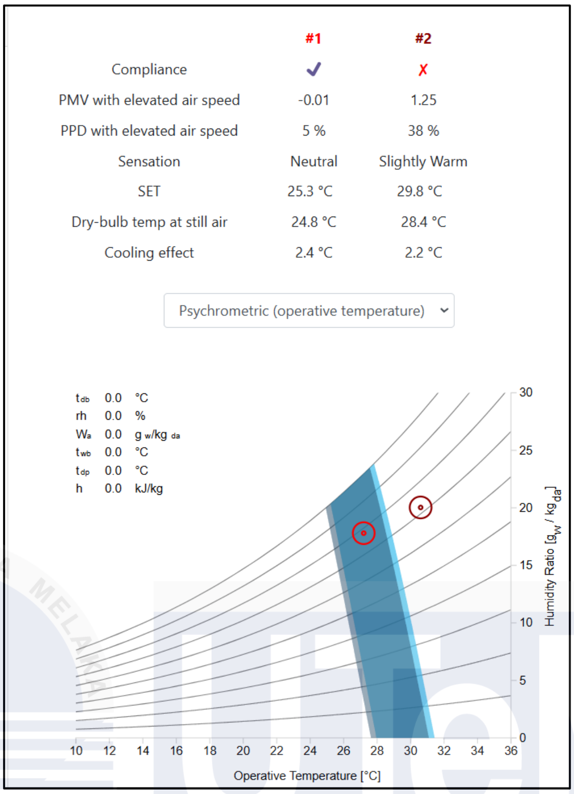

Figure 4.7 Result when analyze the data using CBE Thermal Comfort Tool

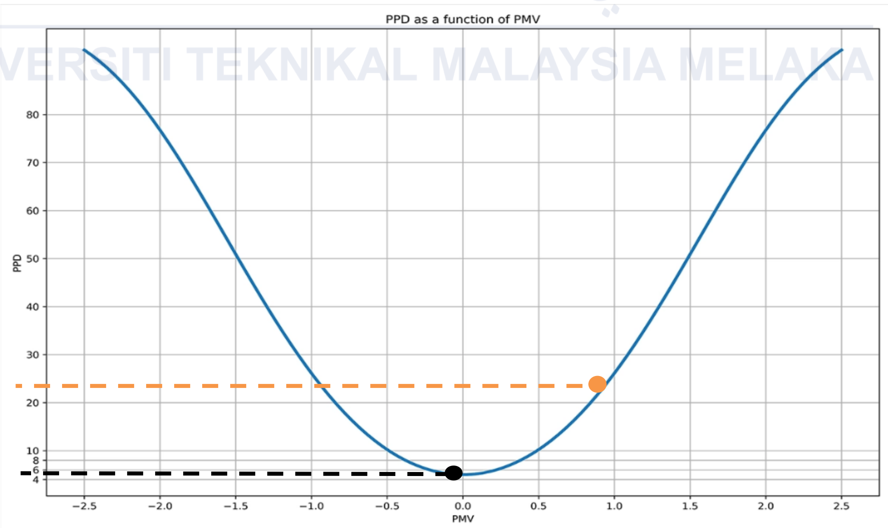

Figure 4.8 Value of PMV and PPD curve for class A

Table 4.4 Result of PMV and PPD for every 30-minute at class A

Time	**Velocity (m/s)**	**T Deg (°C)**	**Relative Humidity (%)**	**Metabolic Rate (met)**	**Clothing Insulation (clo)**	**PMV**	**PPD (%)**
8:53:29	0.64	27.20	78.10	1	0.61	-0.01	5
9:23:29	0.64	27.40	78.50	1	0.61	0.07	5
9:53:29	0.64	27.80	76.60	1	0.61	0.19	6
10:23:29	0.65	28.00	75.40	1	0.61	0.24	6
10:53:29	0.55	28.40	73.20	1	0.61	0.44	9
11:23:29	0.50	28.70	72.20	1	0.61	0.58	12
11:53:29	0.56	29.10	71.80	1	0.61	0.66	14
12:23:29	0.56	29.20	71.50	1	0.61	0.69	15
12:53:29	0.56	29.45	71.00	1	0.61	0.78	18
13:23:29	0.57	29.60	70.80	1	0.61	0.74	17
13:53:29	0.57	30.20	70.00	1	0.61	0.9	22
14:23:29	0.52	30.60	69.70	1	0.61	0.92	23

Result in Figure *4.9* below shows a comparison of thermal comfort conditions, to be expected for a classroom environment in class B using parameters such as air temperature, mean radiant temperature, air speed, relative humidity, metabolic rate, and clothing level. Class B generally allows a wider acceptable comfort range compared to Class A, with a slightly higher tolerance for temperature and humidity fluctuations. Input 1 is observed with thermal comfort standards while the PMV is 0.43, which is within the comfort range (-0.5 to +0.5) as per ASHRAE 55-2010. A PMV of 0.43 suggests a slight leaning towards thermal neutrality, indicating that most occupants would find this temperature comfortable. Moreover, input 2 does not comply with thermal comfort standards as the PMV is 2.38, which is well above the acceptable range for comfort (-0.5 to +0.5). A PMV of 2.38 shows a strong sensation of warmth, making this environment uncomfortable for most occupants.

Figure *4.10* shows the lines that were plotted with the value of PMV and PPD from

7.30 am to 1.30 pm. The PPD of input 1 is 9%, which is also within the acceptable limit of 10% for Class B spaces, meaning that only 9% of people are expected to feel uncomfortable in this environment. This low PPD value confirms that most occupants would be comfortable in this environment. The PPD for input 2 is 91%, which is far above the acceptable limit. This high value implies that 91% of occupants would likely feel discomfort due to the excessive warmth, which does not meet the ASHRAE Standard 55-2010 criteria for a comfortable environment. Table *4.5* displays the results for the PMV and PPD values issued for every 30 minutes in class B.

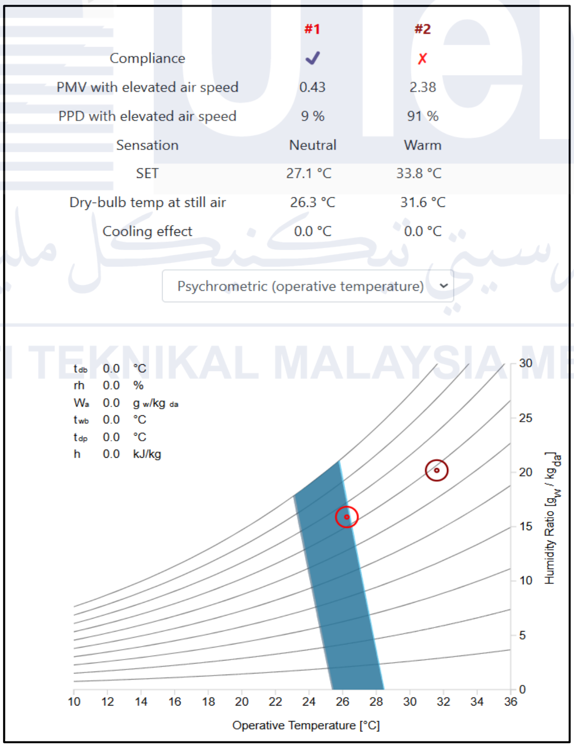

Figure 4.9 Result when the data analyzed using CBE Thermal Comfort Tool

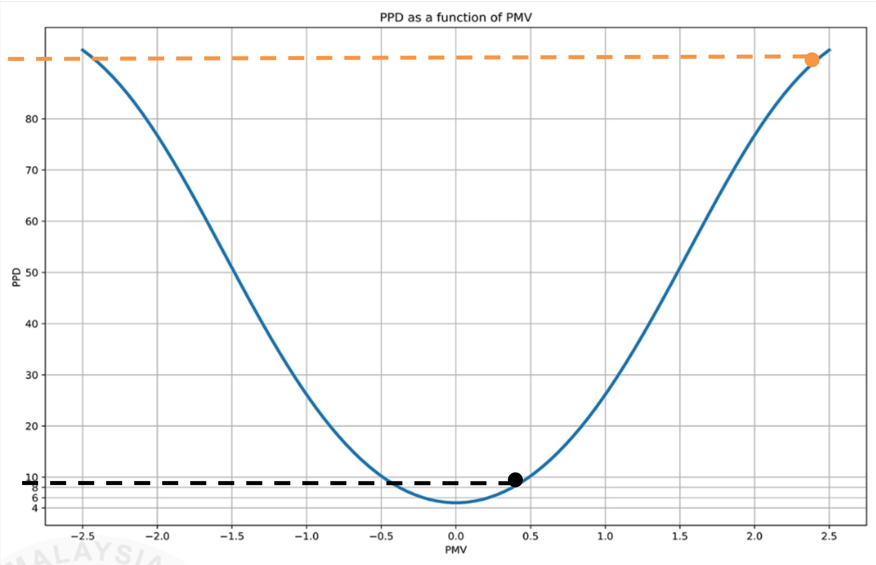

Figure 4.10 PMV and PPD value curve for Class B

Table 4.5 Result of PMV and PPD for every 30-minute at Class B

Time	**Velocity (m/s)**	**Tdeg (°C)**	**Relative Humidity (%)**	**Metabolic Rate (met)**	**Clothing Insulation (clo)**	**PMV**	**PPD (%)**
8:01:23	0.12	26.25	73.95	1	0.61	0.43	9
8:31:23	0.12	26.40	75.45	1	0.61	0.51	10
9:01:23	0.11	26.55	76.15	1	0.61	0.58	12
9:31:23	0.13	27.00	76.30	1	0.61	0.71	16
10:01:23	0.13	27.30	76.25	1	0.61	0.82	19
10:31:23	0.13	27.65	75.65	1	0.61	0.95	24
11:01:23	0.14	28.60	75.00	1	0.61	1.33	42
11:31:23	0.14	29.65	73.70	1	0.61	1.7	62
12:01:23	0.14	30.15	72.95	1	0.61	1.89	71
12:31:23	0.13	30.50	71.95	1	0.61	1.99	76
12:31:23	0.13	31.30	69.80	1	0.61	2.27	87
13:31:23	0.11	31.60	68.45	1	0.61	2.38	91

Figure *4.11* illustrated the thermal comfort satisfaction rate by using CBE Tool Software. As the PMV and PPD value were based on the surrounding conditions, it showed that 32% of the occupants felt slightly warm during afternoon reading. This is because the value of air temperature inside the building is 29.05 ℃. Furthermore, the value of PMV that were analyzed by CBE Tool for total 6 hours durations are between 0.16 and 1.13 while the PPD value was 6% and 32% respectively. Based on the result, it can conclude that the reading during afternoon does not comply with ASHRAE-55 standards.

Figure *4.12* shows the line that was plotted with the value of the PMV and PPD from 7.30 am to 1.30 pm. The result showed that the value of PMV during afternoon session, this class is not following the standard. This is because the value that was needed to be was between -0.5 and 0.5 to achieve the comfortable surroundings. Table *4.6* displays the results for the PMV and PPD values issued every 30 minutes at class C.

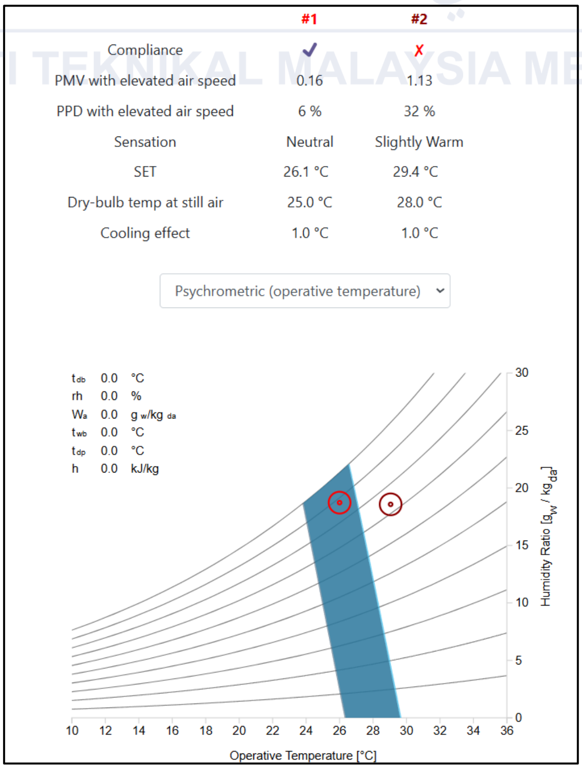

Figure 4.11 Result when the data analyzed using CBE Thermal Comfort Tool

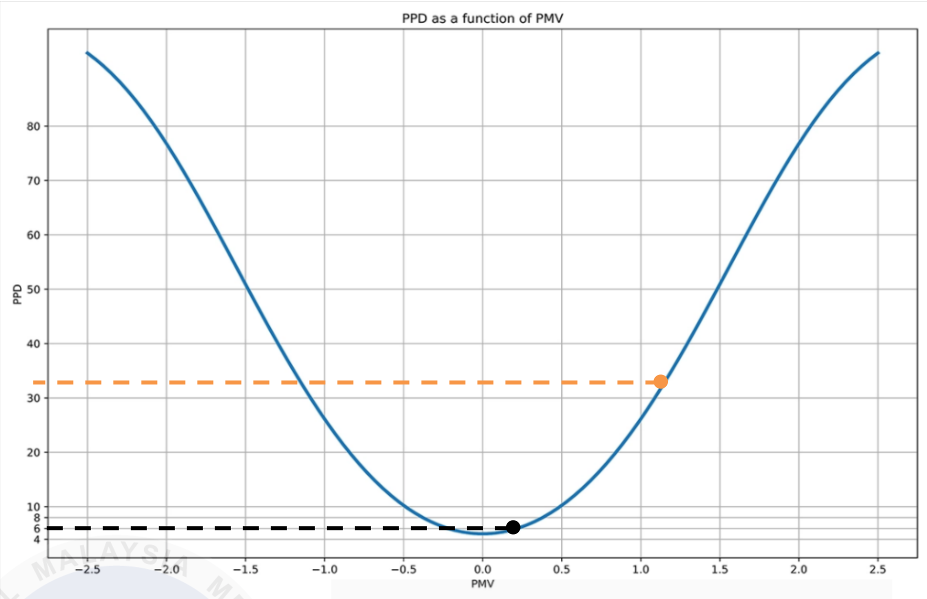

Figure 4.12 PMV and PPD value for Class C

Table 4.6 Result of PMV and PPD every 30-minute at Class C

Time	Velocity (m/s)	T deg ℃	Relative Humidity (%)	Metabolic Rate (met)	Clothing Insulation (clo)	PMV	PPD (%)
7:57:01	0.25	25.20	88.05	1	0.61	0.16	6
8:27:01	0.41	25.70	84.35	1	0.61	-0.25	6
8:57:01	0.40	25.95	84.90	1	0.61	-0.14	5
9:27:01	0.41	26.40	84.50	1	0.61	-0.02	5
9:57:01	0.42	26.95	82.40	1	0.61	0.16	6
10:27:01	0.41	27.70	79.45	1	0.61	0.41	9
10:57:01	0.40	28.05	77.40	1	0.61	0.53	11
11:27:01	0.38	28.85	72.95	1	0.61	0.79	18
11:57:01	0.35	29.05	71.45	1	0.61	0.88	22
12:27:01	0.26	29.10	71.65	1	0.61	1.08	30
12:57:01	0.24	29.50	71.90	1	0.61	1.12	32
13:27:01	0.24	29.90	70.00	1	0.61	1.13	32

Malaysia experiences humid, hot weather all year round. Because of this, it is challenging to be satisfied with thermal comfort for thermal sensation. Using the CBE Tool program, Figure *4.13* showed the thermal comfort satisfaction rate. 92% of the students reported feeling uncomfortable in the afternoon, according to the PMV and PPD values based on the surrounding conditions. This is due to the structures inside the air temperature of 31.85 °C. Additionally, the PMV values that were examined by the CBE Tool for a total of six hours ranged from 1.62 to 2.43, and the PPD values were between 57% and 92%. Based on the result, it can be concluded that this class has a discomfort reading of temperature because the material of building that not suitable for learning lesson.

Figure *4.14* shows the line that was plotted with the value of PMV and PPD from 7.30 am until 1.30 pm. The results showed that class D PMV value did not meet the standards set. This is since to create a nice environment, the value that was required was between -0.5 and 0.5. At class D, the PMV and PPD values issued every 30 minutes are shown in Table *4.7*.

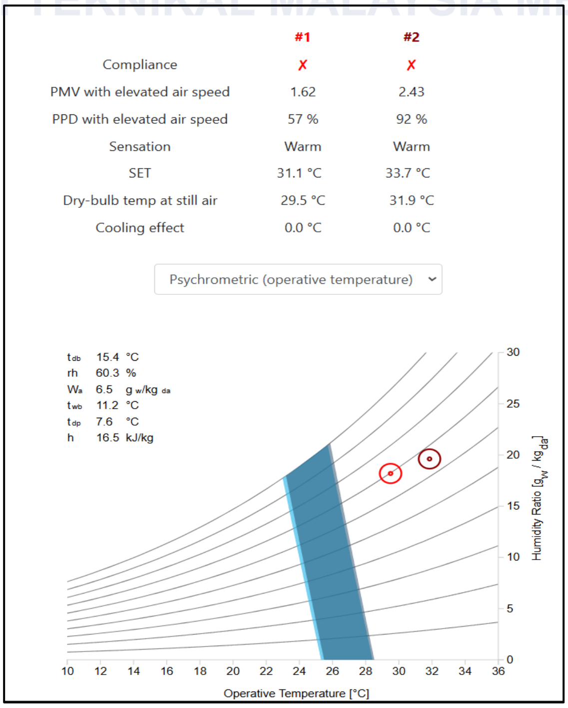

Figure 4.13 Result when the data analyzed using CBE Thermal Comfort Tool

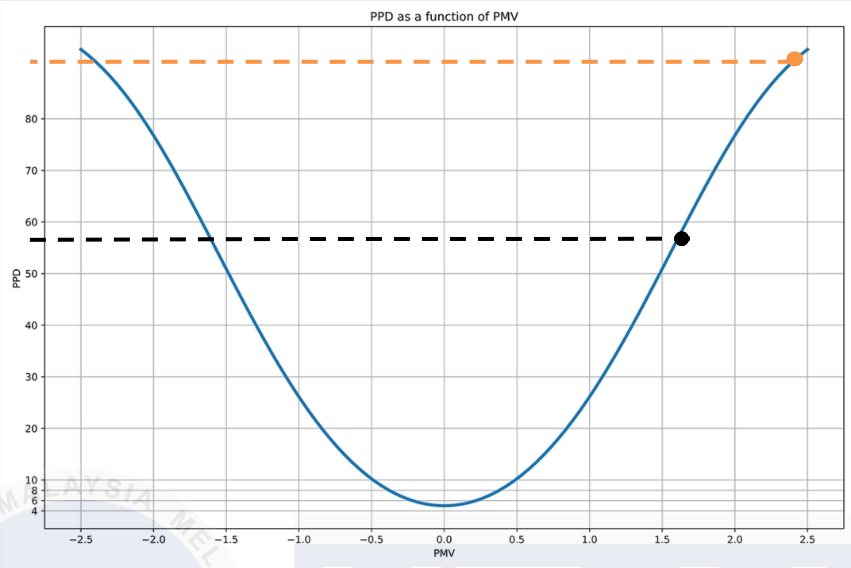

Figure 4.14 PMV and PPD value on PPD curve for Class D

Table 4.7 Result of PMV and PPD for every 30 minutes at class D

Time	**Velocity (m/s)**	**T deg (℃)**	**Relative Humidity (%)**	**Metabolic Rate (met)**	**Clothing Insulation (clo)**	**PMV**	**PPD (%)**
8:04:59	0.107	29.5	69.8	1	0.61	1.62	57
8:34:59	0.102	29.6	69.7	1	0.61	1.66	60
9:04:59	0.099	29.7	69.55	1	0.61	1.7	62
9:34:59	0.108	29.85	69.45	1	0.61	1.74	64
10:04:59	0.112	30.05	69.1	1	0.61	1.8	67
10:34:59	0.109	30.3	68.8	1	0.61	1.9	72
11:04:59	0.117	30.65	68.5	1	0.61	2.02	77
11:34:59	0.122	30.85	68.1	1	0.61	2.08	80
12:04:59	0.127	31.15	67.5	1	0.61	2.19	84
12:34:59	0.122	31.4	66.9	1	0.61	2.28	87
13:04:58	0.13	31.65	66.4	1	0.61	2.36	90
13:34:58	0.126	31.85	65.65	1	0.61	2.43	92

Result in Figure *4.15* below represents thermal sensation for class E using CBE Tool software. Both input sensations are warm which falls outside the central comfort zone. The PMV value for both input 1 and 2 is 1.56 and 2.17 exceed the acceptable range indicating thermal comfort. The higher PMV values, the higher sensation which aligns with the "warm". The value of PPD for input 2 is 84% higher than input 1, 54% meaning that more than half of the occupants are likely dissatisfied with thermal conditions.

Figure *4.16* shows the line that was plotted value of PMV and PPD for both conditions. Although there is some air movement 0.15 m/s, it may not be sufficient to create a significant cooling effect, especially at high temperature and humidity levels. Table *4.8* shows the result of the 30-minute average at class E.

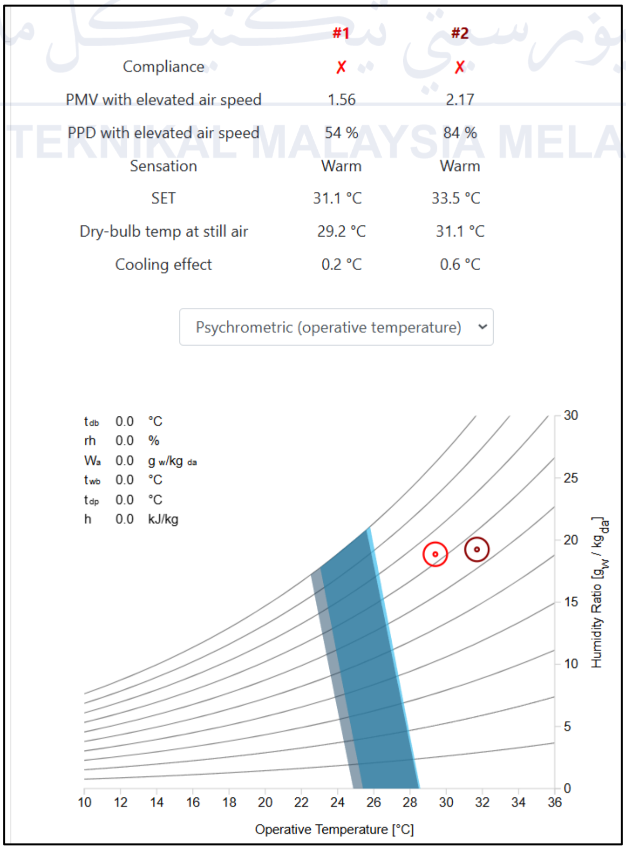

Figure 4.15 Result when the data analyze using CBE Thermal Comfort Tools

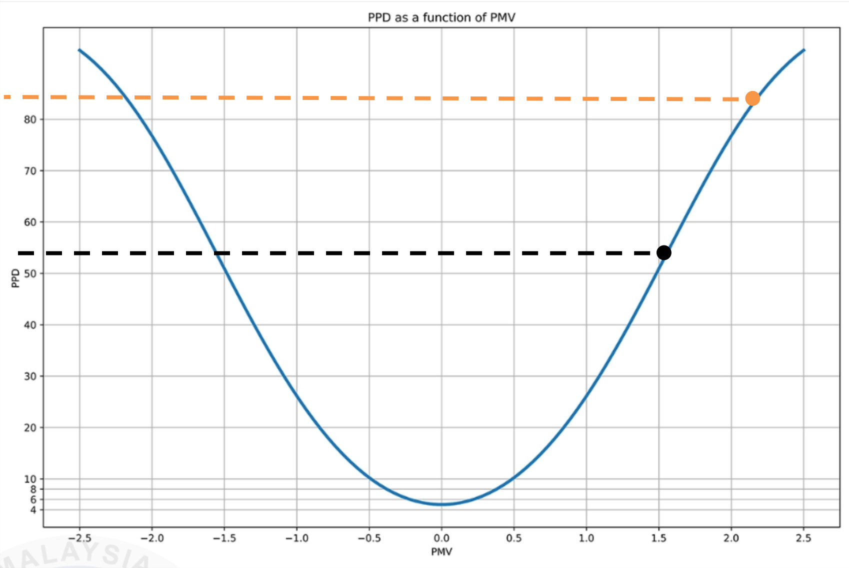

Figure 4.16 PMV and PPD value on PPD curve for Class E

Table 4.8 The result of PMV and PPD for every 30-minute at class E

Time	**Velocity (m/s)**	**T deg (°C)**	**Relative Humidity (%)**	**Metabolic Rate (met)**	**Clothing Insulation (clo)**	**PMV**	**PPD (%)**
8:04:49	0.15	29.40	72.70	1	0.61	1.56	54
8:34:49	0.17	29.50	73.80	1	0.61	1.61	57
9:04:49	0.15	29.60	73.50	1	0.61	1.64	59
9:34:49	0.15	29.80	72.90	1	0.61	1.71	62
10:04:49	0.15	29.80	72.70	1	0.61	1.71	62
10:34:49	0.16	30.00	72.30	1	0.61	1.73	63
11:04:49	0.15	30.10	72.00	1	0.61	1.81	68
11:34:49	0.15	30.30	71.80	1	0.61	1.88	71
12:04:49	0.15	30.50	71.00	1	0.61	1.95	74
12:34:49	0.14	30.90	69.20	1	0.61	2.12	82
13:04:49	0.16	31.20	67.90	1	0.61	2.12	82
13:34:49	0.15	31.70	65.00	1	0.61	2.32	89

Figure *4.17* shows the result of the data by using CBE Tools software. A PMV of 1.29 for input 1 and 2.24 for input 2 shows thermal discomfort, as those inside are probably feeling hot or warm. As a result, the PPD values are very high, 86% for input 2 and 40% for input 1, indicating that some of the occupants would probably be dissatisfied with these conditions. These numbers are much greater than the PPD of 10% or less, which is what ASHRAE recommends for the reason to maintain appropriate comfort levels.

Figure *4.18* shows the line relationship between PMV and PPD for both conditions from 7.30 am until 1.30 pm. The result shows the result is 86% while the PMV is 2.24 showing increase occupant discomfort, where higher PMV values correlate with higher PPD. Table *4.9* displays the results for the PMV and PPD values issued for every 30-minute at class F.

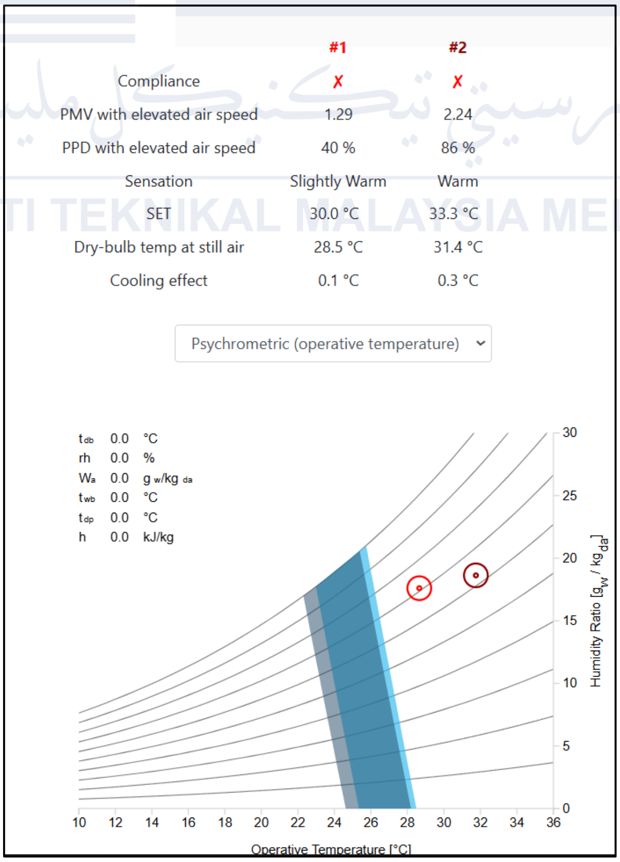

Figure 4.17 The result of the data by using CBE Thermal Comfort Tools software

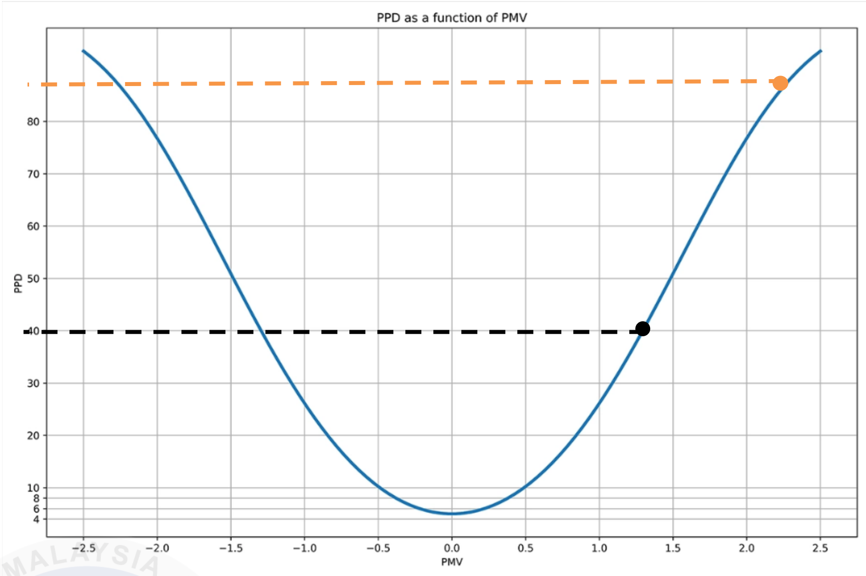

Figure 4.18 PMV and PPD value on PPD curve for Class F

Table 4.9 Result of PMV and PPD every 30-minute at Class F

Time	Velocity (m/s)	T Deg (℃)	Relative Humidity (%)	Metabolic Rate (met)	Clothing Insulation (clo)	PMV	PPD (%)
8:04:49	0.15	28.65	71.00	1	0.61	1.29	40
8:34:49	0.14	28.55	71.60	1	0.61	1.28	39
9:04:49	0.15	28.75	71.30	1	0.61	1.31	41
9:34:49	0.14	28.95	70.65	1	0.61	1.42	47
10:04:49	0.13	29.10	70.30	1	0.61	1.43	47
10:34:49	0.13	29.45	69.00	1	0.61	1.55	54
11:04:49	0.14	29.80	67.35	1	0.61	1.67	60
11:34:49	0.14	30.10	66.75	1	0.61	1.76	65
12:04:49	0.14	30.55	65.65	1	0.61	1.92	73
12:34:49	0.13	31.00	64.50	1	0.61	2.09	81
13:04:49	0.14	31.35	63.30	1	0.61	2.22	86
13:34:49	0.13	31.75	62.80	1	0.61	2.35	90

4.4.1 Correlation between PMV, PPD and Questionnaire

According to the CBE Tool's results, the class did not satisfy the ASHRAE 55-2010 standards for thermal comfort. However, when the questionnaire was given verbally in class, the students' responses varied. It indicates that everything will be in sync.

Most students in the chosen class at the school stated that they were uncomfortable in the classroom, according to the results of the seven-point thermal sensation test. The majority of the 15 students in Class A who felt neutral were male. They have a neutral feeling rather than being hot or cold. However, because there aren't any windows or orientation buildings regarding the sun and wind, students who sit next to windows tend to respond to quite warm conditions. The remaining students, however, reported feeling neutral.

The total number of students in class B is 28. Due to a lack of windows, an orientation building and class are next to the road, 15 out of 28 students reported feeling warm. Just 16 students reported feeling neutral, which indicates that both male and female students. About 15 students in class C reported feeling neutral, while the other students reported feeling warm. The thermal feeling for mild warmth is +1, according (ASHRAE standard 55-2010, 2013)

About 3 classes claimed that they experience warm condition and most of the students are from class D, E, and F at the IBS block including female and male. The warm value is +2, so the value between the range of -3 to +3. They declared that they felt warm during the afternoon because the orientation building in relation to sun and wind. Figure *4.19* shows the differences in air temperature values for six different classes based on the PMV and PPD results. Time increases in conjunction with the temperature. The results show that students are uncomfortable in the building during class because of the rising temperatures.

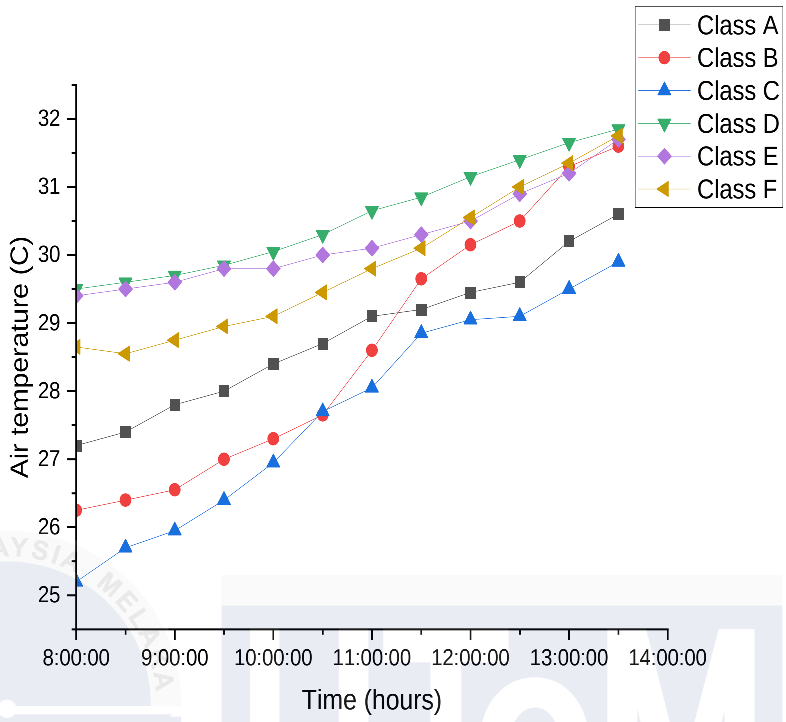

Figure 4.19 Air temperature value at different classrooms

Based on the result of PMV and PPD shown in Figure 4.19, it shows the difference value of air temperature for 6 classrooms. As the temperature increases, time also increases. According to the findings, the rise in temperature creates an uncomfortable environment for students in the building during their educational sessions. It is because based on ASHRAE standard the acceptable range for comfortable temperature is between 19.4°C to 27.8°C but the result states that the thermal sensation for those six (6) classrooms are between slightly warm to warm. The result of thermal comfort by using CBE Thermal Comfort Tool and the survey distributed has a difference answer. If the surrounding temperature was said to be slightly warm to warm, the students said that they felt neutral or cold. Therefore, the feedback that the students gave is not significant with the ASHRAE standard.

4.5 Correlation between air temperature and air velocity

From site evaluation, the data showed that class B and block IBS that consist of class D, E, and F are faces sunlight and the temperature that get higher value was class D. Class B, which is located near the other side of the road. The air temperature showed a steady increase throughout the day, reflecting the influence of direct sunlight and outside temperature from roadside. Meanwhile, the air velocity showed fluctuating trends, indicating possible changes in ventilation or airflow patterns during the day. Direct sunlight exposure may have contributed to the temperature increase, emphasizing the need for adequate ventilation to maintain a comfortable indoor environment for the classroom.

The following figure represents Classes D, E, and F in the IBS block for the air velocity in m/s versus air temperature in °C as a function of time. Since these classrooms face the sun, their window temperatures rise very quickly throughout the day in all three classrooms. It seems that the air temperature always rises from about 24°C in the morning at 8:00 AM to more than 30°C at 2:00 PM. This reflects the effect of direct sunlight on internal thermal conditions in these classrooms. This means that sun-facing orientation of IBS block contributes to heat accumulation and may lead to negative impacts on comfort for students and teachers.

For Class D, the air velocity changes a little but remains relatively constant, indicating moderate airflow in the classroom. Class E, however, shows irregular patterns of air velocity, with sharp changes at different times of the day. Similarly, Class F also displays different air velocity, indicating inconsistent airflow. Some may be due to the design adopted at IBS block that may limit prefabricated units to natural ventilation or how its airflow is structured within the whole building.

Generally, the current thermal and ventilation system in Classes D, E, and F of the IBS block represents changing temperatures and variation in airflow with time.

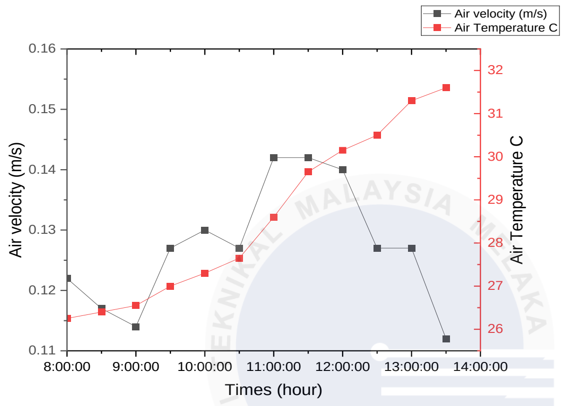

Figure 4.20 correlation between air temperature and air velocity in class B

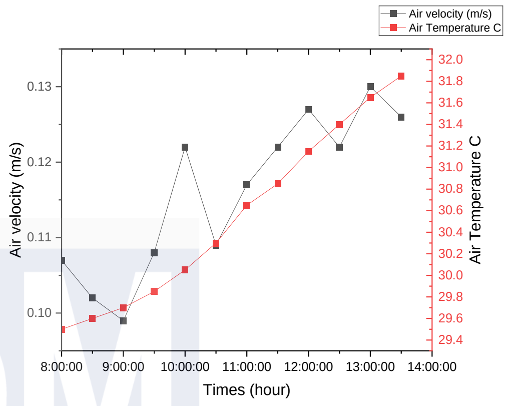

Figure 4.21 Correlation between air temperature and air velocity in class D

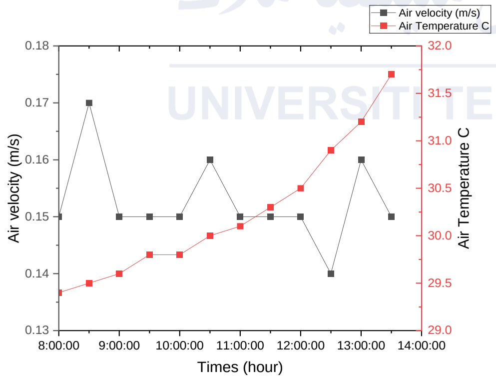

Figure 4.22 Correlation between air temperature and air velocity in class E

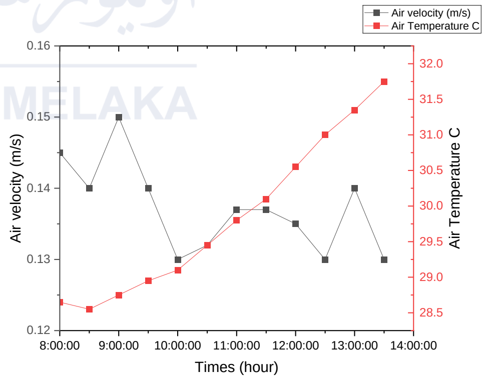

Figure 4.23 Correlation between air temperature and air velocity in class F

4.6 Psychological Effect for Thermal Comfort Toward Students

Students often feel tired and sleepy after doing activities, whether they are at home or in school. They also face difficulties in focusing on a single task, which leads to fatigue. This issue becomes worse when they are exposed to heat, as it causes discomfort and affects their concentration. During the survey, one of the questions asked was: "How do you feel right now during the learning process?". Table *4.10*, Table *4.11*, Table *4.12*, Table *4.13*, Table *4.14* and Table *4.15* show the results of respondents between 6 classes about the condition they felt during class session.

Data from Classes A to F show the students' conditions and feelings of comfort based on the conditions. The data for Class A indicated that more than half of the students felt tired, representing approximately 53.9% of the class, as the main cause of discomfort. The low condition experienced by students was 25.6%. Both dizzy and sleepy were same value which are 10.3% each. No students felt hungry, indicating that fatigue and hot conditions were the two main factors leading to discomfort in this class. Overall, most of the students in Class A were uncomfortable; fatigue was the main issue. The greatest discomfort due to heat was from 50% of the students in Class B, followed by sleepy, reported by 32.1%, and hungry at 17.9%. No students felt dizzy or tired. From this, hot and tired condition related problems appear to have played a major role in affecting the comfort of students in Class B, explaining that most students were uncomfortable in their environment.

For Class C, thermal discomfort was again the most significant issue, with 44.8% of students feeling hot. Sleepy condition affected 38% of the class, while hungry condition affected 17.2%. No cases of dizziness or tiredness were reported. In fact, the data showed that Class C was also generally uncomfortable due to a mix of heat and tiredness, like Class B, but less affected by hungry conditions. In Classes D, E and F, heat discomfort continued to dominate.

In Class D, 66.6% of students reported feeling hot, while dizzy conditions and sleepy affected 16.7% each. In Class E, sleepy and hot were reported by 40% of students each, while dizzy affected 20% students. Class F reported hot as the main issue at 61.53%, with both dizziness and tiredness affecting 19.2% students. Among these classes, most students felt uncomfortable, with heat being the most frequently reported issue. Other factors contributing to discomfort included sleepiness and fatigue, while hunger was not a major issue in any of the classes. Addressing these concerns can help improve overall student comfort.

Table 4.10 Student's condition during class session in Class A

Condition	Frequency	Percentage (%)
Dizzy	4	10.3
Sleepy	4	10.3
Hungry	-	-
Tired	21	53.9
Hot	10	25.6

N= 39

Table 4.11 Student's condition during class session in Class B

Condition	Frequency	Percentage (%)
Dizzy	-	-
Sleepy	9	32.1
Hungry	5	17.9
Tired	-	-
Hot	14	50

N= 28

Table 4.12 Students' condition during class session in Class C

Condition	Frequency	Percentage (%)
Dizzy	-	-
Sleepy	13	44.8
Hungry	-	-
Tired	11	38
Hot	5	17.2

N= 29

Table 4.13 Student's condition during class session in Class D

Condition	Frequency	Percentage (%)
Dizzy	5	16.7
Sleepy	5	16.7
Hungry	-	-
Tired	-	-
Hot	20	66.6

N= 30

Table 4.14 Student's condition during class session in Class E

Condition	Frequency	Percentage (%)
Dizzy	5	20
Sleepy	10	40
Hungry	-	-
Tired	-	-
Hot	10	40

N=25

Table 4.15 Student's condition during class session in Class F

Condition	Frequency	Percentage (%)
Dizzy	5	19.2
Sleepy	-	-
Hungry	-	-
Tired	5	19.2
Hot	16	61.53

N=26

4.7 Summary

Chapter 4 of this study presents the results and discussion on the indoor thermal comfort conditions at SK Durian Tunggal, evaluated using the Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) indices. Data were collected using Velocicalc devices and structured questionnaires, then analyzed with the CBE Thermal Comfort Tool (Version 2.5.6) and OriginPro software. The findings reveal that air temperature in classrooms ranged from 25-27°C in the morning to 30-32°C by afternoon, exceeding the recommended comfort range of 23-26°C. Relative humidity started at 60-90% but often fell outside the ideal range of 40-70%, while air velocity varied across classrooms, with only Class C maintaining acceptable levels.

Morning sessions showed better thermal comfort, with PMV values close to neutrality and PPD rates below 10%. However, afternoon sessions recorded PMV values above +1 and PPD rates exceeding 20%, indicating discomfort due to increased heat and humidity. Classrooms facing direct sunlight experienced the worst conditions, highlighting the need for shading, insulation, and improved ventilation. These findings underline the importance of monitoring thermal conditions to optimize classroom environments, ensuring student comfort and productivity during learning hours.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study successfully assessed the thermal comfort of classrooms in SK Durian Tunggal using the Predicted Mean Vote (PMV) and Percentage Dissatisfaction (PPD) index, fulfilling its objective of identifying and analyzing environmental factors that influence thermal comfort. Findings revealed significant variations in comfort levels between morning and afternoon sessions, with morning conditions offering better thermal neutrality, PMV close to 0 and PPD below 10% compared to afternoons, where PMV values exceeded +1 and PPD percentages increased to 20% and above, reflecting significant discomfort.

Environmental parameters such as air temperature, relative humidity and air velocity were analyzed, showing that many classrooms were above the recommended comfort range, especially during the afternoons. The recorded classroom conditions often were above the thermal comfort parameters set by the Department of Occupational Safety and Health (DOSH) and ASHRAE 55 standards. DOSH recommends indoor temperatures of 23°C to 26°C and relative humidity levels between 40% and 70%, but afternoon temperatures increase to 30°C to 32°C, with humidity exceeding 70% in some cases.

Classrooms with sun-facing orientation and insufficient ventilation systems were identified as having the worst thermal conditions, highlighting the critical need for design improvements. The project also demonstrated the practical application of tools such as the CBE Thermal Comfort Tool and the Velocicalc device in assessing and visualizing thermal conditions. This study provides valuable insights into the challenges of achieving thermal comfort in tropical climates, highlighting the importance of creating conducive learning environments. Furthermore, it highlights the direct impact of thermal comfort on students' well-being, concentration, and academic performance. These findings form a solid foundation for addressing thermal comfort issues in similar educational settings and guide future efforts to sustainably improve classroom environments.

5.2 Recommendations

To enhance findings and increase the validity of results, a few realistic recommendations are proposed for future studies and improvements in the education system.

First, adaptive strategies such as exploring changes in student behavior, like adjusting clothing, seating arrangements, or using personal cooling devices (e.g., portable fans), could be investigated. Additionally, redesigning school uniforms with breathable and moisture-wicking materials may reduce heat stress.

The integration of advanced ventilation systems should be explored, focusing on hybrid solutions that combine natural and mechanical ventilation to improve air circulation. Future studies should identify energy-efficient HVAC systems and air purifiers that maintain air velocity within the comfort range (0.15-0.50 m/s) and enhance indoor air quality, creating a healthier and more comfortable learning environment.

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APPENDICES

APPENDIX A
Questionnaire distribution towards students

Questionnaire for students towards thermal comfort in their school

Nama: ____ Umur: __________

Jantina: ______________________________________ Tarikh: _________

Berat: ___ kg Tinggi: _____cm

1. Adakah anda berasa selesa pada keseluruhan hari ini?

Lebih sejuk	Sejuk	Selesa	Panas	Lebih panas

2. Nyatakan keadaan yang anda rasai sekarang ini?

Sangat selesa	Selesa	Tidak selesa	Sangat tidak selesa

3. Bagaimana anda menilai keseluruhan suhu bilik pada masa ini?

Sangat panas	Panas	Sedikit panas	Natural	Sedikit sejuk	Sejuk	Sangat sejuk

4. Sekiranya anda diberi pilihan, keadaan bilik darjah yang mana anda inginkan?

Lebih sejuk	Sejuk	Tidak berubah	Panas	Lebih panas

5. Di manakah kedudukan anda semasa sesi pengajaran & pembelajaran dilaksanakan?

Tingkap	Di belakang kelas	Di Tengah kelas	Di depan kelas

6. Adakah anda berpuas hati dengan suhu persekitaran bilik darjah pada waktu ini?

Boleh diterima	Tidak boleh diterima

7. Antara pilihan di bawah, gambarkan apa yang anda rasa ketika berada di dalam kelas sekarang?

Pening	Mengantuk	Lapar	Letih	Panas

8. Nyatakan ciri – ciri pakaian yang anda pakai hari ini.

Pakaian	Ya	Tidak
Baju lengan panjang		
Paju lengan pendek		
Seluar panjang		
Seluar pendek		
Tudung		
Stoking		
Skirt		

APPENDIX B

Gantt Chart

	PSM 1														PSM 2													
ACTIVITY	WEEK																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
PSM 1 Briefing &Title Selection																												
Study Research																												
Background, Problem Statement																												
Objective, Scope																												
Literature Review (Journal)																												
Methodology																												
Site Selection																												
Apply Permission for Collecting Data																												
Draft Report Submission																												
Data Collection																												
Data Analysis																												
Update Report																												
Overall Report																												
Presentation																												
Final Report Submission																												
Others																												
Log Book Weekly																												
Report Progression																												

APPENDIX C

Data collection based on different parameters using TSI Velocicalc for class A

Sample	Date	Time	Vel ft/min	T deg C	H %rh
1	8/7/2024	8:38:29	127	27.3	77.7
2	8/7/2024	8:53:29	123	27.1	78.5
3	8/7/2024	9:08:29	132	27.3	78.5
4	8/7/2024	9:23:29	118	27.5	77.8
5	8/7/2024	9:38:29	134	27.7	76.3
6	8/7/2024	9:53:29	117	27.8	76.8
7	8/7/2024	10:08:29	125	27.9	76.1
8	8/7/2024	10:23:29	127	28.1	74.6
9	8/7/2024	10:38:29	106	28.4	73.6
10	8/7/2024	10:53:29	110	28.4	72.8
11	8/7/2024	11:08:29	87	28.5	71.8
12	8/7/2024	11:23:29	109	28.8	72.5
13	8/7/2024	11:38:29	110	29	71.6
14	8/7/2024	11:53:29	110	29.2	71.9
15	8/7/2024	12:08:29	107	29.1	71.4
16	8/7/2024	12:23:29	113	29.2	71.5
17	8/7/2024	12:38:29	112	29.4	70.9
18	8/7/2024	12:53:29	108	29.5	71.1
19	8/7/2024	13:08:29	116	29.4	72.3
20	8/7/2024	13:23:29	109	29.2	74.4
21	8/7/2024	13:38:29	106	28.8	75.5
22	8/7/2024	13:53:29	8	28.5	76.3
23	8/7/2024	14:08:29	14	27.7	81.2
24	8/7/2024	14:23:29	26	26.7	85.4

APPENDIX D
Data collection based on different parameters using TSI Velocicalc for class B

Sample	Date	Time	Vel ft/min	Tdeg C	H%rh
1	8/8/2024	7:46:23	23	26.2	73.3
2	8/8/2024	8:01:23	25	26.3	74.6
3	8/8/2024	8:16:23	21	26.4	75.2
4	8/8/2024	8:31:23	25	264	75.7
5	8/8/2024	8:46:23	22	26.4	76.1
6	8/8/2024	9:01:23	23	26.7	76.2
7	8/8/2024	9:16:23	26	26.9	76.3
8	8/8/2024	9:31:23	24	27.1	76.3
9	8/8/2024	9:46:23	25	27.2	76.4
10	8/8/2024	10:01:23	26	27.4	76.1
11	8/8/2024	10:16:23	26	27.5	75.8
12	8/8/2024	10:31:23	24	27.8	75.5
13	8/8/2024	10:46:23	27	28.2	75.3
14	8/8/2024	11:01:23	29	29	74.7
15	8/8/2024	11:16:23	28	29.5	73.8
16	8/8/2024	11:31:23	28	29.8	73.6
17	8/8/2024	11:46:23	28	30.1	73.2
18	8/8/2024	12:01:23	27	30.2	72.7
19	8/8/2024	12:16:23	22	30.4	72.2
20	8/8/2024	12:31:23	28	30.6	71.7
21	8/8/2024	12:46:23	23	31	70.5
22	8/8/2024	13:01:23	27	31.6	69.1
23	8/8/2024	13:16:23	24	31.6	68.5
24	8/8/2024	13:31:23	20	31.6	68.4

APPENDIX E

Data collection based on different parameters using TSI Velocicalc for class C

Sample	Date	Time	Vel ft/min	T deg C	H %rh
1	8/9/2024	7:42:01	38	26.2	87.2
2	8/9/2024	7:57:01	61	25.8	88.9
3	8/9/2024	8:12:01	85	25.7	84.6
4	8/9/2024	8:27:01	77	25.7	84.1
5	8/9/2024	8:42:01	82	26	83.6
6	8/9/2024	8:57:01	75	25.9	86.2
7	8/9/2024	9:12:01	86	26	86.1
8	8/9/2024	9:27:01	76	26.8	82.9
9	8/9/2024	9:42:01	89	26.7	83
10	8/9/2024	9:57:01	77	27.2	81.8
11	8/9/2024	10:12:01	81	27.7	79.7
12	8/9/2024	10:27:01	80	27.7	79.2
13	8/9/2024	10:42:01	82	28	777
14	8/9/2024	10:57:01	75	28.1	77.1
15	8/9/2024	11:12:01	76	28.6	74.3
16	8/9/2024	11:27:01	73	29.1	71.6
17	8/9/2024	11:42:01	73	29	71.7
18	8/9/2024	11:57:01	65	29.1	71.2
19	8/9/2024	12:12:01	54	29	71.6
20	8/9/2024	12:27:01	48	29.2	71.7
21	8/9/2024	12:42:01	44	29.1	71.6
22	8/9/2024	12:57:01	49	29	72.2
23	8/9/2024	13:12:01	47	29	73.1
24	8/9/2024	13:27:01	48	29.1	73.1

APPENDIX F

Data collection based on different parameters using TSI Velocicalc for class D

Sample	Date	Time	Vel ft/min	T deg C	H %rh
1	8/14/2024	7:49:59	22	29.5	69.8
2	8/14/2024	8:04:59	20	29.5	69.8
3	8/14/2024	8:19:59	21	29.6	69.7
4	8/14/2024	8:34:59	19	29.6	69.7
5	8/14/2024	8:49:59	18	29.7	69.6
6	8/14/2024	9:04:59	21	29.7	69.5
7	8/14/2024	9:19:59	21	29.8	69.5
8	8/14/2024	9:34:59	21	29.9	69.4
9	8/14/2024	9:49:59	22	30	69.2
10	8/14/2024	10:04:59	22	30.1	69
11	8/14/2024	10:19:59	22	30.2	68.9
12	8/14/2024	10:34:59	21	30.4	68.7
13	8/14/2024	10:49:59	22	30.6	68.6
14	08/142024	11:04:59	24	30.7	68.4
15	8/14/2024	11:19:59	22	30.8	68.2
16	8/14/2024	11:34:59	26	30.9	68
17	8/14/2024	11:49:59	25	31.1	67.7
18	8/14/2024	12:04:59	25	31.2	67.3
19	8/14/2024	12:19:59	25	31.3	67
20	8/14/2024	12:34:59	23	31.5	66.8
21	08/142024	12:49:58	26	31.6	66.5
22	8/14/2024	13:04:58	25	31.7	66.3
23	8/14/2024	13:19:58	24	31.8	65.9
24	8/14/2024	13:34:58	25	31.9	65.4

APPENDIX G
Data collection based on different parameters using TSI Velocicalc for class E

Sample	Date	Time	Vel ft/min	T deg C	H %rh
1	8/16/2024	7:49:49	28	29.5	71.9
2	8/16/2024	8:04:49	32	29.3	73.4
3	8/16/2024	8:19:49	32	29.4	73.8
4	8/16/2024	8:34:49	33	29.5	73.7
5	8/16/2024	8:49:49	31	29.5	73.6
6	8/16/2024	9:04:49	30	29.6	73.4
7	8/16/2024	9:19:49	30	29.7	73.1
8	8/16/2024	9:34:49	31	29.8	72.7
9	8/16/2024	9:49:49	29	29.8	72.6
10	8/16/2024	10:04:49	30	29.8	72.7
11	8/16/2024	10:19:49	31	29.9	72.5
12	8/16/2024	10:34:49	32	30	72
13	8/16/2024	10:49:49	31	30	72
14	8/16/2024	11:04:49	30	30.1	72
15	8/16/2024	11:19:49	29	30.2	71.9
16	8/16/2024	11:34:49	30	30.3	71.7
17	8/16/2024	11:49:49	31	30.4	71.4
18	8/16/2024	12:04:49	30	30.6	70.6
19	8/16/2024	12:19:49	28	30.8	69.3
20	8/16/2024	12:34:49	29	30.9	69
21	8/16/2024	12:49:49	32	31.1	68.4
22	8/16/2024	13:04:49	32	31.3	67.4
23	8/16/2024	13:19:49	30	31.6	65.5
24	8/16/2024	13:34:49	30	31.8	64.5

APPENDIX H

Data collection based on different parameters using TSI Velocicalc for class F

Sample	Date	Time	Vel ft/min	T deg C	H %rh
1	8/15/2024	7:49:49	28	28.7	70.8
2	8/15/2024	8:04:49	29	28.6	71.2
3	8/15/2024	8:19:49	27	28.5	71.6
4	8/15/2024	8:34:49	28	28.6	71.6
5	8/15/2024	8:49:49	29	28.7	71.5
6	8/15/2024	9:04:49	30	28.8	71.1
7	8/15/2024	9:19:49	28	28.9	70.7
8	8/15/2024	9:34:49	27	29	70.6
9	8/15/2024	9:49:49	25	29	70.6
10	8/15/2024	10:04:49	26	29.2	70
11	8/15/2024	10:19:49	26	29.3	69.7
12	8/15/2024	10:34:49	26	29.6	68.3
13	8/15/2024	10:49:49	28	29.7	67.4
14	8/15/2024	11:04:49	26	29.9	67.3
15	8/15/2024	11:19:49	26	30	66.9
16	8/15/2024	11:34:49	28	30.2	66.6
17	8/15/2024	11:49:49	26	30.4	65.9
18	8/15/2024	12:04:49	27	30.7	65.4
19	8/15/2024	12:19:49	26	30.9	64.8
20	8/15/2024	12:34:49	25	31.1	64.2
21	8/15/2024	12:49:49	25	31.3	63.4
22	8/15/2024	13:04:49	30	31.4	63.2
23	8/15/2024	13:19:49	25	31.7	62.6
24	8/15/2024	13:34:49	26	31.8	63

APPENDIX I
Permission letter to conduct research at SK Durian Tunggal

Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya,
76100 Durian Tunggal,
Melaka, Malaysia.

+606 270 1000
+606 270 1022
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20 ULANG TAHUN

FAKULTI TEKNOLOGI KEJURUTERAAN MEKANIKAL DAN PEMBUATAN

Tel: +606 270 1184 | Faks : +606 270 1064

Rujukan Kami (Our Ref): UTeM.46.01/500-25/1
Rujukan Tuan (Your Ref):
Tarikh (Date): 8 Oktober 2021

Sekolah Kebangsaan Durian TunggalTaman
Seri Siantan,76100
Durian Tunggal, Melaka

Tuan/Puan,

PEMOHONAN KEBENARAN MENJALANKAN KAJIAN / PENYELIDIKAN PERGERAKAN ANGIN DANKESELESAAN TERMA BAGI SEKOLAH KEBANGSAAN DURIAN TUNGGAL

Dengan segala hormatnya perkara di atas adalah dirujuk.

2. Merujuk kepada perkara diatas, saya Nur Fara Diniy Binti Azizi (B092110135) adalah pelajar dari Fakuliti Teknologi Kejuruteraan Mekanikal (FTKM) Universiti Teknikal Malaysia Melaka ingin memohon kebenaran daripada pihak tuan/puan bagi menjalankan penyelidikan di peringkat sarjana muda mengenai "Thermal Comfort Assesment Using Predicted Mean Vote (PMV) And Predicted Percentage Dissatisfied (PPD): A Case Study at SK Durian Tunggal" di SekolahKebangsaan Durian Tunggal, Melaka.

3. Untuk makluman pihak tuan/puan, saya akan meletakkan alat pengukuran dan instrumentasi didalam kawasan sekolah. Alatan tersebut tidak akan mengganggu proses pembelajaran di sekolah. Sayajuga akan meletakkan alat itu sebelum pelajar mula datang ke sekolah dan akan mengambil semula alatan ini setelah pelajar pulang. Segala pematuhan SOP akan saya jaga dengan teliti.

4. Selain itu, saya akan melakukan sesi soal jawab bersama murid-murid mengenai tahap keselesaan "Thermal Comfort". Bersama – sama surat ini, saya sertakan lampiran soal selidik yang akan saya ajukan kepada murid – murid. Dengan ini, saya sertakan tarikh dan masa proses penyelidikan ini berjalan dengan lancar.

Tarikh: 5.8.2024 sehingga 14.8.2024
Masa: 7.00 pagi sehingga 2.00 petang

5. Kerjasama daripada pihak tuan amat saya hargai. Semoga dengan kajian ini dapat meningkatkan keselesaan di kalangan murid pra sekolah. Saya boleh dihubungi di talian 010-5463361atau Penyelia Projek Sarjana Muda, Ts. Dr. Amir Abdullah 016-6573835.

Sekian, terima kasih.
Yang benar,

fara diniy
Nur Fara Diniy Binti Azizi

Fakulti Teknologi Kejuteraan Mekanikal
(FTKM)Universiti Teknikal Malaysia Me

APPENDIX J
Turnitin Report

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