THERMAL COMFORT AND ITS RELATION TO VENTILATION APPROACHES IN MOSQUES

MUHAMMAD NORSHAZRIL ALIF BIN ZAKARIA

SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA
2017

THERMAL COMFORT AND ITS RELATION TO VENTILATION APPROACHES IN MOSQUES

By

MUHAMMAD NORSHAZRIL ALIF BIN ZAKARIA

This dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

As partial fulfilment of requirement for the degree of

BACHELOR OF ENGINEERING (HONS.)
(CIVIL ENGINEERING)

School of Civil Engineering,
Universiti Sains Malaysia

June 2017

SCHOOL OF CIVIL ENGINEERING
ACADEMIC SESSION 2016/2017

FINAL YEAR PROJECT EAA492/6
DISSERTATION ENDORSEMENT FORM

Title: Thermal Comfort and its Relation to Ventilation Approaches in Mosques

Name of Student: Muhammad Norshazril Alif Bin Zakaria

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:

______________________ ______________________

(Signature of Supervisor)

Date : Name of Supervisor :

Date :

Approved by:

____

(Signature of Examiner)

Name of Examiner :

Date :

ACKNOWLEDGEMENT

Alhamdulillah, after all of hard work in this year, I would like to express my deepest praise to Allah S.W.T., for given me strength and faith to complete this project. Moreover, it is necessary to express my gratitude to those people who contributed to help me with this project.

First and foremost, my utmost gratitude and appreciation to my supervisor, Dr. Noor Faizah Fitri Md. Yusof for the continuous support and guidance. Her help and advice for writing of this thesis were very helpful and I would have been lost without her. Besides my Supervisor, I would like to thank to my Co-Supervisor, Assc. Prof. Dr. Mohd Rodzi Ismail for great effort in explaining things clearly and for all encouragement and advised given during this project was carried out.

I also thank for financial support from grant 305/PAWAM/6013607 and permission to do their project/grant as my final year project.

Finally, thanks to my beloved parent, Zakaria bin Juhanin and Normah binti Yusop and my friends who inspired my effort. Furthermore, thanks to PhD student, Miss Nur Baitul Izati binti Rasli, Miss Nazatul Syadia binti Zainordin and Mrs. Azrin binti Suroto for their assistance while completing this project and make this project finished successfully.

ABSTRAK

Keselesaan termal ialah kajian tertutup tahap keselesaan rasa oleh penghuni di ruang tertutup. Projek ini membentangkan kajian keselesaan termal yang telah dijalankan di dalam bangunan masjid di sekitar Nibong Tebal, Pulau Pinang, Malaysia. Objektif kajian adalah menentukan kelembapan, suhu dan kelajuan angin mengikut standard yang berkaitan dan mewujudkan hubungan antara sistem pengudaraan dengan Ramalan Undi Purata (PMV) dan Ramalan Peratus Ketidakpuasan (PPD) mengikut ASHRAE Standard-55. Kajian ini telah dilaksanakan pada 6 bangunan masjid pada pukul 12:00 p.m hingga 05:00 p.m. Kajian ini telah dijalankan menilai keadaan terma pada waktu solat Zohor/Jumaat dan Asar. Semasa waktu solat, pengudaraan aktif dihidupkan manakala sebelum dan selepas solat hanta pengudaraan pasif (tingkap dan pintu) sahaja boleh didapati. Hasilnya menunjukkan nilai tertinggi untuk suhu, kelembapan dan kelajuan angin yang direkodkan ialah 34.4°C, 78.5% dan 1.24 m/s di mana tidak mematuhi Industrial Code of Practice 2010. Julat yang boleh diterima bagi suhu ialah 23ºC-26ºC, kelembapan 40%-70% dan kelajuan angin adalah 0.15-0.5 m/s. Tambahan pula, suhu menaik mendadak bagi keenam-enam masjid pada sebelum dan selepas waktu solat kerana hanya pengudaraan pasif boleh didapati pada masa itu. Sementara itu, penurunan suhu semasa solat adalah disebabkan oleh pengudaraan aktif seperti kipas dan penghawa dingin telah dihidupkan. Oleh yang demikian, mendapati bahawa keselesaan termal yang lebih baik adalah semasa waktu solat. Keadaan masjid juga adalah sedikit panas dan hangat. Selain itu, berdasarkan keputusan yang direkodkan untuk memerhati keselesaan haba di dalam bangunan masjid, sebahagian besar bangunan masjid tidak memberi keselesaan termal yang baik dan PPD adalah tinggi.

ABSTRACT

Thermal comfort is the study of indoor comfort level of the occupant in indoor space. This project present the study of thermal comfort that had been carried out in mosque building around Nibong Tebal, Penang, Malaysia. The objective of the study includes determining the compliance level of thermal comfort parameters (relative humidity, temperature and air speed) with relevant standard and establish relationship between ventilation system with Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) according to ASHRAE Standard-55. The study was conducted at 6 mosque building from 12:00 p.m. to 5:00 p.m. In order to asses thermal condition during Zohor/Jumaat and Asar prayer times. During prayer time, active ventilation was switched on meanwhile before and after prayer time only passive ventilation (window and door) available. The result show the highest value for temperature, relative humidity and air speed that being recorded are 34.4 °C, 78.5% and 1.24 m/s which does not comply with Industrial Code of Practice 2010. The acceptable range for temperature is 23°C-26ºC, relative humidity is 40%-70% and air speed is 0.15-0.5 m/s. Furthermore, the temperature build up rapidly before and after prayer time because only passive ventilation was available at that time. Meanwhile, the temperature drop during prayer because during that time, active ventilation such as fans and air conditioner were switched on. Overall observation found that better thermal comfort was during prayer time and environmental sensation condition of the mosque is slightly warm and warm. Moreover, according to result that being recorded and calculated to identity the thermal comfort in mosque building, most mosque building did not provide a good thermal comfort and most of number of occupant dissatisfied is also high.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ASHRAE	**A**merican **S**ociety of **H**eating, **R**efrigerating and **A**ir-conditioning **E**ngineer
ICOP	**I**ndustrial **C**ode of **P**ractice
PMV	**P**redicted **M**ean **V**ote
PPD	**P**redicted **P**ercentage **D**issatisfied
WWR	**W**indow to **W**all **R**atio

NOMENCLATURES

e	Euler's number (2.718)
f_{cl}	clothing factor
h_c	convective heat transfer coefficient
I_{cl}	clothing insulation [clo]
M	metabolic rate [W/m^2] 115 for all scenarios
p_a	vapor pressure of air [kPa]
R_{cl}	clothing thermal insulation
t_a	air temperature [°C]
t_{cl}	surface temperature of clothing [°C]
t_r	mean radiant temperature [°C]
V	air velocity [m/s]
W	external work (assumed = 0)
Tmr	mean radiant temperature, °R
T_N	surface temperature of surface N, °R (calculated or measured)
A_N	area of surface

CHAPTER 1

INTRODUCTION

1.1 Background

To provide an indoor climate that building occupant will find thermally comfortable, thermal comfort standards are required to help building designers to design a building (Nicol and Humphreys., 2002). According to ASHRAE's Standard-55 a comfort zone based on six variables which are air temperature, air velocity, relative humidity, radiant temperature, occupant's clothing insulation and occupant activity level. Occupant can be dissatisfied with the environment, less activities in their task and uncomfortable if temperature and humidity levels in building are too high or too low. The relative humidity should be greater than 30% as dry condition can lead to health problems, such as skin irritation.

In Malaysia, the location is near the equator that may lead to received more heat in the building. The higher solar and terrestrial radiations reaching building envelope cause discomfort to the occupant in the tropical climate (Abdullah et al., 2016). Mosque building is one of the non-industrial building and is an important building typology for muslim especially in Malaysia that majority of population in Malaysia are Muslim as a place for worshipping, preaching and multi-functional community space held in the main prayer hall of mosque building that involve occupancy (Hussin et al., 2014).

Indoor air quality (IAQ) and thermal comfort in public building especially in mosque during prayer time may be concern for a quality of life because a healthy indoor environment as the rapid growth of mosque buildings in Malaysia and especially at prayer time that always receive high attendance require good indoor air quality (Ocak et al., 2012). Indoor air quality has significant effects such as respiratory and cardiopulmonary pathologies and asthma. It is easy to understand that the most important environment in relation to our health is the indoor environment (Sundell, 2004).

The level of the indoor air contaminants is the principle parameter for indoor air quality because people generally spend more than 90% of their time indoors (Klepis, 2001). A good indoor air quality (IAQ) is acceptable when there are not known contaminants at harmful concentration air (ASHRAE, 2007). In Malaysia, legislation started in early 2005 when the Department of Occupational Safety and Health (DOSH) under the Ministry of Human Resources launched a Code of Practice on Indoor Air Quality (2005) (Syazwan et al,. 2012).

1.2 Problem Statement

Thermal comfort and Indoor air quality (IAQ) are very important because it can affect public user's health where they may be exposed to indoor air pollutants. The issues are not new in Malaysia. However, lack of study data and local regulation become one of the problem especially with the non-industrial (Ismail et al., 2010) especially in mosque. A mosque is a special and sacred place where Muslims perform prayers either individually or congregationally and carry out other religious activities for its communities. Therefore, comfortably thermal environment within the prayer hall or main congregational area of the mosque is an important requirement as this could affect the serenity and focus of the worshippers.

The building condition or façade design parameter (e.g. dimension of the building, ventilation, size of doors, type and size of windows) and general activities (e.g. praying) are some of the factors that may lead to affect the level of thermal comfort.

Moreover, poor thermal comfort or thermal discomfort give negative impact in its own right. If it continues over prolonged periods, thermal discomfort may contribute to more serious health impact for individual especially to the occupant in the building. It also cause sleeplessness which may lead to health risk for the person concerned and for others, as well as less work productivity (Mavrogianni, 2015).

1.3 Objectives

The objective of this project is intended to correlate with the problem statement .The aim of this project is intended to achieve the following objectives:

i. To determine the compliance level of thermal comfort parameters (relative humidity, temperature, & air speed) with the relevant standards.

ii. To establish the relationship between ventilation approach and Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) thus its compliance with ASHRAE Standards.

1.4 Scope of the project

This project was carried out at six selected mosques in Nibong Tebal, Pulau Pinang. In this project monitoring record was analysed for the thermal comfort parameter in order to establish the relationship between the thermal comfort parameter which are relative humidity, temperature and air flow with approaches system in mosque buildings.

There are two method that being used to determine thermal comfort in mosque building which are Predicted Mean Value (PMV) and Predicted Percentage Dissatisfied (PPD) by using CBE ASHRAE thermal comfort tools.

In addition, the data exploration in this study will get the sampling for passive and active ventilation. There are four continuous session for this project starting at 12:00 p.m until 5:00 p.m.

1.5 Thesis Outline

This thesis structure will give reader clearly visualize the content of every chapter. The present thesis is organized in five chapter and the brief outline is explained below.

Chapter 1 explains about the introduction of the project as well as the problem statement and project objective. This chapter also gave a short brief of background of thermal comfort and indoor air quality.

Chapter 2 covers the literature reviews that related to the studies for this project that discuss about thermal comfort with their parameter, ventilation and all component related to this project.

Chapter 3 shows the procedure applied which are sampling location, monitoring instrument, the monitoring plan, sampling method and statistical method that being used in order to estimate all thermal comfort parameter and façade design parameter.

Chapter 4 describes the statistical analysis that being obtained from sampling that being carried out. This chapter also discuss in detail the results obtained.

Chapter 5 gives the conclusions of this project and benefits that will get from the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter defines thermal comfort and further description of terms and concepts. Furthermore, this chapter also discuss in an explanation about ventilation system, briefly discuss about the health concern due to effect of poor thermal comfort and the factor that may lead to poor thermal comfort and the indoor environment within in public building especially mosque building.

2.2 Thermal Comfort

Thermal comfort can be defined as that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation. In addition, thermal comfort is the occupant's satisfaction with the surrounding thermal conditions and it is important to deal with designing a building that will occupied by people (ASHRAE Standard-55, 2010). Thermal comfort are issues that must be concern by the building designer, manager and owner in the design and operation of ventilation system and building spaces. Poor condition of thermal comfort may lead an effect occupant's health, creating physical symptoms such as headaches, nose, throat, eye and skin irritation and can also lead to occupant dissatisfaction and discomfort, and a reduction in work performance (Charles et al., 2005).

According to Richard et al., (1994) there are several factor influencing thermal comfort and indoor air quality which are the rate exchange of air with air from outdoor, the concentration of pollutants in outdoor air, the rate emissions from sources indoors, the rate infiltration from sources soil gases, and the rate of removal in the indoor environment.

As stated in ASHRAE Standard-55 (2004) there are six variables to determine comfort zone which are air temperature, air velocity, relative humidity, radiant temperature, occupant's clothing insulation and occupant's activity level. In addition thermal comfort will also depend on the age, health status, gender and the adaption to the local environment and climate of the occupant (Ormandy and Ezratty, 2012). Occupant can be dissatisfied with the environment, uncomfortable and less effective in their task, if the temperature and humidity levels in the building are too high or too low. As stated in Industry Code of Practice in Indoor Air Quality the acceptable range for physical parameters as shown in table 2.1.

Table 2.1: Acceptable range for specific physical parameters

Parameter	Acceptable range
Temperature	23-26 ºC
Relative Humidity	40-70 %
Air speed	0.15 – 0.50 m/s

2.2.1 Temperature

Temperature is one of the basic IAQ measurements that has direct impact on perceived comfort and, in turn to measure of how hot or cold the air is, temperature is the most commonly measured weather parameter. Temperature also can be describe as the kinetic energy, or energy of motion of the gases that make up air. The air temperature can be increases if the molecules move more quickly. Furthermore, air temperature affects the rate of evaporation, relative humidity, air speed and precipitation patterns and types. Usually the temperature expressed in degrees Celsius or Fahrenheit (Fondriest, 2010).

Temperature is one of the fundamental characteristic of the indoor environment. It can be controlled with a degree of accuracy dependent on the building and its ventilation system. Moreover, air temperature may affect occupant on direct indirect way, including thermal comfort, perceived air quality, sick building syndrome (SBS) and performance at work (Seppanen et al., 2006). In addition, air temperature was found to the strongest single predictor of pollutant concentration in many air pollutant prediction studies. (Hubbard and Cobourn, 1998).

2.2.2 Relative humidity

Relative humidity is the actual amount of moisture in the air compared to the total or maximum moisture the air can hold at a given temperature. In addition relative humidity is the ratio (expressed as percentage) of the amount of moisture in the air to the maximum amount that can be present at that temperature (Skilling, 2009). According to Lawrence (2005) he stated that relative humidity is commonly defined as the ratio of the actual water vapour over the saturation vapour pressure and .

Relative humidity in one of the fundamental in air pollution that play an important role as relative humidity and ventilation may lead to very different exposures based on personal measurement versus ambient concentration of air pollutant (Environmental Protection Agency, 2016). The increasing or decreasing of the relative humidity above or below the standard according to Industrial Code of Practice (2010) may cause uncomfortable and unhealthy environment although relative humidity is not considered as a causative agents of health problems (Arundel et al., 1986).

2.2.3 Wind / Air Speed

To providing thermal comfort for the occupants wind and air speed is needed**.** Indoor air speed plays an important role when the temperature and relative humidity more difficult to modify by creating physiological cooling (Ernest et al., 1991). Air speed can be expressed as metre per second (m/s). Usually indoor concentration and physical parameter be influenced by air speed or wind since is affected by both wind direction and air speed. In addition, a high wind speed will enhanced dispersion and decrease outdoor concentration (Elbayoumi, 2014).

2.2.4 Radiant Temperature

Radiant temperature is defined as the enclosing surfaces of a space, which is determined by the emissivity and the temperature of the surfaces. Since it may affect the range of acceptable air temperatures, so the radiant temperature value will affect the thermal comfort zone. For example, higher radiant temperatures allow the occupant to feel comfortable at lower air temperatures, or vice versa (ANSI/ASHRAE Standard-55, 2013). Radiant temperature is equal to air temperature as the difference between the two parameters within indoors is negligible under moderate outdoor conditions (Walikewitz et. al., 2015).

The radiant temperature was found by using the following equation:

$$T_{mr} = T_1A_1 + T_2A_2 + \ldots + T_NA_N / (A_1 + A_2 + \ldots + A_N) \tag{3.1}$$

Where,

T_{mr} = mean radiant temperature, °R

T_N = surface temperature of surface N, °R (calculated or measured)

A_N = area of surface

2.2.5 Clothing Insulation (clo) and metabolic rate (met)

One of the factors of human thermal comfort assessment is clothing insulation. Each type of clothing would affect the thermal comfort of human body (Wu et al., 2016). Clothing insulation can be defined as thermal insulation provided by the clothing. Heat cannot be generated from insulation but it traps pre-existing levels of heat to prevent it loss. Moreover, clothing insulation is intended to keep us warm and also as a shields from excessive warmth (Trepass, 2016).

During prayer time especially for Zohor and Asar worshipper clothing usually similar to those outdoor ensembles in term of their outlook, thickness and colour because once Muslims hears the voice adhan they should leave all his work while wearing clean and proper clothes to attend and perform his salah in the mosque building (Al-Ajmi, 2010). According to Hussin et al., (2014) in Malaysia the most common clothes indicated is traditional malay long sleeves shirt with trousers, traditional malay long sleeves shirt paired with kain sarung, long sleeves shirt paired with normal trousers and normal shirt with kain sarung

According to ASHRAE Standard-55 (2010) activity rate or metabolic rate can be define as the changes of chemical energy into heat and mechanical work by metabolic activities within an organism. Usually metabolic rate is expressed in met units, where 1 met = 58.12 W/m². For activity rate During salah or prayer time is very low because usually worshippers practice worshipping in the mosque building and the movement during prayer is very relax and light activity movement such as standing, bowing, prostrating and sitting (Al-Ajmi, 2010).

2.2.6 Other Factors That Affect Thermal Comfort

The other factors that affect thermal comfort is gender. Human can be categorize into two, namely male and female. So, there is a difference between the nature of male and female. In cool condition female tended to be cooler than males and in the same cool environment, female felt more uncomfortable than male. This is because the temperature of female mean skin was lower than males (Lee and Choi, 2004; Liu et al., 2011; Parsons, 2002).

Furthermore, the other factor that affect thermal comfort is acclimatization. Acclimatization is an adaptation to the environment and one the most important because the people that common to live in area where high humidity and heat are better to tolerate to get a good thermal condition than those who do not (de Dear and Brager, 1998)

2.2.7 Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied

According to ASHRAE standard-55 (2010) there is method of describing thermal comfort which are Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD). As stated by Charles (2003), PMV was developed by Fanger (1970) from laboratory and climate chamber studies, participants were dressed in standardised clothing and completed standardised activities, while exposed to different thermal environments and recorded how hot or cold they felt and later adopted as an ISO standard that refer to a thermal sensation scale scale that runs from cold (-3) to hot (+3) as shown in Table 2.2. The acceptable range value for PMV for an interior space according to ASHRAE 55 is between -0.5 to +0.5.

Table 2.2: Predicted Mean Vote and its relation to thermal sensation scale

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

Next, Predicted Percentage of Dissatisfied (PPD) was used to know how many percentage that occupant satisfied with thermal comfort. The further PMV from 0 or neutral the higher the PPD. 100% PPD is the maximum number of people dissatisfied with their comfort condition. The acceptable range that being recommended by ASHRAE 55 for thermal comfort is less than 10% people dissatisfied for an interior space. The PMV was found by using the following equation:

$$PMV = [0.303e^{-0.036M} + 0.028]\{(M - W) - 3.96E^{-8}f_{cl}[(t_{cl} + 273)^4 - (t_r + 273)^4] - f_{cl}h_c(t_{cl} - t_a) - 3.05[5.73 - 0.007(M - W) - p_a] - 0.42[(M - W) - 59.15] - 0.0173M(5.87 - p_a) - 0.0014M(34 - t_a) \quad (3.2)$$

With

$$f_{cl} = 1.0 + 0.21I_{cl} \quad (3.3)$$

$$t_{cl} = 35.7 - 0.0275(M - W) - R_{cl}\{(M - W) - 3.05[5.73 - 0.007(M - W) - p_a] - 0.42[(M - W) - 58.15] - 0.0173M(5.87 - p_a) - 0.0014M(34 - t_a)\} \quad (3.4)$$

$R_{cl} = 0.155 I_{cl}$ (3.5)

$h_c = 12.1(V)^{1/2}$ (3.6)

Since PPD is a function of PMV, it can be defined as

$PPD = 100 - 95e^{[-(0.3353PMV^4 + 0.2179PMV^2)]}$ (3.7)

Where:

e	Euler's number (2.718)
f_{cl}	clothing factor
h_c	convective heat transfer coefficient
I_{cl}	clothing insulation [clo]
M	metabolic rate [W/m^2] 115 for all scenarios
p_a	vapor pressure of air [kPa]
R_{cl}	clothing thermal insulation
t_a	air temperature [°C]
t_{cl}	surface temperature of clothing [°C]
t_r	mean radiant temperature [°C]
V	air velocity [m/s]
W	external work (assumed = 0)

Based on the above equations, the University of California at Berkeley has developed a web-based tool for thermal comfort calculations according to ANSI/ASHRAE Standard 55 (2013) which aim at providing a free, cross-platform tool that allows designers and other practitioners to perform thermal comfort calculations. This can be done by providing inputs on air temperature, air speed, relative humidity, clothing insulation value and metabolic rate, as well performing other required setting on this CBE Thermal Comfort Tools.

2.3 Effect of poor Thermal Comfort and Indoor air Quality.

Thermal comfort is not just about ensuring a sensation of satisfaction, it is also related to the health occupant of the building. Particularly the health of those most susceptible and fragile to temperatures outside the allowable range, such as the children and elderly (World Health Organization (WHO), 2006). Moreover, poor thermal comfort of thermal discomfort give negative impact in its own right. If it continues over prolonged periods, thermal discomfort may contribute to more serious health impact for individual especially to the occupant in the building. It also cause sleeplessness which may lead to health risk for the person concerned and for others, as well as less work productivity. One of the fundamental parameter of thermal comfort is temperature, thus if the temperature is higher and outside the allowable range, extreme heat exposure will occur and may lead to hyperthermia, which cause the symptoms of heat stress, heat stroke, heat exhaustion, heat syncope and heat cramps (Mavrogianni, 2015).

According to Industrial Code of Practice (2010) they categorized the health effect due to poor IAQ and thermal comfort into 4 which are health effect due to environmental tobacco smoke (ETS), sick building syndrome (SBS), Building related illnesses (BRI) and legionnaire’s disease. ETS can defined as all substances in indoor air came from tobacco smoke and one of the main source is cigarette smoking. Next, the building with occupant experience acute and/comfort effect that appear to be linked to time spent in a particularly building, but there are no exact illness or cause can be identified can be describe as sick building syndrome. In addition, one the commonly causing symptoms typical of the SBS are mechanical ventilation and Indoor air quality (Jaakkola et al., 1991). The symptom usually arise form SBS are nose irritation, fatigue, cough, headache, sore throat or combination of these. For building related illness (BRI), the illness that being identified such as Legionnaire's disease, asthma, hypersensitivity, pneumonitis, and humidifier fever, have directly discover from a particularly building.

2.4 Mosque Building and Religious Practice

Mosque building is one of the non-industrial building and is an important building typology for muslim especially in Malaysia that majority of population in Malaysia are Muslim as a place for worshipping, preaching and muti-functional community space held in the main prayer hall of mosque building that involve occupancy (Hussin et al., 2014). Thus, the mosque is the most important building in determining thermal comfort and indoor air quality because there a lot of people using it everyday. Thermal comfort and indoor air quality (IAQ) issues are not new in Malaysia. However, lack of study data and local regulation become one of the problem especially with the non-industrial (Ismail et al., 2010) especially in mosque. Thermal comfort and Indoor air quality (IAQ) is very important that will impact on public user's health where they may be exposed to indoor air pollutants.

2.5 Façade Design

Building facade not only focus on their design and aesthetic but it also can give comfort to the occupant of the building. In addition, the design of the facade has immense significance for both indoor climate and energy utilization, as there are many energies flows both ways over this boundary between the external and internal environments (Johnsen and Winther, 2015). There are several parameter that should need consider for efficiently complementing the environmental context in façade design. The parameters are orientations, voids and windows openings, vertical and horizontal shading devices, building materials and colours as shown in Figure 2.1. The design strategies of passive design (natural ventilation) should be consider which are responsive towards providing thermal comfort and good indoor air quality to the building occupants (Abdullah et al., 2016).

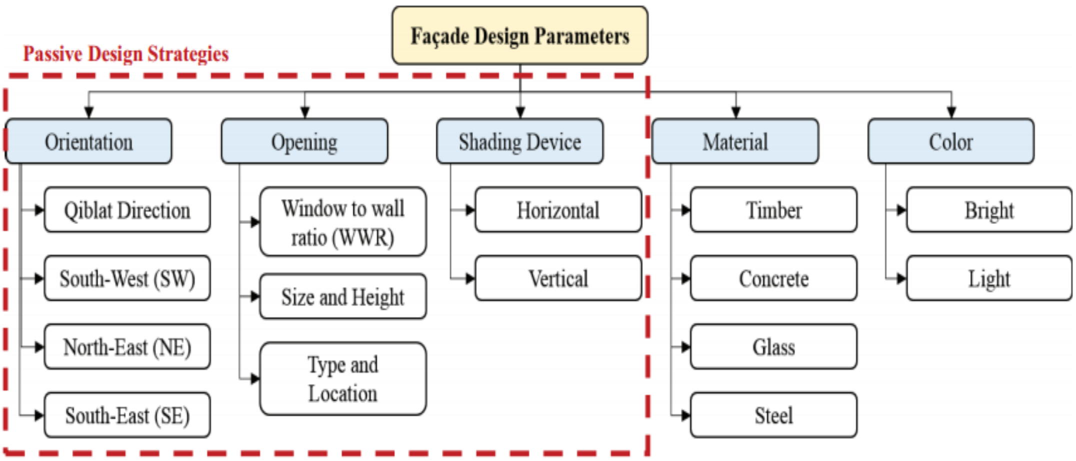

Figure 2.1: Façade design parameter

To determining heat gains into buildings the thermal performance of facade components plays an important role in which can determine the indoor environment, especially for buildings with low internal heat source such as non-industrial building. For this reason, naturally ventilated building design in hot-humid climates needs to pay more attention to orientations, shading devices, material selections, and opening size such as window and door (Wang et al., 2007).

Of all the façade design parameters above (Figure 2.1), window to wall ratio (WWR) is of interest of this study. WWR is the measure of the percentage area of a building's exterior envelope that is made up of glazing, such as windows. ASHRAE 90.1 (2007) recommended that WWR of 0.24 is the ideal value to allow optimum indoor daylight and natural ventilation. Nevertheless, this does not mean that the higher the WWR, the better performance of the windows. The larger the windows, the more heat or light could penetrate to indoors which may cause overheating and glare. Windows with WWR more than 0.30 will create overheating into the building. Table 2.3 shows the recommended WWR values and their respective ratings.

Table 2.3: Recommended WWR values and their rating (ASHRAE 90.1-2007)

WWR	< 0.24 (24%)	0.24 (24%)	> 0.30 (30%)
Rating	POOR	GOOD	OVERHEAT

2.6 Ventilation Approach

To provide an acceptable thermal environment as well as air quality the ventilation is one of the fundamental matter. Ventilation system must be considered when design a room or a building as they are fundamental to comfort and well-being of the human occupants or the performance of industrial processes within these spaces (Awbi, 2003).

Ventilation can be defined as air exchange between outdoor and indoor. It can be categorized into three types which are natural ventilation, mechanical ventilation and infiltration. Natural ventilation involves movement of through building openings such as door and window. Next, for mechanical ventilation involves fans and heating and air-conditioning systems. Undesirable movement of air unidentified movement of air in and out of the structure. When infiltration rates are low, building are characterized as "tight" **(**Boubel et al., 1994). There are several purpose why ventilation system should be designed appropriately which are to create optimal conditions for humans in indoor environments, taking into account their health, comfort, and productivity by providing air for breathing, for removing and diluting indoor pollutants, for adding or removing moisture, and for heating or cooling (Wargocki et al., 2002). The summary of advantages and disadvantages of natural and mechanical ventilation as shown in Table 2.3 From the study, ventilation is one of the main factors that control thermal comfort and air quality, by regulating the indoor temperature, relative humidity, wind speed and concentrations of gases and particles (Halios et al., 2014).

2.6.1 Natural Ventilation System

One of the strategy for achieving acceptable thermal comfort and indoor air quality is natural ventilation essentially based on air supply of fresh air to space and dilution of the indoor pollution concentration. In addition, for designers or architects, natural ventilation is attractive because it can afford of providing an acceptable indoor air quality and thermal comfort needs throughout the full range of climate conditions (Santamouris and Allard, 1998).

From a study, natural ventilation likely to provide a better ventilation to reduce building energy demand clearly to warm and temperate climate. Thus, it can be one of the mitigation measure to global warming (Steemers, 2003; Chappels and Shove, 2005; Shove et al., 2008). Among the benefits of natural ventilation such low capital operation cost, Compatible for providing satisfactory thermal comfort in certain climates and are recognized to reduce the associated problems with air-conditioned buildings. Natural ventilation also have their own weakness such as it is difficult to design and control although the principle itself is not difficult to understand and the Comfort level of occupant easily reduces when hot, humid or cold (Wang et al., 2007).

2.6.2 Mechanical Ventilation System

Mechanical ventilation can be define as a fresh air is supplied and exhausted from the room through a network of supply and exhaust ducting, mechanical plant and terminals. In addition, the system boosts when required to regulate the flow of air for the space. Moreover to recover the energy from the exhaust air, the heat recovery fans was used and also can allow high levels of air movement (Passivent, 2013).

To achieve high standard for thermal comfort and indoor air quality for occupant satisfaction, well-being performance, setting recommendations for mechanical ventilation system should be consider. The recommendation that should be followed such as well maintain to all system component in mechanical ventilation and cleaning, Air speed, air direction, and temperature be controlled by individual, outdoor air supply rate that meets or overcome ASHRAE Standard-62.1 (2004) should be used, thermal conditions that meet ASHRAE Standard-55 (2004) should be delivered and air supply diffusers should be adjust to avoid draft (National Research Council of Canada, 2003).

Table 2.4: Advantage and disadvantages of mechanical and natural ventilation

	Advantages	Disadvantages
Mechanical	• Compatible for all climate and weather with air conditioning or heater as climate dictates • Can be control according to occupant comfort.	• Expensive to install and must be well maintained. • Possibility for noise pollution from the equipment.
Natural	• Compatible for warm and temperate climates moderately useful with natural ventilation. • High ventilation rate capable to achieve. • Lower capital, operational and maintenance costs for simple natural ventilation • Energy saving.	• Difficult to design and control although the principle itself is difficult to understand. • Easily affected by outdoor climate. • Comfort level of occupant easily reduces when hot, humid or cold.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The purpose of monitoring was to collect data for thermal comfort parameter such as temperature, relative humidity and air speed inside the mosque building in Nibong Tebal, Pulau Pinang. Moreover, for this chapter it also include the details of selected monitoring mosque, the selection of monitoring instrument, the monitoring plan, sampling method, statistical method that used and the flow chart of methodology is as shown in Figure 3.1. The mosque building was labelled as M1, M2, M3, M4, M5 and M6.

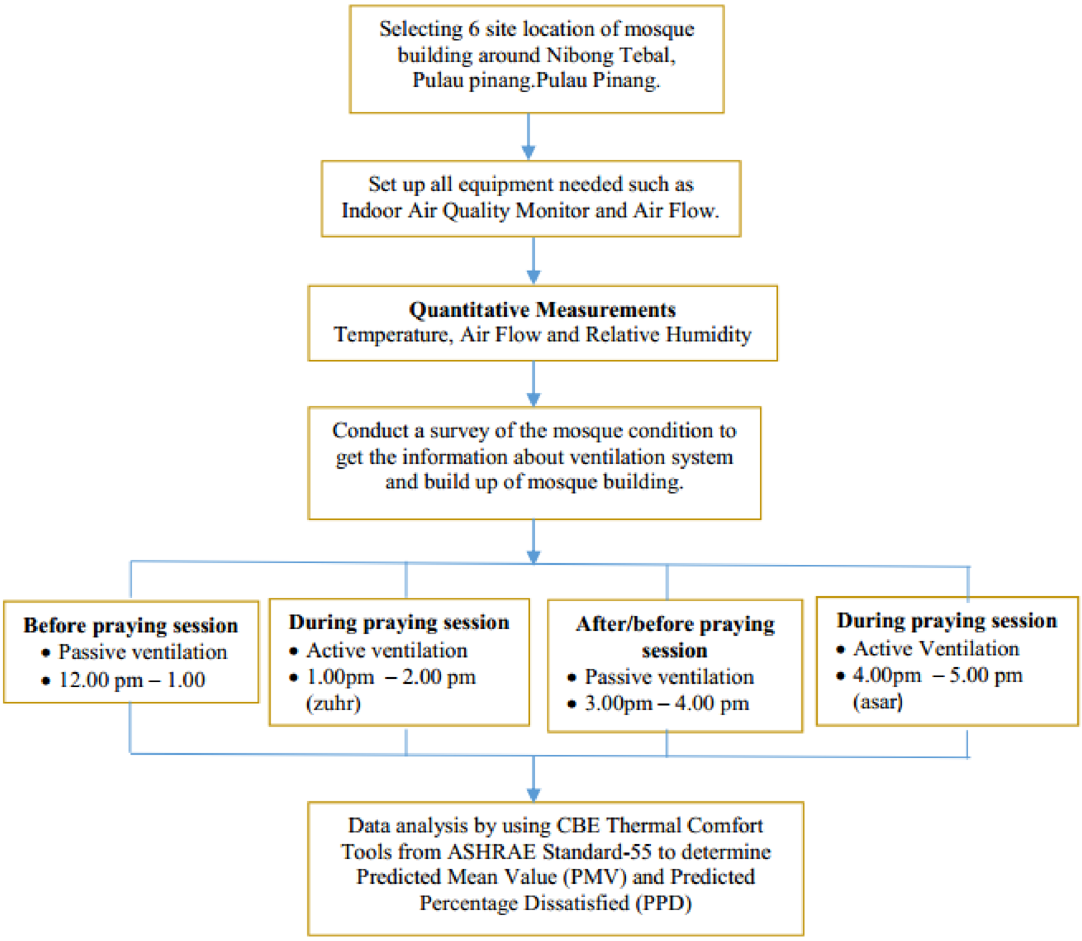

Figure 3.1: Flowchart of methodology

3.2 Study Area

As mentioned early Nibong Tebal was selected as main investigation area to achieve the study objective. Nibong Tebal was located in South of Seberang Perai, Penang, Malaysia. It is bounded with Parit Buntar, Perak on the South Bandar Baharu, Kedah as shown in Figure 3.2. According to The Weather Channel (2016), the end of the year of 2016 the temperature in Nibong Tebal is approximately 28 ºC and the humidity is around 70% to 77%. High thermal environment in building indoor spaces effect these climatic conditions.

Figure 3.2: Location of the selected mosques in Nibong Tebal

3.3 Sampling location

Six mosque building around Nibong Tebal was selected as shown in Table 3.1 and Figure 3.2 as public indoor space to achieve the study objectives. The selected mosque building was chosen to determine the physical parameters of thermal comfort (Temperature, Relative humidity and Air Speed) according to Industrial Code of Practice (2010). From the six mosque building selected, two were monitored on Friday due the high occupancy on Friday afternoon because of the Friday prayer. So, the data sampling for temperature in mosque building in Friday is different from normal day.

Table 3.1: Coordinate of selected Mosque Building

No.	Mosque	Coordinate
1	M1	5°09’44.34”N 100°30’55.29”E
2	M2	50°8’40.44”N 100°29’.31”E
3	M3	5°07’53.48”N 100°28’46.61”E
4	M4	5°07’36.52’N 100°26’37.87”E
5	M5	5°10’00.47”N 100°29’30.31”E
6	M6	5°08’55.68”N 100°25’13.44”E

M1

M2

M3

M4

M5

M6

Figure 3.3: Selected mosque building

3.4 Selection of monitoring instrument

An Indoor Air Quality monitor Model IQ-610 was used to get a data for Temperature (Range: 10° to +70ºC and Accuracy: ±0.3°C) and relative humidity (Range:0 to 100%) Indoor Air Quality Model also can be use to get a data for total volatile organic compound, carbon dioxide, carbon monoxide and ozone. The second instrument used is Air Flow Model Telescoping AS-201 for air speed in mosque building as shown in Figure 3.4.

	
IAQ monitor Model IQ-610	Air Flow Model Telescoping AS-201

Figure 3.4: Selection of monitoring instrument.

3.5 Preparation for monitoring plan

Survey was conducted to get the information about ventilation system, facade design parameters and sample position before monitoring was carried out. There are two types of ventilation system that are natural ventilation (Passive) such as window and door and mechanical ventilation (Active) such as fan and air conditioner. For natural