THERMAL COMFORT & ITS RELATION TO VENTILATION APPROACHES IN THE MAIN PRAYER HALL OF MOSQUE & HOSTEL ROOM, USM ENGINEERING CAMPUS

SHARMIRA BINTI HUSAIN

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By

SHARMIRA BINTI HUSAIN

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Name of Student: SHARMIRA BINTI HUSAIN

I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

Signature:

Approved by:

NOR AZAM RAMLI 13643

(Signature of Supervisor)

Date : 9/8/2022

Name of Supervisor : PROF. DR. NOR AZAM RAMLI

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Approved by:

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Name of Examiner : TS. DR. FATEHAH MOHD OMAR

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ABSTRAK

Kajian ini dijalankan untuk menentukan kepuasan pengguna terhadap persekitaran dalaman bangunan. Kajian ini dilakukan di dua lokasi iaitu di ruangan solat utama masjid Kampus Kejuruteraan Pusat Islam, USM dan bilik asrama di Desasiswa Lembaran (SH2). Kajian ini melibatkan penentuan sama ada piawaian keselesaan terma dipenuhi, termasuk suhu udara dan kelembapan relatif. Data diukur menggunakan Suhu-Kelembapan Relatif (T-Rh) Data Logger dan hasilnya dimuat turun menggunakan perisian T-Rh. Alat Keselesaan Terma Pusat Persekitaran Terbina (CBE) kemudiannya digunakan untuk memasukkan parameter untuk mengira Nilai Min yang Diramalkan (PMV) dan Ramalan Peratusan Tidak Puas Hati (PPD) untuk ASHRAE Standard-55. Parameter yang dimasukkan ialah suhu udara, kelembapan relatif, halaju udara, kadar metabolisme dan tahap pakaian pengguna. Peratusan ketidakpuasan hati ditunjukkan oleh nilai PPD. Keputusan yang diperoleh untuk nilai PMV dan PPD dibandingkan dengan had standard Kod Amalan Industri (ICOP) 2010. Pemantauan bagi kajian ini dijalankan pada dua sesi dalam sehari iaitu 1 P.M – 2 P.M. dan 5 P.M. -6 P.M. untuk kedua-dua lokasi dengan selang satu minit. Suhu tertinggi direkodkan di masjid ialah 33.7°C, pemantauan pada 1 P.M -2 P.M. (Hari 1). Bagi pemantauan di bilik asrama, nilai PMV dan PPD tertinggi yang diperolehi adalah masing-masing 1.6 dan 57%. Secara keseluruhan, keputusan menunjukkan bahawa kebanyakan parameter keselesaan terma yang diukur tidak mematuhi had standard ICOP di mana PMV tidak berada dalam julat $-0.5 < PMV < +0.5$ dan nilai PPD melebihi 10%. Ini disebabkan reka bentuk fasad yang kurang baik dan sistem pengudaraan yang tidak mencukupi di dalam kedua-dua bangunan.

ABSTRACT

This study was conducted to determine users' satisfaction with the building's indoor environment. This study was performed at the main prayer hall of Pusat Islam Engineering Campus, USM and the hostel room in Desasiswa Lembaran (SH2). It involved determining whether the thermal comfort standards were being met, which included the air temperature and relative humidity. The data were measured using Temperature- Relative Humidity (T-Rh) Data Logger, and the result was downloaded using T-Rh software. The Center for the Built Environment (CBE) Thermal Comfort Tool is then used to input the parameters to calculate the Predicted Mean Value (PMV) and Predicted Percentage Dissatisfied (PPD) for ASHRAE Standard-55. The parameters inserted are air temperature, relative humidity, air velocity, metabolic rate and clothing level. The PPD value shows the percentage of dissatisfaction. The PMV and PPD value results were compared with the Industry Code of Practice (ICOP) 2010 standard limit. The monitoring for this study was conducted for two sessions on a day, 1 P.M – 2 P.M. and 5 P.M. -6 P.M. for both locations with minute intervals. The highest temperature recorded in the mosque is 33.7°C, monitoring at 1 P.M -2 P.M. (Day 1). For monitoring in the hostel room, the highest PMV and PPD values obtained were 1.6 and 57%, respectively. Overall, the results indicate that most thermal comfort parameters measured do not comply with the ICOP standard limit, whereby the PMV is not within the range of -0.5 <PMV< +0.5 and PPD is >10%. This is due to poor façade design and inadequate building ventilation systems.

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LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CBE	Centre for the Built Environment
IAQ	Indoor Air Quality
ICOP	Industry Code of Practice on Indoor Air Quality 2010
PMV	Predicted Mean Value
PPD	Predicted Percentage Dissatisfied
RH	Relative Humidity
T	Temperature
USM	Universiti Sains Malaysia

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In our daily lives, we spend most of our time inside buildings. While spending an unusual amount of time indoors might lead to health issues, thermal comfort is primarily concerned with building occupants (Noor et al., 2021). Good thermal comfort is necessary for any building to increase occupants' productivity and satisfaction. The mosque is one of the examples of buildings that need to be given great concern due to its function. A mosque is a symbolic place for Muslims where they can come together for prayers. Mosques are not only used for prayers but also serve as a centre of education and information, for events during the month of Ramadan, and other religious activities. Because of the large number of people that visit mosques, particularly during prayer times, good thermal comfort is necessary. This ensures that worshipers feel comfortable and calm while praying and performing other activities. One of the aspects that will determine users' overall experience within the mosque is the mosque's design. Poor design, which only considers the aesthetic value of the mosque, will lead to thermal discomfort for the users.

Thermal discomfort makes the occupants feel stressed, annoyed and distracted. Other than that, lack of thermal comfort also hurts the health of the occupants (Rasli et al., 2021). Some characteristics of building circumstances, such as the façade's design parameters, including building dimensions, ventilation, size and type of doors and windows and religious activities in mosque buildings, may create thermal discomfort. As a result, for the comfort and health of mosque occupants, indoor thermal comfort must be maintained at an acceptable level.

A sound ventilation system is required to provide thermal comfort in the mosque. Ventilation is a process that brings fresh outdoor air into the building and removes the contaminated indoor air. The ventilation system is divided into two types: natural and mechanical ventilation systems. As the name implies, natural ventilation is a system that uses natural forces to provide fresh air to a building. It is produced by wind diffusion through the building's windows, doors, and openings. Natural ventilation is an attractive management technique because electrical maintenance expenses are eliminated.

Meanwhile, the mechanical ventilation system uses electric fans or air conditioning systems to move air within the building. Natural ventilation is preferable because it can lower costs and protect the environment (Rasli et al., 2021). Despite the aesthetic value of the space, the mosque’s design should provide the best environmental experience to the users while promoting a sustainable energy consumption approach (Sabarinah et al., 2019).

1.2 Problem Statement

Most mosques are poorly designed for indoor temperatures, requiring excessive energy and electrical equipment to maintain the ideal indoor temperatures. The students also face this situation at the hostel, where the rooms have poor design and inadequate ventilation systems. When the temperature is exceptionally high, the energy consumed will also be increased to provide thermal comfort to the occupants. This problem occurs inside the mosque because of the minimal openings and lack of thermal insulation in the mosque’s main hall. The gaps near the ceilings are frequently closed, allowing the warm indoor air to remain at the upper levels. Thermal discomfort will cause uncomfortable conditions for the users while performing their prayers. The mosque's design provides aesthetic value to the building but lacks satisfaction in the environmental aspect. Thus, determining the thermal comfort compliance for both building spaces is essential to assess the effect of existing ventilation on thermal comfort.

1.3 Objectives

The objectives of this study are stated below:

i. To measure air temperature and relative humidity in the hostel room and mosque's main prayer hall.
ii. To compare the physical comfort parameters in the hostel room and prayer hall with the Industry Code of Practice on Indoor Air Quality 2010.
iii. To determine the compliance of thermal comfort and the effect of the ventilation system in reducing the temperature in the hostel room and mosque's main prayer hall.

1.4 Scope of Study

This study mainly focuses on the ventilation system within the hostel room and prayer hall of Pusat Islam Engineering Campus, USM. Ventilation must be a greatly concerned because it will influence the indoor environment of the mosque. A sound ventilation system can provide thermal comfort for users who perform their prayers and other activities. The parameters measured in this study include the air temperature and relative humidity within the hostel room and mosque's main prayer hall since these parameters are significant in this study. The sampling results are then compared with the permissible limit based on ICOP 2010 to determine compliance.

1.5 Expected outcome

The expected outcome of this study is to help the designers in the future design of modern mosques and student hostels with the consideration of thermal comfort and a sound ventilation system, simultaneously reducing the operational cost. Besides that, this study also helps reduce the temperature within the mosque's main prayer hall and hostel room.

1.6 Dissertation outline

This dissertation consists of five chapters. Chapter 1 is an introduction that includes the study background, problem statements, objectives, scope of work and expected outcomes. This chapter helps the reader to get an overview and understand the purpose of this study. Chapter 2 focuses on a literature review, in which some articles and previous research are used to explain the analysis further. Meanwhile, chapter 3 is a research methodology, discussing the procedures to carry out the study to achieve the objectives. This chapter also explains how to collect the data and conduct the monitoring inside the buildings and the analysis method. Chapter 4 is for the result and discussion. This chapter includes the study's findings, an analysis of the result and a discussion. Last but not least, chapter 5 will be the conclusion in which all the things discussed in the previous chapter will be summarised and concluded. Besides that, recommendations can also be made for future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This study is conducted in Malaysia, a country that experiences moderately warm ambient temperature. It assists the architects and designers design the mosque with a good ventilation system. A ventilation system must be adopted to reduce energy use and provide thermal comfort inside the mosque. Thermal comfort is essential in providing a healthy indoor environment, improving urban quality of life, and lowering energy usage.

2.2 What is Thermal Comfort?

Based on BS EN ISO 7730, the term thermal comfort can be defined as the state of mind which express satisfaction with the thermal environment. Thermal comfort affects human physiological and psychological, and working performance. Ensuring appropriate thermal comfort is extremely important because an urban mosque is not only a congregational place for worship but also a venue for urban social-culture gatherings such as providing accommodation (retreat), welfare, education and other social and cultural activities. When the space accommodates those functional activities, it requires energy demands to cool the structure. Al-Hamoud et al. (2009) agreed that thermal concerns are vital in most buildings involving people's occupancy.

Thermal comfort is essential in determining the quality of the indoor environment in the urban mosque. The indoor thermal environment should enhance human productivity and performance. A good indoor environment in the mosque can increase people's occupancy and concentration level (Fauziah Hanum Abdullah et al., 2016). People desire a temperature that is neither too hot nor too cold in their rooms (Nasir et al., 2013). However, there is a lack of research on the effect of thermal comfort in determining the quality of an indoor space of an urban mosque. Therefore, the comfort conditions in urban mosques should be thoroughly investigated to establish aspects of thermal comfort that affect people's occupancy and concentration levels.

Increased cooling demand due to using mechanical systems such as air conditioning to promote comfort would result in increased energy consumption and electricity costs. Some mosques in hot and humid climates, like Malaysia, are mechanically air-conditioned to provide the necessary thermal comfort for the occupants. Besides, mosques have a unique operation schedule compared to other buildings (Abdou et al., 2005). Mosques are commonly used for congregational prayers five times per day, Friday prayers, and seasonal occupation for different events. This high volume of worshippers during the intermittent operation schedule requires energy for air conditioning in the main praying hall and natural ventilation in the vast prayer hall to meet the cooling demand (Fauziah Hanum Abdullah et al., 2016). However, the increasing air conditioning usage in Malaysian mosques appears to raise electricity consumption in mosque operations regularly.

2.3 Thermal Comfort Parameters

Thermal comfort is difficult to measure since it is subjective. The significant parameters that must be measured are air temperature and relative humidity. Other parameters contributing to thermal comfort are air speed, clothing, and metabolic rate.

2.3.1 Factors Affecting Thermal Comfort Inside the Buildings

Thermal comfort inside a building is influenced by several factors such as air temperature, relative humidity, and air movement of the surrounding space. This air movement is usually related to the ventilation system inside the building. Rasli et al. (2021) reported that the high indoor air temperatures recorded inside the prayer halls could be because of the lack of cross and stack ventilation. According to MS 1525:2007, stack ventilation improves the airflow across space because of the air density differences within the main prayer hall. Users' thermal comfort is a significant concern in places with many occupants, such as mosques (Ahmad et al., 2012). Hence, the ventilation system must ensure good air movement within the building. In addition, a sound ventilation system will provide thermal comfort for the users while performing their activities inside the mosque.

(a) Openings inside the building

Several factors influence the temperature inside the mosque. One of the factors is the window opening and upper gaps inside the mosque walls and dooms. The doorless and wide opening within the main prayer hall allows free air or cross ventilation which also provides a cooling effect (Noor, Muhammad, & Lim C. H., 2021). Adequate larger openings on the top of the dome could give much better airflow within the mosque than domes with only many openings on the side or no openings. An opening near the dome allows stack ventilation to cool the heated dome, releasing the hot air and allowing cooler air to enter the lower areas (Fathimah, Sabarinah, & Nurul Liyana, 2019). Besides that, Rasli et al. (2021) said that increased openings on facade walls through passive design allow for adequate air circulation in interior spaces.

(b) Design of buildings

The other factor that influences the temperature inside the mosque is the design. Mosque designs have always included environmentally friendly building envelopes. The prayers envelope whether walls, floors, roofs, fenestration and doors with historic features such as courtyards, clerestories, and roof openings have produced a significant and inspirational human comfort zone. The materials for the floors, the roofs with apertures, the walls with windows, and the clerestories were all carefully chosen (El-Darwish and Rana, 2016). Building conditions or façade design parameters such as dimensions of the building, ventilation, size of doors, type and size of windows and general activities like praying are some factors that may interrelate to influence the level of thermal comfort (Rasli et al., 2019).

Generally, previously built mosques in past decades can be described as environmentally sustainable due to the vernacular style in construction and materials used (Mohamad & Nangkula, 2010). Historic Islamic civilisations inspired most designs in terms of layouts and architecture. They represent Islamic architecture's glory, power, and magnificence (Adnan & Basma, 2010). Aziz (2016) highlighted Cyberjaya Mosque in Malaysia as a green and sustainable design with a plan that is well suited to a hot and humid climate. The mosque not only makes use of modern materials but also provides excellent cooling strategies to reduce the building’s overall cooling load. The centre courtyard of the mosque allows for natural ventilation. At the same time, the hot air in the main prayer hall is released through the openings or ventilators located in its glass dome structure. Therefore, no daytime air conditioning and lighting are required (Noor Muhammad et al., 2021).

In mosque buildings, facade design is a significant factor that can lower air temperature and ensure proper ventilation systems. The facade is a barrier between the exterior and internal surroundings, influencing indoor environmental conditions, building thermal performance, and occupants' satisfaction (AmirHosein et al., 2012). According to Askari and Dola (2009), "facade is the first and most impactful connection between humans and the built environment. The outer shell of a building is not only a reflection of the architectural character of a region, but also a representation of local cultural, social, climatic, political, and economic circumstances."

Furthermore, because considerable energies flow across this boundary between the exterior and internal environments, the facade's design is essential for indoor climate and energy usage (Johnsen and Winther, 2015). Therefore, providing a functional design for urban mosque façades will benefit the functional characteristics of urban mosques in Malaysia. Façade design can be solved through the implementation of passive design, such as the opening parameter that allows sufficient air to circulate into internal space, the orientation of the building of the mosque, and the shading device that can avoid the heat that is directly through the wall of the building of the mosque (Fauziah Hanum Abdullah et al., 2016).

Figure 1.1 illustrates different facade designs in Malaysia's urban mosque façade design. The facades have an impact on both visual comfort and thermal comfort. Environment, social and cultural considerations, designer conceptions, political viewpoints, economics, historical importance, and other factors can influence the implementation of façade design (Fauziah Hanum Abdullah *et al.,* 2016).

a) Masjid Jamek, Kuala Lumpur b) Masjid India, Kuala Lumpur

c) Masjid As-Syakirin, Kuala Lumpur d) Masjid Al- Bukhary, Kuala Lumpur

Figure 2.1: Example of Urban Mosque in Malaysia

The facade should be well-designed to complement the surrounding environment. According to Abdel-Aziz and Shuqair (2014), one of the factors that impact facade design is responsive environmental parameters. The parameters are orientations, voids and windows openings, vertical and horizontal shading mechanism, building materials and colours. Some facade design parameters, such as the opening parameter that allows air to ventilate into the indoor environment, building orientation, and shading device, complement passive design techniques that provide thermal comfort to building occupants (Fauziah Hanum Abdullah et al., 2016).

Since the facade plays a significant role in the building's energy consumption, designing the facade for minimum energy demand for heating, cooling, ventilation, and lighting while maximising the use of natural energy flows provided by the external climate becomes a significant challenge (Johnsen and Winther, 2015). Regarding energy consumption, it is essential to design a mosque facade that meets the demand for natural ventilation (Baharudin & Ismail, 2014) and effective shading without relying on the mechanical system excessively. Baharudin and Ismail (2014) also pointed out that allowing natural lighting and ventilation into the building interior will reduce energy usage and mechanical maintenance costs. Furthermore, several studies have demonstrated that natural ventilation in buildings reduces operating costs, improves thermal comfort, and improves interior air quality. As a result, urban mosques' facade design needs to be designed passively to reduce energy consumption (Fauziah Hanum Abdullah et al., 2016).

Furthermore, according to ASHRAE 90.1, 24 per cent of the glazing area of the building outside envelope, such as windows, is the ideal percentage for optimum internal lighting and natural ventilation. In contrast, more than 30 per cent would bring overheating into the building. Larger glazed roofs or walls contribute to poor thermal comfort by causing internal heat gain due to solar radiation, particularly in air-conditioned buildings where the cooling load is increased (Abdullah & Wang, 2011).

Besides that, Liu et al. (2017) identified that heat transmission from the outside to the inside can be minimised through moisture transfer in the building. Furthermore, the climatic issue can be solved by the double-shelled dome. The external dome can play a vital role in protecting the internal dome from the heat of the sun's energy, reducing the temperature within the mosque (Varzaneh et al., 2014). Better natural ventilation can be improved by having a proper opening at the correct location of a building and a good layout that can regulate the entering air circulation throughout the interior spaces of the building (Izudinshah et al., 2018).

Based on MS2577:2014, there are seven types of mosque design around the world which vary according to cultural, regional and geographic conditions. Generally, the mosque is single or multi-domed in a rectangular layout which consists of architectural elements such as a pulpit, minaret, mihrab and courtyard. Suitable thermal, acoustic, and visual comfort conditions should be provided in the mosques for users to worship efficiently and comfortably (Atmaca & Zorer, 2020). In Malaysia, the mosque’s design usually has pyramidal roofs, an Ottoman-style and Iran and Middle East architecture (Abdul Rahim et al., 2014). Figures 1.2, 1.3 and 1.4 show mosques’ designs according to their respective regions.

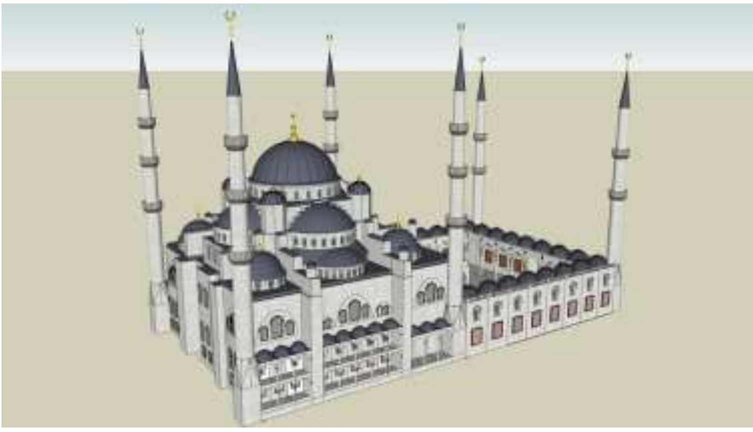

Figure 2.2: Sultan Ahmed Mosque (Istanbul, Turkey) with Ottoman Style

Figure 2.3: Kampung Laut Mosque in Kelantan (pyramidal-shaped roof)

Figure 2.4: Mosque in Iran and the Middle East ("Iwan" (vaulted space))

The roof is an integral part of the building envelope, and it is also vital to evaluate the thermal performance of buildings since it acts as a thermal barrier (Jiangdong & Mingfang, 2018). The inclined roof design absorbs more solar energy than the perpendicular roof design, and the building's shape (height, length, and width) significantly impacts energy consumption (Mirrahimi et al., 2016). Mosque interior design is a single volume (approximately 10 ft or slightly more than 10 ft of floor-to-ceiling height). It can also be a combination of single and double volumes, which is more than 10 ft of floor-to-ceiling elevation at the area next to the mihrab (Rasli et al., 2019). According to Chua and Chou (2010), increasing the height of a structure can improve outdoor ventilation.

Most mosques in Malaysia use air conditioning systems to cool down the air temperature for the users. Air Conditioning Split Units (ACSUs) are chosen because it is low in cost and easy to install and maintain. However, ACSUs use a lot of electricity and increase the level of carbon emission (Abdullah *et al.*, 2016). The indoor air quality in mosques with ASCUs is also worse than in mosques without ASCUs. According to Rasli et al. (2019), the concentrations of three chemical air pollutants (TVOC, O_3, and CH_2O) in air-conditioned mosques are greater than in non-air-conditioned mosques, which could be due to a lack of ventilation. Meanwhile, the extensive usage of ACSUs has been linked to dampness issues, resulting in moisture that promotes bacterial and fungal growth (Shan et al., 2019).

As air conditioning leads to high energy demand, developing and utilising cooling and heating technologies with low energy consumption is crucial. A study by Ali et al. (2022) suggested that a natural ventilation system is the alternative (characteristics) to the mechanical air conditioning device, in which natural forces are used to ventilate (i.e., wind), and the temperature is maintained within safe and comfortable limits. The systems are dependable, energy-efficient, and low-maintenance (Wang and Malkawi, 2019). As a result, natural ventilators should be used instead of conventional mechanical systems whenever natural ventilation systems may improve indoor air quality while lowering energy consumption.

(c) Ventilation System

The worshipper generally uses mosques five times a day to perform their prayers. Mosque has become a place for Muslims to find peace and tranquillity. Therefore, it is essential to achieve as much thermal comfort in the mosque for the occupants as they perform their activities (Noman, Kamsah, & Kamar, 2016). Thus, studying mosque envelopes is crucial to providing a comfortable indoor environment (Bakhlah & Hassan, 2015). The roof is a section of a mosque envelope most exposed to the sun. To offer a well-designed mosque, the roof should be investigated to reduce solar radiation, such as by increasing movement (Fathimah, Sabarinah, & Nurul, 2019). A sound ventilation system inside the hostel room is also essential to ensure students' thermal satisfaction while studying.

Natural ventilation is a passive method used for a long time, even before mechanical ventilation systems were invented. It is currently a viable option referred to as a passive cooling approach for reducing excessive energy usage (Sacht & Lukiantchuki, 2017). The main benefit of natural ventilation is the ability to achieve a high ventilation rate during hot weather for cooling without the need for active cooling, resulting in a more comfortable indoor environment (Di Turi & Ruggiero, 2017). The stack effect phenomena should be embraced and utilised as one of the mosque's central natural ventilation systems. By having an opening on the dome, when the air is calm, the heated dome will release the hot air and enable cooler air to enter via the lower portions (Fathimah, Sabarinah, & Nurul, 2019). This system has been applied to cisterns to allow the outflow of moist air and dry air, allowing the water at the bottom of the cistern to cool (Najafi et al., 2015).

(d) Environmental Factors

Thermal comfort inside the building is influenced by several factors, including air temperature, relative humidity, ad air movement.

(d)(i) Air Temperature (T)

Air temperature is the temperature surrounding the human body, typically measured in degrees Celsius (ºC). This environmental parameter is measured widely as it influences our daily activities. A previous study by Wafi & Ismail (2010) stated that the comfortable temperature for Malaysian students is 28.5 ºC. It is suggested that the occupants can adapt themselves by using active and passive ventilation to experience thermal comfort.

(d)(ii) Relative Humidity (RH)

Relative humidity can be defined as the ratio of the air's vapour pressure to its saturation vapour pressure. Relative humidity can reach more than 70% at workplaces without air conditioning or if the outdoor weather may impact the inside thermal environment. Indoor humidity can vary widely and may be influenced by drying mechanisms.

(d)(iii) Air Movement

This parameter can be defined as the rate at which air moves across the person and may aid in cooling them if the air is cooler than the surrounding area. The difference in pressure between the inside and outside of a building causes air to travel through it. This pressure difference may be caused by mechanical power such as a fan or natural forces like wind-induced pressure differences and stack effects.

(e) Individual Factors

Two factors influenced the thermal comfort inside the building: clothing insulation and metabolic rate.

(e)(i) Clothing Insulation

The clothing insulation effect is very much influencing thermal comfort. If the occupant wears too much clothing, it will cause thermal discomfort even though the environment inside the building is not warm or hot.

(e)(ii) Metabolic Rate

The impacts of metabolic rate or activities performed can contribute to thermal comfort. More heat will be produced if the occupants do more physical activities. Thus, more heat must be removed from our bodies to avoid overheating. It is also necessary to consider physical characteristics such as body weight and size, age and fitness level concerning thermal comfort.

2.4 ASHRAE Standard 55-2004

This study has used two standards: ICOP 2010 and ASHRAE Standard 55-2004. ICOP standard was mainly used to determine the permissible limit of air temperature, relative humidity and air movement. The result was compared with this standard to identify whether the parameters comply with the standard. Meanwhile, ASHRAE Standard 55-2004 is used to determine whether the PMV and PPD values are within the permissible limit or not. Both PMV and PPD values are essential since they evaluate the thermal comfort of the occupants. As a result of variations in the pressure distribution outside and inside the building, airflow patterns are created. Air will travel from areas of high pressure to those of low pressure.

2.5 PMV and PPD Method

PMV and PPD methods were used in this study to determine thermal comfort. An index called PMV aims to estimate the average vote of a significant number of people on a seven-point thermal sensation scale. When an occupant's internal heat generation and heat loss are equal, thermal equilibrium is reached. Besides that, the permissible limit of PMV should be within +0.5 to -0.5. Physical activity levels, clothing insulation, as well as the features of the thermal environment can all have an impact on a person's body heat balance. The PMV index has a +3 and -3 scale, respectively, with +3 denoting too hot and -3 denoting too cold.

The PPD, or index, which produces a quantitative prediction of the percentage of thermally unsatisfied occupants (i.e., too hot or cold), can be calculated once the PMV has been established. In essence, PPD provides the proportion of people expected to feel local discomfort. According to the standard, the allowable limit for PPD value is 10%.

CHAPTER 3

METHODOLOGY

3.1 Overview

The research approach of this study is the quantitative method. This research focused on the different buildings with different ventilation systems, mosque buildings and student hostels, to find the best design for natural ventilation. The primary activity involved in this study is field monitoring at the site and data collection. The indoor temperature and relative humidity were measured, and thermal comfort was evaluated.

3.2 Flow Chart

Figure 3.1 shows the overall steps of conducting this study to achieve the objectives of this study.

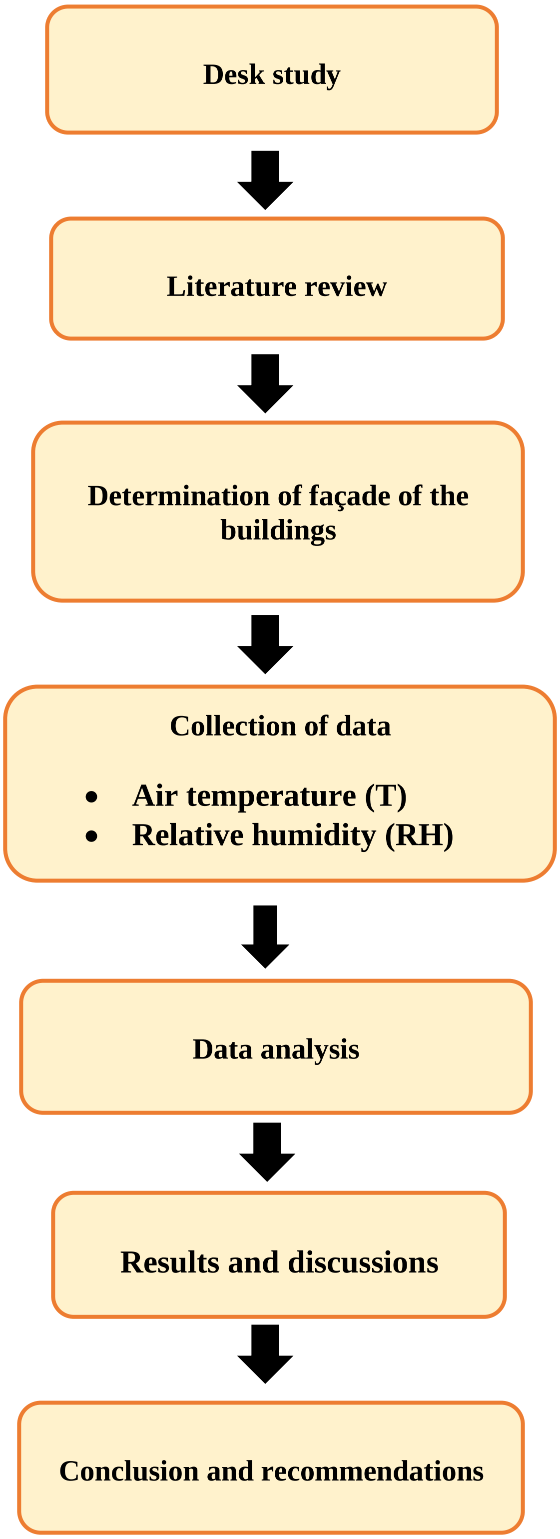

Figure 3.1: The Schematic Flow of Overall Steps for the Study

3.3 Sampling Locations

This study was conducted at two locations which are a hostel room and prayer hall at Pusat Islam USM, Engineering Campus. USM is situated in three neighbouring states; Nibong Tebal, Pulau Pinang, Bandar Baharu, Kedah and Parit Buntar, Perak. This mosque uses passive and mechanical ventilation (fan) within the main prayer hall. The mosque has a longitude of N5.144724 and a latitude of E100.493959.

Each hostel room consists of three students and three single beds at each corner of the room. The standard ventilation system in the room is natural ventilation, in which the outdoor airflow into indoor spaces naturally without using mechanical ventilation like fans. Figure 3.2 shows the monitoring location of the hostel room, which Lembaran. The overview of Pusat Islam and the hostel room is illustrated in Figures 3.3, 3.4, 3.5, 3.6 and 3.7. The data were measured in these two locations to obtain the result of various ventilation strategies.

Figure 3.2: The Location of Monitoring at Hostel Room in SH2 Lembaran

Figure 3.3: Pusat Islam in USM Engineering Campus

Figure 3.4: Overview of Prayer Hall of Pusat Islam Facing the Qibla

Figure 3.5: Dome of the mosque

Figure 3.6: The Door and Windows inside the Main Prayer Hall of Pusat Islam

Figure 3.7: Overview Inside the Hostel Room

3.4 Monitoring Instrument

The T-Rh Data Logger was used to measure the temperature (ºC) and humidity (RH %) inside the mosque's main prayer hall and hostel's room. Figure 3.8 shows the instrument used for measuring the data. The devices were placed inside and outside the building to see the differences in temperature for both locations. The T-Rh Data Logger is placed at 1.2m above the floor at one sampling point and at least 0.5m from walls, corners or any vertical surfaces. The data for indoor and outdoor were measured simultaneously. Readings of all the parameters were obtained after 1 hour of monitoring.