ROOF DESIGNS AND AFFECTING THERMAL COMFORT FACTORS IN A TYPICAL NATURALLY VENTILATED MALAYSIAN MOSQUE

By

SHAFIZAL MAAROF

(0543482)

Submitted in accordance with the requirements for the degree of Doctor of Philosophy

(PhD)

Cardiff University

School of Architecture

2014

Form: PGR_Submission_2014

NOTICE OF SUBMISSION OF THESIS FORM: POSTGRADUATE RESEARCH

APPENDIX 1:
Specimen layout for Thesis Summary and Declaration/Statements page to be included in a Thesis

DECLARATION

This work has not been submitted in substance for any other degree or award at this or any other university or place of learning, nor is being submitted concurrently in candidature for any degree or other award.

Signed .... (candidate) Date 12-3-2015

STATEMENT 1

This thesis is being submitted in partial fulfillment of the requirements for the degree of PhD ....(insert MCh, MD, MPhil, PhD etc, as appropriate)

Signed .... (candidate) Date 12-3-2015

STATEMENT 2

This thesis is the result of my own independent work/investigation, except where otherwise stated. Other sources are acknowledged by explicit references. The views expressed are my own.

Signed .... (candidate) Date 12-3-2015

STATEMENT 3

I hereby give consent for my thesis, if accepted, to be available online in the University's Open Access repository and for inter-library loan, and for the title and summary to be made available to outside organisations.

Signed .... (candidate) Date 12-3-2015

STATEMENT 4: PREVIOUSLY APPROVED BAR ON ACCESS

I hereby give consent for my thesis, if accepted, to be available online in the University's Open Access repository and for inter-library loans **after expiry of a bar on access previously approved by the Academic Standards & Quality Committee.**

Signed .... (candidate) Date ....

ACKNOWLEDGEMENTS

I would like to thank God for giving me the opportunity to further my study at this level. The experience that I got through the journey of the study is priceless. The challenges and hardship in conducting the research have taught me to be a better person. I would also like to thank my wife, Ruzita and my children, Atiqah, Haikal Uzair and Farhan for being with me and giving support and sacrifices throughout the journey. I know that all of you have tolerated so many things in your lives to make the study a success. A special thank too for those who have helped me in this study especially the Mosque Authority of the selected mosques who had allowed me to stay and conduct the study inside the mosques. Not to forget, all the staff of Welsh School of Architecture, Cardiff University who has been very helpful in assisting me during my stay in Cardiff. Lastly, to my late beloved mother who passed away while I was thousands miles away from you, I always pray that God will grant His blessings for you at all time. I am sorry that I could not be with you during your last moment.

Abstract

The local climate of Malaysia with high air temperature and relative humidity and inconsistent air movement throughout the day provides challenges for architects and designers to design a building including a mosque that can provide better indoor thermal condition. Thermally uncomfortable indoor environment in a typical Malaysian mosque can be sensed due to the poor attendance of believers during communal prayers conducted five times a day at the mosque. A study was carried out in four typical mosques in Malaysia to investigate the thermal comfort level together with what and how the thermal comfort factors affecting the condition. They study also looks at the influence of roof design of the mosque in affecting thermal condition inside the prayer hall since the roof design is a significant feature of the building not only as a filter to the outdoor climate but also as the identity of the building and the society. From the investigation, it has been revealed that air temperature is the primary factor in affecting thermal comfort. When the air temperature is at neutral or comfort temperature, the presence of other factors can be ignored. However, when the primary factor is no longer at its neutral condition, the secondary factors which are air movement and humidity will play their roles in influencing thermal comfort in naturally ventilated mosques in Malaysia. In many cases, air movement is always desirable and able to improve the thermal comfort level. Therefore, the need for the availability of air movement should be particularly considered in designing a mosque to ensure that the mosque is thermally comfortable. The research has also discovered that the pitched and doomed roofs have different abilities to control the distribution of air, for examples, the pitch roof mosque has the ability to circulate the air inside the prayer hall to achieve the equilibrium state whereas the domed roof mosque has the ability to stratify the air according to the temperature where the coolest air located at the lowest level of the space. With the pitch roof, a mosque is able to create air movement inside the space whereas the dome roof mosque will provide stagnant but cooler air at the active level due to the stratification process. Due to these findings, the pitched roof mosque is considered a better option for this climate for its ability to provide natural air circulation inside the space which is desirable by the users. With the understanding on the ability of the roof designs namely, domed and pitched roof in controlling air movement of the interior and the interdependencies of the main factors affecting thermal comfort, strategies for improvement on the design of the mosque can be made to achieve better indoor thermal condition of the prayer hall.

Keywords: thermal comfort, air temperature, air movement, naturally ventilated, mosque, roof design.

Contents

List of Figures

List of Tables

CHAPTER ONE - INTRODUCTION

1.1 INTRODUCTION

A building is designed to provide comfort for the users. The variation in the building design from one climatic region to the other indicates that the factors affecting thermal comfort also differ from one another. Therefore, the understanding of the factors affecting thermal comfort and the influences on the building design is necessary in producing an effective passive building design.

In many cases, air temperature has been considered as the major influencing factor to the thermal comfort. Other factors such as humidity and wind movement may have played a different role in affecting thermal comfort depending on the types of the climate. For examples, the air movement may not be favourable for a country that has a moderate climate but become desirable for a country with a hot and humid climate. It is important to understand how these factors affecting each other in influencing thermal comfort even though it is unanimously accepted that the air temperature is the main factor affecting the thermal comfort. The presence of other physical factors such as the humidity and air movement varies the thermal comfort perception based on the climate and with the understanding of how these factors cross affecting each other, a modification of building design can be carried out to tackle the thermally uncomfortable situation caused by the factors.

In Malaysia, a mosque is considered as one of the important buildings. The designs of the typical mosques are similar in many areas, for examples, the space layouts of the current mosque developments are fairly the same with the prayer hall become the main space located in the middle of the building surrounded by other supporting spaces such as verandah-way, offices and utilities. They are however, significantly differ in roof designs and can be grouped into two main characteristics which are the domed and pitched roof designs. In many buildings including mosques located in tropical countries such as Malaysia, the roof is the important feature of a building due to the climatic factors which has heavy precipitation and hot temperature. The current trend of providing mechanical air conditioning system to many existing and new mosques signals that the indoor environment of the contemporary mosque is not thermally comfortable. The option of providing mechanical air conditioning system has become a major alternative in an attempt to produce a thermally comfortable indoor environment in Malaysian mosques. It is the easiest solution to the problem of thermal discomfort caused by the high air temperature and humidity which is common to any tropical country such as Malaysia. Such action is proven to be effective in providing thermally comfortable environment however it also brings destructive consequences to the environment as well as to the occupants.

An alternative method to provide thermally comfortable indoor environment that is energy efficient and environmental friendly is highly demanded at this turn of the century. This issue has been discussed extensively by many researchers throughout the world and it has been agreed that the major determinant of the thermal indoor environment of a building is the building design itself. The climatic influences have always been the major issues to be considered in designing a passive building. However, the approaches architects and designers took in designing a building has been changed parallel with the development of the technology. Looking at the traditional or historical buildings of a certain country, it is obvious that the environmental factors, especially the weather, has been the main consideration in designing the building by giving careful attention to the building envelope to shelter the users from the intolerable climatic condition. With the introduction of the mechanical air conditioning system, this approach has been forgotten and the climatic factors have not been considered as the main issues in the design development process due to the capability of the system to provide the desired thermal indoor condition. For the past few decades, researches have revealed that the use of the mechanical air conditioning system has major disadvantages especially on the issues of pollution and sustainability.

With this concern, numerous researches have been conducted to investigate an alternative method to replace the cooling using the mechanical system which is proven to be energy consuming and sometimes unhealthy. Passive design has been seen as one of the approach that is energy efficient and environmentally friendly to achieve a comfortable thermal indoor condition by improving the design of the building especially the building envelope to filter the heat from the outside. Researches aiming to mitigate the transfer of heat into the interior ranging from the determination of the indoor thermally comfortable condition to the choices of passive design have been conducted quite extensively throughout the world. However, the majority of the research conducted is mostly dealt with the thermal comfort condition in the moderate climate countries. Only a few researches that dealt with the thermal comfort issues in tropical countries can be found and most of them focus on the thermal comfort condition for tropical climate on residential buildings. Unfortunately, little knowledge can be found on the issue of thermal comfort and passive design of mosques in the tropical countries, particularly Malaysia.

Being an important building, a mosque carries a bigger role than just accommodating congregational prayer. It is also considered as a center for the community where many social events relating to the disseminating of religious knowledge conducted. Besides that, it also carries the pride of the community and depending on the types of the mosques they also act as a landmark or monument to the country. This is not only happening in Malaysia but also to the other Islamic countries as pointed out by Serageldin (1990) that a mosque has been considered as an icon to portray the Islamic identity of the country. The role of the mosque as a tool to express the spirit of solidarity and political power among Muslim communities is also agreed by Grabar (1997). As a tool and being an important building to the community, the mosque should also reflect the concern of protecting and preserving the environment through its design that is environmentally friendly. The application of the two common roof designs which are the domed roof and the pitched roof may have contributed to the poor indoor thermal comfort condition if they were not designed appropriately in relation to the overall design since the space layouts or plans of the mosques are fairly similar to one another.

It can be evidenced in Malaysia, being one of the Islamic political government, the architecture of the mosque especially the selection of the roof design is often copied from Middle Eastern model. Many issues relating to the architecture of the mosque has been discussed by architects and academicians. Mohamad Rasdi et al (2006) argue the relevance of using the Middle Eastern, Mid Asian and African model as a reference in Malaysian mosque architecture. He believes that the representation of Islam in architecture should be more related to the 'socio-economic and regionalistic concerns' (2002). Similarly, Gregory also questions the applicability of the foreign architecture model being implemented in Malaysia. It does not reflect the sensitivity to the culture and tropical environment. Ismail (2008) in her research also agrees that the design of the mosque, specifically referring to the state mosque, is more personal which is influenced by the views of the political leaders rather than the suitability of the design to the climate and culture. The selection of the roof designs requires many considerations especially when dealing with thermal comfort.

It is evidenced in the previous research that the selection of the mosque design especially on the roof design is more towards the identity rather than to the aspects relating to the environmental physics such as thermal comfort of the building. Thermal comfort has become an important issue nowadays as it relates to the issue of sustainability. It does not only help to reduce the energy usage but it also helps to improve the productivity. The increase in the number of research conducted on this field in Malaysia recently shows the growing awareness and significance of thermal comfort in affecting the human behavior and performance. For examples, the research by Kubota et al (2009) focusing on the improving the indoor thermal condition through the use of night ventilation techniques in terraced houses, the thermal comfort study on the schools by Hussein and Rahman (2009) and the office comfort condition by Daghigh et al (2009) show the effort to improve the indoor thermal condition of the important spaces involved in the everyday life. Surprisingly, little published information can be established on the indoor thermal condition and comfort issue on mosques despite being considered as an important building in Malaysia.

As mentioned earlier, the majority of the mosques in Malaysia has similar plans of space layouts but differ in the roof design application. Investigating the influence of the roof design to the thermal condition inside a mosque and the factors affecting the thermal comfort are crucial to ensure that the design of a new mosque can address the important elements of the building and appropriate measures can be strategized to improve the thermal indoor environment. By understanding the importance of each factors relating to thermal condition and comfort, design strategies relating to the roof design can be produced to improve the thermal comfort level of the indoor.

1.2 PURPOSE OF THE RESEARCH

The purpose of the research is to investigate the effectiveness of domed and pitched roof design in providing thermally comfortable indoor environment in typical naturally ventilated Malaysian mosques. The roof designs of the mosques are selected to be studied because of their important functions; not only that the roof filters the harsh climatic elements such as rain and heat but the roof also provides an identity to the building and culture. The significant variation on the design of the mosques can also be strongly evident more in the roof design than in the spatial layout. The research will also focus on the issue of thermal comfort because of the uniqueness of the tropical climate of Malaysia with high air temperature and humidity throughout the year which can make the thermal condition of the indoor environment become very uncomfortable in most of the time if a building was design inappropriately.

1.3 RESEARCH SCOPE

The research investigates the perception of the thermal comfort inside the prayer halls of selected mosques to inquire the interdependency of the factors affecting thermal comfort. However the investigation is limited to three main physical variables, namely, air temperature, air movement and relative humidity. The selection of mosques to be studied is based on the roof design since the majority of the mosque designs in Malaysia can be grouped into two bigger clusters based on the roof designs. In general, there are two distinguished characteristics of overall mosque designs in Malaysia which are the domed and pitched roof mosques. The pitched roof mosques are considered as traditionally or regionally influenced and the domed roof are foreign influenced. The investigation is only conducted on the selected mosques that fall under the categories. Mosques that have roof designs other than domed and pitched roof are not investigated in the research. Table 1.1 shows the summary of the aims, objectives and the methods of investigation involved in the research.

Research Problem: The physical factors, namely air temperature, relative humidity and air movement and the roof design affecting thermal comfort and condition in a typical naturally ventilated Malaysian mosque.

MAIN Research Question:(How) How are physical environmental factors - air temperature, relative humidity and air movement and roof designs affected thermal comfort and condition (what) in typical naturally ventilated pitched and domed roof mosques in Malaysia(who)?

CONSTRUCT	DISCRIPTION OF Research Question	SUB-Research Question	Research Objectives	STRATEGY OF INQUIRY
WHAT	Thermal Comfort And Condition	What is thermal comfort and factors affecting thermal comfort level of building occupants? What are the current thermal situation in a typical mosque in Malaysia	To identify the meaning of thermal comfort and factors affecting thermal comfort. To identify the current thermal situation in a mosque and the causes	Literature Review
HOW	physical environmental factors - air temperature, relative humidity and air movement affecting thermal comfort	What are the relationships established by the air temperature, relative humidity and air movement in affecting thermal comfort level in naturally ventilated Malaysian mosques?	To establish a relationship between air temperature, relative humidity and air movement in influencing thermal comfort in the context of typical naturally ventilated Malaysian mosques.	Survey
HOW	the mosque roof design affecting thermal condition	How thermal condition and therefore thermal comfort level is affected by the mosque roof designs in naturally ventilated pitched and domed roof mosques in Malaysia?	To analyse the influence of the design of the roof in influencing thermal comfort condition and therefore thermal comfort level in a pitched and domed roof mosque in Malaysia.	Simulation for the roof design
WHO	naturally ventilated pitched and domed roof mosque in Malaysia	What are the typical design characteristics that have been employed in designing a naturally ventilated mosque in Malaysia?	To identify typical characteristics of naturally ventilated Malaysian mosques.	Literature Review

Table 1. 1- Summary on the research questions, objectives and strategies of inquiry for the research

In investigating the issue, there are several objectives which need to be achieved (refer Table 1.1). They are:

i. **to identify the meaning of thermal comfort and factors affecting thermal comfort in a tropical countries such as Malaysia.**

This is achieved through literature review regarding the thermal comfort including the definition, factors and methodology and building design influences. It also includes thermal comfort issues focusing on the tropical countries and Malaysia.

ii. **to establish a relationship or interdependency between air temperature, relative humidity and air movement in influencing thermal comfort in the context of typical naturally ventilated Malaysian mosques.**

This is achieved through analysis on the survey conducted at the selected mosques. The survey inquires the thermal perception, thermal comfort level, condition on additional comfort factors such as air movement and relative humidity and preferences vote.

iii. **to investigate the applicability of the evaluative scales currently used in the context of naturally ventilated building for tropical climate countries.**

This is achieved through the analysis from the survey collected on the thermal perception using the ASHRAE scale and Bedford Scale.

iv. **to analyze the influence of the design of the roof in influencing thermal comfort condition and therefore thermal comfort level in a pitched and domed roof mosque in Malaysia.**

This is achieved using the simulation process with the aid of software HTB2 and WinAir4 developed by Cardiff University. The data is analyzed and compared between the pitched and domed roof. Based on the findings, suggestions are made to improve the design in producing thermally comfortable environment.

1.3 OUTLINE OF THE THESIS

The research starts with the introduction to issue of thermal comfort in a typical Malaysian mosque and the possible causes of the setback encountered. It continues with the aim and the objectives of the research and the description of the following chapters.

It follows with Chapter Two that reviews of the previous conducted research in thermal comfort condition particularly on the approaches of the thermal comfort study which includes methods of data collection and evaluation for naturally ventilated building in tropical countries. This chapter also discusses the relationship of the building design and the climatic condition and the influence of these factors to the thermal indoor environment.

Chapter 3 of the thesis reviews the background of the building type studied which is a mosque. It also talks about the development of the Mosque architecture in

Malaysia which touches the transformation of the mosque design influenced by the various factors happened through the time. It finally concludes the chapter by discussing the general characteristics of the contemporary Malaysian mosque architecture.

Chapter 4 describes the methodologies involved in conducting the research. The discussion includes the criteria in the selection of building samples and the participants, methods of data acquisition which are divided into qualitative and quantitative and data analysis methods. The chapter concludes by explaining the relevant of the methods selected.

Chapter 5 shows and analyses the result gathered from the conducted survey and the field measurement of the air temperature and humidity in the prayer hall of the selected mosques. Four typical mosques are selected for the purpose of the study. For each mosque, the chapter discusses the analysis of the data from the conducted survey on the thermal comfort condition experienced by the participants in the selected mosques. The factors affecting the thermal comfort condition is also discussed based on the analysis conducted. The chapter continues with the determination of the tolerable range of the indoor thermal comfort condition and concludes based on the analysis of the four mosques.

Chapter 6 shows and explains the results obtained from the investigation based on the simulation using the available software. It compares the results between the two typical mosques types which are the pitched and domed roof designs. The issues that are covered include the thermal condition or air temperature resulted from the application of the two most popular roof designs in Malaysia. The investigation also looks at the influence of the roof design in affecting the air movement inside the space.

Chapter 7 discusses the finding obtained from the Chapter 5 and Chapter 6 by creating linkages or relationships. Generalization based on the obtained results regarding the thermal comfort condition of the prayer hall of the mosques selected is made. It also proposes the scale to be used in evaluating the tolerable range of air temperature to maintain comfort and suggests a tolerable air temperature to be considered in the evaluation of the building regarding the thermal comfort condition. It also suggests the guidelines in improving the design of the contemporary mosque designs in Malaysia to improve the thermal comfort condition.

Finally, Chapter 8 concludes by summarizing the thesis and concluding the findings from the study. The constraints and limitations of the research are pointed out and future research is suggested.

CHAPTER 2 – MALAYSIA AND ITS MOSQUES

2.1 INTRODUCTION

This chapter presents an overview of Malaysia and the mosques that have been developed in the country. The following chapter reviews the factors affecting the thermal comfort and related researches focusing in tropical countries. This chapter starts by introducing the background of the researched country, Malaysia which includes the climate, population and the religion. Following that, the chapter continues with development of the mosque architecture in Malaysia and the current issues related to the thermal comfort and thermal condition inside the mosques.

2.2 BACKGROUND OF MALAYSIA

2.2.1 INTRODUCTION

Figure 2. 1 - Maps of Malaysia (from www.mapsofworld.com)

Malaysia is located in the Southeast Asia. The total area of the country is about 329,750 kilometres square which consists of 328,550 kilometres square of land and 1,200 kilometres square of water. It consists of two parts which are West Malaysia and East Malaysia. West Malaysia and East Malaysia is separated by the South China Sea. West Malaysia is a peninsular bordering Thailand at the north and Singapore at the south; and East Malaysia, which is one third of the north part of Borneo Island bordering Indonesia and Brunei. It is located between latitude of 0.8^0North and 7.5^0North and longitude 99.5^0East and 119.5^0East.

2.2.2 CLIMATE

Located closed to the Equator, Malaysia is experiencing a hot and humid climate throughout the year with the average air temperature ranging from 23.7 degree to 31.3^0 Celsius throughout the days and the highest maximum temperature recorded is 36.9^o Celsius based on the Malaysian Meteorological Service records. Even though the range is quite significant, the diurnal temperature range is quite minimal. This condition has major influences to the architecture and culture of the people. Along with this high temperature throughout the year, Malaysia also has high content of humidity in the air. The relative humidity is between 67% and 95% with the annual rainfall of 2,500mm which is considered heavy. Generally, the climate can be characterized as “uniform temperature, high humidity and copious rainfall”. Figure 2.2 shows the average temperature of Kuala Lumpur for each month.

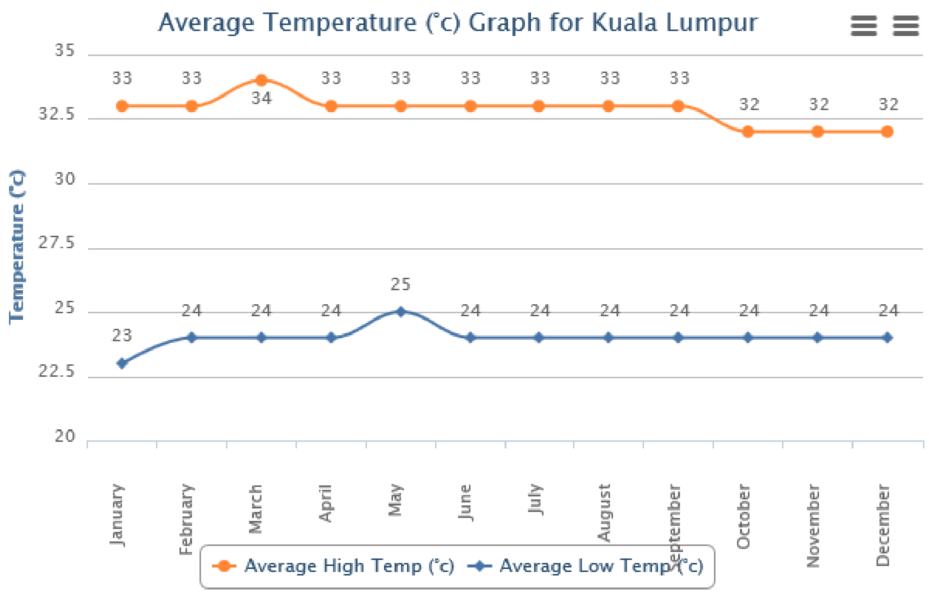


Figure 2. 2 - Average temperature for Kuala Lumpur (Data taken from year 2000 to 2012 from http://www.worldweatheronline.com/)

2.2.3 Wind Flow

The general characteristics of the wind flow in the country are relatively light and variable. Based on the wind flow pattern, there are four seasons that are categorized according to the direction of the flow. They are the southwest monsoon, northeast monsoon and two shorter periods of inter-monsoon seasons (figure 2.3).

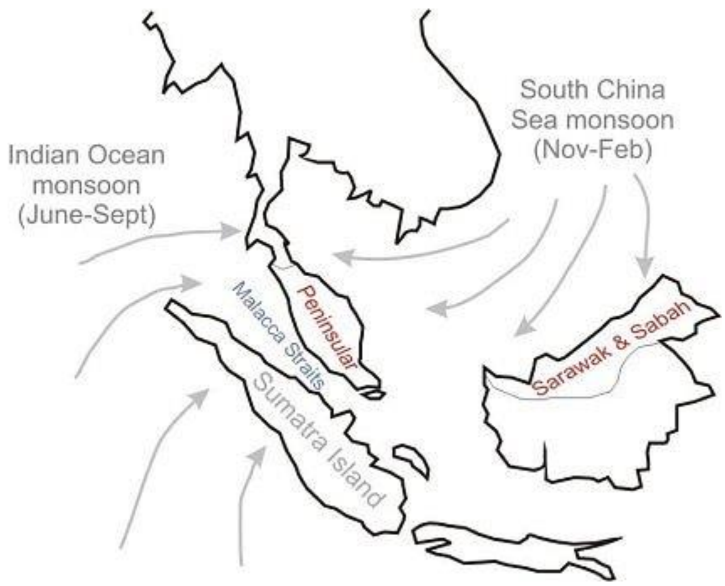


Figure 2. 3 - The monsoon seasons in Malaysia (from https://juinkadsuki.files.wordpress.com)

The southwest monsoon season starts in June until September with the direction of southwesterly wind with a speed of about 15 knots which is light. The northeast monsoon season usually commences in early November and ends in March. During this season, the wind direction is from east or northeast at a speed between 10 to 20 knots. During this season the wind speed at the east coast of Peninsular Malaysia may reach up to 30 knots or more. The winds during the two inter-monsoon seasons are, however generally light and variable. The wind especially the areas closer to the ocean can clearly be marked especially when the sky is clear. This is due to the location of Malaysia which is surrounded by the ocean. During daytime especially in the afternoon the sea breezes often develop and reach up to several tens of kilometers inland. On the other hand, during night time the reverse process takes place and land breezes of weaker strength can also develop over the coastal areas.

2.2.4 Rainfall Distribution

The rainfall distribution in Malaysia can be categorized according the rainy season because of the seasonal wind flow and the topography of the country. The existence of the mountain ranges in the middle of the country blocks the wind flow to arrive at the other part of the country making the two areas having the opposite rainy season, for examples, during the northeast monsoon season, the exposed areas like the east coast of Peninsular Malaysia, Western Sarawak and the northeast coast of Sabah experience heavy rain spells. On the other hand, inland areas or areas which are sheltered by mountain ranges are relatively free from its influence.

There are three distinctly seasons of the rainfall in Malaysia. The east coast of Malaysia will be experiencing a heavy rainfall in the months of November, December and January and a dry season in the months of June and July. The west coast especially the southwest will experience the heavy rainfall from the months of May until August. Figure 2.4 shows the average rainfall in Kuala Lumpur, the capital city of Malaysia.

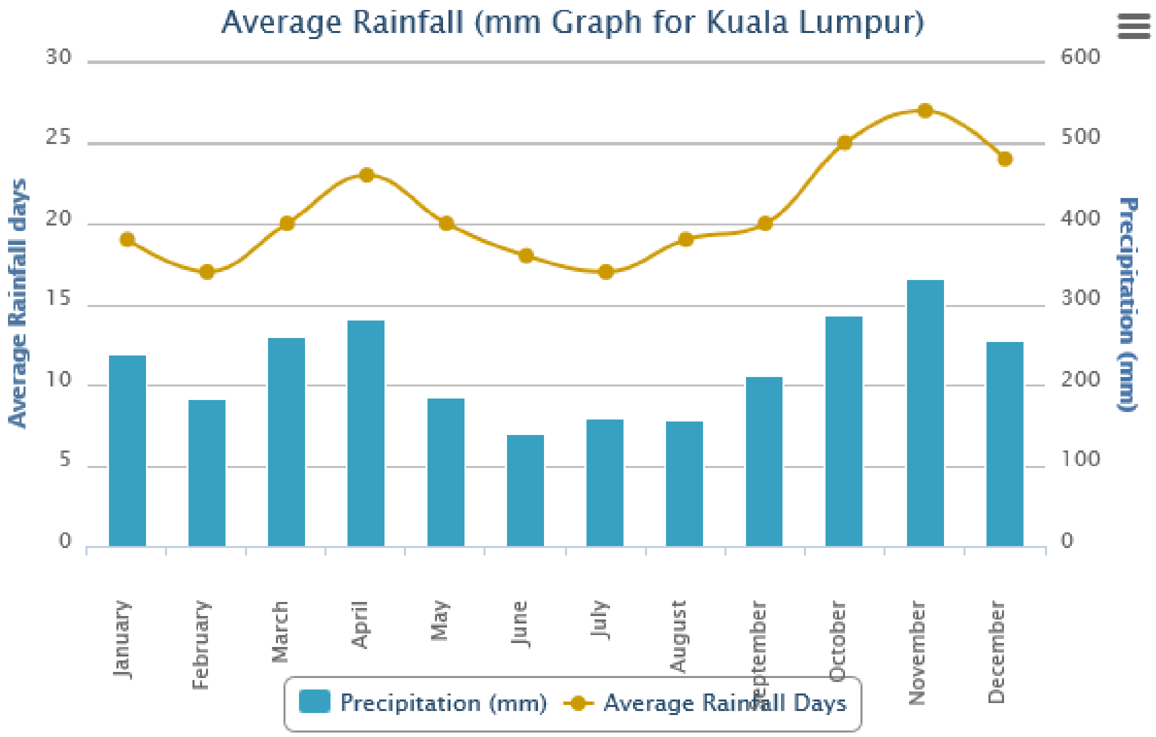


Figure 2. 4 - The average rainfall of Kuala Lumpur (Data taken from year 2000 to 2012 from http://www.worldweatheronline.com/)

2.3 POPULATION

Demographically, it has a population of 27,565,821 which comprises 14,112,667 males and 13,453,154 females. (July 2010 est.). The distribution based on the race is Malays and other Bumiputera groups make up 65% of the population, Chinese 26%, Indians 7.1% and other unlisted ethnic groups 1%. The Malays are the biggest community in Malaysia as they opened the country hundreds years ago. It started out by the opening of Melaka in 1500s by Parameswara who was originally from Sumatera, Indonesia. Due to its strategic location, it had become a very famous trader port. Other powerful countries saw this as an opportunity and wanted to widen their empire by conquering the port. As a result, Malaysia, also known as Malaya during that time, had been conquered by many countries. Britain was one of the countries that had ruled Malaysia. During the British rule, many changes had been made. One of the changes that had impacted the population of the country is the migration of labours from China and India. They were brought in to help the British to collect as much wealth from the natural resources that were plenty in Malaysia during that time. The Chinese were brought to work at the tin mines and the Indians were forced to work in the rubber plantation. When Malaysia received its independent in 1957, all the migrated races had been accepted as the citizens of the Malaysia. As for today, the Chinese is the second largest community and followed by the Indians. The Chinese people have also become the biggest community involved in trade and business in the country compared to other races but the Malay community controls the politics and the administration of the country.

2.4 RELIGION AND CULTURE

Islam is the official religion of the country, however, the citizens are free to practice other religions, such as, Christian, Buddhist, Daoist, Hindu, and Sikh. As the majority of the population is Malays, the Islamic religion followers are the biggest community in Malaysia. Islam was brought to Malaysia in the 13th century by the Indian traders. Since then, the followers of the religion had grown tremendously. The religion has strong influence to the culture. In Islam, rules are provided not only to a religious ceremony but also to daily activities which include the appropriate ways to behave in a community including the way one dressed, talked, ate, etc. As the majority of the population practices Islam, many of other races tend to adapt to the same norms introduced by Islam. The culture which is mostly based on Islam has also been influenced by other traditions practiced by different races.

Each of the races has its own distinctive religious building. Being an Islamic country, a mosque in Malaysia plays an important role in the society (Nasir, 1984; Ali,1993). Not only it representing the official religion of the country and the architecture of its location, but most importantly, it also brings the community together through the congregated prayers and many gatherings conducted at the mosque (Means, 1969). As one of the important building in the community and the country, closer attention has been made to the architecture of the building. As a result, the architecture of the mosque in Malaysia has gone through many steps of development influenced by the various social aspects and environmental factors. The current architecture styles of Malaysian mosques try to incorporate both of the social and environmental factors to produce a mosque that is not only spiritually stimulating but also communally functioning and climatically responsive.

In Malaysia, there are two famous types of mosque designs which are heavily influenced by the roof. They are pitched roof mosque and domed roof mosque. Complaints have been heard that some mosques are uncomfortable due to the excessive thermal energy experienced by the users.

2.5 WHAT IS A MOSQUE?

In Islamic community a mosque is called a 'masdjid' derived from Arabic word which means to 'prostate' (Gazalba, 1975; Asfour, 2009) which is one of the actions during the prayer. A mosque in Islam is considered a sacred building. The sacredness of the building, however, is more related to the function of the building rather than the architecture. It is a place of worship to submit oneself to God (Bosworth, 1986; Rasdi 1998). Traditionally, only religious related activities can be conducted inside the mosque. Therefore, there are some ethics that need to be followed when visiting the mosque which are mostly related to the dressing code and behavioural guidelines.

2.5.1 The Elements of a Mosque

A mosque is actually started with a simple building. It is a place of worship that has been agreed by the group or the community. The basic mosque design is composed of three main elements; the mihrab, the minaret and the prayer space

(Polk, Serageldin, 1990; Holod and Khan, 1997; Frishman and Khan, 1994;Asfour, 2009). The mihrab is the one of the four walls enclosing the prayer hall that marks the facing direction of the prayer. It is oriented toward the direction of Mecca (kibla'), the holy city of Islam. The minaret is a tower located outside the mosque. It is used as a place to call(azan) for the community to congregate for the prayer. It is normally the highest structure in the community and also used as a landmark. The prayer hall is the place where the congregational prayer and other religious activities are conducted. It is considered the sacred place of the mosque. Among the three elements, the prayer space is the most occupied space and accessible to the public almost at all time during the hours of operation.

The prayer hall is normally situated at the centre of the building. It is the biggest and hierarchically, the most dominant space among other spaces created inside the mosque. Various methods in space arrangement have been implemented according to the culture of a country to bring the essence of dominance and sacredness to the prayer hall. In Ottoman architecture, the idea of arranging secondary spaces around a primary space is common as pointed out by Jale Nejdet Erzen(p.58). This type of configuration is important in Islamic architecture because it expresses the importance and the sacredness of the main space by creating layers of spaces. Layers of space, in addition to this, also create buffer zone spiritually as a space of purifying before entering the main sacred space and technically as a barrier 'against noise and exposure'. Similarly, Ludovico Micara believes that the use of enclosure is the most fundamental concept in mosque architecture as it 'delimits the space and separates the place of architecture from all that is without: the urban fabric; or the landscape and the natural world' in an attempt to create the sacredness of the space.

A lot of attention has been given in emphasizing the importance of the prayer hall in a mosque. Not only the inside, the outside space of the mosque are given careful attention in the decoration and space quality. Calligraphy and arabesque are among the style used in decorating the spaces inside and outside the mosque. The most common practice is to use a special roof design covering the prayer hall. A domed roof is one of the popular roof types that have been used in mosques throughout the world. In fact, the dome itself has been considered as one of the main features in Islamic architecture as the dome represents the vault of heaven (Asfour, 2009). Originated from the Ottoman Turkish era in the 15th century, the central dome mosque type has become very popular in other Islamic country. A single dominant dome is placed at the center of the prayer hall to bring the spirit of togetherness and openness towards God. The earlier mosque type which is originated from the Umayyad Dynasty is called hypostyle or Arab plan mosques. This mosque type uses columns in a large number as a support to the building. Due to its rigidness, the style has not been very popular. The dome roof has replaced this style and has been proven to be effective in minimizing the heat gain for this climate(Asfour, 2009; Hameed, 2011; Hadavand et al, 2008). This condition, however, is still under question for other climatic regions. Regardless of this, the application of dome roof for mosque is universal.

Malaysia, being one of the Islamic countries, also incorporates a domed roof as the main roof structure for many of its recent mosque developments. Its synonymy with the Islamic architecture may have strongly influenced the universality of its use in Malaysia and other countries. Traditionally, the pitched roof is the typical roof design for this climatic region including Malaysia. The transformation from the traditional pitched roof to the dome roof has taken stages of process of developments. Besides domed roof, other types of roofs that are more modern have also been produced such as the 'folded-plate roof' of Masjid Negara, Kuala Lumpur and 'umbrella-shaped roof of concave conoids' of State Mosque, Negeri Sembilan. Due to the importance of the prayer hall space and the unknown suitability of the dome roof in providing thermally comfortable indoor environment, it is necessary to study the influence of the dome roof into the prayer hall space in Malaysia.

The development of the mosque design in Malaysia is influenced by many factors, socially, politically and environmentally (Ismail, 2008). The review on the development of the mosque design in Malaysia provides information on the influences that lead to the current mosque development.

2.6 The Development of Malaysian Mosque: Islamic vs. Traditional Identity

Islam, as the main religion in Malaysia, places an influential factor in the design of buildings especially Islamic religious buildings such as mosques and 'madrasahs'. Islamic architecture being originated in the Middle East countries has many strong elements and forms that are unfamiliar to the traditional architecture of

Malaysia. At certain stage in the development of mosques in Malaysia, direct copying of forms of mosques from the Middle East can be evidenced. This eclectic style of mosque continues for several decades in the country until Malaysia receives her independence. The ignorance of the local identity of Malaysia in the mosque architecture has started to create discussions among Malaysians (Dunster, Rasdi, 1998). As a result, the contemporary mosque design is expected to portray the national identity by incorporating the traditional culture and at the same time, to show that Islam is the major religion of the country (Vlatseas, 1990; Yeang, 1992).

The traditional architecture of Malaysia can be traced back at the dwellings of the earliest settlement in Malaysia. The settlement started in a village called 'kampung' whereby the people were led by a leader and normally the people were related to each other. As they were related, issue of privacy was not a major factor to them and this can be seen from the fenceless house and open plan houses which allowed one area to be a multifunction area. As the society became more complex, the element of privacy started to become more important and be considered in the design process. New areas or spaces in the house started to be introduced which mainly to separate between men and women. Starting with just a main house and a kitchen, the additional spaces was later added such as the verandah and later on, the middle house. The verandah was designed for the area of entertaining non-relative guests and the middle house was used as a family area and the main house was intended for entertaining relatives. The design of the traditional houses were relatively different depending on the states they were located in Malaysia, however, there are three main attributes shared by the houses which are the stilts, open plan and pitched roof (Vlatseas, 1990).

The roof had become the main element in the traditional Malaysian architecture. It covered bigger areas compared to other elements in a building. The main purpose was to provide shelter from the heavy rain and shade other elements from the direct sunlight to reduce the heat generation during the day. Additional feature such as carved grilles was also incorporated into the design of the roof to allow heat dissipation from the building. The roof, too, had been designed to identify the community of the local people. Each of the state in Malaysia owned a typical design of roof such as 'Bumbung Lima' for the state of Perak, Minangkabau roof for Negeri Sembilan and high pitched roof for Kelantan and Terengganu and this design 'distinguished the house styles from one region to the other' (1990).

Similar ideas and concepts had been applied in other types of building as well. The earlier designs of mosques were basically originated and followed the traditional styles of dwellings with modification on the space layout adjusting to the need of a mosque. However, the importance of the roof as a dominant element in providing shelter and community identification was maintained throughout the development of mosque design in Malaysia. The changes and variation of roof design can be seen in the mosque development as the time changed.

Looking at the development of mosque architecture in Malaysia, the earlier form of the mosques follows the simple Malay house form with a simple gable roof using the ‘wooden house on stilts’ construction (Fee, 1998). The existing example of this type of mosque is Masjid Kampung Laut, Kota Bharu, Kelantan (figure 2.6) which was built two and a half centuries ago. This type of mosque was considered the purest form of mosque design in Malaysia since the design was based on the regional influences which can be distinguished by the use of minarets, square plan layout and most dominantly the two or three-tiered roof (Bruce, 1996). The use of the roof form may be duplicated from the old mosque of Indonesia as many of the Malay Muslims are descendants of ethnic groups from Kalimantan, Acheh, Sulawesi and Java (Ahmad, 1999; Nasir, 1995). The royal Mosque of Demak as pictured in figure 2.5 is an example of the typical traditional mosque in Indonesia.

Figure 2. 5 - Picture of The Royal Mosque Demak, Indonesia (from http://mukzizatislam.blogspot.com

With the increase contact with the outside world mostly through trades, foreign influences started to be incorporated into the design of the mosques. Masjid Tengkerah (1728) (Figure 2.7) and Masjid Kampung Kling (1748), both located in

Melaka which once was the busiest port in the world and considered the centre of Islam for Malay Peninsula (Yahaya, 1998), displayed the strong influences of Chinese and Indian through the addition of the brick minaret (Vlatseas, 1990).

Figure 2. 6 - Picture of Masjid Kampung Laut, Malaysia

Figure 2. 7 - Picture of Masjid Tengkerah, Melaka

(http://www.trekearth.com/gallery/Asia/Malaysia/photo173681.htm)

When British and Dutch occupied the country, they changed the mosque architecture in Malaysia into a new form. The replacement of the form timber construction was started by the Dutch (Ahmad, 1990). The traditional look of the mosques began to change to a more modern look with the incorporation of brick masonry and arches which had become the dominant architectural features. At the same time, the migration of the Chinese and Indian workers which later on converted to Islam had contributed to the influence of mosque design (Kohl, 1984). Indian immigrants had put their influence in the mosque design by incorporating large central space and small onion shaped dome (Vlatseas, 1990).

The design of mosque had gone another modification with the introduction of the colonial element such as the clock tower minaret and the use of dome. The first mosque built by the British was the Ubudiah Mosque, Kuala Kangsar in 1913 which strongly reflects the identity of colonial building. Among the common characteristics of the mosque which can be seen in many mosques of the same era were the horizontal banding and onion shaped domes (Vlatseas, 1990). One of the prominent changes made was the use of prominent size of central dome and this application was repeatedly used in future mosque development. Masjid Zahir, Kedah (1912), Masjid Syed Alwi, Perlis (1933) and Sultan Sulaiman Mosque, Klang (1932) are some of the examples of mosques that applied central dome. In addition to this, timber was no longer been used and it had been replaced by bricks, stone, cast iron and steel (Raalah, 2002). During this period, most of the mosques build were dedicated to the Malay sultanates to show the respect of British to the Malay rulers and this had resulted in a building that is more place-like than a place of worship (Omer, 2000; Ahmad, 1999). This is also intended to show the power of the ruling authority at that time. Most of the mosques were designed and built by the British architects who did not really understand the culture of the local people and the Islamic religion. As a result, both factors had not been well incorporated into the design. Most of the mosques of that period were referred from the design of mosques in India and adapted with the combination of western elements (Rasdi, 2003; Hisham, 1990). This was the era where domes were first introduced in the mosque designs in the country. This type of mosque design had prevailed through the period of British occupation.

When the independence was gained in 1957, the needs for the new mosque design which could reflect the country identity emerged (Vlatseas, 1990; Yeang, 1992). With the western education background, local architects were beginning to consider incorporating traditional culture which revealed the strong sense of rationality and functionalism into the mosque design (Yeang, 1992). Masjid Negara, Kuala Lumpur and Masjid Negeri, Negeri Sembilan were among the designs generated with the influence of traditional elements by the local architects after the independence from the British. At this stage the environmental factors such as climate and culture were still became the main priority in the design process (Soon, 1989, PETA, 1961). As the technology developed, the air conditioning system was introduced to Malaysia. With the high temperatures and humidity during the day, the air conditioning system seemed to work efficiently in producing comfortable environment inside a building. With this latest development in technology, the design of mosque had gone another modification. 'The principle of orientation, natural ventilation and implementation of sun shading seemed to become obsolete' (Vlatseas,1990:223). The concern for the environmental effects to the building was regarded as unimportant due to the available technology. With this notion in mind coupled with the influence of modernist design principles, a new style of mosque architecture appeared which tried to incorporate regeneration of Islamic architecture element in the mosque design. As the decade changed, the importance of the environment had become an important issue in architecture. Meetings were held at the international level to discuss the environmental issue in relation to the architectural industry. Rio Declaration and Kyoto Agreement were among the important outcomes of the meetings that were greatly concerned about the issue of sustainability (Muller, 2002). Environmental sustainability which dealt with reducing pollution and preserving the environment and social sustainability concerning identity, culture and tradition were among the important issues discussed. With the realization of the importance of the environment and national identity, 'attempts were made to develop architectural models that were more responsive to Malaysia's climate and at the same time expressive of national and regional ideals' (Vlatseas, 1990: 273).

With the increasing awareness in protecting the earth, the government of Malaysia has started introducing schemes to promote sustainable building. Currently the Green Building Index scheme has been introduced by the government to encourage building developers and architects to produce buildings that are sustainable. Incentives such as tax exemptions are initiated to attract the building industries to practice green building concept by ‘increasing the efficiency of resource use – energy, water, and materials – while reducing building impact on human health and the environment during the building’s lifecycle, through better siting, design, construction, operation, maintenance, and removal’ as stated in the intention of the Green Building Index organization. The increasing number of building that that has been awarded as green building shows that Malaysia is committed in practicing sustainable development.

Information is essential in producing green buildings. Since the introduction of Green Building Index in 2010, only one mosque had been awarded with the status of green building. It can be said that the lack of knowledge or information on this type of building may have led to the small numbers of mosque being recognized as green building. The issue of identity of Islamic building has to be blended well with the issue of sustainability to make the building acceptable as a green building. It can be seen that the use of the dome as the main roof structure has been seen to prevail with the current development. The review of the development of the mosque shows that the incorporation of the dome and a bigger scale mosque which are different from the traditional mosque were influenced by the need to show the power of the rulers. In many cases the mosque models were copied from other countries. The regional which include the social and environmental issue were not seriously being considered in the design. In a traditional mosque, these issues were the main issues affecting the design. Further studies especially on the important structure or element of a mosque, the roof, is critically needed.

2.7 Typical Characteristics of Contemporary Malaysian Mosques

Each design of a mosque in Malaysia is unique by itself, however, many of the contemporary mosques in Malaysia shares similar characteristics such as the space arrangement, roof design, orientation, materials and construction. These main characteristics are applied in the majority of the mosque development in the country. Additional features are added to inject the sense of local and traditional values into the building. Current development on the mosque design requires the architects and designers to promote the concept of Islam in its architecture. It can be evidenced that the influence of the Middle-eastern mosque model is still prevailed through the use of dominant domes (Ismail, 2008; Rasdi 2003:25)

Despite the use of dominant domes as the roof structures, many mosque designs share similarities. A characteristic that is the same in all mosques of Malaysia is the orientation. Direction to qiblat which is 292 degree is the most important consideration in mosque design (Petherbridge, 1995:202). Another similarity can be seen on the space arrangement. Space arrangement is critical in mosque design because it directly affects the main space of the mosque which is the prayer hall. As described earlier in this chapter, the idea of making the transition space between the prayer hall and the outside or creating an enclosure around the prayer hall are among the methods used to express the higher level of space hierarchy and sacredness to the prayer hall. In Malaysia, this is achieved by using the transition space by providing verandah around the prayer hall and this is derived from the traditional architecture of Malaysia. Traditionally verandah is used as a space to entertain guess. In mosque design, the verandah has a similar function which is used as a place to socialize since socializing is prohibited inside the sacred prayer hall. In addition to this, the verandah also acts as a buffer or filtration space from the outside before entering the prayer hall. The degree of openness between the verandah to the outside and between the verandah and the prayer hall is also differentiated through the use of enclosure. A clear separation between the verandah and the prayer hall can be sensed by the introduction of decorated timber panel wall presenting the flora and fauna or geometrical pattern to compare the importance and the sacredness of the prayer hall from the outside world.

The prayer hall encompasses the main space of the mosque. Normally, it is square on shape and the space is oriented to the direction of Mecca (qibla') which is marked by the minbar. The idea of making the prayer hall as one vast central space, as described by Le Corbusier, is one of the universal criteria of the space. This is normally achieved through the use of an open plan with no or minimal numbers of column. The idea of centrality is further accentuated with the application of a special roof design.

In general, there are two types of roof, the domed and the pitched roof that are commonly used for the mosques in Malaysia. The domed roof has been used rather frequently especially in a larger scale mosque compared to the pitched roof since it is believed to bring more spiritual values associated with Islam to the space.

Name	Images	Category	Description
Masjid Al Azim, Melaka		Pitched Roof	Officially opened in 1990. A state mosque of Melaka Can occupy up to 11, 700 people
Masjid Putra, Putrajaya		Domed roof	Completed in September 1999 A state mosque Can occupy up to 10, 000 people
Masjid Tuanku Mizan, Putrajaya		Domed Roof	Completed in 2009 A state mosque Can occupy up to 20, 000 people
Masjid Kariah Panchur Jaya, Negeri Sembilan		Domed roof	Completed in 2007 A community mosque Can occupy up to 1000 people
Masjid At Taqwa, Paroi, Negeri Sembilan		Domed Roof	Completed in 2011 A community mosque Can accommodate up to 1000 people

Table 2. 1 – Some of the development of mosques in Malaysia from year 1990 until 2011

Table 2. 1 shows some of the mosque developments from year 1990 until 2011. The universal acceptance of the use of dome as an indication of the building as a mosque is perhaps one of the main reasons of the wider use of dome roof compared to the pitched roof. Pitched roof, on the other hand, has always been considered the traditional roof design for the country and this region due to its capability to drain water quickly. It is also considered as one of the strongest regional identity of the country and the surrounding area.

Rasdi (2003) disagrees with the use of dome in Malaysian mosque as the dome is an imported characteristic of the Middle–eastern mosque. It does not reflect the national identity. The suitability of the use of dome has been questioned in relation to the image and identity reflected by it. Disagreement toward the use of dome instead of pitched roof in mosque design is mainly due to the issue of identity portrayed by these two roof designs. The study on the influence of these two roof designs on responding to the local climate especially on the thermal comfort issue may lead to the answer of which roof performs better in this climate. Many of the research conducted are mainly focusing on the pitched roof concentrated on residential buildings since the pitched roof is the most common roof type used in this region. The application of the pitched roof design in a bigger scale building such as a mosque is still minimal and the study on the influence of the pitched roof on thermal condition for a bigger scale building has not been conducted extensively. Table 2.2 displays some of the traditional mosque developments that apply pitched roof in Malaysia.

Name	Images	Category	Decsription
Masjid Jamek Seremban, Negeri Sembilan		Pitched Roof	Was built in 1900 A community mosque Originally can accommodate 1000 people but after renovated it can occupy 2000 people
Masjid Kariah Kampung Jerjak,		Pitched roof	Was built in 1905 but has been renovated many times. A commun ity mosque Can occupy up to 300 people
Masjid Kariah Kampung Kuala Talang		Pitched roof	Was built in 1985 A community mosque Can occupy up to 300 people
Masjid Al Hasanah, Bangi , Selangor		Pitched with a dome	Completed in 2000 A community mosque Can occupy up to 1000 people

Table 2. 2 - Pictures of traditonal mosques applying pitched roof for the mosque.

2.8 CONCLUSION

The strong influence of the use of dome in Islamic architecture and in mosque design creates conflict with the strong regional and traditional characteristics of the pitched roof. Both of these roof designs have distinctive characteristics and unarguably relevant to be used in a mosque design. The performance of these roof designs in sheltering the prayer hall from the heat gain which concerned many users may have become a valuable point in making the selection on which type of mosque is appropriate to be used. However, little information is known on the performance of these roofs in bigger scale buildings such as mosques and therefore more research on the building performance is necessary to provide better understanding on how these roofs behave in affecting the indoor thermal environment. This information may help to improve the current design especially on the roof design since many current mosque developments in Malaysia have similar characteristics in the major space arrangement, orientation and construction.

CHAPTER 3

LITERATURE REVIEW ON THERMAL COMFORT IN TROPICS

3.1 What is Thermal Comfort?

Thermal comfort is defined as 'that condition of mind which expresses satisfaction with the thermal environment.' (ASHRAE, 1992; ISO, 1994). Through this definition, it can be implied that the thermal comfort is about the 'condition of mind' or the psychological aspect of human beings resulted from the responses to the physical environmental conditions. As it deals with the psychological aspect of human beings, according to Parson (1995), individual differences and personal preferences such as culture, mood and personality and other personal and organizational factors affect the response toward the thermal comfort condition besides the physical factors. According to Cooper (1982), thermal comfort involves 'social constructs, which reflect the beliefs, values, expectations and aspirations of those who construct them' and in addition, it is also affected by environmental and memory (Brager and deDear, 2003). Hensen defined thermal comfort as 'a state in which there are no driving impulse to correct the environment by the behaviour' (2004). In general, thermal comfort can be summarized as a condition that no changes is required to improve the condition due to the satisfaction with the current condition that is affected by physical and psychological factors.

3.2 FACTORS AFFECTING THERMAL COMFORT FOR TROPICAL COUNTRIES.

The thermal comfort factors that have become the main concern for these regions are air temperature, relative humidity, air movement and mean radiant temperature. These factors are also known as physical factors and they are contributed by the nature and cannot be changed. Other factors which are called personal factors are metabolic rates and clothing level. These factors vary from one person to the other and can be adjusted according to the preferences of the person. Figure 3.1 displays the influence of these factors in affecting the thermal comfort of a human being.

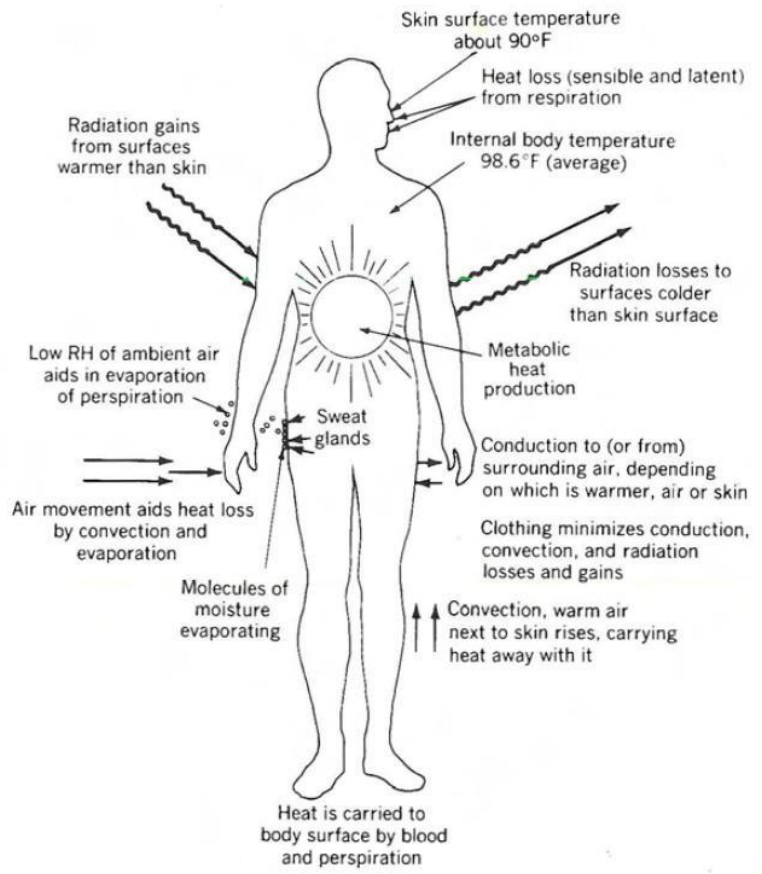


Figure 3. 1 - The mechanism of thermal comfort factors affecting a human being (from http://www.hvacairconditioningdesign.com)

3.2.1 Air Temperature - is also known as the dry-bulb temperature or ambient temperature. It is the measurement of the coldness or hotness of the surrounding air and measured with a thermometer in Celsius or Fahrenheit unit. It plays an important role in influencing the thermal comfort level of a space because the air is the medium that most of the heat from the environment will be transferred to the body of building occupants. The heat from the human body will be transfer to the air when the air temperature is cooler than human body, and similarly the heat from the air will be transferred to the human body when the air is hotter than the human body (refer to Figure 3.1).

Due to the significant influence of air temperature on thermal comfort, many studies conducted are aimed to determine the comfort temperature acceptable. ASHRAE has suggested that for a summer condition, the optimum air temperature is 24.5^0 Celsius which is based on the environmental climatic laboratory condition. In this case, the influence of the outdoor air temperature has not been considered in determining the temperature.

The indoor air temperature is heavily influenced by the outdoor temperature for a naturally ventilated building. It is important to consider the outdoor air temperature when determining the comfort temperature for a naturally ventilated building. Studies have shown that the mean outdoor temperature is related to the indoor comfort temperature experienced by the occupants (Auliciems &deDear, 1978; Brager and deDear, 1998; deDear and Auliciems, 1993; Humphreys, 1978).

The study by Humphreys (1978) discovered that the comfort temperatures are linearly related to the mean outdoor temperature. The relationship derived is:

$$T_c = 0.534T_o + 11$$

where T_c is comfort temperature and T_o is mean outdoor temperature. The study of the relationship between the mean outdoor temperature and the indoor comfort temperature has been continued by Auliciems in 1978. By revising the results produced by Humphreys (1978) and adding additional data from more field studies, Auliciems proposed an equation that relates the indoor comfort temperature (T_c) to the outdoor air temperature (T_o) and indoor air temperature (T_i). The equation is:

$$T_c = 0.48\ T_i + 0.14 + T_o + 9.22$$

Nicol in his study in Pakistan (1995) has also come out with an equation that relates the outdoor temperature and comfort temperature. The equation is:

$$T_c = 0.38\ T_o + 17.0$$

In his recent study, Nicol (2004) has incorporated a wider range of comfort temperature which is mostly influenced by the outdoor climate patterns that led to the derivation of the optimum comfort temperature, T_{comf} , that is based on the mean outdoor dry bulb temperature, $T_{a,out}$. The equation is:

$$T_{comf} = 0.31T_{a,out} + 17.8$$

The range of the temperature with the 90% acceptability is 5^0 and 7^0 Celsius for 80% acceptability, both centred on the optimum temperature, T_{comf}, aiming to discover the temperature or combination of thermal variables (temperature, humidity and air velocity) which subjects consider ‘neutral’ or ‘comfortable’. With these equations, it shows that there is no standardized comfort temperature especially for naturally ventilated buildings. It incorporates other influences into the thermal comfort. By giving a range as suggested by Nicol (2004), it allows other factors especially physical factors to be considered since these factors are always present in our environment.

This method has been applied by Dalilah et al (2008) and Mohazabieh (2010) in the study of assessing thermal comfort in high rise buildings in Malaysia. In the study by Dalilah et al(2008), it is determined that the neutral temperature is 26.4^0 Celsius depending on the location of the buildings. However, based on the field study, the neutral temperature produced is at 30.93^0 Celsius. Mohazabieh et al (2010) predicts the neutral temperature is between 25.5^0 Celsius and 27^0 Celsius. These results support that there is no standardized comfort temperature as it depends on the microclimate of the place and human adaptation.

3.2.2 Air Velocity - The existence of air movement inside a space may have various effect based on the climate and activities performed in the space. In a temperate climate zone, the draught may be considered as a nuisance since it brings cold air into the space especially during winter time (Oseland, 1994). For a hot and humid area, the present of cold air is desirable due to the hot condition and high content of humidity in the air throughout the year. With the present of air movement, the process of evaporation can be speed up to provide cooling sensation. The moving air helps to aid heat loss through the process of evaporation and convection (refer to Figure 3.1).

Earlier studies have proofed that air velocity can increase the tolerance to air temperature (Xu et al, 1996; Wu, 1989; Fountain and Bauman, 199; Tanabe et al,1987; Tanabe and Kimura, (1994). It has been suggested by DeWall (1993) that air movement inside buildings need to be set between 0.1 -1.5 m/s to provide indoor thermal comfort.. The study in Malaysian terraced house by Nugroho et al (2007) discovers that the air movement available at 1m/s is not sufficient in providing thermal comfort when the temperature is above the comfort level based on the PMV prediction. On the other hand, a study by Md Zain et. Al (2007) found that comfort temperature which is estimated at 28.69^0 Celsius for the office environment in Malaysia has only 44% of the respondents feel comfortable when there is no air movement but with 0.7m/s air movement, the thermal comfort can be 100%. This is probably is caused by the different activity level conducted at both places as emphasized by Griefahn et al (2000) that persons were less sensitive to draught when working at an increased activity level than working at lower activity level. An air flow that is less than 0.2m/s would not be enough while more than 2.0 m/s will create other related problem.

Based on the findings, it can be assumed that the effectiveness of air movement in influencing the thermal comfort level varies based on the activities conducted by a person and the condition of the air temperature at a specific situation.

3.2.3 Humidity – is usually referred as the amount of water in the form of water vapour in a volume of air. Relative Humidity (RH) is the ratio of the amount of water vapour contained in the volume of air to the maximum amount of water vapour that can be held by the air at that specific temperature. The excessive presence of humidity in the air hampers the evaporative process of the sweat produced in reaction to the warm feeling (refer to Figure 3.1). The sweat produced is expected to evaporate to the air to cool down the body. Without the process of evaporation, the cooling of the body does not take place. Instead, it produces the feeling of stuffiness which leads to thermal discomfort. In a country with a moderate climate, this problem may not be considered critical due to the low air temperature throughout most of the year. The effect of the humidity may not be felt because the body does not release as much sweat due to the cold air. However, the humidity content has become a major concern in providing thermal comfort for the hot and humid countries due to the high air temperature throughout the year. Sweating is inevitable in this country because of the high air temperature. This condition becomes worse because the content of humidity in the air for this country is also high and this slower down the process of evaporation. Dehumidification is the only way to reduce the thermal discomfort caused by humidity and this can be achieved through sufficient air flow (Nugroho et al, 2007)

3.2.4 Radiant Temperature - The Radiant Temperature is often described as the temperature received from the radiating heat of the surfaces enclosing a space. The Mean Radiant Temperature (MRT) is the average temperature of the surfaces around a cubical space and it can be measured using the globe thermometer. For the moderate climate, a difference of 1 degree Celsius between the ambient air temperature and MRT is desirable because of the higher heat generated by the surfaces helps the body to keep warm. For the hot and humid climate, lower MRT is more desirable because it can absorb the heat from the air to provide a cooler environment. Cooler surfaces around a human body helps the radiation of body heat to a cooler surface too (refer Figure 3.1) releasing heat energy to make the person feeling cooler.

3.2.5 Clothing Insulation – is referred to the amount of layering of clothing worn. It is ranged from 0 (naked) to 1 (heavily clothed). Table 3. 1 shows the examples of the

Item of Clothing	Value associated with Item of Clothing		
Shirts	Light Short Sleeve 0.14	Heavy Short Sleeve 0.25	
	Light Long Sleeve 0.22	Heavy Long Sleeve 0.29	
Sweater	Light 0.20	Heavy 0.37	
Jacket	Light 0.22	Heavy 0.49	
Trousers	Light 0.26	Medium 0.32	Heavy 0.44
Socks	Light 0.03	Heavy 0.04	
Shoes	Shoes 0.04	Boots 0.08	
Underwear	0.05		

Table 3. 1 - The examples of clothing value for the clothing items (from http://www.esru.strath.ac.uk/)

values of clothing items. In many cases, clothes are worn to protect the body to lose heat to the colder environment. Heavier clothes are expected to have better insulation. For a hot and humid country, wearing lighter clothes to allow the body to release more heat is suggested by many researches. However, in some cases, wearing lighter clothes may not be an option due to the culture and the religion constraints. Therefore, the consideration of the clothing in evaluating thermal comfort situation of a space can be crucial.

3.2.6 Metabolic Rates – are referred to the energy that we produce as a result of the activities conducted. The body gets warmer as the activity increases and therefore, more heat needs to be released from the body. This affects the thermal comfort based on the condition of the space, for examples, a gymnasium where aggressive activities occurred may need cooler air temperature compared to a living area. Figure 3.2 illustrates the metabolic rates according to the activities conducted.

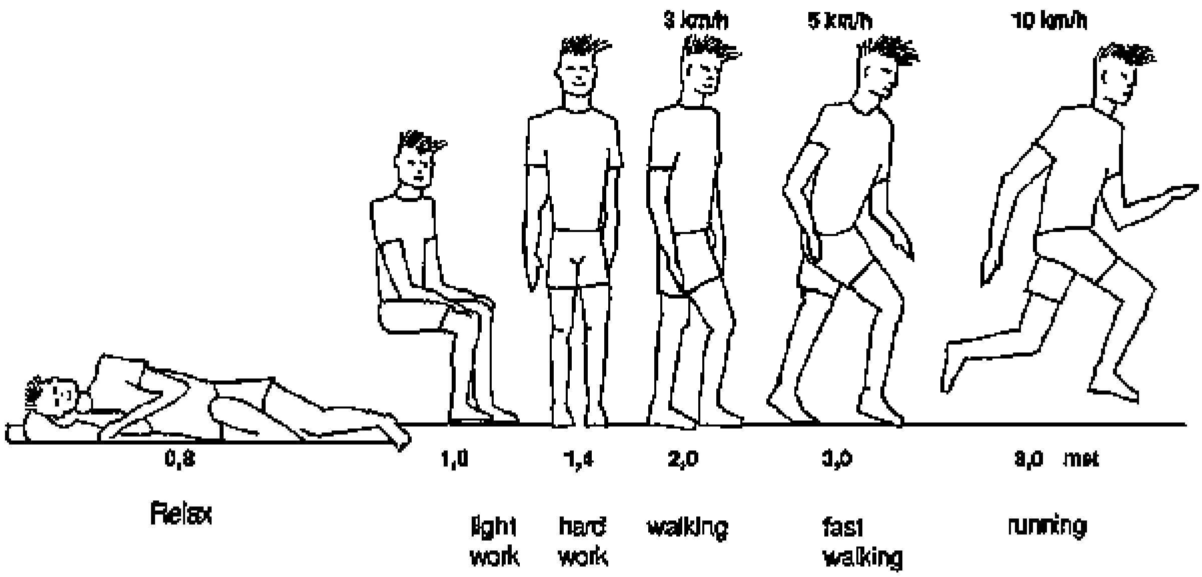


Figure 3. 2 - Examples of metabolic rates in relation to the activities conducted (from http://collections.infocollections.org/)

Based on the research conducted earlier, it seems that air temperature is the most important element in affecting thermal comfort level. Other factors seem to contribute to the thermal comfort level either by improving or worsening the thermal comfort situation depending on the situation. Many of the earlier research seemed to consider these factors as a joint factor which means that these factors are always giving an impact regardless of the situation. Due to the variation on the results established from the earlier research, some of the factors may not act as a joint factor but rather a contributing factor that can be ignored at certain situation.

3.3 THERMAL COMFORT IN TROPICAL COUNTRIES

The issue of thermal comfort has long been discussed by many architects and academicians. In the tropical countries, the issue of achieving thermally comfortable condition is focused on the cooling of the indoor environment (Karyono, 1993; Busch, 1990; deDear, Leow and Foo, 1991;Wong, 2003; Hussein and Rahman, 2009)). Generally, the average air temperature for this region is within the range of 26 degree Celsius to 30 degree Celsius and with this range of temperatures, the indoor condition will be under the uncomfortable category based on the psychrometric chart. For a free running building located in this region, achieving a suggested comfortable air temperature according to the available standards could be difficult since the indoor climate condition of the building is heavily dependent on the outdoor climate. In addition to this, there are other factors such as relative humidity, air movement and clothing that are equally significant in influencing the thermal comfort level for this climatic region.

The thermal comfort is considered as the most important aspect in indoor environmental quality as building occupants are very sensitive to the operative temperatures compared with the other three parameters’ of indoor environmental quality which are the indoor air quality, noise level and illumination level. It does not only affect the behaviour of occupants but it also influences the building performance in terms of its practicality and energy efficiency (Yao et al, 2009).

Extensive research on the issue of thermal comfort has been done in the last 50 years especially in the temperate climate which is more focused on the heating of the building. As the awareness grows, the research has been expanded to other climatic regions with hotter climate such as the tropics including the hot and humid area such as Malaysia, Indonesia, Singapore and Indonesia.

The hot and humid areas are generally located close to the equator. The climate of these countries as an overall is fairly the same, however with the location and geographical condition of the countries, each country has its own unique climate. The earliest investigation was conducted by Webb in 1949 which led to the derivation of the Equatorial Climate Index (ECI). Based on the index, the ideal air velocity is 0.2 m/s with the relative humidity of 70% and the ideal temperature of 28.86^0 Celsius. However, the prediction is only based on the dry and wet bulb temperature and wind speed but excluded activity level and clothing value in the derivation. The study involved a small number of participants which may not represent the majority of the community. The study should involve bigger representation of the community.

In 1952, a study by Ellis in Singapore concludes that European men and women that have gone acclimatization process have similar thermal comfort level with the Asian men and women. The study involves 34 Europeans and 100 Asians. Race, gender and sex have insignificant influences on thermal comfort.

Another study was conducted in 1978 which corrected the optimum ideal temperature to 26.4° Celsius. The study was conducted at the hawker centres in Singapore and found that the thermal comfort condition is affected by the combination effects of air temperature, relative humidity and roof thermal radiation (Rao and Ho, 1978).

In 1990, Busch conducted a study on offices in Bangkok , Thailand. The neutral temperature or effective temperature for the air conditioned buildings and naturally ventilated building is 24.54° Celsius and 28.54° Celsius.

Mallick(1996) in his investigation had also discovered that people are highly adaptive to the surrounding environment by changing the behavioural patterns and lifestyle preferences. The process of acclimatization also had a strong influence in the comfort preferences study. In his 1996 study involving a group of architectural students living in urban housing in Dhaka, Bangladesh, Mallick discovered that the participants were able to tolerate high relative humidity and temperature for comfort mainly due to the adaptation to the specific climate. The study also found that the estimated comfort temperature was between the range of 24^0 Celsius and 32^0 Celsius with the relative humidity between 50% and 90% under still-air condition and with the movement of air at 0.3 m/s, the range increased by $2.4\ ^0$ Celsius for the lower count and 2.2^0 Celsius for the upper limit. The air movement was a contributing factor in providing thermal comfort environment, on the other hand, according to this study, despite a wide range of recorded relative humidity which ranged from 50% to 95%, the humidity had little influence to the thermal comfort level due to the long term conditioning even though there is a decrease in comfort temperature when the humidity is higher (Mallick, 1996).

Singapore and Indonesia are among the countries in Southeast Asia that are actively conducting research in the thermal comfort issues. For examples, in 2003, Wong and Khoo conducted a thermal comfort study in naturally ventilated classrooms in Singapore. The study discovered that the neutral temperature derived from the TSV is 28.8^0Celsius. Earlier studies conducted by Busch in Thailand and deDear et al in Singapore have also found that 28.5^0 Celsius is the neutral temperature for a naturally ventilated building. The readings obtained are quite close for the neutral temperature in the similar climate region. On the other hand, the PMV based on Fanger's equation and the ASHRAE standard 55-92 were found to be inapplicable in the study of thermal comfort for the area of hot-humid climate. ASHRAE Standard 55 predicted comfort temperature is far lower than the actual comfort temperature based on the field study. The Fanger's PMV model similarly shows discrepancy by being higher at lower temperature (Wong et al). The study by

Wong et al in 2002 in naturally ventilated public housing in Singapore also revealed that thermal perception of +2 and +3 is still considered comfortable. Similar to the finding by Mallick's, the study also found that there is a strong correlation between the thermal comfort perception and wind sensation.

In 2004, Feriadi and Wong conducted an investigation regarding the thermal comfort perception, evaluation of the thermal comfort prediction and the behavioural action that influence thermal comfort perception in naturally ventilated houses in Indonesia. The study concluded that the prediction using the ASHRAE and Bedford Scale is irrelevant in predicting the thermal comfort condition for tropical climate. The finding also suggested that adaptive behaviour may influence the neutral temperature to be higher than it was supposed to, however, cooler temperature is still preferable, if possible. Earlier, Karyono conducted a field study on the thermal comfort, which samples are divided into various categories and groups, for a multi storey office building in Jakarta, Indonesia. The groups are categorized by gender, age, ethnic background and physical characteristics. The study concluded that it is statistically insignificant between the neutral temperature between male and female, subjects under 40 and over 40 years old and between different ethnic backgrounds as well as between thin and normal subjects. The study also revealed that the neutral temperature is increased in the late afternoon compared to the early morning by 3^0 Celsius.

The majority of the research conducted in tropical countries focuses on predicting the thermal comfort based on the neutral or comfort temperature for specific building types which include residential, offices and schools. In many cases the evaluated comfort temperature agrees with other research and falls within the acceptable range. However, the use of PMV has been found to be inaccurate in predicting thermal comfort for this region when compared with the actual thermal sensation vote (TSV). The subjective scale which is the ASHRAE and Bedford scale applied may have been interpreted differently by the locals. Besides the PMV equation, the applicability of the thermal sensation scale and Bedford scale in evaluating thermal comfort condition for this region is yet to be studied.

The previous research has investigated three main physical variables that have been the main concern of the research which are air temperature, relative humidity and air movement. They have been proven to tremendously affect the thermal comfort level. However, the interdependent of the variables in influencing thermal comfort for this region has not been investigated.

3.4 THERMAL COMFORT STUDIES IN MALAYSIA

The number of studies on the determination of the acceptable thermal comfort level for naturally ventilated buildings in Malaysia has increased in recent years. The knowledge on the issue is important as it provides references in providing thermally comfortable indoor environment that can save the usage of energy. Among the studies are discussed below. Table 3.2 summarizes the studies that have been

Author	Findings/ Discoveries	Comments
Thermal Comfort Factors		
Nugroho et. al (2007)	Air movement is one of the methods to improve thermal comfort due to the humid condition. However, with the speed of 1m/s, air movement cannot provide thermal comfort.	Previous research has shown that there are three main factors influencing thermal comfort in Malaysia; RH, air movement and temperature. Respondents are more sensitive to air temperature than other thermal comfort factors. Air movement is capable of improving thermal comfort level, however the speed or velocity of moving air must be sufficient enough in order for the moving air to improve the thermal comfort level. It is important to investigate which factor is more dominant than the others and to determine whether the existence of other factors as a 'joint' factor or 'contributing' factor.
Md Zain et. al (2007)	Air movement at 0.7m/s can provide thermal comfort only when the temperature is at comfort temperature which is estimated at 28.7 degree Celsius	
Hussein and Rahman (2009)	Studied on the influence of relative humidity to the indoor climate in mechanically ventilated classrooms. Discovered that respondents were more sensitive to the air temperature rather than air movement and relative humidity.	
Kubota et al (2009)	Studied the effectiveness of night ventilation for cooling. Discovered that night ventilation is not sufficient to provide thermal comfort during day time due to high humidity even though it managed to reduce the peak temperature by 2 degree Celsius. Suggested that full day ventilation is a better option to cool down spaces inside the house.	
Al-Mofeez and Numan (2011)	Discovered that the speed or velocity of air is the primary factor in determining the effectiveness of convective cooling.	
Methods of Predicting Thermal Comfort Level		
Dahlan et. al (2008)	PMV has been used to predict the thermal comfort. The result showed some discrepancies with the actual vote	PMV has been found to be inaccurate in predicting thermal comfort for a naturally ventilated building in tropical countries especially Malaysia. POE which is based on the actual sensation votes combine with physical measurement is the suitable technique in predicting the thermal comfort level. PMV may need to be revised in order to be used for this region.
Khalil and Hussein (2009)	Suggested that Post Occupancy Evaluation(POE) is a prominent tool to indicate satisfaction and comfort level of the building occupants by combining the subjective measurement with physical measurement	
Mohazabieh et. al (2010)	Studied about the thermal perception in a multi storey building using PMV and actual sensation vote. Discovered that the PMV is not accurate in predicting thermal comfort compared to the actual vote due to the humidity variation. PMV stresses more on the air temperature.	
Elements of Building and Building Design		
Al-Obaidi and Woods (2010)	Study the effect of façade orientation and heat gain. Discovered that the exposed wall of terraced houses should be on North-south axis to minimize solar heat gain.	Most of the research focuses on the building façade only.The roof of a building in Malaysia is an important building element since it is the filter that covers the spaces inside the building and being the element that is exposed longer that other building elements due to the location of sun throughout the day.
Dahlan et. al (2008)	A study on a high rise hostel discovered that the shaded façade has better thermal comfort condition. The author suggested that the radiation has a significant impact to the thermal comfort level	

Table 3. 2 - The summary of the research conducted in Malaysia

conducted in Malaysia focusing on the issues of thermal comfort and building designs.

Nugroho et al (2007) investigates the thermal environment and comfort condition of a terraced house in Malaysia based on field measurement and simulation. The authors study the influence of air movement on thermal comfort level based on the climatic condition of Malaysia and discover that the air movement available at 1m/s is not sufficient in providing thermal comfort. The PMV is used in predicting the thermal comfort condition and produces the result that the thermal comfort condition is uncomfortable at most of the time. The author agrees that air movement is one of the methods to improve the thermal comfort level due to the humid condition. However the level of importance between the air temperature, air movement and humidity in affecting thermal comfort level has not been discussed.

Md Zain et al (2007) explore the possible means and ways of improving and increasing the effectiveness of energy efficiency strategies of buildings in Malaysia through the influence of air movement in bringing thermally comfortable indoor environment. They discover that the air movement of 0.7 m/s is efficient in providing thermally comfortable environment only at comfort temperature. The comfort temperature is estimated at 28.69 ^{0}C.This shows that the influence of air movement in improving thermal comfort level varies depending on the condition of other factors of thermal comfort. Other factors may have greater significance in affecting thermal comfort depending on the condition of other influencing factors. The factors should be seen as interrelated with one another. With the knowledge of thermal comfort behavior of human, energy utilization and behavior of buildings, the strategies can be produced to improve the indoor thermal condition and energy usage.

Dahlan et al (2008) conduct an investigation on thermal comfort condition of high rise hostels in Malaysia with a variation on the façade condition and find out that the shaded façade has better thermal comfort condition. The authors have suggested that the radiation has a significant impact to the thermal comfort level. The PMV has been used to predict the thermal comfort condition and the result shows some discrepancies with the actual vote. In this investigation, the authors have considered other thermal comfort factors in predicting thermal comfort level. However the interdependence of the thermal comfort factors has not been investigated.

In 2009, Hussein and Rahman study the influence of relative humidity to the indoor climate in mechanically ventilated classrooms in Malaysia and the accepted level of indoor thermal comfort based on the subjective responses. The neutral temperature established from the study based on the PMV regression is 25.9^{0}C with a comfort range of 24.4^{0}C and 27.4^{0}C and based on TSV regression is 28.4^{0}C with the acceptable range of 26.0^{0}C to 30.7^{0}C.The study reveals that the respondents are more sensitive to the temperature(thermal sensation) compared to the relative humidity and air movement. However, the investigation has not shown when air movement and relative humidity becomes significant in affecting thermal comfort.

The importance of air movement and relative humidity should be investigated as they are important elements in affecting thermal comfort for this region.

Kubota et al (2009) study the use of night ventilation for cooling purposes in residential building which is a terraced house. The study has found that the night ventilation has reduced the peak temperature by 2^0C but it is not sufficient in providing daytime thermal comfort due to the high humidity conditions. It is suggested that full day ventilation is a better option to cool down the spaces inside the house. This finding suggests the interdependence of the physical factor of thermal comfort is important in evaluating thermal comfort.

Khalil and Husin (2009) states that the post occupancy evaluation (POE) is a prominent tool that able to indicate satisfaction and comfort level needs by building occupants as lessons learned to identify problems in indoor environment. By using the occupants as the benchmark of evaluation, the results reflect the actual occupants' perceived comfort and productivity levels. Therefore, the use of subjective measurement combined with physical measurement should be encouraged in evaluating an existing and occupied building.

Mohazabieh et al (2010) study the perception of non-Malaysian residents on thermal comfort condition in a multi storey residential building using the PMV and actual thermal sensation vote. The PMV is found to be inaccurate in predicting the thermal comfort condition when compared to the actual thermal sensation vote. The authors indicate that the difference in the PMV vote is due to the humidity variations and the PMV only stresses on the air temperature. They also emphasizes that the importance of other variables varies with the region but the issue has not been discussed in the research. The neutral temperature is between 26.5^0 Celsius – 27.0^0 Celsius.

Al-Obaidi and Woods (2010) conduct an investigation on the orientation effect on the indoor thermal condition in terraced houses. The study focuses on the orientation of the façade and they conclude that the exposed walls of the terrace houses should be on the North-South axis to minimize solar heat gain. Other building elements such as the roof and floor have not been covered in the research.

Al-Mofeez and Numan (2011) study the effectiveness of wall-mounted oscillating fan in providing thermal comfort which can reduce energy consumption. The study discovers that the combination of AC and oscillating fan can reduce the energy by increasing the set temperature of thermostat. At 0.6 m/s the temperature set for the thermostat is 27.84^0C. They conclude that air velocity is a primary factor which determines convective cooling and thus directly influences the corresponding air temperature for human thermal comfort.

It has been evidenced from the review that most of the building studied focuses on the residential buildings especially terraced houses in Malaysia(Dalilah et al, 2008; Kubota et al, 2009; Al-Obaidi and Woods, 2010; Mohazabieh et al, 2010, Nugroho et al, 2007). Public buildings except schools (Hussein and Rahman, 2009;Rahman and Kannan, 1996) that has bigger single spaces such as community halls and mosques which are important buildings in the community have not been covered in the research. The study on the public buildings that are important to the community such as mosques should be carried out.

In addition to this, many of the research are focussed on the determination of acceptable thermal comfort range by comparing between the results obtained by the PMV and actual votes of the respondents. The PMV has been proven to be inaccurate in predicting the thermal comfort condition(Dalilah et al, 2008; Mohazabieh et al, 2010; Hussein and Rahman, 2009). The comfort temperature obtained based on the actual votes varies based on the building design and location however it falls within the range of 80% of the acceptability rates when compared with the results from earlier research conducted in the other hot and humid countries such as Singapore, Indonesia and Thailand. The use of actual votes should be encouraged when deals with existing and occupied building as mentioned by Kalil and Husin.

The previous research has also looked at the influence of the physical factors such as air temperature, relative humidity and air movement in affecting thermal comfort condition in naturally ventilated buildings. For example, the air movement plays an important role in aiding building occupants to improve thermal comfort condition depending on the air temperature and humidity content in the air(Md Zain et al, 2007; NUgroho et al, 2007;). With high relative humidity, air movement may not be enough to provide thermally comfortable environment (Hussein and Rahman, 2009; Mohazabieh et al, 2010;Kubota et al, 2009). These factors have been proven to be contributors to the determination of thermal comfort. However, most of the research considers the influence of each factor in relation to thermal comfort. They are interrelated and how the factors work as an interdependent group has not been investigated.

In general there is a gap on the interdependency of the physical factors in affecting thermal comfort in naturally ventilated buildings especially in mosques. The building element that has been investigated is focussed on the façade. The knowledge on the influence of the roof in contributing to the determination of thermal comfort level is still lacking.

3.5 EVALUATIVE METHODS IN THERMAL COMFORT

There are two types of thermal comfort models that have been applied in assessing thermal comfort. The first model is based on the static or controlled lab environment and the second model is based on the adaptive method which is based on the field study investigation.

3.5.1 Static / controlled lab studies

The model was developed by Fanger in 1970 which is known as Fanger's Predicted Mean Vote (PMV). By using data from other researchers' studies (McNall, Jaax, Rohles, Nevins and Springer, 1967) and his study (1967), Fanger has developed a comfort equation which combined the six variables affecting thermal comfort. He later expanded the comfort equation which is known as PMV index. This index also relates the thermal condition to the ASHRAE thermal sensation scale. Prediction on thermal comfort condition using the PMV index or Fanger's comfort equation needs the measured sum of the related temperatures and variables. The predicted comfort temperature in many indoor settings is 25.6^{o}Celsius. According to ASHRAE, the acceptable thermal environment is achieved when 80% of the occupants accept the environment as thermally comfortable.

With the PMV index, thermal comfort standard is setup. ASHRAE Standard 55 (ASHRAE, 1992) which is derived from the PMV has suggested the optimum temperature for the winter is 22^{o} Celsius with the acceptable range between 20-23^{o} Celsius. Whereas, for the summer, the optimum temperature suggested is 24.5^{o} Celsius with the comfortable range between 23-26^{o} Celsius. This summer range is applicable when the activity level is 1.2 met, relative humidity at 50%, air flow is less than 0.15m/s and clo. level is 0.5.

3.5.2 Adaptive studies

The adaptive approach is based on the findings from field studies conducted involving survey and field measurement of the thermal comfort variables investigated (Nicol and Humphreys, 2002). In this approach, the real experience of thermal comfort from the users is recorded using the descriptive scale such as ASHRAE or Bedford scale. The data is then analyzed and used to predict the ‘comfort temperature’ or ‘comfort condition’ (Nicol and Humphreys, 2002).

Both of these models approach the issue of thermal comfort in a different perspective. The static or closed lab experiment is based on the thermoregulation and heat balance theories (Charles, 2003). With these theories, the thermal comfort variables studied can be controlled and the responses can be monitored accordingly. The focus of the study is more toward the quantifiable aspect of the thermal comfort variables. The adaptive model sees thermal comfort as an experience influenced not only by the quantifiable thermal comfort variables but also the psychological and social factors. It involves the actual users and environment in predicting the actual thermal comfort perception. Each of the models has its own advantages and disadvantages. Depending on the scope and context of the research, the appropriate model can be determined. The following section reviews the applicability of the models in predicting thermal comfort.

3.6 APPLICABILITY OF THE THERMAL COMFORT MODELS

2.2.1 Fanger’s Predicted Mean Vote (PMV) model

Fanger’s Predicted Mean Vote (PMV) model has been applied in many thermal comfort researches since it was established in 1970. Charles in her 2003 report has reviewed the applicability of the model in predicting thermal comfort condition based on the studies conducted by earlier researchers. She concludes that the applicability of PMV model in field study settings does not accurately reflect the actual thermal sensation and in many cases, the PMV predicts the thermal comfort condition more accurately in air-conditioned buildings than naturally ventilated buildings.

It is quite apparent that there is a lot of discrepancies between the results obtained from the PMV and the actual thermal sensation on naturally ventilated buildings. The studies by Oseland (1996), Busch (1990) and deDear et al (1991) confirmed that the PMV model has bigger discrepancies in predicting thermal comfort in naturally ventilated building ranging from 2.8^0 Celsius to 3.6^0 Celsius.

The use of PMV requires accurate data input of the measured variables. The PMV model considers six thermal comfort variables which are air temperature, mean radiant temperature, relative humidity, air movement, clothing level and metabolic rate. As mentioned by Fanger (1994) that inaccurate data leads to 'poor prediction', it is critical to provide accurate data of these variables to accurately predict the thermal comfort condition. Most of the inaccuracy is resulted from the clothing value and metabolism rate (Charles, 2003). Research done in tropical countries especially in naturally ventilated buildings has indicated the inaccuracy of PMV in evaluating thermal comfort for this region. Djongyang and Njormo also believe that despite the widely used and compatible ASHRAE standards, a 'different level of comfort parameters' is required for different climatic region such as the tropics (2010).

2.2.2 Adapative Thermal Comfort model

The adaptive thermal comfort model is introduced as an alternative in predicting thermal comfort condition after the realization of factors affecting thermal comfort includes ‘contextual factors and past thermal history’ (deDear and Brager, 1998) and it is not only based on the physical environmental factors. With this realization, the increasing number of study involving field survey has been conducted in different countries and building types to investigate the parameters affecting the thermal comfort. A field study has the advantage of recording the actual thermal sensation and comfort experienced by the users. As mentioned by Gossauer and Wagner (2007), ‘field studies consider the whole indoor environment of the surveyed people’ and with the information, the building occupants’ perception on the thermal environment generated by a building type can be studied. Kuchen and Fisch(2009) also agree that the feedback from ‘subjects’ diagnosis’ is an important tool in evaluating thermal comfort condition.

There are three class of thermal comfort studies as described by Brager and deDear (1998). They are:

a. Class I – The study allows a careful investigation on a building. The equipment used must be in accordance with the specifications stated by the ASHRAE 55 (ASHRAE, 2004) and ISO 7730. The measurement requires laboratory grade instrumentation with at least three reading at different height.
b. Class II- The procedure can be used in studying the behavioral adjustment and control on subjective responses. In this procedure, the measurement of the variables needed to calculate the PMV and PPD is taken at the same time and place where the questionnaire survey is conducted.

c. Class III – This is the simplest procedure which involves the indoor air temperature and probably relative humidity. The measurement of the physical variables does not have to be simultaneously.

The descriptive or rating scale that is used in recording thermal sensation is based on the ASHRAE thermal sensation scale which employs seven scales. The ASHRAE thermal sensation scale is referring only to the thermal sensation as thermal comfort involves other influencing factors. Therefore, it is assumed that a thermally comfortable condition is achieved when there is no thermal sensation present or at neutral level. Another rating scale that is quite frequently used is Bedford scale. Similar to the ASHRAE Thermal Sensation scale, it has seven thermal sensation scales. However, it differs in the description of each scale. For examples, the 'neutral' thermal sensation under the ASHRAE is described as 'comfortable' under the Bedford scale. The 'warm' and 'cool' scales are described as 'comfortably warm' and 'comfortably cool'. The inclusion of the term 'comfortable' in explaining the scale may have different perception since the meaning of comfortable involves not only thermal sensation but other aspects as well. The ASHRAE scale, on the other hand, is precisely describing the thermal sensation. Therefore, even though the two thermal sensation scales are almost the same, the results obtained may differ due to the perceptions. It is interesting to see the perception of Malaysians who experienced hot and humid climate in responding to the two scales as they may interpret the description differently.

It is obvious that the use of PMV in predicting thermal comfort condition is useful when the availability of the building occupants is limited. The use of the PMV needs accurate measurement and it is more suitable for a building with a controlled environment. For an occupied free-running building, a field study using adaptive thermal comfort model is more appropriate since the actual result can be obtained from the users' of the building.

3.7 Conclusion

Thermal comfort for the tropical countries has become an important issue since the standards established are more applicable to the moderate climate countries. As a result, the PMV which is based on the closed lab environment is inaccurate in predicting the thermal comfort level when compared with the actual vote from the users especially in naturally ventilated buildings in tropical climate. As the indoor climate is heavily dependent on the outdoor climate condition, the interdependence of the physical factors which are the air temperature, relative humidity and air movement may have play an important role in affecting thermal comfort. The influence of each single factor to thermal comfort has been studied by earlier researcher. However, the significant of each variable in conjunction with other variables has not been investigated. In addition to this the application of subjective measurement using ASHRAE thermal sensation scale or Bedford scale may have contributed to the inaccuracy of the results obtained from the respondents due to the different interpretation of the descriptive sensation. This is still to be discovered.

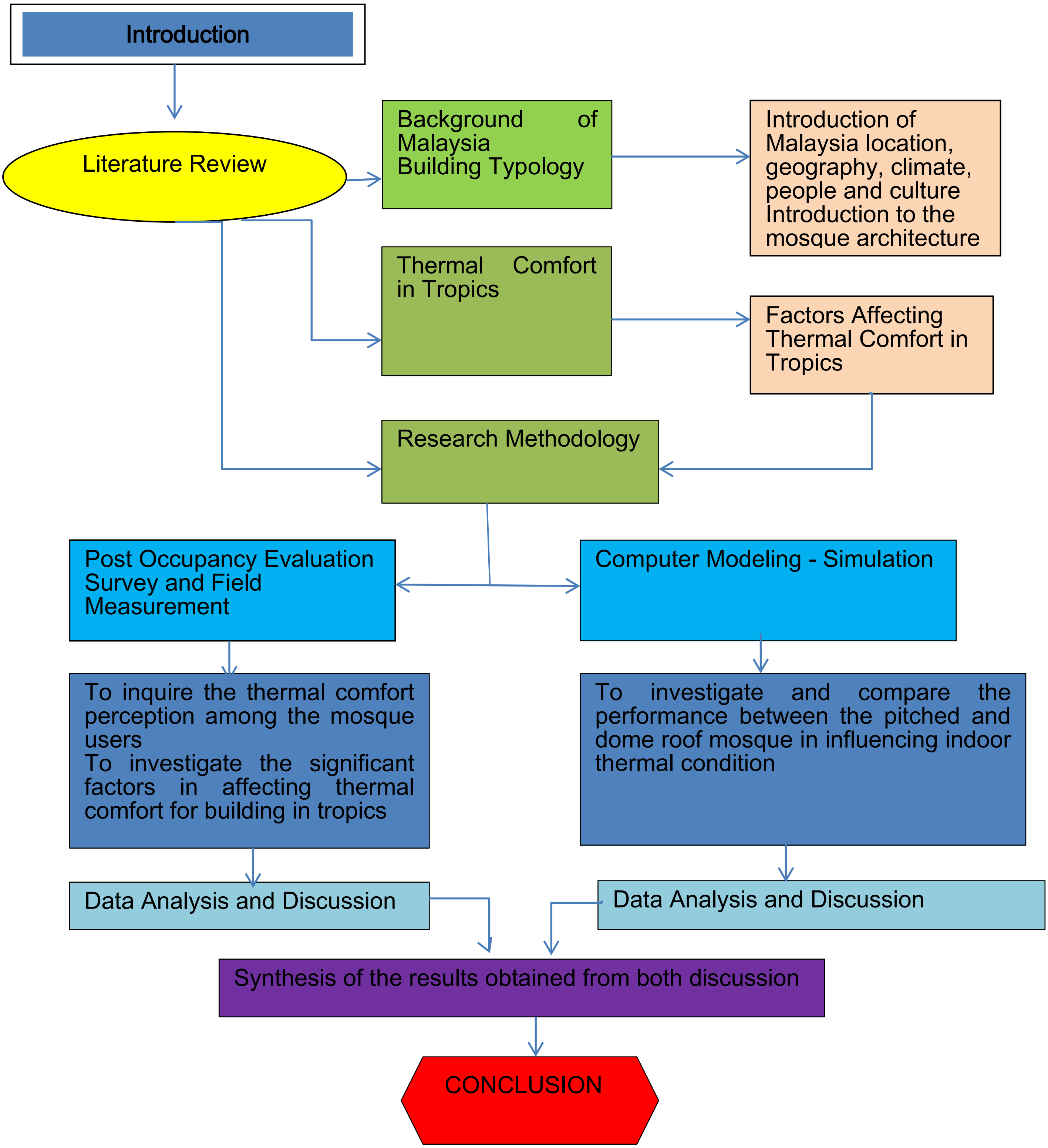
In terms of building design, many of the research conducted focus on the influence of façade to the thermal condition. Many buildings in the tropical countries put a bigger role on the roof element to protect the interior from the harsh climate. Little information is known on how the roof behaves in influencing the thermal condition and therefore the comfort level of the space it covers. Many of the conducted investigation focused on the spaces that were occupied for a long time with varied activities such as spaces inside a house or an office. In a mosque, the occupants are normally stayed for no longer than one hour and therefore, the expectation on the thermal comfort condition may not be the same with other spaces. In addition to that, the restriction on the activities that can be conducted and clothing regulations or ethics in a mosque may have influenced the perception on the thermal comfort. The investigation on the comfort culture on a mosque will try to discover the answer.

CHAPTER 4 - METHODOLOGY

4.1 INTRODUCTION

Chapter 4 introduces the methodology applied in conducting the research which covers the topics of the selection of building samples and participants, data acquisition and data analysis methods. The previous chapter describes the building typology studied and the development of the local architecture of Malaysia focusing on the mosques. This chapter starts with the introduction on the two distinguished methods designed for this study. The first method is the field study involving survey using questionnaires and field measurement. This chapter explains the process involved in conducting the field study including the execution of the survey and field measurement during the data collection process. The chapter then continues with the explanation of the analysis process. Following this, the chapter briefly describes the second method involved in the study which is based on the computer modeling. It includes a brief introduction on the software used which is HTB2 and WinAir4. It also explains the investigative process involved in the study. Finally, the chapter concludes by justifying the relevance of the method chosen in conducting the research. The flow of the research is shown in Figure 4.1.

Figure 4. 1 -Flow chart of the research process



4.2 BACKGROUND

Conducting a study on a specialized building such as a mosque requires careful procedures. It is important to determine appropriate approaches to be applied in carrying the study since the building carries some sensitivity issues that relate directly to a religious practice and spiritual aspect of people lives. There are constraints that need to be considered in conducting the research. For examples, various aspects related to the adaptive behaviour including variables such as clothing, metabolic rates and air movement preference may have enormously affected the decision of the thermal comfort evaluation. These variables are difficult to measure and generalize since these variables are unique and personal. In addition to this, being a public building that is accessible as early as 5.00 am until 10.00 pm, it is difficult to have a controlled environment for the study. The conducted research must not interrupt the daily activities conducted in the mosques and must follow all the rules and regulation stated by the mosque authorities which is normally related to the Islamic religion.

With these issues in mind, it is apparent that the ideal approach is through the field or case study which is based on the survey and the field measurement of the concerned variables at the actual condition of the building. Through this approach, the influence of the adaptive behaviour is expected to have been included in the decision making by the participants. The activities conducted in the mosques are fairly minimal in variation which can produce a fairly general and accurate outcome.

The availability of the computer modeling software also contributes substantially in the study through the simulation process. As discussed earlier in Chapter 2, the roof of the mosque in Malaysia carries a big role not only as the identification of the building but also to provide shelter from the harsh condition of the hot and humid climate of Malaysia. Understanding the behaviour of the roof in transferring the heat to and from the internal space is crucial in helping architects to understand in designing a passively controlled mosque that is thermally comfortable. HTB2 and WinAir4 are selected to conduct the simulation process to gather the required simulated data in the study. The use of the computer modeling approach allows the study of the building to be conducted without interfering with the activities inside the mosque which may create discomfort to the users. Details of the both methods applied in the study are discussed in the following sections.

4.3 THE CASE STUDY

The case study involves the real users under the actual condition. The involvement of the users of the building in inquiring information is an important approach in data collection because the information given is directly from the experience of the users. This approach which is also known as Post Occupancy Evaluation (POE) is often left out and therefore there is little knowledge about the performance of a building in relation to the user satisfaction. A good building must be able to response to the environment and the user needs (Clements-Croome, 2009). Therefore, it is very important to include as many information regarding the practicality of the previous buildings which can be given by the users. Without the

Post Occupancy Evaluation, this information will not be available and there is a potential of the same mistake to be repeated. As mentioned by Bordass(2003), a problem in a building can only be detected when an investigation is conducted due to a failure. He also added that there is a minimal inclusion of in-use experience and this insufficiency leads to poor design in meeting users' needs and satisfaction. It is highly recommended to conduct Post Occupancy Evaluation because it provides feedback from the end users that can be used to reduce the dissatisfaction by understanding where the dissatisfaction is generated from (Leaman and Bordass (2007)). Many experimental or laboratorial studies are based on theories and do not include the experience of the users. This may result in inaccurate conclusion as the perception of human being is ever changing as well as the relationship between users and a building (Bordass, 2003).

In evaluating a building after its completion, there are four techniques that have been discussed (Bordass (2003); Leaman and Bordass (2007)). These techniques can be used on its own or combination of the techniques according to the needs of the study. The first technique in evaluating the building is through personal observation which can be included with a quick measurement or data acquisition method. This method however can be improved when combined with the questionnaires and interviews. Facilitated discussion can also be conducted especially when a specific or sensitive information is required. The last technique is through the physical monitoring, measurement and analysis of the building performance. For this study, adopting the approach discussed earlier, a set of questionnaires is distributed to the participant to inquire the experience of the thermal comfort inside the space. At the same time, the measurement of the factors affecting thermal comfort is also being conducted. Information from both of these techniques will be analyzed to determine the performance of the space studied. The stages of methods involved in the study are described below.

4.3.1 Selection of Buildings

Four mosques have been selected for the study. Chapter 2 has introduced the building type and the common characteristics of the mosques in Malaysia. It has been identified that most of the mosque in Malaysia share similar characteristics. All the selected mosques must share the same characteristics. Among them is the plan of the prayer space must be square in plan. This is because most of the prayer halls of a mosque are square in plan and this is derived from the Kaaba, the house of Allah in Mekkah. The square plan is applied because it represents the equality and stability. Another feature that the selected mosques must have is that the three sides of the prayer hall must be surrounded by a verandah. This is typical in many mosques in Malaysia. The verandah provides transition spaces between the outside and inside creating a different spirit of spaces from common spaces to the sacred spaces. This will also enable the halls of prayer hall to be shaded and creating a buffer zone between the outside and inside. The openings will be located at these three sides of the prayer hall walls. Another side of the prayer hall which is called the mihrab wall is covered and normally embellished with Islamic motives. The orientation of the mosque is all the same with the mihrab wall oriented to the kiblah which is 292.7 degree from the north. There are two typical designs of mosques in Malaysia that can be categorized into two main groups which are based on the roof designs. They are the pitched and domed roof designs. Figure 4.2 and 4.3 illustrate the typical designs of the pitched and domed roof mosque in Malaysia.

In selecting the mosques to be sampled, besides the characteristics discussed before, the mosque must be **naturally ventilated**. The successful of the design in responding to the climatic influences is one of the objectives that are studied. Mosques that use the air conditioning system are not selected since the mechanical system can control the thermal condition and comfort level inside a space. The design of the building may not consider the climatic influences since the indoor condition can be corrected by the mechanical system. It is important to study how the typical design of a mosque responding to the climatic factors without much help of the mechanical system. Therefore the study only focuses on the naturally ventilated buildings.

As the one of the concerns of the study is to investigate the performance of the two roof designs namely the pitched and domed roof, two samples for each type of the roof designs are selected. There are many variations of the pitched and domed roof design applied. For the study, the pitched roof design selected is the three-tiered-roof design and the domed roof style selected is the half hemispherical

Sketches of a typical pitched roof mosque

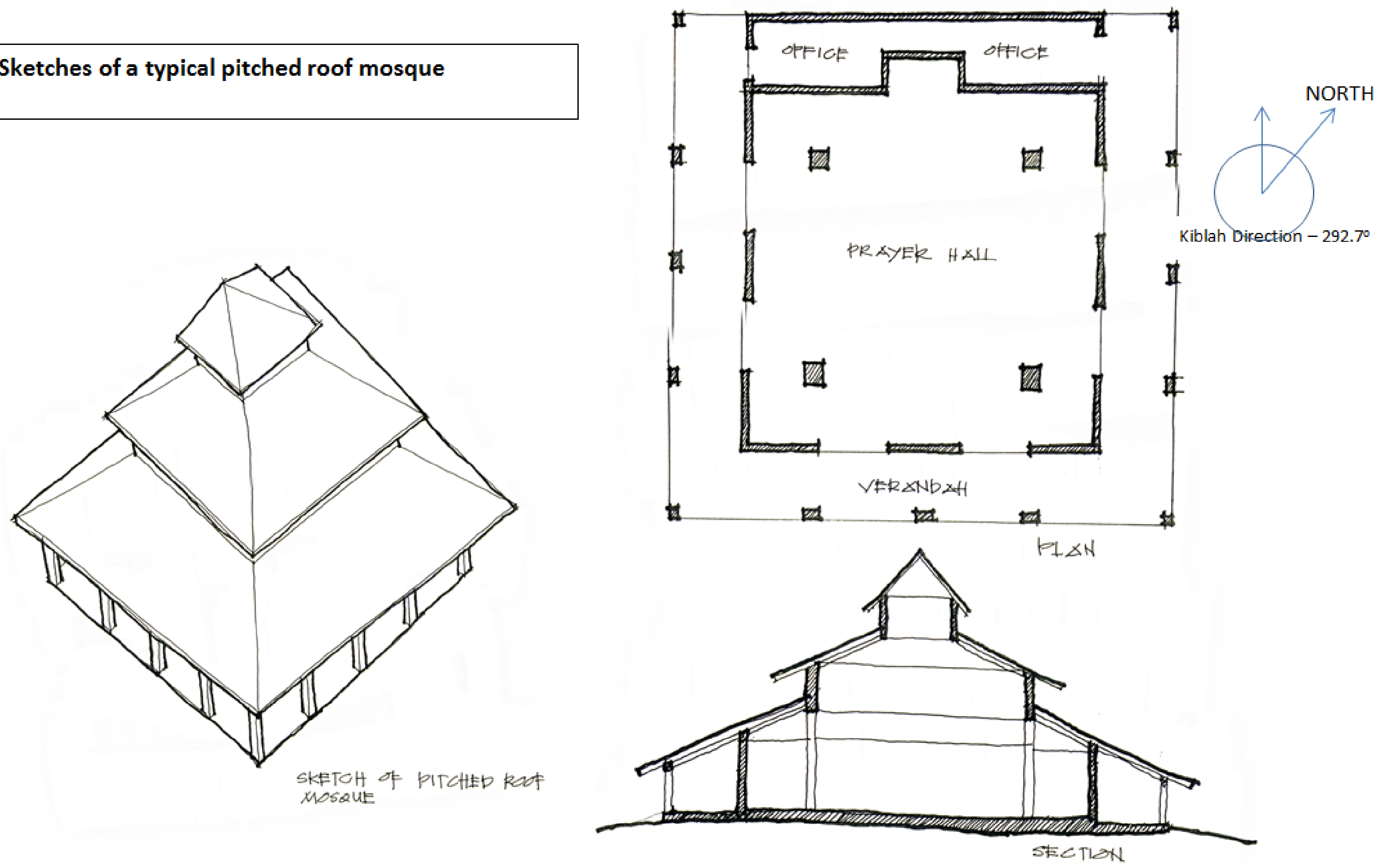
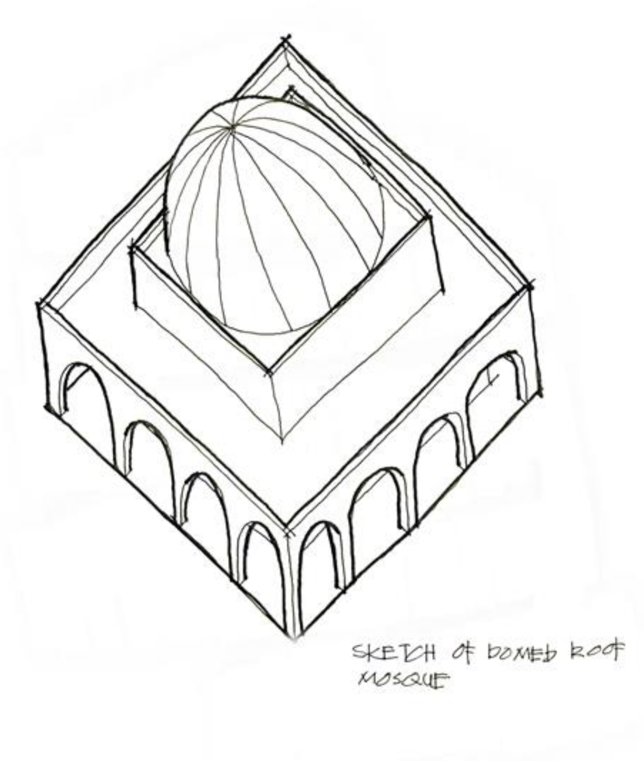


Figure 4. 2 - Sketches of a typical pitched roof mosque

Sketches of a typical domed roof mosque



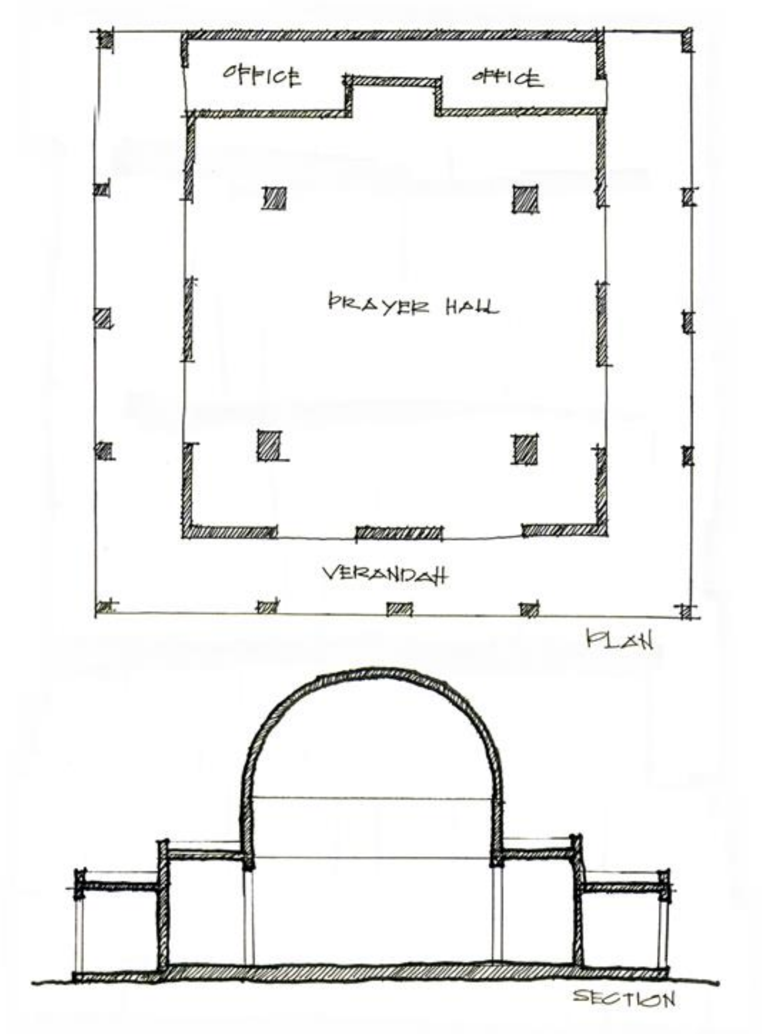


Figure 4. 3 - Sketches of a typical domed roof mosque

dome as shown in Figure 4.2 and 4.3 respectively. The three tiered pitched roof design is selected because it is among the original traditional roof design being applied in the mosque in Malaysia and commonly used due to its capability to cover wider spaces. Similarly, the half hemispherical dome is the simplest and commonly used in mosque designs. Another variation for the selection is the sizes of the mosques. The mosques selected vary in sizes ranging from approximately 6500 m^2 to 100 m^2 . Such variation is to determine whether sizes affect the function of roof design in affecting thermal condition inside the prayer hall.

Based on the criteria, four mosques have been selected. They share a lot of similarities but mainly differ in the application of the roof design as discussed earlier. The mosques that have been selected are:

a. Al Azim Mosque, Melaka. (2.2^0 North, 102.3 East)

Figure 4. 4 - The aerial view of the mosque (Google map)

Completed in 1990, the Al Azim mosque (Figure 4.4) has been seen as the state landmark of Melaka, Malaysia. Not only it represents the most important building in the Islamic society but it also embraces the local traditional Malay architecture mainly through the roof design as pictured in Figure 4.5. As pictured in Figure 4.4, the building is oriented towards the direction of Kiblah which is 292.7 ^{0} from the north and this orientation is the same in all mosque construction. This is the direction that the believers have to face during their prayer. In addition to this, it can also be evidenced that the main building which the prayer hall is square in plan.

Figure 4. 5 - The side view of Al Azim Mosque, Melaka

The mosque is located about five (5) kilometres from the town of Melaka and has a total area of approximately 6741 square metres that houses facilities such as the prayer hall which is the main space and supported by other facilities such as VIP room, Imam room, ablution area, library and exhibition room. The prayer hall itself has an area of approximately 5351 square metres which can accommodate of approximately 10,000 users at one time. There are four groups of three giant columns located at the four corners of the prayer hall as displayed in Figure 4.6 to support the huge roof structure, otherwise the space is an open plan and column free space. The roof is a 3-tiered roof as displayed in Figure 4.5 which is embellished

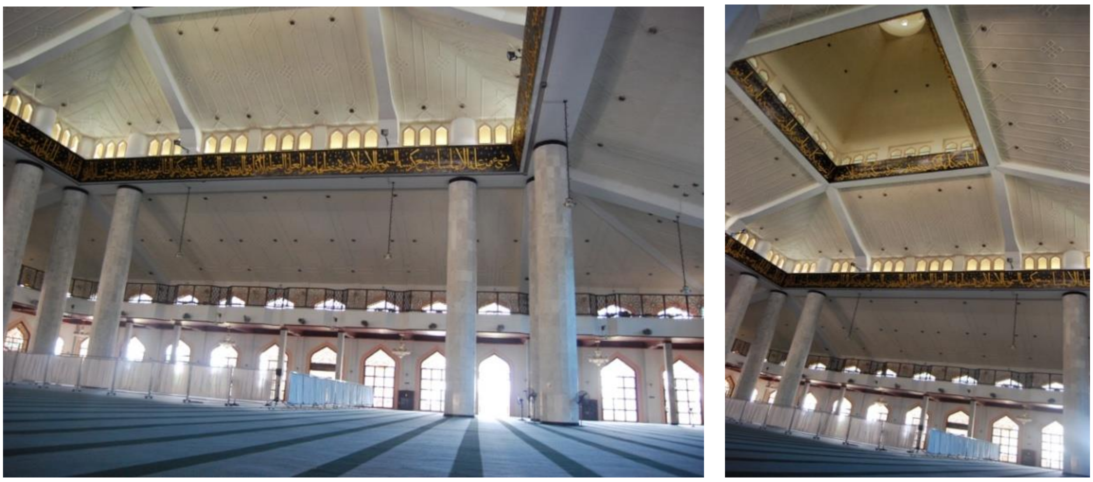


Figure 4. 6 – The views of the prayer hall in Al Azim Mosque, Melaka

Figure 4. 7- The view of the verandah at Al Azim Mosque, Melaka

by a small dome at the highest point of the roof. A six-meter passageway (Figure 4.7) is provided around the prayer hall for easy access into the hall as well as to act as a transition space before entering the prayer hall. There is a mezzanine level provided, however, it is only used for special occasion.

b. Jamek Mosque, Seremban. (2.7 North, 101.9 East)

Figure 4. 8 - The aerial view of Jamek Mosque, Seremban (from Google Map)

The mosque was constructed in 1924 on the site donated by the family of Syeikh Abdul Kadir. It is one of the oldest mosques in Seremban that is still in use. It is located in the middle of the city of Seremban and can be conveniently accessed by the people of the town. Most of the users of the mosque are the visitors of the town. As shown in Figure 4.8, the mosque is also oriented to the kiblah direction which is 292.7 ^{0} from the north and the main building that houses the prayer hall is square in plan. These characteristics are common in a typical mosque of Malaysia. The mosque as pictured in Figure 4.9 has gone several modifications to ensure its

Figure 4. 9 - Jamek Mosque, Seremban, Negeri Sembilan, Malaysia

structure stability and its occupancy capability. Extension such as creating vast area of verandah around the main prayer hall has been made to allow the increasing number of the users especially during the Friday noon prayer. This area can be used

as a relaxing or socializing area as this type of activity is prohibited inside the prayer hall. Traditional method of construction using pitched roof is implemented in the original main prayer hall of the mosque. Currently it can occupy up to 1000 people.

Figure 4. 10- The view of the prayer hall in Jamek Mosque, Seremban, Negeri Sembilan

The typical space arrangement of the Malaysian mosques is also evidenced in this building as shown in Figure 4.10. The main space which is square in shape is located at the centre of the building and surrounded by verandah (Figure 4.11) at the three sides of the prayer hall. The side without the verandah is where the *mihrab* wall is situated.

Figure 4. 11 – The view of the verandah at Jamek Mosque, Seremban, Negeri Sembilan

c. Sikamat Mosque, Seremban, Negeri Sembilan. (2.7 North, 102.0 East)

Figure 4. 12 - The aerial view of Sikamat Mosque, Seremban

The Sikamat Mosque was completed and started its operation in 2003. It is located in the district of Sikamat in Seremban and intended to serve the community of the

Figure 4. 13 - Siakamat Mosque, Seremban, Malaysia

nearby areas. As pictured in Figure 4.12, the Sikamat Mosque is also oriented toward the Kiblah which is 292.7^{0} from the north and the prayer hall is also square in plan. The mosque can occupy up to 3,500 people at one time. Besides the mosque, other facilities such as classrooms, a library and counseling offices are provided within the complex of the mosque. The main feature of the mosque is the blue dome covering the main prayer hall as displayed in Figure 4.13. It can be seen from far as it is built over a three-storey-high space of a prayer hall. The dome is made from polycarbonate materials as it is easier and faster in constructing the dome. It is a lightweight material and therefore, only smaller pillars are required to support the roof weight. Due to these reasons, the material has been used widely in constructing dome in Malaysian mosques. Traditionally, the concrete is used as the material to construct the dome due its ability to be molded into a specific shape. Figure 4.14 shows the prayer hall of the mosque, the space that is being investigated in the research.

Figure 4. 14 – The view of the prayer hall in Sikamat Mosque, Seremban, Negeri Sembilan

d. Al Mizan Mosque, Putrajaya. (2.9 North, 101.7 East)

Figure 4. 15 - The aerial view of the Al Mizan Mosque, Putrajaya (Goole map)

Al Mizan mosque (Figure 4.15) is the smallest mosque among the selected mosques. It is located in Precinct 8, Putrajaya, Malaysia. It is intended to serve a smaller local community. It has an area of approximately 324 meter square and can occupy up to 250 people at a time. It has a concrete dome that covers the central part of the prayer hall. Other part of the roof is a flat concrete roof. Located in a small and confined site, the mosque is designed to be an open facade mosque as an attempt to make the space feel spacious by making the outdoor as part of the indoor environment. Vegetation of different heights and density around the perimeter of the site is used to create shades to the prayer hall which is normally shaded by the outer wall of the mosque. Verandah is provided on the three side of the prayer hall, however, the verandah is directly connected to the outdoor garden.

4.3.2 Selection of Participants

The selection of the participants is based on the voluntary basis and randomly selected. This is to ensure that the results collected come from the users that are truly experiencing the condition inside the prayer hall of the mosques. Due to the restriction on the ethical of behavior while in a mosque, only male respondents are selected to answer the questionnaires. The results are still valid since the majority of the users are male.

For a person to be selected as a participant, he must have either completed performing a prayer or been inside the prayer hall for more than 10 minutes. This is to ensure that a participant has engaged with the common activities conducted in a mosque and adapted to the indoor climatic condition. The clothing of the participants is visually estimated at around 0.6 clo. value. This value is basically conformed to the dressing code required to enter a prayer hall of a mosque.

4.3.3 Data Collection

The objective of the data collection process is to gather enough information to be analysed to achieve the objective of the study. The main objective of the study is to investigate the thermal comfort condition and the factors affecting the condition as well as other related issues. To obtain this information, two approaches have been chosen. They are the physical measurement of the main factors affecting the thermal comfort and the survey inquiring the perception of the users on the thermal comfort condition. As mentioned earlier, the combination of the two methods can improve the prediction from the results as it involves the measurement of the physical factors but also the information of the actual users (Bordass, 2003; Leaman and Bordass, 2007).

Prior to the actual data collection, a set of questionnaire (refer to Appendix A) has been produced and a pilot study has been conducted to inquire the suitability and applicability of the questions and the methods. Adjustments and improvements have been made to the questionnaires to ensure that the questionnaires are clear and they cover the necessary information required for the study. Before proceeding to the data collection process, permission to sample the buildings is obtained from the authority. It is important to ensure that the activities conducted do not interfere with the activities and users inside the buildings. The data collection method is also modified to minimize any interruption to the activities and the users inside the mosques. The processes involved in the data collection through the use of survey and physical measurement are described below.

a. Physical Measurement

The first process in data collection is to record the changes of the thermal condition inside the prayer hall of the mosques. The common practice is to measure the common factors affecting the thermal comfort which are air temperature, mean radiant temperature, relative humidity, air movement, clothing value and metabolism. In this research, the field measurement conducted is focused on the two more important factors for this country or region which are the air temperature and relative humidity. This information is instrumentally recorded using the 'Tinytag' data loggers (Figure 4.16). There are factors that are not instrumentally recorded in the research which are the mean radiant temperature and air velocity. The mean radiant temperature is not recorded because it involves the use of black ball temperature which may disturb the activities inside the prayer hall. The air velocity is very inconsistent and in many cases, undetectable by the provided equipment. Therefore, the condition of the air movement will be based on the perception of the respondents as described in the questionnaires.

For measuring the said factors, the 'Tinytag' data logger as pictured in Figure 4.16 is suitable to record them. It has the capacity to record up to 32,000 readings with high accuracy and resolution. Most importantly, the small size of the data loggers makes it unnoticeable and can be placed without giving much interruption to the activities conducted in the mosques. Prior to installing the data loggers, the time

Figure 4. 16- 'Tinytag' data logger to measure the air temperature and relative humidity

on the data loggers is synchronized with each other and with the clock inside the prayer hall. This is crucial because the information from the survey is synchronized with the measurement taken in the prayer hall based on the time. To start, the data loggers are placed at three locations inside the prayer hall at one meter high from the floor as displayed in Figure 4.17. This is to measure the air temperature and relative humidity at the active level of the prayer hall in the mosques. One data logger is placed at the outside of the building under the shaded area to record the external air temperature and relative humidity. The data loggers are set to record the reading at the interval of five (5) minutes for at least three days at each location. At the end of the measurement, the readings recorded are transferred to the computer and tabulated using the Microsoft Excel software for further analysis.

Figure 4. 17 – The data logger is placed at one metre high from the floor level

b. Survey

Concurrently with the climatic data measurement, a set of questionnaires (refer to Appendix A) is distributed to the volunteered participants inside the prayer hall. The participants are randomly selected among the users who have finished conducting the prayer. Before the questionnaire is distributed, a brief explanation on the survey objective is given. The time is recorded on the form when the participants start to answer the questionnaire and they are left to answer the questions which may take them about ten to fifteen minutes. The objective of the activity is to acquire the perception of the users of the selected mosques on the thermal comfort condition in the prayer halls and their preferences according to the condition experienced.

To achieve this, the set of questionnaires has been carefully produced to allow the participants to evaluate and select the thermal sensation they experienced while in the mosque by marking the thermal sensation level based on ASHRAE 7-point scale and the Bedford scale as shown in Table 4.1. The ASHRAE 7-point scale is used to inquire about the thermal sensation and the Bedford scale is used to indicate the level of thermal comfort that the respondents have experienced while in the space.

ASHRAE	Scale		Bedford
Too Hot	3	7	Much Too Warm
Hot	2	6	Too Warm
Warm	1	5	Comfortably warm
Normal	0	4	Comfortable
Cool	-1	3	Comfortably cool
Cold	-2	2	Too Cool
Too Cold	-3	1	Much Too Cool

Table 4. 1 - The ASHRAE 7 thermal sensation scale and Bedford scale

Along with these questions, the participants are also asked about the sensation they experienced regarding the level of air movement, humidity level and their preferences to the existing condition. The air movement inside the mosque is rarely consistent at all time unless mechanical equipment is used. Therefore an assumption is made to the speed of air felt or experienced by the users at the point of time they answer the question. For the purpose of this study, the wind condition is divided into four categories which are calm (< 0. 5 m/s), breezy (between 0.5 m/s and 1.5 m/s), windy (between 1.5 -2.0m/s) and very windy (more than 2.0 m/s). The humidity level they experienced is measured by the level of sweating. It is difficult to sense the level of humidity with our bare skin. The only easy explanation to measure the existence of humidity in the air is through the level of sweat accumulation on the skin which is closely associated with the content of humidity in the air. Due to the fact that the air temperature for the country's climate is almost high and people tend to sweat at all time, the method selected for measuring the perception of the humidity level is thought to be appropriate. Four scales are given which are dry, normal, sweating (humid) and heavy sweating (very humid). In addition, the participants are also asked to choose the condition they would like to be if they are given the chance to change to the existing environment. They are provided with three options to change which are to reduce, unchanged or increase to the three physical environmental conditions which include air temperature, humidity level and air movement condition. At the end of the survey, the time and date are checked to acquire the readings of the air temperature and the relative humidity from the recorded readings from the data loggers. The information is tabulated using the Microsoft Excel 2007 for further analysis.

The survey is only conducted during the specific time which is after each congregational prayer. These are the periods of time during the day that the mosques will have better occupancy compared to any other periods of time. The mosques however, are open from as early as 5.00 am in the morning until 10.00 pm in the evening, and can be accessed during this period however the occupancy level is better during the congregational prayers. Depending on the size of the mosque, 5% to 20% capacity can be achieved during daily congregational prayer. A full capacity can only be achieved during weekly congregational prayer which is on Friday. There are five congregational prayers conducted each day which are:

i. Dawn prayer (subh) – 6.00 am – 7.30 am
ii. Noon prayer (Zuhr) – 1.00 pm – 4.30 pm
iii. Afternoon prayer (Asr) – 4.30 pm – 7.00
iv. Dusk prayer (Maghrib) - 7.30pm – 8.30pm
v. Evening prayer (Isya) – 8.30 – until Dawn prayer

The Friday congregational prayer is not included in the survey due to the disturbance that may occur during the survey which is inappropriate to the religion.

4.3.4 Data Analysis

The analysis of the collected data is intended to provide information regarding the thermal comfort condition inside the prayer hall of the selected mosque. For the purpose of the analysis, instead of using the five periods of time of the congregational prayers, three periods of time which are the noon (from 1.00 pm until 2.30 pm), afternoon (from 3.30 pm until 5.00 pm) and evening (from 7.00 until 9.30 pm) are introduced. These are the duration of time that the mosques are mostly occupied and the condition of the climate during the three periods of times is relatively similar. The Subh prayer time which is early in the morning is not included in the research since the condition during this time is mostly comfortable. There are many objectives planned to be achieved with the analysis. The objectives are:

a. ***To inquire the users' perception on the thermal comfort condition of the two typical types of mosques designs in Malaysia which are the pitched and domed roof mosques.***

The data concerning the thermal comfort sensation are gathered for each of the mosque (refer to Appendix B). The votes counted for this purpose are based on the Bedford scale which is based on the seven scales ranging from 'much too cool' to 'much too warm'. The Bedford scale is selected rather than the ASHRAE 7 thermal sensation scale because the Bedford scale is more relevant in describing the thermal comfort with the addition of word 'comfortable' in the scale compared to the ASHRAE scale which is more related to the thermal sensation rather than thermal comfort perception. Based on the votes received, the results are tabulated and converted to a bar chart. The charts from each type of the mosques are compared to find the perception of the users on the more thermally comfortable mosque.

b. ***To inquire the dominating factor and other contributing factors of thermal comfort inside the prayer halls of the mosques***

Included in the set of questionnaires is the inquiry about the sensation of the factors affecting the thermal comfort that the participants have experienced. The factors include thermal sensation, humidity level and air movement condition. The votes received are collected and tabulated using the bar chart. Cross tabulation between the votes on the thermal comfort sensation and the votes of the sensation on the other factors described earlier can suggest how thermal comfort can be affected by each factor. It can also suggest which factors are influential in influencing the thermal comfort sensation. The votes on the preferences are also investigated to confirm the desired conditions affecting the thermal comfort level.

c. To predict the range of tolerable indoor air temperature for the prayer halls of the selected mosques.

It has been agreed by the researchers that the tolerable range of air temperature is between -1 (cool) and +1 (warm) based on the ASHRAE thermal sensation 7-scale and between 3(comfortably cool) and 5 (comfortably warm) under the Bedford Scale. For determining the tolerable air temperature, the ASHRAE scale and the Bedford scale are applied. With the recorded air temperature and relative humidity, the votes under the two scales of thermal sensation are counted and tabulated. They are averaged and compared. A graph showing the linear regression based on the relationships between the air temperature and the votes based on the two scales is applied to predict the maximum range of tolerable air temperature (when the vote is equal to 1).

d. The appropriate methods of evaluating the thermal comfort condition for this climate and region and specifically for this building type.

ASHRAE 7 thermal sensation scale and Bedford scale are the two frequently used subjective measurement tools in evaluating thermal comfort condition throughout the world. They have been accepted in many countries especially in countries with moderate climate and they are proven to produce acceptable results. The study also looks at the two scales and their applicability for this region and climate. Cross checking analysis between these two indexes is done to come out with a proper and acceptable range of air temperature. The methods adapted in producing the acceptable range is later on suggested to be used in evaluating the thermal comfort condition for the hot and humid countries, specifically, Malaysia.

4.4 COMPUTER MODELING

The availability of computer modeling has helped to investigate the performance of a building without having to build the real building (Li and others, 2007). In this research, an investigation using computer modeling is appropriate as it can minimize the variations created by the real buildings and environment. The objective of using the modeling tool is to investigate and compare the performance of the mosque with the two types of roof based on the generated indoor thermal condition inside the prayer hall of the mosques. The pitched and domed roofs are two most common roof designs applied in Malaysian mosques. The computer modeling is used to simulate the indoor heat gain from the influences of the external conditions and compare the performance between the mosque with the pitched roof and the domed roof.

For this purpose, a software called HTB2 (Alexander, 1996) and WinAir4 are chosen in assisting the investigation. HTB2 is an improved investigation tool of the previous Heat Thermal Balance (HTB) software developed at Welsh School of Architecture, Cardiff (Alexander and Jones, 1996). It is simple but able to simulate the indoor thermal condition based on the various variables such as thermal outdoor conditions including air temperatures and humidity, the materials of the building for each building elements and energy usage as well as the usage patterns by the users (Alexander and Jones, 1996). In comparison with other investigative tools available in the market, HTB2 is chosen for this investigation because it can provide detailed data on short-time scale such as minutes and weeks and this is suitable for this investigation as the investigation will look for the changes happened throughout the day. In addition to this, HTB2 does not require the actual drawing of the building investigated. It only requires the representation of the building as it focuses more on the operation of the occupied buildings. A building is defined as a set of spaces linked together and to the outside with building elements and affected by a set of influences originating from external climatic factors, heating system and other operational system (Alexander and Jones, 1996). Based on these influences, a new result will be generated in the investigated space. As the research is focused on the operation of the building and focusing on one of the building elements which is the roof, the use of HTB2 is appropriate for the investigation. Figure 4.18 shows the fundamental of the processes and interactions of the climatic factors and building elements in HTB2.

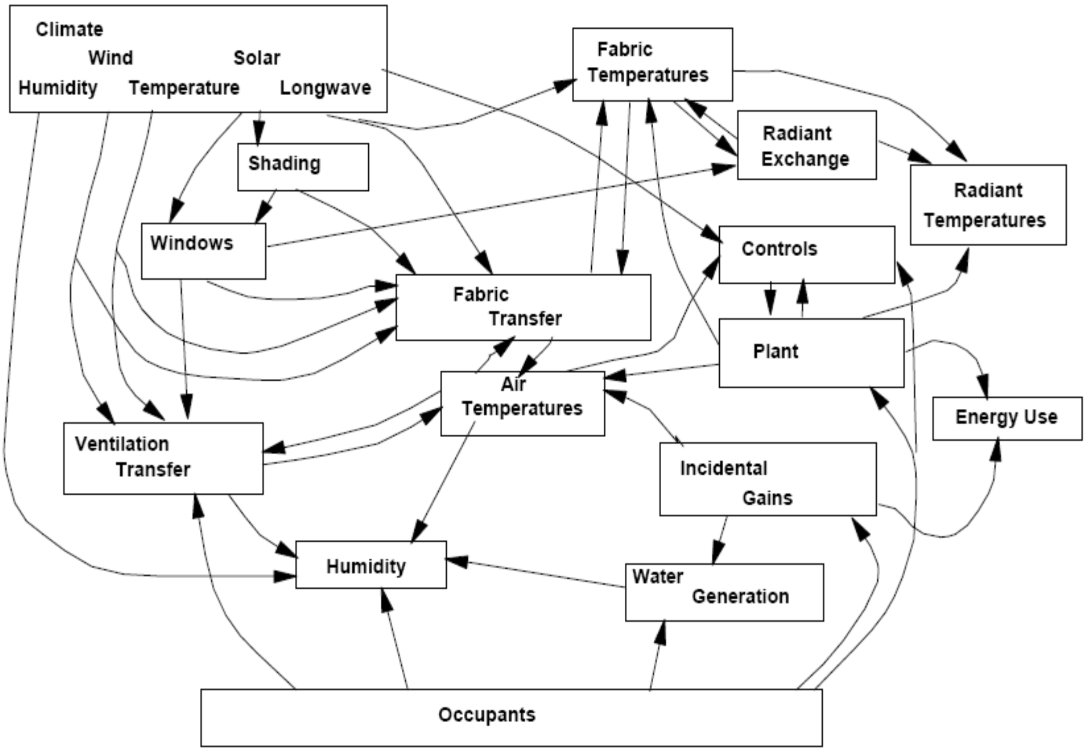


Figure 4. 18 - Fundamental Building Processes and Interactions (Alexander, 1996)

WinAir4 software is also used to show the distribution of air according to the temperature inside the space investigated. The geometry of the building investigated together with the influences acted on the building must be loaded to the system for the system to work. In HTB2, only data will be provided however in WinAir4 the distribution of the temperature around the space can be seen. This will improve the analysis of the thermal condition of the building. Figure 4.19 shows the examples of the output from the simulation conducted using WInAir4.

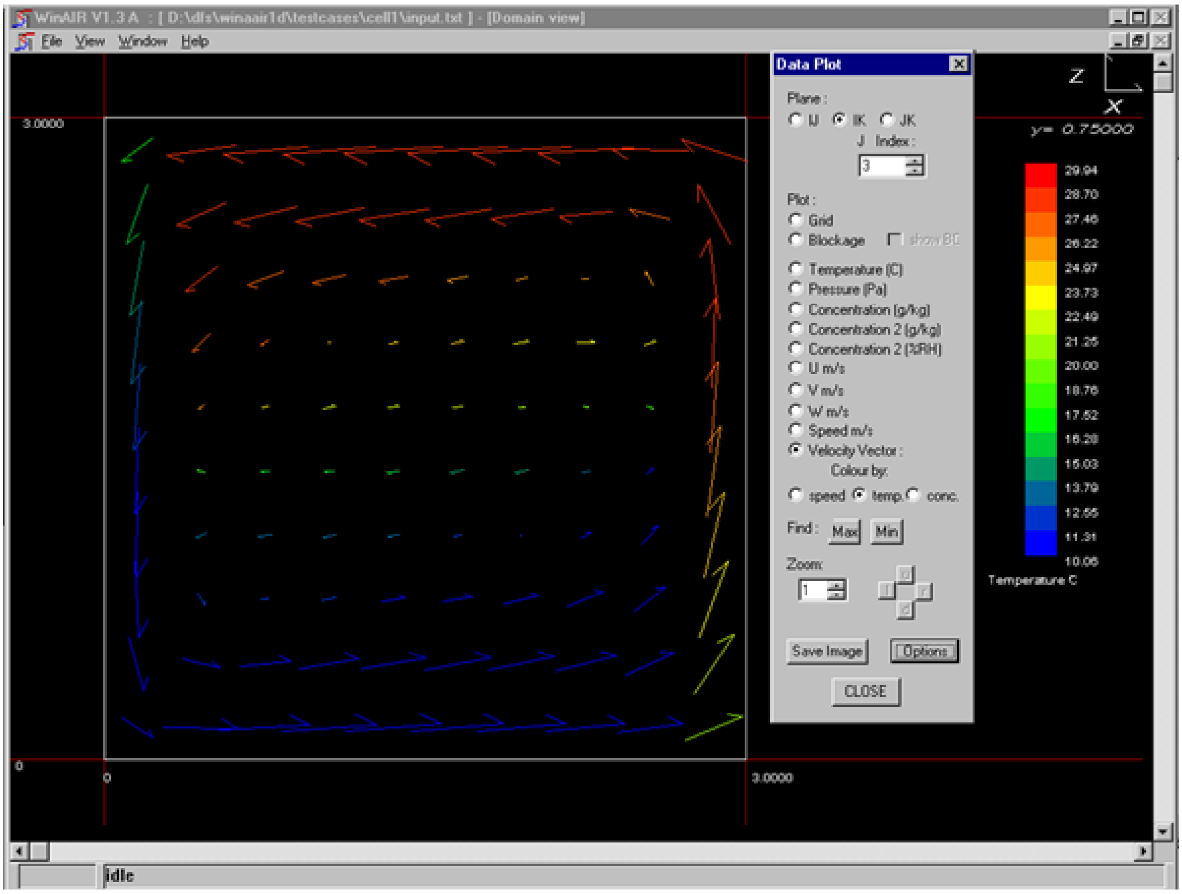


Figure 4. 19 - The output of data plot using WinAir4 showing the air flow and distribution according the temperature inside a space

With the combination of WinAir4 software, the distribution of air temperature inside the space investigated can be visualized.

Before using the thermal simulation tool, a confident study is conducted to inquire the capability of the tool to simulate the situation studied for the building type. In this study, the recorded outdoor temperature from the site is utilized and the results of the space air temperature of the prayer hall from the simulation tool are compared with the recorded temperature form the building samples. It shows that the patterns of the air temperature generated from the tool are very similar to the pattern from the measured reading. Having this validated, the following study is to investigate the performance of two typical designs of Malaysian mosques. To conduct the investigation, the two typical models of Malaysian mosques, a pitched roof mosque and a domed roof mosque, are constructed for the simulation process. Both of them share the same qualities but differ in the roof construction which also affects the volume of the space. The construction types and materials used are the same for both of the buildings except the roof. This information is used in constructing the model in the HTB2 and WinAir4 software with the input of the outdoor climate conditions obtained from the Malaysian Meteorological office.

4.4.1 The Mosque Model – Dome and Pitch

Two models, a domed mosque and pitched mosque are constructed for the purpose of the simulation. The design of Malaysian mosques is relatively similar to each other especially in the space organization. The differences are more distinguished on the appearances of the building which are heavily influenced by the building envelope especially the roof. The two models selected are the most popular designs employed in the Malaysian mosques. The pitched roof is more traditional, whereas the domed roof is claimed to be more Islamic. Figure 4.2 and figure 4.3 show the typical plan and section of the pitched roof mosque and the domed roof mosque respectively.

4.4.2 Data Collection

The data collected for the simulation process are divided into two categories which are the input data, gathered from specification of the buildings modeled, and the output data, generated from the simulation process.

a. The Input

The input data is required to build the model of the building in the simulation tool. The information includes:

i. Building Information

Information that is specified under the building includes the geographical location of the building in terms of its latitude and longitude position. It also includes the details of the building investigated which consist of the materials and their properties, the spaces or zones of the building to be investigated, the building elements, constructions and layout of the elements.

For the purpose of the study, the location selected for the building is Kuala Lumpur(101.7 ^{o}, 2.9^{o}). Kuala Lumpur is the capital city of Malaysia. The city has a complete and sufficient climatic data that is needed as an input for the HTB2.

For the modeled building, the spaces in the mosque are divided into five divisions as shown in the Table 4.2 to represent the spaces making up the whole mosque. However, the study is only focused to the main space which is the prayer hall. The elements of the building such as the walls, floors, roofs and windows are as specified in the Table 4.3.

Space code	Space name	Area (m^2)	Volume (m^3)
1	Prayer hall	900	9951
2	East Verandah	196	1176
3	West verandah	196	1176
4	South Verandah	216	1296
5	Office	180	1080

Table 4. 2 - Space divisions for the modelled mosque

Construction	Description	Material	Width (m)
1	External wall	Plaster, brick, plaster	0.016, 0.105, 0.016
2	Single glazing	Window glass	0.006
3	Solid ground floor	Carpet, concrete, earth	0.015, 0.100, 1.60
4	Internal ceiling	Insulation quilt, plasterboard	0.10, 0.01
5	Roof	Tiles	0.01
6	Internal partition	Plaster, brick(inner), plaster	0.016, 0.105, 0.016
7	Timber grille wall/partition	Timber (oak)	0.19
8	Concrete roofing	Concrete (light mix)	0.450
9	Roof 1	Roof tiles, Styrofoam, plasterboard	0.013, 0.085.0.013
10	Solid ground floor with tiles	Tiles, concrete, earth	0.30, 0.1, 1.6
11	Opening	Void	0.015
12	Dome roofing	Polycarbonate	0.012

Table 4. 3 - Description of building elements for the modelled mosque

ii. Operative Information

Operative information includes the data for the meteorological condition which is provided by the local Meteorological Department for the area of Kuala Lumpur. The simulation is set to take place for ten days allowing to building to the heating up process for two days.

iii. **Services**

The information included in this category is the heating and cooling system, lighting circuits, small power sources, occupants and ventilation characteristics. For the purpose of the study, all the information about services is ignored except the ventilation characteristics. The building is naturally ventilated and no heating and cooling system involved. The involvement of major equipment that contributes to the heat gain is also minimal and the usage of lighting is kept to the minimal as well. As the focus of the research is more to the performance of the building in relation to its construction design, the building elements are given more emphasized in the study.

b. The Output

The output data is the information obtained after the simulation process has been conducted. The software is able to predict the indoor air temperature, relative humidity and mean radiant temperature of the spaces made earlier based on the input data. In addition to this, it can also predict the surface temperature and the energy transferred from surfaces. These are among the output that can be generated through the use of the software.

4.4.3 Data Analysis

Using the data from the Meteorological Office of Malaysia for the outdoor climate condition and the data obtained from specification of the constructed models of a typical pitched roof and domed roof mosques, HTB2 and WinAir4 are employed to produce the predicted indoor thermal condition of the buildings. The results obtained from the simulation are analyzed using the comparative method between the results of two constructed model mosques. The aim of the analysis is to investigate the effects of the indoor thermal condition when the two different types of roof being applied to the same space. The study is focused on the aspects that are listed below. They are:

a. The heat gain and loss pattern

The study is to inquire the heat gain pattern for the two types of the mosques. Using the same building but replacing it with the domed roof and pitched roof, the heat gain and loss pattern can be generated using the HTB2 software. Comparison between the patterns can be made to evaluate the performance of the roof in filtering the outdoor thermal condition into the indoor space.

b. The influence of the opening area and the heat gain

The total area of the openings provided controls the amount of air changes between the inside and outside. This affects the air temperature of the interior and natural ventilation for the purpose of providing thermally comfortable environment. A variation in the size of the openings is tested to investigate the effect on the air temperature.

c. The roof space vs. the prayer hall space

Due to the difference in the roof design, the roof space provided is investigated to inquire if it affects the air temperature of the inside space.

d. Wind movement pattern and air temperature distribution

The influence of the roof design to the pattern of the wind movement is investigated. The geometry of the roof design is different from each other. Therefore it is possible that the air movement pattern is influenced by the roof geometry since other design characteristics are the same.

4.5 Conclusion

Determining the thermal comfort level of a space involves the psychological factors as well as physical factors. Many psychological factors deal with the feeling and personality whereas the physical factors are more towards the measured value. Combining the methods of survey and field measurement in data acquisition is relevant because in the survey, the questionnaire is designed to inquire about the feeling and the perception of the participants. On the other hand, the field measurement records the value of the physical factors affecting the thermal comfort. Combining the results from the two data acquisition produces results that consider not only the physical aspects but also the psychological factors. In addition, the availability of the computer simulation tools enables the investigation on the influence of the building design on the thermal comfort to be conducted without having to interfere with the activities of the building. Combining the three approaches produces thorough investigation regarding the issue of thermal comfort for the typical Malaysian mosques.

CHAPTER 5 – RESULTS AND DISCUSSION
(Survey and Field Measurement)

5.1 INTRODUCTION

This chapter exhibits and discusses the results obtained from the information gathered through the field measurement and survey. Previously, Chapter 4 describes the methodology applied in collecting, obtaining and analysing information regarding the research. Chapter 5 starts with the introduction to the investigation conducted. It follows with the results and discussion of the pilot study conducted earlier on the small scale mosques located in Putrajaya. Then, the chapter continues with the results and discussion on the case studies conducted. It is divided into four sections with each section discusses results from each case study. The result presented in each case study is about the thermal comfort level of prayer halls experienced by the participants involved in the research. It also includes the discussion on the evaluative method and factors affecting thermal comfort level of the space. Based on the information, the section continues with the discussion of the predicted range of acceptable space air temperature for the space. Finally, the chapter summarizes the discussion on the case studies.

5.2 GENERAL BACKGROUND

One of the main reasons to the decreasing numbers of people attending the congregation prayers conducted five times a day is due to the thermally uncomfortable environment inside the prayer hall of many mosques in Malaysia. Even though the buildings play a significant role in the Muslim society which comprises the majority of the Malaysia's population, the buildings fail to function effectively due to this condition. Thus, the issue of thermal comfort condition inside a prayer hall in a mosque has recently become crucially important to ensure that the mosques are functionally well and able to play its important role in making a better society. Recently, many existing mosques designed to be naturally ventilated have been converted to air conditioned mosque in an attempt to tackle the thermally uncomfortable condition inside the prayer hall. This action indicates that the design has failed to provide a thermally comfortable indoor environment. It is rather costly economically and environmentally which contributes to the accumulation of polluted condition of the environment.

One of the reasons for this happening is due to the scarcity of available information regarding the thermal comfort condition for the specific type of building. The lack of understanding or knowledge on the ways of building elements transferring or losing heat to and from the space may have caused the failure to provide comfortable indoor environment. In addition to this, the reference to the acceptable or tolerable indoor air temperature and other condition is either unavailable or wrongly estimated. In order to tackle the problem, the knowledge regarding the matters should be available to be referred and most importantly, guidelines suggesting the tolerable comfort air temperature for the space in Malaysia should be available and correctly interpreted. Currently, specific knowledge and guidelines are lacking for this type of building in this type of climate.

In an attempt to provide the necessary knowledge, a study is conducted on the thermal comfort perception of four selected typical mosques in Malaysia. It is aimed to provide knowledge to be used as a guideline for the future naturally ventilated mosque construction. Four mosques ranged from the state mosques to the community mosques have been selected for the study. They are:

a. Al Azim Mosque, Melaka. – (State mosque)
b. Jamek Mosque, Sereemban. (Community mosque)
c. Sikamat Mosque, Seremban. (District Mosque)
d. Al Mizan Mosque, Putrajaya.(Local Community mosque)

At the earlier stage of the study, a pilot study was conducted on two small scale mosques located in Putrajaya, Malaysia. They are:

a. Al Mizan Mosque, Putrajaya
b. Section 9 Mosque, Putrajaya

5.3 PILOT STUDY

Prior to the actual investigation and data collection process, a pilot study had been conducted on two small scale mosques located in Putrajaya. The purpose of the study is to inquire the suitability of the methodology and to test the understanding of respondents on the questionnaire designed. The investigation was conducted during a noon prayer time between 1.00 pm until 3.30 pm for one day on each mosque. 20 participants had involved in the pilot study. A set of questionnaire asking on the thermal sensation based on the ASHRAE 7 thermal sensation scale was given to participants during the noon prayer time. Besides the thermal sensation scale, the participants were also asked on the thermal comfort level they perceived for every ten minutes. Concurrently, the air temperature, relative humidity and the wind speed inside the space were recorded using the BABUC data logger.

Based on the investigation from the pilot study, it supports the finding by earlier researchers that the use of PMV in predicting the thermal comfort level for a naturally ventilated building in tropical countries is irrelevant. Table 5.1 shows the calculated PMV/PPD based on the recorded variables and the level of comfort experienced by the respondents.

Time	TGLOB	TDRYB	RH	VAIR	PMV	PPD	Comfortable	uncomfortable	Heat	Humidity
1300	28.89	28.27	74.70	0.76	1.43	47.3	18	2	2	
1310	28.89	28.58	73.10	0.74	1.62	57.4	4	16	5	11
1320	28.96	28.39	74.00	0.9	1.4	45.4	0	20	5	20
1330	29.04	28.69	73.40	0.75	1.62	57.4	0	20	5	20
1340	29.77	29.96	66.50	4.49	1.75	64.6	16	4 (Female)	4	4
1350	30.3	30.22	65.30	0.8	1.82	67.9	16	4	4	4
1400	30.22	29.34	68.60	0.7	1.65	59.2	8	12	4	10
1410	29.65	28.89	70.30	0.69	1.67	60.4	2	18	2	16
1420	29.5	28.92	70.30	0.67	1.68	60.7	0	20	4	20
1430	29.38	29	70.80	0.67	1.61	56.8	0	20	6	20
1440	29.38	28.96	72.10	0.67	1.62	57.7	0	20	6	20
1450	29.57	29.27	71.70	0.68	1.69	61.5	0	20	5	20
1500	29.69	29.27	72.00	0.67	1.69	61.5	0	20	6	20
1510	29.69	29.61	74.20	0.83	1.89	71.4	0	20	7	20
1520	29.84	29.31	73.50	0.66	1.71	62.4	0	20	6	20
1530	29.57	29.08	75.70	0.64	1.73	63.4	0	20	6	20
1540	29.42	28.96	74.80	0.7	1.64	58.6	0	20	5	20

Table 5. 1 – The PMV/PPD calculation based on the measured variables with the comfort perception votes at the pitched roof mosque.

It is found out that even though the reading based on the calculated PMV shows a higher number, many of the respondents still perceive the indoor condition as comfortable. The investigation from the pilot study (Figure 5.1) has also shown that the air temperature itself is not directly related to the thermal comfort level itself as experienced by the respondents. According to the calculated PMV, the thermal comfort vote should be higher as the air temperature rises. However, this situation is not reflected on the thermal comfort level voted by the respondents.

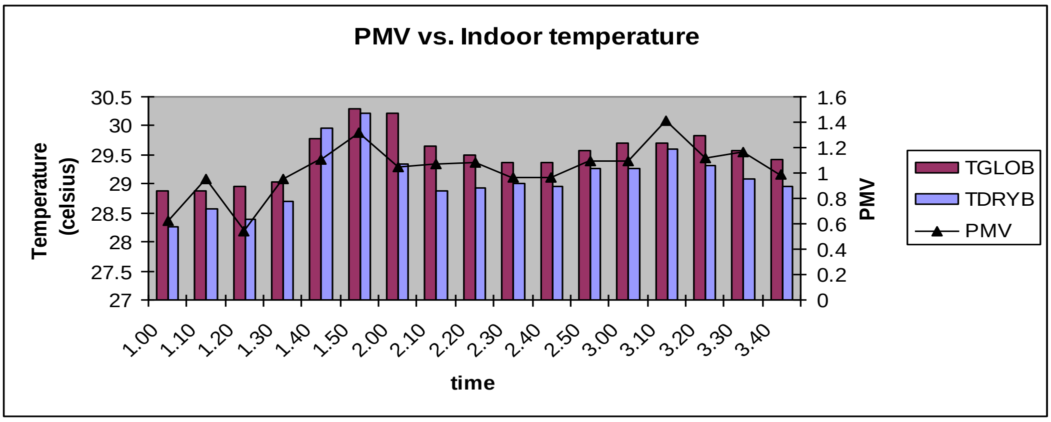


Figure 5. 1 – The calculated PMV vs. indoor air temperature at the pitched roof mosque

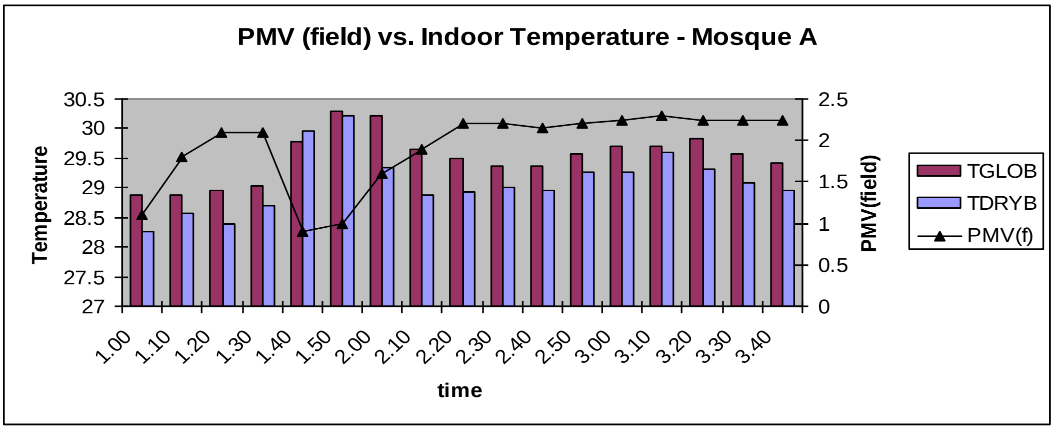


Figure 5. 2 - The PMV based on the field survey vs. indoor air temperature at the pitched roof mosque

Figure 5.2 shows the comparison between the PMV based on the calculation and the field survey. Based on the calculated PMV, the rise on the air temperature is followed by the rise in the PMV value. However, according to the respondents' perception, the PMV can be lower even though the air temperature is higher. The change in the thermal comfort level to a better condition can be evidenced when the wind movement is present as shown in the next figure (Figure 5.3). It is also

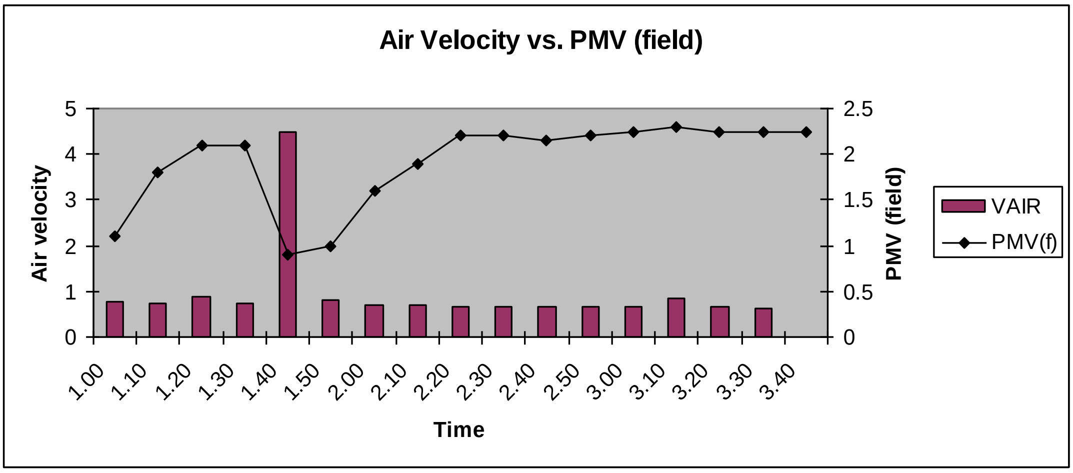


Figure 5. 3 – The velocity of air vs the PMV based on the field survey

observed that only a strong wind can assist in providing thermally comfortable environment. With the wind speed less than 2m/s, the thermal comfort level is insignificantly affected. Further investigations need to be conducted on a larger scale and modification on the questionnaire and methodology relevant to the study is made as discussed in the previous chapter.

5.4 Case Study 1 – Al Azim Mosque, Melaka, Malaysia

A study involving a field measurement and survey has been conducted at the Al Azim Mosque, Melaka, Malaysia. It is a modern building but it implements a traditional design that uses the traditional three tired pitched roof which is very vernacular to Malaysia. A total of 119 respondents are involved in the thermal comfort perception survey conducted for this mosque with the distribution of 41 people for the noon prayer, 24 respondents for the afternoon prayer and 54 participants for the evening prayer time.

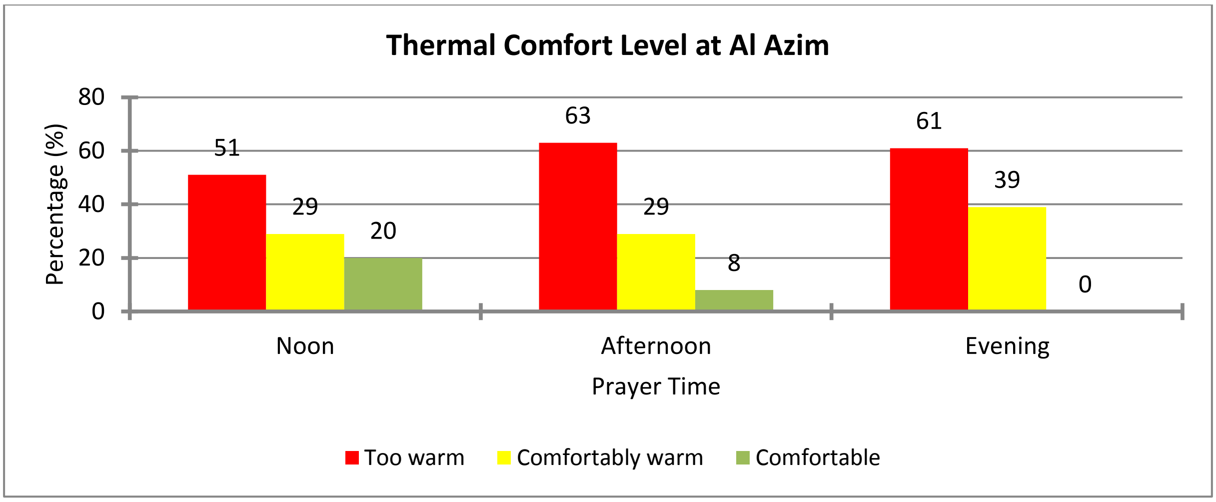
5.4.1 Thermal Comfort Perception

Table 5.2 and Figure 5.4 show the number and percentage of votes received during noon, afternoon and evening time based on the thermal comfort perception.

Column1	Too warm	Comfortably warm	Comfortable	No. Of Participant	Avg. Temp.	Max. T	Min T	Avg RH	Max RH	Min RH
Noon	21	12	8	41	30.3	32.2	29.1	67.6	73.1	65.3
Afternoon	15	7	2	24	30.1	30.6	29.1	75	82.9	69
Evening	33	21		54	29.7	31	28.7	77.4	86	69.4
Avg Temp.	30.3	29.6	29.4							
Min	29.1	28.7	29.1							
Max	32.2	31	29.8							
Avg RH	75.9	70.9	67.6							
Min	65.80%	65.30%	65.5 %RH							
Max	86.00%	76.70%	69.0 %RH							

Table 5. 2 - The average, min and max for the air temperature and relative humidity according to the thermal comfort vote and the periods of prayer time at Al Azim Mosque Melaka.

Based on the responses gathered from the survey, 51% of the respondents consider that the noon time is ‘too warm’. The other 49% consider that the indoor condition is thermally acceptable which is shown by the ‘comfortably warm’ (29%) and ‘comfortable’ (20%) votes. The percentage of votes for the ‘too warm’ condition during the afternoon time increases to 63%. Only 37% of the respondents accept the condition as thermally comfortable. During the evening time, the percentage of the votes for ‘too warm’ which reflected the thermally uncomfortable condition is 61%



Note: Seven levels of Bedford scale are used for the thermal comfort level but only the three levels are shown because no vote is received for comfortably cool, too cool, much too cool and much too warm.

Figure 5. 4 - The percentage of thermal comfort votes based on the Bedford scale according to the prayer times at Al Azim Mosque, Melaka

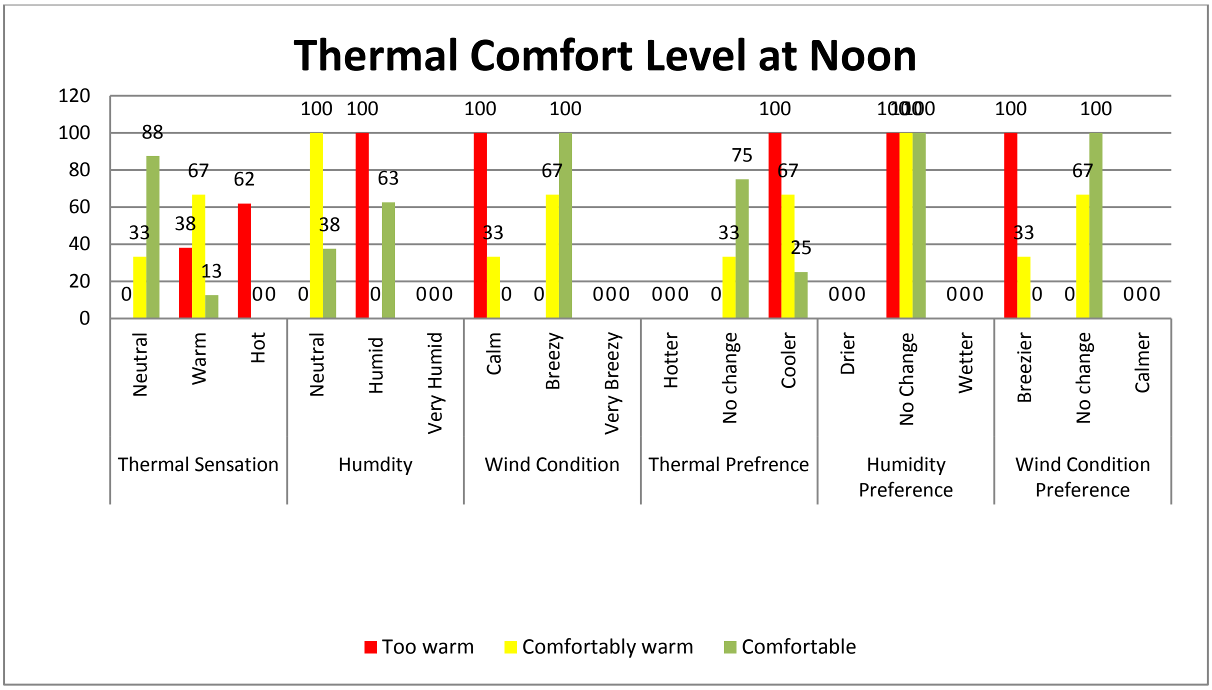
which is less than the votes received during the afternoon time but it is still high compared to the votes received during the noon time. Based on the information, it suggests that the less comfortable period occurs between the afternoon prayer time (4.00 pm) until the evening prayer time (9.30 pm). The average temperature during the noon time is 30.3 degree Celsius with 67.6% of relative humidity (RH). During the afternoon time, the average temperature is 30.6 degree Celsius with 75% of relative humidity and during the evening time, the average is 29.7 degree Celsius for the air temperature with 77.4% of relative humidity (RH).

It is noted that the difference in the average air temperature is relatively small (0.2 – 0.5 ^{0} Celsius) between these periods of time. The small changes in the air temperature are normally insignificant in changing the thermal comfort level. Unlikely in this case, it can be evidenced that even though the changes in the average air temperature are minimal, there is a quite substantial change in the percentage of participants feeling uncomfortable. This may suggest that other contributing factor, such as, the relative humidity may have affected the vote since there is a substantial increase in the average relative humidity recorded which is approximately between 8% and 10% increment during these times. Furthermore, the increase in the relative humidity exceeds the tolerable percentage which is 70%. Further analysis on these variables and their relation to the thermal comfort vote will reveal the importance of these variables in affecting the thermal comfort perception.

5.4.2 Affecting factors and preferences on thermal comfort

Further analysis is conducted on the influence of the air temperature, relative humidity and air movement to the comfort level. Figure 5.5, 5.6 and 5.7 show the votes of thermal comfort in relation to the thermal sensation, humidity level and wind condition at noon, afternoon and evening time. They also show the preferences of the participants if they were given the opportunities to change the condition. Analysing these figures may have given the ideas of how these variables affect the thermal comfort level.

Figure 5.5 shows the votes of the variables in relation to the thermal comfort vote at Al Azim Mosque during the noon time. Based on the figure, it shows that the participants who voted 'too warm' for the thermal comfort vote, also experience the thermal sensation as either 'warm' (38%) or 'hot' (62%) with 'humid' condition and 'calm' air movement. This condition indicates that high humidity with relatively no



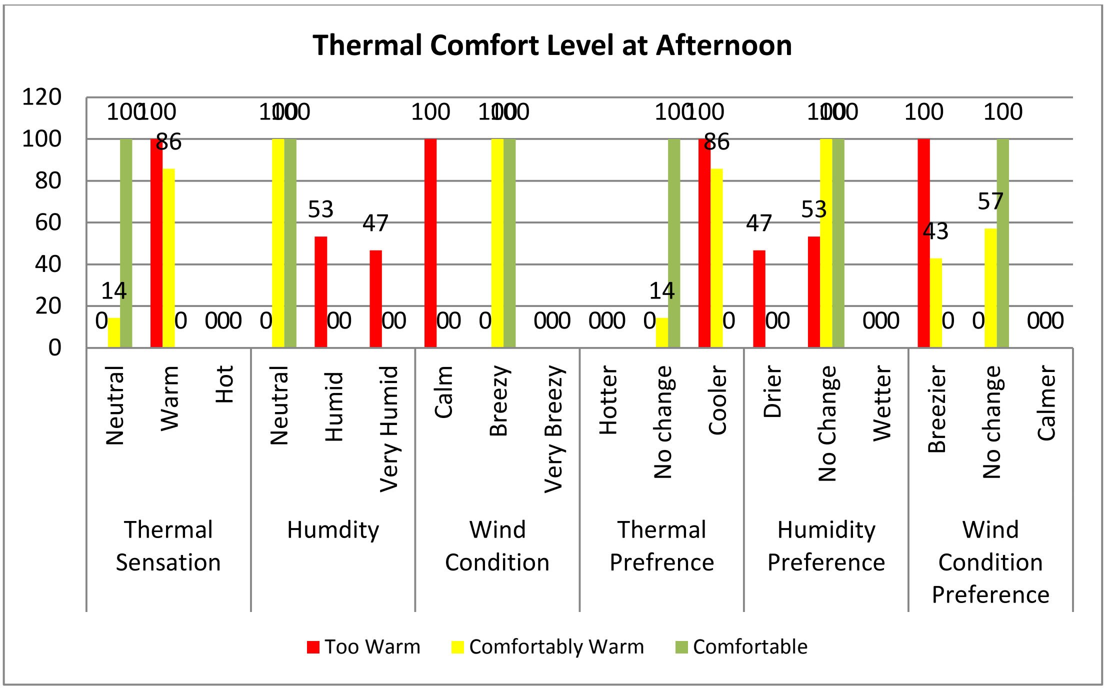
Note: Seven levels of Bedford scale are used for the thermal comfort level but only the three levels are shown because no vote is received for comfortably cool, too cool, much too cool and much too warm.
ASHRAE 7-point scale is used for the thermal sensation but only three points which are neutral, warm and hot are shown because other points do not receive any vote for the period of time investigated.

Figure 5. 5 - The percentage of votes on the thermal sensation, relative humidity, wind condition and preferences vote in relation with the comfort vote based on the Bedford scale at Al Azim Mosque, Melaka during the noon prayer time.

air movement can cause thermal discomfort with either 'warm' or 'hot' categories of air temperature. In this figure, it is also pointed out that the participants feel 'comfortably warm' which is better than the 'too warm' condition when the thermal sensation is either 'warm' (67%) or 'neutral' (33%) with 'neutral' level of humidity (100%) and 'breezy' air condition (67%). However, 33% still votes the condition to be 'comfortably warm' even though the air movement is in the 'calm' condition. This is possible because the thermal sensation they experience is 'neutral' and with no air movement it is still considered 'comfortably warm' due to the acceptable thermal sensation. This suggests that the thermal comfort level improves with the reduction on the air temperature. In many cases the reduction in the humidity level also helps to improve the thermal comfort level depending on the air temperature and wind condition. When the air temperature is considered 'warm', the reaction to cooling down the body by sweating is more likely to happen. When the humidity level is high the ability for the evaporative process of the sweat may not be efficient enough to cool down the body. The reduction of the humidity level in this case, helps the evaporative process by increasing the ability of the air to contain more humidity. When the air temperature is at the 'neutral' level, the ability of the body to react and produce sweat is slower or at minimal rate. The high level of humidity may not be very significant in influencing the thermal comfort level at this condition, however, in some cases that have been discussed earlier it affects the thermal comfort perception especially when there is little air movement. The increment in the air movement has certainly helped to improve the thermal comfort condition which can be clearly evidenced in the votes received by the 'comfortable' condition in which the increment in the wind condition along with the reduction of the air temperature has help the thermal comfort condition even though it shows an increment in the relative humidity. This also suggests that the humid condition can be tolerated when the condition of the air is 'breezy' and the thermal condition is 'neutral'.

The preferences vote has also suggested the importance of the variables to the thermal comfort condition. For examples, all of the participants who felt 'too warm' preferred the air temperature to be cooler as most of them feel 'hot'. Similarly, for those who feel 'warm' also vote the air temperature to be cooler. Only those who feel ‘neutral’ choose the thermal sensation to remain. This suggests that only ‘neutral’ thermal sensation is acceptable since there is no change requested for this condition. Similarly, breezier condition is preferred for all thermal comfort conditions which is shown in figure 5.5. The ‘no change’ votes on the air movement is from those who have experienced the condition to be breezy. Therefore, it can be assumed that the wind movement is a variable that is important in providing thermally comfortable indoor. In the case of the relative humidity, regardless of the condition felt, all the participants prefer the condition to stay the same. This reflects that the influence of the humidity in the air may not be very critical in influencing the thermal comfort condition. Another assumption that can be made is that the level of sensitivity of the human body to react to the change in relative humidity is very poor. Therefore, the presence of the humidity in the air may not be realised.

The next figure (Figure 5.6) shows the relation of the variables to the thermal comfort vote during the afternoon time at the same mosque. Based on the figure, it is obvious that respondents feel ‘comfortable’ when the thermal sensation and humidity level are at ‘neutral’ level and the air condition is ‘breezy’. This is the ideal situation that makes the majority of the respondent feel ‘comfortable’. With the change in the thermal sensation from ‘neutral’ to ‘warm’ as shown in Figure 5.6, the thermal comfort vote has also changed to ‘comfortably warm’ when the other two variables remain unchanged. The ‘warm’ thermal sensation however, may have resulted in poorer thermal comfort condition as shown in the Figure 5.6 when the humidity level is increased and with relatively little air movement. As expected, 'breezier' wind

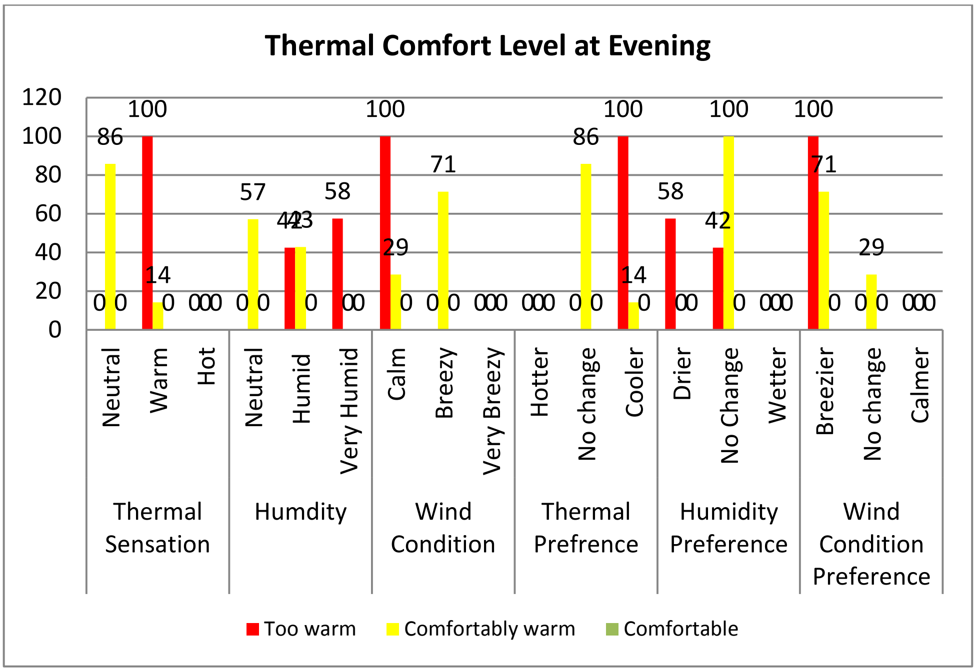


Note: Seven levels of Bedford scale are used for the thermal comfort level but only the three levels are shown because no vote is received for comfortably cool, too cool, much too cool and much too warm.
ASHRAE 7-point scale is used for the thermal sensation but only three points which are neutral, warm and hot are shown because other points do not receive any vote for the period of time investigated.

Figure 5. 6- The percentage of votes on the thermal sensation, relative humidity, wind condition and preferences vote in relation with the comfort vote based on the Bedford scale at Al Azim Mosque, Melaka during the afternoon prayer time.

condition is preferred not only by those who experienced 'calm' air condition but also by some of those who have considered the condition to be breezy. Again, for those who have sensed the thermal condition as 'warm' or 'hot', they prefer the condition to be cooler and similarly, the humidity level to be drier for those who have experienced the condition to be 'very humid'.

A similar result is obtained in Figure 5.7 which shows the percentage of votes of the variables in relation to the thermal comfort perception during the evening time. In Figure 5.7, all of the respondents who feel 'too warm' experience the thermal sensation to be ‘warm’. However, with the ‘humid’ and ‘very humid’ condition and little air movement, the thermal comfort condition cannot be tolerable. It is also



Note: Seven levels of Bedford scale are used for the thermal comfort level but only the three levels are shown because no vote is received for comfortably cool, too cool, much too cool and much too warm.
ASHRAE 7-point scale is used for the thermal sensation but only three points which are neutral, warm and hot are shown because other points do not receive any vote for the period of time investigated.

Figure 5. 7 - The percentage of votes on the thermal sensation, relative humidity, wind condition and preferences vote in relation with the comfort vote based on the Bedford scale at Al Azim Mosque, Melaka during the evening prayer time.

shown here that when the air temperature and the humidity level are considered ‘neutral’ and the wind condition is ‘breezy’, the majority of the participants will considers this condition as ‘comfortably warm’. The major difference among Figure 5..5, 5.6 and 5.7 is that the survey taken for both Figure 5.5 and 5.6 is during the daytime, whereas the survey for figure 5.7 is taken during the evening time. With the outside temperature lower than the indoor air temperature during the night time, there is a possibility that this condition may have influenced the result. The reduction of the outside temperature creates smaller differences between the inside and outside air temperature and this condition may have reduced the movement of air through the temperature difference between the inside and outside. Less air movement means less humidity is transferred from the inside to the outside and this may cause the effect of stuffiness.

Based on the analysis conducted, it can be summarized that the air temperature and wind movement are important factors in influencing the thermal comfort condition for the countries in the hot and humid region such as Malaysia. The relative humidity too, plays a significant role depending on the condition of the previous variables. The high temperature throughout the day, to a certain extent is tolerable due to the process of acclimatization. It is also undisputable that the high temperature throughout the day triggers the body to produce sweat in reaction to cooling it down naturally. Whenever this happens, the presence of the humidity in the air and the air movement plays enormous role in influencing the thermal comfort condition. For examples, with the abundance of humidity in the air, the sweat produced is incapable of reducing the heat through the process of evaporation which is hampered by the high content of humidity in the air. It is also evidenced that when the air temperature falls, the relative humidity increases. This may explain why many participants feel more uncomfortable during the night time compared to the day time even though the air temperature is the same.

The presence of air movement also helps to improve the thermal comfort condition. It assists the cooling down process by transferring the humidity from the body to the air which involves energy exchanges. For the country that has high air temperature and relatively high humidity content, the breezy air condition is favourable. Continuous and strong air movement is required to help to cooling down the body.

5.4.3 Application of ASHRAE 7 thermal Sensation Scale and Bedford scale in predicting acceptable air temperature

During this study, the inspection and comparison among these figures also reveals the discrepancies between the vote based on the ASHRAE 7 thermal sensation scale and Bedford scale. Both of these scales have seven levels of thermal sensation scale but specified and valued differently. It has been agreed among the researchers that the acceptable thermal comfort condition is ranged from 'cool' (-1) to 'warm' (+1) under the ASHRAE scale and from 'comfortably cool' (3) to 'comfortably warm' (5) under the Bedford scale. Figure 5.5, 5.6 and 5.7 show that the majority of the participants who voted ' too warm' under the Bedford scale consider this condition as 'warm' under the ASHRAE 7 thermal sensation scale which is at the different level of thermal comfort sensation scale. The inclusion of word 'comfortable' in the Bedford scale may have distinguished between the 'warm' and 'comfortably warm' condition. With the revealed discrepancies, it can be assumed that the term 'warm' may not be necessarily considered acceptable for this hot and humid climate. In a country with an excess of heat throughout the day, the desirable thermal condition is 'cool' rather than 'warm'. The word 'warm' is normally referring to the heat gain which is not appreciated in this climate. This perception may have been the cause of the difference between the previous votes based on the ASHRAE scale and Bedford scale.

As been agreed among the researchers that the acceptable comfort air temperature ranges from -1 to +1 under both scales, this may not be the case for the building in this climate. With this finding, it can be predicted that by using the agreed range to predict the thermally comfortable air temperature, it may lead to a misleading figure. Therefore, based on the observation, it is suggested that the maximum tolerable air temperature based on the ASHRAE scale should be at zero (0) level which is also called 'neutral' temperature.

Further analysis on the votes is conducted to reveal the highest tolerable air temperature and the relationships of the thermal comfort level with the air

Ambient Air Temperature	slightly cool(-1)	neutral (0)	slightly warm (1)	warm (2)	comfortably cool(2)	comfortable (0)	comfortably warm (1)	too warm (2)	much too warm	TSV scale	Comfort vote (CV)
28.7	0	2	0	0	0	0	2	0	0	0.00	0.12
29.1	0	12	5	0	0	3	11	3	0	0.29	1.00
29.4	0	16	12	0	0	8	11	9	0	0.43	1.04
29.8	0	4	22	0	0	1	11	14	0	0.85	1.50
30.2	0	0	18	1	0	0	0	19	0	1.05	2.00
30.6	0	0	11	0	0	0	3	8	0	1.00	1.45
31	0	0	3	2	0	0	2	3	0	1.40	1.20
31.4	0	0	1	5	0	0	0	6	0	1.83	2.00
31.8	0	0	0	2	0	0	0	2	0	2.00	2.00
32.2	0	0	0	3	0	0	0	3	0	2.00	2.00

Table 5. 3 - The average value of scale based on the ASHRAE and Bedford scale voted by the participants

temperature. The analysis is based on the ASHRAE 7 point thermal sensation scale (TSV) and the Bedford scale (CV). Table 5.3 shows the votes received on the recorded air temperature. In Table 5.3, the votes received are totalled and averaged according the ASHRAE scale (TSV scale) and Bedford scale (Comfort vote (CV)). For the purpose of comparison, the same value according to the level of sensation

has been given to the Bedford scale. Comparatively, from the result, it shows that the votes under the Bedford scale are relatively higher than the average vote under the ASHRAE scale.

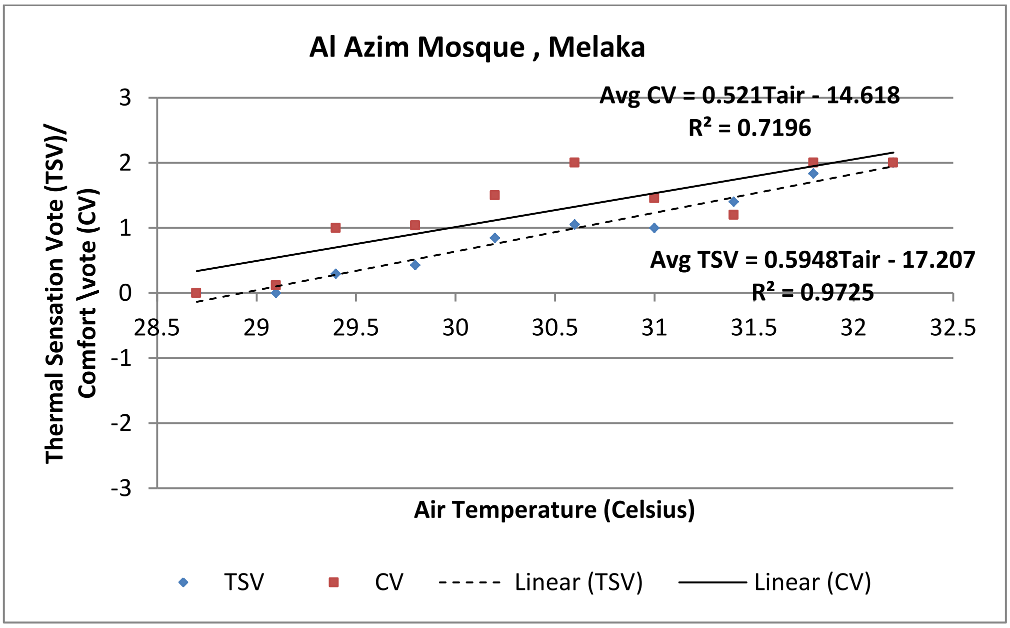


Figure 5. 8 - Linear regression of the thermal sensation/comfort vote vs. air temperature at Al Azim Mosque, Melaka

Figure 5.5 shows the correlation between the air temperature and the vote received based on TSV and CV. The TSV shows better correlation with the air temperature with the R^2 value of 0.9725. Based on the TSV, the equation of the regression line is:

$$Avg\ TSV = 0.5948T_{air} - 17.207$$

With the equation, it can be determined that the upper limit of tolerable air temperature (when TSV = 1) is **30.3** degree Celsius. Similarly, the regression line from the CV vote produces:

$$CV = 0.521\ T_{air} – 14.62$$

Using this equation, the upper limit of tolerable air temperature (when Cv = 1) is **29.4** degree Celsius which is 1 degree Celsius lower from the TSV equation.

The stronger correlation with TSV may have resulted from the precise description of the thermal sensation based on the ASHRAE scale. Both Bedford and ASHRAE scale are basically identical. The only difference is the addition of word 'comfortable' to the thermal sensation scale. As discussed earlier, the term 'comfortable' is more related to the psychological aspect rather than the thermal sensation itself. Therefore, the outcome of the votes based on the Bedford scale may have been influenced by other psychological factors. Due to this reason, it is more precise to predict the thermal comfort condition based on thermal sensation using the ASHRAE scale since it has stronger correlation and the thermal sensation is clearly described. However based on the earlier finding, the range of the acceptable thermal comfort from -1 to +1 may not be appropriate to be used for this climate since the warm condition is interpreted as an excess of heat. Therefore, in the case of the naturally ventilated building in the tropics, the maximum tolerable air temperature should be based on the neutral temperature (when TSV =0). In this case, the neutral temperature is 23.9 degree Celsius.

5.5 CASE STUDY 2 : JAMEK MOSQUE, SEREMBAN, MALAYSIA

Jamek Mosque, Seremban is a community mosque that can accommodate up to 1000 people at a time. It is one of the oldest mosques that are still being used. It has traditional characteristics with the main feature of the three tiered pitched roof. Compared to the Al Azim mosque, the Jamek Mosque can be considered as a smaller version of the Al Azim Mosque. A total of 131 respondents have participated in the survey conducted in the Jamek Mosque, Seremban. Out of 131 respondents, 51 of them participate during the noon time, 31 participants during the afternoon and 49 during the evening time (Table 5.4).

5.5.1 Thermal comfort perception

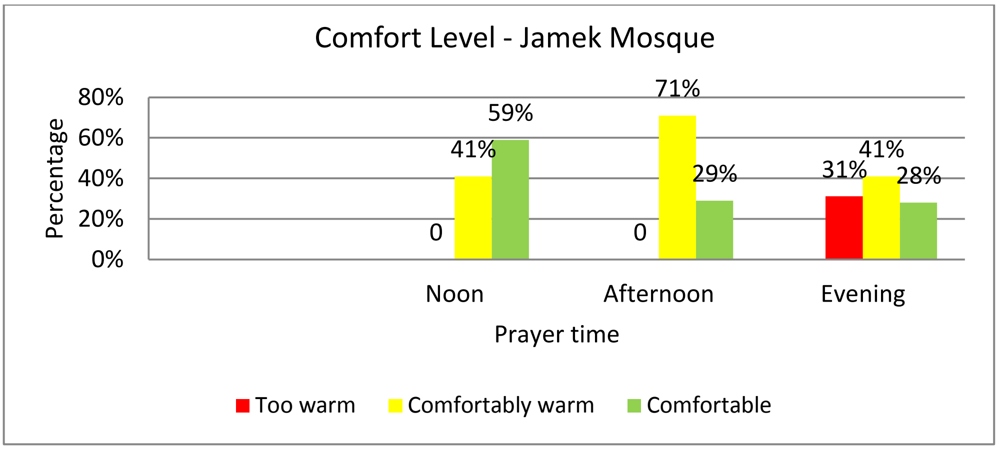
Table 5.4 shows the results of the votes received on the thermal comfort

Time		Too warm	Comfortably warm	Comfortable	No. Of Participant	Avg. Temp.	Max. T	Min T	Avg RH	Max RH	Min RH
Noon		0	41%	59%	51	29	31.4	26.9	74.8	85.1	68
Afternoon		0	71%	29%	31	29.2	31.4	26.9	75.7	89.5	64.5
Evening		31%	41%	28%	49	28.9	32.2	26.5	81.5	95.5	70.3
Avg To		29.1	28.1	28.6							
AvgTi		28.9	28.4	28.2							
Max To		32.2	31.8	29.8							
Max Ti		32.2	31.8	29.8							
Min To		25.8	25.4	27.2							
Min Ti		25.1	25.4	26.5							
avg RH		81.2	82.1	77.5							
Max		98.5	100	93							
Min		70.3	64.5	68.8							

Table 5. 4 - The average, min and max for the air temperature and relative humidity according to the thermal comfort vote and the periods of prayer time at Sikamat Mosque Seremban.

perception with the average value of the air temperature and relative humidity in relation to the periods of time and comfort vote. Based on the votes received as shown in the Table 5.4, the participants express that they feel acceptably comfortable at all time during the noon and afternoon prayer time. Only 31% feel slightly uncomfortable with the ‘too warm’ condition during the evening prayer time.

The air temperature has always been considered the main variable affecting the level of comfort of a space. Based on the recorded values, the average air temperature during the afternoon time is 29.2 degree Celsius which is slightly higher than the noon time which is 29.0 degree Celsius. The average air temperature for the evening time is slightly lower at 28.9 degree Celsius. It is clear that there is a little difference among them which is about 0.3 degree Celsius. Such a little change normally has insignificant effect on the thermal comfort condition. A relatively bigger difference is essential to influence the changes in the thermal comfort condition and this is evidenced only in the relative humidity. The average relative humidity recorded is 74.8% for the noon, 75.7% for the afternoon and 81.5% for the evening



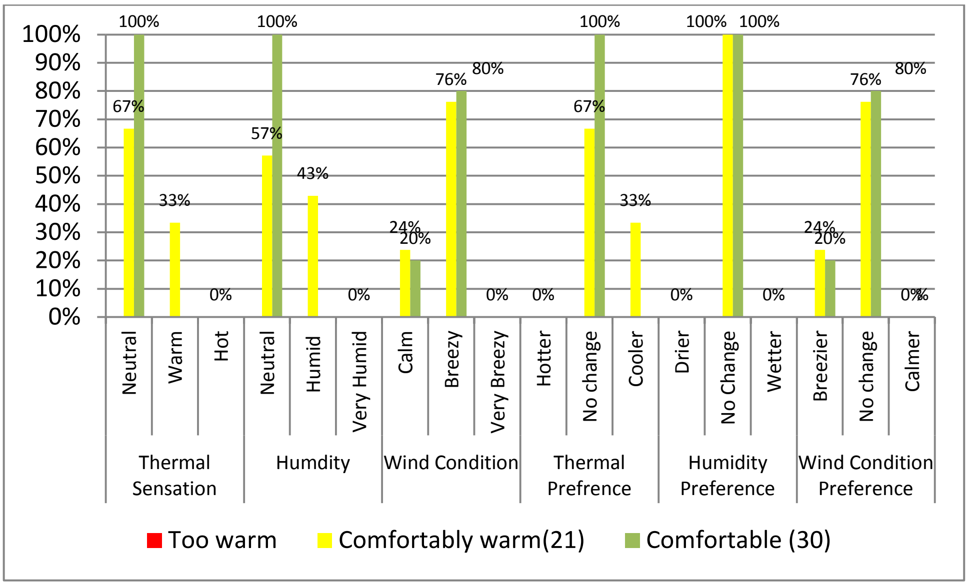
Note: Seven levels of Bedford scale are used for the thermal comfort level but only the three levels are shown because no vote is received for comfortably cool, too cool, much too cool and much too warm.

Figure 5. 9 – The percentage of thermal comfort votes based on the Bedford scale according to the prayer times at Jamek Mosque, Seremban.

time. The ‘slightly uncomfortable’ votes during the evening time may have been influenced by the increase in the relative humidity as it shows a relatively big jump during the period of time. Figure 5.9 shows the thermal comfort perception votes in relation to the period of time. It is shown that the ‘slightly uncomfortable’ condition is only experienced during the evening time whereas during the noon and afternoon time, the thermal comfort condition is considered acceptable. Based on the average air temperature, it is obvious that the air temperature does not cause the thermal discomfort because the average temperature recorded during this time is the lowest among the three periods of time. As noted earlier, the substantial change occurs in the relative humidity which is 81.5%. Being one of the main problems in thermal comfort for tropical countries with the hot and humid climate, it is possible that the relative humidity can cause the thermal discomfort. Analysing the coexistence of other variables in relation to the thermal comfort perception reveals the importance of each variable to the condition of thermal comfort level.

5.5.2 Affecting factors and preferences on thermal comfort

The following figures (Figure 5.10, 5.11 and 5.12) show the distribution of the votes on thermal comfort perception in relation to the variables investigated such as thermal sensation, humidity, wind condition and the preferences according to the periods of investigation. The cross examination can justify the influence of the variables in affecting the thermal comfort condition. Figure 5.10 represents the votes received during the noon time. There are only two thermal comfort conditions voted which are ‘comfortably warm’ and ‘comfortable’. By cross checking between the votes received by the variables and the thermal comfort perception, the investigation



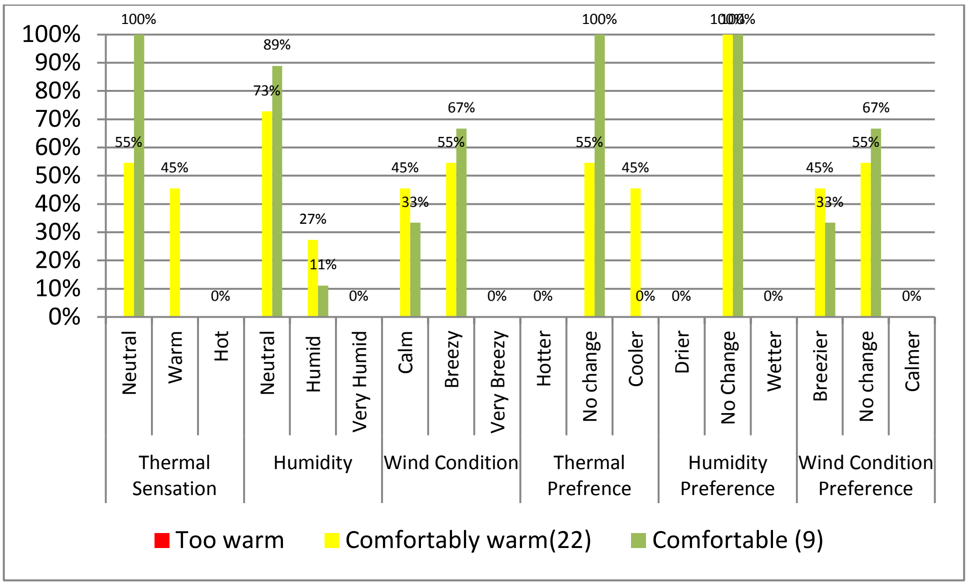
Note: Seven levels of Bedford scale are used for the thermal comfort level but only the three levels are shown because no vote is received for comfortably cool, too cool, much too cool and much too warm.
ASHRAE 7-point scale is used for the thermal sensation but only three points which are neutral, warm and hot are shown because other points do not receive any vote for the period of time investigated.

Figure 5. 10 - The percentage of votes on the thermal sensation, relative humidity, wind condition and preferences vote in relation with the comfort vote based on the Bedford scale at Jamek Mosque, Seremban during the noon prayer time.

reveals the variables that are associated with and affected the thermal comfort perception. For examples, the ‘comfortable’ perception is one of the conditions voted which is considered the ideal condition agreed by many researchers. Under this condition, it is clearly represented by the votes received that the thermal perception experienced by the respondents is ‘neutral’ (100%) with the level of humidity at ‘neutral’ (100%). The wind condition is mostly ‘breezy’ (80%) but some of them also experience ‘calm’ (20%) air condition. It is assumed that when the combination of variables present at this condition, the thermal comfort perception is considered comfortable. Another thermal comfort perception voted is ‘comfortably warm’. Under this condition, the thermal perception experienced is either ‘neutral’ (67%) or ‘warm’(33%) with the humidity level felt either ‘neutral’ (57%) or ‘humid’ (43%). Along with this, it is also recorded that the air condition is mostly breezy (76%) and only 24% of the respondents experience the air to be ‘calm’. There is no clear indication on the coexistence of the variables that may have influenced the thermal comfort vote. Based on the votes, there are eight possibilities of the combination of variables that may lead to the ‘comfortably warm’ condition. However, by eliminating the possibilities of the combination that may lead to a different thermal comfort perception, the acceptable combination can be produced. Based on Figure 5.10, the majority votes under ‘comfortably warm’ condition are the same with the votes under ‘comfortable’ category. It is clear that when the combination of the variables present under this situation, the predicted thermal comfort perception is ‘comfortable’. Therefore, by eliminating the majority votes that match the ‘comfortable’ votes, a clear combination of variables that may lead to ‘comfortably warm’ can be predicted. In this case, the combination is ‘warm’ thermal sensation with ‘calm’ air and ‘humid’. Only the majority votes are chosen to be eliminated since the chances to have the combination of the variables that matched is bigger.

The preference votes also emphasize the relevance of this elimination method. For examples, the respondents who have voted ‘neutral’ for the variables prefer the condition not to be changed. However, for those who feel warm, they prefer to have a cooler air temperature and similarly, for those who have experienced calm air movement earlier, prefer the wind condition to be breezier. The level humidity on the contrary, receives 'unchanged' vote even though there are cases where the level of humidity is considered high.

Figure 5.11 represents the votes received during the afternoon time. Similar to

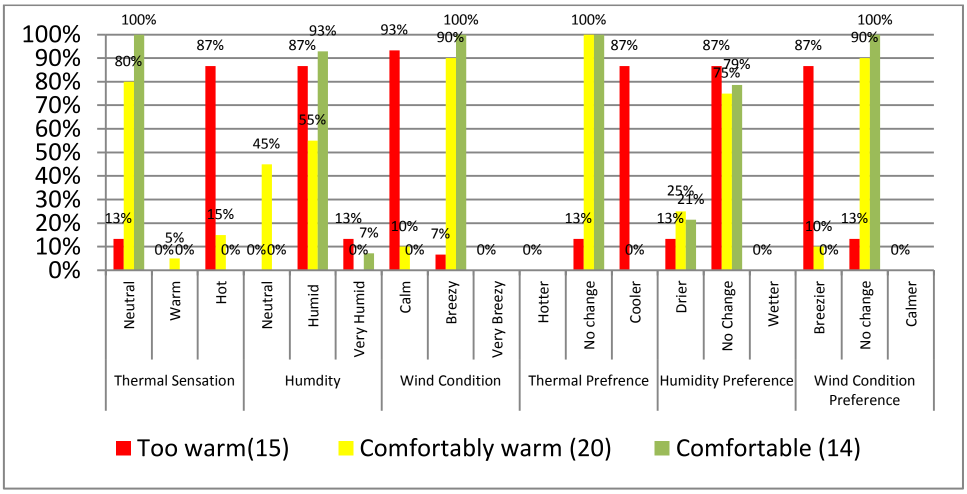


Note: Seven levels of Bedford scale are used for the thermal comfort level but only the three levels are shown because no vote is received for comfortably cool, too cool, much too cool and much too warm.
ASHRAE 7-point scale is used for the thermal sensation but only three points which are neutral, warm and hot are shown because other points do not receive any vote for the period of time investigated.

Figure 5. 11 - The percentage of votes on the thermal sensation, relative humidity, wind condition and preferences vote in relation with the comfort vote based on the Bedford scale at Jamek Mosque, Seremban during the afternoon prayer time.

Figure 5.10, only two thermal comfort conditions, which are 'comfortably warm' and 'comfortable', are voted during this time. Again, the 'comfortably warm' condition is associated with either 'neutral'(55%) or 'warm'(45%) sensation of thermal perception accompanied with the 'neutral' (73%) or 'humid'(27%) level of humidity. The wind condition experienced at this thermal comfort perceived is either 'breezy' (55%) or 'calm' (45%). There is no clear indication for the coexistence of the variables for the ‘comfortably warm’ condition. A much clearer indication can be seen under the ‘comfortable’ vote. It is shown that the ‘comfortable’ thermal comfort perception is associated with the ‘neutral’ level of thermal sensation and ‘neutral’ level of humidity with ‘breezy’ air condition. In this case, it is also evidenced that the majority votes of ‘comfortably warm’ is the same with the majority votes of ‘comfortable’ condition. Since the presence of the variables voted by the majority of the respondents for the ‘comfortably warm’ is the same with the ‘comfortable’ vote, it can be assumed that the predicted thermal comfort perception should be the same. Based on this assumption, the process of elimination can be conducted to predict the combination of the condition for the variables that mostly lead to ‘comfortably warm’ condition. For this period of time, after the eliminating the majority votes for the variables of the ‘comfortably warm’, the only condition that is associated with the ‘comfortably warm’ is the ‘warm’ thermal sensation with ‘humid’ and ‘calm’ air. The differences between the two thermal comfort perceptions are now can be distinguished. It is obvious that the changes in the thermal sensation and humidity level influence the thermal comfort perception. This is evidenced in the above figure and Figure 5.10 where the changes from the ‘warm’ thermal sensation and ‘humid’ condition under the ‘comfortably warm‘ to the ‘neutral’ thermal sensation and ‘neutral’ humidity level can improve the thermal comfort perception to ‘comfortable’. The help of air movement in improving the thermal comfort sensation is also evidenced from these figures. The preference votes also suggest that 'breezier' condition is preferred by those who experienced calm air and no changed is needed by those who voted the existing condition to be breezy. It is also suggested by the votes that the 'neutral' thermal sensation is more favourable since those who voted the thermal sensation as 'warm' prefer the condition to be cooler. Similar to the previous case, the level of humidity is voted to remain unchanged.

Figure 5.12 shows the votes received for the evening period. During this



Note: Seven levels of Bedford scale are used for the thermal comfort level but only the three levels are shown because no vote is received for comfortably cool, too cool, much too cool and much too warm.
ASHRAE 7-point scale is used for the thermal sensation but only three points which are neutral, warm and hot are shown because other do not receive any vote for the period of time investigated.

Figure 5. 12 - The percentage of votes on the thermal sensation, relative humidity, wind condition and preferences vote in relation with the comfort vote based on the Bedford scale at Jamek Mosque, Seremban during the evening prayer time.

period of time, three (3) thermal comfort conditions have been experienced. They are 'too warm', 'comfortably warm' and 'comfortable'. In this figure, it shows that the 'too warm' condition is associated with the 'hot' (87%) and 'neutral' (13%) thermal sensation with the 'humid' (87%) and 'very humid' (13%) condition as well as 'calm' (93%) and 'breezy' (3%) air movement. By considering the majority votes only, it can be determined that the ‘too warm’ condition is mostly associated with ‘hot’ thermal sensation with ‘humid’ and ‘calm’ air. It is also indicated that there is a match between the combined majority votes for the ‘comfortable’ and ‘comfortably warm’ votes. Assuming that when the same conditions of the variables present the same thermal comfort perception is expected to be the same. Between the two conditions, the choice that has higher percentage will be selected as the expected condition. In this case, the ‘comfortable’ thermal comfort perception is selected since the condition has higher percentage. By eliminating the votes of ‘comfortably warm’ that has been identified to have the same conditions with the ‘comfortable’ situation, the ‘comfortably warm’ condition is now associated with either the ‘warm or ‘hot’ thermal sensation with ‘neutral’ level of humidity and ‘calm’ air. The ‘too warm’ thermal comfort perception is clearly associated with the ‘hot’ thermal sensation with ‘humid’ and ‘calm’ air condition. The change from ‘comfortably warm’ to ‘too warm’ situation is therefore predicted as a result of the change in the thermal sensation from ‘warm’ to ‘hot’ and humidity level from ‘neutral’ to ‘humid’. The obvious difference between the ‘comfortably warm’ and ‘comfortable’ situation can be evidenced in the wind condition. The ‘comfortable’ condition has breezy wind condition whereas the wind condition for the ‘comfortably warm’ condition is ‘calm’ which means relatively little wind movement can be sensed.

Looking at the results obtained from three periods of time, it can be evidenced that the thermal sensation or air temperature has always affected the thermal comfort perception. In many cases, the ‘neutral’ level of thermal sensation has been seen as the preferred condition. The 'warm' thermal sensation may sometimes be accepted however it depends on the condition of other variables. Without the air movement, this thermal sensation can become unacceptable. It has also been evidenced in the survey that the condition of air movement plays an important role in affecting the thermal comfort perception. In many instances, the preferred wind condition is the 'breezy' condition regardless of the thermal comfort perception. The humidity level may have its own role in affecting the thermal comfort perception, however based on the preference vote most of the respondents choose the condition not to be changed. One of the reasons is that the human body is not sensitive to the level of humidity in the air. For the effect of the humidity to be sensed, the humidity must be at the extreme condition such as too dry (below 40%) or too humid (above 80%). In many cases, the relative humidity is at the acceptable range.

5.5.3 Application of ASHRAE 7 thermal Sensation Scale and Bedford scale in predicting acceptable air temperature

		ASHRAE Thermal sensation scale					**Bedford scale**				
Nvotes	Tind	Slightly cool	neutral	slightly warm	warm	**Tsensation**	comfortably cool	comfortable	comfortably warm	too warm	**Cvote**
11	25.4	8	3	0	0	**-0.7**	7	4	0	0	**-0.6**
7	25.8	1	6	0	0	**-0.1**	1	6	0	0	**-0.1**
4	26.1	0	4	0	0	**0.0**	0	0	4	0	**1.0**
6	26.5	0	6	0	0	**0.0**	0	2	2	2	**1.0**
9	26.9	0	9	0	0	**0.0**	0	5	4	0	**0.4**
10	27.2	0	10	0	0	**0.0**	0	4	6	0	**0.6**
12	27.6	0	11	1	0	**0.1**	0	6	6	0	**0.5**
17	27.9	0	17	0	0	**0.0**	0	11	6	0	**0.4**
6	28.3	0	6	0	0	**0.0**	0	3	3	0	**0.5**
9	28.7	0	9	0	0	**0.0**	0	5	4	0	**0.4**
14	29.1	0	14	0	0	**0.0**	0	8	6	0	**0.4**
6	29.4	0	6	0	0	**0.0**	0	5	1	0	**0.2**
3	29.8	0	3	0	0	**0.0**	0	2	1	0	**0.3**
6	30.2	0	3	3	0	**0.5**	0	0	6	0	**1.0**
6	30.6	0	3	3	0	**0.5**	0	6	0	0	**0.0**
7	31	0	0	7	0	**1.0**	0	7	0	0	**0.0**
5	31.4	0	0	3	2	**1.4**	0	0	3	2	**1.4**
8	31.8	0	0	0	8	**2.0**	0	0	3	5	**1.6**
6	32.2	0	0	0	6	**2.0**	0	0	0	6	**2.0**

Table 5. 5 - The average value of scale based on the ASHRAE and Bedford scale voted by the participants

As explained earlier, the ASHRAE scale is more related to the thermal sensation rather than the thermal comfort condition and the Bedford scale is more towards the thermal comfort level since the inclusion of the word ‘comfortable’ in the evaluative scale. Based on the figures, it can be evidenced that when the air temperature is below the neutral level both of the scales prediction is coherent. The same coherency is also evidenced when the temperature is above the scale of 1. The inconsistency occurs when the temperature is between the scale of 0 and 1. The Bedford scale, in many cases, shows a higher scale compared to ASHRAE scale within this range. The logical reason is that the Bedford scale is more related to the thermal comfort level rather than just the thermal sensation itself. Thermal comfort is dependent on many variables depending on the climate zone. For the tropical climate, the air movement beside the air temperature is one of the major influencing factors for the thermal comfort. The humidity content in the air is equally important but its effect is dependent on the air temperature and wind condition. On the other hand, the ASHRAE scale is directly related to thermal sensation which can easily be sensed by the human body. Due to this, the inconsistency occurs between the two scales.

Based on the votes, a linear regression is constructed for the two scales. Figure 5.13 shows the regression line for the thermal sensation/comfort vote against the air temperature. Due to the inconsistency of the evaluated scale to the air temperature, the comfort vote has R^2 = 0.2688 with the equation of:

$$C_{vote} = 0.1565\ T_{air} - 3.9173$$

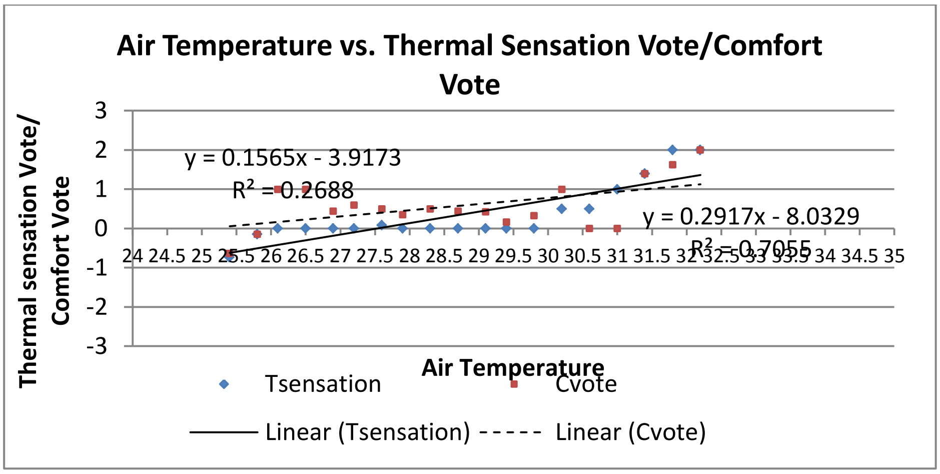


Figure 5. 13 - Linear regression of the thermal sensation/comfort vote vs. air temperature at Jamek Mosque, Seremban

The thermal sensation vote based on the ASHRAE scale is more consistent and accurate in relation to the air temperature. The linear regression produces an equation :

$$T_{sensation} = 0.2917\ T_{air} - 8.0329 \text{ with } R^2 = 0.7055$$

With this equation, the 'neutral' air temperature is predicted at 25.0^0 Celsius. The maximum tolerable air temperature that has been agreed by the researchers (when $T_{sensation} = 1$) is predicted at 31.0^0 Celsius.

5.6 CASE STUDY 3: MASJID QARIAH SIKAMAT, SEREMBAN, MALAYSIA

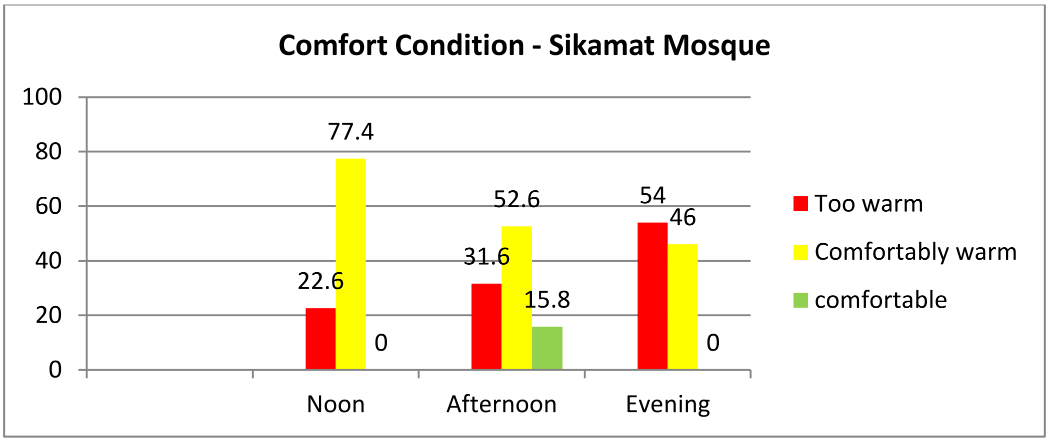
Masjid Qariah Seremban was completed in 2004 to cater for the population of the surrounding areas. It is a complex which consists of the main building which is the prayer hall and two supporting wings to house a library, a counseling centre, classrooms and offices.

The prayer hall of the mosque is square in plan and it can accommodate up to 2500 people at one time. It has a mezzanine level which covers one third of the floor area. Around the prayer hall, a 20-foot-verandah is provided to support the overflow of the occupants especially during the Friday prayer. From the outside, the prayer hall is marked by a majestic dome that hovers over the prayer hall. Locating the mosque will not be a problem because of the prominent dome structure and furthermore accompanied by the tall minaret which is among the main elements in the mosque design.

Between the external and the internal, the veranda, besides providing additional spaces for praying, acts as a transitional space. The separation between the external world and the internal space of the mosque which is considered sacred is required in any mosque.

5.6.1 Thermal comfort perception

Figure 5.14 shows the votes collected during the three periods of the praying times which are noon, afternoon and evening. A total of 165 participants have responded to the questionnaire given which is about the thermal sensation they experienced. 53 respondents participate during the noon time, 38 of them during the afternoon and the rest of the respondents participate during the evening time. Based on the votes received, it shows that most participants feel either ‘comfortably warm’ or ‘too warm’ during the three periods of the praying time for this mosque. Only



Note: Seven levels of Bedford scale are used for the thermal comfort level but only the three levels are shown because no vote is received for comfortably cool, too cool, much too cool and much too warm.

Figure 5. 14 - The percentage of thermal comfort votes based on the Bedford scale according to the prayer times at Sikamat Mosque, Seremban

15.8% of the participants from the afternoon praying time feel comfortable during that time. The figure also shows that more participants (54%) feel 'too warm' during the evening praying time compared to the other two praying times (31.6% for the afternoon and 22.6% for the noon).

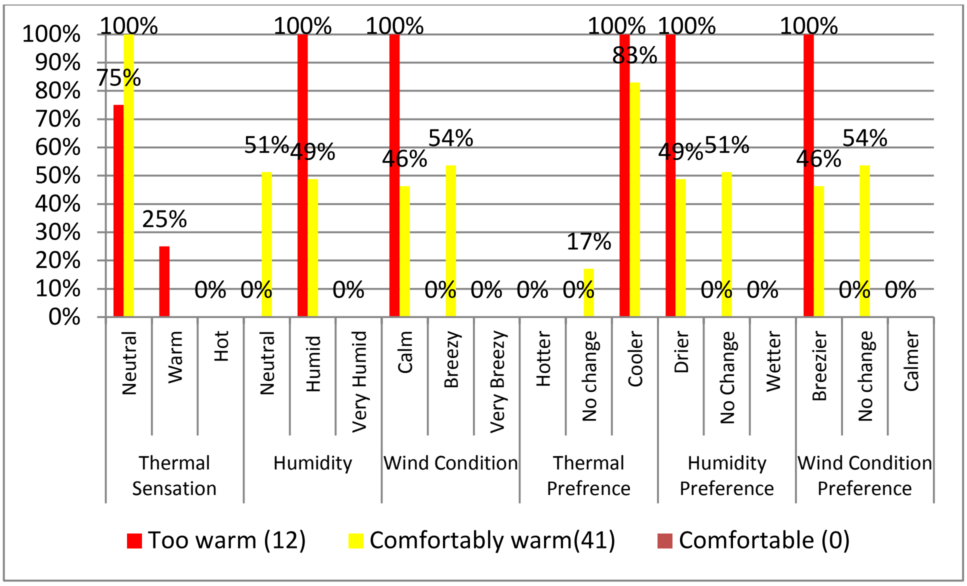
Time		Too warm	Comfortably warm	comfortable	No. Of Participant	Avg. Temp.	Max. T	Min T	Avg RH	Max RH	Min RH
Noon		22.6	77.4	0	53	28.4	30.2	26.1	73.3	83.5	63.9
Afternoon		31.6	52.6	15.8	38	29.3	31.4	26.5	74.4	85.6	64
Evening		54	46	0	74	29.4	32.2	26.5	75.9	88.1	58.7
Avg To		29.4	28.5	30.4							
AvgTi		30	28.3	30.7							
avg RH		73	76.3	67.1							
Max To		31.4	31.8	31							
Max Ti		32.2	31.8	31.4							
Max RH		88.1	85.9	70.6							
Min To		25.8	26.1	29.8							
Min Ti		27.6	26.1	30.2							
Min RH		58.7	63.4	64							

Table 5. 6 - The average, min and max for the air temperature and relative humidity according to the thermal comfort vote and the periods of prayer time at Sikamat Mosque Seremban.

Table 5.6 shows the average air temperature and relative humidity according to the period of praying times and thermal sensation experienced. The average air temperature during the three periods of praying time shows small differences among them. The average air temperature is 28.4 during the noon, 29.3 during the evening and 29.4 during the evening. The average relative humidity during these periods of time also shows small differences between 1.1% and 2.5%. The small differences in relative humidity and air temperature are insignificant to determine the influential factors affecting the difference in the thermal sensation. Looking at the 'comfortable' situation, it is shown that the average temperature for this situation is 30.7 degree Celsius with the average relative humidity of 67.1%. The 'too warm' situation records the average air temperature of 30.0 degree Celsius, which is lower than the 'comfortable' situation, with the average relative humidity of 73% which is slightly higher than the average relative humidity of the 'comfortable' situation. With these recorded values, it can be interpreted that the higher relative humidity may have affected the participants to feel 'too warm'. This assumption is also supported by the data recorded for the 'comfortably warm' situation. The average air temperature is 28.3 degree Celsius with the average relative humidity of 76.3%. The average air temperature is lower but the relative humidity is higher than the average air temperature recorded for the 'comfortable' situation. Even though, the air temperature recorded is lower, the respondents felt the condition is warmer and there is a possibility that the higher relative humidity affects the thermal comfort condition. Looking at the presence of other variables that are important in affecting thermal comfort condition helps to justify the assumptions.

5.6.2 Affecting factors and preferences on thermal comfort

A cross checking on the votes received on the variables in relation to the thermal comfort condition reveals the variables affecting the result of the level on thermal comfort condition. Figure 5.15, 5.16, and 5.17 show the charts of the votes received on the variables investigated during the noon, afternoon and evening time

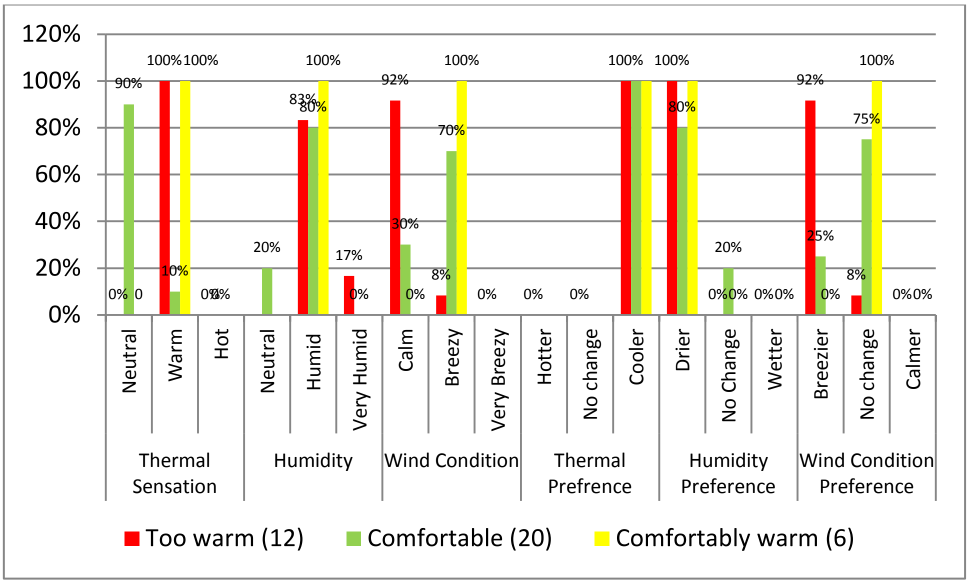


Note: Seven levels of Bedford scale are used for the thermal comfort level but only the three levels are shown because no vote is received for comfortably cool, too cool, much too cool and much too warm.
ASHRAE 7-point scale is used for the thermal sensation but only three points which are neutral, warm and hot are shown because other points do not receive any vote for the period of time investigated.

Figure 5. 15 - The percentage of votes on the thermal sensation, relative humidity, wind condition and preferences vote in relation with the comfort vote based on the Bedford scale at Sikamat Mosque, Seremban during the noon prayer time.

respectively. During the noon time, only two conditions of thermal comfort situations which are ‘comfortably warm’ and ‘too warm’. Based on the votes, all of the respondents who felt ‘comfortably warm’ sense the thermal condition as ‘neutral’. Along with this, 51% of them feel that the humidity level is ‘neutral’ and 49% of them consider it as ‘humid’. At the same time, 54% of them consider the wind condition as ‘breezy’ and 46% experienced ‘calm’ air. It is noted that the differences between the ‘neutral’/‘humid’ and ‘calm’ / ‘breezy’ are relatively small, therefore, it is difficult to determine the variables that are more influential in affecting the thermal comfort condition based on the ‘comfortably warm’ category. However, based on the ‘too warm’ category, it can be concluded that all of them who feel thermally uncomfortable are due to the ‘calm’ and ‘humid’ condition since the majority of the respondents consider the thermal sensation as ‘neutral’ which is the same with the ‘comfortably warm’ category. This is also supported by the preferences vote by them which they choose the humidity level to be ‘drier’ and the wind condition to be ‘breezier’. Despite the fact that the majority of them consider the thermal sensation as ‘neutral’, they still prefer the condition to be ‘cooler’.

The following figure (Figure 5.16) shows the results for the afternoon time. Three categories of thermal comfort conditions which are ‘too warm’, ‘comfortably warm’ and ‘neutral’ have been recorded during this time. As in other earlier cases, the ‘neutral’ thermal sensation is associated with ‘comfortable’ (90%) thermal comfort perception. At the same time, the majority of the respondents who feel ‘comfortable’ also experienced the air to be ‘humid’ (80%) and ‘breezy’ (70%). There is 30% of the respondents who preferred the condition to be breezier and this is resulted from the 30% of the respondents who feel the air as ‘calm’. This indicates that even though the air temperature is felt to be neutral, the movement of air is still favourable in providing thermally comfortable environment.

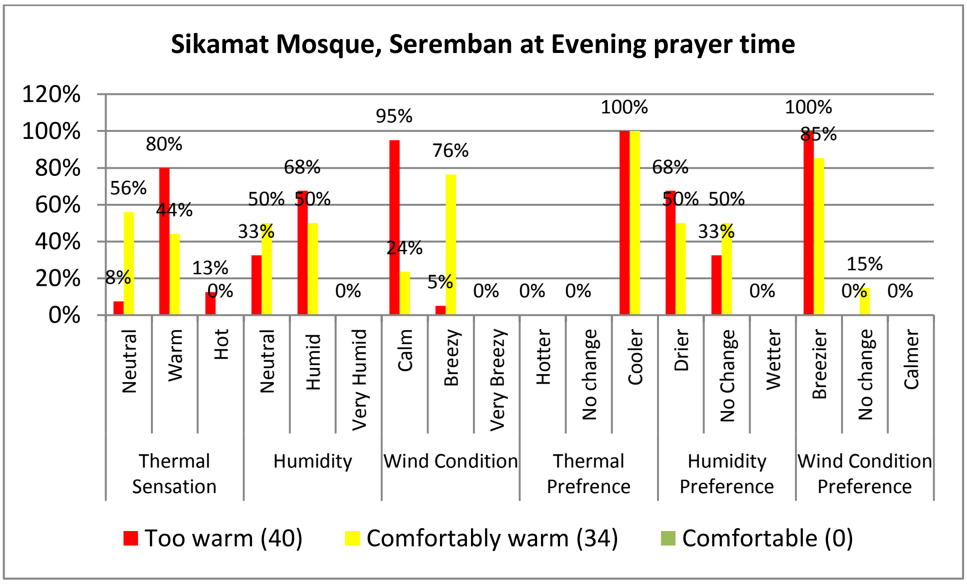


Note: Seven levels of Bedford scale are used for the thermal comfort level but only the three levels are shown because no vote is received for comfortably cool, too cool, much too cool and much too warm.
ASHRAE 7-point scale is used for the thermal sensation but only three points which are neutral, warm and hot are shown because other points do not receive any vote for the period of time investigated.

Figure 5. 16 - The percentage of votes on the thermal sensation, relative humidity, wind condition and preferences vote in relation with the comfort vote based on the Bedford scale at Sikamat Mosque, Seremban during the afternoon prayer time.

The 'warm' thermal sensation is normally related to the 'comfortably warm' in thermal comfort perception. Depending on the existence of other variables such as the humidity and the wind condition, the thermal comfort perception can vary. For examples, in this case, the 'warm' thermal perception is related to both 'comfortably warm' and 'too warm' condition. Both conditions are also associated with 'humid' condition of air but differed in the condition of wind. The 'comfortably warm' condition is associated with the breezy wind condition whereas the 'too warm' condition is related with the 'calm' air. Again, the importance of the wind movement is evidenced in affecting the thermal comfort. The presence of wind movement in this case helps to improve the thermal comfort perception. This is also supported by the preference votes that indicate the higher preference towards the breezier wind condition.

The influence of wind movement to the thermal comfort perception is also evidenced during the evening prayer time as indicated in Figure 5.17. There are only two thermal comfort perceptions which are ‘comfortably warm’ and ‘too warm’ recorded during this time. The ‘comfortably warm’ condition is better than ‘too warm’



Note: Seven levels of Bedford scale are used for the thermal comfort level but only the three levels are shown because no vote is received for comfortably cool, too cool, much too cool and much too warm.
ASHRAE 7-point scale is used for the thermal sensation but only three points which are neutral, warm and hot are shown because other points do not receive any vote for the period of time investigated.

Figure 5. 17 - The percentage of votes on the thermal sensation, relative humidity, wind condition and preferences vote in relation with the comfort vote based on the Bedford scale at Sikamat Mosque, Seremban during the evening prayer time.

condition. Both of them are associated with the similar condition of the two variables which are the humidity and thermal sensation. The significant difference can be seen in the wind condition. The ‘comfortably warm’ condition is mostly associated with the breezy wind condition whereas the ‘too warm’ condition is linked to the calm air. In this case, it is also noted that the 'neutral' thermal sensation is linked with the 'comfortably warm' condition and the 'warm' thermal sensation is linked with the 'too warm' thermal perception. The inconsistencies between the thermal sensation vote and the thermal perception vote suggest that the thermal sensation needs to be evaluated together with other influential variables in determining the thermal comfort perception .

5.6.3 Application of ASHRAE 7 thermal Sensation Scale and Bedford scale in predicting acceptable air temperature

The following table (Table 5.7) shows the average scale received by the thermal sensation vote based on the ASHRAE and thermal comfort vote based on the

No. Of votes	Tind	slightly cool	neutral	slightly warm	warm	**Ts**	comfrtably cool	comfortable	comfortably warm	too warm	**CV**
2	26.1	0	2	0	0	**0.0**	0	0	2	0	**1.0**
8	26.5	0	8	0	0	**0.0**	0	0	8	0	**1.0**
15	26.9	0	15	0	0	**0.0**	0	0	15	0	**1.0**
15	27.2	0	15	0	0	**0.0**	0	0	15	0	**1.0**
9	27.6	0	8	1	0	**0.1**	0	0	8	1	**1.1**
10	27.9	0	5	5	0	**0.5**	0	0	4	6	**1.6**
14	28.3	0	9	5	0	**0.4**	0	0	7	7	**1.5**
10	28.7	0	7	3	0	**0.3**	0	0	7	3	**1.3**
9	29.1	0	7	2	0	**0.2**	0	0	7	2	**1.2**
7	29.4	0	7	0	0	**0.0**	0	0	2	5	**1.7**
7	29.8	0	7	0	0	**0.0**	0	0	3	4	**1.6**
8	30.2	0	0	8	0	**1.0**	0	2	1	5	**1.4**
13	30.6	0	0	13	0	**1.0**	0	1	4	8	**1.5**
17	31	0	0	17	0	**1.0**	0	2	7	8	**1.4**
10	31.4	0	0	10	0	**1.0**	0	1	4	5	**1.4**
9	31.8	0	0	5	4	**1.4**	0	0	1	8	**1.9**
1	32.2	0	0	0	1	**2.0**	0	0	0	1	**2.0**

Table 5. 7 - The average value of scale based on the ASHRAE and Bedford scale voted by the participants

Bedford scale. For the purpose of the comparison, the 7 scales given to the Bedford scale has been changed to follow the ASHRAE scale. The average of the votes received based on the two scales in relation to the measured air temperature is tabulated in Table 5. 7. Based on the average received by the ASHRAE and Bedford scale, it is obvious that both of them are perceived differently by the respondents. The Bedford scale, in all occasions, shows higher average readings in comparison with the ASHRAE scale. The bigger differences can be seen when the reading is between 0 and 1 under the ASHRAE scale. As the reading on the ASHRAE scale increases, the differences between the two scales are becoming smaller and eventually become the same. As discussed earlier in the earlier cases, the ASHRAE scale evaluative description is specifically related to the thermal sensation whereas the Bedford scale is also related to the thermal sensation scale but with the addition of word comfortable in some of the evaluative scale. This may have changed the perception with the inclusion of word 'comfortable'. In the area that has warm and hot temperature throughout the year, the influences in thermal comfort may have been caused by other variables besides air temperature. The high heat may have become very common and tolerable due to the process of the acclimatization and therefore there is a possibility that higher air temperature can be considered as neutral by the respondents in term of thermal sensation. In term of thermal comfort level, the presence of air movement normally helps to improve the thermal comfort condition and the high humidity often reduces the level of thermal comfort. The air temperature or the heat by itself can be very influential if it reaches the intolerable limit. Therefore, it is important to correctly estimating the tolerable limit. It may be different from the suggested by the ASHRAE or Bedford scale because of different climate and culture. From the previous observation it seem that the heat have not been seen as favourable for this climate due to high air temperature throughout the day. Therefore, the word warm may have been interpreted differently by the local respondents. It has also been seen that the air temperature under the scale 1(warm) has been considered as unacceptable under the Bedford scale. Due to this it is advisable to predict the tolerable limit of the air temperature when the scale is 0 which is also called as neutral temperature. Figure 5.18 shows the linear regression based on the

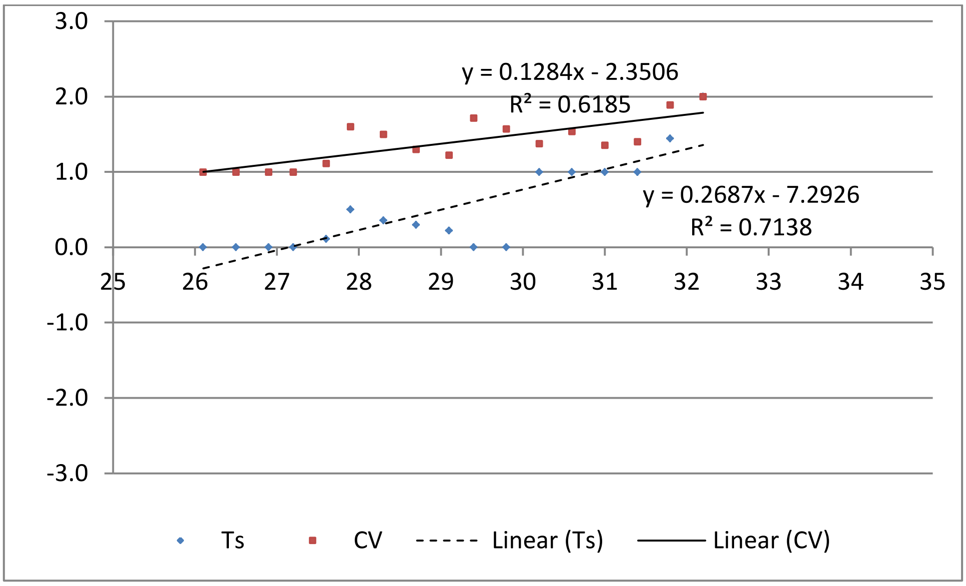


Figure 5. 18 - Linear regression of the thermal sensation/comfort vote vs. air temperature at Sikamat Mosque, Seremban.

the average value of thermal sensation and comfort vote scale. The comfort vote is based on the Bedford scale. As this is more related to the air temperature, the comfort vote shows more inconsistencies compared to the thermal sensation vote which is based on the ASHRAE scale. Based on the linear regression, the comfort vote produces an equation:-

$$\text{Comfort vote} = 0.1284\ T_{air} - 2.3506 \ (\text{with } R^2 = 0.6185)$$

Based on the suggested tolerable limit using the neutral temperature it is predicted that the neutral temperature based on the Bedford scale is 18. 3^0 Celsius. Using the agreed range (when the Cv is=1), the upper limit is 26.1^0 Celsius. Based on the thermal sensation scale, the linear regression produces an equation of:

$$Tvote = 0.2687\ T_{air} - 7.2926 \text{ (with } R^2 = 0.7138)$$

Based on this equation, the neutral temperature is 27.14^0 Celsius. Based on the agreed tolerable range which is when the Tvote = 1, the predicted air temperature is 30.86^0 Celsius.

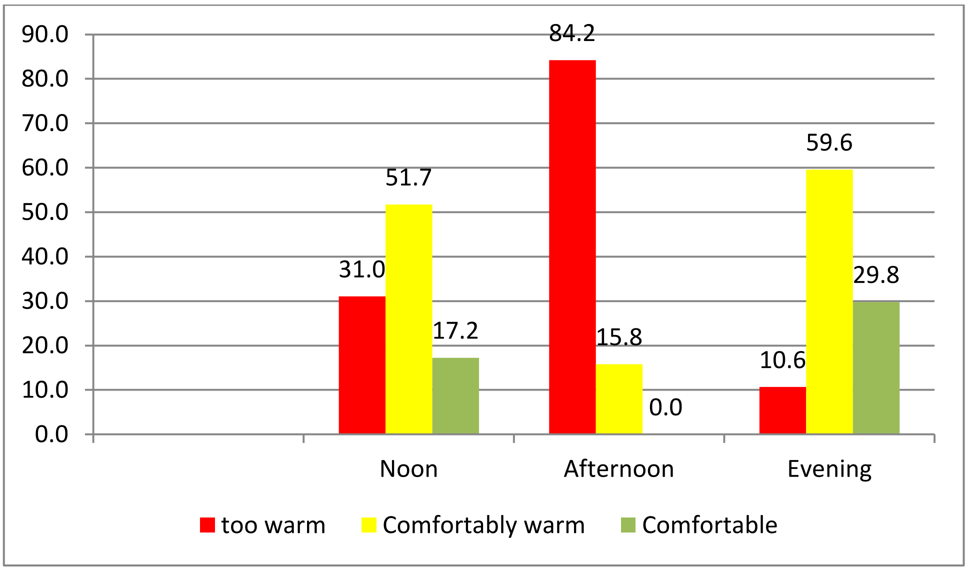
The prediction using the ASHRAE scale (thermal sensation vote) is more accurate compared to the Bedford scale. This is because the descriptive on the ASHRAE scale is more precise in relation to the air temperature whereas the Bedford scale is more toward the overall thermal comfort situation which may include other variables as well. Because of that, the tolerable limit of the air temperature for this case study is 27.14^0 Celsius. This air temperature is also called the ‘neutral’ temperature.

5.7 AL MIZAN MOSQUE, PUTRAJAYA

Al Mizan is the smallest mosque among the four selected mosques. It can accommodate about 250 people at one time in the prayer hall. As described earlier in Chapter Four, the mosque has a centralised domed roof with an open facade design which is differ from the other mosques. A total of 114 participants are involved in the survey to gather the information on the thermal comfort perception of the prayer hall. Out of 114, 29 participants involved during the noon time, 38 participants during the afternoon time and 47 people during the evening time.

5.7.1 Thermal Comfort Perception

Three thermal comfort situations have been recorded during the survey as pictured in Figure 5.19. The afternoon period receives the highest vote (84.2%) on



Note: Seven levels of Bedford scale are used for the thermal comfort level but only the three levels are shown because no vote is received for comfortably cool, too cool, much too cool and much too warm.

Figure 5. 19 – The percentage of thermal comfort votes based on the Bedford scale according to the prayer times at Al Mizan Mosque,Putrajaya.

'too warm' condition with only 15.8% experienced this period of time as 'comfortably warm'. Between the noon and evening periods of time, the evening period is considered to be more acceptable with the total votes of 89.4% for 'comfortable' and 'comfortably warm' condition whereas the noon time only receives approximately 69% of the votes. Table 5.8 shows the average air temperature and relative humidity according to the period of time and the thermal comfort situation voted. Based on Table 5.8, the average air temperatures during the noon and the afternoon are about the same with relatively small differences but quite high with 30.1 degree Celsius for the noon and 30.9 degree Celsius for the afternoon. The air temperature during the night time shows a substantial drop which is 27.4 degree Celsius.

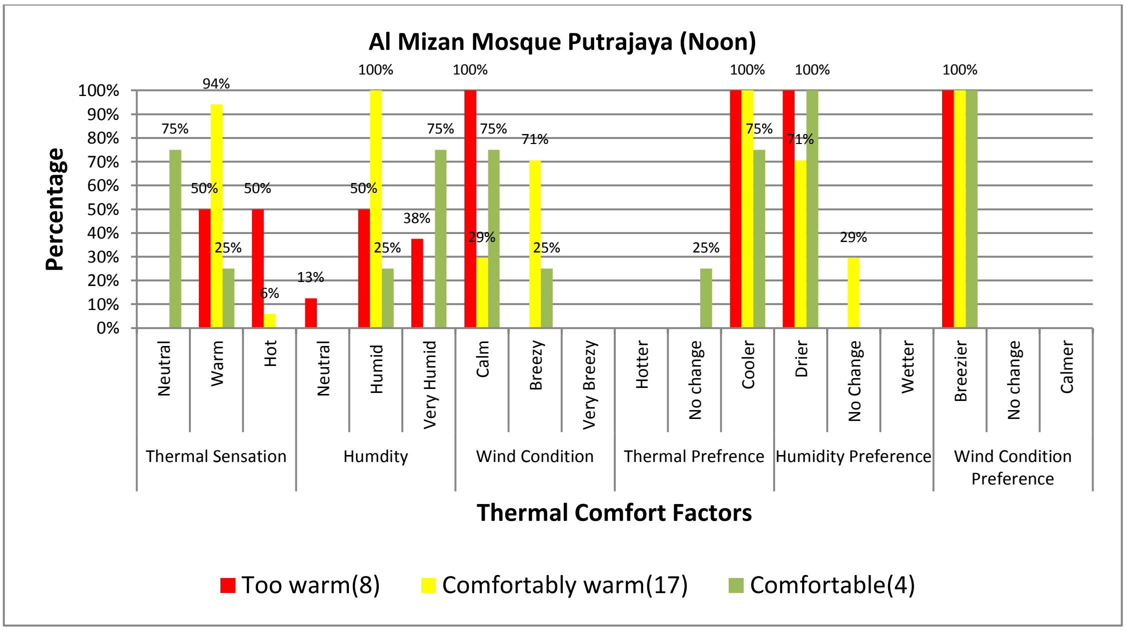
Time	too warm	Comfortably warm	Comfortable	No. Of Participant	Avg. Temp.	Max. T	Min T	Avg RH	Max RH	Min RH
Noon	31.0	51.7	17.2	29	30.1	32.5	26.7	75.7	92	69.6
Afternoon	84.2	15.8	0.0	38	30.9	37.5	26.9	70.7	90.1	32
Evening	10.6	59.6	29.8	47	27.4	29.8	25.4	78	95.1	50
Avg To	30.4	28.7	27.7							
AvgTi	30.6	28.4	27.6							
Max To	38.4	34.3	32.6							
Max Ti	37.5	31.5	30.7							
Min To	25.8	25.8	26.5							
Min Ti	25.8	25.4	26.5							
Avg RH	73	73.9	83.7							
Max RH	95	95.1	88.3							
Min RH	32.2	50	69.6							

Table 5. 8 – The average, min and max for the air temperature and relative humidity according to the thermal comfort vote and the periods of prayer time. At Al Mizan Mosque Putrajaya.

This is reflected in the increase on the percentage of people voting the situation during the evening time as thermally acceptable. The average relative humidity between the periods of time differs with the noon time at 75.7%, afternoon time at 70.7% and evening time at 78%. Based on this observation, it can be predicted that the high air temperature which occurs during the afternoon and noon time has caused the thermal comfort experienced to be less acceptable compared to the evening time which has lower average air temperature. The differences on the average relative humidity between the periods of time show little influences on the thermal comfort situation. For examples, the evening period has higher average of relative humidity (78%), which normally affects the thermal comfort level to be unacceptable, compared to the afternoon period (70.7%). Surprisingly, the afternoon period has more votes for being less thermally comfortable. It is very apparent that the average air temperature for the evening time is the highest among the three. There is also a possibility that the relative humidity recorded is still tolerable to the respondents and with the low air temperature (27.4 Celsius) that is recorded during the evening time the influence of the relative humidity at 78% may have not been significant. The presence of air movement may have also affected the votes recorded. A cross checking on the variables affecting the vote is necessary to identify the causes.

5.7.2 Affecting factors and preferences on thermal comfort

Figure 5.20, 5.21 and 5.22 show the association of the variables affecting the thermal comfort level to the thermal comfort perception of the respondents during noon, afternoon and evening period of time respectively. Figure 5.19 shows the votes received during the noon time. There are three thermal comfort situations recorded during this time which are ‘too warm’, ‘comfortably warm’ and ‘comfortable’. Along with these votes, the participants are also asked on the thermal sensation, the humidity and the wind movement that they experienced along with these thermal comfort sensations. By cross checking the votes received on these variables, it reveals the variables associated with the thermal comfort sensation they



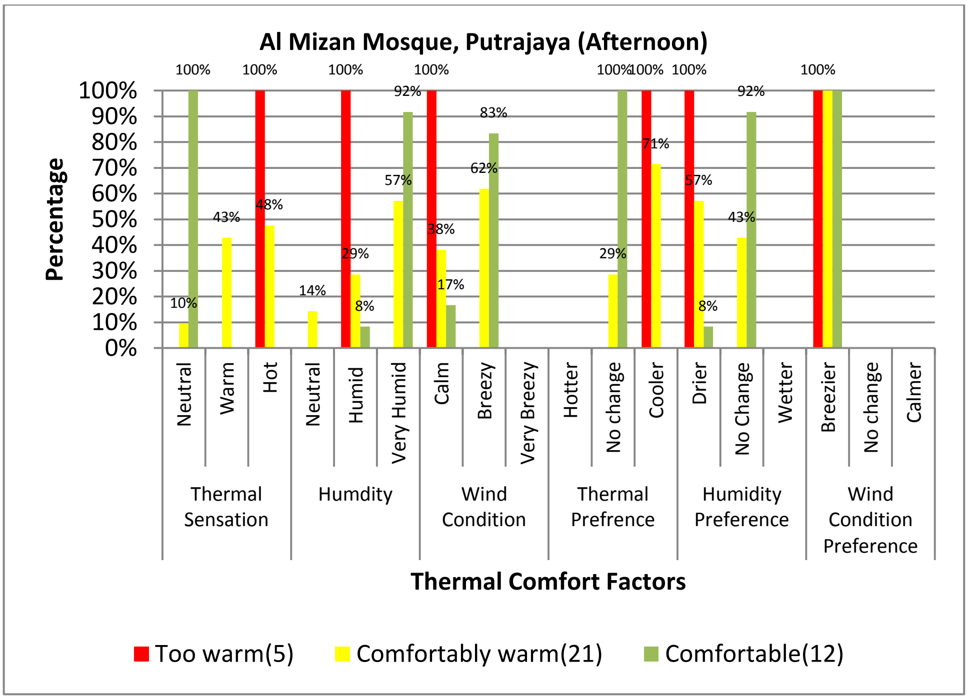
Note: Seven levels of Bedford scale are used for the thermal comfort level but only the three levels are shown because no vote is received for comfortably cool, too cool, much too cool and much too warm.
ASHRAE 7-point scale is used for the thermal sensation but only three points which are neutral, warm and hot are shown because other points do not receive any vote for the period of time investigated.

Figure 5. 20 - The percentage of votes on the thermal sensation, relative humidity, wind condition and preferences vote in relation with the comfort vote based on the Bedford scale at Al Mizan Mosque, Putrajaya during the noon prayer time.

experienced. Based on the votes received, the 'comfortable' situation is mostly associated to the 'neutral ' (75%) and 'warm' (25%) thermal sensation with either 'humid' (25%) or 'very humid' (75%) condition and 'calm' (75%) or 'breezy' (25%) wind condition. The 'comfortably warm' condition is associated with the 'warm' (94%) and 'hot' (6%) thermal sensation with the 'humid' (100%) condition and 'calm' (29%) or 'breezy' (71%) air movement. The unacceptable comfort condition which is 'too warm' is associated with 'warm' (30%) and 'hot' (70%) thermal sensation with either 'humid'(50%) or 'very humid' (38%) condition and 'calm' (100%) air movement.

Based on these observation, it can be said that with the ‘neutral’ thermal sensation, there is a higher possibility that the condition to be ‘comfortable’ regardless of the situation of other variables. In contrast, when the thermal sensation is under the ‘hot’ condition, the thermal comfort condition predicted will most probably be unacceptable as the condition becomes ‘too hot’. The ’warm’ thermal sensation however, shows three possibilities of thermal comfort conditions depending on other variables. The most expected thermal comfort condition when the thermal sensation is ‘warm’ is ‘comfortably warm’. However, the graph also indicates that for this situation to be ‘comfortably warm’, the humidity level should be under the ‘humid’ category with the ‘breezy’ air condition. This condition can become ‘too warm’ when there is little air movement present as indicated in the graph regardless of the humidity level. This indicates that the influence of air movement to the thermal comfort level is significant and it is reflected in the preferences’ votes where all participants would like the condition to be breezier regardless of how thermally comfortable they experienced. For the preferences’ votes on the thermal sensation, the majority of the participants would like the condition to be cooler including for those who voted the thermal sensation to be ‘neutral’. For humidity, the actual condition that most of the participants experienced is either ‘humid’ or ‘very humid’ and as for the preferences, the participants would prefer the condition to be drier.

The next figure (Figure 5.21) shows the votes received during the afternoon time. Similar to the situation at the noon time, three conditions of thermal comfort situations which are' comfortable', 'comfortably warm', and 'too warm' have been



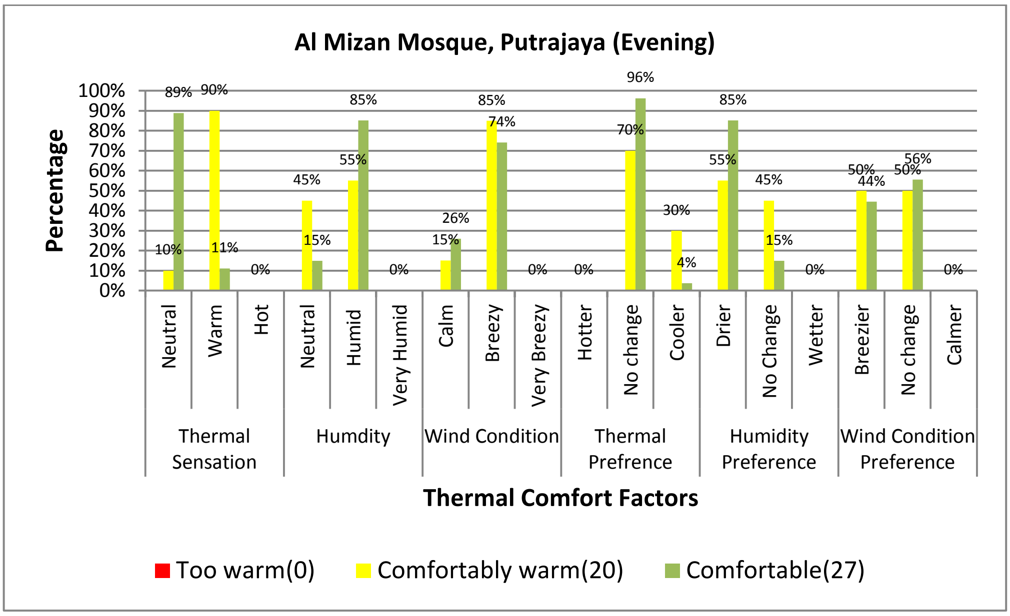
Note: Seven levels of Bedford scale are used for the thermal comfort level but only the three levels are shown because no vote is received for comfortably cool, too cool, much too cool and much too warm.
ASHRAE 7-point scale is used for the thermal sensation but only three points which are neutral, warm and hot are shown because other points do not receive any vote for the period of time investigated.

Figure 5. 21- The percentage of votes on the thermal sensation, relative humidity, wind condition and preferences vote in relation with the comfort vote based on the Bedford scale at Al Mizan Mosque, Putrajaya during the afternoon prayer time

recorded. The 'comfortable' situation is again associated with the 'neutral' thermal sensation. It is also shown that along with this thermal sensation, the humidity level experienced by the respondents who voted the situation as 'comfortable' is either 'very humid' (92%) or 'humid' (8%) and the wind conditions is considered either 'breezy' (83%) or 'calm' (17%). It seems that the presence of high humidity does not affect the 'comfortable' situation. One of the possibilities is because the thermal sensation experienced (neutral) does not cause them to sweat which in return, does not affected by the high humidity in the air. The other possibility is the presence of air movement which helps the evaporative process to cool down the body. It is for certain that without the air movement and the 'hot' thermal sensation with the 'humid' condition, the thermal comfort situation becomes 'too warm' and unacceptable. This is shown by the vote of 'too hot' in Figure 5.21. It is also shown that the 'warm' thermal sensation results in 'comfortably warm' thermal sensation. However, the 'comfortably warm' thermal comfort condition is also be associated with the 'neutral' and 'hot' thermal sensation as pictured in the figure. Together with these thermal sensations, it is also recorded that the humidity level experienced are varied. They are 'neutral' (14%), 'humid' (29%) and 'very humid' (57%) and the air movement conditions are 'calm' (38%) and 'breezy' (68%). This suggests that depending on the presence and condition of other variables, the 'neutral' thermal sensation which is normally considered 'comfortable' and the 'hot' thermal sensation which is normally unacceptable can be reversed. For examples, the 'breezy' air condition may have helped to improve the thermal comfort perception when the thermal sensation is 'warm' and the humidity level is high which is shown under the 'comfortably warm' vote where the 'breezy' condition makes the condition as 'comfortably warm' even though there is a higher percentage of participants experiencing 'hot' (48%) and 'warm' (43%) thermal sensation.

Regardless of the thermal sensation and thermal comfort experienced during this time, all of the participants prefer the environment to be breezier than what they have had experienced. For those who voted the thermal sensation to be ‘neutral’, they prefer not to change the thermal sensation. However, the majority of participants who voted for ‘warm’ and ‘hot’ prefer the condition to be cooler. For the humidity level, the majority of the participants who voted the thermal comfort condition as ‘too hot’ and ‘comfortably warm’ prefer the humidity level to be drier. For those who voted for ‘comfortable’ prefer the condition to be unchanged despite many of them feel that the humidity level is ‘very humid’. The presence of the humidity in the air is difficult to be sensed. The indication that there is a high humidity on the air is through the amount of sweat accumulated on the skin. In many cases, the presence of high humidity does not influence the thermal comfort condition when the thermal sensation is low or at the neutral level. The presence of air movement, in some cases, also lessens the effect of humidity to the thermal comfort sensation.

The next figure (Figure 5.22) represents the vote received during the evening time. Only two thermal comfort conditions recorded during this time. They are the ‘comfortably warm’ and ‘comfortable’ condition. The major difference between these two votes is on the thermal sensation experience. The majority of participants who voted for the ‘comfortably warm’ thermal comfort condition experiences ‘warm’ (90%) thermal sensation, whereas the majority of the participant who voted for ‘comfortable’ option experience ‘neutral’(89%) thermal sensation. Based on the votes, the ‘comfortable’ situation is also associated with the ‘neutral’ (15%) and ‘humid’ (85%) condition. The condition of wind during this period of time is mostly ‘breezy’ (74%) and ‘calm’ (26%). Similarly, besides the ‘warm’ thermal sensation, the ‘comfortably warm' condition is also associated with the 'neutral' (45%) level of humidity and 'humid' (55%) condition with the 'breezy' (85%) and ' calm' (15%) wind condition.



Note: Seven levels of Bedford scale are used for the thermal comfort level but only the three levels are shown because no vote is received for comfortably cool, too cool, much too cool and much too warm.
ASHRAE 7-point scale is used for the thermal sensation but only three points which are neutral, warm and hot are shown because other points do not receive any vote for the period of time investigated.

Figure 5. 22 – The percentage of votes on the thermal sensation, relative humidity, wind condition and preferences vote in relation with the comfort vote based on the Bedford scale at Al Mizan Mosque, Putrajaya during the evening prayer time.

Based on the rules of the majority, it can be predicted that in most cases, even though the condition of air is 'humid' the participants still feel 'comfortable' when the thermal sensation is at the 'neutral' level. The 'breezy' air condition that has been felt by 74% of the respondents during this time may have improved the thermal comfort condition but according to the preferences votes, the majority of the respondents who feel comfortable prefer the condition of air movement to be unchanged (56%) and the other 44% of the respondents prefer breezier wind condition. Almost all participants which is about 96% of them vote to maintain the existing ‘neutral’ thermal sensation but prefer the air condition to be drier (85%).

Similarly, when the thermal comfort condition is considered ‘comfortably warm’, about 90% of the respondents experience ‘warm’ thermal sensation with 55% of them feels the air condition as ‘humid’. The other 45% of them feel that the level of humidity during that time as ‘neutral’. It is also recorded that the wind condition experienced by the majority of respondents is ‘breezy’ (85%) which may have assisted them to feel more thermally comfortable. Even though the respondents feel ‘warm’, only 30% of them prefer the thermal condition to be cooler with the majority of them which is 70% wants the thermal condition to be maintained. Despite the fact that the majority of them feel the wind condition is breezy, about 50% of them prefer the condition to be breezier with the other 50% favour the condition to remain.

5.7.3 Application of ASHRAE 7 thermal Sensation Scale and Bedford scale in predicting the acceptable air temperature

Table 5.9 shows the votes received under the ASHRAE and Bedford scales and the average scale based on the votes. A linear regression based on the average scale is established for both of the scales as shown in Figure 5.23. Based on the regression made, it can be seen that the thermal sensation scale (Tsv) based on the ASHRAE scale is more linearly related to the air temperature compared to the Bedford scale. Based on the regression, the equation produced under the ASHRAE scale is:

$$TSV = 0.27755T_{air} – 7.2602 \text{ (with } R^2 = 0.9083\text{)}$$

T air	no of participa nt	slightly cool	neutral	slightly warm	too warm	hot	comforta bly cool	comforta ble	comforta bly warm	too warm	much too warm	**Avg TSV**	**Avg CV**
25.4	1	0	1	0	0	0	0	1	0	0	0	**0.0**	**0.0**
25.8	3	0	3	0	0	0	0	3	0	0	0	**0.0**	**0.0**
26.1	3	0	3	0	0	0	0	2	1	0	0	**0.0**	**0.3**
26.5	7	0	7	0	0	0	0	7	0	1	0	**0.0**	**0.3**
26.7	1	0	1	0	0	0	0	1	0	0	0	**0.0**	**0.0**
26.9	8	0	8	0	0	0	0	3	0	0	0	**0.0**	**0.0**
27.2	15	0	8	7	0	0	0	10	5	0	0	**0.5**	**0.3**
27.6	19	0	5	14	0	0	0	4	15	0	0	**0.7**	**0.8**
27.9	2	0	1	1	0	0	0	1	1	0	0	**0.5**	**0.5**
28.2	1	0	1	0	0	0	0	1	0	0	0	**0.0**	**0.0**
28.3	3	0	3	0	0	0	0	2	1	0	0	**0.0**	**0.3**
28.7	3	0	2	1	0	0	0	2	1	0	0	**0.3**	**0.3**
29.1	8	0	0	8	0	0	0	1	7	0	0	**1.0**	**0.9**
29.2	3	0	0	3	0	0	0	1	2	0	0	**1.0**	**0.7**
29.3	1	0	0	1	0	0	0	0	1	0	0	**1.0**	**1.0**
29.6	2	0	0	2	0	0	0	0	2	0	0	**1.0**	**1.0**
29.7	3	0	0	2	1	0	0	0	2	1	0	**1.3**	**1.3**
29.8	5	0	0	5	0	0	0	0	4	1	0	**1.0**	**1.2**
30.7	1	0	0	1	0	0	0	0	1	0	0	**1.0**	**1.0**
30.9	1	0	0	1	0	0	0	0	0	1	0	**1.0**	**2.0**
31	1	0	0	1	0	0	0	0	1	0	0	**1.0**	**1.0**
31.1	1	0	0	1	0	0	0	0	0	1	0	**1.0**	**2.0**
31.3	1	0	0	1	0	0	0	0	0	1	0	**1.0**	**2.0**
31.4	1	0	0	1	0	0	0	0	1	0	0	**1.0**	**1.0**
31.5	1	0	0	1	0	0	0	0	1	0	0	**1.0**	**1.0**
32.1	1	0	0	0	1	0	0	0	0	1	0	**2.0**	**2.0**
32.2	1	0	0	0	1	0	0	0	0	1	0	**2.0**	**2.0**
32.4	1	0	0	0	1	0	0	0	0	1	0	**2.0**	**2.0**
32.5	1	0	0	0	1	0	0	0	0	1	0	**2.0**	**2.0**
34.3	1	0	0	0	1	0	0	0	1	0	0	**2.0**	**1.0**
34.8	2	0	0	0	1	1	0	0	1	1	0	**2.5**	**1.5**
35.2	1	0	0	0	1	0	0	0	1	0	0	**2.0**	**1.0**
36.1	3	0	0	0	0	3	0	0	1	2	0	**3.0**	**1.7**
36.6	3	0	0	0	0	3	0	0	3	0	0	**3.0**	**1.0**
37	3	0	0	0	0	3	0	0	1	2	0	**3.0**	**1.7**
37.5	2	0	0	0	0	2	0	0	2	0	0	**3.0**	**1.0**

Table 5. 9 - The average value of scale based on the ASHRAE and Bedford scale voted by the participants

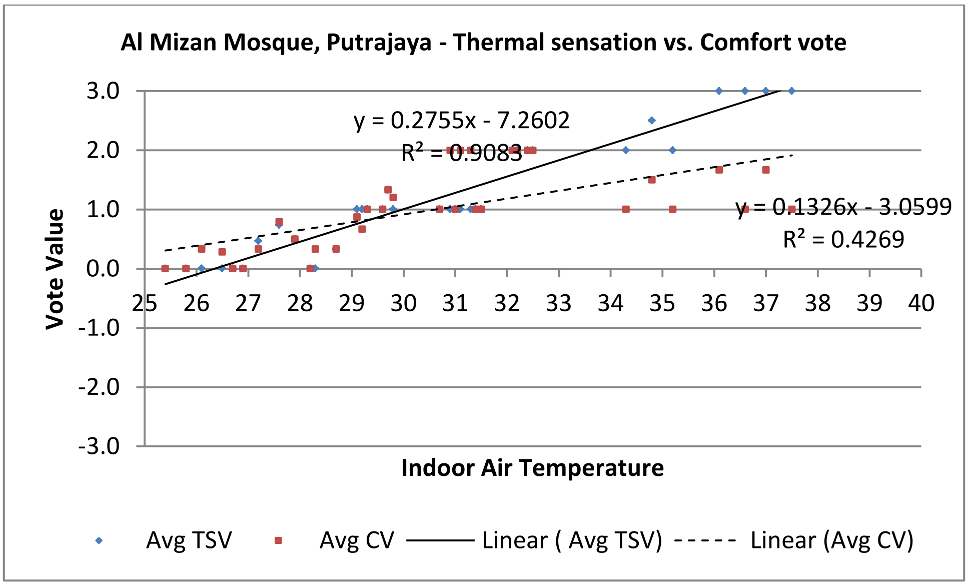


Figure 5. 23 – Linear regression of the thermal sensation/comfort vote vs. air temperature at Al Mizan Mosque, Putrajaya

Using this equation, the calculated neutral temperature (when TSV = 0) is 26.35 degree Celsius. It is also been agreed by researchers that the maximum tolerable air temperature based on the ASHRAE scale is when TSV = 1. Using the same equation, the predicted maximum tolerable air temperature is 29.98 degree Celsius.

5.8 DISCUSSION

The two typical types of Malaysia mosques which are the pitched and domed roof have been selected for the study. The results have shown that there is no significant indication reflecting that one design is better than the other in terms of providing thermally comfortable indoor condition. For examples, the Jamek Mosque, Seremban which has a pitched roof recorded higher percentage of respondents who feel that the thermal comfort condition is acceptable. However, the Al Azim Mosque in Melaka that has a pitched roof as well recorded a higher percentage of respondents who consider the indoor thermal condition as unacceptable compared to the other two domed roof mosques(refer to Table 5.10). Therefore it can be concluded that the roof design of the mosque has no direct relationship in affecting the indoor thermal comfort condition of the prayer hall in the mosque. The overall design of the mosque needs to be considered to understand how the building design affects the indoor thermal comfort condition. Table 5.10 shows the comparison on the votes received on the thermal comfort condition and derived neutral temperature and the upper limit of tolerable air temperature of the selected mosques.

	Pitched				Domed			
	Al Azim (State)		Jamek Mosque (Community)		Sikamat Mosque (District)		Al Mizan Mosque (Local Community)	
	Acceptable	Unacceptable	Acceptable	Unacceptable	Acceptable	Unacceptable	Acceptable	Unacceptable
Noon	49%	51%	100%	0	77%	23%	69%	31%
Afternoon	37%	63%	100%	0	68%	32%	16%	84%
Evening	39%	61%	69%	31%	46%	54%	89%	11%
Neutral Temperature (at '0' scale)	23.9		25.0		27.1		26.4	
Upper lim Temperature (warm – at '1' scale)	30.3		31.0		30.9		30.0	

Table 5. 10 – Comparison on the acceptable and unacceptable thermal comfort condition among the mosques.

Based on the percentages recorded it shows that the state mosque which is the biggest mosque among the four mosques has the largest percentage of respondents who feel the space as thermally unacceptable. It follows by the second largest mosque which is the district mosque, the local community mosque which is the smallest mosque and finally the community mosque. The least acceptable thermal comfort condition occurs in the biggest mosque and the thermal comfort condition improves as the size of the mosques becomes smaller. However, in this study, the community mosque (Jamek Mosque) which is the second smallest and has a pitched roof design recorded the best acceptance on thermal comfort level. This indicates that a bigger mosque has bigger chances to be less acceptable in terms of thermal comfort and the design of the roof and the size may have a relationship in affecting the thermal comfort condition.

The size of the space designed is crucial in influencing the indoor thermal comfort condition. A typical prayer hall space is square in plan. Therefore, the increment in the floor area is proportionately related with the distance between the walls that make up the space. As the floor area increases, the distance between the walls that provide the openings also increases. For a naturally ventilated building, the distance between the outlets and inlets is important in influencing the thermal comfort condition of the space. With the increment in the distance between the walls that provide the outlets and inlets for the air changes, the cross ventilation that helps to improve the thermal comfort condition has become less effective causing less exchanges to occur between the inside and the outside. As a result, the replacement of hot air with the cold air cannot happen effectively causing the accumulation of heated air inside the space. The spaces that are farther than the openings are the areas that are mostly affected. This problem causes worse effect during the evening prayer time (between 7 pm and 10 pm). During this time, the outdoor air temperature reduces faster compared to the indoor air temperature due to the trapped air. With the lower air temperature of the outdoor, the users are able to sense the higher temperature of the indoor. This action psychologically and physically activates the reaction towards the excess of heat experienced causing them to sweat. With the trapped air, the humidity in the air cannot be released to the outside due to the cooler air temperature and higher relative humidity. The evaporative process from the sweat that is supposed to cool down the body cannot take place and in returns, causes the feeling of 'stuffiness' which leads to thermally uncomfortable condition.

An open facade building is one of the ways of allowing the air changes to occur effectively. This is evidenced in one of the mosques. It has an open facade prayer hall which allows the exchanges between the outdoor and indoor to happen uninterruptedly. The evening prayer time has been experienced by the respondents to be the most comfortable period of time which is in contrast with other mosques. Under this condition, the indoor thermal comfort condition is heavily dependent on the outdoor climatic condition. If the outdoor climatic condition were under the tolerable range, the indoor thermal comfort condition should be the same due to the effective changes of air between the inside and the outside. However, this open facade concept becomes a disadvantage when the outdoor air temperature is beyond the tolerable range. The high air temperature affects the thermal comfort level when the temperature reaches beyond the tolerable limit.

Therefore, determining the tolerable limit is important in providing the accurate estimation to be used in many applications regarding the thermal comfort level. The PMV method which is based on the ASHRAE scale has been widely used in predicting the thermal comfort level of the indoor space. It has been agreed that the acceptable range of thermally acceptable comfort condition is between -1 and 1 under the PMV calculation. Based on the ASHRAE thermal sensation scale, the range falls between ‘cool’ and ‘warm’ scale. The use of the PMV and ASHRAE scale has been found by many researches to be inaccurate in predicting the thermal comfort condition for naturally ventilated building especially a building that is located in a tropical climate. This study has also revealed that there is a discrepancy between the thermal sensation under the ASHRAE scale and Bedford scale. It has been found that the ‘warm’ scale under the ASHRAE is not always evaluated as the same with the ‘comfortably warm’ under the Bedford scale even though it is intended to be the same. The culture of the local people may have influenced the perception of the terms.

As explained by Hedge in his notes, thermal sensation and thermal comfort are not the same. Thermal sensation is closely related to the way the skin senses the heat. On the other hand, the thermal comfort is influenced by psychological elements which may involve other variables besides air temperature. The addition of the word ‘comfort’ in Bedford scale has the potential of influencing the perception. The perception of the word ‘warm’ to this community too is different when it is compared with the classification under the Bedford scale. In many cases, the ‘warm’ situation which is considered tolerable and acceptable has not always resulted in ‘comfortably warm’ under the Bedford scale. It often relates to the ‘too warm’ condition which becomes intolerable. This situation occurs in most cases when the air movement is sensed to be little. This implies that the ‘warm’ description of thermal sensation scale cannot be used as the upper limit of tolerable air temperature for this tropical region. In a tropical region, the nature of the climate is humid and hot. The content of humidity in the air is always at the high level throughout the day. The increase in the air temperature from the tolerable limit is capable of creating very thermally uncomfortable condition. When the body senses the excess of heat, the sweating reaction will start and the accumulation of sweat on the skin due to the its inability to evaporate because of high content of humidity in the air causes the person to feel uncomfortable. There is an occasion where the warm condition can be acceptable with the presence of continuous air movement. However it is a risk to use the ‘warm’ (or 1) as the tolerable limit.

Based on the findings, when the thermal sensation is at the ‘neutral’ level, regardless of the conditions of other variables, the majority of the respondents feel thermally comfortable. The use of the air temperature or thermal sensation besides other variables as a guide in providing thermal comfort is very appropriate. It is the only thermal comfort variable that is also related to the building design. For examples, the building elements such as walls and roofs control the heat transferred to the interior space. The design of the openings is intended to provide natural ventilation which also influences the air temperatures of the interior. Other variables, such as, humidity is strongly dependent on the condition of air. The humidity by itself is insignificant in influencing the thermal comfort. Due to the importance of the air temperature in influencing thermal comfort, a practical tolerable air temperature should be provided as a measuring stick in evaluating the performance of the building. As pointed earlier, the air temperature at the ‘neutral’ (0) level provides thermal comfort sensation and should be used as the maximum ‘expected’ air temperature for a building. The presence of other variables can be ignored when this air temperature is achieved. Table 5.11 shows the ‘neutral’ air temperature and the air temperature at scale 1. The ‘neutral’ temperature recorded for the mosques selected ranges from 23.9 degree Celsius to 27.1 which give the average of 25.6

degree Celsius. This figure could be used as the attempted indoor air temperature for any naturally ventilated mosque to ensure the thermal comfort condition can be achieved at all time.

Even though the air temperature plays a dominant role in affecting thermal comfort, the presence and importance of other variables must be acknowledged too. Corrective measurement can be made if the attempted temperature cannot be met. According to the study, the air movement has been considered as a major 'corrective' variable to many unfavourable thermal comfort conditions.

The study has revealed that in most of the cases, regardless of the thermal sensation condition, the breezy wind condition is favourable. In some cases where the thermal sensation is considered neutral, the air movement in the space is still favourable. This indicates that the neutral temperature that has been considered comfortable can be improved if the air movement is present. There is a possibility that the neutral temperature may not be the same as the neutral temperature defined under the PMV. It has also been discovered that the thermal discomfort is mostly due to the little air movement that can be sensed by the body. Without the strong wind movement, the replacement of the liquid (sweat) from the body is unable to occur causing the accumulation of heat which causes thermal discomfort. With the presence of strong and continuous wind movement, the high air temperature can be tolerated. The strong and continuous air movement helps in speeding up the evaporative process in cooling down the body. Without the aid of the strong wind, the evaporative process cannot happen naturally due to the high content of humidity in the air.

The presence of high humidity in the air causes the evaporative process to slow down. It is difficult to sense the presence of the humidity in the air. One of the ways to know whether the humidity level is high or low is through the accumulation of sweat on the skin. The high accumulation of the sweat on the skin reflects the high humidity level in the air which refrain the sweat to evaporate to the air. In this research, the level of sweating is utilised in estimating the level of humidity since the presence of the humidity in the air cannot be easily sensed by the human body as compared to thermal sensation. As a result of this, it is not surprising to see that many of the respondents prefer the humidity to be maintained when they are asked about their preference on the humidity.

5.9 CONCLUSION

The investigation using the survey and field measurement on the thermal comfort perception among the mosque users in Malaysia has revealed that they feel thermally comfortable when the temperature is between 23.9^0 Celsius and 27.1^0 Celsius which is called the neutral temperature. At this range, it can be assumed that the influence of other variables such as humidity and air movement does not affect the thermal comfort perception. Humidity, however, will become effective in influencing the thermal comfort perception after the air temperature exceeds the neutral temperature. Air movement, on the other hand, is always desirable regardless of the situation. The presence of air movement, however can improve the thermal comfort perception especially when the air temperature and relative humidity is higher.

The case studies have also shown that the application of thermal sensation scale based on the ASHRAE scale is still questionable in predicting thermal comfort level for a naturally ventilated building in a hot and humid country such as Malaysia. The range that is agreed by many researchers as acceptable cannot be applied for a naturally ventilated building in this type of climate. The 'warm' sensation that is sometime desirable for a temperate climate can be sensed as an excess heat for the people of the tropical climate country. Therefore, it is possible that the thermal condition they experienced is not the same as the people in the temperate climate. Based on the observation done, for prediction based on the PMV scale, instead of using scale '1' as the maximum tolerable range, scale '0' which is also known as ‘neutral’ temperature is suggested to be used as the maximum tolerable range for this type of climate. There is no minimum range that can be predicted from the case studies since there is no occurrence that the air temperature is below the neutral level or cooler.

In addition to this, it has also been revealed that there is no direct relationship between thermal comfort level and the roof design. However, there is a possibility that the design of the roof and the size of the building may have a connection with the thermal comfort level of the space. Further investigation on the influence of the design to the thermal condition inside the space is explained in the next chapter.

CHAPTER 6 – RESULTS AND DISCUSSION: HTB2 and WinAir4 Simulation

6.1 Introduction

Chapter 6 presents and discusses the results from the simulation conducted based on the two typical mosque designs in Malaysia which are the pitched roof and domed roof mosque using the software called HTB2 and WinAir4 developed by Cardiff University. The purpose of the simulation is to investigate the thermal condition inside the prayer hall resulted from the use of the two common roof designs which are the pitched roof and domed roof mosques. The results from the two modelled buildings are compared in order to determine which roof type produces better indoor thermal environment, and therefore thermal comfort level, under the same state of outdoor condition. The previous chapter presents and discusses the results based on the conducted survey on thermal comfort perception of the four selected mosques representing the two typical mosque designs in Malaysia. In this chapter, the results from the simulation process using the said software on both designs are analysed and compared. The analysis and comparison are based on the focus areas described later in the chapter. Based on the analysis and comparison, conclusion on which roof design performs better in providing thermally comfortable space for the tropical climate such as Malaysia is delivered.

6.2 The simulation

As discussed earlier in the Chapter 4, two typical mosque designs which are pitched and domed roof mosques are modelled for the simulation. Both of the designs are differed mainly on the roof design which includes materials and other characteristics resulted from the design such as materials and volume. The simulation was run for the period of ten days with the allowance of three days for the space to heat up. The first part of the analysis based on the simulation is to determine the selection of data for the investigation. Not all of the data can be used due to the process of heating up the building that needs to take place before the air temperature inside the building becomes stabilised. To ensure the reliability of the results, the considered data should be opted from the period when the building reaches the 'steady' or 'balance' condition. This is the condition where the internal thermal condition of the building has become consistent due to the completed process of heating up the space. This is the stage where the variables from the outdoor can directly influence the heating and cooling process of the indoor spaces without major interferences from other factors. The condition will change if the outside condition is changed.

Figure 6.1 shows the pattern of the air temperature produced for the domed mosque model for the duration of ten days allowing the heating up process to take place for the first two days. Figure 6.2 shows the pattern for the pitched roof model for the same duration of time. In the domed mosque simulation (Figure 6.1), it is observed that the air temperature of the space becomes fairly constant depending on the outdoor temperature after day 6. This means that the process of heating up

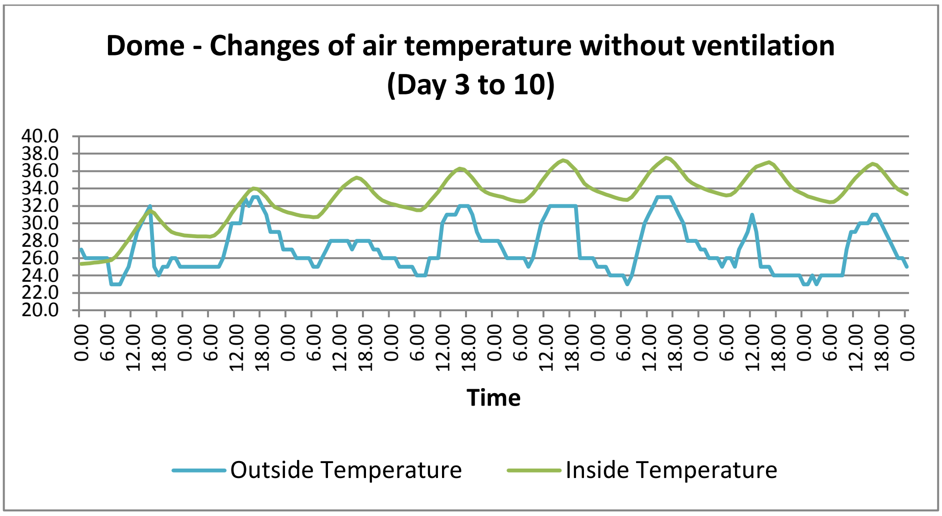


Figure 6.1- Changes of air temperature pattern of a domed roof mosque

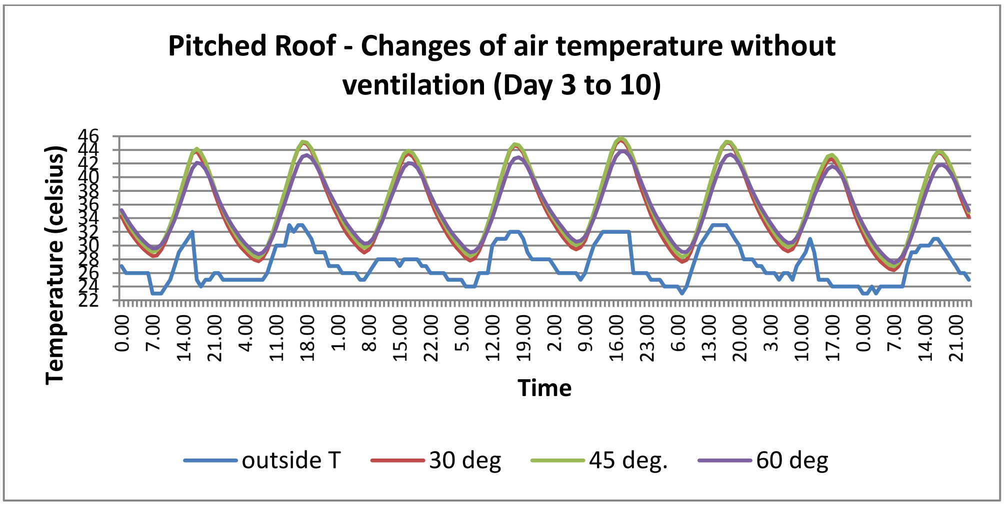


Figure 6. 2- Changes of air temperature pattern of the pitched roof mosque at 30 degree, 45 degree and 60 degree pitch.

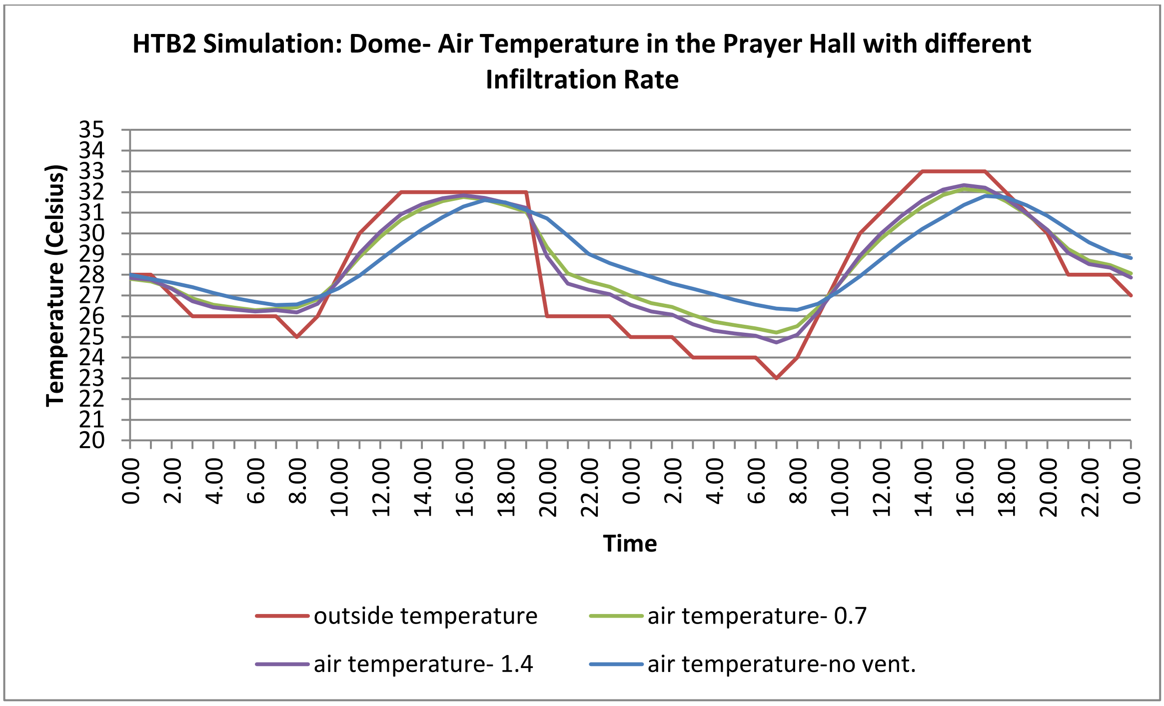
the space takes approximately about 6 days before it stabilizes. On the other hand, the air temperature inside the pitched roof mosque (Figure 6.2) becomes fairly constant as early as after day 3.This means that the heating up process for a pitched roof mosque completed after day 3. Based on this observation and the notion that the relevant data that need to be used is the data after the stabilization process, the data accumulated after day 6 for both of these modelled mosques can be used for the comparative analysis. However, for the purpose of the study, the results obtained from the day seven and eight are chosen because the pattern of the outdoor air temperature at this time reflected the typical outdoor temperatures of Malaysia and the results from the simulation process have also shown that the patterns of heat gain and loss are very closed to the typical pattern of heat gain and loss in a typical mosque under a typical outdoor climate.

As explained earlier, the simulation conducted is aiming to investigate the performance of both mosque roof designs in controlling the indoor thermal condition which is mostly based on air temperature. In pursuing this aim, the study is divided into focussed areas which are:

6.2.1 The relationship between the infiltration rate and heat gain and loss

Naturally ventilated buildings are designed to allow or promote the air exchanges between the indoor and outdoor to occur due to the natural forces. As a result, the indoor air temperature for naturally ventilated buildings is heavily dependent on the outdoor air temperature and therefore, the determination for the areas of opening allowing the air to flow into and out of the indoor space is important in controlling the indoor air temperature. For a building in a tropical country, it is a typical problem for the indoor air temperature to be higher than the outdoor air temperature. One of the strategies suggested to control the indoor thermal comfort condition is to maintain the indoor air temperature below the outdoor air temperature, especially when the outdoor air temperature exceeds the limit of tolerable air temperature. If a naturally ventilated building is capable in maintaining this condition, it can be considered that the building is efficient enough in filtering the heat from the outside into the inside.

Based on the simulation runs for the domed mosque using HTB2 software, the pattern of heating and cooling process for both of the modelled mosques are observed. Figure 6.3 shows the changes of air temperature inside the prayer hall of a typical dome mosque in relation to the changes of the infiltration rate which is defined by the area of the openings provided.



Note: Infiltration rate is the flow rate of outside air in volume into a building which is also known as the air exchange rate. It is based on the number of air exchanges occurred per hour. The 0.7/h of air changes per hour (ACH) is used when the window area is 10% of the floor area and 1.4/h of ACH is when the window area is 20% of the floor area.

Figure 6. 3- The heat gain-loss pattern (changes of air temperature) according to the infiltration rate of 1.4/h and 0.7/h and with no ventilation for the dome mosque

For the purpose of the study, two sizes of opening are selected. The first design has a total opening of 10% of the total floor area for the undisturbed flow of air which is the minimum area required according to the Uniform Building of By-Laws of Malaysia 1984. For the purpose of comparison, another design that has 20% of the floor area for the opening area is also established. Based on the 10% and 20% of undisturbed opening area in relation to the floor area, the calculated infiltration rates are 0.7/h ACH and 1.4/h ACH respectively. Using these values, a simulation is conducted to record the air temperature of the spaces investigated. Figure 6.3 shows that the indoor air temperature inside the prayer hall is closer to the outdoor air temperature with a difference of about 1 degree Celsius when the infiltration rate is higher (1.4/h ACH). This suggests that bigger openings will produce the same indoor air temperature as the outdoor air temperature since bigger openings allow effective air exchanges between the inside and outside. The next figure (Figure 6.4) shows the changes of the indoor space air temperature in relation to the outdoor air temperature using the infiltration rate of 1.4/h ACH.

It is also observed that during most of the daytime (between 10 a.m. to 6 p.m.) the indoor air temperature is maintained below the outdoor air temperature. This means that the heat is successfully filtered by the building elements throughout the period even though it is a naturally ventilated building, resulting in a lower air temperature compared to the outside temperature. Maintaining the indoor temperature below the outdoor temperature is crucial in providing the thermal comfort condition especially when the outdoor temperature is above the tolerable limit. With the opening that permit the infiltration rate of 1.4 ACH, it is proven that the domed mosque roof is capable of maintaining the indoor temperature during this period of time (from 10 a.m. to 8 p.m.).

The pattern, however, changed after this period of time. It is recorded that between 8 p.m. until 10.00 p.m., the indoor air temperature becomes higher than the outdoor air temperature. This is the period of time when outdoor starts to cool down. When the outdoor temperature starts to cool down, the indoor temperature starts to fall down as well but at a slower rate compared to the outdoor. This may be due to the slower exchanges of air between the inside and outside. The size of the opening may not be enough to allow the exchange of the air from the inside to the outside leaving the indoor air temperature to be higher than the outdoor. As a result, during this period of time, the air temperature of the indoor space is always higher than the outdoor temperature. This condition can become undesirable because it leads to the feeling of thermally uncomfortable due to a significant difference of air temperature between the inside and outside. Referring to Figure 6.3, the period of this condition occurs between approximately 7.00 pm until10. 00 pm where the air temperature recorded is above the acceptable air temperature (above 28^0 C). The humidity in the air may have also played its role in affecting thermal comfort during this time. It is also expected that when the air temperature reduces, the relative humidity rises. With this situation, it adds more to the thermal discomfort due to the inability for the sweat to evaporate due to the high content of humidity in the air. This creates the feeling of stuffiness.

For the pitched roof mosque, the simulated results show fairly the same pattern with the domed mosque. Figure 6.4 shows the air temperature and mean radiant temperature inside the prayer hall of a modelled pitched roof for day 7 and 8.

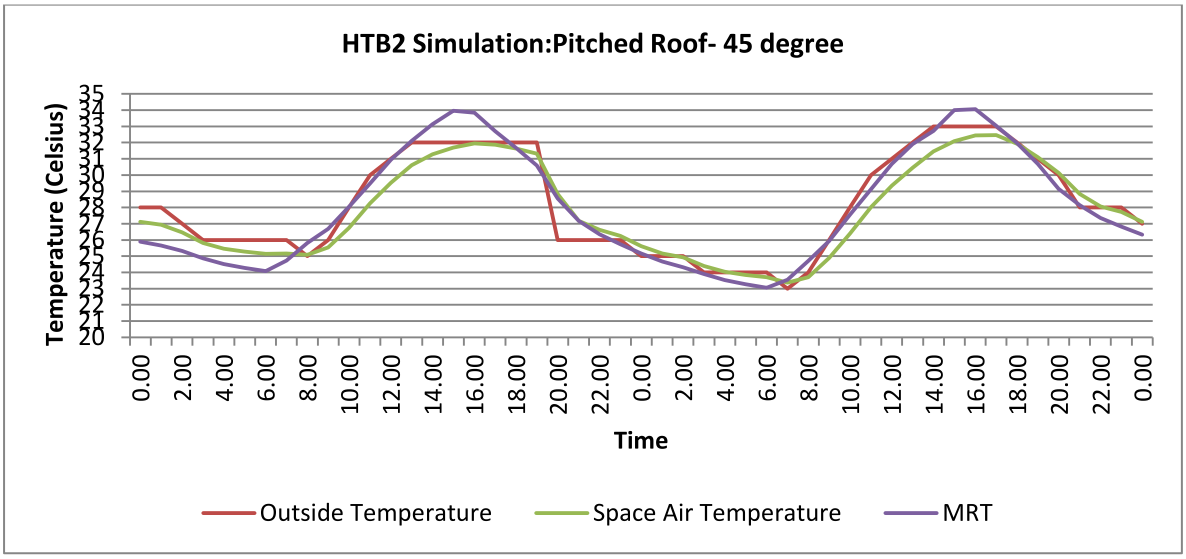


Figure 6. 4- The air temperature and mean radiant temperature of the prayer hall for the 45 degree pitch

The simulated results show that the indoor air temperature for the pitched roof mosques is maintained below the outdoor air temperature especially during the daytime when the tolerable air temperature is exceeded. The significant difference between the pitched and domed roof mosque that can be observed is that the pitched roof mosque cools faster than the domed roof. As a result, the air temperature inside the pitched roof is cooler than the domed roof mosque during the cooling down process which is between 6.00 p.m. and 7.00 a.m. This situation will allow the indoor air temperature to be below than the outdoor temperature at almost all the time.

As suggested by earlier researchers, a good naturally ventilated building should be able to maintain the indoor air temperature to be lower than the outdoor air temperature. In addition to this, it should also be able to cool down quickly to ensure the thermal comfort condition can be achieved. It has been observed from the study that both of these roof designs are capable of maintaining the indoor temperature below the outdoor air temperature as suggested by the researchers. However, the pitched roof mosque has the advantage of the ability to cool down faster compared to the domed mosque. This ability may have been resulted from the form and design itself. Further analysis is conducted on the next section. Based on that notion, it can be concluded that the pitched roof mosque performs better than the domed roof mosque.

6.2.2 Roof Space vs. Prayer Hall

One of the features suggested by Lin in order to reduce the heat gain inside a naturally ventilated building is to provide a roof space. In many mosque designs in Malaysia, a roof space has become one of the features incorporated into the design. For a mosque, this roof space is commonly covered either with the dome shape roof or a pitched roof. The simulation conducted on the pitched and domed roof mosques shows that the roof spaces provided by the domed roof and pitched roof act differently. Figure 6.5 and 6.6 show the recorded simulated results on the domed and the pitched roof mosques respectively. In this investigation the overall prayer hall space is divided into two sections which are the roof space encompassing the space below the specialised roof design and the prayer hall space encompassing the rest of the space. A virtual layer of separation is placed in between the space which allows the natural act of heat transfer to occur according to the temperature differences as suggested by the HTB2 manual.

For the case of the domed roof (Figure 6.5), it is observed from the graph that the air temperature for both spaces which are the roof and prayer hall increases as

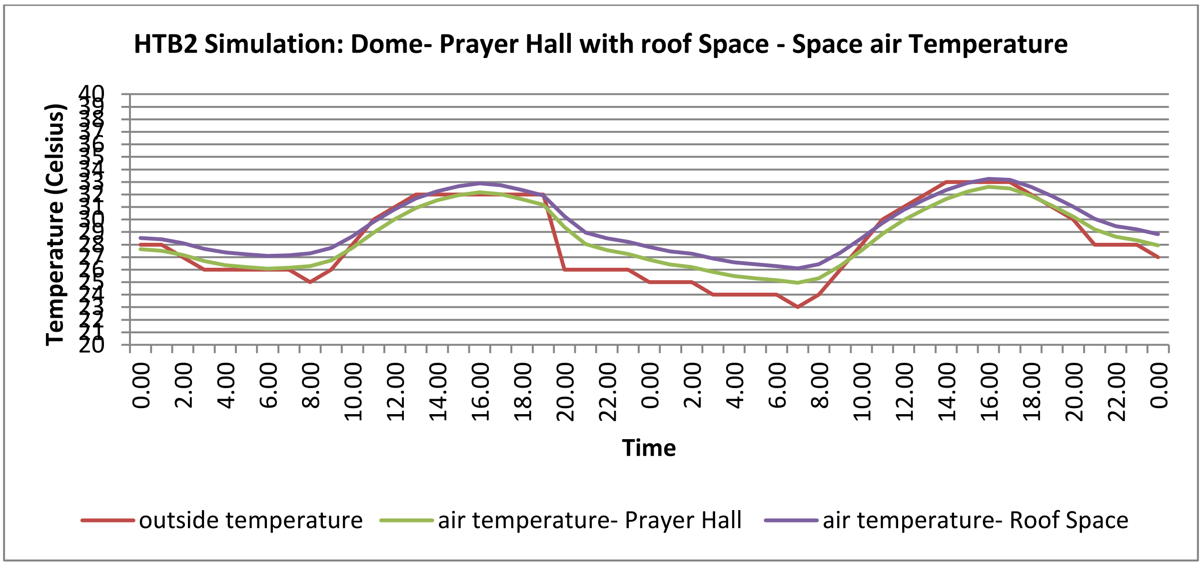


Figure 6. 5 - The space air temperature of the roof space and prayer hall in the domed mosque

the outdoor temperature increases. It is also noted that the rate of heating up the air temperature is fairly the same between the roof space and the prayer hall. However, the air temperature for the prayer hall is always maintained below the outdoor temperature especially during the heating up process, whereas the air temperature for the roof space is either almost the same or higher than the outdoor air temperature. It is calculated that the difference between the air temperature for the roof and prayer hall space is calculated at about 1 degree Celsius or less throughout the day.

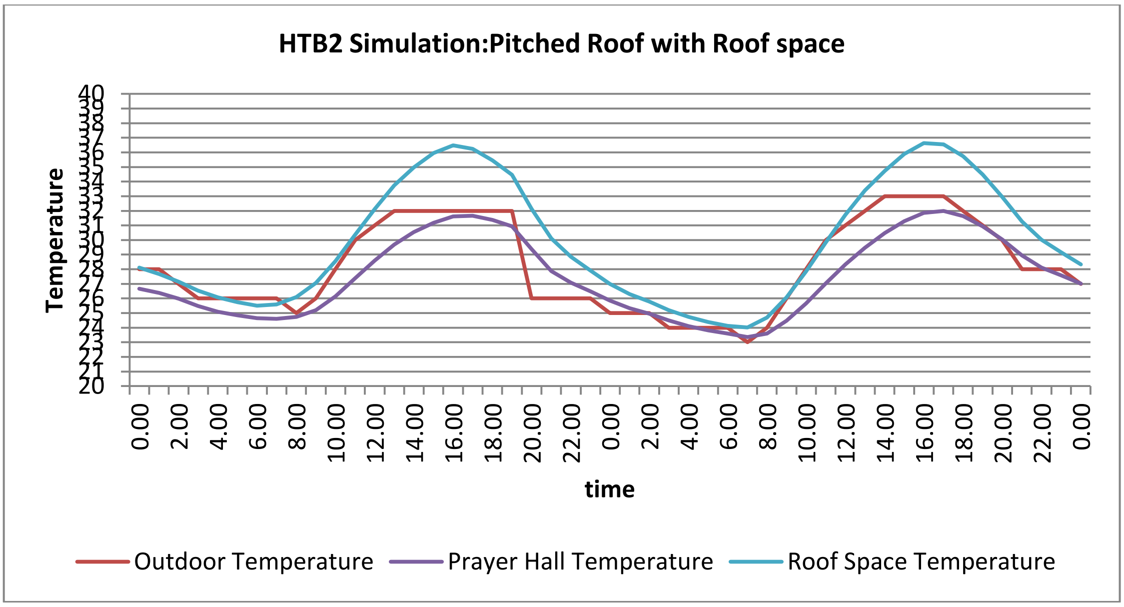


Figure 6. 6- The comparison of the space air temperature between the roof space and the prayer hall in the pitched roof mosque

For the pitched roof (Figure 6.6), the air temperature for both of the spaces increases when the outdoor temperature rises and similarly reduces when the outdoor air temperature cools down. However, based on the simulation, it can be seen that the air temperature in the roof space is heated up and cooled down faster than the air temperature of the prayer hall making a huge difference in air temperature between the two areas during the peak time. The recorded difference for the air temperature in the roof space and the prayer hall is between 1 degree Celsius and 5 degree Celsius depending on the period of time.

Figure 6.7 shows the comparison between the air temperature inside the prayer hall of the domed and pitched roof mosque. Comparing the two results, it shows that the space air temperature for the prayer in both of the mosque designs is slightly varied in the air temperature depending on the time of the day with the

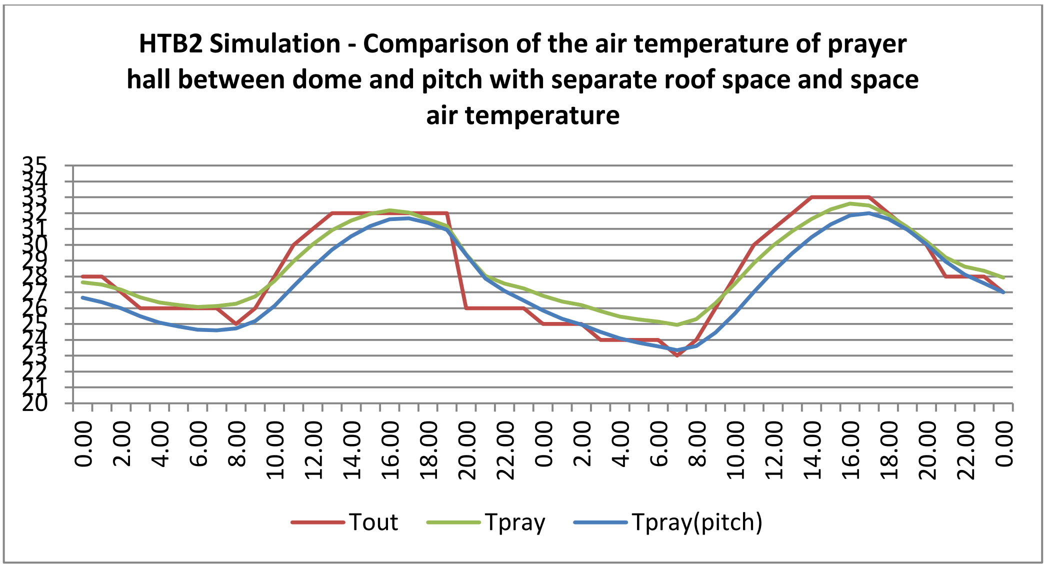


Figure 6. 7 - The comparison between the domed and pitched roof mosque on the space air temperature of the prayer hall

average of less than two degree Celsius difference. In all cases, the air temperature of the prayer hall spaces is always lower for the pitched roof mosque compared to the domed roof mosque. This may have resulted from the ability of the pitched roof mosque to cool down faster compared to the domed roof mosque as discussed in the previous section.

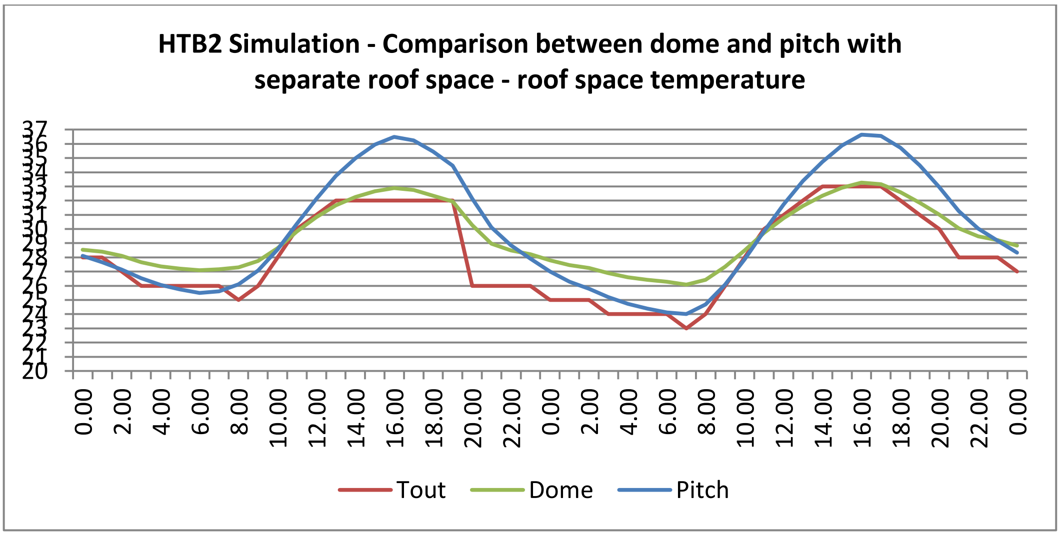


Figure 6. 8 - The comparison between the pitched and domed roof on the roof space air temperature

Figure 6.8 shows the air temperature of the roof space for the domed and pitched roof modelled mosques. From the simulation, it can be observed that the heating and cooling pattern for the roof space of the domed and pitched roof is not similar with the pattern observed at the prayer hall space. From the graph, it can be evidenced that the air temperature of the roof space for the pitched roof mosque is significantly higher than the domed roof mosque especially during the peak time of heating. Inversely, the air temperature for the pitched roof mosque is significantly lower than the domed roof mosque during the cooling process. This condition results in a bigger difference between the air temperature of the roof space and the prayer hall for the pitched roof mosque. However, a smaller difference of less than one (1) degree Celsius is recorded for the domed roof mosque.

Natural ventilation can happen through two means which are cross ventilation and stack effect ventilation. As discussed in Chapter 2, stack effect ventilation is caused due to the significant difference of air temperature between the lower and upper part of a space, whereas, cross ventilation occurs due to the difference in pressure which may be resulted from the forces of air movement. Referring to this theory, the significant difference of the air temperature between the two levels of the spaces is seen to be beneficial in helping to improve the natural ventilation inside the space. In this study, it has been shown that the air temperature inside the roof space of the pitched roof mosque is significantly higher than the domed roof mosque, and if compared with the difference of the air temperature between the roof space and the prayer hall of the domed roof mosque, the difference is relatively small. With this finding it can be concluded that the pitched roof mosque can adopt the stack effect ventilation in ventilating the space. Correct placement of windows or openings at the higher level can improve the natural ventilation of the prayer hall. Due to the significant differences of air temperature inside the prayer hall and roof space created by the pitched roof, it allows the circulation of the air inside the space due to the different pressure created by the variation of the air temperature. When the air is heated, it becomes less dense and it rises. The colder air which is denser than the hot air will fill the lower part of the space and this mechanism continues to maintain the air changes and ventilation. This mechanism may have not been possible if the difference of the air temperature between the upper and lower part of the space is relatively small as occurred at the domed roof mosque as shown in Figure 6.4. The difference between the air temperature for the roof space and the prayer hall is relatively small which is less than one (1) degree Celsius. The small difference may not be enough to promote the 'stack effect' ventilation to be effective for the space in the domed roof mosque.

In conclusion, it has been observed that the rate of heating and cooling down of the prayer hall and roof space differs between the domed and pitched roof mosque. The domed roof shows a slower rate of heating and cooling down in comparison with the pitched roof. For a naturally ventilated building located in a tropical climatic zone, it is advised to design a building that is able to cool faster. This allows the indoor air to achieve the state where the air temperature is lower than the outdoor air temperature in a shorter time to ensure the space is thermally comfortable. The pitched roof has the ability to cool down faster allowing longer time for the air temperature to heat up. In addition to this, it is also been observed that the distinctive temperature difference between the roof space and the prayer hall in the pitched roof mosque can be benefited in promoting natural ventilation.

6.2.3 Mean Radiant Temperature

Mean Radiant Temperature (MRT) has been considered as one of the important factors affecting the thermal comfort condition of a space. The significant differences between the ambience air temperature and the MRT can affect the thermal comfort perception of the occupants. MRT is the average temperature felt by the user, resulted from the surface temperature around the space. The MRT is directly related to the heat transferred by the surfaces of the space. Because of this, the spaces that are exposed directly to the sun play an important role in radiating the heat from the sun to the inside space. It is important to determine the elements of a building that are highly contributed to the MRT in order to strategise actions to improve the thermal comfort condition of the space.

The simulation using the HTB2 is conducted to obtain the result on the MRT produced by the surrounding surfaces of the prayer hall and the roof space. The simulated results based on the pitched and the domed roof mosques are plotted to analyse the building elements that are most affected by the sun. Figure 6.9 shows the result from the simulation run under the domed roof mosque. Based on the simulated results, it is shown that the MRT of the roof space is higher in comparison with the MRT of the prayer hall. The differences ranging from 1 degree Celsius to about 6 degree Celsius is recorded throughout the day and the differences become greater as the building cools down. The material and the construction of the surfaces may have played a bigger role in influencing the MRT of the spaces. For examples, the roof space for the dome roof is made of concrete which has the ability to store

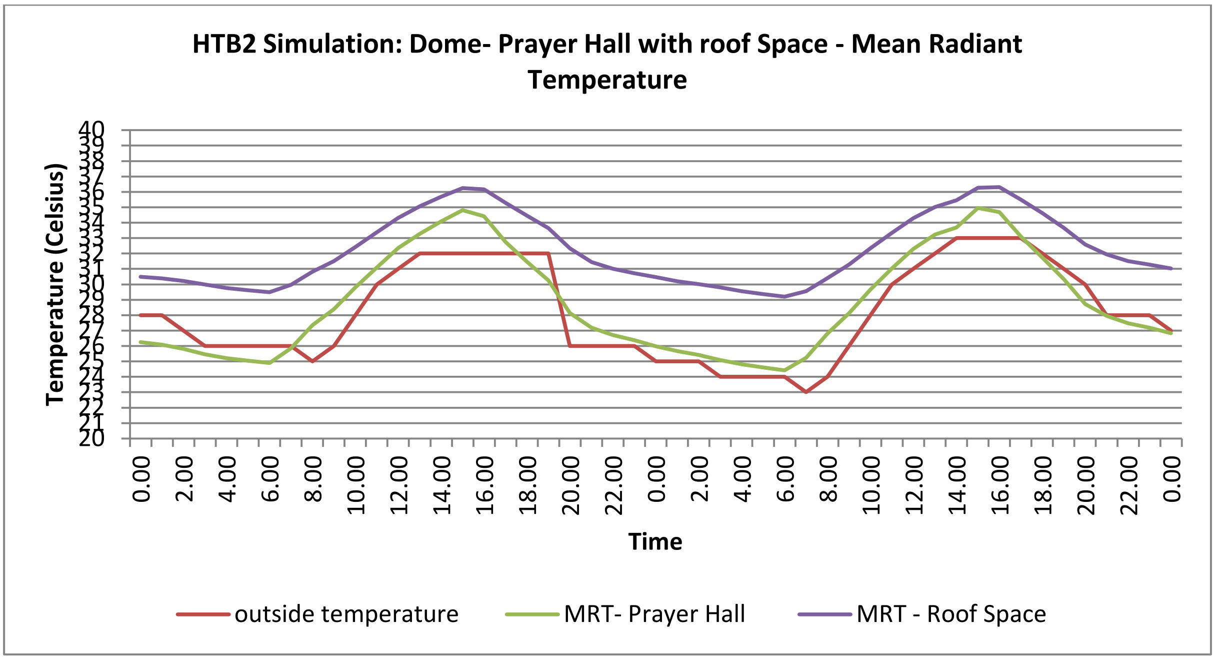


Figure 6. 9 - The Mean Radiant Temperature at the roof space and prayer hall of the domed roof mosque

the heat for a longer time. With this property, the concrete dome takes longer time to transfer the heat absorbed to the indoor space during the heating up process. Depending on the climate, this ability may be an advantage as it stores the heat before releasing it to the space. As the space is heated up according to the changes of the outdoor air temperature, the heat releases from the roof surfaces is minimised due to the property that concrete has. This reduces the sensation of heat felt by the users of the space. With this property, the concrete dome roof also takes longer time to cool down. This may affect the thermal comfort level especially during the cooling down process of the building. This is the situation when the outdoor air temperature is cooler than the indoor air temperature. For a hot and humid country, it is always thermally comfortable to enter a space that is cooler than the outdoor. The ability to store heat may become disadvantage during this period of time where the heat absorbed is now released to the interior as the air temperature cools down. The air temperature for this climate has small diurnal range and therefore, the cooling down of the temperature often does not even reach the suggested thermally comfortable air temperature. This situation can become worse because as the air temperature reduces, normally the relative humidity rises. With the release of the heat from the surfaces of the dome and the high content of humidity in the air, the thermal comfort level may not be achieved.

Contrastingly, the MRT of the prayer hall which is resulted mainly from the walls surrounding the area increases and reduces at a faster rate compared to the MRT of the roof space but at the same time the heat generated is always lower compared to the MRT of the roof surfaces. This indicates that the wall surfaces transfer less heat to the interior spaces compared to the roof surfaces. One of the reasons is that the wall surfaces of the mosque are mostly shadowed by the large overhangs of the roof and not directly exposed to the sun. There is less direct sunlight hits the wall and therefore less heat transmitted resulting in lower MRT. In addition to this, most of the materials used for the wall construction are made of timber which has lower value of transmitting heat energy.

Based on the observation, it can be assumed that the roof is a critical element to be considered in designing a domed mosque as it transmitted a lot of heat into the indoor space. The roof has the longest exposure time to the direct sunlight compared to the walls. The selection of the materials and construction types for the roof are very important in designing as it has bigger influence to the thermal comfort level inside the building. The wall may not play such an important role in influencing the indoor thermal condition by the means of transmitting the heat energy to the interior space as most of the time, the wall is shadowed by the large overhangs provided by the roof elements. Therefore, the selection of the material is less critical for the wall.

A different pattern of mean radiant temperature has been recorded for the pitched roof mosque. Figure 6.10 shows the pattern of the mean radiant temperature

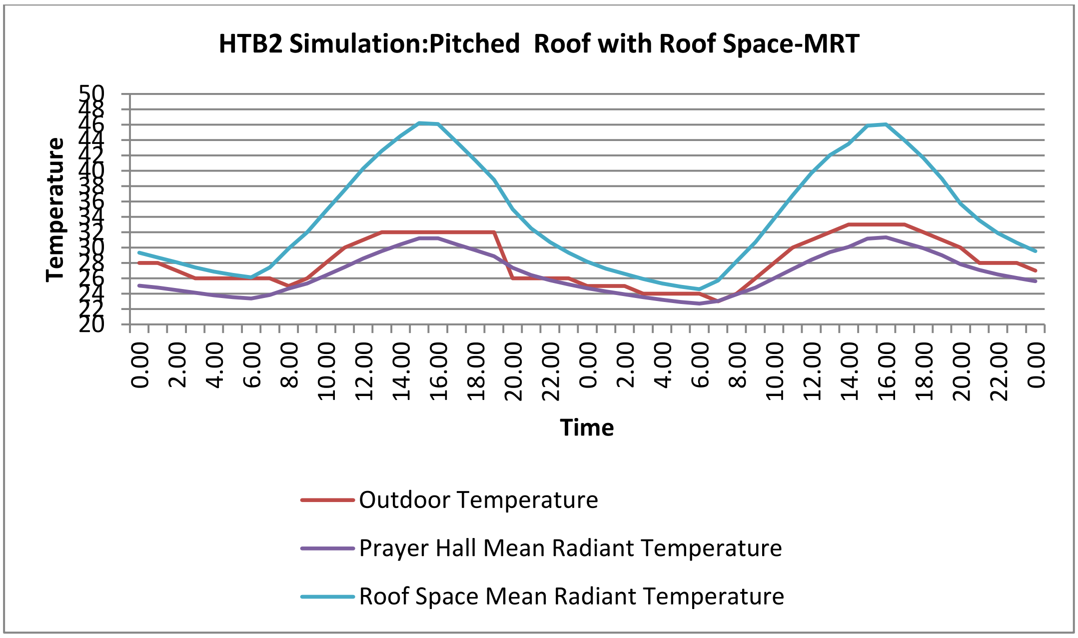


Figure 6. 10 – Mean Radiant Temperature for the Prayer Hall and Roof Space of Pitched Roof Mosque

for the roof and prayer hall spaces under the pitched roof. It is recorded that the differences between 1 degree Celsius and more than 7 degree Celsius can be observed between the MRT of the roof space and the prayer hall space. The differences of the MRT recorded between the space become greater as the building heats up and the differences is at the maximum point when the building reaches the highest temperature. Based on this simulation results, it is clearly shown that the MRT for the roof space of the pitched roof is significantly higher than the MRT of the prayer hall itself.

In this study, the effect of having the different degrees of the pitched roof is also investigated. Figure 6.11 shows the air temperature originated from the different

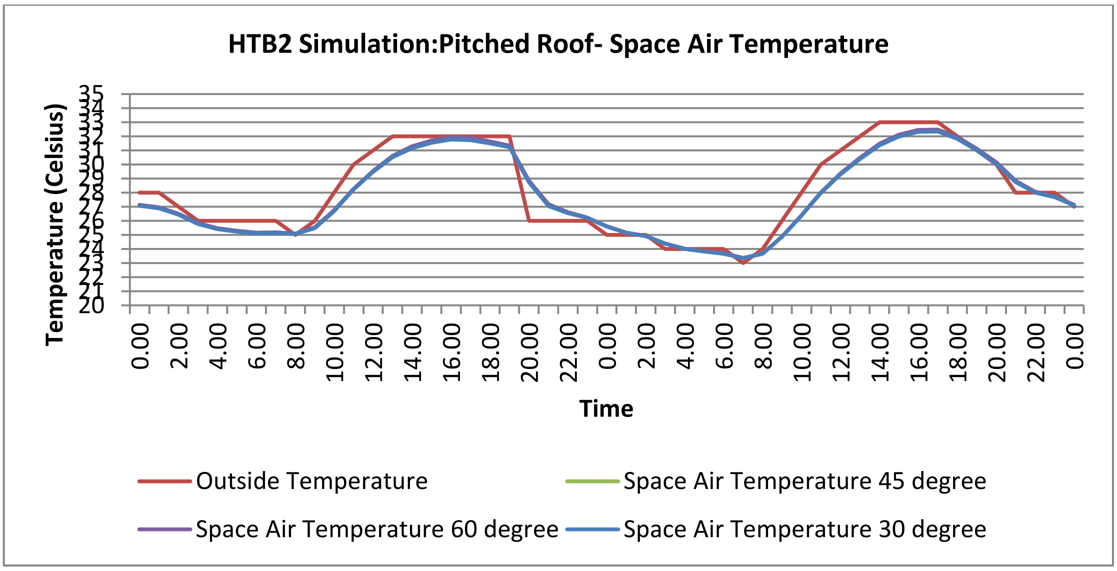


Figure 6.11- The comparison of the air temperature for the different degrees of pitch roof

degrees of the pitched roof. The three types of the slope degrees normally use in the pitched construction is 30, 45 and 60 degrees. Based on the simulation, the differences in the degree of the pitch do not have any influence to the space air temperature. Figure 6.11 shows the recorded space air temperature of the prayer hall with the application of 30, 45 and 60 degree pitch roof. The space air temperature recorded shows little differences despite the degrees of the pitched roof changed. Similarly, the changes in the degree of the pitched roof do not significantly affect the MRT of the space as shown in the following figure (Figure 6.12).

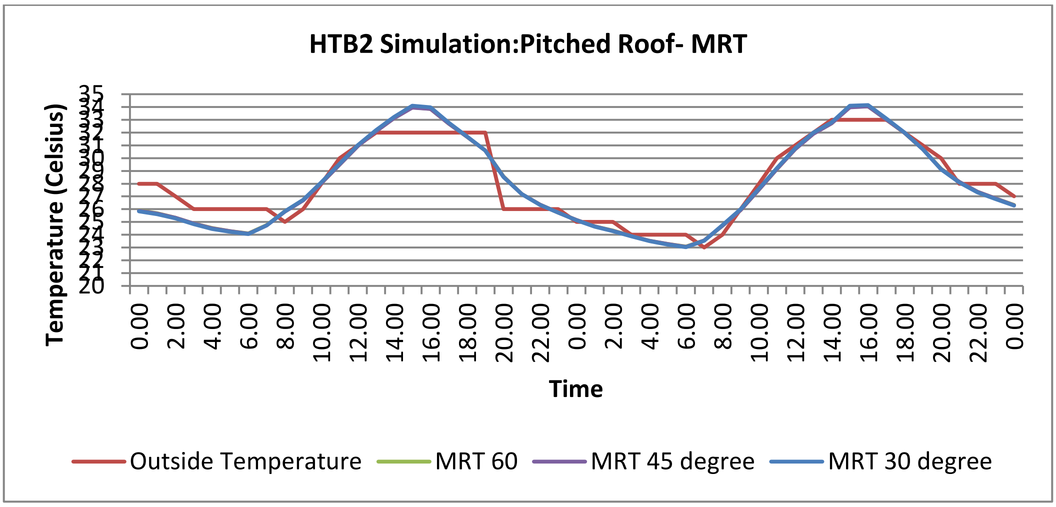


Figure 6. 12 – The Mean Radiant Temperature of the space for the pitched roof mosque with 60^{o} , 45^{o}, 30^{o} pitch.

Therefore, it can be concluded that the space air temperature and the mean radiant temperature (MRT) produced from the pitched roof is not affected by changing the slope of the pitched.

6. 2.4 Air movement and temperature distribution pattern

Air movement is one of the variables that affect the thermal comfort perception in a naturally ventilated building in a tropical country. With the hot and humid condition throughout the day, it is essential to have air movement to improve the quality of thermal comfort condition of the interior. The existence of air movement will assist the cross ventilation and air exchanges process. In addition, it will also help the body to cool down through the process of evaporation of the sweat produced. As discussed earlier, there are two passive methods that can be employed to assist the movement of air of the interior space of the building. They are 'cross' ventilation which is based on the pressure condition between the outlet and the inlet and 'stack effect' ventilation which is dependent on the vertical air temperature differences. The software WinAir4 is employed to assist in inquiring the patterns of the air movement for both types of mosques. The software will be able to show the distribution pattern of air movement and temperature.

Figure 6.13 shows the distribution pattern of air movement and temperature inside the modelled domed roof mosque at 0.25 meter high from the floor level. This

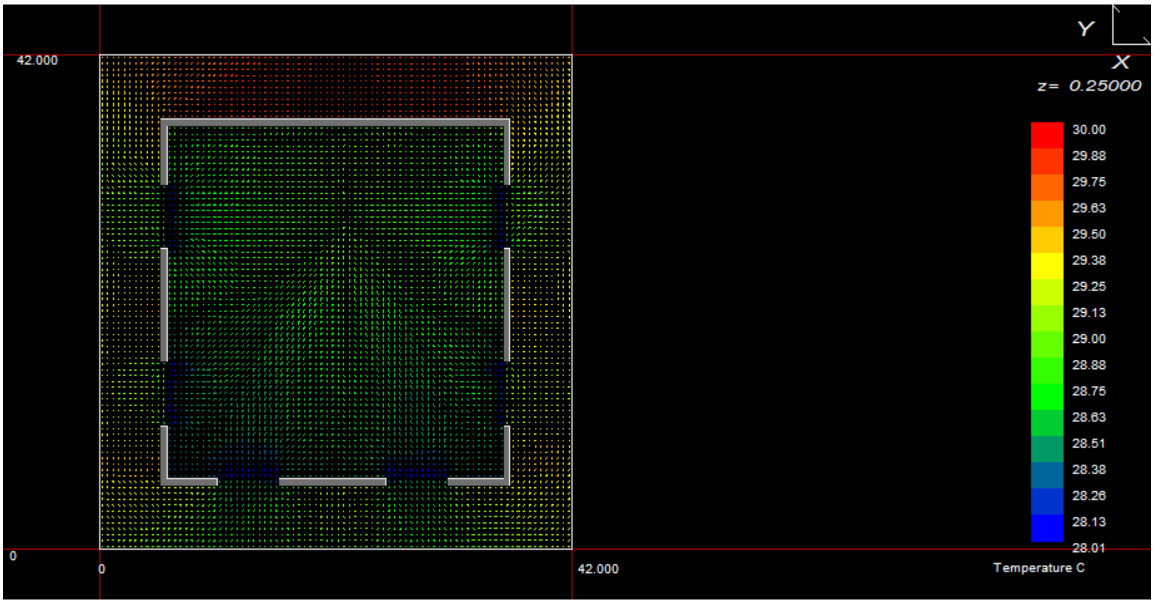


Figure 6. 13 – Air movement and temperature pattern in a prayer hall of a dome mosque – horizontal view.

is the sitting down level or the level where the activities took place. Six openings which are the doors to the prayer hall are opened to allow the air to move into the prayer hall. Based on the simulation, the air movement is able to influence the air temperature of the area closer to the openings.

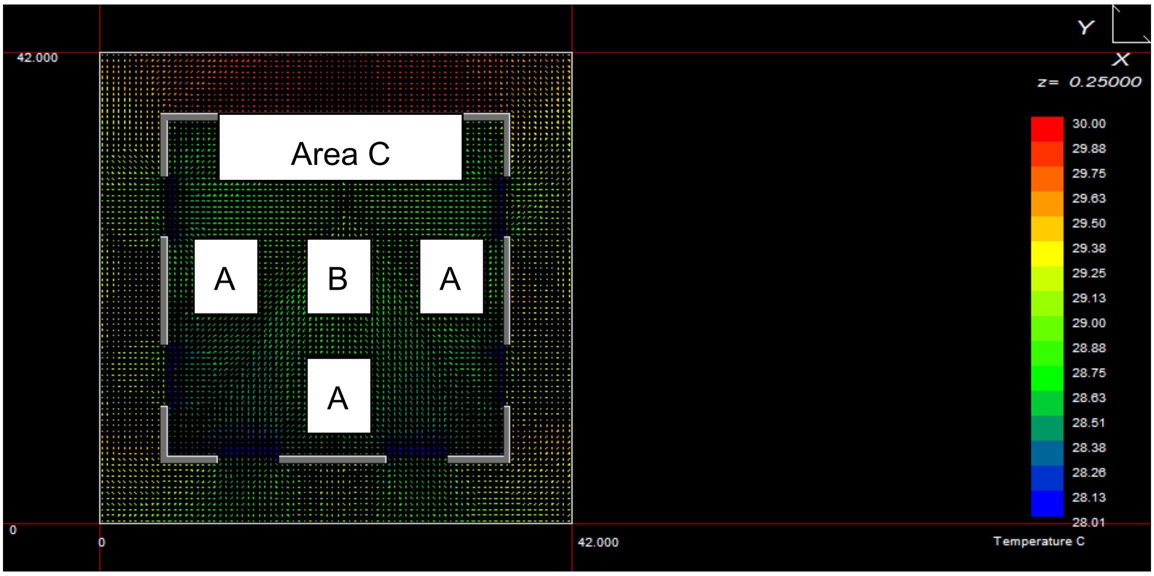


Figure 6. 14 – The indication of the areas that have weaker air movement.

Figure 6.14 shows the areas that have weaker air movement inside the prayer hall. There are three areas that have weaker air movement which are the area that is blocked by the wall (Area A), the centre part of the prayer hall (Area B)and the front area which is next to the mihrab wall (Area C). Area C is the area that need to be occupied first during the congregational pray. Without enough air movement, the users that are occupying those areas will feel thermally uncomfortable faster than the others who are located at the other areas that have air movement.

Figure 6.15 shows the vertical distribution of air temperature for the domed mosque. Based on the simulation, it is clearly noticed that the air temperature is stratified well in this mosque with the placement of the coolest layer of air temperature located at the lowest level and the hottest layer is located at the highest

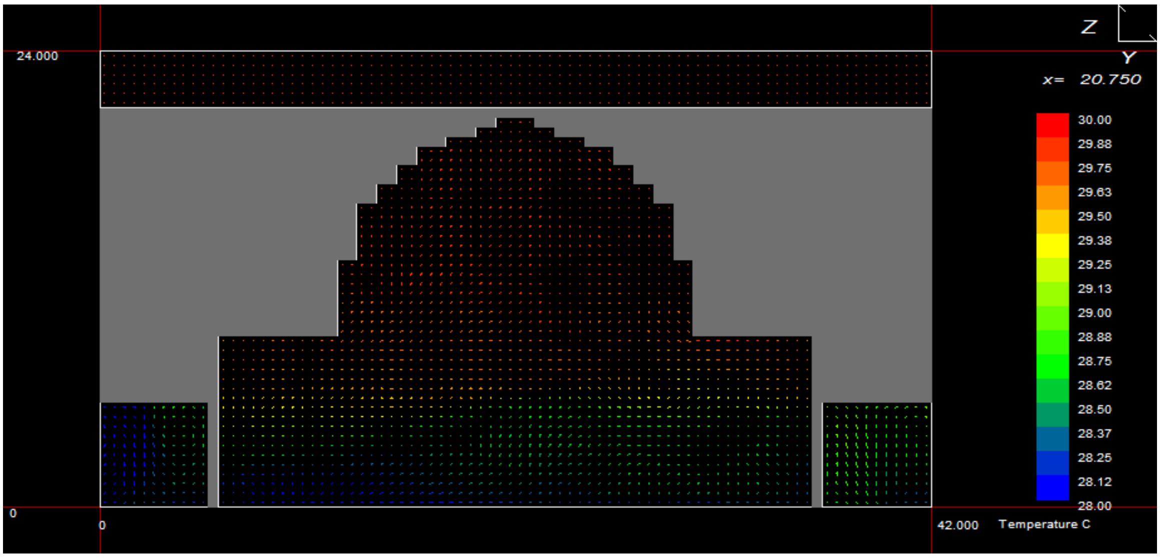


Figure 6. 15 – The distribution of air temperature in the prayer hall of a domed mosque

level which is under the dome roof. It can also be observed that the air movement is fairly weak. Based on these findings, it can be summarized that the air movement inside a domed mosque is relatively calm. This may be because the design of the roof allows the air to be stratified according to the temperature creating layers of air according to the temperature at different heights.

The ability to stratify the air temperature can be seen as an advantage or disadvantage for a domed mosque. In a larger size mosque, it is difficult to have effective cross ventilation due to the bigger distance from the inlet to the outlet as can be seen in Figure 6.14. With this obstacle, there is always a possibility that the exchanges of the air from the inside to the outside may not be very effective resulting in a cooler or hotter accumulated air temperature inside the space. With the ability of the domed roof mosque to stratify the air, the coolest layer of air can be obtained at the lowest level which is the active level of the mosque. This will ensure that the air temperature at this level is the lowest and most probably desirable at all time if the coolest air temperature is acceptable to the occupants.

This situation, however, can be a disadvantage when the coolest air may not be cool enough to be considered thermally comfortable by the occupants. As this building is naturally ventilated, the indoor air temperature is heavily dependent on the outdoor air temperature. The air temperature for the indoor rises proportionately to the outdoor air temperature and during the afternoon time, the outdoor air temperature rises beyond the tolerable range. When this situation occurs, the coolest air is no longer acceptable and at this stage, the situation can become thermally uncomfortable. As a natural reaction of a human body, sweat will be produced. With this situation, the air movement is required to increase the body cooling through the process of evaporation of the produced sweat due to the high content of humidity in the air. Due to the layering of air temperature inside a domed roof mosque, air movement inside the mosque is relatively weak and the ‘aided’ evaporative process cannot happen effectively without the assistance of air movement.

A different pattern of air distribution can be evidenced in the modelled pitched roof mosque model. Figure 6.16 shows the vertical distribution of air movement and temperature inside the pitched roof mosque. As illustrated in the figure, the air is unstably stratified compared to the domed roof mosque. This means that the layer of air temperature is not evenly distributed according to the temperature, being the coolest layer at the bottom and the hottest layer being at the top as evidenced

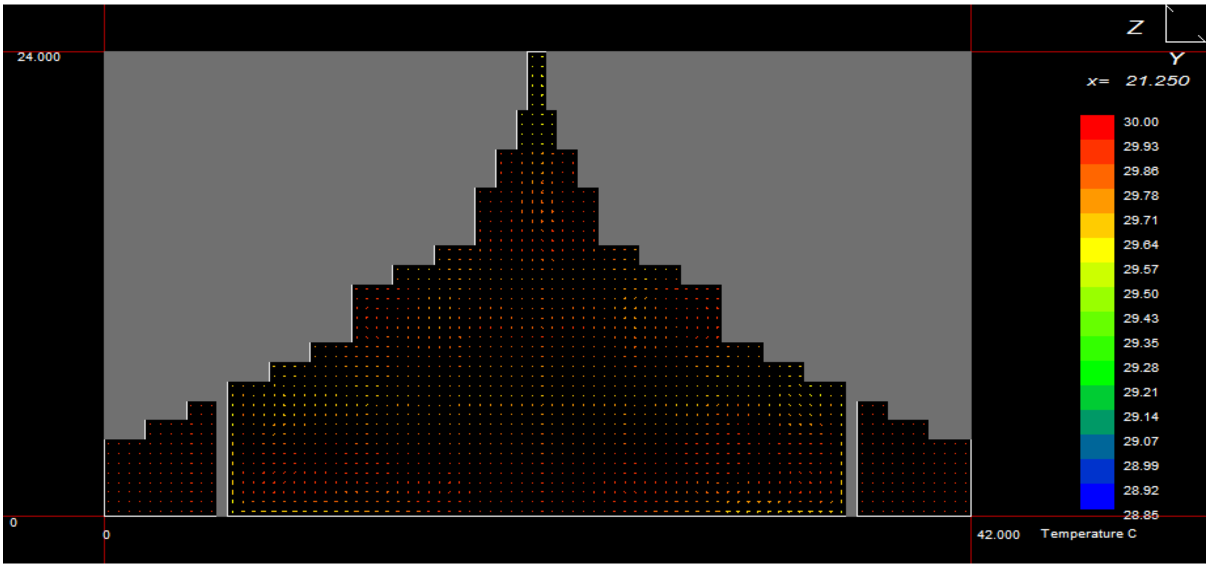


Figure 6. 16 – The air distribution inside a prayer hall of a pitched roof mosque.

in the prayer hall of a domed mosque. The unevenly distributed air according to the temperature occurs due to the design of the pitched roof. With the pitched or pyramid form roof, the area of the space under the pyramid reduces as it get higher. This situation will also create higher pressure area as it gets higher. Contrastingly, the air will become lighter and lower in pressure as it gets hotter. The air will rise to occupy the highest part of the building. Due to the high pressure formed by the shape of the pyramid as the level gets higher, the low pressure air will be pushed to a lower part, thus creating a reversed effect. As a result of this, no stratification of air happened. Instead, the air circulation is created in the space until it reaches the equilibrium state. This can be evidenced in Figure 6.17.

Figure 6.17 shows the horizontal distribution of air movement and temperature at the active level of the pitched roof mosque. There are many variation of temperature zones can be evidenced at this level. The coolest zone is located next to the opening and followed by the area next to the wall around the space. The air temperature is gradually increased as it moves closer to the centre of the space.

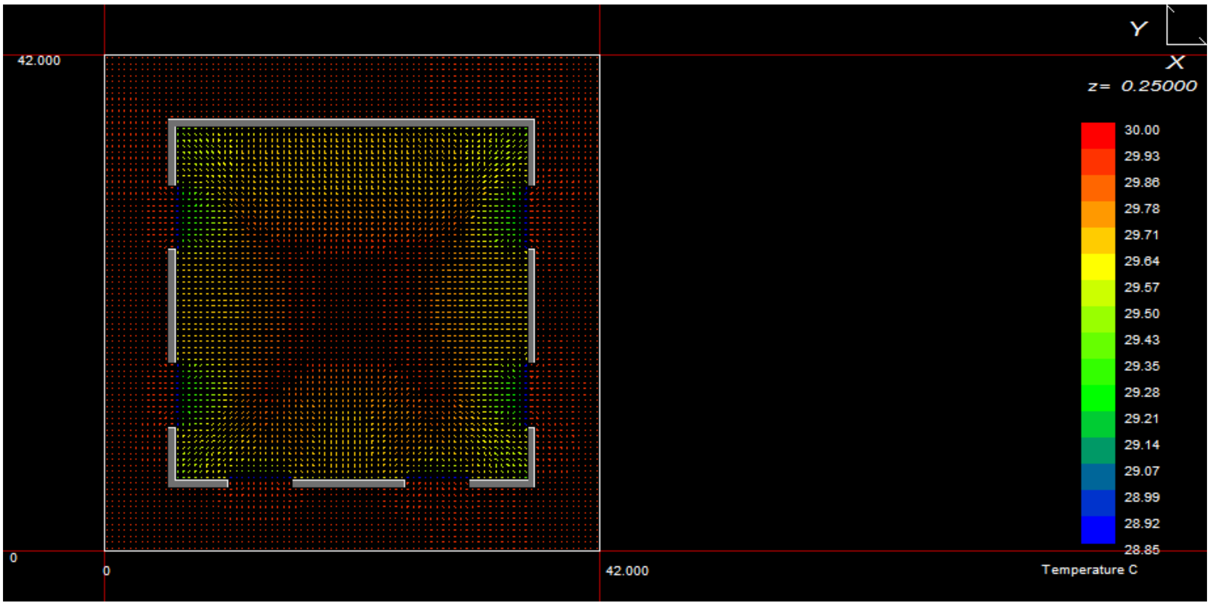


Figure 6. 17 – The air movement pattern and air temperature distribution at the active level in aprayer hall od a pitched roof mosque

As illustrated, the air circulation is relatively very active within the space. This is due to form of the pitched roof as explained earlier. This is the advantage of the pitched roof mosque. The air can be circulated creating an active air movement naturally. This will result in a better indoor environment by allowing the cooling of the occupants' body to happen through the process of evaporation aided by the air movement. At the same time, the air will be mixed up to achieve an equilibrium temperature. Considering this, it is important to consider the materials for the building to ensure that the minimal heat is transferred to the interior space to maintain low air temperature inside the space. Any heat gain will be transferred and distributed evenly in the space which may cause uncomfortable feeling. It is also an advantage to have circulated air based on the pressure because without the present of air movement from the outside, the air still has the ability to circulate and therefore the process of cooling the building can occur regardless of the wind condition.

6. 3 CONCLUSION

A simulation using HTB2 and WinAir4 has revealed that each of the domed and pitched roof design acts differently in influencing the thermal condition inside the prayer hall. Firstly, based on the conducted simulation, it is found that the average air temperature produced inside the prayer hall is relatively the same between both models. However, the simulation has also revealed that the duration of heating and cooling time between both models differs significantly where the pitched roof heats and cools faster compared to the domed roof. Secondly, it has also been found that when the roof space is separated from the prayer hall space, it will produce higher air temperature compared to the prayer hall space. The difference between the two spaces, however, is higher in the pitched roof compared to the domed roof mosque. The MRT of the roof spaces are also significantly higher for both of the roofs indicating that the roof is the main building element that is transferring the heat to the inside compared to other building elements such as walls and floor. In addition, changing the pitch level has insignificant changes to the air temperature for the pitched roof. Thirdly, it has also been discovered that the pattern of air movement and temperature distribution resulted from the roof design has a major difference between the pitched and domed roof mosque. The simulation using WinAir4 reveals that a domed roof mosque produces a clear stable stratification of air temperature with the coolest air temperature located at the bottom layer and the hottest located at the top level. A pitched roof mosque, on the other hands, produces no stratification of air temperature due to the pyramidal form of the roof. Instead, the air temperature is distributed in the space to achieve an equilibrium state. As a result of that, there is an active air circulation happens in the pitched roof mosque. The domed roof mosque shows a very stratified layer of air according to the temperature and leaving the air to be static and calm. The ability to stratify the air temperature allows the active level of the prayer hall to have the lowest temperature. As the building is naturally ventilated, there is a possibility that the lowest temperature may not be considered thermally comfortable. The heat transferred from the outdoor to the indoor has to be seriously considered if this type of the roof is to be used. In addition to this, the relative humidity is at the highest because the air temperature is the lowest at the active level. Due to the constant condition of the air paired with the high humidity level resulted from the stratification, this condition may create the feel of stuffiness. Air circulation is needed to assist the transfer of the sweat from the body to the air. Without enough air circulation, the process cannot take place efficiently. The pitched roof mosque, on the hand, is not able to create stratification due to the different pressures created from the shape of the roof. Instead of stratified air temperature, the indoor air is circulated to reach the equilibrium state. The temperature of the indoor air in this case is distributed evenly in the space and depending on the materials selected for the building elements the air temperature can be controlled. One of the benefits of using this type of roof is the air circulation created by the roof. With the geometry, the air circulation is activated due to the balancing act of the pressure and temperature influences on the air density. This allows the building to cool faster and helps the process of evaporation.

Based on the findings, it can be concluded that the pitched roof mosque will perform better in a naturally ventilated building located in the hot and humid climate countries such as Malaysia. .

Chapter 7 – Discussion and Proposal

7.1 Introduction

Chapter 7 discusses the result and analysis obtained from Chapters 5 and 6. Chapter 5 discusses the results and analysis based on the conducted survey and Chapter 6 explains the results and analysis based on the conducted simulation using HTB2 and WinAir4 software. Chapter 7 starts with the summary of the findings from both investigations. It follows with the discussion on the comfort culture of the local people and proposes the criteria that need to be considered in the thermal comfort evaluation. The chapter continues on the suggestion of the best roof design to be applied for Malaysia mosques in relation to the climate and comfort culture. It also discusses the design guidelines that can be considered in designing a naturally ventilated mosque based on the linkages obtained from the discussion on the thermal comfort perception and results from the simulation. Finally, the chapter concludes with the summary of the findings and suggestions.

7.2 Thermal Comfort Condition in a Typical Malaysian Mosque

Four mosques representing the typical Malaysian mosques have been selected for the investigation of the thermal comfort level inside the prayer halls. Two of the mosques are pitched roof and the other two mosques are domed roof mosques. The results in Chapter 5 have shown that the thermal comfort level varies from one mosque to the others and it is not directly related to the roof designs. The percentage of the participants who consider the thermal comfort condition as acceptable cannot be reflected by the types of the roof design alone.

Table 7.1 shows the percentage of the votes received for the four selected mosques. As described in Chapter 4 earlier, Mosque 1(Al Azim Mosque) and Mosque 2(Jamek Mosque) are the pitched roof mosques. Both of them share similarities in design, however they differ in term of size. Similarly, Mosque 3 (Sikamat Mosque) and Mosque 4 (Al Mizan Mosque) have a domed roof but they differ in term of size and facade design. Mosque 4 is smaller than Mosque 3 and has an open facade design. In term of size, Mosque 1 is the largest, followed by Mosque 3, Mosque 2 and Mosque 1.

TIME	PITCHED				DOMED			
	Mosque 1 (9,700 capacity		Mosque 2 (2,000 capacity)		Mosque 3 (3,500 capacity)		Mosque 4 (250 capacity)	
	Acceptable	Unacceptable	Acceptable	Unacceptable	Acceptable	Unacceptable	Acceptable	Unacceptable
Noon	49%	51%	100%	0%	77%	23%	69%	31%
Afternoon	37%	63%	100%	0%	68%	32%	16%	84%
Evening	39%	61%	69%	31%	46%	54%	89%	11%
Average(%)	**42**	**58**	**90**	**10**	**64**	**36**	**58**	**42**

Table 7. 1 - Percentage of votes for the acceptable and unacceptable thermal comfort condition in pitched roof and domed roof mosques.

Based on the ASHRAE standard that requires 80% of the votes to be acceptable for a space to be considered thermally comfortable, only one mosque (Mosque 2) meets the standard. Mosque 2 has the best thermal comfort condition followed by Mosque 3, Mosque 4 and Mosque 1. In terms of the thermal comfort condition in relation to the periods of time, all mosques, except Mosque 2, fail to provide acceptable thermal comfort condition during the noon and afternoon time which is the daytime period. Besides the good thermal comfort perception received by the Mosque 2 during daytime, it fails to provide the same condition during the evening time. Instead, Mosque 4 provides thermally comfortable environment (89% vote) during the evening time. The application of the pitched roof in Mosque 2 may have contributed to the thermally comfortable environment provided during the daytime however the pitched roof itself cannot be considered as a better roof design since Mosque 1 which is also a pitched roof mosque does not produce the same thermally comfortable environment as Mosque 2. In fact, Mosque 1 which is also the largest mosque among the four mosques is the least thermally comfortable mosque. Mosque 3, which is the second largest mosque and applies domed roof has better thermal comfort according to the votes received.

Another observation that can be made based on the collected data is that the effectiveness of the pitched and domed roof design may also be associated with the size of the prayer hall of the mosque. Based on the survey, Mosque 2 which is the pitched roof mosque and the third largest or medium size mosque is considered the best followed by Mosque 3 which is a domed roof mosque and the second largest (district mosque). Mosque 4 which is a dome mosque is the third best and has the smallest size or community size mosque and finally Mosque 1 which is the pitched roof mosque and also the largest (state mosque) is the worst in terms of respondents' perception on the thermal comfort. From this arrangement it can be interpreted that a pitched roof mosque may function well for a medium or smaller size mosque since the larger pitched roof mosque (Mosque 1) does not provide a good thermally indoor condition. On the other hand, it can also be suggested that a domed roof mosque may work well with a bigger size mosque since the second largest mosque (Mosque 2) that applies domed roof design is capable of providing better thermally indoor environment compared to Mosque 1 and Mosque 4.

The size of the buildings affects many factors pertaining to the indoor thermal condition. One of the factors is the exposure of the building elements to the sun. A bigger size building may have increased areas of building elements such as building facades and roof exposed to the sun which may affect the thermal condition. The size of a building may also affect the natural ventilation especially cross ventilation. For the case of a mosque, the basic geometry for the prayer hall is square in plan. With this configuration, the width and the length of space is definitely affected as the size increases. Therefore, the distance between the inlet and outlet opening is proportionately increased as the size of the prayer hall increases. Slim buildings are usually has better cross ventilation due to the closer distance between the inlet and the outlet point.

It is also noticed that the evening period has the least acceptable votes despite the fact that the air temperature during this time is the lowest except for Mosque 4. The major difference between Mosque 4 and other mosques is that the facade of Mosque 4 is open to the outside whereas other mosques have internal walls that separate the indoor space with the outside. With this condition, the huge openings allow the air exchanges to occur effectively and therefore, improve the indoor thermal condition of the prayer hall. This situation may have affected the thermal comfort condition of the indoor space during the evening time since the outdoor air temperature during this time is lower. With a greater ability to exchange the indoor air with the cooler outdoor air, it can certainly improve the thermal condition during evening time. With these varied results received by the pitched and domed roof mosques, it can be assumed that the roof design alone have insignificant effect to the thermal comfort condition inside the mosque. **The thermal comfort level of each mosque is unique and cannot be determined only by the design of the roof, in this case, the pitched and domed roof.**

Being the surface that is exposed directly to the sun for the longest time, it is predicted that the roof would affect the thermal comfort condition by increasing the air temperature of the indoor space. This prediction may be true if the building is an enclosed building and not a free running or naturally ventilated building. As a free running or naturally ventilated building, the indoor thermal condition is heavily dependent on the outdoor climatic condition. Normally, the heat transferred to the internal space is originated from the building elements that are directly exposed to the sun. However, the results have shown that this is not the case for the naturally ventilated building that is heavily dependent on the outdoor thermal condition. It seems that the heat generated from the roof has been balanced through the air exchanges between the outside and inside. The indoor air temperature for the selected mosques is found to be influenced by the outdoor temperature which is varies from one mosque to the other. The simulation of the modelled buildings has also shown that the influence of the outdoor air temperature to the indoor temperature for both of the pitched and domed roof is almost the same when enough openings created to allow effective air exchanges between the indoor and outdoor.

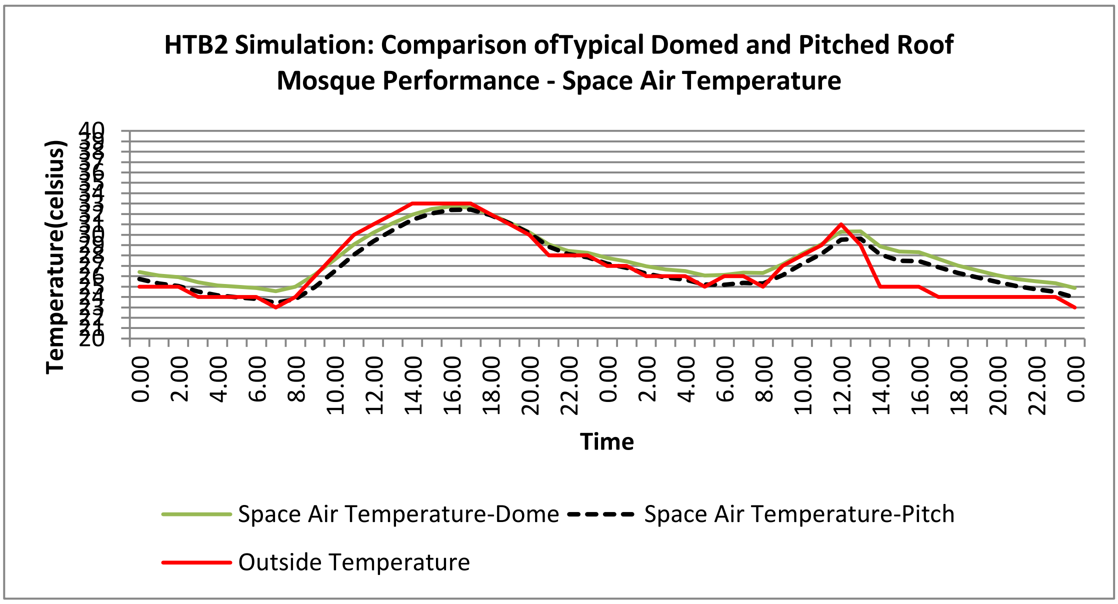


Figure 7. 1 - Comparison between the performance of the pitched and domed roof on space air temperature

Figure 7.1 and 7.2 show the comparison of the mosque performance based on the space air temperature and mean radiant temperature. Both of the figures show that both of the roof designs are actually producing almost similar pattern of heat gain and loss of almost the same value with a small differentiation of about 1 degree Celsius. Earlier research (Auliciems &deDear, 1978; Brager and deDear, 1998; deDear and Auliciems, 1993; Humphreys, 1978; Nicol, 2004) agrees that the indoor air temperature is directly affected by the outdoor air temperature and other factors

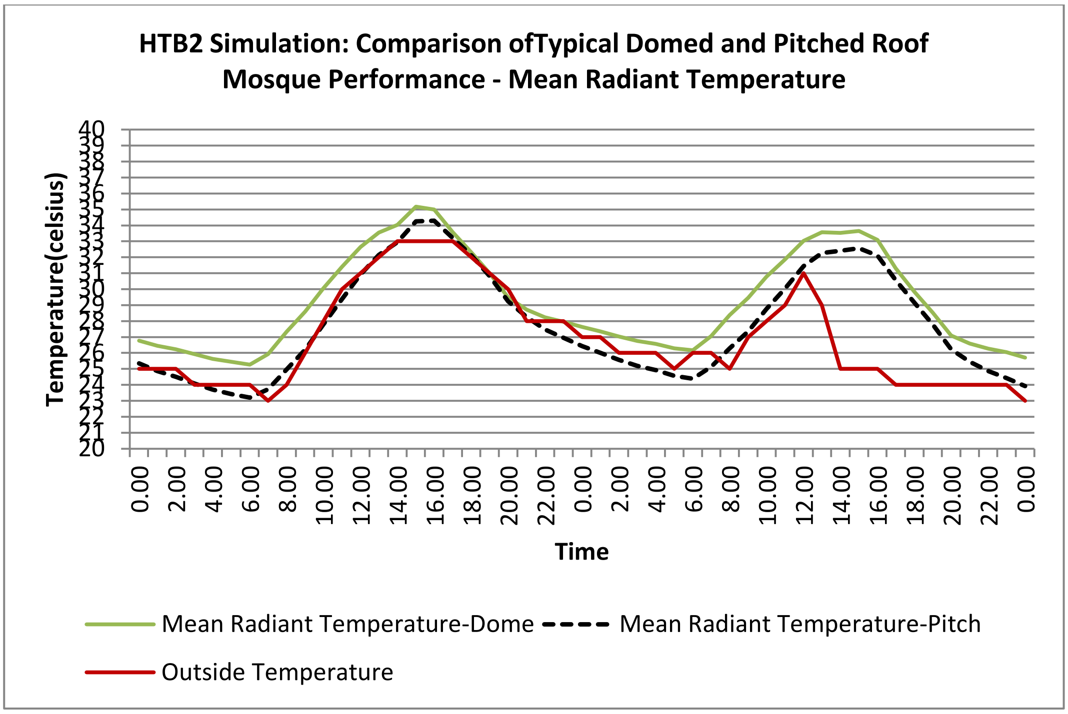


Figure 7. 2- Comparison between the performance of the pitched and domed roof on mean radiant temperature

such as mean radiant temperature are less influential in affecting the thermal comfort condition. Factors that are directly related to the condition of air such as relative humidity and air movement may have stronger influential role in affecting thermal comfort since in naturally ventilated building, the most influential factor is the outdoor air condition and both of these factors are directly influenced by the outdoor condition.

Based on these findings, it can be summarized that, the thermal comfort condition in naturally ventilated Malaysian mosques cannot be determined based on the roof design only. The effectiveness of the roof design in affecting the thermal comfort condition is also related to the size and the openings provided by the facades of the buildings. These design related factors may also be associated with the physical factors affecting thermal comfort such as air temperature, air movement and relative humidity. The following section discusses the relationships of the factors to one another in influencing thermal comfort in naturally ventilated Malaysian mosques.

7.3 FACTORS AFFECTING THERMAL COMFORT LEVEL

As been discussed earlier, the condition of the outside air especially the temperature strongly affects the indoor thermal comfort condition in a naturally ventilated building. Other thermal comfort factors that are directly related to the air condition are the air movement and relative humidity. In the study, these factors have been found to be a 'supporting' contributor rather than a 'joint' contributor to the thermal comfort condition. The 'supporting' contributor is defined as a factor that only affects thermal comfort condition when the main factor, which is, in this case, air temperature, is no longer under the 'natural' condition. The 'joint' contributor, on the other hand, is defined as a factor that contributes to the thermal comfort in all

	Mosque	Comfortably warm		Comfortable		Suggested Temperature	
		Air Temp(^{0}C)	RH (%)	Air Temp(^{0}C)	RH (%)	Neutral (0)	(1)
1.	Al Azim	29.6	70.9	29.4	67.6	23.9	30.3
2.	Jamek	28.4	82.1	28.2	77.5	25.0	31.0
3.	Sikamat	28.3	76.3	30.7	67.1	27.1	30.9
4.	Al Mizan	28.4	73.9	27.6	83.7	26.4	30.0

Table 7. 2 - The average air temperature and relative humidity based on the votes and the predicted neutral temperature using the regression method.

condition. This is elaborated in the following session. Table 7.2 summarizes the findings on the average air temperature and relative humidity under 'comfortably warm' and 'comfortable' condition and the predicted neutral temperature using the regression method based on the votes received.

7.3.1 Space Air Temperature and Thermal Comfort

There is no doubt that air temperature is an important factor in influencing thermal comfort level. For a tropical climate country such as Malaysia, a typical daily air temperature is ranging from 25 degree Celsius (early am hour) to 36 degree Celsius with more than 70% of relative humidity. For those who have not experienced this condition, they may consider the situation as intolerable and thermally uncomfortable. However, the local people who have lived with the condition throughout their lives may have different perceptions. Based on the findings in Chapter 5, the research has revealed that the air temperature alone may not be significant enough to influence the thermal comfort level. According to the ASHRAE and Bedford scale, the 'comfortably warm' sensation vote under the Bedford scale and 'warm' under ASHRAE scale is considered as the highest tolerable limit for acceptable thermal comfort condition. Referring to Table 7.2, the range of the air temperature for the 'comfortably warm' condition is from 28.3 ^{0} Celsius to 29.6 ^{0} Celsius. It is also noticed that the range of the 'comfortable' condition collected from the field survey is from 28.2 ^{0} Celsius to 30.7 ^{0} Celsius. If compared between the two ranges, the 'comfortable' condition has bigger range than 'comfortably warm' condition and the most upper range for the 'comfortable' condition even exceeds the most upper range of the 'comfortably warm' condition. Compared to the comfort temperature suggested by the Fanger's Thermal comfort equation which is 25.6^0 Celsius, it is obvious that the respondents from this survey have higher tolerance toward the air temperature. The wider range of temperature that has been established for the ‘comfortable’ category also shows that the increase in the air temperature, under certain circumstances, does not necessarily and directly change the thermal comfort perception. The presence of other variables that is related to the air condition such as the relative humidity and air movement has to be considered in predicting the thermal comfort perception.

7.3.2 Humidity and Thermal Comfort

The high percentage of relative humidity has been considered problematic in providing thermally comfortable environment especially when the average daily air temperature is always higher than the suggested comfort temperature. The ideal relative humidity is between 50% and 60%. Relative humidity that is more than that becomes undesirable because it affects the thermal comfort level. The research, however has found that the effect of higher content of humidity in the air (higher percentage of relative humidity) is only felt when the air temperature experienced is an excess. When the air temperature is at the comfort level, the higher content of humidity in the air plays insignificant role in influencing the thermal comfort sensation. However, the research has also shown that the tolerable air temperature (when the air temperature is under ‘warm’ category) can become thermally uncomfortable situation with the present of high humidity in the air especially when there is no air movement. For a country with high air temperatures almost at all time, the humidity has a significant role in influencing the thermal comfort level.

7.3.3. Wind Condition and Thermal Sensation

The wind condition has been found to affect the thermal comfort condition considerably especially in a tropical country. Depending on the climatic zones, the air movement or also known as draught can be a nuisance especially for the moderate climate countries. For a tropical country that has hot and humid climate such as Malaysia, the air movement is desirable at all time. It helps to cool down the body and improve the perception of thermal comfort with the presence of air movement. The findings in Chapter 5 shows that the air movement is preferred at all time regardless of the other conditions of the variables which are the humidity and air temperature. It provides the extra cooling sensation even though the thermal condition is sensed to be neutral and comfortable. In addition to this the air movement helps the cooling process by transferring the moisture from the body to the air. The same situation has also been recorded in which the condition is felt to be cooler with the present of air movement even though the air temperature has actually been increased (Wigo & Knez, 2005).

With these findings, the level of importance for each thermal comfort variables for the hot and humid countries, specifically Malaysia can be explained as shown in the next figure (Figure 7.3). Referring to Figure 7.3, air temperature is the major influence in thermal comfort for all climatic zones. The variance that can be found between other climatic zones regarding the influence of air temperature is the ability to tolerate high air temperature. For this research, it is found that the air temperature

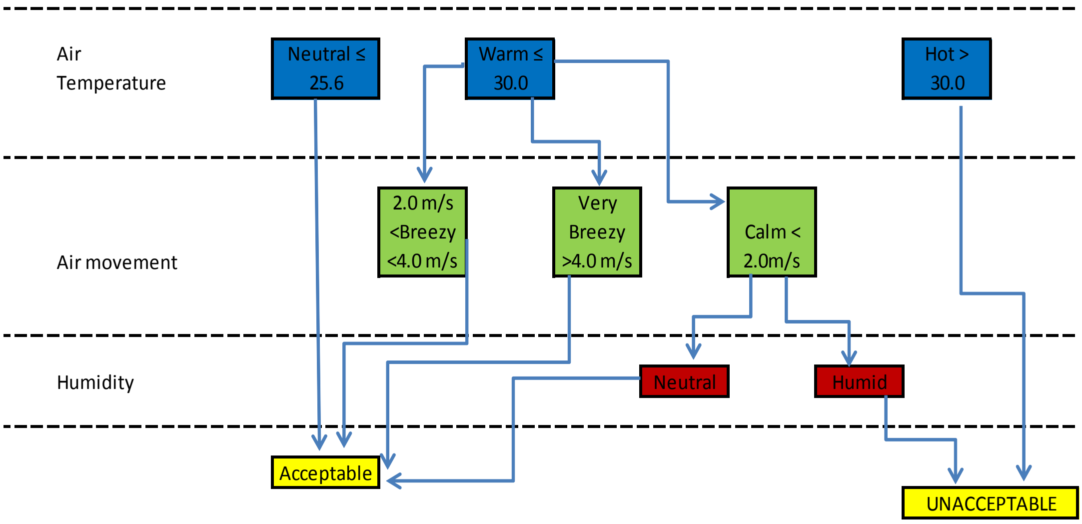


Figure 7. 3 - The filtration process to show the importance of physical factor in influencing thermal comfort

can be tolerated up to 30.7 ^{0} Celsius depending on the condition of other variables. The research has also found that when the air temperature is at the neutral level, the thermal comfort level is always acceptable regardless of the conditions of the other two variables, namely air movement and relative humidity. Therefore, the condition of the other two variables can be ignored in determining the thermal comfort level because they have insignificant effect to the thermal comfort level when the air temperature is at the neutral level.

When the air temperature starts to be warmer than the neutral temperature, the possibility of becoming thermally uncomfortable arises. The air movement condition at this point is critical in influencing the thermal comfort condition. Without the presence of air movement, the thermal comfort level becomes unacceptable. This is because the sweat that is produced due to the excess heat experienced, keeps the heat of the body at the same level when here is no evaporative cooling process occurred. This process, however, can happen naturally when the humidity level is at the neutral level. However, with the high humidity level that is already exist in the air of hot and humid countries the process could not be possible. The assistance of the air movement is required to help the process to happen. The air movement must be strong enough to be felt by the user. Slower air velocity which cannot be felt by the skin of human body has insignificant effect in cooling down the body. When there is little air movement present, the role of the humidity in influencing the thermal comfort level becomes more significant. The combination of 'warm' thermal sensation, 'calm' air movement and 'neutral' level of humidity is still tolerable due to the ability of the sweat produced to evaporate naturally. The condition changes to become unacceptable when the air is humid which prevents the process of evaporation to happen naturally. Regardless of the condition of the humidity and wind condition, when the air temperature is considered 'hot', the thermal comfort level becomes unacceptable.

Based on these observations, it is obvious that the air temperature is the primary element in determining the thermal comfort level. At the correct and appropriate air temperatures, the influences of other variables are not significant in influencing the thermal comfort level as pictured in the figure. Therefore, it can be concluded that the relative humidity and air movement are classified as 'contributing' factors rather than 'joint factors' due to their insignificances in influencing thermal comfort condition. It is therefore recommended that the optimum air temperature which can ignore the influences form the other two contributing factors to be established so that it can be used as a reference in designing building or evaluating thermal comfort.

7.4 THERMAL COMFORT RANGE AND INDEXES

The issue of the applicability of the evaluative scale such as ASHRAE in evaluating thermal comfort especially in naturally ventilated building has been discussed frequently by other researchers. Most of the research conducted on naturally ventilated buildings in tropical countries found that the thermal comfort predicted using the scale is not accurate. The analysis of the study also reveals that the acceptable range of thermal comfort condition which is based on the ASHRAE seven thermal sensation scale (between -1(cool) and +1(warm)) may not be suitable to be used for naturally ventilated buildings in the hot and humid countries such as Malaysia. The 'cool' condition is rarely achievable and the 'warm' condition is perceived as an additional heat which only causes thermally uncomfortable environment.

Referring to the Table 7.2, the importance of air temperature in influencing the thermal comfort level can be evidenced. For examples, the average of the air temperature for the 'comfortably warm' situation is ranged from 28.3^0 Celsius to 29.6^0 Celsius. Similarly, the predicted 'warm' temperature based on the ASHRAE scale range from 30.0^0 Celsius to 31.0^0 Celsius. Both of these values show a minimal variation when compared to the range of the 'comfortable' condition and 'neutral' temperature. The small range indicates that the air temperature can only be tolerated until it reaches a specific temperature, in this case, 31^0 Celsius. If we look at the filtration process of the thermal comfort factor (Figure 7.3), the influence of other variables become effective when the air temperature is under 'warm' category in which excessive heat energy is sensed by the body. This indicates that the 'warm' category cannot be used as a benchmark for the tolerable estimated air temperature as other variables may contribute to the thermally uncomfortable environment. The small range of air temperature recorded for this category also indicates that the air temperature at this level can easily be affected by the other variables, in this case air movement and relative humidity. Comparatively, when the air temperature is at neutral level, the influences of other variables are insignificant and can be ignored. Therefore in designing a building the targeted air temperature should be benchmarked at the neutral category for this climatic region. Based on these situations, it is suggested that the limit of acceptable thermal comfort condition should be placed at 0(neutral) using the ASHRAE scale.

The perception towards the description on the thermal sensation scales may also be viewed differently. A perception is usually influenced by the experience and therefore it is unique to an individual. For a country with a moderate climate the presence of a little heat may be desired. On the other hand, for a country with a hot and humid condition the warm condition experienced in a moderate country may have been considered as neutral by the people due to the acclimatization process. Instead, the warm condition in hot and humid countries may have been considered as very hot to the people in a moderate country. This depends on their experiences. In a country with a hot and humid condition throughout the year, additional heat is an excessive and not desirable at all time due to the existing high air temperature during the day throughout the year. Based on this opinion and the discussion earlier it is therefore inaccurate to apply the range of scale that is considered tolerable as suggested by the ASHRAE scale to the hot and humid country such as Malaysia.

The ASHRAE has also suggested that in most indoor condition the comfort temperature is around 25.6 ^{0} Celsius. Using the neutral category under the ASHRAE thermal sensation scale, the predicted neutral air temperature which is produced from the linear regression based on the respondent votes is ranged from 23.9 ^{0} Celsius to 27.1^0 Celsius for the four mosques selected. Based on these figures, the average air temperature is 25.6 ^{0} Celsius with the standard deviation of 1.43. It is an agreement with the value that is proposed by the ASHRAE. Therefore, it is valid to use this value which is 25.6^0 Celsius as the indoor comfort air temperature to be achieved when designing a building. It is expected that when the air temperature is within the range, the influences from other variables such as the humidity and the air movement are minimal and therefore, thermal comfort condition can be achieved regardless of the condition of other variables.

The ASHRAE thermal sensation scale also suggests that the range of the thermally acceptable comfort condition is ranged from -1 or ‘cool’ to +1 or ‘warm’. It has been argued by Charles (2003) that the thermal sensation scale is based on the thermal sensation and cannot be used to measure the thermal comfort since thermal comfort are influenced by many other factors and not just by thermal sensation. It cannot be argued that other variables affected the thermal comfort perception however the significance of each variables varies according to the local climate and culture. For examples, in a moderate climate, the air movement often brings discomfort as the air is normally cool. For a hot and humid country, the air movement is desirable to help to cool down the body as the air temperature and humidity is always high throughout the day. Based on this condition, the research has studied the three important physical variables, namely, air temperature, relative humidity

and air temperature that can affect the thermal comfort level for the hot and humid country, specifically Malaysia. As illustrated in the Figure 7.3, the air temperature is the primary variable of thermal comfort level. However, only at certain temperature, the presence of other variables can be ignored as the effect is insignificance. Therefore, for the hot and humid country, it is inappropriate to use the thermal sensation scale to predict the thermal comfort condition of a building since other factors may have affected the thermal comfort level as the temperature changes.

The research also suggests that the incorporation of the humidity and air movement into the evaluative thermal sensation scale may produce better evaluative result. The suggestion for the proposed thermal comfort sensation scale is illustrated in the next figure (Figure 7.4).

Thermal Sensation (TS)(ASHRAE)	Too Cold (-3)	Cold (-2)	Cool (-1)	Neutral (0)	Warm (+1)	Hot (+2)	Too Hot (+3)
Air Movement(VA)	Very Breezy (0)		Breezy (1)		Calm(2)		
Humidity (H)	Neutral (0)		Humid (1)		Very Humid (2)		

Figure 7. 4 – Proposed Thermal Comfort Perception scale for naturally ventilated building in hot and humid climate

In evaluating the thermal comfort condition of a space in a hot and humid area, three variables are included to get an improved result which does not only consider the thermal sensation but also the humidity and air movement. For the thermal sensation scale, the ASHRAE seven thermal sensation scale is applied as it has been accepted throughout the world. Into this existing scale, the air movement scale is added which is divided into three simple categories which are calm(2), breezy (1) and very breezy (0). The same scale has also been given to the humidity which is neutral (0), humid (1) and very humid (2). To determine the thermal comfort level, the score from the three scales are added and divided by three to get an average. If the answer falls between -1 and +1, the space can be considered as thermally comfortable and acceptable. In other words, it can be written as:

Thermal Comfort = (Thermal sensation(TS) + Air Movement (VA) + Humidity (H))/3

This addition is to improve the evaluation on thermal comfort as the evaluation tool also considers the humidity and air movement. With this combination, the evaluation is not just on thermal sensation but also consider other important variables in evaluating thermal comfort especially for the region with hot and humid climate like Malaysia. The issue has been discussed quite widely especially on the application of the scale on the naturally ventilated building especially in a tropical country and with the introduction of the combination, it can help to produce better prediction on the thermal comfort condition for the region that the thermal comfort is highly affected by the relative humidity and air movement.

7.5 DESIGN GUIDELINES PROPOSAL

Thermal comfort can be achieved if the design of a building considers and responds well to the factors affecting the thermal comfort especially the physical factors. These factors are air temperature, relative humidity and air movement. As discussed earlier in this chapter, the air temperature is the primary factor affecting the thermal comfort of the indoor space followed by the air movement and finally relative humidity. For a naturally ventilated building, the indoor air temperature is heavily dependent on the outdoor air temperature. Similarly, the relative humidity of the indoor is also influenced by the outdoor climatic conditions. Both of these factors, the air temperature and relative humidity, are inversely correlated. Theoretically, when the air temperature increases, the relative humidity reduces as the hotter air has the ability to contain more moisture compared to the cooler air. Therefore, the change in the air temperature also affects the relative humidity. Due to this, by controlling the rate of air exchanges from the outside to the inside, both of the air temperature and relative humidity can be controlled. In addition to this, the movement of air, in many ways, helps in improving the thermal comfort perception. It has been shown that the air temperature is favoured at all time regardless of the condition of air temperature. These issues have to be considered in designing a building in order to provide a thermally comfortable indoor environment.

The two most popular designs of the mosque in Malaysia is the domed mosque and pitched roof mosque. The domed mosque design has become more popular recently compared to the pitched roof mosque. Arguments about its insensitivity to the cultural and traditional sensitivity are still being discussed. Little is also known about the suitability of these designs in responding to the climatic factors in providing thermal comfort indoor environment. Based on the simulation using HTB2 and WinAir4, a different effect has been revealed resulting from the use of the two types of the roof. Based on the findings which have been discussed in Chapter 6, guidelines are proposed to help the designers in designing a mosque that can provide thermally comfortable indoor environment with minimal assistance of mechanical equipment.

As the air temperature is the primary element that determines the thermal comfort, a closer attention should be given on how to maintain a low air temperature inside the space. For a naturally ventilated building, controlling the air temperature that goes into the building is not possible. Changing the air temperature is only possible with the help of an air conditioning system. However, maintaining the indoor temperature below the outdoor temperature can be done and this is one of the measures suggested in order to keep the indoor space thermally comfortable. Improving the natural ventilation is an important measure to tackle the problem of thermal discomfort as found out earlier that the air movement is favourable in maintaining the thermal comfort. There are many ways that can be applied to the design to improve the thermal indoor condition. However, based on the findings obtained from the research, concentration on these two objectives is thought to be more significant in an attempt to design a naturally ventilated mosque that can passively provide a thermally comfortable indoor condition. The objectives are:

a. Reducing the Mean Radiant Temperature (MRT)

Since the air temperature that goes in the building cannot be manipulated naturally, controlling the MRT is the best way to improve the indoor thermal condition. MRT can be described as the average temperature from the surfaces of the space that can be felt by a person occupying the space. To maintain the thermal comfort level of the space, it is suggested that the maximum differences between the air temperature and the MRT is about 2 ^{0} Celsius above the air temperature. This is only true for a moderate country that experiences moderate temperature and require additional heat. For a building that is located in a tropical region, a cooler surface is preferred to absorb the heat energy from the air temperature. There are many ways that have been suggested by the researchers that can be applied in designing the mosque.

One of the ways is to provide shade to the surfaces making up the space, for this case, the prayer hall. Malaysia is located close to the equator (2°30 N 112°30 E). Due to this, the sun is located above the head at most of the time throughout the daytime. The role of the roof in shading the surfaces especially the wall bordering the prayer hall becomes critical as it reduces the heat conduction and radiation from the walls to the prayer hall. It has been evidenced in recent mosque development that the roof has been extended beyond the building line to provide shade to the walls of the prayer hall. An additional space which is called a verandah or passageway has also been introduced to create an intermediate space between the outside and the prayer hall in an attempt to reduce the heat transmission from the outside. Even though these measures have been implemented, a careful study to determine the size of the overhang or extension is required in proposing the extension especially when the position of sun is low which happens during the early morning and late afternoon. It has been identified through the observation that the overhangs provided especially in a large mosque are unable to provide shade to the walls during these periods of time due to the bigger distance from the floor to the overhangs allowing the direct sunlight to fall on the walls. In some cases, the prayer hall is located at an elevated level and this exposes the building elements especially the walls to the direct sunlight. The introduction of vegetation especially trees can be introduced to filter the sunlight that reaches the wall and this measure is more effective if the prayer hall is located at the ground level that allows the filtration of the sunlight by the trees and vegetation to take place.

It has also been revealed in the research that the roof element creates higher MRT in comparison with the other building elements. Obviously, the element is exposed longer to the sunlight compared to other elements and this allows the materials to be heated up and radiated the heat to the inside. Therefore, selecting the appropriate materials to be used as the roof materials is important. It is suggested that the materials suitable to be used for this climate are the materials that have low heat conductivity and retention properties. This means that the materials are able to reduce the heat transfer from the outside to the inside and able to cool down quickly. The simulation conducted based on the common materials and construction method used for both roofs indicates that the dome roof which is predominantly made of concrete heats up slower and has lower MRT in comparison with the pitched roof which is mainly constructed using clay tiles with ceiling and timber frames. In reducing the heat transfer to the interior space, the concrete roof due to its low conductivity properties is able to retain the heat in the structure. The thickness of the construction allows the structure to keep some of the heat before releasing it to the interior space. The materials that are used in the pitched roof construction have low conductivity too. However, the thickness of the materials is unable to retain the heat and therefore releasing most of the heat absorbed to the interior space. Due to this reason too, the cooling process of the pitched roof is faster when compared to the domed roof.

Both of these roofs have their advantages and disadvantages. The ability of the domed roof to provide low MRT during the day is appreciated. However during the evening time the MRT becomes higher when compared to the MRT provided by the pitched roof during the evening time. It also creates a bigger difference between the outdoor and indoor operative temperature which is not advisable. Based on the survey conducted, it is also recorded that the evening is the period that many of the occupants feel less comfortable even though the recorded air temperature is lower. This situation explains why the thermal comfort condition is at worst during the evening time.

The problem with pitched roof is the high MRT recorded during the afternoon time. It has been suggested that one of the ways to reduce the radiation of heat from the roof element is to provide appropriate insulation. Reflective insulation is one of the methods suggested to reduce the transfer of the heat through radiation. Proper installation of the reflective insulation is advised to ensure the effectiveness of the materials.

b. Improving the natural ventilation

Air movement is one of the criteria that have been requested by the respondents in the preference survey. Knowing that the importance of the air movement in providing thermal comfort for this region especially for this building type, measures to improve the air movement or ventilation for the building have to be considered as a main priority in the design process. The simulation conducted on the domed roof and the pitched roof mosque has revealed that each of the building acts differently in terms of the air circulation inside the space.

The domed roof, besides the ability to store heat for a longer time, has the ability to stratify the air according to the temperature. The hotter air is lighter and less dense compared to the cooler air which is denser. Due to this the hotter air accommodates the higher parts of the volume while the denser air occupies the lower part of the space. The benefit of this ability is the lowest layer of air is always the coolest air in the space. For a naturally ventilated building, it is quite common to have the indoor and outdoor air temperature to be the same because of the uncontrollable air temperature that enters the indoor space. Due to no differentiation between the indoor and outdoor air temperature, the air is quite stagnant at this level because there is not enough temperature difference to activate the movement. Since the air movement is desirable at all times this condition is not so favourable. With the stagnant air, the influence of relative humidity may be significant to the thermal comfort condition. The condition is only acceptable when the air temperature is at or below the suggested neutral temperature which is 25.6 degree Celsius. This temperature only occurs when the building is not in use which is during the early morning time or late night time.

The pitched roof, on the other hand, is able to circulate the air with different temperature in the space. No stratification of air temperature occurs in the pitched roof mosque. Instead, the air is moved around the space to achieve the equilibrium state. The ability to move the air around the space is due to the variation of air density as a result of the roof shape which has been discussed earlier in Chapter Six. With this situation, an active movement of air can be seen inside the pitched roof mosque. Due to the natural forces, the air movement cannot be sensed physically by the body. However, with the air movement, it allows the distribution of the humidity as well which in returns helps the evaporative process to take place.

Natural ventilation can happen effectively when there is a difference of pressure between the inlet and outlet and in vertical temperature. Cross ventilation is caused by the high pressure at the inlet point and the low pressure at the outlet point. It is caused by the wind force that pushes the cooler air inside the space to replace the hot air by pushing it out through the outlet. The effectiveness of the cross ventilation is based on the positioning of the inlet and outlet which should be aligned. Stack effect ventilation on the other hand, is caused by the difference in the density of the air as a result of temperature change. In order for the stack effect to happen the space must have lower and upper openings. The stack effect ventilation is more effective if the distance between the lower and the upper opening is greater as the pressure differences becomes greater due the temperature differences. The lighter and hotter air will rise and be replaced by the cooler air at the lower level. Both of these measures are the options that can be applied to both of the mosques. The question is, which measure is more appropriate and effective to be applied to the mosque?

As discussed earlier, the domed mosque has the ability to stratify the air temperature which means that the coolest air will be located at the lowest level and the hotter air will rise to the upper level. The active level of the mosque is between the floor level up to 2 meter level. Due to this stratified air according to the temperature, it is important to maintain the air temperature at the active level. The effective way to maintain the air temperature at this level is through cross ventilation. Cross ventilation is relied on the availability of the inlets and outlets. Therefore, providing ample openings as inlets at one side and outlets at the opposite side may help the cross ventilation. The openings should be high enough to allow the exchanges of hot and cold air at this active level. Openings that are too high may not be effective as the domed mosque may not be able to effectively stratify the air according to the temperature. It is advisable to maintain the height of the opening to the height of the active zone required only to ensure that the temperature at this level is at the lowest possible temperature by exchanging it with the outdoor temperature.

Due to the ability to stratify the air according to the temperature, there is a temperature difference between the lower and the upper part of the space. The differences in air temperature according to the heights of the space also allow the natural ventilation which is called stack effect ventilation to occur. Openings at the lower and upper parts of the space have to be provided to allow the flow of the air. Due to the temperature difference, the hotter air rises as it is lighter than the cooler air. It leaves the lower part to be at the low pressure condition which allows cooler air to enter the space. The hotter air will flow to the outside through the openings made at the upper level. This happens when there is a pressure difference between the inside and the outside. The outside pressure has to be lower to allow the hotter indoor air temperature that has higher pressure to flow to the outside.

Unlike the domed roof, the pitched roof mosque allows the air to circulate in the space to achieve the state of equilibrium due to the pyramid shape. With this condition, instead of stratifying the air, the temperature of the air is at the average at all times. To maintain the air temperature at the lowest possible, the exchanges of the air between the indoor and the outdoor must be efficient. The cross ventilation must efficiently takes place by providing the inlet and outlet across each other. As suggested by other researchers, the inlet must be wider to allow as much air to enter at the active level. The cross ventilation to allow the air exchanges is more critical for the pitched roof mosque compared to the domed mosque. The air is mixed through the air circulation to produce an average or equilibrium air temperature. Due to this process the air inside the space will get hotter if there is no air exchange between the outside and the inside. To ensure that the air temperature is maintained at the lowest possible, the hotter air needs to be replaced by the cooler air. Therefore, effective and ample openings to act as inlets and outlets for the air are necessary.

The continuous air movement resulted from the pyramid shape of the roof helps to distribute the humidity in the space. The continuous movement of air may not be felt by the bare skin however, it helps to distribute the humidity around the space. As a result the relative humidity is almost the same at any level of the space. The air movement can also help to cool down the body through the process of evaporation of the sweat. Compared to the domed roof, the air is stratified. The lowest layer of air is the coolest air. In many cases, in a naturally ventilated building located in the hot and humid area, the air temperature is often higher than the preferred temperature. When the air is at the coolest condition, the relative humidity is normally at the highest. With this condition, and the high outside air temperature, there is a possibility that thermally uncomfortable environment will occur which mostly resulted from the high content of humidity and the stagnant of air due to the stratification of the air.

The stack effect ventilation is another method to promote natural ventilation. This application requires the air temperature difference between the lower and upper part of the building. Since the ability of the pyramid to circulate the air due to the reverse effect of pressure and density, it is less beneficial to employ the stack effect ventilation for the pitched roof mosque.

With these findings, it is suggested that the selection of the roof designs between the domed and pitched roof must also be associated with the size of the mosque and the opening design. A bigger mosque is more suitable to apply domed roof as the size will also provide a bigger difference in height of the building to allow the stack effect ventilation to occur. The ability of the domed roof to stratify the air improves the effectiveness of the stack effect ventilation. Cross ventilation is not efficient for a bigger mosque due to the greater distance between the inlet and the outlet of the air. A smaller mosque where cross ventilation can occur effectively, a pitched roof is more relevant as its ability to circulate the air inside the space will provide continuous air movement which is desirable for the hot and humid country such as Malaysia. This will also influence the design of the opening to ensure that the cross ventilation can happen effectively.

7.6 Conclusion

It has been found that the thermal comfort factors affecting the mosque users are primarily influenced by the air temperature called the 'primary factor' and assisted by 'contributing factors' which are the relative humidity and air movement.

The presence of air movement is desirable at all time but the relative humidity is only effective in influencing the thermal comfort when the air temperature is beyond the neutral temperature, especially when the air is stagnant. Due to this finding, it is important for a naturally ventilated building to have efficient natural ventilation to ensure that the level of thermal comfort inside the space is tolerable. The presence of air movement, in many circumstances, is able to improve the thermal comfort level.

The study on the influence of the two types of roof designs which are the domed and pitched roof has revealed that both of the design will have the same effect to the air temperature inside the prayer hall since both of the designs are naturally ventilated and the indoor air temperature is heavily dependent on the outdoor temperature. However, both of the designs have been found to be able to influence the air distribution and movement inside the prayer hall in a different manner. The major difference between the domed and pitched roof mosque is that the domed mosque has the ability to stratify the air according to the temperature layering the coolest air at the lowest level and the hottest air at the highest level. This situation will create a stagnant air situation inside the space. The pitched roof, on the other hand, is able to mix the cool and hot air to achieve the state of equilibrium creating an active air movement inside the space naturally.

Based on the findings on the thermal comfort culture and the influences of the two roof designs inside the prayer hall, it can be concluded that the pitched roof design is more suitable to be applied for Malaysia which has hot and humid climate. This is due to the reason that the pitched roof mosque has the ability to circulate the air creating continuous air movement inside the space assisting the evaporative process to happen which can cool down the body. Even though the air movement may not be felt by the users, this continuous air movement will help to reduce the feeling of stuffiness. The thermal comfort culture of the place also supports that the air movement is highly desirable at all time regardless of the situation and with the ability of the pitched roof to circulate the air without the assistance of the mechanical equipment, it is highly recommended to use the pitched roof design for the mosque in Malaysia.

CHAPTER 8 – CONCLUSION

8.1 INTRODUCTION

The intention of the research is to study the thermal comfort condition in typical naturally ventilated Malaysian mosques which are significantly characterized by the roof designs either domed or pitched roof. Along with this investigation, the study also looks at important factors affecting the thermal comfort level for this type of building and at the same time to reveal the best roof design to be applied in Malaysian mosques that is able to produce better indoor thermal condition. The two most popular roof designs applied at the mosques which are the domed and pitched roof mosques have been questioned on their suitability and relevance to the local culture and Islamic religion. Both designs have been seen to have their own strengths in relating to the culture and religion and therefore it is difficult to justify which roof design is better than the other. The information on how these two designs responding to the local climate may help in determining which design is better to be applied for this country and region. The design should not only respond well to the culture and religion but most importantly to the climate. In searching for the information which involves the thermal comfort culture of the local people, many surprising findings have been unearthed. These findings, later on, lead to the suggestions to improve the mosque designs. This chapter summarizes the findings, and discusses the implication that they may have on future investigations.

8.2 RESEARCH PROCESS, AIMS AND OBJECTIVES

The aim of the research is to study the effectiveness of the two typical mosque roof designs which are the domed and pitched roof design in providing thermally comfortable indoor environment in a typical naturally ventilated mosque of Malaysian. The investigation has been conducted using survey and field measurement and simulation. Figure 8.1 shows the process involved in the investigation.

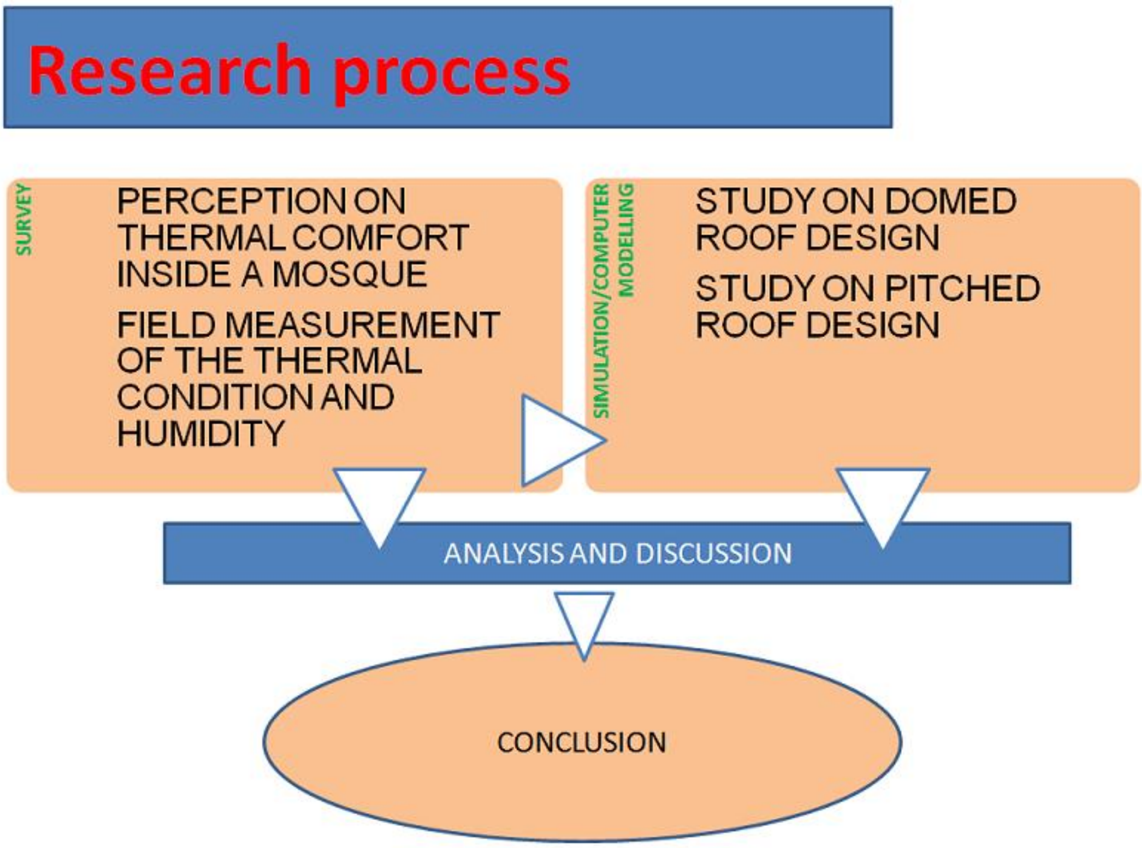


Figure 8. 1 - The research process diagram

The objectives of the research using the survey and field measurement approach are:

- The users perception on the thermal comfort condition of the two types of the mosques which are the pitch and domed roof mosques.
- The dominating factor of thermal comfort level and other contributing factors
- The range of tolerable indoor air temperature for the prayer hall of the selected mosques
- The appropriate methods of evaluating the thermal comfort condition for this climate and region and specifically for this building type.

The objectives of the research using simulation based on the software HTB2 and Win Air4 are:

- The heat gain and loss pattern
- The influence of the opening area and the heat gain
- The roof space vs. the prayer hall space
- Wind movement pattern and air temperature distribution

8.3 FINDINGS

Several findings have been discovered during the investigation. Table 8.1 shows the summary of the objectives for and findings obtained from the survey and field measurement methods. Firstly, based on the analysis conducted on the data collected through the survey and field measurement approach, it is found that there is no direct relationship between thermal comfort with the roof design by itself. The

Survey and Field Measurement Method

Objectives	Findings
• The users perception on the thermal comfort condition of the two types of the mosques which are the pitch and domed roof mosques.	• There is no direct relationship between thermal comfort with the roof design by itself.
• The dominating factor of thermal comfort level and other contributing factors	• The thermal comfort is significantly governed by the air temperature. When the air temperature is considered 'neutral', the other factors (ie: relative humidity, air movement) are ineffective in influencing thermal comfort. • Air movement is always preferable in any condition.
• The range of tolerable indoor air temperature for the prayer hall of the selected mosques	• The range of the neutral temperature is between 23.9 Celsius and 27.1 Celsius .
• The appropriate methods of evaluating the thermal comfort condition for this climate and region and specifically for this building type.	• Based on ASHRAE Thermal sensation scale, the acceptable condition for thermal comfort is between scale 'cool' and 'warm'(-1 and 1). However, for tropical climate zone which rarely experience 'cool' climate, the acceptable condition should be only under 'neutral' scale.

Table 8. 1 - The summary of the objectives and findings obtained from the survey and field measurement methods.

roof design in some ways, affects the thermal comfort. However there is no direct relationship between thermal comfort and the roof designs investigated which are the pitched and domed roof designs. The thermal comfort prediction cannot be based on the roof design itself. Instead, the total design including the facade and openings must be considered in evaluating thermal comfort. However, there is a pattern that shows a smaller mosque has better thermal comfort condition. Instead of the roof design, the size together with the roof design acts as a factor in influencing the thermal comfort condition.

Secondly, it is also discovered that the thermal comfort is significantly governed by the air temperature. When the air temperature is considered ‘neutral’, the other factors (ie: relative humidity, air movement) are ineffective in influencing thermal comfort. The humidity would only have its influence when the air temperature was beyond the tolerable limit with little air movement. Based on these findings, it is suggested that the ‘neutral’(0) level using the ASHRAE scale for the thermal sensation should be used as the optimum or desired condition omitting the scale ‘warm’(+1) as an acceptable range suggested by the ASHRAE. At this level, the condition of other variables could be ignored. Rather than to accommodate many variables which may lead to some complication, concentrating on one major variable at a time would be an effective way of tackling the problem. Based on this suggestion, it was proposed that the optimum or desired air temperature is 25.6 degree Celsius. The range of the tolerable temperature suggested is between 23.9 Celsius and 27.1 Celsius. The suggested temperature was lower than what has been suggested by other earlier researchers. Most of the research found that the neutral temperature for naturally ventilated building was around 28 degree Celsius which was fairly high when compared to the predicted neutral temperature from the study. The reason that the air temperature proposed by this study was lower is most probably due to the clothing restriction. In a mosque, the users are required to dress appropriately according to the guidelines provided. The normal clothing for man has to cover all the body part and only exposing the head, hand and feet. Some of the users also wear headwear called 'songkok' when performing their prayers. The restrictions on the way to dress unable the user to make changes to the way they dress when staying inside the mosque. With this type of clothing it is estimated that the clo. value is about 0.75 -0.80. Due to the restriction to respond adaptively, the air temperature desired is lower than it has been estimated earlier by other research. This is the desired indoor air temperature to be achieved for the space of prayer hall in a mosque only.

Thirdly, it is also found that air movement is always preferable in any condition If the desired air temperature as mentioned above is unattainable, the next corrective measure is to provide or promote air movement in the space. It has to be sensible by the human body and continuous to ensure that the thermal comfort level can be maintained.

Table 8.2 summarizes the objectives for and findings from the simulation method using the HTB2 and WinAir4 software developed by Cardiff University. Based on the simulation utilizing the HTB2 and WinAir4 software, a number of findings had been discovered. Based on the simulation using HTB2 (refer Table 8.2), there were little differences pertaining to the thermal condition inside the prayer hall of the two modeled mosques. In general, the average air temperature recorded for

Objectives	Simulation Using HTB2 and WinAir4	Findings
HTB2	The heat gain and loss pattern	The average air temperature produced inside the prayer hall is relatively the same between both domed and pitched roof models. Heating and cooling time differs. Pitched roof heats up and cools down faster than the domed roof.
	The influence of the opening area and the heat gain	Bigger openings allow the heating and cooling process faster until the indoor air temperature reaches the same temperature with the outside air temperature
	The roof space vs. prayer hall space	If the roof and prayer hall is separated, the air temperature inside the roof space is higher than the prayer hall. The difference is higher in a pitched roof compared to the domed roof. The MRT is also higher in the roof space indicating that the roof is the main building element transferring the heat to the inside.
WinAir4	Wind movement pattern and air temperature distribution	Significant differences in the pattern of air movement and air distribution between the domed and pitched roof mosque Domed roof has the ability to stratify the air according to the temperature. The lowest layer being the cooler and the highest layer being the hottest Pitched roof is able to circulate the air inside the prayer hall space to achieve an equilibrium temperature by mixing the hot and cool air

Table 8. 2 - The summary of the objectives and findings from the simulation process

the two types of the mosques was fairly the same between the domed and pitched roof mosques. In many naturally ventilated building, the indoor temperature is heavily dependent on the outdoor air temperature. To a certain point, the indoor air temperature will reach the equilibrium state where the indoor air temperature is equal with the outdoor air temperature. Due to this situation, the predicted air temperature for the space was fairly the same for both types of designs. The significant difference can only be seen on the duration taken by the space to cool down. The pitched roof mosque heated up and cooled down faster than the domed roof mosques. The ability to cool down faster has been suggested as one of the good characteristics of a naturally ventilated building located in a hot and humid area. Based on this notion, the pitched roof design was more appropriate to be applied for the area. Further investigation using the HTB2 also showed that the roof space under the pitched roof was hotter than the roof space under the dome roof while the prayer halls under these two roofs had approximately the same air temperature. It also showed that the roof space under the pitched roof cooled faster than the roof space under the domed roof. In addition to this, the Mean Radiant Temperature predicted by using the HTB2 for the roof space when compared to the prayer hall was higher. This showed that the roof contributed bigger heat energy to the interior space when compared to other building elements such as the floors and walls. It is therefore suggested that careful attention should be given to the selection of roof materials and construction to reduce the radiant heat generated from the roof.

WinAir4 was applied to visualize the distribution of the air and the air movement pattern inside the space. Surprisingly, the simulation produced a distinctive variation in the distribution of the air inside the prayer hall of the domed and pitched roof mosque. The domed roof mosque had the ability to stratify the air according to the temperature whereas the pitched roof mosque averaged the air temperature inside the space by creating continuous air circulation. This finding produced information that helps in the understanding of the building behaviour and therefore, measures can be advised to improve the design to produce a thermally comfortable indoor environment.

Survey and Field Measurement	Simulation
• The thermal comfort level of each mosque is unique and cannot be determined only by the design of the roof.	• **Reducing the Mean Radiant Temperature**. Minimising the heat transfer from the building elements especially the roof being the most exposed building elements to the sun.
• The air temperature is the '**primary**' factor affecting thermal comfort whereas the air movement and relative humidity are the '**contributing**' factors.	• **Improving the natural ventilation**. Air movement is always desirable at all time. Applying the correct measure in providing natural ventilation is crucial to ensure the effective natural ventilation to happen
• Air movement is always desirable at any condition	
• The evaluative method of inferring thermal comfort may need to be changed due to the different perception of thermal experience. Neutral temperature should be used in determining the ideal or acceptable temperature. Scale of Relative Humidity and air movement need to be incorporated in the evaluative method.	
Conclusion	• Pitched roof mosques are better than the domed roof mosques in providing thermally comfortable indoor environment due to their ability to circulate the air to achieve a state of equilibrium creating continuous air movement provided that good cross ventilation is present. Smaller and medium scale mosque • In domed mosques the air is stratified according to the temperature and therefore creating stagnant air condition. Stack effect ventilation is effective to be used. Large scale mosque.

Table 8. 3 - The outcomes from both methods and the conclusion

Chapter 7 discussed and provided synthesis between the findings from the survey and the simulation. Table 8.3 shows the outcomes from both approaches and the conclusion based on the outcomes. Based on the results, the better selection of the roof design on the mosque can be determined and proposals to improve the design are suggested. From the Survey and Field Measurement findings, it is undisputable that the air temperature is the major factor in affecting the thermal comfort. The research had revealed that the air movement was equally as important as air temperature in affecting the thermal comfort in this type of climate. The air movement is preferred in almost all condition of air temperature either neutral or warm condition.

Another suggestion that is made resulted from the investigation is to improve the evaluative scale by incorporating the scale of humidity and air movement sensation into the ASHRAE Thermal Sensation Scale in predicting the thermal comfort condition for a naturally ventilated building located in a tropical country that has hot and humid climate. It has been argued that the ASHRAE Thermal Sensation scale is not applicable in predicting the thermal comfort perception especially for a naturally ventilated building in tropical countries. It is just referring to the thermal sensation, whereas the thermal comfort is comprised of other variables. Despite the fact that it is not relevant, the ASHRAE Thermal Sensation scale is still being referred in predicting the thermal comfort condition. The incorporation of perception on the level of humidity and wind condition adds the consideration of two more factors that are highly influential in affecting the thermal comfort for a building located in the hot and humid climate. With this incorporation the application of the revised ASHRAE Thermal Sensation scale can be more relevant in evaluating the thermal comfort condition for the tropical countries. Further testing on the scales must be conducted before the scale can be used.

The analysis from the simulation is suggesting that minimizing the heat transfer from the building elements especially the elements that are directly exposed to the sun. With the location of the country that is closer to the equator, the position of the sun is almost on top of the head during daytime exposing the roof directly to the sun almost at all time during the day. Therefore it is necessary to reduce the heat transfer from the roof of a building. In addition to this, it is also suggested that the ventilation inside the mosque has to be effective either using cross ventilation or stack effect ventilation. Both of the mosques show different behavior in distributing the air inside the space and therefore correct approach in selecting the types of natural ventilation is important in order to improve the thermal comfort level inside the space.

Based on all the findings discovered during the research, it is finally concluded that the pitched and the domed roof of a mosque acts differently especially in air movement and temperature distribution inside the space it covers. The domed roof mosque was more suitable to apply the 'stack effect' concept due to its capability to stratify the air according to the temperature. This creates a difference in temperature between the lower which is the inlet and the upper part which is the outlet. With this ability, it is also suggested that the domed roof is more suited to a bigger scale mosque. A mosque that has a larger built up area has a difficulty in cross ventilation due to the larger distance between the inlet and outlet. Therefore, the exchanges of the cooler air from the outside to the inside may not occur efficiently. The larger built up area of the mosque is normally complimented with the height. With the sufficient distance created between the lower inlet and the upper outlet assisted with the ability to stratify the air according to the temperature, the 'stack effect' ventilation can happen effectively in the domed roof mosque. In addition to this, the stratification of the air keeps the lower part of the prayer hall space which is also the active level at the lowest temperature at all time. The design guideline proposal should focus on improving the 'stack effect' ventilation rather than cross ventilation.

In the case of the pitched roof mosque, unlike the domed roof mosque, the stratification of the air did not happen in the prayer hall space. Instead, the air was circulated inside the space to reach the equilibrium state. The pyramid shape created a lower density area at the lower level and a higher density as it goes higher. The air that enters the space is higher in density at the lower level due to its cooler condition and lower density as the air rises to a higher level due to the increase in the temperature. This reversal effect created by the shape of the pyramid allows the air to be circulated to reach the equilibrium state. With this action the air temperature of the prayer hall is well distributed and there is a bigger potential that the prayer hall space can be hotter if the exchanges between the inside and outside air does not occur effectively. The most appropriate way to ventilate the space is through the cross ventilation method. The 'stack effect' ventilation is less efficient due to the smaller differences in the air temperature between the lower and upper part of the prayer hall space. As the cross ventilation is more appropriate for this design, it can be concluded that the pitched roof mosque is more practical to be applied for a small to medium range mosque. The cross ventilation is dependent on the differences of pressure at the point of inlet and outlet. The inlet must have higher pressure than the outlet in order for the cross ventilation to occur. A small or medium size mosque has shorter distance between the walls as the majority of the floor plan for the prayer hall is square in shape. The shorter distance allows the air from the outside to enter the space and with sufficient pressure at the inlet point, the air is able to move through the space and push the hotter air to the outside. Enough pressure is required for the air to move through the space. A bigger mosque needs higher pressure to allow the air to pass through the spaces. If the pressure were insufficient, the air that enters the space was circulated in the space to achieve the equilibrium state. The air exchange between the indoor and outdoor does not happen effectively and therefore, there is a higher possibility of the indoor thermal condition to be unsatisfactory which may happen in a larger scale mosque.

Based on this finding and referring to the thermal comfort culture investigated earlier which said that air movement is desirable at all time, the pitched roof has the advantage in providing better thermal indoor condition compared to the domed roof because of its capability to circulate the indoor air creating air movement which is desirable for naturally ventilated buildings. With this finding, other issues that are related to the effectiveness of natural ventilation of the building can be strategized such as the size of the mosque and opening design to ensure the effectiveness of the pitched and domed roof design in providing thermally comfortable indoor condition. It is hope that the findings and information from the research can be used in designing future mosques and inspires others in conducting further research on the related issues.

8.4 CONSTRAINTS AND LIMITATIONS

In conducting the research, there are many constraints and limitation that have been encountered. First of all, in the thermal comfort culture investigation, the respondents are only males. No female respondent has participated in the survey. This is due to the ethics in communicating in the studied premises. In a mosque, it is considered unethical to communicate between a woman and man. There is a separation of area allocated inside the prayer hall where only women are allowed to enter. The research requires the respondents to be in the space and with this limitation the survey from the female respondents is not obtained. Therefore, the results obtained may only apply to men thermal comfort culture. It is, however, still a relevant study since the users of the mosque are mostly males.

In addition to this, the context of the research is a public religious area. Many precautions have to be taken in considerations especially on the equipment utilised in gathering the information. A robust and small equipment is needed to avoid damages to the equipment and at the same to avoid any interruption or interference with the activity conducted inside the mosque. With these constraints, Tinytag data loggers were used due to its size and durability. The equipment is capable to record the air temperature and relative humidity of the space. The Mean Radiant Temperature (MRT) requires a black globe thermometer and due to its size and installation which may affect the activities inside the mosque, the MRT is not recorded. It is therefore assumed to be equal with the air temperature. An assumption is also made to the speed of the air movement experienced by the respondents. The hot wire anemometer which is suitable to record the indoor air movement is very fragile and expensive equipment. The availability of the equipment to be used in this environment is not possible. In addition to this, the method of the survey conducted which may happen concurrently with other respondents also contribute to the decision on choosing the assumption rather than the actual measurement.

With these constraints, the focus of the study is only to obtain a valid air temperature that can be referred to in investigating the issue of thermal comfort especially in a mosque building. Other variables are based on the perceptions of the respondents only. The study also focuses on the typical design of Malaysian mosque that has a square plan with either a single domed roof or a tiered pitched roof. These are the basic common designs that are applied currently in the Malaysian mosque. Findings and suggestions that are made to improve the design of the mosque may only applicable to the design that has similar roof design.

8.5 IMPLICATION ON THE MOSQUE DEVELOPMENT

The roof design of a mosque is very important symbolically and functionally. It carries spiritual meanings and sometimes displays the identity of the local architecture. It has been argued that the domed roof has better spiritual connection with the Islamic religion as it is originated from the Middle East countries and it expresses the sense of universal as the majority of the mosque in the world employs domes as the main feature of the roof design. On the other hand, it lacks the traditional or vernacular values of Malaysia. The pitched roof has the advantage of presenting and relating to the traditional and vernacular aspects but spiritually it seems to be more related to residential rather than spiritual building. Both of the roof designs have their own strengths and weaknesses in term of relating to the religion and the traditional values of the country. There are many factors in considering the roof design of the mosque as discussed in Chapter 3. However, one of the important aspects of designing a public building such as a mosque is to provide a thermally comfortable indoor space. If a roof design were known to be able to provide better thermal condition inside the space, it is much easier to select which roof design is better to be applied.

The knowledge provided by the research offers a practical solution in determining the roof designs that is more practical to be applied based on the scale and locality of the mosque. For examples, a domed roof has been found appropriate to be applied at larger scale mosques due to the ability of the roof design to stratify the air temperature. A domed roof mosque is also known for its majestic look. It requires bigger structures to carry the force generated by the dome. It is therefore concluded that the domed roof is appropriate if applied to a larger scale mosque not only for the aesthetic or identity reasons but also for the thermal comfort requirement. In other words, the application of the domed roof mosque is appropriate to a state or district mosque category that is intended to occupy more than 5,000 users at one time. This category of mosque is normally considered as a landmark for the place and requires the monumental and grand image. The dome has the characteristics and appears to be more grandeur than a pitched roof mosque.

In contrast, the pitched roof is more applicable to a community or local community mosque which is intended to house less than 5, 000 occupants at a time. For a community building, the sense of humbleness needs to be provided in a building for a building to be accepted as a part of the community. The pitched roof mosque in a way is humble to the surrounding as it is echoing the architecture of the residential units around it. The size of the pitched roof may be bigger than the residential roof but the linkage between the residential units and the religious building is very strong through the use of the same roof design. In addition to this, the pitched roof has the ability to circulate the air inside the space to reach an equilibrium state. This creates continuous air movement which is important in helping the evaporative cooling process. However, this situation also provides higher air temperature than the outdoor. To improve this, the exchanges of the air between the indoor and outdoor through cross ventilation must be very effective to prevent the indoor air temperature to be higher than the outdoor. A smaller scale mosque is necessary as it provide better cross ventilation due the shorter distance between the air outlet and inlet points.

Each of the roof design possesses a unique character as discussed earlier. By understanding the behaviour of the building, modification can be made to improve the design which in return improves the condition too. For examples, the domed roof mosque has the unique ability to stratify the air according to the temperature and this situation is also suitable for the stack effect ventilation. With this understanding, the design can be improved through the study and modification relating to the stack effect ventilation. The application of the cross ventilation may have not worked well with the domed roof mosque since the colder air will be placed at the lower level due to the stratification. The hotter air will not be replaced effectively and the indoor thermal condition will remain the same due to the wrong application of natural ventilation system. Unlike the domed mosque, the pitched roof mosque has the ability to mix the air contained inside the space to create an equilibrium state. In this case, the cross ventilation must be effective to transport the hotter air to the outside of the building. For the cross ventilation to happen effectively, the size of the room must be appropriate to allow the air to move from the inlet through the spaces and finally to the outlet. The stack effect ventilation may have not work well because there is no temperature difference between the lower level and the upper level. Therefore it is suggested that the pitched roof is more applicable to be used for a smaller size mosque and the dome roof is applicable to a bigger size mosque that can provide enough height to allow the air stratification which in returns improve the stack effect ventilation. With the exposure of the knowledge, changes that lead to the betterment of the thermal condition inside the prayer hall of a mosque can be made. It also opens up the new investigation that is intended to improve the thermal comfort inside a mosque which will be discussed in the next section.

The study has also shown that air movement is critical in affecting thermal comfort besides other variables. The high temperature can be tolerated when there is a presence of continuous air movement. The studies by Mallick(1996) and Wong et al (2002) also found that air movement increases the tolerance toward higher temperature. In addition to this, the study has also discovered the thermal comfort condition inside the prayer halls for the three periods of time which are noon, afternoon and evening. Based on the air temperature, the thermal comfort level should have shown an improvement due to the decrease in the air temperature. However, it is recorded that the most thermally uncomfortable period is during the evening time, when the temperature of the air is usually lower than the temperature recorded during the noon and afternoon time. This is due to the stagnant air and high humidity content in the air inside the prayer hall during this period resulting from the lower outdoor air temperature compared to the indoor air temperature at this time. With this finding, it is suggested that the design of the mosque should consider the cooling strategies during the evening time or night cooling strategies. The findings on the behaviour of the mosque and the users are expected to be considered in designing future mosques. The selection of roof design should be obvious based on the scale of the building as it addresses the spiritual, social and environmental aspects. The building should also focus on the appropriate natural ventilation system that not only considers day time ventilation but most importantly the night time ventilation as this period of time records higher percentage of thermal comfort dissatisfaction.

The research has also suggested the Thermal Comfort Sensation scale as an alternative to the existing thermal sensation scale in predicting thermal comfort for a hot and humid area such as Malaysia. It is based on the ASHRAE Thermal Sensation scale and it incorporates the perception of air movement and humidity which is based on simple three scales. The inclusion of the two more variables in the thermal sensation scale may have partially solved the arguments that the ASHRAE thermal sensation scale is only based on the thermal sensation and not considering other factors. The scale can become the stepping stone to a new research on improving the prediction of thermal comfort in tropical countries especially Malaysia.

8.6 FUTURE RESEARCH

With the revelation of the information on the thermal comfort culture of the mosque users and the unique behaviour of the domed and pitched roof mosque in responding to the climatic factors especially on the air movement pattern inside the prayer hall, it may create an interest in exploring these issues further. Even though many issues pertaining to thermal comfort have been discussed extensively, the investigation based on the localized thermal comfort culture on the specific building types, especially institutional buildings are still abundant to be explored. This research has proven that the thermal comfort culture inside a mosque is different due to the activities conducted and dress regulation. Therefore, the generalized ideas about the thermal comfort culture for a specific climate region may not be applicable to be used for a specific building type. Cultural and activities influences on thermal comfort level can be further studied.

Each building is unique in its own way, but in many building types especially institutional or public buildings the layout and space requirement share some similarities. The activities and the users of the space are also sometimes specified. Variations may exist however the general specification is available to be used as the base of the investigation. Some of the building types are libraries, institutional school, community halls and religious buildings such as temples and churches. The research on the thermal comfort culture of these places or buildings will provide information that may help designers and architects in designing future buildings.

The roof has also been seen as an important building element in a tropical country because not only it protects the indoor from the outside climate but it also influences the indoor thermal condition especially the air movement. Further investigation on the relationship between the roof design and the thermal condition can be a beneficial study. New development can be made to the roof design to improve the existing condition resulted from the current condition. It is practically viable with the availability of the Computational Fluid Dynamics software which allows the investigation without having to build the building.

Another area that needs further attention is the development of thermal sensation scale that is more suited for the tropical countries. It has been suggested earlier that the influences of the physical factors on thermal comfort vary with the condition of the climate. The established thermal sensation scales are more applicable for the moderate climate countries. The need to develop the tropical thermal sensation or comfort scale is crucial to better interpret the thermal comfort condition.

All in all, it has been evidenced that many issues related to thermal comfort and building design especially in naturally ventilated buildings located in the region with hot and humid climate have not been covered to the required extent. An investigation involving greater numbers of various levels of respondents for a longer period of time is necessary in producing a more reliable and generalized results.

8.6 CONCLUDING REMARKS

On the whole, besides the findings from the research, the process that I have gone through in conducting the research has helped me to be an independent researcher. With these experiences, I am confident that I will be able to conduct further research on the related issued focusing on the thermal comfort issues especially for naturally ventilated buildings in the tropics. It is also hoped that more investigation and exploration regarding thermal comfort investigation especially for the tropical countries can be conducted.

APPENDIX A

SET OF QUESTIONNAIRES

I would like to invite you to participate in this survey. It will take about 10 – 15 minutes of your time to answer all the questions based on your immediate experience. Your identity will remain anonymous. For your information, this questionnaire is entirely voluntary. If you do not wish to complete it, or any part of it, you are under no obligation to do so.

The objective of the survey is to gather information on the users' perception on the thermal comfort level of the prayer hall inside the selected mosques. It comprises of factors such as air temperature, relative humidity and air movement.

The collected information will be analysed to determine the most influential factors affecting the comfort level and other factors influencing the overall thermal comfort condition.

The survey is part of the PhD research on the Contemporary Mosque Designs in Malaysia. Any inquiry regarding this matter can be forwarded to these emails:

Maarofs@cf.ac.uk or JonesP@cf.ac.uk

Note: This questionnaire is entirely voluntary. If you do not wish to complete it , or any part of it, you are under no obligation to do so.

I would like to thank you for your time and cooperation in participating in the survey.

Shafizal Maarof

Sample Name

Time: Date:

Recorded Air Temperature

Recorded Relative Humidity

a) Please tick (/) in the appropriate box. (*Sila tandakan (/) di kotak yang bersesuaian*)

1. Gender (*Jantina*)

Male (*Lelaki*)

Female (*Perempuan*)

2. Age (*Umur*)

Below 25

25- 35 years old

36 -45 years old

46-55 years old

Above 55 years old

b) Please describe how do you feel under these categories (*Sila nyatakan bagaimana anda rasa berdasarkan kategori berikut*)

1. Thermal Sensation (based on the ASHRAE scale)

Too Hot (*Sangat Panas*)	+3
Hot (*Panas*)	+2
Warm (*Sedikit Panas)*	+1
Neutral	0
Cool (*Sedikit sejuk*)	-1
Cold (*Sejuk*)	-2
Too Cold (*Sangat Sejuk*)	-3

2. Comfort (*Keselesaan*)

Much too hot (*Tersangat Panas*)	7
Too Hot (*Sangat Panas*)	6
Comfortably warm (*panas yang selesa*)	5
Comfortable (*Selesa*)	4
Comfortably cool (*Sejuk yang Selesa*)	3
Too cool (*sangat sejuk*)	2
Much too cool (*Tersangat Sejuk*)	1

3. Air Movement (*Pergerakan udara*)

Very windy (*sangat berangin*)

Windy(*berangin*)

Breezy (*sedikit berangin*)

Calm (*Tenang*)

4. Humidity (*Kelembapan*)

Very humid/heavy sweating (*sgt lembap/sgt berpeluh)*

Humid/ sweating (*lembap/berpeluh*)

Slightly humid/light sweating (*sedikit lembap/ sedikit berpeluh)*

Neutral

Dry (Kering)

c. Preferences

For the most comfortable situation, I would like to be:

(*Untuk keselesaan yang sempurna, saya inginkan:)*

1. Thermal Preference

Warmer (*sedikit panas*)

No change (*tiada perubahan*)

Cooler (*sedikit sejuk*)

2. Air movement

Breezier (*lebih berangin*)

No change (*tiada perubahan*)

More calm (*lebih tenang*)

3. Humidity

More humid (*lebih lembap*)

No change (*tiada perubahan*)

Drier (*lebih lembap*)

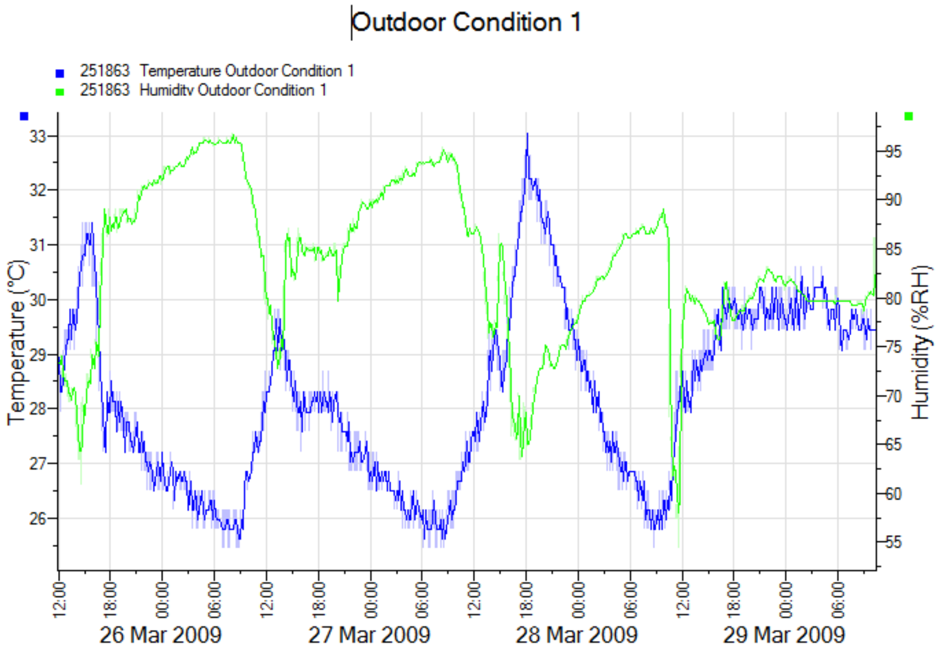
Thank you for your participation.

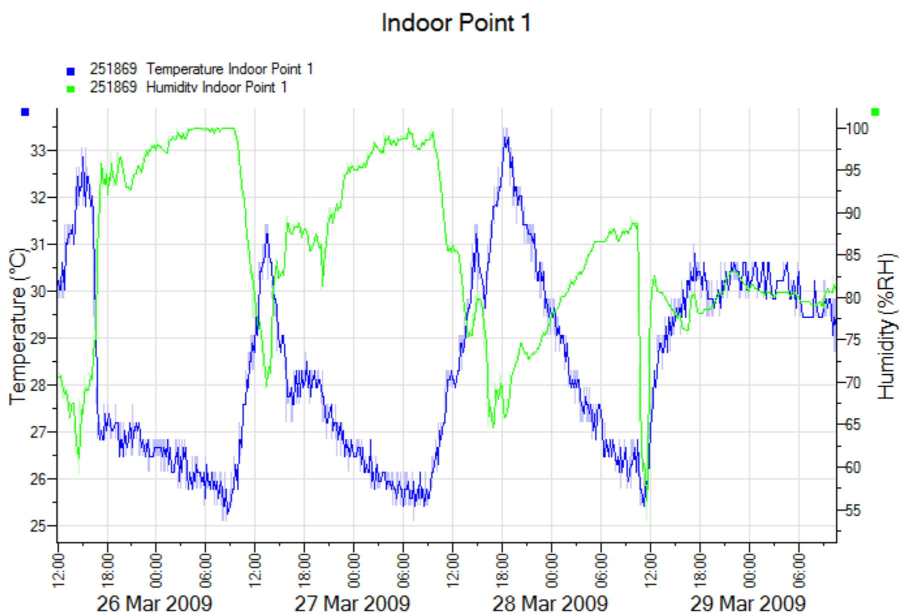
APPENDIX B

COMPILED DATA FROM FIELD MEASUREMENT AND SURVEY

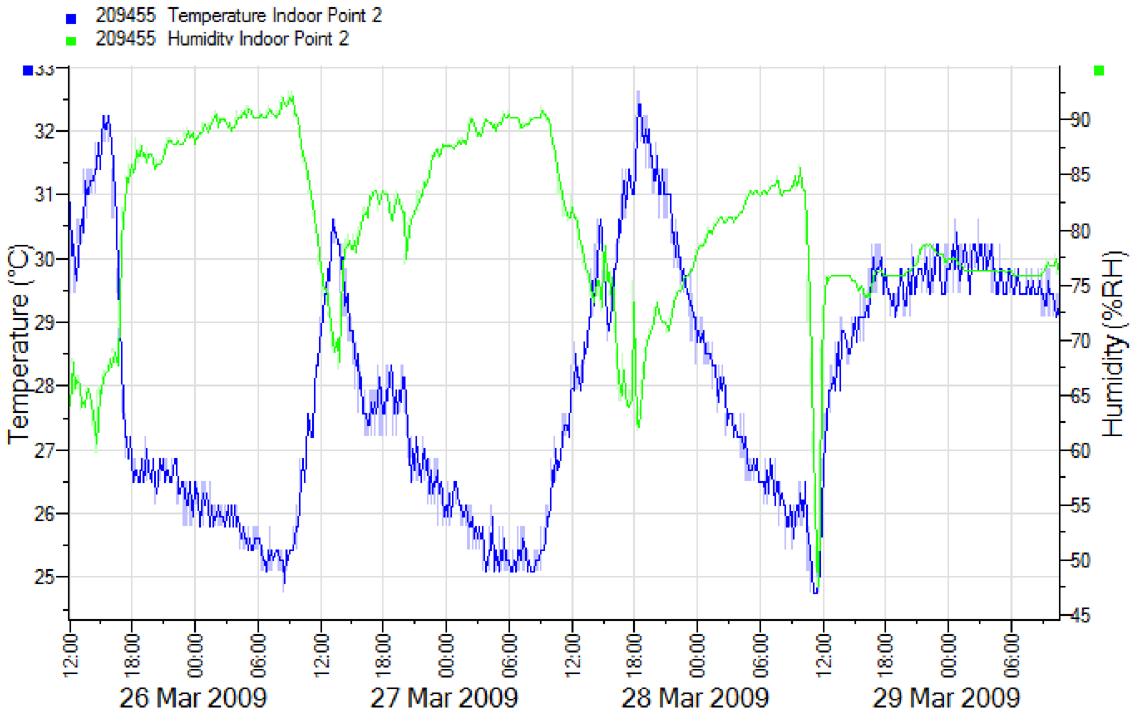
1. FIELD MEASUREMENT DATA FROM TINYTAG DATA LOGGER

i. MASJID JAMEK, SEREMBAN, NEGERI SEMBILAN

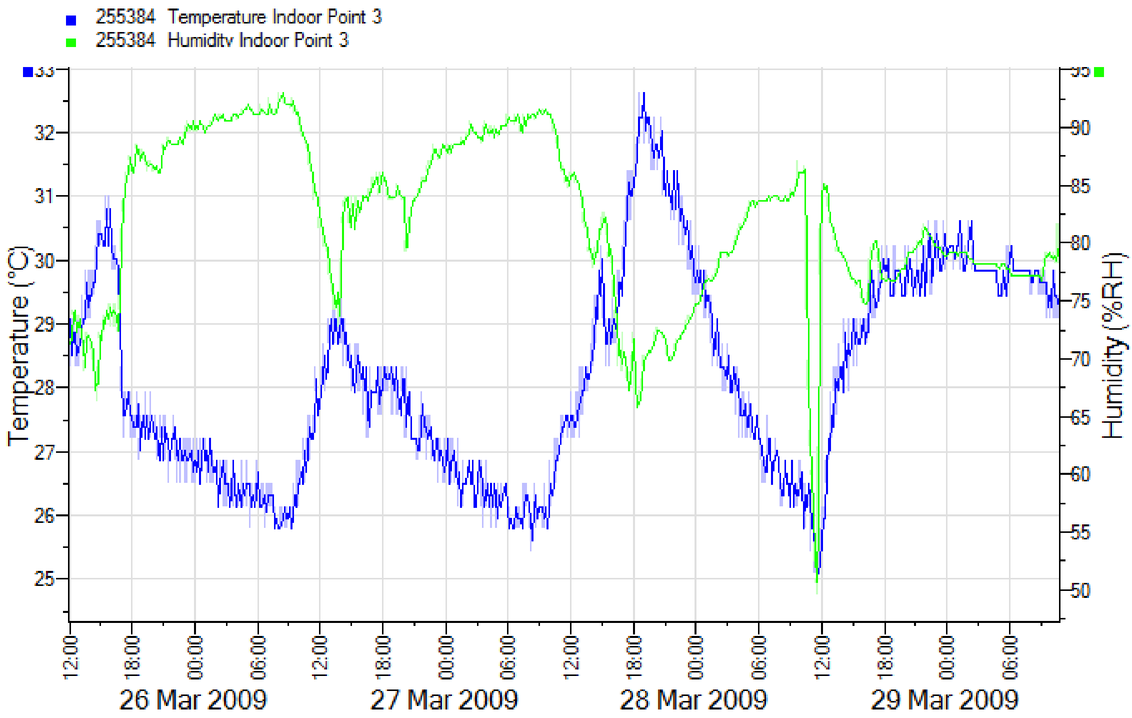




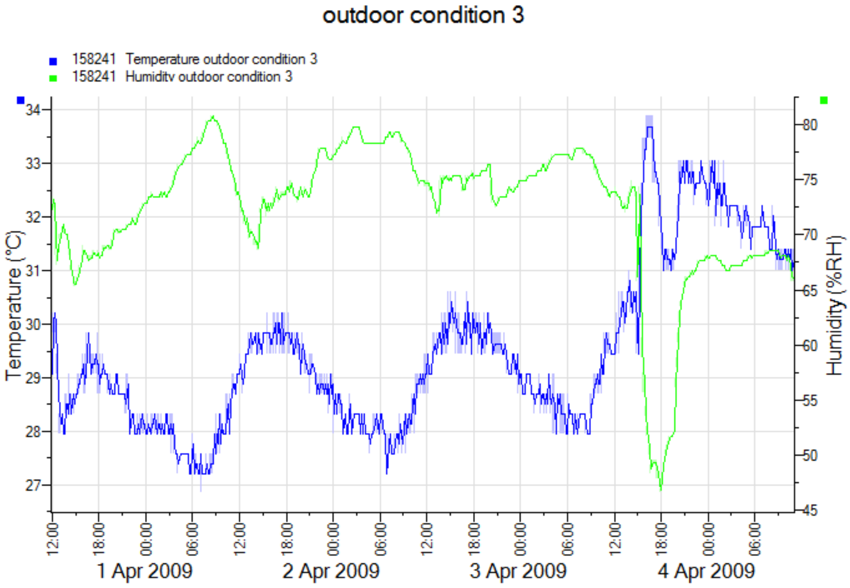
Indoor Point 2

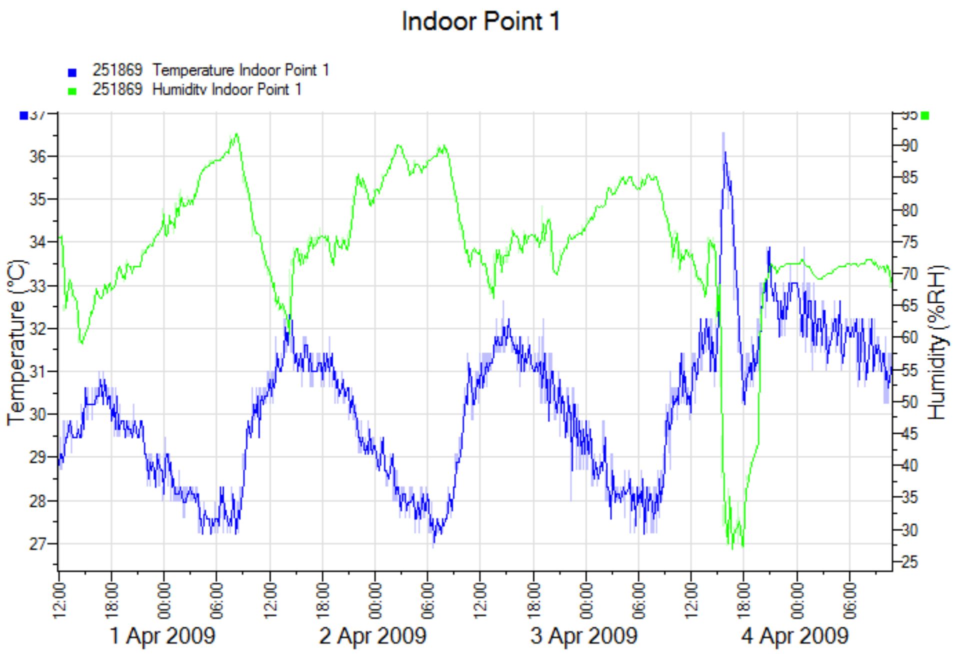


Indoor Point 3

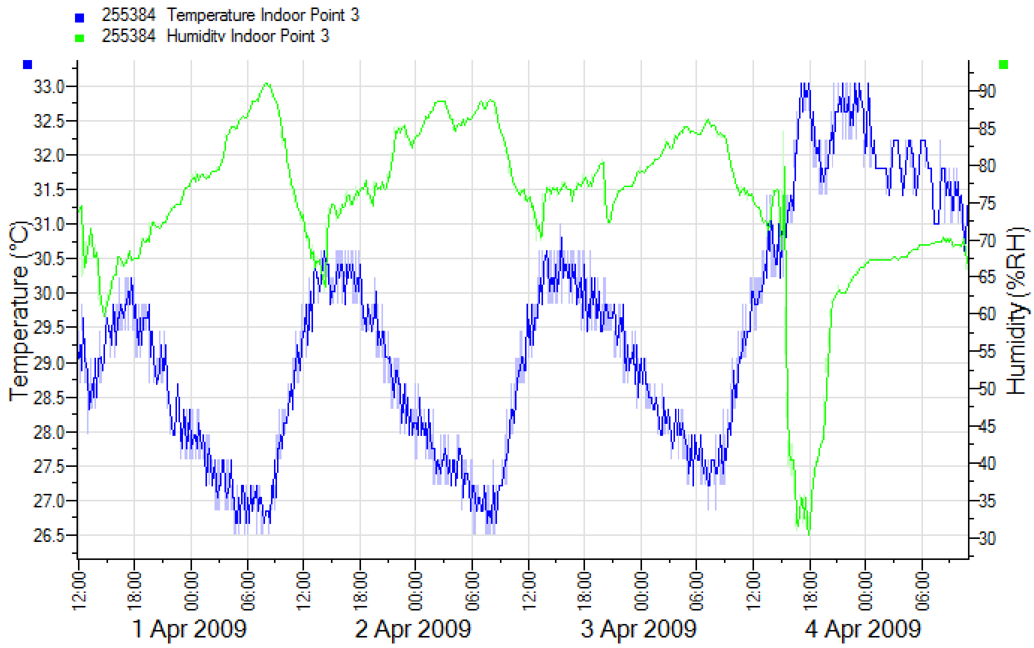


ii. MASJID AL AZIM, MELAKA, MALAYSIA

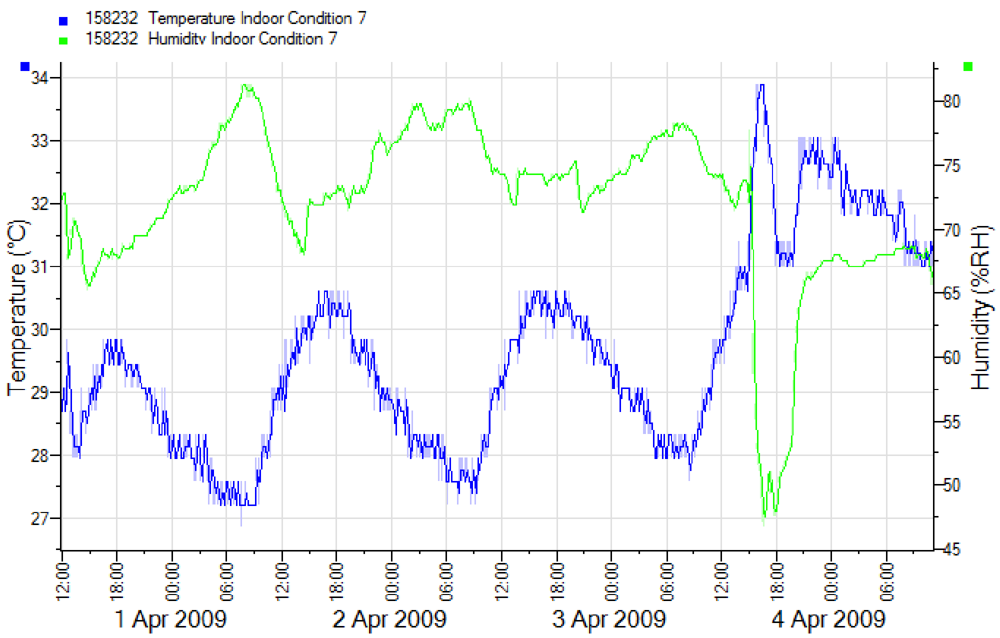




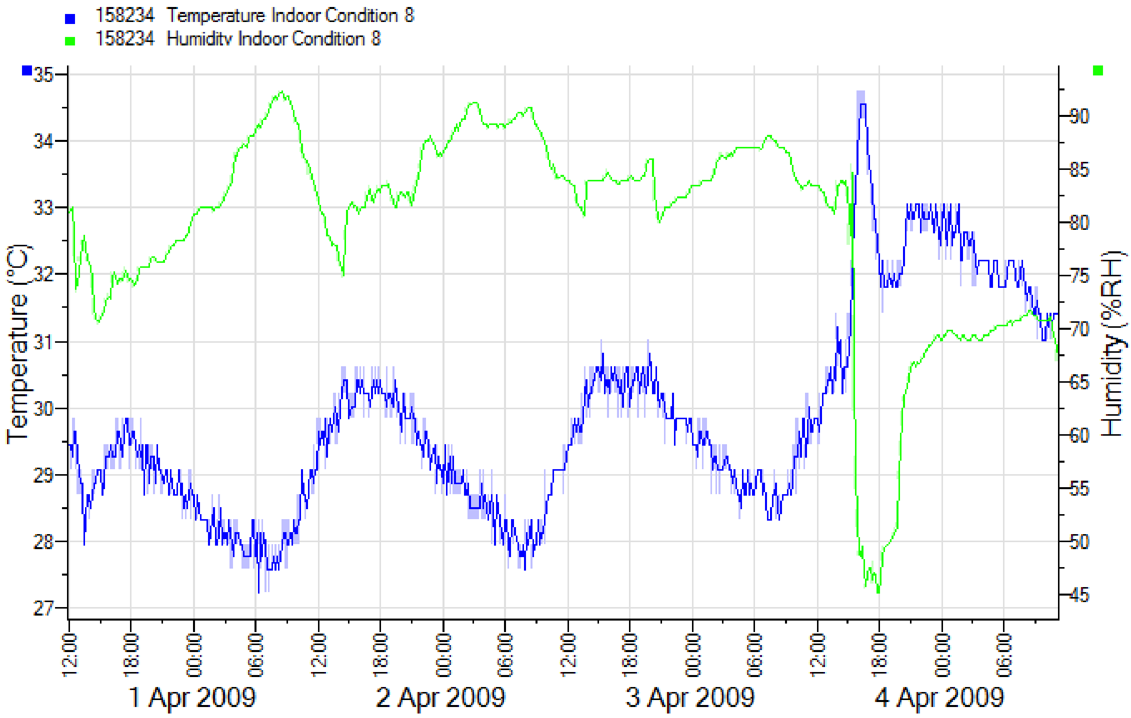
Indoor Point 3



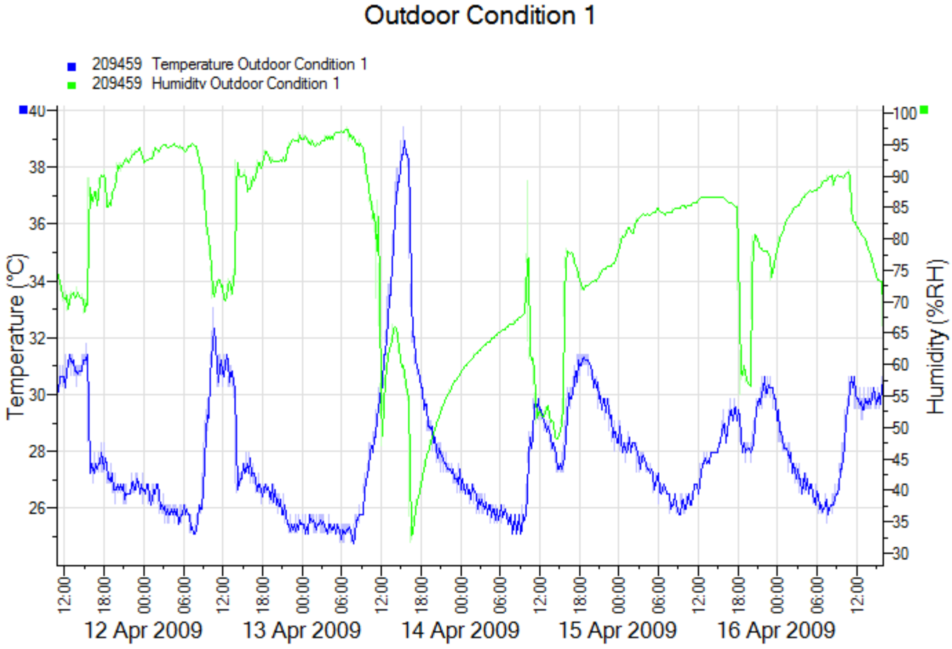
Indoor Condition 7

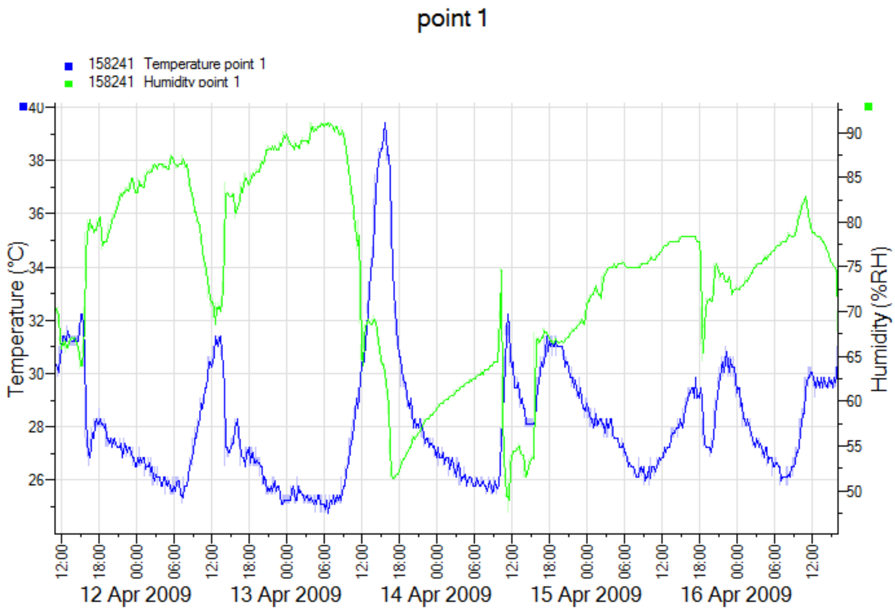


Indoor Condition 8

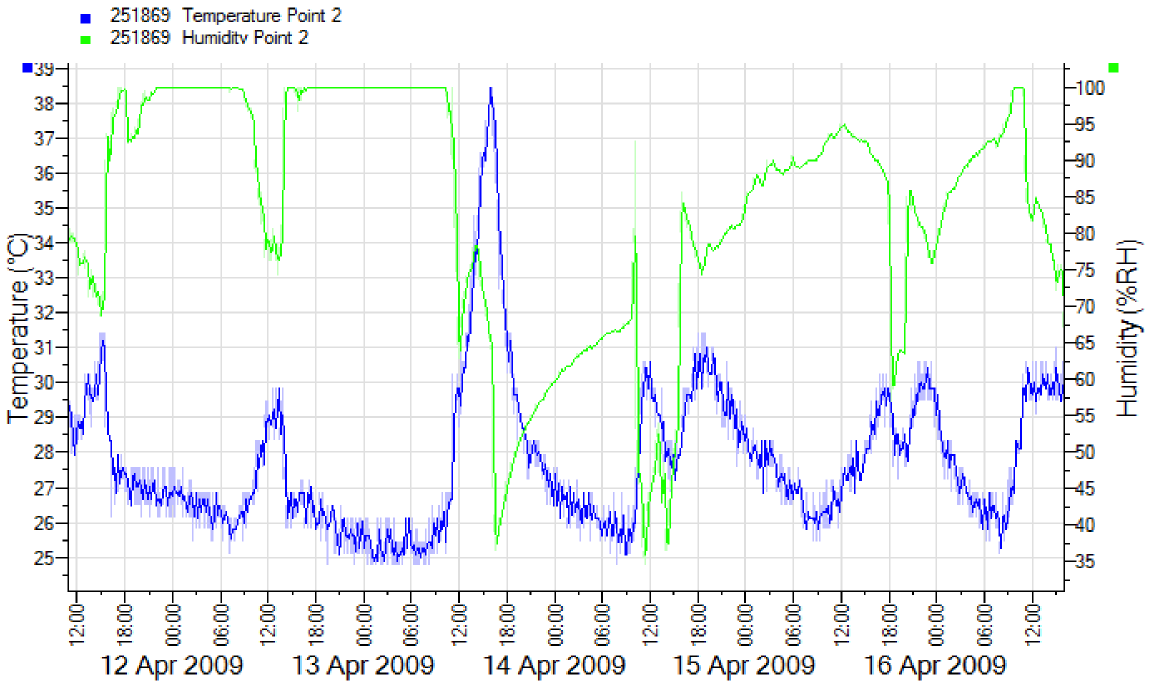


iii. MASJID AL MIZAN, PUTRAJAYA MALAYSIA

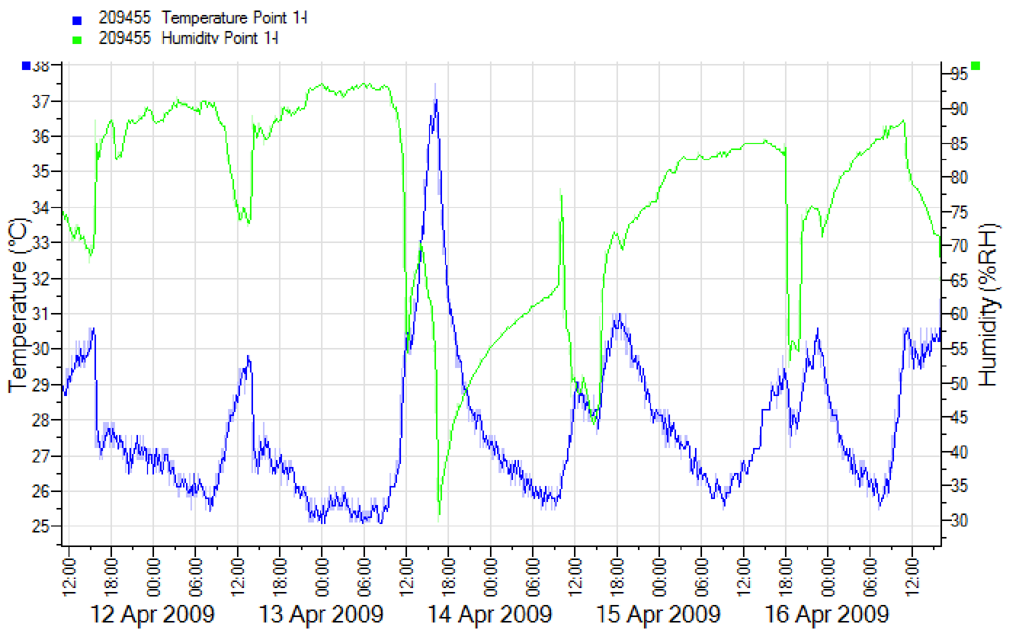




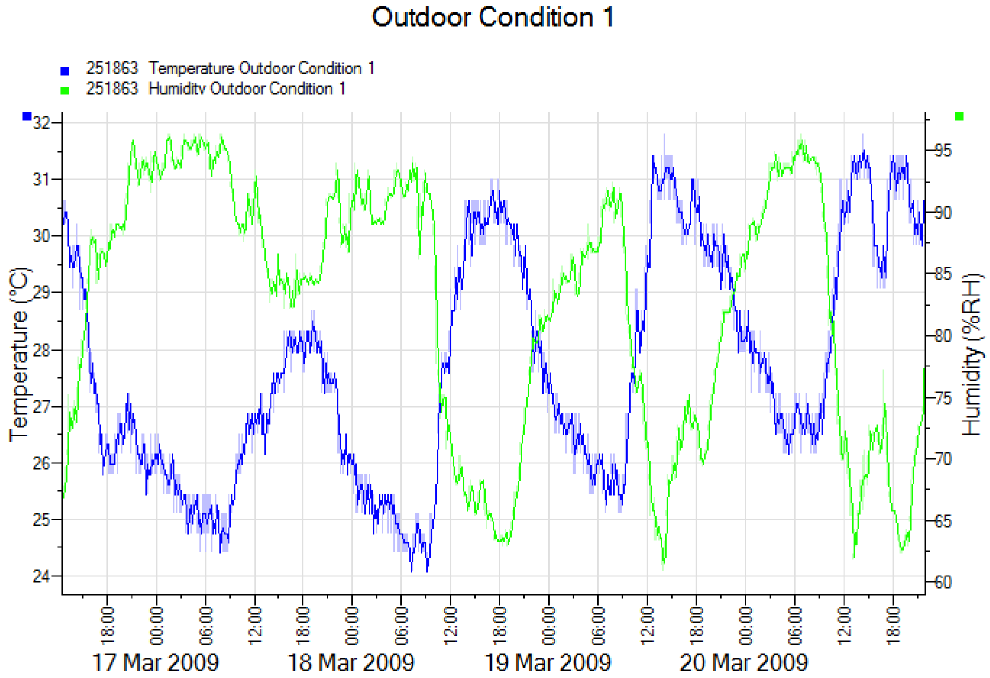
Point 2

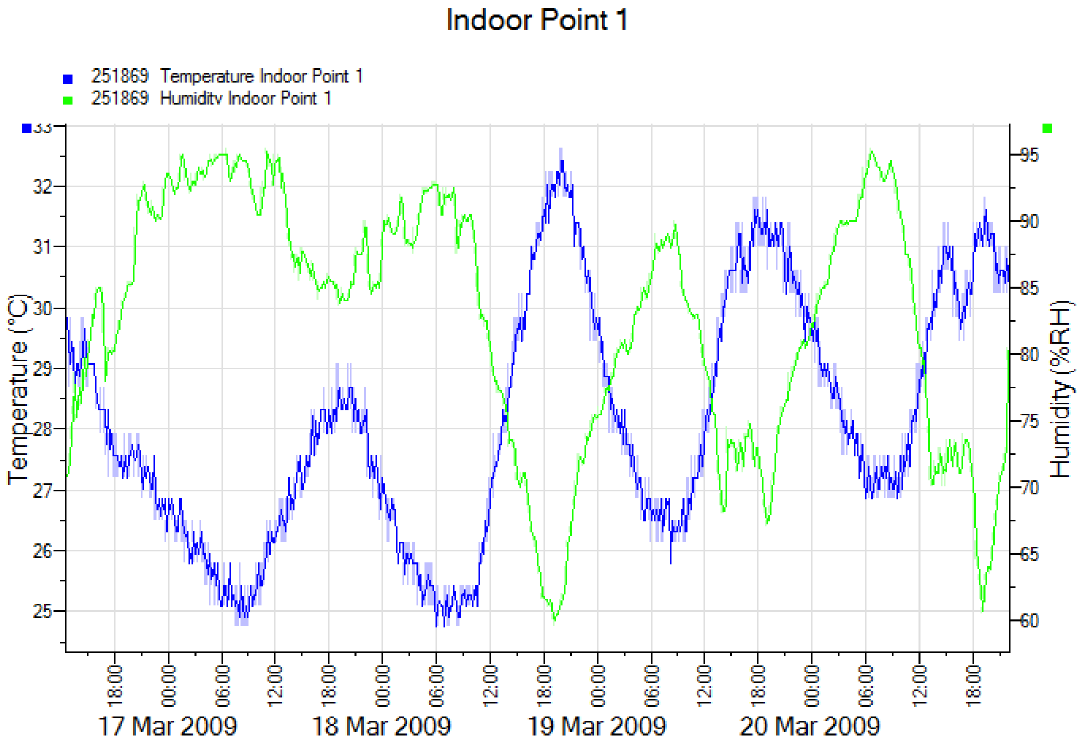


Point 1-I

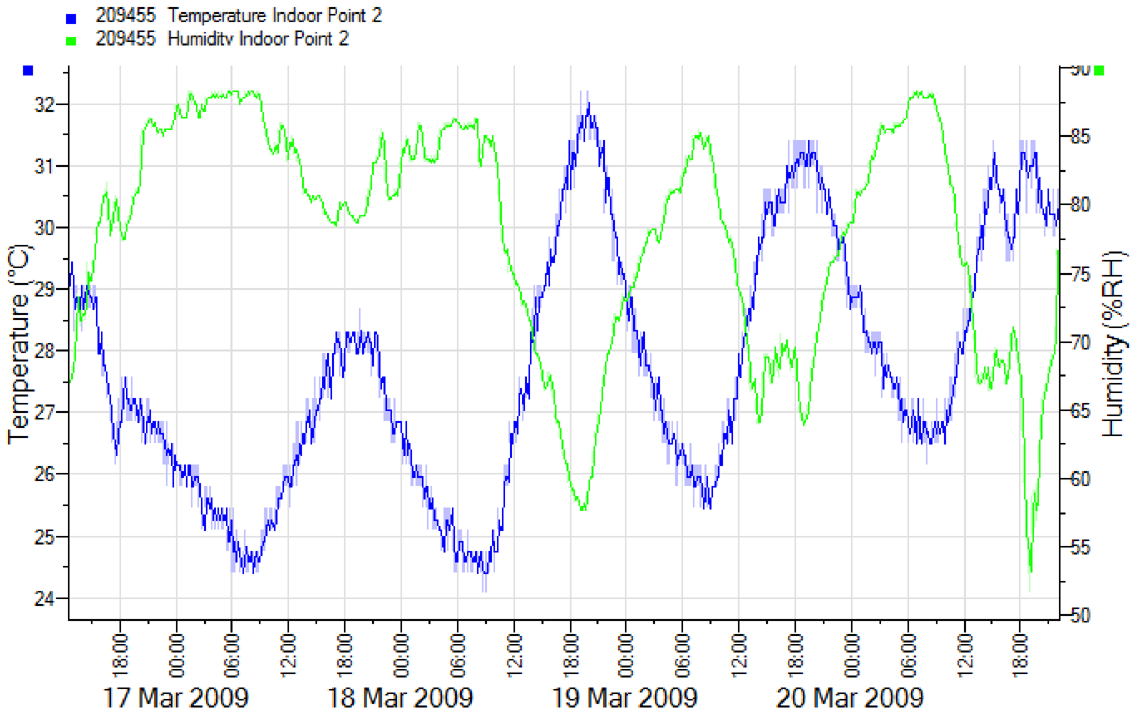


iv. Masjid Sikamat, Seremban, Negeri Sembilan

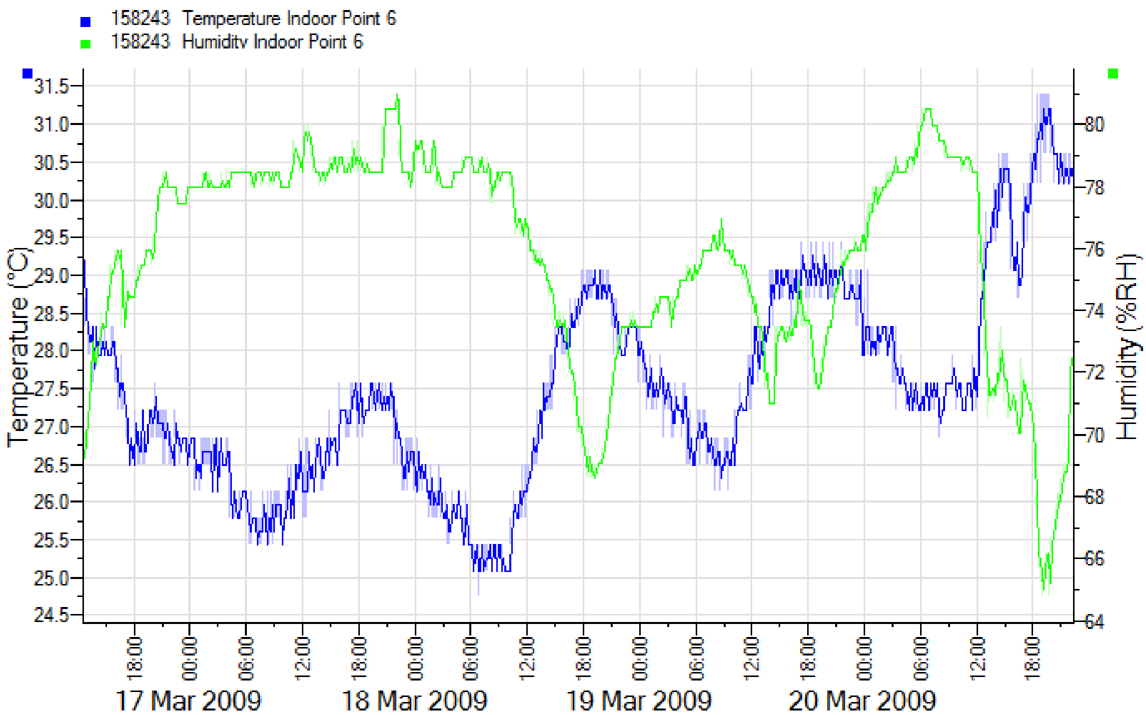




Indoor Point 2



Indoor Point 6



2. Compilation of data from questionnaire

i. MASJID AL MIZAN, PUTRAJAYA

time	Nos.	Sex	Outdoor Temp	Indoor Temp	RH	Thermal Sensation	Comfort Level	Wind Condition	Relative Humidity	Thermal Pref.	Wind Pref.	RH Pref.
		1-Male				Very Cold - (-3)	Much too Cold (-3)	1- Calm	Very dry (-2)	Hotter (1)	Breezier (1)	Drier (1)
		2-Female				Cold - (-2)	Too Cold (-2)	2-Breezy	Dry (-1)	Unchanged (0)	Unchanged (0)	Unchanged(0)
						slightly Cold - (-1)	Comfortably cool (-1)	3-Very Windy	Neutral (0)	Cooler(-1)	Calmer(-1)	More Humid (-1)
						Neutral (0)	Comfortable (2-0)		Humid (1)			
						Warm (1)	Comfortably warm (1)		Very Humid (2)			
						Hot (2)	Too Warm (0 - 2)					
						Very Hot (3)	Much too warm(-1 - 3)					
Noon prayer	1	1	31.4	29.8	74.3	1	2	2	1	-1	1	1
11/4/2009	2	1	31	29.7	74.4	1	1	2	1	-1	1	1
	3	1	30.8	29.8	72.3	1	1	1	1	-1	1	1
	4	1	31.2	29.6	72.3	1	2	2	1	-1	1	1
	5	1	31.6	29.7	73.9	1	1	1	1	-1	1	1
	6	1	31.1	29.2	73.1	1	1	1	1	-1	1	1
	7	1	31.2	29.8	72.8	1	1	2	1	-1	1	1
Noon prayer	8	1	31	29.7	74.4	2	0	1	2	-1	1	1
12/4/2009	9	1	30.8	29.3	76.1	1	0	1	1	-1	1	1
	10	1	31.2	29.8	74.2	1	1	2	1	-1	1	1
	11	1	30.4	29.1	76.2	1	1	2	1	-1	1	1

	12	1	29.3	29.2	86.7	1	1	1	1	-1	1	1
	13	1	28.1	28.2	90.5	0	0	1	2	0	1	1
	14	1	29.6	29.6	86.7	1	1	2	1	-1	1	1
	15	1	26.7	27.2	92	0	0	1	2	0	1	1
	16	1	27	26.7	91.8	0	0	1	2	0	1	1
	17	1	30.8	29.2	76.2	1	1	1	1	-1	1	1
Noon Prayer	18	1	31.2	29.1	75.6	1	2	2	1	-1	1	1
13/4/2009	19	1	32.6	30.7	69.6	1	2	2	0	-1	1	1
	20	1	33.3	30.9	69.9	1	1	1	0	-1	1	1
	21	1	33.1	31	69.9	1	1	2	0	-1	1	1
	22	1	33.7	31.1	70.4	1	1	1	1	-1	1	1
	24	1	33.5	31.3	70.4	1	1	1	1	-1	1	1
	24	1	33.9	31.4	70.7	1	1	2	1	-1	1	1
	25	1	34.3	31.5	71	1	1	2	1	-1	1	1
	26	1		32.1	71.4	2	3	1	1	-1	1	1
	27	1	34.3	32.4	72	2	3	2	1	-1	1	1
	28	1	34.8	32.5	72.7	2	3	1	2	-1	1	1
	29	1	35.4	32.2	73.6	2	3	1	2	-1	1	1
				30.06206897	75.69310345							
				32.5	92							
Afternoon				26.7	69.6							
11/4/2009	30	1	27.6 °C	27.6 °C	86.1 %RH	1	0	1	2	0	1	1
	31	1	27.6 °C	27.9 °C	83.6 %RH	1	1	2	2	0	0	1
	32	1	27.6 °C	27.6 °C	83.6 %RH	1	1	2	2	0	0	1
	33	1	27.6 °C	27.6 °C	84.1 %RH	1	1	2	2	0	0	1
	34	1	27.6 °C	27.2 °C	86.1 %RH	1	0	1	2	-1	1	1
	35	1	27.6 °C	26.9 °C	87.1 %RH	0	1	2	2	0	0	1
	36	1	27.6 °C	27.2 °C	86.1 %RH	0	1	2	2	0	0	1

	37	1	27.6 °C	27.6 °C	86.6 %RH	0	1	2	2	0	0	1
	38	1	27.6 °C	27.2 °C	88.6 %RH	0	0	1	2	0	1	1
	39	1	27.6 °C	27.6 °C	88.6 %RH	0	0	1	2	0	1	1
	40	1	27.6 °C	27.6 °C	88.6 %RH	0	0	1	2	0	1	1
12/4/2009	41	1	27.9 °C	27.9 °C	88.6 %RH	0	0	1	2	0	1	1
	42	1	27.6 °C	27.2 °C	89.6 %RH	0	0	1	2	0	1	1
	43	1	26.9 °C	27.6 °C	89.1 %RH	0	0	1	2	0	1	1
	44	1	27.2 °C	27.6 °C	88.6 %RH	0	0	1	2	0	1	1
	45	1	27.2 °C	27.2 °C	88.6 %RH	0	0	1	2	0	1	1
	46	1	27.2 °C	27.6 °C	89.1 %RH	1	0	1	2	-1	1	1
	47	1	27.2 °C	27.6 °C	89.6 %RH	1	0	1	2	-1	1	1
	48	1	27.2 °C	27.6 °C	90.1 %RH	1	0	1	2	-1	1	1
	49	1	27.6 °C	26.9 °C	89.6 %RH	0	0	1	2	0	1	1
	50	1	26.9 °C	26.9 °C	89.6 %RH	0	0	1	2	0	1	1
	50	1	26.9 °C	26.9 °C	89.6 %RH	0	0	1	2	0	1	1
	52	1	27.2 °C	27.6 °C	89.6 %RH	1	0	1	2	0	1	1
13/4/2009	53	1	38.5 °C	37.0 °C	59.4 %RH	3	3	1	0	-1	1	1
	54	1	38.5 °C	37.0 °C	57.9 %RH	3	3	2	0	-1	1	0
	55	1	38.0 °C	37.5 °C	57.4 %RH	3	3	2	0	-1	1	0
	56	1	38.5 °C	37.5 °C	56.4 %RH	3	3	2	0	-1	1	0
	57	1	38.0 °C	37.0 °C	56.4 %RH	3	3	1	0	-1	1	0
	58	1	37.5 °C	36.6 °C	49.5 %RH	3	3	2	-1	-1	1	-1
	59	1	35.7 °C	36.1 °C	38.6 %RH	3	3	1	-1	-1	1	-1
	60	1	34.8 °C	36.6 °C	35.2 %RH	3	3	2	-1	-1	1	-1
	61	1	33.9 °C	36.1 °C	33.7 %RH	3	3	2	-1	-1	1	-1
	62	1	33.1 °C	36.6 °C	32.2 %RH	3	3	2	-1	-1	1	-1
	63	1	32.2 °C	36.1 °C	32.7 %RH	3	3	1	-1	-1	1	-1
	64	1	31.8 °C	35.2 °C	36.7 %RH	2	3	2	-1	-1	1	-1
	65	1	32.2 °C	34.3 °C	38.6 %RH	2	3	2	-1	-1	1	-1

	66	1	31.8 °C	34.8 °C	40.1 %RH	2	3	2	-1	-1	1	-1
	67	1	31.0 °C	34.8 °C	40.1 %RH	3	3	1	-1	-1	1	-1
				30.9 °C	70.7 %RH							
				37.5 °C	90.1 %RH							
				26.9 °C	32.2 %RH							
Evening												
11/4/2009	68	1	26.9 °C	27.6 °C	83.5 %RH	1	2	2	1	0	0	1
	69	1	27.2 °C	27.6 °C	83.1 %RH	1	2	2	1	0	0	1
	70	1	27.6 °C	27.2 °C	82.6 %RH	1	2	2	1	0	0	1
	71	1	26.9 °C	27.2 °C	83.1 %RH	1	2	2	1	0	0	1
	72	1	26.9 °C	27.6 °C	83.1 %RH	1	2	2	1	0	0	1
	73	1	26.5 °C	27.6 °C	83.5 %RH	1	1	2	1	0	0	1
	74	1	26.5 °C	27.6 °C	84.0 %RH	1	2	2	1	0	0	1
	75	1	26.9 °C	27.2 °C	84.5 %RH	1	1	2	1	0	0	1
	76	1	27.2 °C	27.2 °C	85.9 %RH	1	1	2	1	0	0	1
	77	1	26.5 °C	26.9 °C	85.5 %RH	0	1	2	1	0	0	1
	78	1	26.9 °C	27.2 °C	85.9 %RH	0	1	2	1	0	0	1
	79	1	26.1 °C	27.2 °C	86.4 %RH	1	1	2	1	0	0	1
	80	1	26.9 °C	27.2 °C	87.4 %RH	0	2	2	1	0	0	1
	81	1	26.9 °C	27.6 °C	87.9 %RH	1	2	2	1	0	0	1
	82	1	26.9 °C	26.9 °C	87.9 %RH	0	2	2	1	0	0	1
	83	1	26.5 °C	26.5 °C	87.9 %RH	0	2	2	1	0	0	1
	84	1	26.9 °C	26.5 °C	88.4 %RH	0	1	2	1	0	0	1
	85	1	26.9 °C	26.5 °C	88.4 %RH	0	1	2	1	0	0	1
	86	1	26.9 °C	27.2 °C	87.9 %RH	0	1	2	1	0	0	1
	87	1	26.5 °C	27.2 °C	87.9 %RH	1	2	2	1	0	0	1
	88	1	26.5 °C	26.9 °C	88.4 %RH	0	2	2	1	0	0	1
	89	1	26.9 °C	26.5 °C	88.4 %RH	0	2	2	1	0	0	1

	90	1	26.9 °C	26.9 °C	88.4 %RH	0	2	2	1	0	0	1
	91	1	26.9 °C	27.6 °C	88.4 %RH	1	1	2	1	0	0	1
	92	1	26.5 °C	26.5 °C	88.4 %RH	-1	-1	1	1	0	0	1
12/4/2009	93	1	25.8 °C	26.5 °C	93.1 %RH	-1	0	2	1	0	1	1
	94	1	25.8 °C	25.8 °C	93.1 %RH	-1	0	2	1	0	1	1
	95	1	25.8 °C	26.1 °C	93.6 %RH	-1	0	2	1	0	1	1
	96	1	25.8 °C	25.8 °C	95.1 %RH	-1	0	2	1	0	1	1
	97	1	25.8 °C	26.1 °C	94.6 %RH	-1	0	2	1	0	1	1
	98	1	25.8 °C	26.1 °C	94.6 %RH	-1	-1	1	1	0	1	1
	99	1	25.8 °C	25.8 °C	94.1 %RH	-1	-1	1	1	0	1	1
	100	1	25.8 °C	26.5 °C	94.6 %RH	0	1	1	1	0	1	1
	101	1	25.8 °C	25.4 °C	95.1 %RH	-1	-1	1	1	0	1	1
13/4/2009	102	1	28.3 °C	29.8 °C	50.0 %RH	1	1	2	0	-1	1	0
	103	1	28.7 °C	29.1 °C	50.0 %RH	1	1	2	0	-1	1	0
	104	1	28.3 °C	28.7 °C	50.5 %RH	0	1	2	0	-1	1	0
	105	1	27.9 °C	29.1 °C	50.5 %RH	1	1	2	0	-1	1	0
	106	1	28.3 °C	29.1 °C	50.5 %RH	1	1	2	0	-1	1	0
	107	1	27.9 °C	29.1 °C	51.0 %RH	1	1	2	0	-1	1	0
	108	1	27.6 °C	29.1 °C	51.0 %RH	1	1	2	0	-1	1	0
	109	1	27.9 °C	28.3 °C	51.5 %RH	0	1	1	0	0	1	0
	110	1	28.3 °C	28.7 °C	51.5 %RH	0	1	1	0	0	1	0
	111	1	27.9 °C	29.1 °C	51.5 %RH	1	1	1	0	0	1	0
	112	1	27.6 °C	28.7 °C	51.5 %RH	1	1	2	0	0	1	0
	113	1	28.3 °C	28.3 °C	52.0 %RH	0	1	1	0	0	1	0
	114	1	27.6 °C	28.3 °C	52.0 %RH	0	1	1	0	0	1	0
				27.4 °C	78.0 %RH							114
				29.8 °C	95.1 %RH							
				25.4 °C	50.0 %RH							

ii. MASJID AL AZIM, MELAKA, MALAYSIA

time	Nos.	Sex	Outdoor Temp	Indoor Temp	RH	Thermal Sensation	Comfort Level	Wind Condition	Relative Humidity	Thermal Pref.	Wind Pref.	RH Pref.
		1-Male				Very Cold - (-3)	much too cold (-3)	1- Calm	Very dry (-2)	Hotter (1)	Breezier (1)	Drier (1)
		2-Female				Cold - (-2)	too cool(-2)	2-Breezy	Dry (-1)	Unchanged(0)	Unchanged (0)	Unchanged(0)
						slightly Cool- (-1)	Comfortably cool (-1)	3-Very Windy	Neutral (0)	Cooler(-1)	Calmer(-1)	More Humid (-1)
						Neutral (0)	Comfortable(0)		Humid (1)			
						Slightly Warm (1)	Comfortably warm (1)		Very Humid (2)			
						Warm (2)	Too Warm (2)					
						Hot (3)	Much too warm (3)					
NOON	1		28.3 °C	29.8 °C	68.5 %RH	1	2	1	1	-1	1	0
	2		28.3 °C	29.8 °C	69.0 %RH	1	2	1	1	-1	1	0
	3		27.9 °C	29.8 °C	69.0 %RH	1	2	1	1	-1	1	0
	4		27.9 °C	29.4 °C	67.5 %RH	0	0	2	1	-1	0	0
	5		27.9 °C	29.8 °C	67.5 %RH	1	2	1	1	-1	1	0
	6		27.9 °C	29.1 °C	66.0 %RH	0	1	1	0	0	1	0
	7		28.3 °C	29.4 °C	66.0 %RH	0	1	1	0	0	1	0
	8		28.7 °C	29.4 °C	66.5 %RH	0	0	2	0	0	0	0
	9		28.3 °C	29.4 °C	66.5 %RH	1	2	1	1	-1	1	0
	10		28.7 °C	29.4 °C	65.5 %RH	1	1	2	0	-1	0	0
	11		28.3 °C	29.4 °C	65.5 %RH	1	0	2	1	-1	0	0
	12		29.1 °C	29.1 °C	67.8 %RH	0	0	2	1	0	0	0
	13		29.4 °C	29.4 °C	67.3 %RH	1	1	2	0	-1	0	0
	14		29.4 °C	29.1 °C	68.8 %RH	0	0	2	1	0	0	0
	15		29.4 °C	29.1 °C	67.8 %RH	0	0	2	1	0	0	0
	16		29.4 °C	29.4 °C	69.3 %RH	0	1	2	0	0	0	0

	17		29.4 °C	29.8 °C	67.3 %RH	1	1	2	0	-1	0	0
	18		29.4 °C	29.8 °C	65.3 %RH	1	1	2	0	-1	0	0
	19		29.4 °C	29.8 °C	67.3 %RH	0	1	2	0	0	0	0
	20		29.8 °C	29.8 °C	66.3 %RH	0	0	2	0	0	0	0
	21		29.8 °C	29.4 °C	67.8 %RH	0	0	2	0	0	0	0
	22		29.8 °C	29.8 °C	67.8 %RH	1	1	1	0	-1	1	0
	23		29.4 °C	29.8 °C	66.3 %RH	1	1	1	0	-1	1	0
	24		29.8 °C	30.2 °C	67.3 %RH	1	2	1	1	-1	1	0
	25		29.8 °C	29.4 °C	67.3 %RH	0	0	2	0	0	0	0
	26		29.4 °C	30.2 °C	65.8 %RH	2	2	1	1	-1	1	0
	27		29.4 °C	31.4 °C	67.5 %RH	2	2	1	1	-1	1	0
	28		29.4 °C	31.0 °C	66.5 %RH	2	2	1	1	-1	1	0
	29		29.4 °C	31.4 °C	68.5 %RH	2	2	1	1	-1	1	0
	30		29.8 °C	31.4 °C	69.0 %RH	2	2	1	1	-1	1	0
	31		29.4 °C	31.0 °C	66.5 %RH	2	2	1	1	-1	1	0
	32		29.8 °C	31.4 °C	66.0 %RH	2	2	1	1	-1	1	0
	33		29.8 °C	31.4 °C	66.0 %RH	2	2	1	1	-1	1	0
	34		29.8 °C	31.8 °C	66.0 %RH	2	2	1	1	-1	1	0
	35		29.8 °C	31.8 °C	73.1 %RH	2	2	1	1	-1	1	0
	36		30.6 °C	31.4 °C	69.0 %RH	1	2	1	1	-1	1	0
	37		30.2 °C	31.0 °C	69.0 %RH	1	2	1	1	-1	1	0
	38		30.2 °C	31.0 °C	69.0 %RH	1	1	2	0	-1	0	0
	39		30.2 °C	32.2 °C	69.6 %RH	2	2	1	1	-1	1	0
	40		30.6 °C	32.2 °C	68.5 %RH	2	2	1	1	-1	1	0
	41		30.2 °C	31.0 °C	69.0 %RH	1	1	2	0	-1	0	0
	42		30.6 °C	32.2 °C	68.0 %RH	2	2	1	1	-1	1	0
AFTERNOON	43		29.8 °C	29.8 °C	69.5 %RH	1	1	2	0	-1	0	0
	44		29.1 °C	29.8 °C	69.0 %RH	1	1	2	0	-1	0	0

	45		29.1 °C	29.8 °C	69.0 %RH	1	1	2	0	-1	0	0
	46		29.4 °C	29.1 °C	69.0 %RH	0	1	2	0	0	0	0
	47		30.2 °C	29.4 °C	69.0 %RH	0	0	2	0	0	0	0
	48		29.4 °C	29.4 °C	69.0 %RH	0	0	2	0	0	0	0
	49		29.4 °C	30.2 °C	81.3 %RH	1	2	1	2	-1	1	-1
	50		29.8 °C	30.6 °C	81.3 %RH	1	2	1	2	-1	1	-1
	51		29.8 °C	29.8 °C	81.3 %RH	1	2	1	2	-1	1	-1
	52		30.2 °C	30.2 °C	81.8 %RH	1	2	1	2	-1	1	-1
	53		30.2 °C	30.2 °C	82.9 %RH	1	2	1	2	-1	1	-1
	54		29.4 °C	30.2 °C	82.9 %RH	1	2	1	2	-1	1	-1
	55		29.8 °C	30.2 °C	82.9 %RH	1	2	1	2	-1	1	-1
	56		29.4 °C	30.2 °C	71.9 %RH	1	2	1	1	-1	1	0
	57		29.8 °C	30.2 °C	71.9 %RH	1	2	1	1	-1	1	0
	58		29.8 °C	30.6 °C	71.9 %RH	1	2	1	1	-1	1	0
	59		30.2 °C	30.6 °C	72.8 %RH	1	2	1	1	-1	1	0
	60		30.2 °C	30.6 °C	72.8 %RH	1	1	2	0	-1	1	0
	61		29.4 °C	30.6 °C	72.8 %RH	1	1	2	0	-1	1	0
	62		29.8 °C	30.6 °C	72.4 %RH	1	1	2	0	-1	1	0
	63		30.2 °C	30.2 °C	76.3 %RH	1	2	1	1	-1	1	0
	64		29.4 °C	30.2 °C	76.3 %RH	1	2	1	1	-1	1	0
	65		30.6 °C	30.2 °C	75.8 %RH	1	2	1	1	-1	1	0
	66		30.2 °C	30.2 °C	75.8 %RH	1	2	1	1	-1	1	0
EVENING	67		28.7 °C	29.4 °C	75.7 %RH	1	2	1	1	-1	1	0
	68		29.1 °C	29.4 °C	75.7 %RH	0	1	2	0	0	1	0
	69		29.4 °C	29.4 °C	75.7 %RH	0	1	2	1	0	0	0
	70		29.4 °C	28.7 °C	75.7 %RH	0	1	2	1	0	0	0
	71		29.1 °C	29.1 °C	75.7 %RH	0	1	2	1	0	0	0
	72		28.7 °C	29.4 °C	76.2 %RH	1	2	1	1	-1	1	0
	73		29.1 °C	29.1 °C	76.7 %RH	1	2	1	1	-1	1	0

74		29.1 °C	29.4 °C	76.7 %RH	1	2	1	1	-1	1	0
75		29.1 °C	29.1 °C	76.7 %RH	1	1	2	1	-1	1	0
76		29.1 °C	29.1 °C	76.7 %RH	1	1	1	1	-1	1	0
77		29.1 °C	29.4 °C	76.7 %RH	1	2	1	1	-1	1	0
78		29.1 °C	29.1 °C	76.7 %RH	0	1	2	1	0	1	0
79		29.1 °C	28.7 °C	76.2 %RH	0	1	2	1	0	1	0
80		28.7 °C	29.4 °C	76.2 %RH	1	2	1	1	-1	1	0
81		28.7 °C	29.4 °C	76.2 %RH	1	2	1	1	-1	1	0
82		28.3 °C	29.1 °C	76.2 %RH	1	2	1	1	-1	1	0
83		28.7 °C	29.1 °C	69.4 %RH	0	1	1	0	0	1	0
84		28.7 °C	29.4 °C	69.4 %RH	0	1	1	0	0	1	0
85		28.3 °C	29.1 °C	69.4 %RH	0	1	2	0	0	0	0
86		28.7 °C	29.1 °C	69.4 %RH	0	1	2	0	0	0	0
87		28.7 °C	29.1 °C	69.4 %RH	0	1	2	0	0	0	0
88		28.3 °C	29.1 °C	69.4 %RH	1	2	1	1	-1	1	0
89		28.7 °C	29.1 °C	69.4 %RH	0	1	2	0	0	1	0
90		29.8 °C	29.8 °C	73.3 %RH	0	1	2	0	0	1	0
91		29.1 °C	29.8 °C	72.8 %RH	1	2	1	1	-1	1	0
92		29.1 °C	29.4 °C	72.8 %RH	0	1	2	1	0	1	0
93		29.1 °C	29.4 °C	72.8 %RH	0	1	2	0	0	1	0
94		29.4 °C	29.8 °C	72.8 %RH	1	1	2	1	-1	1	0
95		29.8 °C	29.4 °C	72.8 %RH	0	1	1	0	0	1	0
96		29.4 °C	29.4 °C	72.8 %RH	0	1	1	0	0	1	0
97		29.4 °C	29.8 °C	73.3 %RH	0	1	1	0	0	1	0
98		29.1 °C	29.8 °C	73.3 %RH	1	2	1	1	-1	1	0
99		29.4 °C	29.8 °C	73.3 %RH	1	2	1	1	-1	1	0
100		28.7 °C	29.4 °C	72.8 %RH	1	2	1	1	-1	1	0
101		29.1 °C	29.8 °C	72.8 %RH	1	2	1	1	-1	1	0
102		29.4 °C	29.8 °C	82.4 %RH	1	2	1	2	-1	1	-1

	103		29.8 °C	29.8 °C	82.4 %RH	1	2	1	2	-1	1	-1
	104		29.4 °C	30.2 °C	82.9 %RH	1	2	1	2	-1	1	-1
	105		29.4 °C	29.4 °C	82.9 %RH	1	2	1	2	-1	1	-1
	106		29.1 °C	29.8 °C	82.9 %RH	1	2	1	2	-1	1	-1
	107		29.4 °C	29.8 °C	82.9 %RH	1	2	1	2	-1	1	-1
	108		28.7 °C	29.8 °C	82.4 %RH	1	2	1	2	-1	1	-1
	109		29.4 °C	30.6 °C	85.5 %RH	1	2	1	2	-1	1	-1
	110		29.8 °C	30.6 °C	85.5 %RH	1	2	1	2	-1	1	-1
	111		29.8 °C	30.2 °C	86.0 %RH	1	2	1	2	-1	1	-1
	112		29.8 °C	31.0 °C	86.0 %RH	1	2	1	2	-1	1	-1
	113		29.8 °C	30.6 °C	86.0 %RH	1	2	1	2	-1	1	-1
	114		30.2 °C	30.6 °C	86.0 %RH	1	2	1	2	-1	1	-1
	115		29.8 °C	30.6 °C	86.0 %RH	1	2	1	2	-1	1	-1
	116		29.4 °C	30.2 °C	86.0 %RH	1	2	1	2	-1	1	-1
	117		30.2 °C	30.2 °C	86.0 %RH	1	2	1	2	-1	1	-1
	118		30.2 °C	30.2 °C	83.9 %RH	1	2	1	2	-1	1	-1
	119		29.4 °C	30.2 °C	81.8 %RH	1	2	1	2	-1	1	-1
	120		29.8 °C	30.6 °C	81.3 %RH	1	2	1	2	-1	1	-1

iii. MASJID JAMEK, SEREMBAN NEGERI SEMBILAN, MALAYSIA

time	Nos.	Sex	Outdoor Temp	Indoor Temp	RH	Thermal Sensation	Comfort Level	Wind Condition	Relative Humidity	Thermal Pref.	Wind Pref.	RH Pref.
		1-Male				Very Cold - (-3)	much too cold (-3)	1- Calm	Very dry (-2)	Hotter (1)	Breezier (1)	Drier (1)
		2-Female				Cold - (-2)	too cool(-2)	2-Breezy	Dry (-1)	Unchanged(0)	Unchanged (0)	Unchanged(0)
						slightly Cool- (-1)	Comfortably cool (-1)	3-Very Windy	Neutral (0)	Cooler(-1)	Calmer(-1)	More Humid (-1)
						Neutral (0)	Comfortable(0)		Humid (1)			
						Slightly Warm (1)	Comfortably warm (1)		Very Humid (2)			
						Warm (2)	Too Warm (2)					
						Hot (3)	Much too warm (3)					
Noon												
	1		29.1 °C	29.8 °C	69.0 %RH	0	1	2	0	0	0	0
	2		28.7 °C	30.2 °C	68.0 %RH	0	0	2	0	0	0	0
	3		29.1 °C	30.6 °C	69.6 %RH	0	0	2	0	0	0	0
	4		29.4 °C	31.4 °C	68.5 %RH	1	0	2	0	-1	0	0
	5		29.1 °C	31.0 °C	68.5 %RH	1	0	2	0	-1	0	0
	6		29.4 °C	31.0 °C	68.0 %RH	1	0	2	0	-1	0	0
	7		29.8 °C	28.7 °C	71.3 %RH	0	1	1	0	0	1	0
	8		29.8 °C	29.4 °C	71.3 %RH	0	1	1	0	0	1	0
	9		29.4 °C	29.1 °C	69.8 %RH	0	1	1	0	0	1	0
	10		29.1 °C	29.1 °C	68.8 %RH	0	1	1	0	0	1	0
	11		29.8 °C	29.4 °C	71.3 %RH	0	1	2	0	0	0	0
	12		29.1 °C	29.1 °C	78.7 %RH	0	1	2	0	0	0	0
	13		29.1 °C	29.1 °C	77.2 %RH	0	1	2	0	0	0	0
	14		29.1 °C	29.1 °C	76.7 %RH	0	1	2	0	0	0	0
	15		29.4 °C	28.7 °C	75.7 %RH	0	1	2	0	0	0	0

	16		29.8 °C	28.7 °C	76.7 %RH	0	1	2	0	0	0	0
	17		29.1 °C	28.7 °C	75.7 %RH	0	1	2	0	0	0	0
	18		29.1 °C	29.4 °C	74.2 %RH	0	1	2	0	0	0	0
	19		29.1 °C	29.4 °C	72.0 %RH	0	1	1	0	0	1	0
	20		29.1 °C	30.2 °C	73.0 %RH	1	0	2	0	-1	0	0
	21		29.1 °C	30.2 °C	70.6 %RH	1	0	2	0	-1	0	0
	22		29.4 °C	30.6 °C	69.2 %RH	1	0	2	0	-1	0	0
	23		29.8 °C	30.6 °C	70.6 %RH	1	0	2	0	-1	0	0
	24		29.1 °C	30.2 °C	69.2 %RH	0	0	2	0	0	0	0
	25		29.1 °C	30.6 °C	68.7 %RH	0	0	1	0	0	1	0
	26		27.6 °C	28.3 °C	85.1 %RH	0	0	2	1	0	0	0
	27		27.9 °C	29.1 °C	83.6 %RH	0	0	2	1	0	0	0
	28		27.9 °C	28.7 °C	82.6 %RH	0	0	2	1	0	0	0
	29		28.3 °C	28.7 °C	83.1 %RH	0	0	1	1	0	1	0
	30		27.9 °C	29.1 °C	82.6 %RH	0	0	2	1	0	0	0
	31		27.9 °C	29.1 °C	80.6 %RH	0	0	1	1	0	1	0
	32		27.6 °C	28.3 °C	80.1 %RH	0	0	1	1	0	1	0
	33		27.9 °C	29.1 °C	79.1 %RH	0	0	1	1	0	1	0
	34		27.9 °C	28.7 °C	78.1 %RH	0	0	2	1	0	0	0
	35		27.9 °C	28.7 °C	78.1 %RH	0	0	2	0	0	0	0
	36		28.3 °C	26.9 °C	73.9 %RH	0	1	2	0	0	0	0
	37		27.9 °C	27.6 °C	74.4 %RH	0	1	2	0	0	0	0
	38		27.9 °C	27.6 °C	75.4 %RH	0	1	2	0	0	0	0
	39		27.9 °C	27.2 °C	75.9 %RH	0	1	2	0	0	0	0
	40		28.3 °C	27.9 °C	75.4 %RH	0	1	2	0	0	0	0
	41		28.7 °C	27.9 °C	75.4 %RH	0	1	2	0	0	0	0
	42		28.3 °C	27.9 °C	75.4 %RH	0	1	2	0	0	0	0
	43		27.9 °C	27.9 °C	75.9 %RH	0	1	2	0	0	0	0
	44		28.3 °C	27.6 °C	75.9 %RH	0	1	2	0	0	0	0

	45		27.9 °C	28.3 °C	75.9 %RH	0	1	2	0	0	0	0
	46		27.9 °C	28.3 °C	75.9 %RH	0	1	2	0	0	0	0
	47		27.9 °C	27.9 °C	75.9 %RH	0	1	2	0	0	0	0
	48		28.7 °C	27.9 °C	75.9 %RH	0	1	2	0	0	0	0
	49		28.3 °C	27.9 °C	75.9 %RH	0	1	2	0	0	0	0
	50		28.7 °C	27.9 °C	75.9 %RH	0	1	1	0	0	1	0
	51		29.1 °C	28.7 °C	75.9 %RH	0	1	2	0	0	0	0
afternoon	52		30.2 °C	31.0 °C	73.6 %RH	1	0	2	1	-1	0	0
	53		29.1 °C	29.4 °C	75.6 %RH	0	0	1	0	0	1	0
	54		29.4 °C	29.8 °C	74.6 %RH	0	0	1	0	0	1	0
	55		29.4 °C	29.1 °C	76.1 %RH	0	0	2	0	0	0	0
	56		29.1 °C	27.9 °C	83.1 %RH	0	1	2	0	0	0	0
	57		28.3 °C	27.6 °C	87.6 %RH	0	1	2	0	0	0	0
	58		28.3 °C	26.9 °C	89.5 %RH	0	1	2	1	0	0	0
	59		28.3 °C	27.2 °C	87.6 %RH	0	0	2	1	0	0	0
	60		28.3 °C	27.6 °C	81.1 %RH	0	0	2	1	0	0	0
	61		27.2 °C	27.6 °C	80.6 %RH	0	0	2	1	0	0	0
	62		27.9 °C	27.6 °C	82.1 %RH	0	0	2	1	0	0	0
	63		28.3 °C	27.2 °C	82.1 %RH	0	0	2	0	0	0	0
	64		28.3 °C	27.9 °C	81.1 %RH	0	0	2	0	0	0	0
	65		28.3 °C	27.2 °C	81.1 %RH	0	0	2	0	0	0	0
	66		27.9 °C	27.6 °C	81.1 %RH	0	0	2	0	0	0	0
	67		29.4 °C	30.2 °C	73.1 %RH	0	0	2	0	0	0	0
	68		29.4 °C	30.6 °C	73.6 %RH	1	0	1	0	-1	1	0
	69		30.2 °C	30.6 °C	67.0 %RH	1	0	2	0	-1	0	0
	70		30.2 °C	30.2 °C	67.5 %RH	1	0	1	0	-1	1	0
	71		30.2 °C	31.0 °C	64.5 %RH	1	0	1	0	-1	1	0
	72		30.6 °C	31.0 °C	66.0 %RH	1	0	1	0	-1	1	0
	73		30.2 °C	31.0 °C	68.0 %RH	1	0	1	0	-1	1	0

	74		30.2 °C	31.0 °C	66.5 %RH	1	0	1	0	-1	1	0
	75		30.6 °C	31.4 °C	65.5 %RH	1	0	1	0	-1	1	0
	76		29.8 °C	29.4 °C	73.9 %RH	1	0	1	1	-1	1	0
	77		29.8 °C	29.4 °C	73.9 %RH	0	1	1	0	0	1	0
	78		29.8 °C	29.1 °C	73.9 %RH	0	1	1	0	0	1	0
	79		29.1 °C	29.1 °C	74.4 %RH	0	1	1	0	0	1	0
	80		29.4 °C	29.1 °C	73.9 %RH	0	1	2	0	0	0	0
	81		29.1 °C	29.1 °C	73.9 %RH	0	1	2	0	0	0	0
	82		29.1 °C	29.8 °C	73.9 %RH	0	1	2	0	0	0	0
EVENING	83		27.9 °C	26.5 °C	95.5 %RH	0	-1	1	2	0	0	1
	84		27.6 °C	26.5 °C	95.0 %RH	0	0	2	1	0	0	1
	85		27.9 °C	26.5 °C	94.5 %RH	0	-1	2	2	0	0	1
	86		27.9 °C	26.9 °C	94.0 %RH	0	0	2	1	0	0	0
	87		27.6 °C	27.2 °C	94.5 %RH	0	0	2	1	0	0	0
	88		27.2 °C	26.9 °C	93.0 %RH	0	0	2	1	0	0	0
	89		27.6 °C	26.9 °C	93.0 %RH	0	0	2	2	0	0	0
	90		27.2 °C	26.9 °C	93.5 %RH	0	0	2	2	0	0	1
	91		27.6 °C	26.5 °C	92.5 %RH	0	0	2	2	0	0	1
	92		27.2 °C	26.9 °C	93.0 %RH	0	1	2	1	0	0	1
	93		27.2 °C	26.9 °C	93.0 %RH	0	1	2	2	0	0	0
	94		27.6 °C	27.2 °C	93.0 %RH	0	0	2	2	0	0	0
	95		27.2 °C	27.2 °C	92.5 %RH	0	0	2	2	0	0	1
	96		27.2 °C	26.9 °C	92.5 %RH	0	1	2	2	0	0	1
	97		27.9 °C	27.2 °C	93.0 %RH	0	1	2	2	0	0	1
	98		27.9 °C	27.9 °C	83.1 %RH	0	0	2	1	0	0	1
	99		28.3 °C	27.9 °C	82.6 %RH	0	0	2	1	0	0	0
	100		27.9 °C	27.9 °C	82.6 %RH	0	0	2	1	0	0	0
	101		27.9 °C	27.6 °C	82.1 %RH	0	0	2	1	0	0	0
	102		27.6 °C	27.9 °C	82.1 %RH	0	0	2	1	0	0	0

	103		27.9 °C	27.9 °C	81.6 %RH	0	0	2	1	0	0	0
	104		28.3 °C	28.3 °C	81.6 %RH	0	1	2	1	0	0	0
	105		28.3 °C	28.3 °C	82.6 %RH	0	0	2	1	0	0	0
	106		28.3 °C	27.9 °C	80.6 %RH	0	1	2	1	0	0	0
	107		27.9 °C	27.9 °C	77.8 %RH	0	1	2	1	0	0	0
	108		27.9 °C	27.6 °C	76.8 %RH	0	1	2	1	0	0	0
	109		28.3 °C	27.6 °C	78.2 %RH	0	1	2	1	0	0	0
	110		27.2 °C	27.2 °C	78.7 %RH	0	1	2	1	0	0	0
	111		27.9 °C	27.2 °C	79.2 %RH	0	1	2	1	0	0	0
	112		27.9 °C	26.9 °C	80.6 %RH	0	1	2	1	0	0	0
	113		27.9 °C	26.5 °C	80.6 %RH	0	1	2	1	0	0	0
	114		27.2 °C	26.5 °C	81.1 %RH	0	1	2	1	0	0	0
	115		31.4 °C	32.2 °C	70.3 %RH	2	-1	1	1	-1	1	0
	116		31.8 °C	32.2 °C	70.8 %RH	2	-1	1	1	-1	1	0
	117		32.2 °C	32.2 °C	70.8 %RH	2	-1	1	1	-1	1	0
	118		31.8 °C	32.2 °C	70.3 %RH	2	-1	1	1	-1	1	0
	119		31.4 °C	31.8 °C	70.8 %RH	2	-1	1	1	-1	1	0
	120		31.8 °C	31.4 °C	71.3 %RH	2	-1	1	1	-1	1	0
	121		31.0 °C	31.8 °C	71.3 %RH	2	-1	1	1	-1	1	0
	122		31.4 °C	32.2 °C	71.3 %RH	2	-1	1	1	-1	1	0
	123		31.4 °C	31.4 °C	72.2 %RH	2	-1	1	1	-1	1	0
	124		31.0 °C	31.8 °C	72.2 %RH	2	-1	1	1	-1	1	0
	125		31.4 °C	31.8 °C	72.7 %RH	2	-1	1	1	-1	1	0
	126		31.8 °C	31.8 °C	72.7 %RH	2	-1	1	1	-1	1	0
	127		31.0 °C	31.4 °C	72.2 %RH	1	0	2	1	-1	0	0
	128		31.8 °C	31.8 °C	72.2 %RH	2	0	2	1	-1	0	0
	129		31.4 °C	31.8 °C	72.2 %RH	2	0	1	1	-1	1	0
	130		31.4 °C	31.8 °C	72.2 %RH	2	0	1	1	-1	1	0
	131		31.4 °C	32.2 °C	72.2 %RH	2	-1	1	1	-1	1	0

iv. MASJID SIKAMAT, SEREMBAN, NEGERI SEMBILAN

NO.	TIME	Outdoor Temp	Indoor Temp	RH	Thermal Sensation	Comfort Level	Wind Condition	Relative Humidity	Thermal Pref.	Wind Pref.	RH Pref.
					Very Cold -(-3)	Much too cool (-3)	1- Calm	Very dry (-2)	Hotter (1)	Breezier (1)	Drier (1)
					Cold - (-2)	Too cool	2-Breezy	Dry (-1)	Unchanged(0)	Unchanged (0)	Unchanged(0)
					slightly Cold - (-1)	Comfortably cool(-1)	3-Very Windy	Neutral (0)	Cooler(-1)	Calmer(-1)	More Humid (-1)
					Neutral (0)	Comfortable (0)		Humid (1)			
					Warm (1)	Comfortably warm (1)		Very Humid (2)			
					Hot (2)	Too warm (2)					
	NOON				Very Hot (3)	Much too warm (3)					
1		30.2 °C	29.1 °C	68.2 %RH	0	0	1	0	-1	1	0
2		30.2 °C	29.1 °C	68.7 %RH	0	0	1	0	-1	1	0
3		30.2 °C	28.3 °C	69.6 %RH	0	0	1	0	-1	1	0
4		29.4 °C	28.7 °C	70.1 %RH	0	0	1	0	-1	1	0
5		29.4 °C	29.1 °C	71.5 %RH	0	0	1	0	-1	1	0
6		29.8 °C	29.1 °C	73.5 %RH	0	0	1	0	-1	1	0
7		29.4 °C	28.7 °C	73.0 %RH	0	0	1	0	-1	1	0
8		29.4 °C	28.7 °C	71.5 %RH	0	0	1	0	-1	1	0
9		26.1 °C	26.1 °C	83.1 %RH	0	0	2	1	0	0	1
10		26.1 °C	26.9 °C	83.5 %RH	0	0	2	1	-1	0	1
11		26.9 °C	26.5 °C	82.6 %RH	0	0	2	1	0	0	1
12		26.9 °C	26.1 °C	82.6 %RH	0	0	2	1	0	0	1
13		26.5 °C	26.9 °C	81.6 %RH	0	0	2	1	0	0	1
14		26.9 °C	26.5 °C	81.6 %RH	0	0	1	1	0	1	1
15		26.5 °C	26.5 °C	81.1 %RH	0	0	2	1	0	0	1
16		26.9 °C	26.5 °C	80.6 %RH	0	0	2	1	0	0	1
17		27.2 °C	26.9 °C	81.1 %RH	0	0	1	1	-1	1	1
18		27.2 °C	26.9 °C	81.1 %RH	0	0	2	1	-1	0	1

19		29.4 °C	27.6 °C	78.7 %RH	0	0	1	1	-1	1	1
20		28.7 °C	27.6 °C	78.7 %RH	0	0	1	1	-1	1	1
21		29.4 °C	27.2 °C	78.2 %RH	0	0	2	1	-1	0	1
22		29.4 °C	26.9 °C	78.2 %RH	0	0	2	1	-1	0	1
23		29.4 °C	27.2 °C	79.2 %RH	0	0	2	1	-1	0	1
24		29.4 °C	27.6 °C	78.7 %RH	0	0	1	1	-1	1	1
25		29.8 °C	27.6 °C	78.7 %RH	0	0	1	1	-1	1	1
26		29.8 °C	27.6 °C	78.7 %RH	0	0	2	1	-1	0	1
27		30.6 °C	27.2 °C	78.2 %RH	0	0	2	1	-1	0	1
28		30.2 °C	27.9 °C	76.7 %RH	0	0	2	1	-1	0	1
29		31.0 °C	28.7 °C	68.2 %RH	0	0	1	0	-1	1	0
30		31.0 °C	28.3 °C	66.8 %RH	0	0	2	0	-1	0	0
31		31.0 °C	28.7 °C	66.8 %RH	0	0	1	0	-1	1	0
32		30.6 °C	29.1 °C	66.3 %RH	0	0	2	0	-1	0	0
33		31.0 °C	28.7 °C	66.8 %RH	0	0	2	0	-1	0	0
34		30.6 °C	28.7 °C	66.8 %RH	0	0	2	0	-1	0	0
35		31.0 °C	29.4 °C	67.2 %RH	0	0	2	0	-1	0	0
36		30.6 °C	29.1 °C	67.2 %RH	0	0	2	0	-1	0	0
37		30.6 °C	29.4 °C	65.8 %RH	0	0	2	0	-1	0	0
38		31.4 °C	29.1 °C	64.9 %RH	0	0	1	0	-1	1	0
39		31.0 °C	29.8 °C	64.4 %RH	0	0	2	0	-1	0	0
40		31.0 °C	29.8 °C	63.9 %RH	0	0	1	0	-1	1	0
41		31.8 °C	29.8 °C	63.9 %RH	0	0	1	0	-1	1	0
42		31.4 °C	29.4 °C	72.0 %RH	0	-1	1	1	-1	1	1
43		31.4 °C	29.4 °C	70.5 %RH	0	-1	1	1	-1	1	1
44		31.4 °C	29.4 °C	71.5 %RH	0	-1	1	1	-1	1	1
45		31.0 °C	29.4 °C	71.0 %RH	0	-1	1	1	-1	1	1
46		31.0 °C	29.8 °C	71.5 %RH	0	-1	1	1	-1	1	1
47		31.0 °C	29.8 °C	71.5 %RH	0	-1	1	1	-1	1	1

48		31.0 °C	29.4 °C	71.5 %RH	0	-1	1	1	-1	1	1
49		31.4 °C	29.8 °C	71.5 %RH	0	-1	1	1	-1	1	1
50		31.4 °C	30.2 °C	71.5 %RH	1	-1	1	1	-1	1	1
51		31.4 °C	29.8 °C	71.0 %RH	0	-1	1	1	-1	1	1
52		31.0 °C	30.2 °C	71.0 %RH	1	-1	1	1	-1	1	1
53		31.4 °C	30.2 °C	71.5 %RH	1	-1	1	1	-1	1	1

	AFTERNOON	27.2 °C	27.6 °C	81.1 %RH	0	1	2	1	-1	0	1
1		26.9 °C	27.6 °C	81.6 %RH	0	1	2	1	-1	0	1
2		27.2 °C	27.2 °C	78.7 %RH	0	1	2	1	-1	0	1
3		27.2 °C	27.2 °C	77.8 %RH	0	1	2	1	-1	0	1
4		26.9 °C	27.2 °C	77.8 %RH	0	1	2	1	-1	0	1
5		26.1 °C	27.2 °C	77.8 %RH	0	1	2	1	-1	0	1
6		26.5 °C	26.9 °C	78.7 %RH	0	1	2	1	-1	0	1
7		26.5 °C	26.5 °C	78.7 %RH	0	1	2	1	-1	0	1
8		26.5 °C	26.9 °C	79.2 %RH	0	1	2	1	-1	0	1
9		28.3 °C	28.3 °C	85.6 %RH	0	1	2	1	-1	0	1
10		28.3 °C	27.6 °C	85.1 %RH	0	1	1	0	-1	1	0
11		27.9 °C	27.9 °C	85.1 %RH	0	1	2	1	-1	0	1
12		28.3 °C	27.9 °C	85.6 %RH	0	1	1	0	-1	1	0
13		28.3 °C	27.9 °C	84.1 %RH	0	1	1	1	-1	1	1
14		28.3 °C	28.3 °C	85.1 %RH	0	1	1	0	-1	1	0
15		27.9 °C	28.3 °C	85.1 %RH	0	1	2	1	-1	0	1
16		27.9 °C	28.3 °C	85.1 %RH	0	1	1	0	-1	1	0
17		27.9 °C	28.3 °C	85.1 %RH	0	1	2	1	-1	0	1
18		30.2 °C	31.0 °C	67.0 %RH	1	2	2	1	-1	0	1
19		30.2 °C	31.0 °C	66.5 %RH	1	2	1	1	-1	1	1
20		30.6 °C	31.0 °C	66.5 %RH	1	2	1	1	-1	1	1

21		30.2 °C	30.6 °C	66.5 %RH	1	2	1	1	-1	1	1
22		30.6 °C	30.6 °C	66.5 %RH	1	2	1	1	-1	1	1
23		30.6 °C	31.0 °C	66.0 %RH	1	2	1	1	-1	1	1
24		30.6 °C	31.0 °C	66.0 %RH	1	2	1	1	-1	1	1
25		31.0 °C	31.0 °C	65.5 %RH	1	2	1	1	-1	1	1
26		30.6 °C	31.0 °C	64.5 %RH	1	0	2	1	-1	0	1
27		31.0 °C	31.4 °C	64.5 %RH	1	0	2	1	-1	0	1
28		30.6 °C	31.0 °C	64.0 %RH	1	0	2	1	-1	0	1
29		29.8 °C	30.2 °C	70.6 %RH	1	0	2	1	-1	0	1
30		30.2 °C	30.2 °C	69.6 %RH	1	0	2	1	-1	0	1
31		30.2 °C	30.6 °C	69.2 %RH	1	2	1	1	-1	1	1
32		29.8 °C	30.6 °C	69.2 %RH	1	0	2	1	-1	0	1
33		30.2 °C	30.2 °C	69.6 %RH	1	2	1	1	-1	1	1
34		30.2 °C	31.0 °C	70.1 %RH	1	2	1	2	-1	1	1
35		30.2 °C	31.0 °C	70.1 %RH	1	2	1	2	-1	1	1
36		30.2 °C	30.6 °C	69.6 %RH	1	1	2	1	-1	0	1
37		30.2 °C	31.0 °C	68.7 %RH	1	1	2	1	-1	0	1

	EVENING	25.8 °C	27.6 °C	80.2 %RH	1	2	1	1	-1	1	1
1		26.9 °C	26.9 °C	80.6 %RH	0	1	2	1	-1	0	1
2		26.9 °C	27.2 °C	80.6 %RH	0	1	1	0	-1	1	0
3		26.5 °C	27.2 °C	80.6 %RH	0	1	1	0	-1	1	0
4		26.5 °C	26.9 °C	80.6 %RH	0	1	1	0	-1	1	0
5		26.9 °C	27.2 °C	81.1 %RH	0	1	2	1	-1	0	1
6		26.1 °C	26.9 °C	80.6 %RH	0	1	1	0	-1	1	0
7		26.5 °C	26.9 °C	81.1 %RH	0	1	1	0	-1	1	0
8		26.5 °C	27.2 °C	81.6 %RH	0	1	1	0	-1	1	0
9		26.5 °C	27.2 °C	81.6 %RH	0	1	2	1	-1	0	1
10		26.9 °C	27.2 °C	82.1 %RH	0	1	2	1	-1	0	1

11		26.9 °C	26.9 °C	83.1 %RH	0	1	1	0	-1	1	0
12		27.2 °C	26.9 °C	83.5 %RH	0	1	1	0	-1	1	0
13		27.2 °C	27.2 °C	85.0 %RH	0	1	2	1	-1	0	1
14		26.5 °C	26.5 °C	85.0 %RH	0	1	2	1	-1	0	1
15		26.5 °C	27.2 °C	85.5 %RH	0	1	2	1	-1	0	1
16		26.5 °C	26.5 °C	85.5 %RH	0	1	2	1	-1	0	1
17		26.9 °C	26.5 °C	85.5 %RH	0	1	2	1	-1	0	1
18		27.2 °C	26.9 °C	85.9 %RH	0	1	2	1	-1	0	1
19		26.9 °C	26.9 °C	85.5 %RH	0	1	2	1	-1	0	1
20		28.3 °C	28.3 °C	84.1 %RH	0	2	1	1	-1	1	1
21		27.9 °C	29.1 °C	84.6 %RH	1	2	1	1	-1	1	1
22		27.9 °C	28.7 °C	85.6 %RH	1	2	1	1	-1	1	1
23		27.2 °C	28.7 °C	85.6 %RH	1	2	1	1	-1	1	1
24		27.2 °C	28.3 °C	85.1 %RH	0	2	1	1	-1	1	1
25		27.2 °C	29.1 °C	85.6 %RH	1	2	1	1	-1	1	1
26		27.9 °C	27.9 °C	85.1 %RH	0	2	1	1	-1	1	1
27		27.6 °C	28.3 °C	85.6 %RH	1	2	1	1	-1	1	1
28		27.2 °C	28.7 °C	86.6 %RH	1	2	1	1	-1	1	1
29		27.6 °C	28.3 °C	87.6 %RH	1	2	1	1	-1	1	1
30		27.9 °C	27.9 °C	87.6 %RH	1	2	1	1	-1	1	1
31		27.2 °C	28.3 °C	88.1 %RH	1	2	1	1	-1	1	1
32		27.6 °C	28.3 °C	87.6 %RH	1	2	1	1	-1	1	1
33		27.2 °C	28.3 °C	87.6 %RH	1	2	1	1	-1	1	1
34		27.2 °C	27.9 °C	87.6 %RH	1	2	1	1	-1	1	1
35		27.6 °C	27.9 °C	87.6 %RH	1	2	1	1	-1	1	1
36		27.2 °C	27.9 °C	87.6 %RH	1	2	1	1	-1	1	1
37		27.6 °C	27.9 °C	87.6 %RH	1	2	1	1	-1	1	1
38		29.8 °C	31.8 °C	58.7 %RH	2	2	2	0	-1	1	0
39		29.4 °C	31.8 °C	58.7 %RH	2	2	2	0	-1	1	0

40		30.2 °C	31.8 °C	59.6 %RH	2	2	1	0	-1	1	0
41		30.2 °C	32.2 °C	59.6 %RH	2	2	1	0	-1	1	0
42		29.8 °C	31.8 °C	60.1 %RH	2	2	1	0	-1	1	0
43		29.8 °C	31.4 °C	60.1 %RH	1	2	1	0	-1	1	0
44		29.4 °C	31.4 °C	60.1 %RH	1	2	1	0	-1	1	0
45		29.8 °C	31.8 °C	60.1 %RH	1	2	1	0	-1	1	0
46		29.4 °C	31.8 °C	61.1 %RH	1	2	1	0	-1	1	0
47		29.8 °C	31.8 °C	62.0 %RH	1	2	1	0	-1	1	0
48		29.1 °C	31.4 °C	63.0 %RH	1	2	1	0	-1	1	0
49		29.1 °C	31.8 °C	63.4 %RH	1	2	1	0	-1	1	0
50		29.4 °C	31.4 °C	63.4 %RH	1	2	1	0	-1	1	0
51		29.4 °C	31.8 °C	63.4 %RH	1	1	2	0	-1	0	0
52		29.8 °C	31.0 °C	63.9 %RH	1	1	2	0	-1	0	0
53		29.8 °C	31.0 °C	64.9 %RH	1	1	2	0	-1	0	0
54		29.1 °C	31.4 °C	64.9 %RH	1	1	2	0	-1	0	0
55		29.1 °C	31.0 °C	64.9 %RH	1	1	2	0	-1	0	0
56		28.7 °C	31.4 °C	66.3 %RH	1	1	2	0	-1	0	0
57		29.1 °C	31.0 °C	66.3 %RH	1	1	2	0	-1	0	0
58		29.1 °C	31.4 °C	67.2 %RH	1	1	2	0	-1	0	0
59		29.1 °C	31.4 °C	66.8 %RH	1	1	2	0	-1	0	0
60		29.8 °C	31.4 °C	71.1 %RH	1	2	1	1	-1	1	1
61		29.4 °C	30.6 °C	71.5 %RH	1	2	1	1	-1	1	1
62		30.2 °C	30.6 °C	71.5 %RH	1	2	1	1	-1	1	1
63		29.4 °C	30.6 °C	72.5 %RH	1	1	2	1	-1	0	1
64		29.8 °C	31.0 °C	73.0 %RH	1	1	2	1	-1	0	1
65		29.1 °C	31.0 °C	73.0 %RH	1	1	2	1	-1	0	1
66		29.1 °C	30.6 °C	73.0 %RH	1	2	1	1	-1	1	1
67		29.4 °C	30.6 °C	73.5 %RH	1	2	1	1	-1	1	1
68		29.1 °C	30.2 °C	73.5 %RH	1	2	1	1	-1	1	1

69		29.1 °C	30.6 °C	73.9 %RH	1	1	2	1	-1	0	1
70		29.8 °C	30.6 °C	73.9 %RH	1	1	2	1	-1	0	1
71		30.2 °C	30.2 °C	73.9 %RH	1	2	1	1	-1	1	1
72		29.8 °C	30.2 °C	74.4 %RH	1	1	2	1	-1	0	1

APPENDIX C

I) HTB2 CODING FOR PITCHED ROOF

METEOROLOGICAL FILE

Climatic data – pitch roof

```
30101   25.0   24.0  ,,  94   1.5  ,,   0.0   0  ,,  0.8
30102   25.0   23.0  ,,  89   1.5  ,,   0.0   0  ,,  0.8
30103   25.0   23.0  ,,  89   1.0  ,,   0.0   0  ,,  0.8
30104   25.0   23.0  ,,  89   0.5  ,,   0.0   0  ,,  0.8
30105   24.0   23.0  ,,  94   1.0  ,,   0.0   0  ,,  0.8
30106   24.0   23.0  ,,  94   1.0  ,,   0.0   0  ,,  0.8
30107   24.0   23.0  ,,  94   1.5  ,, 105.0  40  ,,  0.8
30108   24.0   23.0  ,,  94   1.5  ,,   250.0 80,,  0.8
30109   26.0   24.0  ,,  89   3.1  ,,   320.0 100,,  0.8
30110   28.0   24.0  ,,  79   3.6  ,,   400.0 120,,  0.8
30111   30.0   24.0  ,,  70   4.6  ,,   450.0 180,,  0.8
30112   31.0   24.0  ,,  66   4.1  ,,   500.0 200,,  0.8
30113   32.0   24.0  ,,  62   3.1  ,,   520.0 220,,  0.8
30114   30.0   24.0  ,,  70   4.1  ,,   550.0 250,,  0.8
30115   30.0   25.0  ,,  74   2.6  ,,   580.0 260,,  0.8
30116   30.0   25.0  ,,  74   2.6  ,,   500.0 210,,  0.8
30117   32.0   24.0  ,,  62   1.5  ,,   320.0 150,,  0.8
30118   31.0   24.0  ,,  66   3.6  ,,   210.0  80,,  0.8
30119   29.0   24.0  ,,  74   2.1  ,,   110.0  40,,  1
30120   26.0   23.0  ,,  83   3.1  ,,   0.0     0,,  1
30121   26.0   24.0  ,,  89   2.1  ,,   0.0     0,,  1
30122   26.0   25.0  ,,  94   2.1  ,,   0.0     0,,  1
30123   25.0   24.0  ,,  94   2.6  ,,   0.0     0,,  1
30124   25.0   24.0  ,,  94   0.0  ,,   0.0     0,,  1
30201   25.0   24.0  ,,  94   1.5  ,,   0.0     0,,  0.8
30202   25.0   24.0  ,,  94   1.5  ,,   0.0     0,,  0.8
30203   25.0   24.0  ,,  94   1.5  ,,   0.0     0,,  0.8
30204   24.0   24.0  ,, 100   0.5  ,,   0.0     0,,  0.8
30205   24.0   24.0  ,, 100   1.5  ,,   0.0     0,,  0.8
30206   24.0   24.0  ,, 100   0.0  ,,   0.0     0,,  0.8
30207   25.0   24.0  ,, 94    1.0  ,,   105.0  40,,  0.8
30208   25.0   24.0  ,, 94    1.5  ,,   250.0 80,,  0.8
30209   26.0   24.0  ,, 89    1.0  ,,   320.0 100,,  0.8
30210   27.0   25.0  ,, 89    3.1  ,,   400.0 120,,  0.8
30211   28.0   25.0  ,, 84    2.6  ,,   450.0 180,,  0.8
30212   30.0   24.0  ,, 70    4.6  ,,   500.0 200,,  0.8
30213   31.0   24.0  ,, 66    3.6  ,,   520.0 220,,  0.8
30214   25.0   24.0  ,, 94    1.5  ,,   550.0 250,,  0.8
```

30215	26.0	24.0	,,	89	1.0	,,	580.0	260,,	0.8
30216	27.0	25.0	,,	89	3.1	,,	500.0	210,,	0.8
30217	28.0	25.0	,,	84	2.6	,,	320.0	150,,	0.8
30218	30.0	24.0	,,	70	4.6	,,	210.0	80,,	0.8
30219	31.0	24.0	,,	66	3.6	,,	110.0	40,,	0.8
30220	29.0	25.0	,,	79	2.6	,,	0.0	0,,	1
30221	28.0	24.0	,,	79	2.1	,,	0.0	0,,	0.8
30222	27.0	24.0	,,	84	2.1	,,	0.0	0,,	0.8
30223	27.0	24.0	,,	84	2.1	,,	0.0	0,,	0.8
30224	27.0	24.0	,,	84	3.6	,,	0.0	0,,	0.8
30301	26.0	24.0	,,	89	4.1	,,	0.0	0,,	0.8
30302	26.0	24.0	,,	89	2.6	,,	0.0	0,,	0.8
30303	26.0	24.0	,,	89	3.1	,,	0.0	0,,	0.8
30304	26.0	24.0	,,	89	4.1	,,	0.0	0,,	0.8
30305	26.0	24.0	,,	89	2.6	,,	0.0	0,,	0.8
30306	26.0	24.0	,,	89	3.6	,,	0.0	0,,	0.8
30307	23.0	22.0	,,	94	3.1	,,	105.0	40,,	1
30308	23.0	22.0	,,	94	2.1	,,	250.0	80,,	1
30309	23.0	22.0	,,	94	1.0	,,	320.0	100,,	1
30310	24.0	23.0	,,	94	0.5	,,	400.0	120,,	1
30311	25.0	24.0	,,	94	1.5	,,	450.0	180,,	0.8
30312	27.0	25.0	,,	89	2.1	,,	500.0	200,,	0.8
30313	29.0	25.0	,,	79	2.1	,,	520.0	220,,	0.8
30314	30.0	26.0	,,	79	2.1	,,	550.0	250,,	0.8
30315	31.0	26.0	,,	75	1.5	,,	580.0	260,,	0.8
30316	32.0	26.0	,,	70	2.1	,,	500.0	210,,	0.8
30317	25.0	23.0	,,	89	4.1	,,	320.0	150,,	1
30318	24.0	23.0	,,	94	1.5	,,	210.0	80,,	0.8
30319	25.0	24.0	,,	94	0.5	,,	110.0	40,,	0.6
30320	25.0	24.0	,,	94	0.0	,,	0.0	0,,	0.8
30321	26.0	25.0	,,	94	1.0	,,	0.0	0,,	0.8
30322	26.0	24.0	,,	89	1.5	,,	0.0	0,,	0.8
30323	25.0	24.0	,,	94	1.5	,,	0.0	0,,	0.8
30324	25.0	24.0	,,	94	1.5	,,	0.0	0,,	0.8
30401	25.0	24.0	,,	94	1.5	,,	0.0	0,,	0.8
30402	25.0	24.0	,,	94	1.0	,,	0.0	0,,	0.8
30403	25.0	24.0	,,	94	2.1	,,	0.0	0,,	0.8
30404	25.0	24.0	,,	94	1.5	,,	0.0	0,,	1
30405	25.0	23.0	,,	89	1.0	,,	0.0	0,,	0.8
30406	25.0	23.0	,,	89	1.0	,,	0.0	0,,	0.8
30407	25.0	23.0	,,	89	1.0	,,	105.0	40,,	0.8
30408	25.0	23.0	,,	89	1.5	,,	250.0	80,,	0.8
30409	26.0	24.0	,,	89	2.1	,,	320.0	100,,	0.8
30410	28.0	24.0	,,	79	2.1	,,	400.0	120,,	0.8
30411	30.0	24.0	,,	70	4.6	,,	450.0	180,,	0.8
30412	30.0	24.0	,,	70	3.6	,,	500.0	200,,	0.8
30413	30.0	24.0	,,	70	3.6	,,	520.0	220,,	0.8
30414	33.0	24.0	,,	59	1.5	,,	550.0	250,,	0.8
30415	32.0	25.0	,,	66	3.1	,,	580.0	260,,	0.8
30416	33.0	25.0	,,	63	4.6	,,	500.0	210,,	0.8
30417	33.0	23.0	,,	55	4.1	,,	320.0	150,,	0.8

30418	32.0	23.0	,, 59	4.1	,,	210.0	80,,	0.8
30419	31.0	23.0	,, 62	3.1	,,	110.0	40,,	0.8
30420	29.0	24.0	,, 74	1.5	,,	0.0	0,,	0.8
30421	29.0	25.0	,, 79	1.0	,,	0.0	0,,	0.8
30422	29.0	24.0	,, 74	1.5	,,	0.0	0,,	0.8
30423	27.0	25.0	,, 89	1.5	,,	0.0	0,,	0.8
30424	27.0	25.0	,, 89	2.1	,,	0.0	0,,	0.8
30501	27.0	24.0	,, 84	2.1	,,	0.0	0,,	0.8
30502	26.0	24.0	,, 86	3.6	,,	0.0	0,,	0.4
30503	26.0	24.0	,, 89	3.1	,,	0.0	0,,	0.8
30504	26.0	24.0	,, 89	1.5	,,	0.0	0,,	0.8
30505	26.0	24.0	,, 89	2.1	,,	0.0	0,,	0.8
30506	25.0	24.0	,, 94	2.1	,,	0.0	0,,	0.8
30507	25.0	24.0	,, 94	1.0	,,	105.0	40,,	0.8
30508	26.0	24.0	,, 89	1.5	,,	250.0	80,,	0.8
30509	27.0	24.0	,, 84	2.6	,,	320.0	100,,	0.8
30510	28.0	25.0	,, 84	3.1	,,	400.0	120,,	0.8
30511	28.0	25.0	,, 84	2.6	,,	450.0	180,,	1
30512	28.0	25.0	,, 84	0.5	,,	500.0	200,,	1
30513	28.0	25.0	,, 84	1.0	,,	520.0	220,,	0.8
30514	28.0	25.0	,, 84	3.6	,,	550.0	250,,	1
30515	27.0	25.0	,, 89	2.6	,,	580.0	260,,	1
30516	28.0	24.0	,, 79	3.1	,,	500.0	210,,	0.8
30517	28.0	24.0	,, 79	2.6	,,	320.0	150,,	0.8
30518	28.0	25.0	,, 84	2.1	,,	210.0	80,,	0.8
30519	28.0	24.0	,, 79	3.6	,,	110.0	40,,	0.8
30520	27.0	24.0	,, 84	1.5	,,	0.0	0,,	0.8
30521	27.0	24.0	,, 84	1.5	,,	0.0	0,,	0.8
30522	26.0	24.0	,, 89	1.5	,,	0.0	0,,	0.8
30523	26.0	23.0	,, 83	2.1	,,	0.0	0,,	0.8
30524	26.0	23.0	,, 83	1.5	,,	0.0	0,,	0.8
30601	26.0	23.0	,, 83	1.5	,,	0.0	0,,	0.8
30602	25.0	24.0	,, 94	0.5	,,	0.0	0,,	0.8
30603	25.0	24.0	,, 94	0.5	,,	0.0	0,,	0.8
30604	25.0	24.0	,, 94	1.0	,,	0.0	0,,	0.8
30605	25.0	24.0	,, 94	1.0	,,	0.0	0,,	0.8
30606	24.0	24.0	,,100	1.5	,,	0.0	0,,	0.8
30607	24.0	23.0	,, 94	1.0	,,	105.0	40,,	0.8
30608	24.0	23.0	,, 94	1.5	,,	250.0	80,,	0.8
30609	26.0	24.0	,, 89	2.1	,,	320.0	100,,	0.7
30610	26.0	24.0	,, 89	2.1	,,	400.0	120,,	0.7
30611	26.0	24.0	,, 89	2.1	,,	450.0	180,,	0.7
30612	30.0	25.0	,, 74	1.5	,,	500.0	200,,	0.8
30613	31.0	25.0	,, 70	1.5	,,	520.0	220,,	0.8
30614	31.0	24.0	,, 66	2.1	,,	550.0	250,,	0.8
30615	31.0	25.0	,, 70	3.1	,,	580.0	260,,	0.8
30616	32.0	25.0	,, 66	5.7	,,	500.0	210,,	0.8
30617	32.0	24.0	,, 62	4.6	,,	320.0	150,,	1
30618	32.0	24.0	,, 62	3.6	,,	210.0	80,,	0.8
30619	31.0	23.0	,, 62	3.1	,,	110.0	40,,	0.8
30620	29.0	24.0	,, 74	2.1	,,	0.0	0,,	0.8

30621	28.0	24.0	,,	79	1.5	,,	0.0	0,,	0.8
30622	28.0	25.0	,,	84	1.0	,,	0.0	0,,	0.8
30623	28.0	25.0	,,	84	1.0	,,	0.0	0,,	0.8
30624	28.0	25.0	,,	84	0.0	,,	0.0	0,,	0.8
30701	28.0	26.0	,,	89	0.5	,,	0.0	0,,	0.8
30702	27.0	25.0	,,	89	0.0	,,	0.0	0,,	0.8
30703	26.0	25.0	,,	94	1.0	,,	0.0	0,,	0.8
30704	26.0	25.0	,,	94	1.5	,,	0.0	0,,	0.8
30705	26.0	25.0	,,	94	0.0	,,	0.0	0,,	0.8
30706	26.0	25.0	,,	94	0.0	,,	0.0	0,,	0.8
30707	26.0	25.0	,,	94	0.0	,,	105.0	40,,	1
30708	25.0	24.0	,,	94	1.5	,,	250.0	80,,	1
30709	26.0	24.0	,,	89	0.5	,,	320.0	100,,	0.8
30710	28.0	25.0	,,	84	1.0	,,	400.0	120,,	0.8
30711	30.0	25.0	,,	74	2.1	,,	450.0	180,,	0.8
30712	31.0	25.0	,,	70	1.0	,,	500.0	200,,	0.8
30713	32.0	25.0	,,	66	2.1	,,	520.0	220,,	0.8
30714	32.0	24.0	,,	57	4.1	,,	550.0	250,,	0.7
30715	32.0	24.0	,,	57	4.1	,,	580.0	260,,	0.7
30716	32.0	24.0	,,	57	4.1	,,	500.0	210,,	0.7
30717	32.0	24.0	,,	57	4.1	,,	320.0	150,,	0.7
30718	32.0	24.0	,,	57	4.1	,,	210.0	80,,	0.7
30719	32.0	24.0	,,	57	4.1	,,	110.0	40,,	0.7
30720	26.0	24.0	,,	90	4.1	,,	0.0	0,,	1
30721	26.0	24.0	,,	90	2.1	,,	0.0	0,,	1
30722	26.0	24.0	,,	89	0.5	,,	0.0	0,,	0.8
30723	26.0	24.0	,,	89	1.0	,,	0.0	0,,	0.8
30724	25.0	24.0	,,	94	0.5	,,	0.0	0,,	0.8
30801	25.0	24.0	,,	94	1.0	,,	0.0	0,,	0.8
30802	25.0	24.0	,,	94	0.0	,,	0.0	0,,	0.8
30803	24.0	23.0	,,	94	0.0	,,	0.0	0,,	0.8
30804	24.0	23.0	,,	94	0.0	,,	0.0	0,,	0.8
30805	24.0	23.0	,,	94	1.5	,,	0.0	0,,	0.8
30806	24.0	23.0	,,	94	1.0	,,	0.0	0,,	0.8
30807	23.0	23.0	,,	100	1.0	,,	105.0	40,,	0.8
30808	24.0	23.0	,,	94	0.0	,,	250.0	80,,	0.8
30809	26.0	23.0	,,	83	0.0	,,	320.0	100,,	0.8
30810	28.0	24.0	,,	79	0.0	,,	400.0	120,,	0.8
30811	30.0	23.0	,,	66	1.5	,,	450.0	180,,	0.8
30812	31.0	24.0	,,	66	2.6	,,	500.0	200,,	0.8
30813	32.0	23.0	,,	59	4.1	,,	520.0	220,,	0.8
30814	33.0	24.0	,,	59	4.6	,,	500.0	250,,	0.8
30815	33.0	22.0	,,	52	3.6	,,	580.0	260,,	0.8
30816	33.0	22.0	,,	52	3.6	,,	500.0	210,,	0.8
30817	33.0	21.0	,,	49	4.1	,,	320.0	150,,	0.8
30818	32.0	21.0	,,	52	3.1	,,	210.0	80,,	0.8
30819	31.0	21.0	,,	55	3.1	,,	110.0	40,,	0.8
30820	30.0	21.0	,,	58	2.1	,,	0.0	0,,	0.8
30821	28.0	23.0	,,	74	1.5	,,	0.0	0,,	0.8
30822	28.0	23.0	,,	74	1.5	,,	0.0	0,,	0.8
30823	28.0	22.0	,,	70	0.0	,,	0.0	0,,	0.8

30824	27.0	24.0	,,	84	3.1	,,	0.0	0,,	0.8
30901	27.0	24.0	,,	84	2.6	,,	0.0	0,,	0.8
30902	26.0	24.0	,,	89	2.6	,,	0.0	0,,	0.8
30903	26.0	24.0	,,	89	1.0	,,	0.0	0,,	0.8
30904	26.0	24.0	,,	89	2.6	,,	0.0	0,,	0.8
30905	25.0	24.0	,,	94	1.0	,,	0.0	0,,	0.8
30906	26.0	24.0	,,	89	0.0	,,	0.0	0,,	0.8
30907	26.0	24.0	,,	89	0.5	,,	105.0	40,,	0.8
30908	25.0	24.0	,,	94	1.0	,,	250.0	80,,	0.8
30909	27.0	24.0	,,	84	0.0	,,	320.0	100,,	0.8
30910	28.0	25.0	,,	84	1.0	,,	400.0	120,,	0.8
30911	29.0	24.0	,,	74	2.1	,,	450.0	180,,	0.8
30912	31.0	24.0	,,	66	4.1	,,	500.0	200,,	0.8
30913	29.0	24.0	,,	74	4.6	,,	520.0	220,,	0.8
30914	25.0	24.0	,,	94	3.1	,,	550.0	250,,	1
30915	25.0	24.0	,,	94	1.5	,,	580.0	260,,	1
30916	25.0	24.0	,,	94	2.1	,,	500.0	210,,	1
30917	24.0	23.0	,,	94	1.0	,,	320.0	150,,	1
30918	24.0	23.0	,,	94	0.5	,,	210.0	80,,	1
30919	24.0	23.0	,,	94	1.0	,,	110.0	40,,	1
30920	24.0	23.0	,,	94	2.1	,,	0.0	0,,	1
30921	24.0	23.0	,,	94	4.1	,,	0.0	0,,	1
30922	24.0	22.0	,,	89	4.6	,,	0.0	0,,	1
30923	24.0	22.0	,,	89	2.1	,,	0.0	0,,	1
30924	23.0	22.0	,,	94	2.1	,,	0.0	0,,	0.8
301001	23.0	22.0	,,	94	2.6	,,	0.0	0,,	0.8
301002	24.0	22.0	,,	89	3.1	,,	0.0	0,,	0.8
301003	23.0	22.0	,,	94	2.1	,,	0.0	0,,	1
301004	24.0	22.0	,,	89	3.1	,,	0.0	0,,	0.8
301005	24.0	22.0	,,	89	2.6	,,	0.0	0,,	0.8
301006	24.0	22.0	,,	89	1.5	,,	0.0	0,,	0.8
301007	24.0	22.0	,,	89	1.0	,,	105.0	40,,	0.8
301008	24.0	22.0	,,	89	0.0	,,	250.0	80,,	0.8
301009	24.0	23.0	,,	94	1.0	,,	320.0	100,,	0.8
301010	27.0	24.0	,,	84	1.0	,,	400.0	120,,	0.8
301011	29.0	25.0	,,	79	2.6	,,	450.0	180,,	0.8
301012	29.0	25.0	,,	79	3.6	,,	500.0	200,,	0.8
301013	30.0	25.0	,,	74	3.6	,,	520.0	220,,	0.8
301014	30.0	25.0	,,	74	3.6	,,	550.0	250,,	0.8
301015	30.0	25.0	,,	74	3.6	,,	580.0	260,,	0.8
301016	31.0	25.0	,,	70	3.1	,,	500.0	210,,	0.8
301017	31.0	25.0	,,	70	3.6	,,	320.0	150,,	0.8
301018	30.0	24.0	,,	70	3.1	,,	210.0	80,,	0.8
301019	29.0	23.0	,,	70	1.5	,,	110.0	40,,	0.8
301020	28.0	25.0	,,	84	2.1	,,	0.0	0,,	1
301021	27.0	24.0	,,	84	2.1	,,	0.0	0,,	1
301022	26.0	24.0	,,	89	1.5	,,	0.0	0,,	0.8
301023	26.0	24.0	,,	89	0.5	,,	0.0	0,,	0.8
301024	25.0	23.0	,,	89	1.0	,,	0.0	0,,	1
301101	25.0	24.0	,,	94	0.0	,,	0.0	0,,	1
301102	25.0	24.0	,,	94	1.5	,,	0.0	0,,	0.8

301103 25.0 24.0 ,, 94 2.1 ,, 0.0 0,, 0.8
301104 25.0 24.0 ,, 94 1.5 ,, 0.0 0,, 0.8
301105 25.0 24.0 ,, 94 1.5 ,, 0.0 0,, 0.8
301106 25.0 24.0 ,, 94 1.0 ,, 0.0 0,, 0.8
301107 25.0 24.0 ,, 94 1.5 ,, 105.0 40,, 0.8
301108 26.0 24.0 ,, 89 1.5 ,, 250.0 100,, 0.8
301109 27.0 24.0 ,, 84 3.1 ,, 320.0 120,, 0.8
301110 29.0 24.0 ,, 74 3.6 ,, 400.0 160,, 0.8
301111 29.0 24.0 ,, 74 3.6 ,, 450.0 200,, 0.8
301112 31.0 23.0 ,, 62 1.5 ,, 550.0 250,, 0.8
301113 31.0 25.0 ,, 70 1.5 ,, 620.0 285,, 0.8
301114 29.0 25.0 ,, 79 4.1 ,, 680.0 320,, 0.8
301115 27.0 24.0 ,, 84 4.1 ,, 720.0 350,, 1
301116 27.0 24.0 ,, 84 2.1 ,, 600.0 250,, 1
301117 27.0 24.0 ,, 84 1.5 ,, 420.0 180,, 0.8
301118 27.0 25.0 ,, 89 1.5 ,, 210.0 80,, 0.8
301119 26.0 23.0 ,, 83 3.6 ,, 110.0 40,, 0.8
301120 25.0 23.0 ,, 89 1.5 ,, 0.0 0,, 1
301121 25.0 23.0 ,, 89 1.5 ,, 0.0 0,, 0.8
301122 25.0 23.0 ,, 89 1.5 ,, 0.0 0,, 0.8
301123 24.0 23.0 ,, 94 2.6 ,, 0.0 0,, 0.8
301124 27.0 24.0 ,, 84 3.1 ,, 0.0 0,, 0.8
301201 27.0 24.0 ,, 84 2.6 ,, 0.0 0,, 0.8
301202 26.0 24.0 , , 89 2.6 , , 0.0 0 , ,
0.8
301203 26.0 24.0 , , 89 1.0 , , 0.0 0
, , 0.8
301204 26.0 24.0 , , 89 2.6 , , 0.0 0 ,
, 0.8
301205 25.0 24.0 , , 94 1.0 , , 0.0 0 ,
, 0.8
301206 26.0 24.0 , , 89 0.0 , , 0.0 0 ,
, 0.8
301207 26.0 24.0 , , 89 0.5 , , 105.0 40
, , 0.8
301208 25.0 24.0 , , 94 1.0 , , 250.0
100 , , 0.8
301209 27.0 24.0 , , 84 0.0 , , 320.0
120 , , 0.8
301210 28.0 25.0 , , 84 1.0 , , 400.0
160 , , 0.8
301211 29.0 24.0 , , 74 2.1 , , 520.0
200 , , 0.8
301212 31.0 24.0 , , 66 4.1 , , 650.0
250 , , 0.8
301213 29.0 24.0 , , 74 4.6 , , 720.0
285 , , 0.8
301214 25.0 24.0 , , 94 3.1 , , 800.0
320 , , 1
301215 25.0 24.0 , , 94 1.5 , , 820.0
350 , , 1

301216 25.0 24.0 , , 94 2.1 , , 600.0
250 , , 1
301217 24.0 23.0 , , 94 1.0 , , 420.0
180 , , 1
301218 24.0 23.0 , , 94 0.5 , , 210.0 80
, , 1
301219 24.0 23.0 , , 94 1.0 , , 110.0 40
, , 1
301220 24.0 23.0 , , 94 2.1 , , 0.0 0 ,
, 1
301221 24.0 23.0 , , 94 4.1 , , 0.0 0 ,
, 1
301222 24.0 22.0 , , 89 4.6 , , 0.0 0 ,
, 1
301223 24.0 22.0 , , 89 2.1 , , 0.0 0 ,
, 1
301224 23.0 22.0 , , 94 2.1 , , 0.0 0 ,
, 0.8
301301 23.0 22.0 , , 94 2.6 , , 0.0 0 ,
, 0.8
301302 24.0 22.0 , , 89 3.1 , , 0.0 0 ,
, 0.8
301303 23.0 22.0 , , 94 2.1 , , 0.0 0 ,
, 1
301304 24.0 22.0 , , 89 3.1 , , 0.0 0 , ,
0.8
301305 24.0 22.0 , , 89 2.6 , , 0.0 0 ,
, 0.8
301306 24.0 22.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
301307 24.0 22.0 , , 89 1.0 , , 105.0 40
, , 0.8
301308 24.0 22.0 , , 89 0.0 , , 250.0
100 , , 0.8
301309 24.0 23.0 , , 94 1.0 , , 320.0
120 , , 0.8
301310 27.0 24.0 , , 84 1.0 , , 400.0
160 , , 0.8
301311 29.0 25.0 , , 79 2.6 , , 520.0
200 , , 0.8
301312 29.0 25.0 , , 79 3.6 , , 650.0
250 , , 0.8
301313 30.0 25.0 , , 74 3.6 , , 720.0
285 , , 0.8
301314 30.0 25.0 , , 74 3.6 , , 800.0
320 , , 0.8
301315 30.0 25.0 , , 74 3.6 , , 820.0
350 , , 0.8
301316 31.0 25.0 , , 70 3.1 , , 600.0
250 , , 0.8

301317 31.0 25.0 , , 70 3.6 , , 420.0
180 , , 0.8
301318 30.0 24.0 , , 70 3.1 , , 210.0 80
, , 0.8
301319 29.0 23.0 , , 70 1.5 , , 110.0 40
, , 0.8
301320 28.0 25.0 , , 84 2.1 , , 0.0 0 ,
, 1
301321 27.0 24.0 , , 84 2.1 , , 0.0 0 ,
, 1
301322 26.0 24.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
301323 26.0 24.0 , , 89 0.5 , , 0.0 0 ,
, 0.8
301324 24.0 23.0 , , 94 1.0 , , 0.0 0 ,
, 0.8
301401 24.0 23.0 , , 94 1.0 , , 0.0 0 ,
, 0.8
301402 24.0 23.0 , , 94 1.5 , , 0.0 0 ,
, 0.8
301403 24.0 23.0 , , 94 0.0 , , 0.0 0 ,
, 0.8
301404 24.0 23.0 , , 94 0.5 , , 0.0 0 ,
, 0.8
301405 25.0 23.0 , , 89 0.0 , , 0.0 0 ,
, 0.8
301406 25.0 23.0 , , 89 1.0 , , 0.0 0 ,
, 0.8
301407 25.0 23.0 , , 89 0.0 , , 105.0 40
, , 0.8
301408 24.0 23.0 , , 94 2.1 , , 250.0
100 , , 1
301409 25.0 23.0 , , 89 2.6 , , 320.0
120 , , 0.8
301410 27.0 23.0 , , 79 2.1 , , 400.0
160 , , 0.8
301411 28.0 23.0 , , 74 2.6 , , 520.0
200 , , 0.8
301412 30.0 24.0 , , 70 1.5 , , 650.0
250 , , 0.8
301413 31.0 24.0 , , 66 1.0 , , 720.0
285 , , 0.8
301414 30.0 25.0 , , 74 5.7 , , 800.0
320 , , 0.8
301415 31.0 25.0 , , 70 4.1 , , 820.0
350 , , 0.8
301416 31.0 25.0 , , 70 5.7 , , 600.0
250 , , 0.8
301417 30.0 24.0 , , 70 4.6 , , 420.0
180 , , 1

301418 27.0 23.0 , , 79 4.6 , , 210.0 80
, , 1
301419 26.0 22.0 , , 78 0.5 , , 110.0 40
, , 0.8
301420 26.0 23.0 , , 83 3.1 , , 0.0 0 ,
, 0.8
301421 25.0 23.0 , , 89 4.1 , , 0.0 0 ,
, 0.8
301422 25.0 23.0 , , 89 4.1 , , 0.0 0 ,
, 1
301423 25.0 23.0 , , 89 3.1 , , 0.0 0 ,
, 0.8
301424 24.0 23.0 , , 94 3.1 , , 0.0 0 ,
, 0.8
301501 24.0 23.0 , , 94 2.1 , , 0.0 0 ,
, 0.8
301502 24.0 23.0 , , 94 2.1 , , 0.0 0 ,
, 0.8
301503 24.0 22.0 , , 89 1.0 , , 0.0 0 ,
, 0.8
301504 24.0 22.0 , , 89 1.0 , , 0.0 0 , ,
0.8
301505 24.0 22.0 , , 89 2.1 , , 0.0 0 ,
, 0.8
301506 23.0 22.0 , , 94 1.0 , , 0.0 0 ,
, 0.8
301507 24.0 22.0 , , 89 1.0 , , 105.0 40
, , 0.8
301508 24.0 22.0 , , 89 1.5 , , 250.0
100 , , 0.8
301509 25.0 22.0 , , 83 0.5 , , 320.0
120 , , 0.8
301510 27.0 22.0 , , 74 4.6 , , 400.0 160 ,
, 0.8
301511 28.0 23.0 , , 74 4.1 , , 520.0
200 , , 0.8
301512 30.0 22.0 , , 62 6.7 , , 650.0
250 , , 0.8
301513 30.0 23.0 , , 66 5.7 , , 720.0
285 , , 0.8
301514 31.0 23.0 , , 62 5.7 , , 800.0
320 , , 0.8
301515 31.0 23.0 , , 62 5.1 , , 820.0
350 , , 0.8
301516 31.0 23.0 , , 62 4.6 , , 600.0
250 , , 0.8
301517 30.0 23.0 , , 66 4.1 , , 420.0
180 , , 0.8
301518 30.0 23.0 , , 66 4.1 , , 210.0 80
, , 0.8

301519 28.0 22.0 , , 70 5.7 , , 110.0 40 , , 0.8
301520 26.0 23.0 , , 83 4.6 , , 0.0 0 , , 0.8
301521 26.0 23.0 , , 83 4.1 , , 0.0 0 , , 0.8
301522 26.0 23.0 , , 83 3.1 , , 0.0 0 , , 0.8
301523 25.0 23.0 , , 89 3.1 , , 0.0 0 , , 0.8
301524 25.0 23.0 , , 89 2.1 , , 0.0 0 , , 0.8
301601 25.0 23.0 , , 89 3.6 , , 0.0 0 , , 0.8
301602 25.0 23.0 , , 89 4.1 , , 0.0 0 , , 0.8
301603 25.0 23.0 , , 89 2.6 , , 0.0 0 , , 0.8
301604 25.0 23.0 , , 89 3.1 , , 0.0 0 , , 0.8
301605 25.0 23.0 , , 89 2.1 , , 0.0 0 , , 0.8
301606 25.0 23.0 , , 89 1.5 , , 0.0 0 , , 0.8
301607 25.0 23.0 , , 89 2.6 , , 105.0 40 , , 0.8
301608 25.0 23.0 , , 89 2.1 , , 250.0 100 , , 0.8
301609 26.0 23.0 , , 83 2.6 , , 320.0 120 , , 0.8
301610 28.0 23.0 , , 74 3.6 , , 400.0 160 , , 0.8
301611 29.0 23.0 , , 70 4.1 , , 520.0 200 , , 0.8
301612 30.0 23.0 , , 66 3.1 , , 650.0 250 , , 0.8
301613 30.0 23.0 , , 66 1.5 , , 720.0 285 , , 0.8
301614 30.0 23.0 , , 66 3.1 , , 800.0 320 , , 0.8
301615 27.0 23.0 , , 79 3.6 , , 820.0 350 , , 0.8
301616 26.0 23.0 , , 83 2.1 , , 600.0 250 , , 1
301617 26.0 23.0 , , 83 1.5 , , 420.0 180 , , 0.8
301618 26.0 24.0 , , 89 1.5 , , 210.0 80 , , 1
301619 26.0 24.0 , , 89 1.5 , , 110.0 40 , , 1

301620 25.0 24.0 , , 94 0.5 , , 0.0 0 ,
, 1
301621 25.0 24.0 , , 94 2.1 , , 0.0 0 ,
, 0.8
301622 25.0 23.0 , , 89 2.1 , , 0.0 0 ,
, 0.8
301623 25.0 23.0 , , 89 2.1 , , 0.0 0 ,
, 0.8
301624 25.0 23.0 , , 89 2.1 , , 0.0 0 ,
, 0.8
301701 25.0 23.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
301702 25.0 23.0 , , 89 2.6 , , 0.0 0
, , 0.8
301703 24.0 23.0 , , 94 1.5 , , 0.0 0 , ,
0.8
301704 24.0 23.0 , , 94 2.1 , , 0.0 0 ,
, 0.8
301705 24.0 23.0 , , 94 1.5 , , 0.0 0 ,
, 0.8
301706 24.0 23.0 , , 94 2.1 , , 0.0 0 , ,
0.8
301707 24.0 23.0 , , 94 2.6 , , 105.0 40
, , 1
301708 24.0 23.0 , , 94 1.5 , , 250.0
100 , , 0.8
301709 24.0 23.0 , , 94 2.1 , , 320.0
120 , , 1
301710 25.0 23.0 , , 89 2.6 , , 400.0
160 , , 0.8
301711 27.0 23.0 , , 79 2.1 , , 520.0
200 , , 0.8
301712 26.0 24.0 , , 89 1.5 , , 650.0
250 , , 1
301713 28.0 24.0 , , 79 1.5 , , 720.0
285 , , 0.8
301714 30.0 23.0 , , 66 1.0 , , 800.0
320 , , 0.8
301715 31.0 25.0 , , 70 3.6 , , 820.0
350 , , 0.8
301716 31.0 24.0 , , 66 3.1 , , 600.0 250 ,
, 0.8
301717 31.0 23.0 , , 62 2.6 , , 420.0
180 , , 0.8
301718 31.0 24.0 , , 66 1.5 , , 210.0 80 ,
, 0.8
301719 30.0 23.0 , , 66 2.1 , , 110.0 40
, , 0.8
301720 29.0 24.0 , , 74 1.5 , , 0.0 0 ,
, 0.8

301721 28.0 24.0 , , 79 1.0 , , 0.0 0 ,
, 0.8
301722 27.0 24.0 , , 84 1.0 , , 0.0 0 , ,
0.8
301723 27.0 24.0 , , 84 0.5 , , 0.0 0 ,
, 0.8
301724 26.0 24.0 , , 89 0.5 , , 0.0 0
, , 0.8
301801 26.0 24.0 , , 89 1.5 , , 0.0 0 , ,
0.8
301802 26.0 24.0 , , 89 1.5 , , 0.0 0
, , 0.8
301803 26.0 23.0 , , 83 1.5 , , 0.0 0 , ,
0.8
301804 25.0 23.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
301805 25.0 23.0 , , 89 0.0 , , 0.0 0 , ,
0.8
301806 25.0 23.0 , , 89 0.5 , , 0.0 0 ,
, 0.8
301807 25.0 23.0 , , 89 0.0 , , 105.0 40
, , 0.8
301808 25.0 23.0 , , 89 1.0 , , 250.0
100 , , 0.8
301809 26.0 23.0 , , 83 3.1 , , 320.0 120 ,
, 0.8
301810 27.0 23.0 , , 79 1.0 , , 400.0 160 ,
, 0.8
301811 29.0 23.0 , , 70 1.0 , , 520.0
200 , , 0.8
301812 31.0 23.0 , , 62 2.1 , , 650.0
250 , , 0.8
301813 31.0 24.0 , , 66 4.1 , , 720.0
285 , , 0.8
301814 32.0 24.0 , , 62 3.6 , , 800.0
320 , , 0.8
301815 32.0 24.0 , , 62 5.1 , , 820.0
350 , , 0.8
301816 33.0 24.0 , , 59 4.1 , , 600.0
250 , , 0.8
301817 33.0 23.0 , , 55 4.1 , , 420.0
180 , , 0.8
301818 32.0 23.0 , , 59 3.6 , , 210.0 80
, , 0.8
301819 31.0 23.0 , , 62 3.1 , , 110.0 40
, , 0.8
301820 30.0 23.0 , , 66 2.1 , , 0.0 0 ,
, 0.8
301821 29.0 23.0 , , 70 1.0 , , 0.0 0 ,
, 0.8

301822 29.0 24.0 , , 74 0.0 , , 0.0 0 ,
, 0.8
301823 28.0 24.0 , , 79 0.0 , , 0.0 0 ,
, 0.8
301824 27.0 24.0 , , 84 0.5 , , 0.0 0 ,
, 0.8
301901 26.0 24.0 , , 89 0.5 , , 0.0 0 ,
, 0.8
301902 26.0 24.0 , , 89 0.5 , , 0.0 0 ,
, 0.8
301903 27.0 23.0 , , 79 2.1 , , 0.0 0 ,
, 0.8
301904 26.0 23.0 , , 83 0.0 , , 0.0 0 ,
, 1
301905 26.0 24.0 , , 89 0.5 , , 0.0 0 ,
, 1
301906 25.0 24.0 , , 94 0.5 , , 0.0 0 , ,
0.8
301907 25.0 24.0 , , 94 1.5 , , 105.0 40
, , 0.8
301908 25.0 24.0 , , 94 1.0 , , 250.0
100 , , 0.8
301909 27.0 24.0 , , 84 2.1 , , 320.0
120 , , 0.8
301910 29.0 25.0 , , 79 3.6 , , 400.0
160 , , 0.8
301911 30.0 24.0 , , 70 3.1 , , 520.0
200 , , 0.8
301912 32.0 24.0 , , 62 3.6 , , 650.0
250 , , 0.8
301913 31.0 25.0 , , 70 1.5 , , 720.0
285 , , 0.8
301914 32.0 25.0 , , 66 2.6 , , 800.0
320 , , 0.8
301915 30.0 25.0 , , 74 5.1 , , 820.0
350 , , 0.8
301916 30.0 25.0 , , 74 3.1 , , 600.0
250 , , 1
301917 30.0 24.0 , , 70 3.6 , , 420.0
180 , , 1
301918 30.0 24.0 , , 70 3.1 , , 210.0 80
, , 0.8
301919 30.0 24.0 , , 70 2.6 , , 110.0 40 ,
, 0.8
301920 29.0 24.0 , , 74 1.0 , , 0.0 0 ,
, 0.8
301921 29.0 25.0 , , 79 0.0 , , 0.0 0 ,
, 0.8
301922 28.0 25.0 , , 84 1.0 , , 0.0 0 ,
, 0.8

301923 27.0 25.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
301924 27.0 25.0 , , 89 0.5 , , 0.0 0 , ,
0.8
302001 26.0 25.0 , , 94 1.5 , , 0.0 0 ,
, 0.8
302002 26.0 24.0 , , 89 1.5 , , 0.0 0 , , 1
302003 26.0 25.0 , , 94 0.0 , , 0.0 0 ,
, 1
302004 24.0 22.0 , , 89 2.1 , , 0.0 0 ,
, 1
302005 25.0 23.0 , , 89 0.5 , , 0.0 0 ,
, 1
302006 24.0 23.0 , , 94 1.0 , , 0.0 0 ,
, 1
302007 24.0 23.0 , , 94 1.5 , , 105.0 40
, , 0.8
302008 25.0 23.0 , , 89 1.5 , , 250.0
100 , , 0.8
302009 26.0 24.0 , , 89 2.6 , , 320.0
120 , , 0.8
302010 28.0 25.0 , , 84 2.1 , , 400.0
160 , , 0.8
302011 30.0 25.0 , , 74 1.0 , , 520.0
200 , , 0.8
302012 32.0 25.0 , , 66 1.5 , , 650.0
250 , , 0.8
302013 31.0 26.0 , , 75 4.1 , , 720.0
285 , , 0.8
302014 29.0 25.0 , , 79 3.1 , , 800.0
320 , , 1
302015 29.0 24.0 , , 74 0.5 , , 820.0 350 ,
, 1
302016 28.0 25.0 , , 84 1.5 , , 600.0
250 , , 0.8
302017 28.0 25.0 , , 84 3.1 , , 420.0
180 , , 0.8
302018 28.0 25.0 , , 84 1.0 , , 210.0 80
, , 0.8
302019 28.0 25.0 , , 84 1.5 , , 110.0 40
, , 0.8
302020 27.0 25.0 , , 89 0.5 , , 0.0 0 ,
, 0.8
302021 27.0 25.0 , , 89 0.5 , , 0.0 0 ,
, 0.8
302022 27.0 25.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
302023 26.0 25.0 , , 94 0.0 , , 0.0 0 ,
, 0.8
302024 26.0 24.0 , , 89 4.1 , , 0.0 0 ,
, 0.8

302101 25.0 23.0 , , 89 1.5 , , 0.0 0 , ,
0.8
302102 25.0 23.0 , , 89 2.1 , , 0.0 0 ,
, 1
302103 25.0 23.0 , , 89 2.6 , , 0.0 0 ,
, 0.8
302104 24.0 23.0 , , 94 2.1 , , 0.0 0 ,
, 0.8
302105 24.0 23.0 , , 94 1.0 , , 0.0 0 ,
, 0.8
302106 25.0 23.0 , , 89 0.0 , , 0.0 0 ,
, 0.8
302107 24.0 23.0 , , 94 0.5 , , 105.0 40
, , 0.8
302108 25.0 23.0 , , 89 0.5 , , 250.0
100 , , 0.8
302109 26.0 22.0 , , 78 1.0 , , 320.0
120 , , 0.8
302110 27.0 23.0 , , 79 0.5 , , 400.0 160 ,
, 0.8
302111 29.0 23.0 , , 70 0.5 , , 520.0
200 , , 0.8
302112 31.0 24.0 , , 66 2.1 , , 650.0
250 , , 0.8
302113 32.0 23.0 , , 59 3.6 , , 720.0 285 ,
, 0.8
302114 32.0 23.0 , , 59 2.6 , , 800.0
320 , , 0.8
302115 32.0 24.0 , , 62 3.6 , , 820.0
350 , , 0.8
302116 32.0 22.0 , , 55 4.1 , , 600.0
250 , , 0.8
302117 32.0 21.0 , , 52 4.6 , , 420.0
180 , , 0.8
302118 31.0 22.0 , , 58 3.6 , , 210.0 80
, , 0.8
302119 30.0 22.0 , , 62 2.1 , , 110.0 40
, , 0.8
302120 29.0 23.0 , , 70 1.0 , , 0.0 0 ,
, 0.8
302121 29.0 23.0 , , 70 1.5 , , 0.0 0 , ,
0.8
302122 28.0 23.0 , , 74 1.5 , , 0.0 0 ,
, 0.8
302123 27.0 23.0 , , 79 1.0 , , 0.0 0 ,
, 0.8
302124 27.0 23.0 , , 79 1.5 , , 0.0 0 ,
, 0.8
302201 27.0 23.0 , , 79 1.5 , , 0.0 0 ,
, 0.8

302202 26.0 23.0 , , 83 2.6 , , 0.0 0 , ,
0.8
302203 26.0 23.0 , , 83 1.0 , , 0.0 0 ,
, 0.8
302204 23.0 22.0 , , 94 4.6 , , 0.0 0 ,
, 1
302205 23.0 23.0 , , 100 0.5 , , 0.0 0 , , 1
302206 24.0 23.0 , , 94 0.0 , , 0.0 0 ,
, 0.8
302207 24.0 23.0 , , 94 1.5 , , 105.0 40 ,
, 0.8
302208 24.0 23.0 , , 94 1.5 , , 250.0
100 , , 0.8
302209 25.0 23.0 , , 89 1.0 , , 320.0
120 , , 0.8
302210 26.0 23.0 , , 83 1.5 , , 400.0
160 , , 0.8
302211 28.0 24.0 , , 79 1.0 , , 520.0
200 , , 0.8
302212 29.0 25.0 , , 79 1.0 , , 650.0
250 , , 0.8
302213 30.0 24.0 , , 70 1.0 , , 720.0
285 , , 0.8
302214 30.0 24.0 , , 70 2.6 , , 800.0
320 , , 0.8
302215 31.0 24.0 , , 66 2.6 , , 820.0
350 , , 0.8
302216 30.0 24.0 , , 70 3.1 , , 600.0
250 , , 0.8
302217 30.0 23.0 , , 66 3.6 , , 420.0
180 , , 0.8
302218 29.0 23.0 , , 70 3.1 , , 210.0 80
, , 0.8
302219 29.0 23.0 , , 70 1.5 , , 110.0 40
, , 0.8
302220 28.0 24.0 , , 79 0.0 , , 0.0 0 ,
, 0.8
302221 28.0 24.0 , , 79 0.0 , , 0.0 0 ,
, 0.8
302222 27.0 24.0 , , 84 0.5 , , 0.0 0 ,
, 0.8
302223 27.0 24.0 , , 84 0.5 , , 0.0 0 , ,
0.8
302224 27.0 24.0 , , 84 2.1 , , 0.0 0 ,
, 0.8
302301 27.0 24.0 , , 84 1.0 , , 0.0 0 ,
, 0.8
302302 26.0 24.0 , , 89 0.0 , , 0.0 0 ,
, 0.8
302303 26.0 23.0 , , 83 0.5 , , 0.0 0 , ,
0.8

302304 26.0 23.0 , , 83 1.0 , , 0.0 0 ,
, 0.8
302305 25.0 23.0 , , 89 0.0 , , 0.0 0 ,
, 0.8
302306 25.0 23.0 , , 89 0.5 , , 0.0 0 ,
, 0.8
302307 25.0 23.0 , , 89 1.5 , , 105.0 40 ,
, 0.8
302308 26.0 23.0 , , 83 1.5 , , 250.0
100 , , 0.8
302309 28.0 24.0 , , 79 2.6 , , 320.0
120 , , 0.8
302310 31.0 24.0 , , 66 1.5 , , 400.0
160 , , 0.8
302311 32.0 24.0 , , 62 1.5 , , 520.0 200 ,
, 0.8
302312 32.0 24.0 , , 62 1.5 , , 650.0
250 , , 0.8
302313 33.0 25.0 , , 63 2.6 , , 720.0
285 , , 0.8
302314 33.0 25.0 , , 63 2.6 , , 800.0
320 , , 0.8
302315 32.0 25.0 , , 66 2.6 , , 820.0
350 , , 0.8
302316 31.0 25.0 , , 70 3.6 , , 600.0
250 , , 0.8
302317 31.0 25.0 , , 70 3.6 , , 420.0
180 , , 0.8
302318 31.0 25.0 , , 70 3.1 , , 210.0 80
, , 0.8
302319 30.0 25.0 , , 74 1.0 , , 110.0 40
, , 0.8
302320 29.0 25.0 , , 79 0.0 , , 0.0 0
, , 0.8
302321 29.0 25.0 , , 79 0.5 , , 0.0 0 ,
, 0.8
302322 28.0 25.0 , , 84 0.5 , , 0.0 0 ,
, 0.8
302323 28.0 25.0 , , 84 0.5 , , 0.0 0 ,
, 0.8
302324 28.0 24.0 , , 79 1.0 , , 0.0 0 ,
, 0.8
302401 27.0 24.0 , , 84 1.5 , , 0.0 0 ,
, 0.8
302402 26.0 24.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
302403 26.0 24.0 , , 89 2.1 , , 0.0 0 ,
, 0.8
302404 26.0 24.0 , , 89 3.1 , , 0.0 0 ,
, 0.8

302405 26.0 24.0 , , 89 1.5 , , 0.0 0 , , 0.8
302406 26.0 24.0 , , 89 0.5 , , 0.0 0 , , 0.8
302407 26.0 24.0 , , 89 0.5 , , 105.0 40 , , 0.7
302408 27.0 24.0 , , 84 1.0 , , 250.0 100 , , 1
302409 27.0 24.0 , , 84 1.5 , , 320.0 120 , , 1
302410 23.0 22.0 , , 94 2.6 , , 400.0 160 , , 1
302411 24.0 23.0 , , 94 0.0 , , 520.0 200 , , 1
302412 25.0 23.0 , , 89 1.5 , , 650.0 250 , , 0.8
302413 24.0 23.0 , , 94 2.6 , , 720.0 285 , , 1
302414 25.0 23.0 , , 89 1.5 , , 800.0 320 , , 1
302415 27.0 24.0 , , 84 1.5 , , 820.0 350 , , 0.8
302416 28.0 24.0 , , 79 2.1 , , 600.0 250 , , 0.8
302417 28.0 24.0 , , 79 1.0 , , 420.0 180 , , 0.8
302418 27.0 24.0 , , 84 2.1 , , 210.0 80 , , 0.8
302419 27.0 24.0 , , 84 1.0 , , 110.0 40 , , 0.8
302420 26.0 24.0 , , 89 1.5 , , 0.0 0 , , 0.8
302421 26.0 24.0 , , 89 0.0 , , 0.0 0 , , 0.8
302422 26.0 24.0 , , 89 1.0 , , 0.0 0 , , 0.8
302423 26.0 24.0 , , 89 1.5 , , 0.0 0 , , 0.8
302424 25.0 23.0 , , 89 1.5 , , 0.0 0 , , 0.8
302501 25.0 23.0 , , 89 1.5 , , 0.0 0 , , 0.8
302502 25.0 23.0 , , 89 1.5 , , 0.0 0 , , 0.8
302503 24.0 23.0 , , 94 1.0 , , 0.0 0 , , 0.8
302504 24.0 23.0 , , 94 1.0 , , 0.0 0 , , 0.8
302505 24.0 23.0 , , 94 1.0 , , 0.0 0 , , 0.8

302506 24.0 23.0 , , 94 0.5 , , 0.0 0 ,
, 0.8
302507 24.0 23.0 , , 94 1.0 , , 105.0 40 ,
, 0.8
302508 24.0 23.0 , , 94 1.5 , , 250.0
100 , , 0.8
302509 26.0 23.0 , , 83 1.0 , , 320.0
120 , , 0.8
302510 28.0 24.0 , , 79 1.5 , , 400.0
160 , , 0.3
302511 29.0 24.0 , , 74 1.0 , , 520.0
200 , , 0.8
302512 31.0 24.0 , , 66 2.1 , , 650.0
250 , , 0.8
302513 30.0 25.0 , , 74 5.1 , , 720.0
285 , , 0.8
302514 28.0 24.0 , , 79 4.1 , , 800.0
320 , , 1
302515 27.0 24.0 , , 84 3.6 , , 820.0
350 , , 1
302516 26.0 24.0 , , 89 2.1 , , 600.0
250 , , 0.8
302517 30.0 24.0 , , 70 3.1 , , 420.0 180 ,
, 0.8
302518 30.0 24.0 , , 70 2.6 , , 210.0 80
, , 0.8
302519 29.0 25.0 , , 79 1.5 , , 110.0 40
, , 0.8
302520 28.0 24.0 , , 79 2.1 , , 0.0 0 ,
, 0.8
302521 26.0 25.0 , , 94 2.6 , , 0.0 0 , ,
0.8
302522 27.0 24.0 , , 84 1.5 , , 0.0 0 ,
, 0.8
302523 26.0 23.0 , , 83 1.0 , , 0.0 0 ,
, 0.8
302524 25.0 22.0 , , 83 1.0 , , 0.0 0 ,
, 0.8
302601 25.0 23.0 , , 89 1.0 , , 0.0 0 ,
, 0.8
302602 25.0 23.0 , , 89 0.0 , , 0.0 0 ,
, 0.8
302603 25.0 23.0 , , 89 0.0 , , 0.0 0 , ,
0.8
302604 24.0 23.0 , , 94 0.0 , , 0.0 0 ,
, 0.8
302605 24.0 23.0 , , 94 0.0 , , 0.0 0 ,
, 0.8
302606 24.0 23.0 , , 94 0.0 , , 0.0 0 ,
, 0.8

302607 24.0 23.0 , , 94 1.0 , , 105.0 40
, , 0.8
302608 25.0 24.0 , , 94 0.5 , , 250.0 100 ,
, 0.8
302609 27.0 24.0 , , 84 0.0 , , 320.0
120 , , 0.8
302610 29.0 24.0 , , 74 0.5 , , 400.0
160 , , 0.8
302611 30.0 24.0 , , 70 2.1 , , 520.0
200 , , 0.8
302612 31.0 24.0 , , 66 0.5 , , 650.0
250 , , 0.8
302613 29.0 25.0 , , 79 3.6 , , 720.0 285 ,
, 0.8
302614 30.0 26.0 , , 79 4.1 , , 800.0
320 , , 0.8
302615 31.0 25.0 , , 70 1.0 , , 820.0
350 , , 1
302616 30.0 25.0 , , 74 3.6 , , 600.0 250 ,
, 0.8
302617 30.0 25.0 , , 74 3.1 , , 420.0
180 , , 0.8
302618 27.0 21.0 , , 70 3.6 , , 210.0 80
, , 0.8
302619 26.0 23.0 , , 83 2.6 , , 110.0 40
, , 0.8
302620 26.0 23.0 , , 83 2.1 , , 0.0 0 ,
, 0.8
302621 26.0 23.0 , , 83 1.5 , , 0.0 0 ,
, 0.8
302622 25.0 23.0 , , 89 2.1 , , 0.0 0 , ,
0.8
302623 26.0 24.0 , , 89 0.0 , , 0.0 0 ,
, 0.8
302624 26.0 24.0 , , 89 0.5 , , 0.0 0 ,
, 0.8
302701 25.0 23.0 , , 89 2.6 , , 0.0 0 , ,
0.8
302702 24.0 23.0 , , 94 1.5 , , 0.0 0 ,
, 0.8
302703 24.0 23.0 , , 94 1.5 , , 0.0 0
, , 0.8
302704 24.0 23.0 , , 94 0.5 , , 0.0 0 , ,
0.8
302705 24.0 23.0 , , 94 0.5 , , 0.0 0 ,
, 0.8
302706 24.0 23.0 , , 94 1.5 , , 0.0 0 ,
, 0.8
302707 25.0 23.0 , , 89 1.5 , , 105.0 40 ,
, 0.8

302708 25.0 23.0 , , 89 1.5 , , 250.0
100 , , 0.8
302709 27.0 24.0 , , 84 1.5 , , 320.0
120 , , 0.8
302710 28.0 25.0 , , 84 2.1 , , 400.0
160 , , 0.8
302711 29.0 25.0 , , 79 1.5 , , 520.0
200 , , 0.8
302712 29.0 25.0 , , 79 1.5 , , 650.0
250 , , 0.8
302713 30.0 24.0 , , 70 2.1 , , 720.0
285 , , 0.8
302714 31.0 24.0 , , 66 2.1 , , 800.0
320 , , 0.8
302715 31.0 24.0 , , 66 2.1 , , 820.0 350 ,
, 0.8
302716 29.0 25.0 , , 79 3.1 , , 600.0
250 , , 1
302717 28.0 25.0 , , 84 2.1 , , 420.0
180 , , 0.8
302718 29.0 25.0 , , 79 1.5 , , 210.0 80
, , 0.8
302719 28.0 24.0 , , 79 1.5 , , 110.0 40 ,
, 0.8
302720 28.0 24.0 , , 79 0.0 , , 0.0 0 , ,
0.8
302721 27.0 24.0 , , 84 0.5 , , 0.0 0 ,
, 0.8
302722 26.0 24.0 , , 89 1.0 , , 0.0 0 ,
, 0.8
302723 26.0 24.0 , , 89 0.0 , , 0.0 0 ,
, 0.8
302724 25.0 24.0 , , 94 1.0 , , 0.0 0 ,
, 0.8
302801 25.0 24.0 , , 94 0.0 , , 0.0 0 , ,
0.8
302802 25.0 24.0 , , 94 1.5 , , 0.0 0 ,
, 0.8
302803 25.0 23.0 , , 89 0.0 , , 0.0 0 ,
, 0.8
302804 25.0 23.0 , , 89 0.0 , , 0.0 0 , ,
0.8
302805 25.0 23.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
302806 24.0 23.0 , , 94 1.0 , , 0.0 0 ,
, 0.8
302807 24.0 23.0 , , 94 1.0 , , 105.0 40
, , 0.8
302808 25.0 23.0 , , 89 1.5 , , 250.0
100 , , 0.8

302809 27.0 23.0 , , 79 3.1 , , 320.0 120 ,
, 0.8
302810 27.0 23.0 , , 79 2.6 , , 400.0
160 , , 0.8
302811 29.0 24.0 , , 74 2.1 , , 520.0
200 , , 0.8
302812 31.0 23.0 , , 62 1.5 , , 650.0
250 , , 0.8
302813 31.0 24.0 , , 66 0.5 , , 720.0
285 , , 0.8
302814 30.0 24.0 , , 70 2.1 , , 800.0
320 , , 1
302815 32.0 22.0 , , 55 2.6 , , 820.0 350 ,
, 0.8
302816 32.0 23.0 , , 59 3.1 , , 600.0
250 , , 0.8
302817 31.0 23.0 , , 62 3.6 , , 420.0
180 , , 0.8
302818 31.0 22.0 , , 58 2.6 , , 210.0 80
, , 0.8
302819 30.0 22.0 , , 62 2.1 , , 110.0 40
, , 0.8
302820 28.0 23.0 , , 74 2.6 , , 0.0 0 ,
, 0.8
302821 27.0 22.0 , , 74 3.6 , , 0.0 0 ,
, 0.8
302822 26.0 23.0 , , 83 2.6 , , 0.0 0 ,
, 0.8
302823 25.0 23.0 , , 89 2.6 , , 0.0 0 ,
, 0.8
302824 25.0 23.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
302901 25.0 23.0 , , 89 2.1 , , 0.0 0 ,
, 0.8
302902 25.0 23.0 , , 89 1.0 , , 0.0 0 ,
, 0.8
302903 25.0 23.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
302904 25.0 23.0 , , 89 1.0 , , 0.0 0 , ,
0.8
302905 24.0 23.0 , , 94 1.5 , , 0.0 0 ,
, 0.8
302906 24.0 23.0 , , 94 0.5 , , 0.0 0 ,
, 0.8
302907 24.0 23.0 , , 94 0.5 , , 105.0 40
, , 0.8
302908 24.0 23.0 , , 94 2.1 , , 250.0
100 , , 0.8
302909 26.0 23.0 , , 83 2.6 , , 320.0
120 , , 0.8

302910 27.0 24.0 , , 84 2.1 , , 400.0
160 , , 0.8
302911 28.0 25.0 , , 84 2.1 , , 520.0
200 , , 0.8
302912 30.0 25.0 , , 74 2.6 , , 650.0
250 , , 0.8
302913 31.0 24.0 , , 66 2.6 , , 720.0
285 , , 0.8
302914 32.0 24.0 , , 62 2.1 , , 800.0
320 , , 0.8
302915 32.0 25.0 , , 66 1.0 , , 820.0 350 ,
, 0.8
302916 32.0 25.0 , , 66 4.1 , , 600.0
250 , , 0.8
302917 31.0 26.0 , , 75 4.1 , , 420.0
180 , , 0.8
302918 31.0 25.0 , , 70 3.1 , , 210.0 80
, , 0.8
302919 30.0 24.0 , , 70 1.5 , , 110.0 40
, , 0.8
302920 27.0 22.0 , , 74 4.6 , , 0.0 0 ,
, 1
302921 25.0 22.0 , , 83 3.6 , , 0.0 0
, , 0.8
302922 26.0 24.0 , , 89 3.1 , , 0.0 0 , ,
0.8
302923 26.0 24.0 , , 89 2.6 , , 0.0 0 ,
, 0.8
302924 26.0 24.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
303001 25.0 24.0 , , 94 2.6 , , 0.0 0 ,
, 0.8
303002 25.0 23.0 , , 89 4.1 , , 0.0 0 ,
, 0.8
303003 25.0 23.0 , , 89 2.6 , , 0.0 0 , ,
0.8
303004 25.0 23.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
303005 25.0 23.0 , , 89 2.1 , , 0.0 0 ,
, 0.8
303006 25.0 23.0 , , 89 2.1 , , 0.0 0 ,
, 0.8
303007 25.0 23.0 , , 89 2.1 , , 105.0 40 ,
, 0.8
303008 25.0 23.0 , , 89 0.0 , , 250.0
100 , , 0.8
303009 27.0 23.0 , , 79 2.6 , , 320.0
120 , , 0.8
303010 28.0 24.0 , , 79 3.1 , , 400.0 160 ,
, 0.8

303011 29.0 25.0 , , 79 4.1 , , 520.0
200 , , 0.8
303012 30.0 25.0 , , 74 4.1 , , 650.0
250 , , 0.8
303013 31.0 25.0 , , 70 4.6 , , 720.0
285 , , 0.8
303014 32.0 25.0 , , 66 4.1 , , 800.0
320 , , 0.8
303015 32.0 27.0 , , 75 4.6 , , 820.0
350 , , 0.8
303016 31.0 26.0 , , 75 3.1 , , 600.0
250 , , 0.8
303017 26.0 24.0 , , 89 2.1 , , 420.0
180 , , 1
303018 25.0 24.0 , , 94 0.0 , , 210.0 80
, , 1
303019 25.0 23.0 , , 89 0.5 , , 110.0 40
, , 1
303020 25.0 23.0 , , 89 1.0 , , 0.0 0 ,
, 1
303021 25.0 23.0 , , 89 1.5 , , 0.0 0 ,
, 1
303022 25.0 24.0 , , 94 1.5 , , 0.0 0 ,
, 0.3
303023 25.0 24.0 , , 94 0.0 , , 0.0 0 ,
, 0.8
303024 25.0 24.0 , , 94 1.5 , , 0.0 0 , ,
0.8
303101 25.0 24.0 , , 94 1.0 , , 0.0 0 ,
, 0.8
303102 24.0 23.0 , , 94 1.0 , , 0.0 0 ,
, 0.8
303103 24.0 24.0 , , 100 1.5 , , 0.0 0 ,
, 0.8
303104 24.0 24.0 , , 100 1.5 , , 0.0 0 ,
, 0.8
303105 24.0 23.0 , , 94 1.0 , , 0.0 0
, , 0.8
303106 24.0 23.0 , , 94 1.0 , , 0.0 0 ,
, 0.8
303107 24.0 23.0 , , 94 0.5 , , 105.0 40
, , 0.8
303108 24.0 24.0 , , 100 0.5 , , 250.0
100 , , 0.8
303109 25.0 24.0 , , 94 0.0 , , 320.0
120 , , 0.8
303110 27.0 25.0 , , 89 1.0 , , 400.0
160 , , 0.8
303111 28.0 25.0 , , 84 1.5 , , 520.0
200 , , 0.8

303112 30.0 24.0 , , 70 2.6 , , 650.0
250 , , 0.8
303113 30.0 24.0 , , 70 2.1 , , 720.0
285 , , 0.8
303114 31.0 23.0 , , 62 1.5 , , 800.0
320 , , 0.8
303115 32.0 23.0 , , 59 3.1 , , 820.0
350 , , 0.8
303116 32.0 25.0 , , 66 1.5 , , 600.0
250 , , 0.8
303117 32.0 25.0 , , 66 1.5 , , 420.0
180 , , 0.8
303118 30.0 24.0 , , 70 3.1 , , 210.0 80
, , 0.8
303119 29.0 24.0 , , 74 2.1 , , 110.0 40 ,
, 0.8
303120 29.0 24.0 , , 74 2.1 , , 0.0 0 ,
, 0.8
303121 28.0 24.0 , , 79 0.0 , , 0.0 0 ,
, 0.8
303012 27.0 24.0 , , 84 2.1 , , 0.0 0 ,
, 0.8
303123 26.0 23.0 , , 83 1.5 , , 0.0 0 ,
, 0.8

HTB2 – BUILDING FILE : PITCHED ROOF

```
!PROJECTID PITCHED ROOF 45degree
!LOCATION = 101.7 2.9
!DEFINE SPACE = '1 -ROOF Space'
 !VOLUME = 213.33
!END


!MATERIALS FILE = 'STDMAT.LBY'
!MATERIAL USER = 'PITCHMATS.LBY'
!CONSTRUCTION FILE = 'PITCH.CON'
!LAYOUT FILE = 'PITCH.LAY'
```

HTB2 – CONSTRUCTION FILE: PITCHED

```
* construction definition file for mosque
*   uses user defined materials list
!MATERIALS USER FILE = 'JAMEKMATS.LBY'
*   and standard library


!CONSTRUCTION '1 external wall'
!TYPE OPAQUE
!PARTS
* part    material    width       slices
*      :           :          :           :
_ 1   =   34           0.016       0            * plaster
_ 2   =   1           0.105       0            * brick
_ 3   =   34           0.016       0            * plaster
}

!END

!CONSTRUCTION '2 single glazing'
!TYPE TRANSPARENT
!PARTS
* part    material    width       slices      absorp
*      :           :          :           :
_ 1  =     65        0.006        0          1.00    * window
glass
}
!END

!CONSTRUCTION '3 solid ground floor '
!TYPE OPAQUE
!PARTS
* part    material    width       slices
*      :           :          :           :
_ 1   =   @10          0.015       0            * carpet
_ 2   =   @11          0.100       0            * concrete
_ 3   =   @12          1.600       0            * earth
}
!END

!CONSTRUCTION '4 internal ceiling'
!TYPE OPAQUE
!PARTS
* part    material    width       slices
*      :           :          :           :
_ 1   =   @5           0.100       0            * insulation
quilt
_ 2    =    @4              0.010         0                *
plasterboard
```

```
}
!END

!CONSTRUCTION '5  roof'
!TYPE OPAQUE
!PARTS
* part    material    width       slices
*      :           :          :           :
_ 1   =   @8            0.010        0          * tiles
}
!END

!CONSTRUCTION '6 internal partition'
!TYPE OPAQUE
!PARTS
* part    material    width       slices
*      :           :          :           :
_ 1   =   @3            0.016        0          * plaster
_ 2   =   @2               0.105        0            * brick
(inner)
_ 3   =   @3            0.016        0          * plaster
}
!END

!CONSTRUCTION '7 timber grille wall'
!TYPE OPAQUE
!PARTS
* part    material    width       slices
*      :           :          :           :
_ 1   =   49            0.190         0                * oak
(radial)

}
!END

!CONSTRUCTION '8 concrete roofing'
!TYPE OPAQUE
!PARTS
* part    material    width       slices
*      :           :          :           :
_ 1 =       10      0.300      0            * CONCRETE (HEAVY
MIX)
}
!END

!CONSTRUCTION '9 ROOF1'
!TYPE OPAQUE
!PARTS
* part   material    width     slices
*      :          :          :          :
_ 1  =      30      0.013       0      * tiles
```

```
_ 2  =      58      0.085        0      * styrofoam
_ 3  =      36       0.013        0      * p'board
}
!END


!CONSTRUCTION '10 solid ground floor with tiles'
!TYPE OPAQUE
!PARTS
* part    material    width       slices
*      :           :          :           :
_1   =   21           0.030        0            * tiles
_2   =   @11           0.100        0            * concrete
_3   =   @12           1.600        0            * earth
}
!END

!CONSTRUCTION '11 opening'
!TYPE TRANSPARENT
!PARTS
* part    material    width       slices     absorp
*      :           :          :           :
_1   =   @13           0.015        0         1.0    * opening
}
!END

* window type definitions

!WINDOW  = '6MMFLOAT'
!TRANSMISSION =
 0.64  ,  0.80  ,  0.80  ,  0.80,  0.80,  0.78,  0.75,  0.71,  0.60,
0.36, 0.0
!ABSORPTION =
 0.134 , 0.12, 0.12, 0.12, 0.12, 0.14, 0.14, 0.14, 0.14, 0.15,
0.15
!END

!WINDOW = 'OPENING'
!TRANSMISSION =
0.50,  0.50,  0.50,  0.50,  0.50,  0.50,  0.50,  0.50,  0.50,  0.50,
0.0
!ABSORPTION =
0.01,  0.01,  0.01,  0.01,  0.01,  0.01,  0.01,  0.01,  0.01,  0.01,
0.0
!END

_
```

HTB2 – LAYOUT FILE : PITCHED

```
!ELEMENT = '1 south roof'
 !CONSTRUCTION = 9
 !AREA = 22.6
 !ORIENTATION = 67.0
 !TILT = 45.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '2 east roof'
 !CONSTRUCTION = 9
 !AREA = 22.6
 !ORIENTATION = 157.0
 !TILT = 45.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '3 north roof'
 !CONSTRUCTION = 9
 !AREA = 22.6
 !ORIENTATION = 247.0
 !TILT = 45.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '4 south roof'
 !CONSTRUCTION = 9
 !AREA = 22.6
 !ORIENTATION = 337.0
 !TILT = 45.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '5 south wall'
 !CONSTRUCTION = 1
 !AREA = 8.0
 !ORIENTATION = 67.0
```

```
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '6 east wall'
 !CONSTRUCTION = 1
 !AREA = 8.0
 !ORIENTATION = 157.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '7 north wall'
 !CONSTRUCTION = 1
 !AREA = 8.0
 !ORIENTATION = 247.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '8 west wall'
 !CONSTRUCTION = 1
 !AREA = 8.0
 !ORIENTATION = 337.0
 !TILT = 80.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '9 south windows'
 !CONSTRUCTION = 2
 !AREA = 8.0
 !ORIENTATION = 67.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !PATCH TO #29 FIRST = 1
 !SHADING          =          'NONE'
 !WINDOW TYPE      =         '6MMFLOAT'
```

```
 !CLASS = 2
!END

!ELEMENT = '10 east windows'
 !CONSTRUCTION = 2
 !AREA = 8.0
 !ORIENTATION = 157.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !PATCH TO #29 FIRST = 1
 !SHADING           =          'NONE'
 !WINDOW TYPE       =         '6MMFLOAT'
 !CLASS = 2
!END

!ELEMENT = '11 north windows'
 !CONSTRUCTION = 2
 !AREA = 8.0
 !ORIENTATION = 247.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !PATCH TO #29 FIRST = 1
 !SHADING           =          'NONE'
 !WINDOW TYPE       =         '6MMFLOAT'
 !CLASS = 2
!END

!ELEMENT = '12 west windows'
 !CONSTRUCTION = 2
 !AREA = 8.0
 !ORIENTATION = 337.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !PATCH TO #29 FIRST = 1
 !SHADING           =          'NONE'
 !WINDOW TYPE       =         '6MMFLOAT'
 !CLASS = 2
!END
```

TOP LEVEL FILE

```
* Top top Level file for pitched Mosque, Seremban, Standard
!RUNID PITCH Mosque Seremban, standard run at 45 degree pitch

* configure model...
!ENABLE METEOROLOGICAL
!ENABLE FABRIC
!ENABLE RADTRAN STAR
!ENABLE SOLAR


*                        calc ground temp
!ENABLE GROUND TEMP CALCS
!SET GROUND FACTOR = 0.001

* set up run parameters
!SET TIMESTEP = 120.0
!SET RUNLENGTH = 010,00
*                          allow 1st 3 days for runup
!SET BST = 01/13 31/13
!SET DATE = 01/03/2009


* chose output files and data
!OUTPUT INFO = 'PITCH.INF'
!OUTPUT BLOCK FILE = 'PITCH.BLK'
!ENABLE BLOCK REPORT
!ENABLE BLOCK OUTPUT

* connect to further files
!DEFINE BUILDING FILE = 'PITCH.BLD'
!DEFINE METEOR FILE = 'MARCH09.MET'
```

HTB2 – VENTILATION FILE : PITCHED

```
1               * dome mosque
***********     *    simple ACRs, constant air infiltration
1                        * dome roof space
1.70 ,  0.0 ,  0.0     * INFILTRATION RATE INFIL, LOW, HIGH
25.0                     * VENT STAT SETTING
-----------
0
_
```

TOP LEVEL FILE

```
* Top top Level file for Jamek Mosque, Seremban, Standard
!RUNID PITCH Mosque Seremban, standard run at 45 degree pitch

* configure model...
!ENABLE METEOROLOGICAL
!ENABLE FABRIC
!ENABLE RADTRAN STAR
!ENABLE SOLAR
!ENABLE WATER
!ENABLE VENTILATION


*                        calc ground temp
!ENABLE GROUND TEMP CALCS
!SET GROUND FACTOR = 0.001

* set up run parameters
!SET TIMESTEP = 120.0
!SET RUNLENGTH = 010,00
*                          allow 1st 3 days for runup
!SET BST = 01/13 31/13
!SET DATE = 01/03/2009


* chose output files and data
!OUTPUT INFO = 'PITCH0.INF'
!OUTPUT BLOCK FILE = 'PITCH0.BLK'
!ENABLE BLOCK REPORT
!ENABLE BLOCK OUTPUT

* connect to further files
!DEFINE BUILDING FILE = 'PITCH.BLD'
!DEFINE METEOR FILE = 'MARCH09.MET'
!DEFINE VENTILATION = 'PITCH.VNT'
```

BUILDING FILE

```
!PROJECTID PITCHED ROOF 60degree
!LOCATION = 101.7 2.9
!DEFINE SPACE = '1 -ROOF Space'
 !VOLUME = 262.36
!END


!MATERIALS FILE = 'STDMAT.LBY'
!MATERIAL USER = 'PITCHMATS.LBY'
!CONSTRUCTION FILE = 'PITCH.CON'
!LAYOUT FILE = 'PITCH1.LAY'
```

LAYOUT FILE

```
!ELEMENT = '1 south roof'
 !CONSTRUCTION = 9
 !AREA = 32.0
 !ORIENTATION = 67.0
 !TILT = 45.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '2 east roof'
 !CONSTRUCTION = 9
 !AREA = 32.0
 !ORIENTATION = 157.0
 !TILT = 45.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '3 north roof'
 !CONSTRUCTION = 9
 !AREA = 32.0
 !ORIENTATION = 247.0
 !TILT = 45.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '4 south roof'
 !CONSTRUCTION = 9
 !AREA = 32.0
 !ORIENTATION = 337.0
 !TILT = 45.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '5 south wall'
 !CONSTRUCTION = 1
 !AREA = 8.0
 !ORIENTATION = 67.0
 !TILT = 0.0
```

```
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '6 east wall'
 !CONSTRUCTION = 1
 !AREA = 8.0
 !ORIENTATION = 157.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '7 north wall'
 !CONSTRUCTION = 1
 !AREA = 8.0
 !ORIENTATION = 247.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '8 west wall'
 !CONSTRUCTION = 1
 !AREA = 8.0
 !ORIENTATION = 337.0
 !TILT = 80.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '9 south windows'
 !CONSTRUCTION = 2
 !AREA = 8.0
 !ORIENTATION = 67.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !PATCH TO #29 FIRST = 1
 !SHADING           =          'NONE'
 !WINDOW TYPE       =         '6MMFLOAT'
 !CLASS = 2
```

```
!END

!ELEMENT = '10 east windows'
 !CONSTRUCTION = 2
 !AREA = 8.0
 !ORIENTATION = 157.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !PATCH TO #29 FIRST = 1
 !SHADING           =          'NONE'
 !WINDOW TYPE       =         '6MMFLOAT'
 !CLASS = 2
!END

!ELEMENT = '11 north windows'
 !CONSTRUCTION = 2
 !AREA = 8.0
 !ORIENTATION = 247.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !PATCH TO #29 FIRST = 1
 !SHADING           =          'NONE'
 !WINDOW TYPE       =         '6MMFLOAT'
 !CLASS = 2
!END

!ELEMENT = '12 west windows'
 !CONSTRUCTION = 2
 !AREA = 8.0
 !ORIENTATION = 337.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !PATCH TO #29 FIRST = 1
 !SHADING           =          'NONE'
 !WINDOW TYPE       =         '6MMFLOAT'
 !CLASS = 2
!END
```

TOP FILE

```
* Top top Level file for Jamek Mosque, Seremban, Standard
!RUNID PITCH Mosque Seremban, standard run AT 60 DEGREE PITCH

* configure model...
!ENABLE METEOROLOGICAL
!ENABLE FABRIC
!ENABLE RADTRAN STAR
!ENABLE SOLAR
!ENABLE WATER


*                        calc ground temp
!ENABLE GROUND TEMP CALCS
!SET GROUND FACTOR = 0.001

* set up run parameters
!SET TIMESTEP = 120.0
!SET RUNLENGTH = 010,00
*                          allow 1st 3 days for runup
!SET BST = 01/13 31/13
!SET DATE = 01/03/2009


* chose output files and data
!OUTPUT INFO = 'PITCH1.INF'
!OUTPUT BLOCK FILE = 'PITCH1.BLK'
!ENABLE BLOCK REPORT
!ENABLE BLOCK OUTPUT

* connect to further files
!DEFINE BUILDING FILE = 'PITCH1.BLD'
!DEFINE METEOR FILE = 'MARCH09.MET'
```

BUILDING FILE

```
!PROJECTID PITCHED ROOF 30degree
!LOCATION = 101.7 2.9
!DEFINE SPACE = '1 -ROOF Space'
 !VOLUME = 885.6
!END


!MATERIALS FILE = 'STDMAT.LBY'
!MATERIAL USER = 'PITCHMATS.LBY'
!CONSTRUCTION FILE = 'PITCH.CON'
!LAYOUT FILE = 'PITCH1ONLY.LAY'
```

LAYOUT FILE

```
!ELEMENT = '1 south top pitch roof1'
 !CONSTRUCTION = 9
 !AREA = 93.6
 !ORIENTATION = 67.0
 !TILT = 60.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !END

!ELEMENT = '2 east top pitch roof1'
 !CONSTRUCTION = 9
 !AREA = 93.6
 !ORIENTATION = 157.0
 !TILT = 60.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !END

!ELEMENT = '3 west top pitch roof1'
 !CONSTRUCTION = 9
 !AREA = 93.6
 !ORIENTATION = 337.0
 !TILT = 60.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !END

!ELEMENT = '4 north top pitch roof1'
 !CONSTRUCTION = 9
 !AREA = 93.6
 !ORIENTATION = 247.0
 !TILT = 60.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !END

!ELEMENT = '113 south wall'
 !CONSTRUCTION = 1
 !AREA = 8.0
 !ORIENTATION = 67.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
```

```
 !CLASS = 1
!END

!ELEMENT = '114 east wall'
 !CONSTRUCTION = 1
 !AREA = 8.0
 !ORIENTATION = 157.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '115 north wall'
 !CONSTRUCTION = 1
 !AREA = 8.0
 !ORIENTATION = 247.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '116 west wall'
 !CONSTRUCTION = 1
 !AREA = 8.0
 !ORIENTATION = 337.0
 !TILT = 80.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '117 south windows'
 !CONSTRUCTION = 2
 !AREA = 10.0
 !ORIENTATION = 67.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !PATCH TO #29 FIRST = 1
 !SHADING           =          'NONE'
 !WINDOW TYPE       =         '6MMFLOAT'
 !CLASS = 2
!END

!ELEMENT = '118 east windows'
```

```
 !CONSTRUCTION = 2
 !AREA = 10.0
 !ORIENTATION = 157.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !PATCH TO #29 FIRST = 1
 !SHADING           =          'NONE'
 !WINDOW TYPE       =         '6MMFLOAT'
 !CLASS = 2
!END

!ELEMENT = '119 north windows'
 !CONSTRUCTION = 2
 !AREA = 10.0
 !ORIENTATION = 247.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !PATCH TO #29 FIRST = 1
 !SHADING           =          'NONE'
 !WINDOW TYPE       =         '6MMFLOAT'
 !CLASS = 2
!END

!ELEMENT = '120 west windows'
 !CONSTRUCTION = 2
 !AREA = 10.0
 !ORIENTATION = 337.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !PATCH TO #29 FIRST = 1
 !SHADING           =          'NONE'
 !WINDOW TYPE       =         '6MMFLOAT'
 !CLASS = 2
!END
```

TOP LEVEL FILE

```
* Top top Level file for PITCH only, Standard
!RUNID PITCH only, standard run at 30 degree pitch

* configure model...
!ENABLE METEOROLOGICAL
!ENABLE FABRIC
!ENABLE RADTRAN STAR
!ENABLE SOLAR
!ENABLE WATER
!ENABLE VENTILATION


*                        calc ground temp
!ENABLE GROUND TEMP CALCS
!SET GROUND FACTOR = 0.001

* set up run parameters
!SET TIMESTEP = 120.0
!SET RUNLENGTH = 010,00
*                          allow 1st 3 days for runup
!SET BST = 01/13 31/13
!SET DATE = 01/03/2009


* chose output files and data
!OUTPUT INFO = 'PITCH1ONLY.INF'
!OUTPUT BLOCK FILE = 'PITCH1ONLY.BLK'
!ENABLE BLOCK REPORT
!ENABLE BLOCK OUTPUT
!ENABLE REPORT ALL

* connect to further files
!DEFINE BUILDING FILE = 'PITCH1ONLY.BLD'
!DEFINE METEOR FILE = 'MARCH09.MET'
!DEFINE VENTILATION = 'PITCH.VNT'
```

MATERIAL FILE

```
1                  * outer brick
0.840   1700.0    800.0
2                  * inner brick
0.62    1700.0    800.0
3                  * plaster
0.26     800.0    1000.0
4                  * plasterboard
0.16     950.0    840.0
5                  * quilt
0.040    12.0      840.0
8                  * roofing tile
0.84     1900.0   800.0
10                 * carpet
0.055    160.0     1000.0
11                 * concrete
1.40     2100.0     840.0
12                 * earth
1.40     1900.0     1700.0
13                  * opening
0.027    1.12      1005
```

_

II) HTB2 CODING FOR DOMED ROOF MOSQUE

CONSTRUCTION FILE

```
* construction definition file for DOME
*   uses user defined materials list
!MATERIALS USER FILE = 'DOMEMATS.LBY'
*   and standard library


!CONSTRUCTION '1 outer wall'
!TYPE OPAQUE
!PARTS
* part    material    width       slices
*      :           :          :           :
_ 1   =   34           0.016        0            * plaster
_ 2   =   1           0.105        0            * brick
_ 3   =   34           0.016        0            * plaster
}

!END

!CONSTRUCTION '2 single glazing'
!TYPE TRANSPARENT
!PARTS
* part    material    width       slices      absorp
*      :           :          :           :
_ 1  =     65        0.006          0          1.00    * window
glass
}
!END

!CONSTRUCTION '3 solid ground floor '
!TYPE OPAQUE
!PARTS
* part    material    width       slices
*      :           :          :           :
_ 1   =   @10          0.015        0            * carpet
_ 2   =   @11          0.100        0            * concrete
_ 3   =   @12          1.600        0            * earth
}
!END

!CONSTRUCTION '4 internal ceiling'
```

```
!TYPE OPAQUE
!PARTS
* part    material    width       slices
*      :           :           :           :
_ 1   =   @5             0.100        0            * insulation
quilt
_ 2    =    @4                 0.010          0                *
plasterboard
}
!END

!CONSTRUCTION '5  roof'
!TYPE OPAQUE
!PARTS
* part    material    width       slices
*      :           :           :           :
_ 1   =   @8             0.010        0          * tiles
}
!END

!CONSTRUCTION '6 internal partition'
!TYPE OPAQUE
!PARTS
* part    material    width       slices
*      :           :           :           :
_ 1   =   @3             0.016        0          * plaster
_ 2    =    @2                0.105          0             * brick
(inner)
_ 3   =   @3             0.016        0          * plaster
}
!END

!CONSTRUCTION '7 timber grille wall'
!TYPE OPAQUE
!PARTS
* part    material    width       slices
*      :           :           :           :
_ 1    =    49              0.190          0                * oak
(radial)

}
!END

!CONSTRUCTION '8 concrete roofing'
!TYPE OPAQUE
!PARTS
* part    material    width       slices
*      :           :           :           :
_ 1 =       11       0.450       0              * CONCRETE (LIGHT
MIX)
_ 2 =       -1      0.150       0              * cavity
_ 3 =       36      0.013       0              * plasterboard
```

```
}
!END

!CONSTRUCTION '9 ROOF1'
!TYPE OPAQUE
!PARTS
* part   material    width     slices
*      :          :          :          :
_ 1  =      30      0.013        0      * tiles
_ 2  =      58      0.085        0      * styrofoam
_ 3  =      36       0.013        0      * p'board
}
!END


!CONSTRUCTION '10 solid ground floor with tiles'
!TYPE OPAQUE
!PARTS
* part    material    width       slices
*      :           :          :           :
_ 1   =   21           0.030        0             * tiles
_ 2   =   @11           0.100        0             * concrete
_ 3   =   @12           1.600        0             * earth
}
!END

!CONSTRUCTION '11 opening'
!TYPE TRANSPARENT
!PARTS
* part    material    width       slices     absorp
*      :           :          :           :
_1   =    @13             0.015          0           1.0      *
opening
}
!END



!CONSTRUCTION '12 dome roofing'
!TYPE OPAQUE
!PARTS
* part    material    width       slices
*      :           :          :           :
_ 1    =    @14             0.012          0                *
polycarbonate
_ 2   =   -1            0.150        0             * cavity air
_ 3    =    @14             0.012          0                *
polycarbonate
}
!END

!CONSTRUCTION '13 concrete roofing'
```

```
!TYPE OPAQUE
!PARTS
* part    material    width        slices
*      :            :           :            :
_ 1 =       11      0.450      0              * CONCRETE (LIGHT
MIX)
}
!END


* window type definitions

!WINDOW  = '6MMFLOAT'
!TRANSMISSION =
 0.64  ,  0.80  ,  0.80  ,  0.80,  0.80,  0.78,  0.75,  0.71,  0.60,
0.36, 0.0
!ABSORPTION =
 0.134 , 0.12, 0.12, 0.12, 0.12, 0.14, 0.14, 0.14, 0.14, 0.15,
0.15
!END

!WINDOW = 'OPENING'
!TRANSMISSION =
0.50,  0.50,  0.50,  0.50,  0.50,  0.50,  0.50,  0.50,  0.50,  0.50,
0.0
!ABSORPTION =
0.01,  0.01,  0.01,  0.01,  0.01,  0.01,  0.01,  0.01,  0.01,  0.01,
0.0
!END
_
```

MATERIAL FILE

```
1                  * outer brick
0.840   1700.0    800.0
2                  * inner brick
0.62    1700.0    800.0
3                  * plaster
0.26     800.0    1000.0
4                  * plasterboard
0.16     950.0    840.0
5                  * quilt
0.040    12.0      840.0
8                  * roofing tile
0.84     1900.0   800.0
10                 * carpet
0.055    160.0     1000.0
11                 * concrete
1.40     2100.0     840.0
12                 * earth
1.40     1900.0     1700.0
13                  * opening
0.024    1.12      1005
14                  *polycarbonate
0.20     1200.0     1200
```

_

BUILDING FILE

```
!PROJECTID DOME ONLY
!LOCATION = 101.7 2.9
!DEFINE SPACE = '1 -Dome'
 !VOLUME = 1851.0
!END

!MATERIALS FILE = 'STDMAT.LBY'
!MATERIAL USER = 'DOMEMATS.LBY'
!CONSTRUCTION FILE = 'DOME1.CON'
!LAYOUT FILE = 'DOMEONLY.LAY'
```

METEOROLOGICAL FILE

30101	25.0	24.0	,,	94	1.5	,,	0.0	0	,,	0.8
30102	25.0	23.0	,,	89	1.5	,,	0.0	0	,,	0.8
30103	25.0	23.0	,,	89	1.0	,,	0.0	0	,,	0.8
30104	25.0	23.0	,,	89	0.5	,,	0.0	0	,,	0.8
30105	24.0	23.0	,,	94	1.0	,,	0.0	0	,,	0.8
30106	24.0	23.0	,,	94	1.0	,,	0.0	0	,,	0.8
30107	24.0	23.0	,,	94	1.5	,,	105.0	40	,,	0.8
30108	24.0	23.0	,,	94	1.5	,,	250.0	100	,,	0.8
30109	26.0	24.0	,,	89	3.1	,,	320.0	120	,,	0.8
30110	28.0	24.0	,,	79	3.6	,,	400.0	160	,,	0.8
30111	30.0	24.0	,,	70	4.6	,,	480.0	200	,,	0.8
30112	31.0	24.0	,,	66	4.1	,,	550.0	250	,,	0.8
30113	32.0	24.0	,,	62	3.1	,,	620.0	285	,,	0.8
30114	30.0	24.0	,,	70	4.1	,,	680.0	320	,,	0.8
30115	30.0	25.0	,,	74	2.6	,,	720.0	350	,,	0.8
30116	30.0	25.0	,,	74	2.6	,,	600.0	250	,,	0.8
30117	32.0	24.0	,,	62	1.5	,,	420.0	180	,,	0.8
30118	31.0	24.0	,,	66	3.6	,,	210.0	80	,,	0.8
30119	29.0	24.0	,,	74	2.1	,,	110.0	40	,,	1
30120	26.0	23.0	,,	83	3.1	,,	0.0	0	,,	1
30121	26.0	24.0	,,	89	2.1	,,	0.0	0	,,	1
30122	26.0	25.0	,,	94	2.1	,,	0.0	0	,,	1
30123	25.0	24.0	,,	94	2.6	,,	0.0	0	,,	1
30124	25.0	24.0	,,	94	0.0	,,	0.0	0	,,	1
30201	25.0	24.0	,,	94	1.5	,,	0.0	0	,,	0.8
30202	25.0	24.0	,,	94	1.5	,,	0.0	0	,,	0.8
30203	25.0	24.0	,,	94	1.5	,,	0.0	0	,,	0.8
30204	24.0	24.0	,,	100	0.5	,,	0.0	0	,,	0.8
30205	24.0	24.0	,,	100	1.5	,,	0.0	0	,,	0.8
30206	24.0	24.0	,,	100	0.0	,,	0.0	0	,,	0.8
30207	25.0	24.0	,,	94	1.0	,,	105.0	40	,,	0.8
30208	25.0	24.0	,,	94	1.5	,,	250.0	100	,,	0.8
30209	26.0	24.0	,,	89	1.0	,,	320.0	120	,,	0.8
30210	27.0	25.0	,,	89	3.1	,,	400.0	160	,,	0.8
30211	28.0	25.0	,,	84	2.6	,,	480.0	200	,,	0.8
30212	30.0	24.0	,,	70	4.6	,,	550.0	250	,,	0.8
30213	31.0	24.0	,,	66	3.6	,,	620.0	285	,,	0.8
30214	25.0	24.0	,,	94	1.5	,,	680.0	320	,,	0.8
30215	26.0	24.0	,,	89	1.0	,,	720.0	350	,,	0.8
30216	27.0	25.0	,,	89	3.1	,,	600.0	250	,,	0.8
30217	28.0	25.0	,,	84	2.6	,,	420.0	180	,,	0.8
30218	30.0	24.0	,,	70	4.6	,,	210.0	80	,,	0.8
30219	31.0	24.0	,,	66	3.6	,,	110.0	40	,,	0.8
30220	29.0	25.0	,,	79	2.6	,,	0.0	0	,,	1
30221	28.0	24.0	,,	79	2.1	,,	0.0	0	,,	0.8
30222	27.0	24.0	,,	84	2.1	,,	0.0	0	,,	0.8
30223	27.0	24.0	,,	84	2.1	,,	0.0	0	,,	0.8
30224	27.0	24.0	,,	84	3.6	,,	0.0	0	,,	0.8
30301	26.0	24.0	,,	89	4.1	,,	0.0	0	,,	0.8
30302	26.0	24.0	,,	89	2.6	,,	0.0	0	,,	0.8

30303	26.0	24.0	,,	89	3.1	,,	0.0	0,,	0.8
30304	26.0	24.0	,,	89	4.1	,,	0.0	0,,	0.8
30305	26.0	24.0	,,	89	2.6	,,	0.0	0,,	0.8
30306	26.0	24.0	,,	89	3.6	,,	0.0	0,,	0.8
30307	23.0	22.0	,,	94	3.1	,,	105.0	40,,	1
30308	23.0	22.0	,,	94	2.1	,,	250.0	100,,	1
30309	23.0	22.0	,,	94	1.0	,,	320.0	120,,	1
30310	24.0	23.0	,,	94	0.5	,,	400.0	160,,	1
30311	25.0	24.0	,,	94	1.5	,,	480.0	200,,	0.8
30312	27.0	25.0	,,	89	2.1	,,	550.0	250,,	0.8
30313	29.0	25.0	,,	79	2.1	,,	620.0	285,,	0.8
30314	30.0	26.0	,,	79	2.1	,,	680.0	320,,	0.8
30315	31.0	26.0	,,	75	1.5	,,	720.0	350,,	0.8
30316	32.0	26.0	,,	70	2.1	,,	600.0	250,,	0.8
30317	25.0	23.0	,,	89	4.1	,,	420.0	180,,	1
30318	24.0	23.0	,,	94	1.5	,,	210.0	80,,	0.8
30319	25.0	24.0	,,	94	0.5	,,	110.0	40,,	0.6
30320	25.0	24.0	,,	94	0.0	,,	0.0	0,,	0.8
30321	26.0	25.0	,,	94	1.0	,,	0.0	0,,	0.8
30322	26.0	24.0	,,	89	1.5	,,	0.0	0,,	0.8
30323	25.0	24.0	,,	94	1.5	,,	0.0	0,,	0.8
30324	25.0	24.0	,,	94	1.5	,,	0.0	0,,	0.8
30401	25.0	24.0	,,	94	1.5	,,	0.0	0,,	0.8
30402	25.0	24.0	,,	94	1.0	,,	0.0	0,,	0.8
30403	25.0	24.0	,,	94	2.1	,,	0.0	0,,	0.8
30404	25.0	24.0	,,	94	1.5	,,	0.0	0,,	1
30405	25.0	23.0	,,	89	1.0	,,	0.0	0,,	0.8
30406	25.0	23.0	,,	89	1.0	,,	0.0	0,,	0.8
30407	25.0	23.0	,,	89	1.0	,,	105.0	40,,	0.8
30408	25.0	23.0	,,	89	1.5	,,	250.0	100,,	0.8
30409	26.0	24.0	,,	89	2.1	,,	320.0	120,,	0.8
30410	28.0	24.0	,,	79	2.1	,,	400.0	160,,	0.8
30411	30.0	24.0	,,	70	4.6	,,	480.0	200,,	0.8
30412	30.0	24.0	,,	70	3.6	,,	550.0	250,,	0.8
30413	30.0	24.0	,,	70	3.6	,,	620.0	285,,	0.8
30414	33.0	24.0	,,	59	1.5	,,	680.0	320,,	0.8
30415	32.0	25.0	,,	66	3.1	,,	720.0	350,,	0.8
30416	33.0	25.0	,,	63	4.6	,,	600.0	250,,	0.8
30417	33.0	23.0	,,	55	4.1	,,	420.0	180,,	0.8
30418	32.0	23.0	,,	59	4.1	,,	210.0	80,,	0.8
30419	31.0	23.0	,,	62	3.1	,,	110.0	40,,	0.8
30420	29.0	24.0	,,	74	1.5	,,	0.0	0,,	0.8
30421	29.0	25.0	,,	79	1.0	,,	0.0	0,,	0.8
30422	29.0	24.0	,,	74	1.5	,,	0.0	0,,	0.8
30423	27.0	25.0	,,	89	1.5	,,	0.0	0,,	0.8
30424	27.0	25.0	,,	89	2.1	,,	0.0	0,,	0.8
30501	27.0	24.0	,,	84	2.1	,,	0.0	0,,	0.8
30502	26.0	24.0	,,	86	3.6	,,	0.0	0,,	0.4
30503	26.0	24.0	,,	89	3.1	,,	0.0	0,,	0.8
30504	26.0	24.0	,,	89	1.5	,,	0.0	0,,	0.8
30505	26.0	24.0	,,	89	2.1	,,	0.0	0,,	0.8
30506	25.0	24.0	,,	94	2.1	,,	0.0	0,,	0.8

30507	25.0	24.0	,, 94	1.0	,,	105.0	40,,	0.8
30508	26.0	24.0	,, 89	1.5	,,	250.0	100,,	0.8
30509	27.0	24.0	,, 84	2.6	,,	320.0	120,,	0.8
30510	28.0	25.0	,, 84	3.1	,,	400.0	160,,	0.8
30511	28.0	25.0	,, 84	2.6	,,	480.0	200,,	1
30512	28.0	25.0	,, 84	0.5	,,	550.0	250,,	1
30513	28.0	25.0	,, 84	1.0	,,	620.0	285,,	0.8
30514	28.0	25.0	,, 84	3.6	,,	680.0	320,,	1
30515	27.0	25.0	,, 89	2.6	,,	720.0	350,,	1
30516	28.0	24.0	,, 79	3.1	,,	600.0	250,,	0.8
30517	28.0	24.0	,, 79	2.6	,,	420.0	180,,	0.8
30518	28.0	25.0	,, 84	2.1	,,	210.0	80,,	0.8
30519	28.0	24.0	,, 79	3.6	,,	110.0	40,,	0.8
30520	27.0	24.0	,, 84	1.5	,,	0.0	0,,	0.8
30521	27.0	24.0	,, 84	1.5	,,	0.0	0,,	0.8
30522	26.0	24.0	,, 89	1.5	,,	0.0	0,,	0.8
30523	26.0	23.0	,, 83	2.1	,,	0.0	0,,	0.8
30524	26.0	23.0	,, 83	1.5	,,	0.0	0,,	0.8
30601	26.0	23.0	,, 83	1.5	,,	0.0	0,,	0.8
30602	25.0	24.0	,, 94	0.5	,,	0.0	0,,	0.8
30603	25.0	24.0	,, 94	0.5	,,	0.0	0,,	0.8
30604	25.0	24.0	,, 94	1.0	,,	0.0	0,,	0.8
30605	25.0	24.0	,, 94	1.0	,,	0.0	0,,	0.8
30606	24.0	24.0	,,100	1.5	,,	0.0	0,,	0.8
30607	24.0	23.0	,, 94	1.0	,,	105.0	40,,	0.8
30608	24.0	23.0	,, 94	1.5	,,	250.0	100,,	0.8
30609	26.0	24.0	,, 89	2.1	,,	320.0	120,,	0.7
30610	26.0	24.0	,, 89	2.1	,,	400.0	160,,	0.7
30611	26.0	24.0	,, 89	2.1	,,	480.0	200,,	0.7
30612	30.0	25.0	,, 74	1.5	,,	550.0	250,,	0.8
30613	31.0	25.0	,, 70	1.5	,,	620.0	285,,	0.8
30614	31.0	24.0	,, 66	2.1	,,	680.0	320,,	0.8
30615	31.0	25.0	,, 70	3.1	,,	720.0	350,,	0.8
30616	32.0	25.0	,, 66	5.7	,,	600.0	250,,	0.8
30617	32.0	24.0	,, 62	4.6	,,	420.0	180,,	1
30618	32.0	24.0	,, 62	3.6	,,	210.0	80,,	0.8
30619	31.0	23.0	,, 62	3.1	,,	110.0	40,,	0.8
30620	29.0	24.0	,, 74	2.1	,,	0.0	0,,	0.8
30621	28.0	24.0	,, 79	1.5	,,	0.0	0,,	0.8
30622	28.0	25.0	,, 84	1.0	,,	0.0	0,,	0.8
30623	28.0	25.0	,, 84	1.0	,,	0.0	0,,	0.8
30624	28.0	25.0	,, 84	0.0	,,	0.0	0,,	0.8
30701	28.0	26.0	,, 89	0.5	,,	0.0	0,,	0.8
30702	27.0	25.0	,, 89	0.0	,,	0.0	0,,	0.8
30703	26.0	25.0	,, 94	1.0	,,	0.0	0,,	0.8
30704	26.0	25.0	,, 94	1.5	,,	0.0	0,,	0.8
30705	26.0	25.0	,, 94	0.0	,,	0.0	0,,	0.8
30706	26.0	25.0	,, 94	0.0	,,	0.0	0,,	0.8
30707	26.0	25.0	,, 94	0.0	,,	105.0	40,,	1
30708	25.0	24.0	,, 94	1.5	,,	250.0	100,,	1
30709	26.0	24.0	,, 89	0.5	,,	320.0	120,,	0.8
30710	28.0	25.0	,, 84	1.0	,,	400.0	160,,	0.8

30711	30.0	25.0	,,	74	2.1	,,	480.0	200,,	0.8
30712	31.0	25.0	,,	70	1.0	,,	550.0	250,,	0.8
30713	32.0	25.0	,,	66	2.1	,,	620.0	285,,	0.8
30714	32.0	24.0	,,	57	4.1	,,	680.0	320,,	0.7
30715	32.0	24.0	,,	57	4.1	,,	720.0	350,,	0.7
30716	32.0	24.0	,,	57	4.1	,,	600.0	250,,	0.7
30717	32.0	24.0	,,	57	4.1	,,	420.0	180,,	0.7
30718	32.0	24.0	,,	57	4.1	,,	210.0	80,,	0.7
30719	32.0	24.0	,,	57	4.1	,,	110.0	40,,	0.7
30720	26.0	24.0	,,	90	4.1	,,	0.0	0,,	1
30721	26.0	24.0	,,	90	2.1	,,	0.0	0,,	1
30722	26.0	24.0	,,	89	0.5	,,	0.0	0,,	0.8
30723	26.0	24.0	,,	89	1.0	,,	0.0	0,,	0.8
30724	25.0	24.0	,,	94	0.5	,,	0.0	0,,	0.8
30801	25.0	24.0	,,	94	1.0	,,	0.0	0,,	0.8
30802	25.0	24.0	,,	94	0.0	,,	0.0	0,,	0.8
30803	24.0	23.0	,,	94	0.0	,,	0.0	0,,	0.8
30804	24.0	23.0	,,	94	0.0	,,	0.0	0,,	0.8
30805	24.0	23.0	,,	94	1.5	,,	0.0	0,,	0.8
30806	24.0	23.0	,,	94	1.0	,,	0.0	0,,	0.8
30807	23.0	23.0	,,	100	1.0	,,	105.0	40,,	0.8
30808	24.0	23.0	,,	94	0.0	,,	250.0	100,,	0.8
30809	26.0	23.0	,,	83	0.0	,,	320.0	120,,	0.8
30810	28.0	24.0	,,	79	0.0	,,	400.0	160,,	0.8
30811	30.0	23.0	,,	66	1.5	,,	480.0	200,,	0.8
30812	31.0	24.0	,,	66	2.6	,,	550.0	250,,	0.8
30813	32.0	23.0	,,	59	4.1	,,	620.0	285,,	0.8
30814	33.0	24.0	,,	59	4.6	,,	680.0	320,,	0.8
30815	33.0	22.0	,,	52	3.6	,,	720.0	350,,	0.8
30816	33.0	22.0	,,	52	3.6	,,	600.0	250,,	0.8
30817	33.0	21.0	,,	49	4.1	,,	420.0	180,,	0.8
30818	32.0	21.0	,,	52	3.1	,,	210.0	80,,	0.8
30819	31.0	21.0	,,	55	3.1	,,	110.0	40,,	0.8
30820	30.0	21.0	,,	58	2.1	,,	0.0	0,,	0.8
30821	28.0	23.0	,,	74	1.5	,,	0.0	0,,	0.8
30822	28.0	23.0	,,	74	1.5	,,	0.0	0,,	0.8
30823	28.0	22.0	,,	70	0.0	,,	0.0	0,,	0.8
30824	27.0	24.0	,,	84	3.1	,,	0.0	0,,	0.8
30901	27.0	24.0	,,	84	2.6	,,	0.0	0,,	0.8
30902	26.0	24.0	,,	89	2.6	,,	0.0	0,,	0.8
30903	26.0	24.0	,,	89	1.0	,,	0.0	0,,	0.8
30904	26.0	24.0	,,	89	2.6	,,	0.0	0,,	0.8
30905	25.0	24.0	,,	94	1.0	,,	0.0	0,,	0.8
30906	26.0	24.0	,,	89	0.0	,,	0.0	0,,	0.8
30907	26.0	24.0	,,	89	0.5	,,	105.0	40,,	0.8
30908	25.0	24.0	,,	94	1.0	,,	250.0	100,,	0.8
30909	27.0	24.0	,,	84	0.0	,,	320.0	120,,	0.8
30910	28.0	25.0	,,	84	1.0	,,	400.0	160,,	0.8
30911	29.0	24.0	,,	74	2.1	,,	480.0	200,,	0.8
30912	31.0	24.0	,,	66	4.1	,,	550.0	250,,	0.8
30913	29.0	24.0	,,	74	4.6	,,	620.0	285,,	0.8
30914	25.0	24.0	,,	94	3.1	,,	680.0	320,,	1

30915	25.0	24.0	,,	94	1.5	,,	720.0	350,,	1
30916	25.0	24.0	,,	94	2.1	,,	600.0	250,,	1
30917	24.0	23.0	,,	94	1.0	,,	420.0	180,,	1
30918	24.0	23.0	,,	94	0.5	,,	210.0	80,,	1
30919	24.0	23.0	,,	94	1.0	,,	110.0	40,,	1
30920	24.0	23.0	,,	94	2.1	,,	0.0	0,,	1
30921	24.0	23.0	,,	94	4.1	,,	0.0	0,,	1
30922	24.0	22.0	,,	89	4.6	,,	0.0	0,,	1
30923	24.0	22.0	,,	89	2.1	,,	0.0	0,,	1
30924	23.0	22.0	,,	94	2.1	,,	0.0	0,,	0.8
301001	23.0	22.0	,,	94	2.6	,,	0.0	0,,	0.8
301002	24.0	22.0	,,	89	3.1	,,	0.0	0,,	0.8
301003	23.0	22.0	,,	94	2.1	,,	0.0	0,,	1
301004	24.0	22.0	,,	89	3.1	,,	0.0	0,,	0.8
301005	24.0	22.0	,,	89	2.6	,,	0.0	0,,	0.8
301006	24.0	22.0	,,	89	1.5	,,	0.0	0,,	0.8
301007	24.0	22.0	,,	89	1.0	,,	105.0	40,,	0.8
301008	24.0	22.0	,,	89	0.0	,,	250.0	100,,	0.8
301009	24.0	23.0	,,	94	1.0	,,	320.0	120,,	0.8
301010	27.0	24.0	,,	84	1.0	,,	400.0	160,,	0.8
301011	29.0	25.0	,,	79	2.6	,,	480.0	200,,	0.8
301012	29.0	25.0	,,	79	3.6	,,	550.0	250,,	0.8
301013	30.0	25.0	,,	74	3.6	,,	620.0	285,,	0.8
301014	30.0	25.0	,,	74	3.6	,,	680.0	320,,	0.8
301015	30.0	25.0	,,	74	3.6	,,	720.0	350,,	0.8
301016	31.0	25.0	,,	70	3.1	,,	600.0	250,,	0.8
301017	31.0	25.0	,,	70	3.6	,,	420.0	180,,	0.8
301018	30.0	24.0	,,	70	3.1	,,	210.0	80,,	0.8
301019	29.0	23.0	,,	70	1.5	,,	110.0	40,,	0.8
301020	28.0	25.0	,,	84	2.1	,,	0.0	0,,	1
301021	27.0	24.0	,,	84	2.1	,,	0.0	0,,	1
301022	26.0	24.0	,,	89	1.5	,,	0.0	0,,	0.8
301023	26.0	24.0	,,	89	0.5	,,	0.0	0,,	0.8
301024	25.0	23.0	,,	89	1.0	,,	0.0	0,,	1
301101	25.0	24.0	,,	94	0.0	,,	0.0	0,,	1
301102	25.0	24.0	,,	94	1.5	,,	0.0	0,,	0.8
301103	25.0	24.0	,,	94	2.1	,,	0.0	0,,	0.8
301104	25.0	24.0	,,	94	1.5	,,	0.0	0,,	0.8
301105	25.0	24.0	,,	94	1.5	,,	0.0	0,,	0.8
301106	25.0	24.0	,,	94	1.0	,,	0.0	0,,	0.8
301107	25.0	24.0	,,	94	1.5	,,	105.0	40,,	0.8
301108	26.0	24.0	,,	89	1.5	,,	250.0	100,,	0.8
301109	27.0	24.0	,,	84	3.1	,,	320.0	120,,	0.8
301110	29.0	24.0	,,	74	3.6	,,	400.0	160,,	0.8
301111	29.0	24.0	,,	74	3.6	,,	480.0	200,,	0.8
301112	31.0	23.0	,,	62	1.5	,,	550.0	250,,	0.8
301113	31.0	25.0	,,	70	1.5	,,	620.0	285,,	0.8
301114	29.0	25.0	,,	79	4.1	,,	680.0	320,,	0.8
301115	27.0	24.0	,,	84	4.1	,,	720.0	350,,	1
301116	27.0	24.0	,,	84	2.1	,,	600.0	250,,	1
301117	27.0	24.0	,,	84	1.5	,,	420.0	180,,	0.8
301118	27.0	25.0	,,	89	1.5	,,	210.0	80,,	0.8

301119 26.0 23.0 ,, 83 3.6 ,, 110.0 40,, 0.8
301120 25.0 23.0 ,, 89 1.5 ,, 0.0 0,, 1
301121 25.0 23.0 ,, 89 1.5 ,, 0.0 0,, 0.8
301122 25.0 23.0 ,, 89 1.5 ,, 0.0 0,, 0.8
301123 24.0 23.0 ,, 94 2.6 ,, 0.0 0,, 0.8
301124 27.0 24.0 ,, 84 3.1 ,, 0.0 0,, 0.8
301201 27.0 24.0 ,, 84 2.6 ,, 0.0 0,, 0.8
301202 26.0 24.0 , , 89 2.6 , , 0.0 0 , , 0.8
301203 26.0 24.0 , , 89 1.0 , , 0.0 0 , , 0.8
301204 26.0 24.0 , , 89 2.6 , , 0.0 0 , , 0.8
301205 25.0 24.0 , , 94 1.0 , , 0.0 0 , , 0.8
301206 26.0 24.0 , , 89 0.0 , , 0.0 0 , , 0.8
301207 26.0 24.0 , , 89 0.5 , , 105.0 40 , , 0.8
301208 25.0 24.0 , , 94 1.0 , , 250.0 100 , , 0.8
301209 27.0 24.0 , , 84 0.0 , , 320.0 120 , , 0.8
301210 28.0 25.0 , , 84 1.0 , , 400.0 160 , , 0.8
301211 29.0 24.0 , , 74 2.1 , , 520.0 200 , , 0.8
301212 31.0 24.0 , , 66 4.1 , , 650.0 250 , , 0.8
301213 29.0 24.0 , , 74 4.6 , , 720.0 285 , , 0.8
301214 25.0 24.0 , , 94 3.1 , , 800.0 320 , , 1
301215 25.0 24.0 , , 94 1.5 , , 820.0 350 , , 1
301216 25.0 24.0 , , 94 2.1 , , 600.0 250 , , 1
301217 24.0 23.0 , , 94 1.0 , , 420.0 180 , , 1
301218 24.0 23.0 , , 94 0.5 , , 210.0 80 , , 1
301219 24.0 23.0 , , 94 1.0 , , 110.0 40 , , 1
301220 24.0 23.0 , , 94 2.1 , , 0.0 0 , , 1
301221 24.0 23.0 , , 94 4.1 , , 0.0 0 , , 1
301222 24.0 22.0 , , 89 4.6 , , 0.0 0 , , 1
301223 24.0 22.0 , , 89 2.1 , , 0.0 0 , , 1

301224 23.0 22.0 , , 94 2.1 , , 0.0 0 , , 0.8
301301 23.0 22.0 , , 94 2.6 , , 0.0 0 , , 0.8
301302 24.0 22.0 , , 89 3.1 , , 0.0 0 , , 0.8
301303 23.0 22.0 , , 94 2.1 , , 0.0 0 , , 1
301304 24.0 22.0 , , 89 3.1 , , 0.0 0 , , 0.8
301305 24.0 22.0 , , 89 2.6 , , 0.0 0 , , 0.8
301306 24.0 22.0 , , 89 1.5 , , 0.0 0 , , 0.8
301307 24.0 22.0 , , 89 1.0 , , 105.0 40 , , 0.8
301308 24.0 22.0 , , 89 0.0 , , 250.0 100 , , 0.8
301309 24.0 23.0 , , 94 1.0 , , 320.0 120 , , 0.8
301310 27.0 24.0 , , 84 1.0 , , 400.0 160 , , 0.8
301311 29.0 25.0 , , 79 2.6 , , 520.0 200 , , 0.8
301312 29.0 25.0 , , 79 3.6 , , 650.0 250 , , 0.8
301313 30.0 25.0 , , 74 3.6 , , 720.0 285 , , 0.8
301314 30.0 25.0 , , 74 3.6 , , 800.0 320 , , 0.8
301315 30.0 25.0 , , 74 3.6 , , 820.0 350 , , 0.8
301316 31.0 25.0 , , 70 3.1 , , 600.0 250 , , 0.8
301317 31.0 25.0 , , 70 3.6 , , 420.0 180 , , 0.8
301318 30.0 24.0 , , 70 3.1 , , 210.0 80 , , 0.8
301319 29.0 23.0 , , 70 1.5 , , 110.0 40 , , 0.8
301320 28.0 25.0 , , 84 2.1 , , 0.0 0 , , 1
301321 27.0 24.0 , , 84 2.1 , , 0.0 0 , , 1
301322 26.0 24.0 , , 89 1.5 , , 0.0 0 , , 0.8
301323 26.0 24.0 , , 89 0.5 , , 0.0 0 , , 0.8
301324 24.0 23.0 , , 94 1.0 , , 0.0 0 , , 0.8
301401 24.0 23.0 , , 94 1.0 , , 0.0 0 , , 0.8

```
301402    24.0      23.0      , ,  94   1.5  , ,  0.0  0     ,
,    0.8
301403    24.0      23.0      , ,  94   0.0  , ,  0.0  0     ,
,    0.8
301404    24.0      23.0      , ,  94   0.5  , ,  0.0  0     ,
,    0.8
301405    25.0      23.0      , ,  89   0.0  , ,  0.0  0     ,
,    0.8
301406    25.0      23.0      , ,  89   1.0  , ,  0.0  0     ,
,    0.8
301407    25.0      23.0      , ,  89   0.0  , ,  105.0      40
     , ,  0.8
301408    24.0      23.0      , ,  94   2.1  , ,  250.0
     100  , ,  1
301409    25.0      23.0      , ,  89   2.6  , ,  320.0
     120  , ,  0.8
301410    27.0      23.0      , ,  79   2.1  , ,  400.0
     160  , ,  0.8
301411    28.0      23.0      , ,  74   2.6  , ,  520.0
     200  , ,  0.8
301412    30.0      24.0      , ,  70   1.5  , ,  650.0
     250  , ,  0.8
301413    31.0      24.0      , ,  66   1.0  , ,  720.0
     285  , ,  0.8
301414    30.0      25.0      , ,  74   5.7  , ,  800.0
     320  , ,  0.8
301415    31.0      25.0      , ,  70   4.1  , ,  820.0
     350  , ,  0.8
301416    31.0      25.0      , ,  70   5.7  , ,  600.0
     250  , ,  0.8
301417    30.0      24.0      , ,  70   4.6  , ,  420.0
     180  , ,  1
301418    27.0      23.0      , ,  79   4.6  , ,  210.0      80
     , ,  1
301419    26.0      22.0      , ,  78   0.5  , ,  110.0      40
     , ,  0.8
301420    26.0      23.0      , ,  83   3.1  , ,  0.0  0     ,
,    0.8
301421    25.0      23.0      , ,  89   4.1  , ,  0.0  0     ,
,    0.8
301422    25.0      23.0      , ,  89   4.1  , ,  0.0  0     ,
,    1
301423    25.0      23.0      , ,  89   3.1  , ,  0.0  0     ,
,    0.8
301424    24.0      23.0      , ,  94   3.1  , ,  0.0  0     ,
,    0.8
301501    24.0      23.0      , ,  94   2.1  , ,  0.0  0     ,
,    0.8
301502    24.0      23.0      , ,  94   2.1  , ,  0.0  0     ,
,    0.8
301503    24.0      22.0      , ,  89   1.0  , ,  0.0  0     ,
,    0.8
```

```
301504    24.0 22.0       , ,  89   1.0  , ,  0.0  0    ,      ,
     0.8
301505    24.0      22.0       , ,  89   2.1  , ,  0.0  0    ,
,    0.8
301506    23.0      22.0       , ,  94   1.0  , ,  0.0  0    ,
,    0.8
301507    24.0      22.0       , ,  89   1.0  , ,  105.0     40
    , ,  0.8
301508    24.0      22.0       , ,  89   1.5  , ,  250.0
     100  , ,  0.8
301509    25.0      22.0       , ,  83   0.5  , ,  320.0
     120  , ,  0.8
301510    27.0 22.0       , ,  74   4.6  , ,  400.0     160  ,
,    0.8
301511    28.0      23.0       , ,  74   4.1  , ,  520.0
     200  , ,  0.8
301512    30.0      22.0       , ,  62   6.7  , ,  650.0
     250  , ,  0.8
301513    30.0      23.0       , ,  66   5.7  , ,  720.0
     285  , ,  0.8
301514    31.0      23.0       , ,  62   5.7  , ,  800.0
     320  , ,  0.8
301515    31.0      23.0       , ,  62   5.1  , ,  820.0
     350  , ,  0.8
301516    31.0      23.0       , ,  62   4.6  , ,  600.0
     250  , ,  0.8
301517    30.0      23.0       , ,  66   4.1  , ,  420.0
     180  , ,  0.8
301518    30.0      23.0       , ,  66   4.1  , ,  210.0     80
    , ,  0.8
301519    28.0      22.0       , ,  70   5.7  , ,  110.0     40
    , ,  0.8
301520    26.0      23.0       , ,  83      4.6    , ,  0.0  0
    , ,  0.8
301521    26.0      23.0       , ,  83   4.1  , ,  0.0  0    ,
,    0.8
301522    26.0      23.0       , ,  83   3.1  , ,  0.0  0    ,
,    0.8
301523    25.0      23.0       , ,  89   3.1  , ,  0.0  0    ,
,    0.8
301524    25.0      23.0       , ,  89   2.1  , ,  0.0  0    ,
,    0.8
301601    25.0      23.0       , ,  89   3.6  , ,  0.0  0    ,
,    0.8
301602    25.0 23.0       , ,  89   4.1  , ,  0.0  0    ,      ,
     0.8
301603    25.0      23.0       , ,  89   2.6  , ,  0.0  0    ,
,    0.8
301604    25.0      23.0       , ,  89   3.1  , ,  0.0  0    ,
,    0.8
301605    25.0      23.0       , ,  89   2.1  , ,  0.0  0    ,
,    0.8
```

301606 25.0 23.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
301607 25.0 23.0 , , 89 2.6 , , 105.0 40 ,
, 0.8
301608 25.0 23.0 , , 89 2.1 , , 250.0
100 , , 0.8
301609 26.0 23.0 , , 83 2.6 , , 320.0
120 , , 0.8
301610 28.0 23.0 , , 74 3.6 , , 400.0
160 , , 0.8
301611 29.0 23.0 , , 70 4.1 , , 520.0
200 , , 0.8
301612 30.0 23.0 , , 66 3.1 , , 650.0
250 , , 0.8
301613 30.0 23.0 , , 66 1.5 , , 720.0
285 , , 0.8
301614 30.0 23.0 , , 66 3.1 , , 800.0
320 , , 0.8
301615 27.0 23.0 , , 79 3.6 , , 820.0
350 , , 0.8
301616 26.0 23.0 , , 83 2.1 , , 600.0
250 , , 1
301617 26.0 23.0 , , 83 1.5 , , 420.0
180 , , 0.8
301618 26.0 24.0 , , 89 1.5 , , 210.0 80 ,
, 1
301619 26.0 24.0 , , 89 1.5 , , 110.0 40
, , 1
301620 25.0 24.0 , , 94 0.5 , , 0.0 0 ,
, 1
301621 25.0 24.0 , , 94 2.1 , , 0.0 0 ,
, 0.8
301622 25.0 23.0 , , 89 2.1 , , 0.0 0 ,
, 0.8
301623 25.0 23.0 , , 89 2.1 , , 0.0 0 ,
, 0.8
301624 25.0 23.0 , , 89 2.1 , , 0.0 0 ,
, 0.8
301701 25.0 23.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
301702 25.0 23.0 , , 89 2.6 , , 0.0 0
, , 0.8
301703 24.0 23.0 , , 94 1.5 , , 0.0 0 , ,
0.8
301704 24.0 23.0 , , 94 2.1 , , 0.0 0 ,
, 0.8
301705 24.0 23.0 , , 94 1.5 , , 0.0 0 ,
, 0.8
301706 24.0 23.0 , , 94 2.1 , , 0.0 0 , ,
0.8
301707 24.0 23.0 , , 94 2.6 , , 105.0 40
, , 1

301708 24.0 23.0 , , 94 1.5 , , 250.0
100 , , 0.8
301709 24.0 23.0 , , 94 2.1 , , 320.0
120 , , 1
301710 25.0 23.0 , , 89 2.6 , , 400.0
160 , , 0.8
301711 27.0 23.0 , , 79 2.1 , , 520.0
200 , , 0.8
301712 26.0 24.0 , , 89 1.5 , , 650.0
250 , , 1
301713 28.0 24.0 , , 79 1.5 , , 720.0
285 , , 0.8
301714 30.0 23.0 , , 66 1.0 , , 800.0
320 , , 0.8
301715 31.0 25.0 , , 70 3.6 , , 820.0
350 , , 0.8
301716 31.0 24.0 , , 66 3.1 , , 600.0 250 ,
, 0.8
301717 31.0 23.0 , , 62 2.6 , , 420.0
180 , , 0.8
301718 31.0 24.0 , , 66 1.5 , , 210.0 80 ,
, 0.8
301719 30.0 23.0 , , 66 2.1 , , 110.0 40
, , 0.8
301720 29.0 24.0 , , 74 1.5 , , 0.0 0 ,
, 0.8
301721 28.0 24.0 , , 79 1.0 , , 0.0 0 ,
, 0.8
301722 27.0 24.0 , , 84 1.0 , , 0.0 0 , ,
0.8
301723 27.0 24.0 , , 84 0.5 , , 0.0 0 ,
, 0.8
301724 26.0 24.0 , , 89 0.5 , , 0.0 0
, , 0.8
301801 26.0 24.0 , , 89 1.5 , , 0.0 0 , ,
0.8
301802 26.0 24.0 , , 89 1.5 , , 0.0 0
, , 0.8
301803 26.0 23.0 , , 83 1.5 , , 0.0 0 , ,
0.8
301804 25.0 23.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
301805 25.0 23.0 , , 89 0.0 , , 0.0 0 , ,
0.8
301806 25.0 23.0 , , 89 0.5 , , 0.0 0 ,
, 0.8
301807 25.0 23.0 , , 89 0.0 , , 105.0 40
, , 0.8
301808 25.0 23.0 , , 89 1.0 , , 250.0
100 , , 0.8
301809 26.0 23.0 , , 83 3.1 , , 320.0 120 ,
, 0.8

301810 27.0 23.0 , , 79 1.0 , , 400.0 160 ,
, 0.8
301811 29.0 23.0 , , 70 1.0 , , 520.0
200 , , 0.8
301812 31.0 23.0 , , 62 2.1 , , 650.0
250 , , 0.8
301813 31.0 24.0 , , 66 4.1 , , 720.0
285 , , 0.8
301814 32.0 24.0 , , 62 3.6 , , 800.0
320 , , 0.8
301815 32.0 24.0 , , 62 5.1 , , 820.0
350 , , 0.8
301816 33.0 24.0 , , 59 4.1 , , 600.0
250 , , 0.8
301817 33.0 23.0 , , 55 4.1 , , 420.0
180 , , 0.8
301818 32.0 23.0 , , 59 3.6 , , 210.0 80
, , 0.8
301819 31.0 23.0 , , 62 3.1 , , 110.0 40
, , 0.8
301820 30.0 23.0 , , 66 2.1 , , 0.0 0 ,
, 0.8
301821 29.0 23.0 , , 70 1.0 , , 0.0 0 ,
, 0.8
301822 29.0 24.0 , , 74 0.0 , , 0.0 0 ,
, 0.8
301823 28.0 24.0 , , 79 0.0 , , 0.0 0 ,
, 0.8
301824 27.0 24.0 , , 84 0.5 , , 0.0 0 ,
, 0.8
301901 26.0 24.0 , , 89 0.5 , , 0.0 0 ,
, 0.8
301902 26.0 24.0 , , 89 0.5 , , 0.0 0 ,
, 0.8
301903 27.0 23.0 , , 79 2.1 , , 0.0 0 ,
, 0.8
301904 26.0 23.0 , , 83 0.0 , , 0.0 0 ,
, 1
301905 26.0 24.0 , , 89 0.5 , , 0.0 0 ,
, 1
301906 25.0 24.0 , , 94 0.5 , , 0.0 0 , ,
0.8
301907 25.0 24.0 , , 94 1.5 , , 105.0 40
, , 0.8
301908 25.0 24.0 , , 94 1.0 , , 250.0
100 , , 0.8
301909 27.0 24.0 , , 84 2.1 , , 320.0
120 , , 0.8
301910 29.0 25.0 , , 79 3.6 , , 400.0
160 , , 0.8
301911 30.0 24.0 , , 70 3.1 , , 520.0
200 , , 0.8

301912 32.0 24.0 , , 62 3.6 , , 650.0
250 , , 0.8
301913 31.0 25.0 , , 70 1.5 , , 720.0
285 , , 0.8
301914 32.0 25.0 , , 66 2.6 , , 800.0
320 , , 0.8
301915 30.0 25.0 , , 74 5.1 , , 820.0
350 , , 0.8
301916 30.0 25.0 , , 74 3.1 , , 600.0
250 , , 1
301917 30.0 24.0 , , 70 3.6 , , 420.0
180 , , 1
301918 30.0 24.0 , , 70 3.1 , , 210.0 80
, , 0.8
301919 30.0 24.0 , , 70 2.6 , , 110.0 40 ,
, 0.8
301920 29.0 24.0 , , 74 1.0 , , 0.0 0 ,
, 0.8
301921 29.0 25.0 , , 79 0.0 , , 0.0 0 ,
, 0.8
301922 28.0 25.0 , , 84 1.0 , , 0.0 0 ,
, 0.8
301923 27.0 25.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
301924 27.0 25.0 , , 89 0.5 , , 0.0 0 , ,
0.8
302001 26.0 25.0 , , 94 1.5 , , 0.0 0 ,
, 0.8
302002 26.0 24.0 , , 89 1.5 , , 0.0 0 , , 1
302003 26.0 25.0 , , 94 0.0 , , 0.0 0 ,
, 1
302004 24.0 22.0 , , 89 2.1 , , 0.0 0 ,
, 1
302005 25.0 23.0 , , 89 0.5 , , 0.0 0 ,
, 1
302006 24.0 23.0 , , 94 1.0 , , 0.0 0 ,
, 1
302007 24.0 23.0 , , 94 1.5 , , 105.0 40
, , 0.8
302008 25.0 23.0 , , 89 1.5 , , 250.0
100 , , 0.8
302009 26.0 24.0 , , 89 2.6 , , 320.0
120 , , 0.8
302010 28.0 25.0 , , 84 2.1 , , 400.0
160 , , 0.8
302011 30.0 25.0 , , 74 1.0 , , 520.0
200 , , 0.8
302012 32.0 25.0 , , 66 1.5 , , 650.0
250 , , 0.8
302013 31.0 26.0 , , 75 4.1 , , 720.0
285 , , 0.8

302014 29.0 25.0 , , 79 3.1 , , 800.0
320 , , 1
302015 29.0 24.0 , , 74 0.5 , , 820.0 350 ,
, 1
302016 28.0 25.0 , , 84 1.5 , , 600.0
250 , , 0.8
302017 28.0 25.0 , , 84 3.1 , , 420.0
180 , , 0.8
302018 28.0 25.0 , , 84 1.0 , , 210.0 80
, , 0.8
302019 28.0 25.0 , , 84 1.5 , , 110.0 40
, , 0.8
302020 27.0 25.0 , , 89 0.5 , , 0.0 0 ,
, 0.8
302021 27.0 25.0 , , 89 0.5 , , 0.0 0 ,
, 0.8
302022 27.0 25.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
302023 26.0 25.0 , , 94 0.0 , , 0.0 0 ,
, 0.8
302024 26.0 24.0 , , 89 4.1 , , 0.0 0 ,
, 0.8
302101 25.0 23.0 , , 89 1.5 , , 0.0 0 , ,
0.8
302102 25.0 23.0 , , 89 2.1 , , 0.0 0 ,
, 1
302103 25.0 23.0 , , 89 2.6 , , 0.0 0 ,
, 0.8
302104 24.0 23.0 , , 94 2.1 , , 0.0 0 ,
, 0.8
302105 24.0 23.0 , , 94 1.0 , , 0.0 0 ,
, 0.8
302106 25.0 23.0 , , 89 0.0 , , 0.0 0 ,
, 0.8
302107 24.0 23.0 , , 94 0.5 , , 105.0 40
, , 0.8
302108 25.0 23.0 , , 89 0.5 , , 250.0
100 , , 0.8
302109 26.0 22.0 , , 78 1.0 , , 320.0
120 , , 0.8
302110 27.0 23.0 , , 79 0.5 , , 400.0 160 ,
, 0.8
302111 29.0 23.0 , , 70 0.5 , , 520.0
200 , , 0.8
302112 31.0 24.0 , , 66 2.1 , , 650.0
250 , , 0.8
302113 32.0 23.0 , , 59 3.6 , , 720.0 285 ,
, 0.8
302114 32.0 23.0 , , 59 2.6 , , 800.0
320 , , 0.8
302115 32.0 24.0 , , 62 3.6 , , 820.0
350 , , 0.8

302116 32.0 22.0 , , 55 4.1 , , 600.0
250 , , 0.8
302117 32.0 21.0 , , 52 4.6 , , 420.0
180 , , 0.8
302118 31.0 22.0 , , 58 3.6 , , 210.0 80
, , 0.8
302119 30.0 22.0 , , 62 2.1 , , 110.0 40
, , 0.8
302120 29.0 23.0 , , 70 1.0 , , 0.0 0 ,
, 0.8
302121 29.0 23.0 , , 70 1.5 , , 0.0 0 , ,
0.8
302122 28.0 23.0 , , 74 1.5 , , 0.0 0 ,
, 0.8
302123 27.0 23.0 , , 79 1.0 , , 0.0 0 ,
, 0.8
302124 27.0 23.0 , , 79 1.5 , , 0.0 0 ,
, 0.8
302201 27.0 23.0 , , 79 1.5 , , 0.0 0 ,
, 0.8
302202 26.0 23.0 , , 83 2.6 , , 0.0 0 , ,
0.8
302203 26.0 23.0 , , 83 1.0 , , 0.0 0 ,
, 0.8
302204 23.0 22.0 , , 94 4.6 , , 0.0 0 ,
, 1
302205 23.0 23.0 , , 100 0.5 , , 0.0 0 , , 1
302206 24.0 23.0 , , 94 0.0 , , 0.0 0 ,
, 0.8
302207 24.0 23.0 , , 94 1.5 , , 105.0 40 ,
, 0.8
302208 24.0 23.0 , , 94 1.5 , , 250.0
100 , , 0.8
302209 25.0 23.0 , , 89 1.0 , , 320.0
120 , , 0.8
302210 26.0 23.0 , , 83 1.5 , , 400.0
160 , , 0.8
302211 28.0 24.0 , , 79 1.0 , , 520.0
200 , , 0.8
302212 29.0 25.0 , , 79 1.0 , , 650.0
250 , , 0.8
302213 30.0 24.0 , , 70 1.0 , , 720.0
285 , , 0.8
302214 30.0 24.0 , , 70 2.6 , , 800.0
320 , , 0.8
302215 31.0 24.0 , , 66 2.6 , , 820.0
350 , , 0.8
302216 30.0 24.0 , , 70 3.1 , , 600.0
250 , , 0.8
302217 30.0 23.0 , , 66 3.6 , , 420.0
180 , , 0.8

302218 29.0 23.0 , , 70 3.1 , , 210.0 80
, , 0.8
302219 29.0 23.0 , , 70 1.5 , , 110.0 40
, , 0.8
302220 28.0 24.0 , , 79 0.0 , , 0.0 0 ,
, 0.8
302221 28.0 24.0 , , 79 0.0 , , 0.0 0 ,
, 0.8
302222 27.0 24.0 , , 84 0.5 , , 0.0 0 ,
, 0.8
302223 27.0 24.0 , , 84 0.5 , , 0.0 0 , ,
0.8
302224 27.0 24.0 , , 84 2.1 , , 0.0 0 ,
, 0.8
302301 27.0 24.0 , , 84 1.0 , , 0.0 0 ,
, 0.8
302302 26.0 24.0 , , 89 0.0 , , 0.0 0 ,
, 0.8
302303 26.0 23.0 , , 83 0.5 , , 0.0 0 , ,
0.8
302304 26.0 23.0 , , 83 1.0 , , 0.0 0 ,
, 0.8
302305 25.0 23.0 , , 89 0.0 , , 0.0 0 ,
, 0.8
302306 25.0 23.0 , , 89 0.5 , , 0.0 0 ,
, 0.8
302307 25.0 23.0 , , 89 1.5 , , 105.0 40 ,
, 0.8
302308 26.0 23.0 , , 83 1.5 , , 250.0
100 , , 0.8
302309 28.0 24.0 , , 79 2.6 , , 320.0
120 , , 0.8
302310 31.0 24.0 , , 66 1.5 , , 400.0
160 , , 0.8
302311 32.0 24.0 , , 62 1.5 , , 520.0 200 ,
, 0.8
302312 32.0 24.0 , , 62 1.5 , , 650.0
250 , , 0.8
302313 33.0 25.0 , , 63 2.6 , , 720.0
285 , , 0.8
302314 33.0 25.0 , , 63 2.6 , , 800.0
320 , , 0.8
302315 32.0 25.0 , , 66 2.6 , , 820.0
350 , , 0.8
302316 31.0 25.0 , , 70 3.6 , , 600.0
250 , , 0.8
302317 31.0 25.0 , , 70 3.6 , , 420.0
180 , , 0.8
302318 31.0 25.0 , , 70 3.1 , , 210.0 80
, , 0.8
302319 30.0 25.0 , , 74 1.0 , , 110.0 40
, , 0.8

302320 29.0 25.0 , , 79 0.0 , , 0.0 0
, , 0.8
302321 29.0 25.0 , , 79 0.5 , , 0.0 0 ,
, 0.8
302322 28.0 25.0 , , 84 0.5 , , 0.0 0 ,
, 0.8
302323 28.0 25.0 , , 84 0.5 , , 0.0 0 ,
, 0.8
302324 28.0 24.0 , , 79 1.0 , , 0.0 0 ,
, 0.8
302401 27.0 24.0 , , 84 1.5 , , 0.0 0 ,
, 0.8
302402 26.0 24.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
302403 26.0 24.0 , , 89 2.1 , , 0.0 0 ,
, 0.8
302404 26.0 24.0 , , 89 3.1 , , 0.0 0 ,
, 0.8
302405 26.0 24.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
302406 26.0 24.0 , , 89 0.5 , , 0.0 0 ,
, 0.8
302407 26.0 24.0 , , 89 0.5 , , 105.0 40
, , 0.7
302408 27.0 24.0 , , 84 1.0 , , 250.0
100 , , 1
302409 27.0 24.0 , , 84 1.5 , , 320.0
120 , , 1
302410 23.0 22.0 , , 94 2.6 , , 400.0
160 , , 1
302411 24.0 23.0 , , 94 0.0 , , 520.0
200 , , 1
302412 25.0 23.0 , , 89 1.5 , , 650.0 250 ,
, 0.8
302413 24.0 23.0 , , 94 2.6 , , 720.0
285 , , 1
302414 25.0 23.0 , , 89 1.5 , , 800.0
320 , , 1
302415 27.0 24.0 , , 84 1.5 , , 820.0
350 , , 0.8
302416 28.0 24.0 , , 79 2.1 , , 600.0 250 ,
, 0.8
302417 28.0 24.0 , , 79 1.0 , , 420.0
180 , , 0.8
302418 27.0 24.0 , , 84 2.1 , , 210.0 80
, , 0.8
302419 27.0 24.0 , , 84 1.0 , , 110.0 40
, , 0.8
302420 26.0 24.0 , , 89 1.5 , , 0.0 0 , ,
0.8
302421 26.0 24.0 , , 89 0.0 , , 0.0 0 ,
, 0.8

302422 26.0 24.0 , , 89 1.0 , , 0.0 0 ,
, 0.8
302423 26.0 24.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
302424 25.0 23.0 , , 89 1.5 , , 0.0 0 , ,
0.8
302501 25.0 23.0 , , 89 1.5 , , 0.0 0 , ,
0.8
302502 25.0 23.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
302503 24.0 23.0 , , 94 1.0 , , 0.0 0 , ,
0.8
302504 24.0 23.0 , , 94 1.0 , , 0.0 0 ,
, 0.8
302505 24.0 23.0 , , 94 1.0 , , 0.0 0 , ,
0.8
302506 24.0 23.0 , , 94 0.5 , , 0.0 0 ,
, 0.8
302507 24.0 23.0 , , 94 1.0 , , 105.0 40 ,
, 0.8
302508 24.0 23.0 , , 94 1.5 , , 250.0
100 , , 0.8
302509 26.0 23.0 , , 83 1.0 , , 320.0
120 , , 0.8
302510 28.0 24.0 , , 79 1.5 , , 400.0
160 , , 0.3
302511 29.0 24.0 , , 74 1.0 , , 520.0
200 , , 0.8
302512 31.0 24.0 , , 66 2.1 , , 650.0
250 , , 0.8
302513 30.0 25.0 , , 74 5.1 , , 720.0
285 , , 0.8
302514 28.0 24.0 , , 79 4.1 , , 800.0
320 , , 1
302515 27.0 24.0 , , 84 3.6 , , 820.0
350 , , 1
302516 26.0 24.0 , , 89 2.1 , , 600.0
250 , , 0.8
302517 30.0 24.0 , , 70 3.1 , , 420.0 180 ,
, 0.8
302518 30.0 24.0 , , 70 2.6 , , 210.0 80
, , 0.8
302519 29.0 25.0 , , 79 1.5 , , 110.0 40
, , 0.8
302520 28.0 24.0 , , 79 2.1 , , 0.0 0 ,
, 0.8
302521 26.0 25.0 , , 94 2.6 , , 0.0 0 , ,
0.8
302522 27.0 24.0 , , 84 1.5 , , 0.0 0 ,
, 0.8
302523 26.0 23.0 , , 83 1.0 , , 0.0 0 ,
, 0.8

302524 25.0 22.0 , , 83 1.0 , , 0.0 0 ,
, 0.8
302601 25.0 23.0 , , 89 1.0 , , 0.0 0 ,
, 0.8
302602 25.0 23.0 , , 89 0.0 , , 0.0 0 ,
, 0.8
302603 25.0 23.0 , , 89 0.0 , , 0.0 0 , ,
0.8
302604 24.0 23.0 , , 94 0.0 , , 0.0 0 ,
, 0.8
302605 24.0 23.0 , , 94 0.0 , , 0.0 0 ,
, 0.8
302606 24.0 23.0 , , 94 0.0 , , 0.0 0 ,
, 0.8
302607 24.0 23.0 , , 94 1.0 , , 105.0 40
, , 0.8
302608 25.0 24.0 , , 94 0.5 , , 250.0 100 ,
, 0.8
302609 27.0 24.0 , , 84 0.0 , , 320.0
120 , , 0.8
302610 29.0 24.0 , , 74 0.5 , , 400.0
160 , , 0.8
302611 30.0 24.0 , , 70 2.1 , , 520.0
200 , , 0.8
302612 31.0 24.0 , , 66 0.5 , , 650.0
250 , , 0.8
302613 29.0 25.0 , , 79 3.6 , , 720.0 285 ,
, 0.8
302614 30.0 26.0 , , 79 4.1 , , 800.0
320 , , 0.8
302615 31.0 25.0 , , 70 1.0 , , 820.0
350 , , 1
302616 30.0 25.0 , , 74 3.6 , , 600.0 250 ,
, 0.8
302617 30.0 25.0 , , 74 3.1 , , 420.0
180 , , 0.8
302618 27.0 21.0 , , 70 3.6 , , 210.0 80
, , 0.8
302619 26.0 23.0 , , 83 2.6 , , 110.0 40
, , 0.8
302620 26.0 23.0 , , 83 2.1 , , 0.0 0 ,
, 0.8
302621 26.0 23.0 , , 83 1.5 , , 0.0 0 ,
, 0.8
302622 25.0 23.0 , , 89 2.1 , , 0.0 0 , ,
0.8
302623 26.0 24.0 , , 89 0.0 , , 0.0 0 ,
, 0.8
302624 26.0 24.0 , , 89 0.5 , , 0.0 0 ,
, 0.8
302701 25.0 23.0 , , 89 2.6 , , 0.0 0 , ,
0.8

302702 24.0 23.0 , , 94 1.5 , , 0.0 0 ,
, 0.8
302703 24.0 23.0 , , 94 1.5 , , 0.0 0
, , 0.8
302704 24.0 23.0 , , 94 0.5 , , 0.0 0 , ,
0.8
302705 24.0 23.0 , , 94 0.5 , , 0.0 0 ,
, 0.8
302706 24.0 23.0 , , 94 1.5 , , 0.0 0 ,
, 0.8
302707 25.0 23.0 , , 89 1.5 , , 105.0 40 ,
, 0.8
302708 25.0 23.0 , , 89 1.5 , , 250.0
100 , , 0.8
302709 27.0 24.0 , , 84 1.5 , , 320.0
120 , , 0.8
302710 28.0 25.0 , , 84 2.1 , , 400.0
160 , , 0.8
302711 29.0 25.0 , , 79 1.5 , , 520.0
200 , , 0.8
302712 29.0 25.0 , , 79 1.5 , , 650.0
250 , , 0.8
302713 30.0 24.0 , , 70 2.1 , , 720.0
285 , , 0.8
302714 31.0 24.0 , , 66 2.1 , , 800.0
320 , , 0.8
302715 31.0 24.0 , , 66 2.1 , , 820.0 350 ,
, 0.8
302716 29.0 25.0 , , 79 3.1 , , 600.0
250 , , 1
302717 28.0 25.0 , , 84 2.1 , , 420.0
180 , , 0.8
302718 29.0 25.0 , , 79 1.5 , , 210.0 80
, , 0.8
302719 28.0 24.0 , , 79 1.5 , , 110.0 40 ,
, 0.8
302720 28.0 24.0 , , 79 0.0 , , 0.0 0 , ,
0.8
302721 27.0 24.0 , , 84 0.5 , , 0.0 0 ,
, 0.8
302722 26.0 24.0 , , 89 1.0 , , 0.0 0 ,
, 0.8
302723 26.0 24.0 , , 89 0.0 , , 0.0 0 ,
, 0.8
302724 25.0 24.0 , , 94 1.0 , , 0.0 0 ,
, 0.8
302801 25.0 24.0 , , 94 0.0 , , 0.0 0 , ,
0.8
302802 25.0 24.0 , , 94 1.5 , , 0.0 0 ,
, 0.8
302803 25.0 23.0 , , 89 0.0 , , 0.0 0 ,
, 0.8

```
302804    25.0 23.0     , ,  89   0.0  , ,  0.0  0    ,      ,
     0.8
302805    25.0      23.0     , ,  89   1.5  , ,  0.0  0    ,
,    0.8
302806    24.0      23.0     , ,  94   1.0  , ,  0.0  0    ,
,    0.8
302807    24.0      23.0     , ,  94   1.0  , ,  105.0     40
     , ,  0.8
302808    25.0      23.0     , ,  89   1.5  , ,  250.0
     100  , ,  0.8
302809    27.0 23.0     , ,  79   3.1  , ,  320.0     120  ,
,    0.8
302810    27.0      23.0     , ,  79   2.6  , ,  400.0
     160  , ,  0.8
302811    29.0      24.0     , ,  74   2.1  , ,  520.0
     200  , ,  0.8
302812    31.0      23.0     , ,  62   1.5  , ,  650.0
     250  , ,  0.8
302813    31.0      24.0     , ,  66   0.5  , ,  720.0
     285  , ,  0.8
302814    30.0      24.0     , ,  70   2.1  , ,  800.0
     320  , ,  1
302815    32.0 22.0     , ,  55   2.6  , ,  820.0     350  ,
,    0.8
302816    32.0      23.0     , ,  59   3.1  , ,  600.0
     250  , ,  0.8
302817    31.0      23.0     , ,  62   3.6  , ,  420.0
     180  , ,  0.8
302818    31.0      22.0     , ,  58   2.6  , ,  210.0     80
     , ,  0.8
302819    30.0      22.0     , ,  62   2.1  , ,  110.0     40
     , ,  0.8
302820    28.0      23.0     , ,  74   2.6  , ,  0.0  0    ,
,    0.8
302821    27.0      22.0     , ,  74   3.6  , ,  0.0  0    ,
,    0.8
302822    26.0      23.0     , ,  83   2.6  , ,  0.0  0    ,
,    0.8
302823    25.0      23.0     , ,  89   2.6  , ,  0.0  0    ,
,    0.8
302824    25.0      23.0     , ,  89   1.5  , ,  0.0  0    ,
,    0.8
302901    25.0      23.0     , ,  89   2.1  , ,  0.0  0    ,
,    0.8
302902    25.0      23.0     , ,  89   1.0  , ,  0.0  0    ,
,    0.8
302903    25.0      23.0     , ,  89   1.5  , ,  0.0  0    ,
,    0.8
302904    25.0 23.0     , ,  89   1.0  , ,  0.0  0    ,      ,
     0.8
302905    24.0      23.0     , ,  94   1.5  , ,  0.0  0    ,
,    0.8
```

302906 24.0 23.0 , , 94 0.5 , , 0.0 0 ,
, 0.8
302907 24.0 23.0 , , 94 0.5 , , 105.0 40
, , 0.8
302908 24.0 23.0 , , 94 2.1 , , 250.0
100 , , 0.8
302909 26.0 23.0 , , 83 2.6 , , 320.0
120 , , 0.8
302910 27.0 24.0 , , 84 2.1 , , 400.0
160 , , 0.8
302911 28.0 25.0 , , 84 2.1 , , 520.0
200 , , 0.8
302912 30.0 25.0 , , 74 2.6 , , 650.0
250 , , 0.8
302913 31.0 24.0 , , 66 2.6 , , 720.0
285 , , 0.8
302914 32.0 24.0 , , 62 2.1 , , 800.0
320 , , 0.8
302915 32.0 25.0 , , 66 1.0 , , 820.0 350 ,
, 0.8
302916 32.0 25.0 , , 66 4.1 , , 600.0
250 , , 0.8
302917 31.0 26.0 , , 75 4.1 , , 420.0
180 , , 0.8
302918 31.0 25.0 , , 70 3.1 , , 210.0 80
, , 0.8
302919 30.0 24.0 , , 70 1.5 , , 110.0 40
, , 0.8
302920 27.0 22.0 , , 74 4.6 , , 0.0 0 ,
, 1
302921 25.0 22.0 , , 83 3.6 , , 0.0 0
, , 0.8
302922 26.0 24.0 , , 89 3.1 , , 0.0 0 , ,
0.8
302923 26.0 24.0 , , 89 2.6 , , 0.0 0 ,
, 0.8
302924 26.0 24.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
303001 25.0 24.0 , , 94 2.6 , , 0.0 0 ,
, 0.8
303002 25.0 23.0 , , 89 4.1 , , 0.0 0 ,
, 0.8
303003 25.0 23.0 , , 89 2.6 , , 0.0 0 , ,
0.8
303004 25.0 23.0 , , 89 1.5 , , 0.0 0 ,
, 0.8
303005 25.0 23.0 , , 89 2.1 , , 0.0 0 ,
, 0.8
303006 25.0 23.0 , , 89 2.1 , , 0.0 0 ,
, 0.8
303007 25.0 23.0 , , 89 2.1 , , 105.0 40 ,
, 0.8

303008 25.0 23.0 , , 89 0.0 , , 250.0
100 , , 0.8
303009 27.0 23.0 , , 79 2.6 , , 320.0
120 , , 0.8
303010 28.0 24.0 , , 79 3.1 , , 400.0 160 ,
, 0.8
303011 29.0 25.0 , , 79 4.1 , , 520.0
200 , , 0.8
303012 30.0 25.0 , , 74 4.1 , , 650.0
250 , , 0.8
303013 31.0 25.0 , , 70 4.6 , , 720.0
285 , , 0.8
303014 32.0 25.0 , , 66 4.1 , , 800.0
320 , , 0.8
303015 32.0 27.0 , , 75 4.6 , , 820.0
350 , , 0.8
303016 31.0 26.0 , , 75 3.1 , , 600.0
250 , , 0.8
303017 26.0 24.0 , , 89 2.1 , , 420.0
180 , , 1
303018 25.0 24.0 , , 94 0.0 , , 210.0 80
, , 1
303019 25.0 23.0 , , 89 0.5 , , 110.0 40
, , 1
303020 25.0 23.0 , , 89 1.0 , , 0.0 0 ,
, 1
303021 25.0 23.0 , , 89 1.5 , , 0.0 0 ,
, 1
303022 25.0 24.0 , , 94 1.5 , , 0.0 0 ,
, 0.3
303023 25.0 24.0 , , 94 0.0 , , 0.0 0 ,
, 0.8
303024 25.0 24.0 , , 94 1.5 , , 0.0 0 , ,
0.8
303101 25.0 24.0 , , 94 1.0 , , 0.0 0 ,
, 0.8
303102 24.0 23.0 , , 94 1.0 , , 0.0 0 ,
, 0.8
303103 24.0 24.0 , , 100 1.5 , , 0.0 0 ,
, 0.8
303104 24.0 24.0 , , 100 1.5 , , 0.0 0 ,
, 0.8
303105 24.0 23.0 , , 94 1.0 , , 0.0 0
, , 0.8
303106 24.0 23.0 , , 94 1.0 , , 0.0 0 ,
, 0.8
303107 24.0 23.0 , , 94 0.5 , , 105.0 40
, , 0.8
303108 24.0 24.0 , , 100 0.5 , , 250.0
100 , , 0.8
303109 25.0 24.0 , , 94 0.0 , , 320.0
120 , , 0.8

303110 27.0 25.0 , , 89 1.0 , , 400.0
160 , , 0.8
303111 28.0 25.0 , , 84 1.5 , , 520.0
200 , , 0.8
303112 30.0 24.0 , , 70 2.6 , , 650.0
250 , , 0.8
303113 30.0 24.0 , , 70 2.1 , , 720.0
285 , , 0.8
303114 31.0 23.0 , , 62 1.5 , , 800.0
320 , , 0.8
303115 32.0 23.0 , , 59 3.1 , , 820.0
350 , , 0.8
303116 32.0 25.0 , , 66 1.5 , , 600.0
250 , , 0.8
303117 32.0 25.0 , , 66 1.5 , , 420.0
180 , , 0.8
303118 30.0 24.0 , , 70 3.1 , , 210.0 80
, , 0.8
303119 29.0 24.0 , , 74 2.1 , , 110.0 40 ,
, 0.8
303120 29.0 24.0 , , 74 2.1 , , 0.0 0 ,
, 0.8
303121 28.0 24.0 , , 79 0.0 , , 0.0 0 ,
, 0.8
303012 27.0 24.0 , , 84 2.1 , , 0.0 0 ,
, 0.8
303123 26.0 23.0 , , 83 1.5 , , 0.0 0 ,
, 0.8

```
* Top top Level file for Domed Mosque, Seremban, Standard with
ACR 1.7 (.5m/s)
!RUNID DOME Mosque Seremban, standard run for concrete  dome
roofing only

* configure model...
!ENABLE METEOROLOGICAL
!ENABLE FABRIC
!ENABLE RADTRAN STAR
!ENABLE SOLAR
!ENABLE WATER
!ENABLE VENTILATION


*                        calc ground temp
!ENABLE GROUND TEMP CALCS
!SET GROUND FACTOR = 0.001

* set up run parameters
!SET TIMESTEP = 120.0
!SET RUNLENGTH = 010,00
*                          allow 1st 3 days for runup
!SET BST = 01/13 31/13
!SET DATE = 01/03/2009


* chose output files and data
!OUTPUT INFO = 'DOMEONLY.INF'
!OUTPUT BLOCK FILE = 'DOMEONLY.BLK'
!ENABLE BLOCK REPORT
!ENABLE BLOCK OUTPUT
!ENABLE REPORT ALL

* connect to further files
!DEFINE BUILDING FILE = 'DOMEONLY.BLD'
!DEFINE METEOR FILE = 'MARCH09.MET'
!DEFINE VENTILATION = 'DOME.VNT'
```

LAYOUT FILE

```
!ELEMENT = '1 portion 1-1'
 !CONSTRUCTION = 8
 !AREA = 7.973
 !ORIENTATION = 0.0
 !TILT = 9.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '2 portion 2-1'
 !CONSTRUCTION = 8
 !AREA = 8.017
 !ORIENTATION = 0.0
 !TILT = 15.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '3 portion 3-1'
 !CONSTRUCTION = 8
 !AREA = 8.318
 !ORIENTATION = 0.0
 !TILT = 24.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '4 portion 4-1'
 !CONSTRUCTION = 8
 !AREA = 8.922
 !ORIENTATION = 0.0
 !TILT = 34.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '5 portion 5-1'
 !CONSTRUCTION = 8
 !AREA = 10.071
 !ORIENTATION = 0.0
 !TILT = 45.0
 !GROUND REFL = 0.2
```

```
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '6 portion 6-1'
 !CONSTRUCTION = 8
 !AREA = 11.766
 !ORIENTATION = 0.0
 !TILT = 55.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '7 portion 7-1'
 !CONSTRUCTION = 8
 !AREA = 14.203
 !ORIENTATION = 0.0
 !TILT = 64.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '8 portion 8-1'
 !CONSTRUCTION = 8
 !AREA = 11.605
 !ORIENTATION = 0.0
 !TILT = 75.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '9 portion 9-1'
 !CONSTRUCTION = 8
 !AREA = 10.683
 !ORIENTATION = 0.0
 !TILT = 80.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '10 portion 10-1'
 !CONSTRUCTION = 8
 !AREA = 13.709
```

```
 !ORIENTATION = 0.0
 !TILT = 85.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '11 portion 1-2'
 !CONSTRUCTION = 8
 !AREA = 7.973
 !ORIENTATION = 45.0
 !TILT = 9.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '12 portion 2-2'
 !CONSTRUCTION = 8
 !AREA = 8.017
 !ORIENTATION = 45.0
 !TILT = 15.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '13 portion 3-2'
 !CONSTRUCTION = 8
 !AREA = 8.318
 !ORIENTATION = 45.0
 !TILT = 24.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '14 portion 4-2'
 !CONSTRUCTION = 8
 !AREA = 8.922
 !ORIENTATION = 45.0
 !TILT = 34.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END
```

```
!ELEMENT = '15 portion 5-2'
 !CONSTRUCTION = 8
 !AREA = 10.071
 !ORIENTATION = 45.0
 !TILT = 45.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '16 portion 6-2'
 !CONSTRUCTION = 8
 !AREA = 11.766
 !ORIENTATION = 45.0
 !TILT = 55.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '17 portion 7-2'
 !CONSTRUCTION = 8
 !AREA = 14.203
 !ORIENTATION = 45.0
 !TILT = 64.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '18 portion 8-2'
 !CONSTRUCTION = 8
 !AREA = 11.605
 !ORIENTATION = 45.0
 !TILT = 75.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '19 portion 9-2'
 !CONSTRUCTION = 8
 !AREA = 10.683
 !ORIENTATION = 45.0
 !TILT = 80.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
```

```
 !CLASS = 1
!END

!ELEMENT = '20 portion 10-2'
 !CONSTRUCTION = 8
 !AREA = 13.709
 !ORIENTATION = 45.0
 !TILT = 85.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '21 portion 1-3'
 !CONSTRUCTION = 8
 !AREA = 7.973
 !ORIENTATION = 90.0
 !TILT = 9.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '22 portion 2-3'
 !CONSTRUCTION = 8
 !AREA = 8.017
 !ORIENTATION = 90.0
 !TILT = 15.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '23 portion 3-3'
 !CONSTRUCTION = 8
 !AREA = 8.318
 !ORIENTATION = 90.0
 !TILT = 24.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '24 portion 4-3'
 !CONSTRUCTION = 8
 !AREA = 8.922
 !ORIENTATION = 90.0
 !TILT = 34.0
```

```
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '25 portion 5-3'
 !CONSTRUCTION = 8
 !AREA = 10.071
 !ORIENTATION = 90.0
 !TILT = 45.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '26 portion 6-3'
 !CONSTRUCTION = 8
 !AREA = 11.766
 !ORIENTATION = 90.0
 !TILT = 55.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '27 portion 7-3'
 !CONSTRUCTION = 8
 !AREA = 14.203
 !ORIENTATION = 90.0
 !TILT = 64.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '28 portion 8-3'
 !CONSTRUCTION = 8
 !AREA = 11.605
 !ORIENTATION = 90.0
 !TILT = 75.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '29 portion 9-3'
 !CONSTRUCTION = 8
```

```
 !AREA = 10.683
 !ORIENTATION = 90.0
 !TILT = 80.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '30 portion 10-3'
 !CONSTRUCTION = 8
 !AREA = 13.709
 !ORIENTATION = 90.0
 !TILT = 85.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '31 portion 1-4'
 !CONSTRUCTION = 8
 !AREA = 7.973
 !ORIENTATION = 135.0
 !TILT = 9.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '32 portion 2-4'
 !CONSTRUCTION = 8
 !AREA = 8.017
 !ORIENTATION = 135.0
 !TILT = 15.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '33 portion 3-4'
 !CONSTRUCTION = 8
 !AREA = 8.318
 !ORIENTATION = 135.0
 !TILT = 24.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END
```

```
!ELEMENT = '34 portion 4-3'
 !CONSTRUCTION = 8
 !AREA = 8.922
 !ORIENTATION = 135.0
 !TILT = 34.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '35 portion 5-4'
 !CONSTRUCTION = 8
 !AREA = 10.071
 !ORIENTATION = 135.0
 !TILT = 45.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '36 portion 6-4'
 !CONSTRUCTION = 8
 !AREA = 11.766
 !ORIENTATION = 135.0
 !TILT = 55.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '37 portion 7-4'
 !CONSTRUCTION = 8
 !AREA = 14.203
 !ORIENTATION = 135.0
 !TILT = 64.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '38 portion 8-4'
 !CONSTRUCTION = 8
 !AREA = 11.605
 !ORIENTATION = 135.0
 !TILT = 75.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
```

```
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '39 portion 9-4'
 !CONSTRUCTION = 8
 !AREA = 10.683
 !ORIENTATION = 135.0
 !TILT = 80.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '40 portion 10-4'
 !CONSTRUCTION = 8
 !AREA = 13.709
 !ORIENTATION = 135.0
 !TILT = 85.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '41 portion 1-5'
 !CONSTRUCTION = 8
 !AREA = 7.973
 !ORIENTATION = 180.0
 !TILT = 9.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '42 portion 2-5'
 !CONSTRUCTION = 8
 !AREA = 8.017
 !ORIENTATION = 180.0
 !TILT = 15.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '43 portion 3-5'
 !CONSTRUCTION = 8
 !AREA = 8.318
 !ORIENTATION = 180.0
```

```
 !TILT = 24.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '44 portion 4-5'
 !CONSTRUCTION = 8
 !AREA = 8.922
 !ORIENTATION = 180.0
 !TILT = 34.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '45 portion 5-5'
 !CONSTRUCTION = 8
 !AREA = 10.071
 !ORIENTATION = 180.0
 !TILT = 45.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '46 portion 6-5'
 !CONSTRUCTION = 8
 !AREA = 11.766
 !ORIENTATION = 180.0
 !TILT = 55.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '47 portion 7-5'
 !CONSTRUCTION = 8
 !AREA = 14.203
 !ORIENTATION = 180.0
 !TILT = 64.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '48 portion 8-5'
```

```
 !CONSTRUCTION = 8
 !AREA = 11.605
 !ORIENTATION = 180.0
 !TILT = 75.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '49 portion 9-5'
 !CONSTRUCTION = 8
 !AREA = 10.683
 !ORIENTATION = 180.0
 !TILT = 80.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '50 portion 10-5'
 !CONSTRUCTION = 8
 !AREA = 13.709
 !ORIENTATION = 180.0
 !TILT = 85.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '51 portion 1-6'
 !CONSTRUCTION = 8
 !AREA = 7.973
 !ORIENTATION = 225.0
 !TILT = 9.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '52 portion 2-6'
 !CONSTRUCTION = 8
 !AREA = 8.017
 !ORIENTATION = 225.0
 !TILT = 15.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
```

```
!END

!ELEMENT = '53 portion 3-6'
 !CONSTRUCTION = 8
 !AREA = 8.318
 !ORIENTATION = 225.0
 !TILT = 24.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '54 portion 4-6'
 !CONSTRUCTION = 8
 !AREA = 8.922
 !ORIENTATION = 225.0
 !TILT = 34.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '55 portion 5-6'
 !CONSTRUCTION = 8
 !AREA = 10.071
 !ORIENTATION = 225.0
 !TILT = 45.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '56 portion 6-6'
 !CONSTRUCTION = 8
 !AREA = 11.766
 !ORIENTATION = 225.0
 !TILT = 55.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '57 portion 7-6'
 !CONSTRUCTION = 8
 !AREA = 14.203
 !ORIENTATION = 225.0
 !TILT = 64.0
 !GROUND REFL = 0.2
```

```
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '58 portion 8-6'
 !CONSTRUCTION = 8
 !AREA = 11.605
 !ORIENTATION = 225.0
 !TILT = 75.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '59 portion 9-6'
 !CONSTRUCTION = 8
 !AREA = 10.683
 !ORIENTATION = 225.0
 !TILT = 80.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '60 portion 10-6'
 !CONSTRUCTION = 8
 !AREA = 13.709
 !ORIENTATION = 225.0
 !TILT = 85.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '61 portion 1-7'
 !CONSTRUCTION = 8
 !AREA = 7.973
 !ORIENTATION = 270.0
 !TILT = 9.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '62 portion 2-7'
 !CONSTRUCTION = 8
 !AREA = 8.017
```

```
 !ORIENTATION = 270.0
 !TILT = 15.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '63 portion 3-7'
 !CONSTRUCTION = 8
 !AREA = 8.318
 !ORIENTATION = 270.0
 !TILT = 24.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '64 portion 4-7'
 !CONSTRUCTION = 8
 !AREA = 8.922
 !ORIENTATION = 270.0
 !TILT = 34.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '65 portion 5-7'
 !CONSTRUCTION = 8
 !AREA = 10.071
 !ORIENTATION = 270.0
 !TILT = 45.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '66 portion 6-7'
 !CONSTRUCTION = 8
 !AREA = 11.766
 !ORIENTATION = 270.0
 !TILT = 55.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END
```

```
!ELEMENT = '67 portion 7-7'
 !CONSTRUCTION = 8
 !AREA = 14.203
 !ORIENTATION = 270.0
 !TILT = 64.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '68 portion 8-7'
 !CONSTRUCTION = 8
 !AREA = 11.605
 !ORIENTATION = 270.0
 !TILT = 75.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '69 portion 9-7'
 !CONSTRUCTION = 8
 !AREA = 10.683
 !ORIENTATION = 270.0
 !TILT = 80.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '70 portion 10-7'
 !CONSTRUCTION = 8
 !AREA = 13.709
 !ORIENTATION = 270.0
 !TILT = 85.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '71 portion 1-8'
 !CONSTRUCTION = 8
 !AREA = 7.973
 !ORIENTATION = 315.0
 !TILT = 9.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
```

```
 !CLASS = 1
!END

!ELEMENT = '72 portion 2-8'
 !CONSTRUCTION = 8
 !AREA = 8.017
 !ORIENTATION = 315.0
 !TILT = 15.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '73 portion 3-8'
 !CONSTRUCTION = 8
 !AREA = 8.318
 !ORIENTATION = 335.0
 !TILT = 24.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '74 portion 4-8'
 !CONSTRUCTION = 8
 !AREA = 8.922
 !ORIENTATION = 315.0
 !TILT = 34.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '75 portion 5-8'
 !CONSTRUCTION = 8
 !AREA = 10.071
 !ORIENTATION = 315.0
 !TILT = 45.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '76 portion 6-8'
 !CONSTRUCTION = 8
 !AREA = 11.766
 !ORIENTATION = 315.0
 !TILT = 55.0
```

```
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '77 portion 7-8'
 !CONSTRUCTION = 8
 !AREA = 14.203
 !ORIENTATION = 315.0
 !TILT = 64.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '78 portion 8-8'
 !CONSTRUCTION = 8
 !AREA = 11.605
 !ORIENTATION = 315.0
 !TILT = 75.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '79 portion 9-8'
 !CONSTRUCTION = 8
 !AREA = 10.683
 !ORIENTATION = 315.0
 !TILT = 80.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '80 portion 10-8'
 !CONSTRUCTION = 8
 !AREA = 13.709
 !ORIENTATION = 315.0
 !TILT = 85.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '113 south wall'
 !CONSTRUCTION = 1
```

```
 !AREA = 8.0
 !ORIENTATION = 67.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '114 east wall'
 !CONSTRUCTION = 1
 !AREA = 8.0
 !ORIENTATION = 157.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '115 north wall'
 !CONSTRUCTION = 1
 !AREA = 8.0
 !ORIENTATION = 247.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '116 west wall'
 !CONSTRUCTION = 1
 !AREA = 8.0
 !ORIENTATION = 337.0
 !TILT = 80.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !CLASS = 1
!END

!ELEMENT = '117 south windows'
 !CONSTRUCTION = 2
 !AREA = 10.0
 !ORIENTATION = 67.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !PATCH TO #29 FIRST = 1
 !SHADING           =           'NONE'
```

```
 !WINDOW TYPE        =          '6MMFLOAT'
 !CLASS = 2
!END

!ELEMENT = '118 east windows'
 !CONSTRUCTION = 2
 !AREA = 10.0
 !ORIENTATION = 157.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !PATCH TO #29 FIRST = 1
 !SHADING            =           'NONE'
 !WINDOW TYPE        =          '6MMFLOAT'
 !CLASS = 2
!END

!ELEMENT = '119 north windows'
 !CONSTRUCTION = 2
 !AREA = 10.0
 !ORIENTATION = 247.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !PATCH TO #29 FIRST = 1
 !SHADING            =           'NONE'
 !WINDOW TYPE        =          '6MMFLOAT'
 !CLASS = 2
!END

!ELEMENT = '120 west windows'
 !CONSTRUCTION = 2
 !AREA = 10.0
 !ORIENTATION = 337.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !PATCH TO #29 FIRST = 1
 !SHADING            =           'NONE'
 !WINDOW TYPE        =          '6MMFLOAT'
 !CLASS = 2
!END
```

APPENDIX D -PUBLICATION

PROCEEDINGS OF THE 3RD CIB INTERNATIONAL CONFERENCE ON SMART AND SUSTAINABLE BUILT ENVIRONMENT SASBE 2009.

TITLE: THERMAL COMFORT FACTORS IN HOT AND HUMID REGION: MALAYSIA

Shafizal MAAROF [1]
Phillip JONES Prof. [2]

Keywords: *thermal comfort, air temperature, relative humidity, air movement, hot-humid, international standards, free-running building.*

Abstract

The importance of the parameters influencing the thermal comfort varies with the climate of the countries. In many cases, the air temperature has been considered the major influencing factor to the thermal comfort and many of the indexes produced are mainly focusing to the determination of the comfort temperature. Recent studies have found that the International standard for indoor climate based on Fanger's predicted mean vote equation is inappropriate to be based on in calculating the thermal comfort level for the hot and humid regions.

This paper presents the results of the investigation to determine the crucial factor in influencing the outcome of the comfort level for this area. The two important parameters studied are the air temperature and relative humidity which have become the biggest constraints in providing passively comfortable indoor environment for this region. The study reveals that the relative humidity, in contrast with the results of many thermal comfort studies conducted in different climate regions, is more influential in the comfort level assessment compared to the air temperature. The range of percentage at which relative humidity starts influencing the comfort level is also determined and other significant factors such as the air movement, air velocity and clothing are also studied as the contributing factors to the thermal comfort. A new method of interpreting the thermal comfort level for the region is also suggested based on the findings of the study.

1.0 Introduction

The thermal comfort has been considered by many as the major influencing factors in the indoor comfort level. The International Standards such as ASHRAE ISO 7730 Standard 55(deDear et al) is often used to determine the thermal comfort condition in a building by the architects and professionals. Unfortunately, current researches have obtained evidences that the standards are irrelevant in predicting the comfort level in the tropical countries especially in the countries with hot and humid climate (Mallick, Feriadi, Karyono). Due to this discrepancy, many upcoming researches about thermal comfort in this region have been conducted aiming to establish a more relevant index or range of comfortable temperature for the tropics.

There are five parameters that are important in influencing the indoor thermal comfort of a building. The physical parameters which are the air temperature, air movement, and relative humidity and the external parameters which are the clothing and activity are known as the major factors in the issue. Little is known on how these parameters act in the hot and humid area since many related studies are conducted in the temperate climate regions where the constraints are different. An investigation of the physical parameters was conducted in two small size mosques in Malaysia to find out the importance of these parameters in influencing the thermal comfort level in the hot and humid country such as Malaysia.

2.0 Standards in the Thermal Comfort Assessment for Tropics

Many of the International Standards produced are found to be inadequate for describing the comfort condition in the tropical climate. The majority of the field studies conducted discovered that the international set up is either overestimating or underestimating the comfort condition in this climate (Nicol). This is partly due to the derivation of the standards that are mainly based on the studies conducted in the moderate environmental condition.

One of the international standards frequently used for indoor climate condition is ISO7730 based on Fanger's predicted mean vote (PMV/PPD) equation. The equation of the formula is applied to derive a numerical value depicting the comfort conditions based on the ASHRAE scale. One of the reasons stated by Nicol to the inaccuracy of the standard's prediction is because the small range of the limitation set in the formula. In many case studies conducted in the tropical countries, the measurements recorded, especially in air temperature and velocity are frequently beyond the limitations. The air temperature of 30^0 Celsius is considered normal for this climate and the air movement of more than 1 m/s is desirable to relieve the heat. These two figures are set up as the upper limits in the formula. Another reason that may have an effect to the result is the conducting method of the experiment. Most of the measurement is based on the close-lab environment. In reality, such environment is rarely available and in many field studies, a factor of adaptability is part of the factor which is not in the environment that is fully controlled. In addition to this, the outside climate plays a very influential role in thermal comfort perception for a free-running building. The study by Humphreys and Nicol discovered that the comfort temperatures are linearly related to the mean outdoor temperature. The relationship derived is:

$$T_c = 0.534T_o + 12.9$$

where T_c is comfort temperature and T_o is mean outdoor temperature

Another standard that is frequently referred in evaluating comfort condition is ASHRAE Std 55. A revised version of ASHRAE Std 55, known as Adaptive Comfort Standard (ACS), has been produced to be applied for naturally ventilated buildings since the original version is found to be irrelevant for naturally ventilated buildings. In the revised version, allowance for the warmer indoor temperature is given and to be applied during summer time for the naturally ventilated (NV) buildings. A wider range of indoor temperature was given based on the findings from the occupants in the NV buildings. The wider range is mostly influenced by the outdoor climate patterns (Nicol) which led to the derivation of the optimum comfort temperature, T_{comf}, that is based on the mean outdoor dry bulb temperature, $T_{a,out}$:

$$T_{comf} = 0.31T_{a,out} + 17.8$$

The range of the temperature with the 90% acceptability is 5^0 and 7^0 Celsius for 80% acceptability, both centered on the optimum temperature, T_{comf}, aiming to discover the temperature or combination of thermal variables (temperature, humidity and air velocity) which subjects consider 'neutral' or 'comfortable'. Nicol and Humphreys had also suggested that in evaluating thermal comfort using adaptive principle, there are three main contextual variables that need to be considered which are the climate, building and time.

3.0 Existing research on thermal comfort in the hot and humid areas

The hot and humid areas are generally located close to the equator. Among the countries that are included in the criteria are located in the Southeast region which includes Malaysia, Singapore, Indonesia and Thailand. The earliest investigation was conducted by Webb in 1949 which led to the derivation of the Equatorial Climate Index (ECI). Based on the index, the ideal air velocity is 0.2 m/s with the relative humidity of 70% and the ideal temperature of 28.86^0 Celsius. However, the prediction is only based on the dry and wet bulb temperature and wind speed but excluded activity level and clothing value in the derivation. These two factors are important parameters since they are closely related to social and cultural influence. Mallick in his investigation had also discovered that people are highly adaptive to the surrounding environment by changing the behavioural patterns and lifestyle preferences. The process of acclimatization also had a strong influence in the comfort preferences study. In his 1996 study involving a group of architectural students living in urban housing in Dhaka, Bangladesh, Mallick discovered that the participants were able to tolerate high relative humidity and temperature for comfort mainly due to the adaptation to the specific climate. The study also found that the estimated comfort temperature was between the range of 24^0Celsius and 33^0 Celsius under still-air condition and with the movement of air at 0.3 m/s, the range increased by 2.4 ^{0}C for the lower count and 2.2^0C for the upper limit. The air movement was a contributing factor in providing thermal comfort environment, however, according to this study, despite a wide range of recorded relative humidity which ranged from 50% to 95%, the humidity had little influence to the thermal comfort level due to the long term conditioning (Mallick).

Singapore is one of the countries in this region that is actively conducting research on the thermal comfort on the naturally ventilated building. In 2003, Wong and Khoo conducted a thermal comfort study in naturally ventilated classrooms in Singapore. The study discovered that the neutral temperature derived from the TSV is 28.8^{0}Celsius. Earlier studies conducted by Busch in Thailand and deDear et al in Singapore have also found that 28.5^0 Celsius is the neutral temperature for a naturally ventilated building. The readings obtained are quite close for the neutral temperature in the similar climate region. On the other hand, the PMV based on Fanger's equation and the ASHRAE standard 55-92 were found to be inapplicable in the study of thermal comfort for the area of hot-humid climate. ASHRAE Standard 55 predicted comfort temperature is far lower than the actual comfort temperature based on the field study. The Fanger's PMV model similarly shows discrepancy by being higher at lower temperature(Wong et al). The study by Wong et al in 2002 in naturally ventilated public housing in Singapore also revealed that thermal perception of +2 and +3 is still considered comfortable. Similar to the finding by Mallick's, the study also found that there is a strong correlation between the thermal comfort perception and wind sensation.

Indonesia is another country in the Southeast Asia region that is currently active conducting research pertaining to the comfort level in the hot and humid climate. In 2004, for examples, Feriadi and Wong conducted an investigation regarding the thermal comfort perception, evaluation of the thermal comfort prediction and the behavioural action that influence thermal comfort perception in naturally ventilated houses in Indonesia. The study concluded that the prediction using the ASHRAE and Bedford Scale is irrelevant in predicting the thermal comfort condition for tropical climate. The finding also suggested that adaptive behaviour may influence the neutral temperature to be higher than it was supposed to, however, cooler temperature is still preferable, if possible. Earlier, Karyono conducted a field study on the thermal comfort, which samples are divided into various categories and groups, for a multi storey office building in Jakarta, Indonesia. The groups are categorized by gender, age, ethnic background and physical characteristics. The study concluded that it is statistically insignificant between the neutral temperature between male and female, subjects under 40 and over 40 years old and between different ethnic backgrounds as well as between thin and normal subjects. The study also revealed that the neutral temperature is increased in the late afternoon compared to the early morning by 3^0 Celsius.

4.0 Commons characteristics of the hot-humid climate

In many cases, the outdoor condition of a building especially the climate influences the indoor climate of the building. For the outdoor condition, normally, when the air temperature rises, the relative humidity will decreases. This condition is evidenced in the experiment and the result is shown in Figure 1.

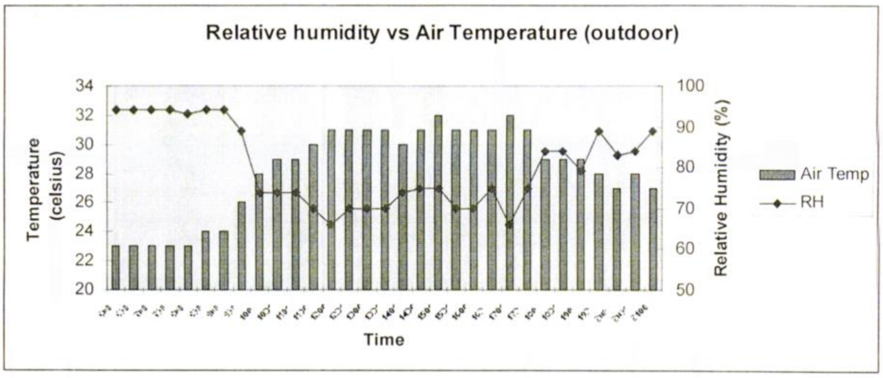


Figure 1:Outdoor relative humidity vs. air temperature

The air temperature and relative humidity are the important factors in determining the comfort level in the hot and humid country. The typical climate of the hot and humid country is the high air temperature at an average of 28 Celsius with an average of 80% of relative humidity. These factors have become the biggest challenge for the architects in designing a passive cooling building. The hot air and high relative humidity have become very problematic in designing naturally ventilated buildings among other contributing factors such as privacy, etc. Due to these extreme conditions, many of the buildings in this country are air conditioned in order to meet the required comfort level due to the little available knowledge on the effect of these variables to the thermal comfort condition. A field study has been conducted to investigate how each of these parameters influences the comfort condition.

5.0 Methodology

In conducting the investigation, two mosques with the same size but vary in terms of roof and fenestration designs are selected. The building type is chosen to minimize the variation in clothing value since the users of the mosques are strictly specified in terms of the dressing code appropriate to be worn in the place. The activities conducted in the mosques are basically categorized as light activities. Twenty participants, which consist of sixteen males and four females, are stationed at various locations inside the prayer hall of the mosques between the hour of 1300 until 1530. This is the period that the heat gain is at the highest level during the day. The air temperature, relative humidity and wind speed are then recorded using the data logger at the interval time of ten minutes. A set of questionnaires is given to each of the participants to record the thermal sensation they experienced during this period of time.

The measurements are recorded using the hot-wire anemometer, hygrometer and thermometer which are connected to the data logger, Babuc M. The equipment is placed at the height of 600mm from the floor level which is equivalent to the sitting position. The questionnaires are designed to acquire the level of thermal comfort of the users using the 7 point ASHRAE scale with the inclusion of the humidity level they experienced. The data collected is then analyzed and compared using the PMV equation and the actual readings.

6.0 Results and Discussion

6.1 Air Temperature and the Comfort Level

Many previous studies concentrated in finding the range of air temperature that the occupants will feel comfortable. The air temperature has been considered as the main factor among others that influences the thermal comfort level. A change in the air temperature will normally change the level of comfort a person experiencing and this is true in many conducted researches. Recent studies conducted in hot and humid countries discovered that the range of the comfortable temperature established based on the research conducted in moderate climate countries is not applicable or relevant to the hot and humid climate countries. The range for the hot and humid countries is wider and higher than the predicted range. A field study also shows that a change in the air temperature does not affect the comfort condition based on the votes given by the respondents in two mosques in Putrajaya, Malaysia. The results are shown in Figure 2 and Figure 3.

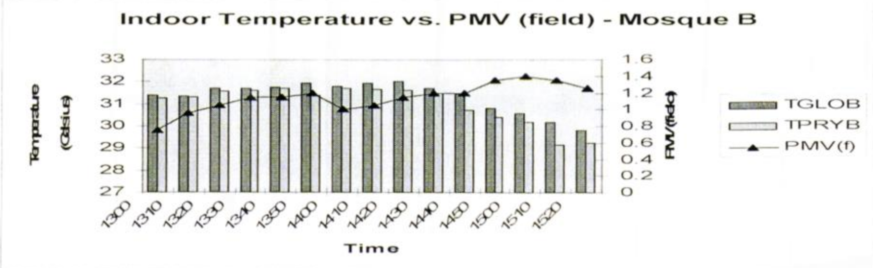


Figure 2: Indoor temperatures. PMV(field)

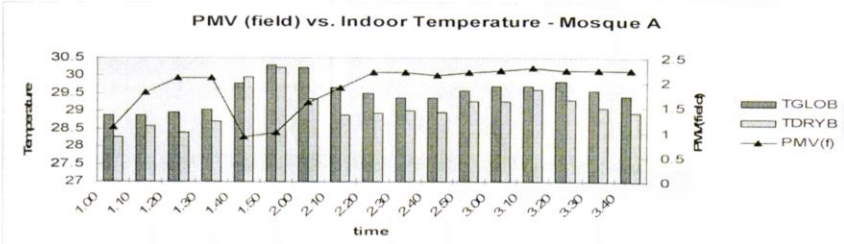


Figure 3: Indoor temperature vs. PMV(field)

In Figure 2 and Figure 3, the changes in PMV recorded based on the respondents' votes do not directly influenced by the change in air temperature or mean radiant temperature. Theoretically, when the temperature increases more than the comfort temperature (21-23 Celsius), the PMV is expected to increase to reflect that the respondent will feel warm or hot. However, in both Figure 2 and 3, the increase in air temperature does not necessarily increase the PMV value and vice versa. In these cases, the air and mean radiant temperature does not strongly influence the thermal comfort level based on the votes given by the participants. From the results, it can be implied that the air temperature has less significance in influencing the thermal comfort level.

6.2 Relative Humidity and the Comfort Level

Early investigation on the influence of relative humidity to the comfort level had concluded that the change on the relative humidity has little change to the thermal comfort level. For tropical countries especially in the hot and humid regions, high relative humidity is one of the biggest obstacles to tackle besides high air and mean radiant temperature. The average percentage of relative humidity of the day is around 80 -85% and in some cases may reach 100% especially early in the morning. Relative humidity is another important factor in thermal comfort because it determines the ability of air particles to absorb heat and evaporate. In order for this to happen, the relative humidity must be low enough to allow evaporative process to happen. The high percentage of relative humidity may retard the process and cause discomfort. Heavy sweating is one of the common problems that cause extreme discomfort in hot-humid area. When the relative humidity is high, sweat produced by the body may not be able to evaporate to help the body to cool. Figure 4 and Figure 5 show the relationship between the relative humidity and the comfort level measured in two mosques in Malaysia.

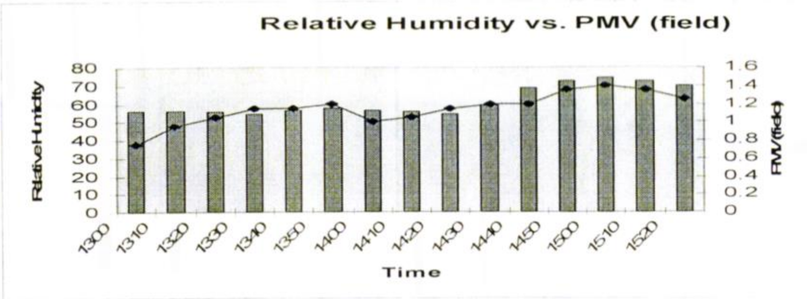


Figure 4: Relative humidity vs. PMV(field)

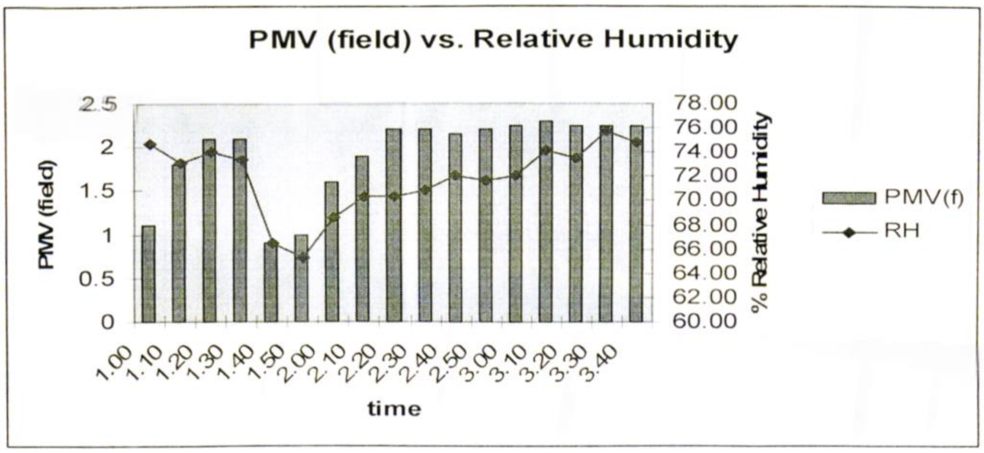


Figure 5:Relative Humidity vs. PMV (field)

In Figure 4, the relative humidity measured is fairly constant and it is followed by the relatively constant result of the PMV based on the votes given by the respondents. It is fairly difficult to predict whether the relative humidity will change the thermal comfort condition of the respondent at this moment. However, the pattern suggests that small changes of the relative humidity percentage can change the comfort level. This is even justified in Figure 5 where it shows quite a huge range of relative humidity measured and PMV votes. It is clearly observed that when there is a reduction in the percentage of the relative humidity, the PMV measured is also reduced which implies that the respondents feel more comfortable in that situation. From the Figure 5, it can also be suggested that with the relative humidity at more than 70%, people will start to experience discomfort after a certain period of time. In Figure 4, however, the comfort votes are fairly low compared to Figure 5 since the percentage of the relative humidity is mostly below 70%.

Figure 6 and Figure 7 show the relationship between the air velocity and the thermal comfort level. Figure 6 indicates that the air velocity is relatively the same throughout the time except at one time where the air velocity reaches more than 4m/s. The measurement is taken with the all the openings closed except the openings on the side of the roof. On the contrary, the measurement in Figure 7 is taken in an open building which allows outside air movement into the interior. It is fully dependent on the cross ventilation aided by the wind speed from the outside which is clearly described by the pattern measured. Inconsistent air flow from the outside through the building can be seen from the readings and therefore it can be suggested that the source of air flow from the outside is fairly unreliable to be used to ensure satisfactory cross ventilation. In an open building, the measured air speed is relatively low with 0.5m/s compared to the closed building with the openings between the roofs which is 1.1m/s.

Figure 6 shows that with the constant air movement the thermal comfort condition is not affected however, with the existence of a very strong air movement, the thermal comfort condition seems to improve tremendously. On the other hand, the constantly changing of the air speed does not improve the thermal comfort condition. This is reflected in Figure 7 where the air velocity is continuously changing throughout the experiment. It is also noted that the air speed is relatively weak and most of the time is unnoticeable. In some cases, the rise in the air velocity causes the votes to increase due to the hot air from the outside.

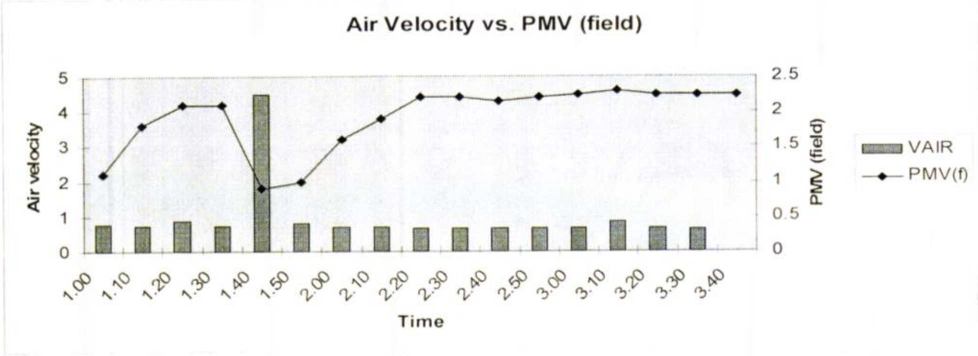


Figure 6: Air velocity vs. PMV(field)

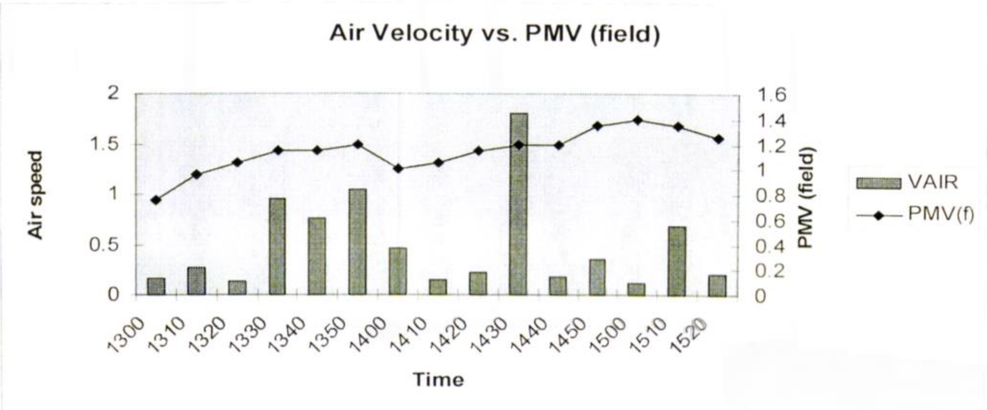


Figure 7: Air velocity vs. PMV (field)

7. Conclusion

Many assumptions can be made from the results above. Looking at the relationship of each parameter with the thermal comfort level may not be appropriate since the votes are mainly focusing on the heat gain or loss experienced. The air temperature is clearly reflected the thermal condition of the space however the thermal comfort condition is also affected strongly by relative humidity and air movement, especially in the hot and humid country where excessive humidity in the air is the biggest obstacle. Based on the investigation, it can be suggested that the range of comfortable air temperature is wider in naturally ventilated buildings in hot and humid countries, in this case, Malaysia. The air temperature of 30 degree Celsius is still considered tolerable. The changes in temperature from lower to higher within this wider range does not affect the comfort vote, however, the small changes in relative humidity have resulted in the changes of comfort vote. The changes in votes are even more substantial if the relative humidity of the indoor space is more than 70%. The air movement, on the other hand, is benefited in the condition where the relative humidity is more than

70% and should be continuous for a period of time rather than just a gust. Higher air velocity compared to the specified by the existing standards is effective in providing comfort to the indoor.

Further investigation is required to inquire how each of these parameters influences each other. These parameters should be studied as a whole rather than separating them in order to understand how each parameter benefiting each other in providing thermal comfort condition in a space. The relationships between these parameters should be established which explain the importance of these parameters in the hot and humid climate.

References

Davis, M.P., Nordin, N. A. Thermal Comfort Housing for Malaysia, China and Arab Countries. Buletin Ingenieur. pp. 35-40.

De Dear, R.J., Brager, G.S. Thermal comfort in naturally ventilated buildings:revisions to ASHRAE Standard 55. Energy and Buildings. vol 34. pp. 563-572.

Feriadi, H.,Wong, N.H. 2004. Thermal comfort for naturally ventilated houses in Indonesia. Energy and Buildings. vol. 36. pp 614-626.

Humphreys, M. A. 1978. Outdoor temperatures and comfort indoors. Building Research and Practice (JCIB)6 (2) (1978). pp. 92-105.

Humphreys, M.A., Nicol, J.F. 2000. Outdoor temperature and indoor thermal comfort – raising the precision of the relationships for the 1998 ASHRAE database of field. ASHRAE Transactions 206(2). pp. 485-492.

Karyono, T.H. 2000. Report on thermal comfort and building energy studies in Jakarta-Indonesia. Building and Environment. vol 35. pp. 77-90.

Mallick, F.H. 1996. Thermal comfort and building design in tropical climate. Energy and Buildings. vol 23. pp. 161-167.

Nicol, J.F. 2004. Adaptive thermal comfort standards in the hot-humid tropics. Energy and Buildings. pp. 628-637.

Nicol, J. F., Humphreys, M.A. 2002. Adaptive thermal comfort and sustainable thermal standardsfor buildings. Energy and Buildings. vol 34. Pp. 563-572.

Wong, N.H., Choo, S.S. 2003. Thermal comfort in classrooms in the tropics. Energy andBuildings.vol.35. pp. 337-351.

Wong, N.H., Feriadi, H., Lim, P.Y., Tham, K.W., Sekhar, C., Cheong, K.W. 2002. Thermal comfort evaluation of naturally ventilated public housing in Singapore.