AN EVALUATION OF PASSIVE COOLING STRATEGIES ON INDOOR THERMAL PERFORMANCE OF AN OFFICE SPACE

SITI KHATIJAH BT ABU BAKAR

A thesis submitted in
fulfillment of the requirement for the award of the
Degree of Master of Civil and Environmental Engineering

Faculty of Civil and Environmental Engineering
Universiti Tun Hussein Onn Malaysia

December 2013

ABSTRACT

This study evaluates the indoor thermal performance in an office space due to the effects of wall materials and night cooling strategies. The combined research methods of this study involved firstly the field measurement and monitoring work on the existing office space at the Development and Property Management Office, Universiti Tun Hussein Onn Malaysia (UTHM). It was to acquire the actual indoor data and provide data for verification of Ecotect simulation program. Secondly, the modelling and simulating of the existing office building in Ecotect so as to evaluate the indoor operative temperature and indoor comfort condition of the office space. The final stage was conducting the parametric study to investigate indoor thermal condition in response to the passive cooling strategies (i.e. changing wall material and night cooling). The study showed that the verification of simulated and measured results indicates a good agreement with discrepancy value less than 10% and can be considered acceptable as suggested by many researchers. It was also found that by changing to high thermal mass wall material could improve building's thermal performance index and reduced peak indoor operative temperature about 1°C. Indoor comfort condition in the office space during the office hours was improved about 22% (on the ground floor) and 30% (on the first floor). The results also demonstrated that night cooling compensate the drawback of high thermal mass material and reduced the indoor operative temperature in the early hour of office hours. High thermal mass wall material offers a high potential alternative wall material construction in providing better indoor environmental condition during the day particularly in office building.

ABSTRAK

Kajian ini menilai prestasi terma dalaman di dalam ruang pejabat disebabkan oleh kesan daripada bahan dinding dan penyejukan malam. Gabungan kaedah kajian ini melibatkan, pertamanya ialah kaedah kerja pengukuran lapangan di ruang pejabat sedia ada di Pejabat Pengurusan Hartabina (PPH), Universiti Tun Hussein Onn Malaysia (UTHM). Kerja pengukuran di lapangan ini adalah untuk memperolehi data dalaman sebenar dan menyediakan data untuk pengesahan data kepada program simulasi Ecotect. Keduanya adalah pembangunan model bangunan pejabat di dalam program simulasi Ecotect berdasarkan bangunan pejabat sedia ada untuk mengkaji suhu dalaman dan keadaan keselesaan dalaman bangunan tersebut. Peringkat terakhir ialah menjalankan kajian parametrik untuk mengkaji keadaan terma dalaman terhadap strategi penyejukan pasif (penukaran bahan binaan dinding dan penyejukan malam). Hasil kajian menunjukkan perselisihan antara keputusan simulasi dan pengukuran di lapangan kurang daripada 10% dan diterima seperti yang dicadangkan oleh para penyelidik. Hasil kajian juga menunjukkan dengan menukar bahan dinding yang mempunyai jisim termal yang tinggi dapat meningkatkan indeks prestasi terma bangunan dan mengurangkan suhu operatif puncak dalaman sebanyak 1°C. Keadaan selesa dalaman di ruang pejabat sepanjang waktu pejabat meningkat sebanyak 22% (tingkat bawah) dan 30% (tingkat atas). Hasil kajian ini juga menunjukkan penyejukan malam dapat mengatasi kelemahan bahan dinding berjisim termal tinggi dan dapat mengurangkan suhu operatif dalaman di awal waktu bekerja. Bahan dinding yang berjisim termal tinggi mempunyai potensi yang tinggi sebagai bahan binaan dinding alternatif dalam menyediakan keadaan persekitaran dalaman yang lebih baik pada waktu siang terutamanya di dalam bangunan pejabat.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

h_c	Convection coefficient
h_r	Radiation coefficient
Q_{gc}	Conduction through window glass
Q_{sol}	Solar radiation through window glass
Q_{wc}	Conduction through opaque wall
T_a	Air temperature (°C)
T_g	Globe temperature (°C)
T_{mrt}	Mean radiant temperature (°C)
T_o	Operative temperature (°C)
T_w	Wet bulb temperature (°C)
U_f	Thermal transmittance of fenestration system
U_w	Thermal transmittance of opaque wall
v_a	Air velocity (m/s)
A	Total wall area (m^2)
ASEAN	Association of Southeast Asian Nations
C	Conduction and convection rate
CF	Solar correction factor
E	Rate of heat loss by evaporation, respiration and elimination
ES	Ecotect simulation
FM	Field measurement
M	Metabolic rate
OTTV	Overall thermal transmittance value
PD	Percentage difference
PMV	Predicted Mean Vote
PPD	Predicted Percentage Dissatisfied (%)
R	Radiation rate
RH	Relative humidity (%)

S	Body heat storage rate
SC	Shading coefficient
WWR	Window to wall ratio
α	Solar absorptivity of the opaque wall

CHAPTER 1

INTRODUCTION

1.1 Research Background

Different climates may need different design strategies for optimum thermal performance of a building. Designing a building that respond to the natural environment can provide a desire level of comfort in the prevailing environment (Baker, 1987). Unfortunately, in modern building technologies, the existing cities are redeveloped to form a series of glass; and concrete blocks of offices and houses which commonly neglect the context of climate and culture. Therefore, unresponsive building design to its climate may affect the building thermal performance.

Thermal performance of a building can be referred to as the process of modelling the heat transfer between the buildings to its surrounding. It calculates and estimates the indoor temperature variation, heating and cooling load; and also the duration of uncomfortable periods. Thermal performance of building involves various heat exchange process such as opaque conduction, solar radiation through glazing; and sensible and latent heat gain. Two types of parameters affecting thermal performance of a building are the unsteady climatic condition (i.e. solar radiation, ambient temperature, wind speed and relative humidity) and design features (i.e. orientation, shading devices and building material properties) (Wong, 2004).

In hot and humid climate like Malaysia, solar radiation receives by building envelope is the major contributor to internal heat gain which may cause overheating in the building. Indoor overheating can be prevented by minimising solar heat gain through fabric, casual gains and ventilation by using active and passive cooling strategies. However, in this type of climate, moderating daytime indoor temperature and minimising heat gain seems to be one of the fundamental design strategies. Therefore, attention will be brought to a passive cooling strategy that has tremendous potential in improving building thermal performance, alleviate the energy demand for cooling purpose and reducing carbon emissions; particularly in office building. In this respect, two interesting passive cooling strategies to be adopted are fabric's thermal mass and night cooling. The benefits of passive cooling must, however, be balanced against the local climate and culture.

1.2 Problem statement

High daytime temperature throughout the year in Malaysia has affected the indoor thermal condition in building, particularly office building. It causes overheating due to excessive heat gain; leading to the dissatisfaction and unhealthy working environment. Thus, the usage of air conditioning in office building is adopted as a simple solution to provide a comfortable working environment and it has becoming a culture in Malaysia.

The term 'fully air conditioning' almost synonym with large prestigious building, particularly commercial offices (Arnold, 1999) so as to control the indoor temperature and humidity to maintain occupants' thermal comfort. In Malaysia, some offices and hotels maintain the indoor temperature as low as 18 to 20°C although the comfortable temperature is about 24°C. Since the indoor temperature is so low, occupants tend to wear sweaters at the working desk (Aun, 2009). This situation clearly illustrates that offices uses more energy than it should and occupant themselves do not understand how the building should operate. Apart from that, underestimating the energy requirement at the early stage could also contribute to the excessive heat gain and energy use of the building.

Therefore, office building has high potential in indoor thermal performance improvement and energy saving. One way to improve the quality of building thermal performance is to use passive cooling technique. Since overheating is common due to solar penetrating through envelope and lack of ventilation, it is significant to study the effect of fabric's thermal mass and night cooling in improving indoor thermal performance. As the thermal performance is improved, the growing of energy consumption for cooling can be alleviated.

1.3 Research Objective

The objectives of this study are:

i. To evaluate the actual indoor thermal condition of office space.
ii. To verify the accuracy of simulated result in terms of operative temperature
iii. To compare the indoor thermal performance of interlocking earth brick (ICEB) with that of common brick

1.4 Scope of Research

In order to carry out this study, scopes of the study have been defined as follows:

i. This study mainly focuses on thermal performance of internal spaces of office building in Malaysia particularly an office building at the Universiti Tun Hussein Onn Malaysia (UTHM) - the Development and Property Management Office is selected as the studied building in this study.
ii. Since field measurement and monitoring work seem to be the best method to evaluate the real thermal performance of indoor spaces, it is employed as a part of the methods to obtain data. The field measurement and monitoring work cover the measurement of indoor comfort parameters which include air temperature (T_o), mean radiant temperature (T_{mrt}) and relative humidity (RH) while outdoor parameter data collected are air temperature (T_a), relative humidity (RH) as well as thermal comfort indices (PMV and PPD).
iii. Thermal Analysis in Ecotect simulation program is utilized in modelling and simulation work and the indoor thermal performance of office space is evaluated in terms of operative temperature.

1.5 Structure of Thesis

This thesis is divided into six chapters. The **first chapter** contains the introduction, objectives, together with a brief overview of the overall thesis.

Chapter two presents a literature review of thermal comfort contributing to the general understanding of the related field. It begins with a general knowledge of climate of Malaysia, follows by an overview of office building and previous study on indoor thermal comfort. A review on alternative wall material and night cooling strategy are also covered in this chapter. Finally, a literature review on computer simulation program and the selection of computer simulation program is discussed.

Chapter three discusses the research method employed in this study. A review on the equipment used during field measurement and monitoring work in order to obtain the actual data is discussed. Besides, a brief explanation on Ecotect simulation program is also included.

Chapter four presents the field measurement work carry out on the selected office building as well as verification between simulated and measured data. This chapter firstly explains the details of the field measurement work including the equipment setup and assumptions made. It follows with the result and analysis of the data measured. Secondly, verification process in order to evaluate the capability and accuracy of Ecotect are discussed in the second part of this chapter.

Chapter five presents parametric study for this research. This chapter concerns with substituting the common wall material to an alternative wall material to investigate the ability of the alternative material in improving indoor comfort condition. Also, the effect of night ventilation in removing warmer air trapped in the building is presented. The results of the parametric study are also discussed in this chapter.

Chapter six concludes and summarizes all the results obtain from this study. The limitations throughout this research study are also outlined and some recommendations for further research study are provided.

1.6 Summary

This chapter has described the research background, description of issues to be addresses as well as its objectives. The scopes of this research also described in order to decide and direct the research works. To give an overview of overall thesis, a review on every chapter in this thesis is delineated. The next chapter is the literature review of this study in order to discuss the particular topic related to this research.

CHAPTER 2

LITERATURE REVIEW

2.1 General Climate of Malaysia

Malaysia which consists of Peninsular and East Malaysia (Sabah and Sarawak), lies between latitudes 1 and 7 degrees North, and longitude 100 and 119 degrees East (Abdullah, 2007). The characteristic features of the climate of Malaysia are uniform temperature, high humidity and abundant rainfall. The winds are generally light particularly in urban environment. Situated in the equatorial doldrum area, it is extremely rare to have a full day with completely clear sky and also rare to have a few days with completely no sunshine except during Northeast Monsoon seasons according to Malaysia Meteorological Department (MMD, 2010).

2.1.1 Sunshine and Solar Radiation

Malaysia naturally has abundant sunshine and solar radiation. However, it is extremely rare to have a full day with completely clear sky even in periods of severe drought. The cloud cover cuts off a substantial amount of sunshine and solar radiation. For most part of the country, the sunniest period of the year occurs during the months of February and March at the end of Northeast Monsoon. In the Northwest, February is the sunniest month with an average of 8.5 hours per day. In the south and central areas, the hottest days are between the months of March to April, while on the East Coast they are between March and April. In general, March is the sunniest month (for the whole Peninsular Malaysia) with the amount of sunshine being 7.5 hours per day. On the average, the amount of sunshine receives in Malaysia is 6 hours per day (Abdullah, 2007; MMD, 2010).

2.1.2 Temperature

Copious rainfall supplies abundant moisture for evaporation, which absorbs large amounts of net radiation, has contributed to uniformly temperature profile in Malaysia. The temperature seldom rises above 36ºC or falls below 20ºC (Abdullah, 2007). The day-time air temperature ranges from 25-35ºC and it is reasonably cool between 21 to 25ºC during the night. The annual variation is less than 3ºC. The daily range of temperature is being from 5 to 10ºC and from 8 to 12 ºC at the coastal and inland stations respectively (Rahman, 2005; MMD, 2010).

2.1.3 Relative Humidity

Malaysia has high humidity with mean monthly relative humidity is between 70 to 90 percent. By day it varies between 55 and 70 percent, and at night it rises above 95 percent which makes evaporation and sleeping difficult. The mean daily minimum can be at the lowest at 42 percent during the dry months and reached the highest up to70 percent during the wet months. The mean daily maximum varies from 94 to 100 percent (Abdullah, 2007; MMD, 2010).

2.1.4 Wind

The wind flow over the country is generally light and variable. However there are some uniform periodic changes in the wind flow patterns. Based on these changes, four seasons can be distinguished – southwest monsoon, northeast monsoon and two shorter inter-monsoon seasons.

The southwest monsoon is usually established in the latter half of May or early June and ends in September. The prevailing wind flow is generally southwesterly from the Indian Ocean blow into the West Coast of the Peninsular and brings light rain. The northeast monsoon usually commences in early November and ends in March. During this season, northeasterly wind blowing from South China Sea sweeps over the country. It brings a lot of rainfall on the East Coast, which is higher in December and may cause flooding in many coastal areas of Kelantan, Terengganu and Pahang. The speed of the wind seldom exceeds 10.7 m/s, except during occasional tropical storm accompanying the heavy showers. The wind in the inter-monsoon season (occur in April in the south and May in the north) are generally light and variable (Abdullah, 2007; Malaysia Meteorological Department, 2010).

In hot and humid climate of Malaysia, the function of building to provide a comfortable indoor environment is a must since high solar radiation; temperature and humidity are contributing to thermal discomfort. In this climate, solar radiation is the major factor contributes to the heat gain in a building (Hidayat, 2004). High proportion of solar radiation heat absorbed by the building fabric will increase the mean radiant temperature of the internal surfaces and rising the resultant temperature inside the building (Abdullah, 2007). Therefore, minimizing the heat gain through the building fabric is important for maintaining indoor thermal condition.

2.2 Office Building

This study focuses on office buildings so as to serve as the classical example of commercial buildings. As mentioned earlier, commercial buildings have significant attribution to the total energy usage. Chow (2010) labelled some of them as "energy wasters" since they often use much more energy than they are designed to use. There are several reasons contributing to this situation including designers underestimating the energy requirement, or occupants misunderstand how the building should operate. Hence, it can be said that commercial buildings have great potential in energy saving and improving its performance.

In Malaysia, the government has shown its initiatives towards improving energy efficient in government and private office building by taking lead in developing its first energy efficiency building in 2005 so called Low Energy

Building (LEO Building) occupied by Ministry of Energy, Green Technology and Water (Abdullah, 2007; Darus & Hashim, 2012). Apart of this building, there are also two energy efficient demonstration office buildings which are Green Energy Office (GEO – occupied by Malaysian Green Technology Center) and Diamond Building (occupied by Suruhanjaya Tenaga). These buildings are used as demonstrated building as well as showcase for energy efficiency and low environmental impact building (Abdullah, 2007). As a result, recently, architects have shifted to design sustainable building and make the practice demanding in the Malaysian building industry market. Moreover, the Malaysian Institute of Architects (MIA) tries to incorporate design guidelines for energy efficiency to ensure minimum energy performance standards particularly in commercial building. (Darus & Hashim, 2012)

Office building is an important building type to consider and can be referred as a home for people who work there - not only for 8 hours a day, but perhaps 4 to 12 hours. Its design, greatly affects the performance and occupants' productivity. Generally, most office buildings have the same pattern of operation which is typically occupied during the day and unoccupied or partially occupied at night and during weekends. They are also dominated by high internal loads basically from lighting, equipment and people during the occupied periods. Therefore, offices are often cooled most time of the year using air conditioning (Al-homoud, 1997). The main reason for mechanically conditioning office buildings is to create comfortable thermal conditions for occupants (ASHRAE, 2001; Charles, 2003).

Recently, demand for high quality buildings seem to increase. Occupants and developers of office buildings ask for healthy and stimulating working environment. Back to 1960s, office was meant as central air-conditioning, a telephone at every desk, and IBM electronic typewriter for each secretary and a new Xerox photocopier at each floor. By the late 1980s, two relentless forces which were the rise of high technology and the competitive global economy had changed the workplace forever (Kohn & Katz, 2002). In the meantime, the advent of computer and other office equipment increased the internal heat gains in most offices.

In line with extra heat gains from office equipment and electric lighting, highly glazed façade, often with poor shading has increased the overheating risk (Gratia & Herde, 2003). Proper design and selection of building components at the early design stage have significant impact in achieving thermal comfort with minimum reliance upon HVAC systems, and therefore minimum energy requirements (Al-homoud, 1997; Gratia & Herde, 2003).

A parametric study using climatic data, carried out by Gratia and Herde (2003) found that factors that have significant impact on energy consumption in buildings are: insulate the building and have good air tightness; limit and control internal gains; good choices of the windows area and orientation; adequate ventilation and thermal inertia.

2.3 Energy and Electricity Consumption in Malaysia

Since independence in 1957, Malaysia has undergone tremendous growth and prosperity by shifting the economic activities from labour-intensive industries to energy and capital-intensive industries, particularly heavy industry. In recent years, Malaysia's energy consumption has increased and become one of the fastest growing building industries worldwide, and this is an area where the corresponding energy demand will significantly increase in the coming area (Daghigh et al., 2009).

Malaysia is going to need more energy as the economy continues to grow and it is expected that 6 GW of new generation capacity to be needed by 2020 to provide energy for businesses and the growing population, representing an increase of about 25 percent over installed capacity in 2009 (Economic Transformation Programme, 2010)

According to the Energy Commission, total electricity generation in Malaysia is 116 114 GWh with a total electricity consumption of 96 646 GWh or 3415 kWh per capita. Having 28.3 million multi-racial population (comprising Malays, Chinese, Indians and others) (Energy Commission, 2009) and expected to grow at rate 2 percent for a period 2000 to 2010 (Department of Statistic, 2011), the energy demand in this country also expected to increase as it is crucial to everyday life and development activities. Hence, the increase in building's electricity consumption will contribute to the higher release of greenhouse gases due to the most of the electricity consumed by building is generated using fossil energy (Raman, 2009; Ng & Akasah, 2011).

Figure 2.1 shows the distribution of electricity consumption by sectors. The National Energy Balance (2009) reported that the commercial sector is the second largest user which consumed 33.1% after industrial sector. While the residential sector turns out to be the third largest user represent 21.6% followed by agricultural and transportation at 0.3% and 0.2%.

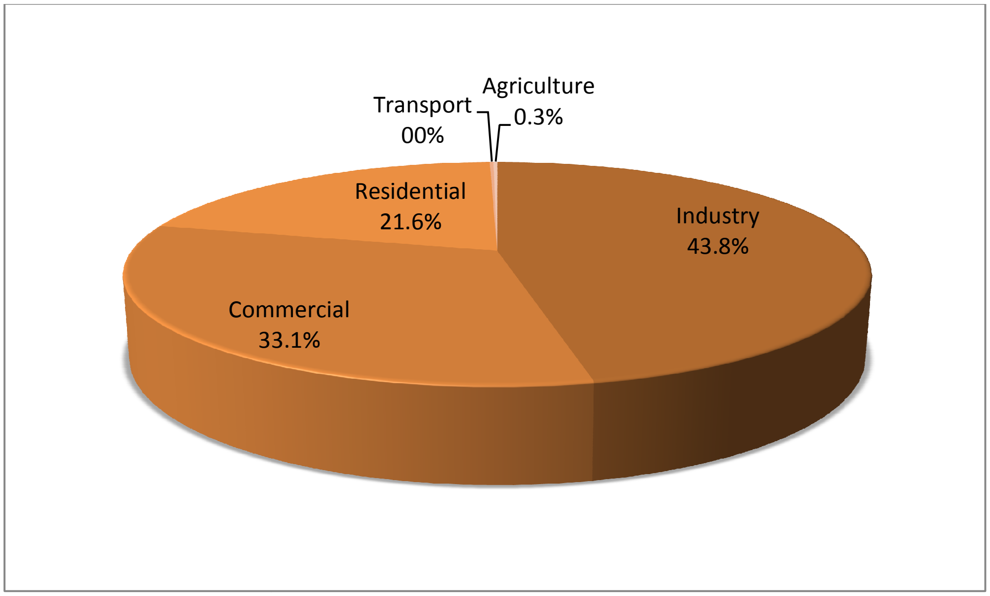

Figure 2.1: Electricity consumption by sectors (Source: National Energy Balance, 2009)

Office building consumed about 55 to 65% for air conditioning, 25 to 35% for lighting, 2 to 6% for lifting and 5 to 15% for others (Ismail, 2007). Table 2.1 shows the distribution of energy consumption distribution for commercial building in Malaysia. Particularly it can be clearly seen that air conditioning recorded the highest energy consumption compare to other system which consumed approximately 57% followed by lighting and lifts consuming 34 and 3% respectively while the remainder consumed by others as shown in Figure 2.2.

Table 2. 1: Energy consumption distribution for commercial buildings in Malaysia (Source: Ismail, 2007)

Building types	Air conditioning (%)	Lighting (%)	Lifts (%)	Hot water, catering, laundry (%)	Miscellaneous (%)
Hotels	50-70	20-30	3-5	15-20	0-10
Shops	40-55	45-55	2-4	NA	0-10
Offices	55-65	25-35	2-6	NA	5-15

NA – Not Available

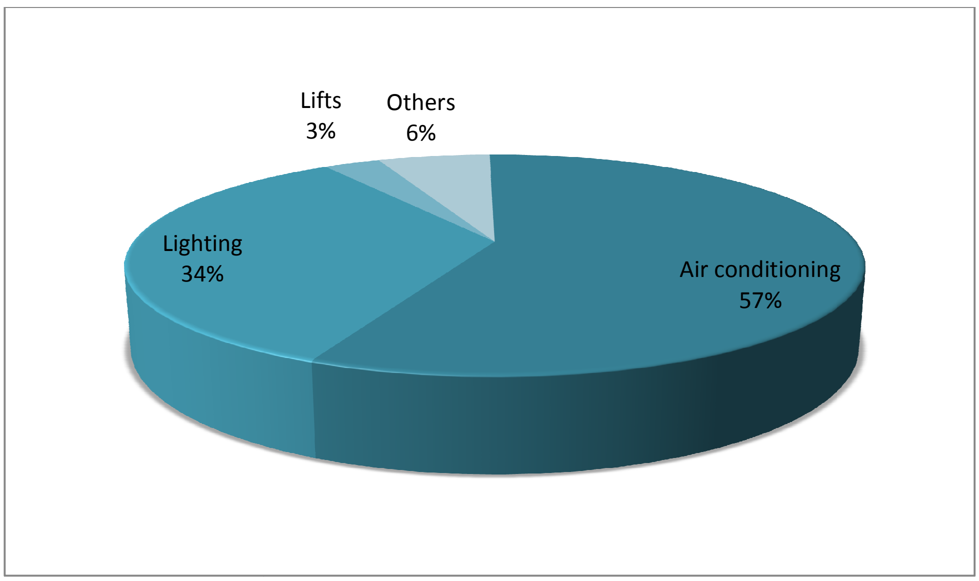

Figure 2.2: Approximate average values of energy consumption in office buildings in Malaysia (Source: Ismail, 2007)

2.4 Thermal Comfort

The conscious mind appears to reach conclusions about thermal comfort from direct temperature and moisture sensations from the skin, deep body temperatures, and the efforts necessary to regulate body temperature. In general, comfort occurs when body temperatures are held within narrow ranges, skin moisture is low, and the physiological effort of regulation is minimized (ASHRAE, 1992). However, expectations a comfortable environment are converging worldwide where a hot environments are being cold while a cold environments are being heated (Andamon, 2006).

Comfort quality of a space is evaluated with its comfort performance. Inadequate comfort conditions can cause numerous undesirable effects on the occupants' behaviour, productivity, health and decreasing of production quality (Ünver, 2004). Thus, people tend to modify their behaviour and environment to conform to societal expectations of thermal comfort (Andamon, 2006). Reducing air temperature using air conditioning system can provide comfortable environment to occupant in a room. Likewise, increasing air movement in the room using fan or natural ventilation also can provide comfort to occupant although air temperature is not reduced.

To determine appropriate thermal conditions, practitioners refer to standards such as ASHRAE Standard 55 and ISO Standard 7730. These standards define temperature ranges that should result in thermal satisfaction for at least 80% of occupants in a space (Charles, 2003).

According to ASHRAE Standard 55, thermal comfort is defined as conditions of mind which expresses satisfaction with thermal environment. Thermal comfort also can be defined as a conditioned when people feel neither too hot nor too cold when their body functions well and also not causing uncomfortable feelings (Aprita, 2004). In physiological terms, thermal comfort is what we experience when the body functions well, with a body temperature constant at around 37ºC.

The comfort condition is the result of simultaneous control of temperature, humidity, cleanliness and air distribution within the occupant's surrounding. These factors include mean radiant temperature as well as the air temperature, odour control and control of the proper acoustic level within the occupant's surrounding (Clifford, 1992). There appears to be no rigid rule as to the best environmental conditions for occupant's comfort. The comfort of an individual is affected by many variables. Health, age, activity level, clothing, sex, food and acclimatization all play their part in determining the best comfort condition for any group of persons. Besides, under the same conditions of temperature, humidity and air movements, a healthy, young man may be slightly warm while an elderly woman is cool.

Fundamental studies of thermal comfort such as acceptable range of dry-bulb temperatures, relative humidity and activity levels were completed in the 1970s. These studies, which led to the development and refinement of ASHRAE Standard 55, were performed at Kansas State University by Ole Fanger and others (Fanger, 1972).

2.4.1 Basic principles of thermal comfort

Thermal comfort is strongly related to thermal balance between the body's heat generations and the release of body heat into its surroundings. Human body continuously produces heat due to metabolic activities which is used as work and dissipated to surrounding to maintain the body temperature (achieve body thermal balance). A state of thermal balance of the body is when heat gains and losses to its surrounding are at equilibrium rate. Equation 2.1 shows relationship between the body's heat production and loss:

Heat production = Heat loss

$$M = E \pm R \pm C \pm S \qquad (2.1)$$

where:

M = metabolic rate

E = rate of heat loss by evaporation, respiration, and elimination

R = radiation rate

C = conduction and convection rate

S = body heat storage rate

There are four different modes of heat transfers between the human body and its environment (Koenigsberger et al., 1973; Egan, 1975; Chadderton, 1991; Abdullah, 2007). The different modes of heat exchanges to maintain the heat balance are as follows:

(i) *Radiation:* Heat gain from the environment is by solar radiation or warm surfaces, whilst radiant heat loss between skin and clothing surfaces and the room depends on the absolute surface temperature, the emissivity, the surface area and the geometric configuration (or the view factor) of the emitting and receiving areas. Thus, a moving person will experience changes in comfort level depending on the location of the hot and cold surfaces in the room.

(ii) *Convection:* Heat transmission from the body to the air in contact with the skin or clothing by natural convection currents or ventilation is a major source of cooling. The rate of convection heat loss is influenced by two factors: speed of air movement and temperatures of air. The body's response to a cool environment is by restricting blood circulation to the skin, involuntary reflex action such as shivering, or in extreme cases, lowering the body temperature.

(iii) *Evaporation:* Heat loss takes place on the skin as insensible perspiration and sweat, and in the lungs through respiration and exhalation. Basically, man loses about one litre of water a day by perspiration. The rate of evaporation depends on the amount of moisture transfer and on the air humidity.

(iv) *Conduction:* Heat exchange depends on thermal conductivity of materials contacting directly with the skin and the surroundings. In other words, it is the temperature difference between the body surface and the object that is in direct contact with the body (i.e. clothing). The rate of conduction also depends on the insulation value of the cloth the body is wearing.

Baker (1987) stated that heat loss to the environment occurs predominantly by three mechanisms (radiation, convection and evaporation) and to a much lesser extent by conduction. Heat transfer between human body and its surrounding in a normal comfort condition is illustrated in Figure 2.3.

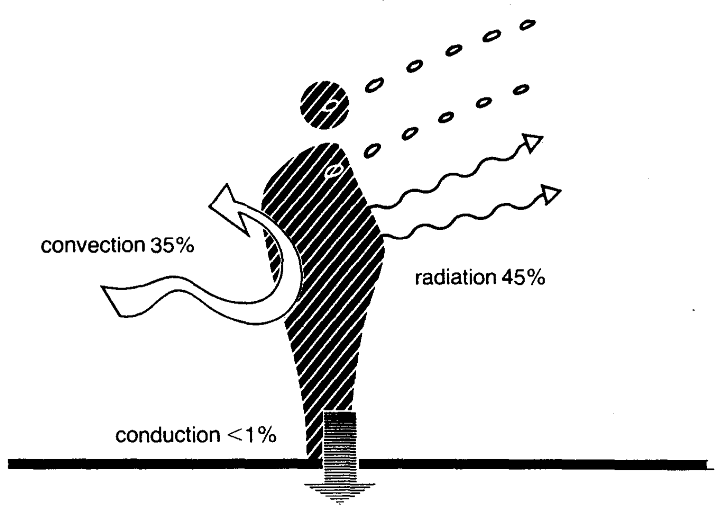

Figure 2.3 Body heat exchanges (Source: Baker, 1987)

The three main mechanisms of heat loss are controlled by four environmental parameters which include mean radiant temperature (T_{mrt}), air temperature (T_a), relative humidity (RH) and air movement.

Basically, our body constantly produces heat from the consumption and digestion of food and the processes are known as metabolism of the energy produced in the body. There are only about 20% of energy produced in the body is utilized in useful work while remaining 80% must be dissipated to the environment (Koenigsberger et al., 1973, Abdullah, 2007). Heat must be continuously dissipated and regulated to maintain normal body temperature at around 37ºC. Insufficient heat loss leads to overheating called *hyperthermia*, and excessive heat loss results in body cooling which is called *hypothermia*. An internal body temperature less than 28ºC can lead to serious cardiac arrhythmia and death; and temperature greater than 46ºC can cause irreversible brain damage. Therefore, the careful regulation of body temperature is critical to maintain body comfort and health (ASHRAE, 1992).

2.4.2 Factors affecting comfort

Basically, thermal comfort conditions considered the six basic parameters which are classified into two major variables such as environmental variables; and personal variables. These parameters can influence thermal condition and the integrated influence of these six parameters can determine thermal comfort responses. However, Auliciems & Szokolay (2007) considered those variables that affect heat dissipation from the body and also thermal comfort to be grouped into three sets as shown in Table 2.2 below.

Table 2. 2: Variables affecting the thermal comfort

Environmental variables	**Personal variables**	**Contributing factors**
Air temperature	Metabolic rate (activity)	Food and drink
Air movement	Clothing	Acclimatization
Humidity		Body shape
Radiation (*can be referred to as mean radiant temperature)*		Subcutaneous fat
		Age and gender
		State of health

(i) *Air temperature*

Temperature is easily measured and alternatively called air temperature or dry bulb temperature which is measured by an accurate thermometer or thermocouple. When measuring air temperature, the thermometer should be shielded to reduce the effects of direct radiation. It is found that in most cases a reasonably comfortable environment can be maintained when two or three of parameters are controlled (Kreider, 2002).

(ii) *Mean radiant temperature*

Mean radiant temperature can be defined as the temperature of an imaginary isothermal enclosure with which a human body would exchange the same radiation as with the actual environment (Kreider, 2002). An equation to calculate mean radiant temperature can be expressed as:

$$T_{mrt} = T_g + 2.35\,(v)^{0.5}\,(T_g - T_a) \tag{2.2}$$

where;

T_{mrt} = mean radiant temperature

T_a = air temperature (dry bulb temperature)

T_g = globe temperature

v = relative air velocity

The commonly used instrument to determine the mean radiant temperature is Vernon's *globe thermometer*, which consists of a hollow sphere 6 in. in diameter, flat black paint coating and a thermometer or thermocouple bulb at its center.

The equilibrium temperature assumes by the globe (the globe temperature as shown in Figure 2.4) results from a balance in the convective and radiative heat exchanges between the globe and its surroundings. This parameter involves the amount of radiant exchange between a person and the surroundings. Cold walls or windows may cause a person to feel cold even the surrounding air may be at a comfortable level. Likewise, sunlight or warm surfaces such as stoves or fireplaces or ceilings may cause a person to feel warmer than the surrounding air temperature would indicate.

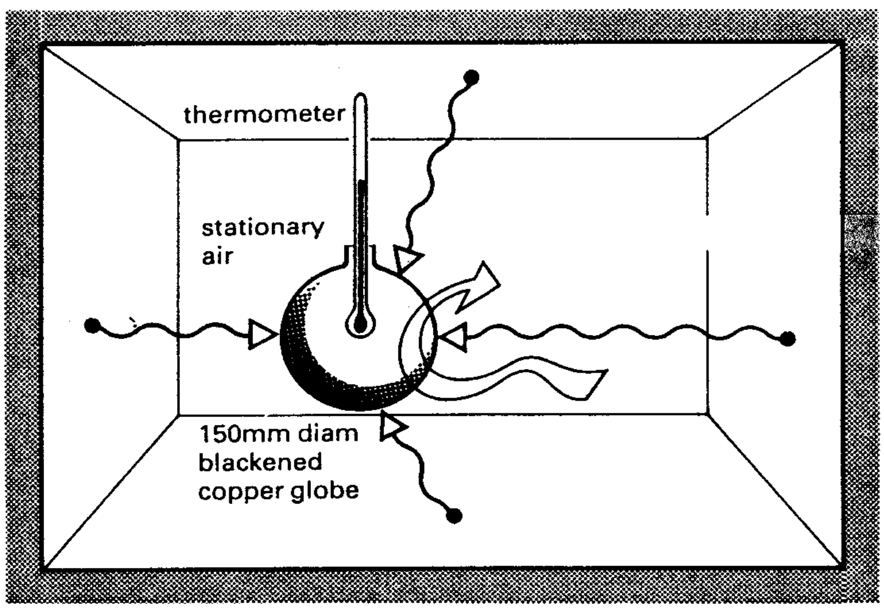

Figure 2.4: Globe thermometer (Source: Baker, 1987)

(iii) *Relative humidity*

Usually, air contains less than the maximum amount of moisture that it is capable to hold. When we compare the amount of moisture contained in an air sample to the maximum it can possibly hold, we are describing relative humidity. Relative humidity is the ratio of mass of water vapour in the air to the mass of water vapour when the air is in saturated state.

A simple method to measure humidity of the air is by measuring the temperature difference before and after it undergoes the adiabatic saturation process. The temperature measured before the process is dry-bulb temperature and the temperature measured after is wet-bulb temperature. Note that, theoretically, wet-bulb temperature is equal to the adiabatic saturation temperature. The larger difference between the dry-bulb and wet-bulb temperatures, the lower the humidity (Parson, 2010).

(iv) *Air velocity*

Continuously moving air is one of the requirements for thermal comfort. It is not only effective in evaporating perspiration but also in speeding convection heat loss from the skin (Allen, 1995). Zain et al. (2007) noted that an air flow of 0.7 m/s will give rise to comfort while if the air flow is more than 1.5 m/s, the space will be comfortable throughout. When air flow less than 0.2 m/s it would not be effective while more than 2.0 m/s will create other related problem (e.g. paper flying from the desk).

(v) *Clothing insulation*

Clothing insulation is measured in units of ‘clo’ (Gagge, Burton, & Bazett, 1941; Charles, 2003). Clothing, through insulation properties, is an important modifier of body heat loss and comfort. If clothing does not provide enough insulation then the wearer may be at risk in the very cold conditions. For dry insulation a value of 1 Clo is defined as providing an insulation of 0.155 m^2K/W (Parson, 2010).

Table 2. 3: Garment insulation values (source: Auliciems & Szokolay, 2007)

Man		clo	Women		clo
underwear	singlets	0.06	underwear	bra + panties	0.05
	T-shirt	0.09		half slip	0.13
	briefs	0.05		full slip	0.19
	long, upper	0.35		long, upper	0.35
	long, lower	0.35		long, lower	0.35
shirt	light, short sleeve	0.14	blouse	light	0.20
	light, long sleeve	0.22		heavy	0.29
	heavy, short sleeve	0.25	dress	light	0.22
	heavy, long sleeve	0.29		heavy	0.70
	+5% for tie or turtle-neck)				
vest:	light	0.15	skirt	light	0.10
	heavy	0.29		heavy	0.22
trousers	light	0.26	slacks	light	0.26
	heavy	0.32		heavy	0.44
pullover	light	0.20	pullover	light	0.17
	heavy	0.37		heavy	0.37
jacket	light	0.22	jacket	light	0.17
	heavy	0.49		heavy	0.37
socks	ankle length	0.04	stockings	any length	0.01
	knee length	0.10		panty-hose	0.01
footwear	sandals	0.02	footwear	sandals	0.02
	shoes	0.04		shoes	0.04
	boots	0.08		boots	0.08

based on ASHRAE 1985

(vi) *Metabolic rate*

Metabolism determines the rate at which energy is converted from chemical to thermal form within the body, and blood circulation controls the rate at which the thermal energy is carried to the surface of the skin. The energy generated by a person's metabolism varies considerably with that person's activity. A unit to express the metabolic rate per unit of body surface area is the 'met', which is defined as the heat produced by a sedentary person and is given the values of 58 Watts produced for every square metre of the body surface area (i.e. 1.0 Met = 58.2 W/m^2) (McQuiston, 2004; Parson, 2010).

Table 2.4: The metabolic rate values (edited from: Auliciems & Szokolay, 2007)

Activity	met	W/m^2
Sleeping	0.7	40
Reclining, lying in bed	0.8	46
Seated, at rest	1.0	58
Standing, sedentary work	1.2	70
Very light work (i.e. shopping, cooking, light industry)	1.6	93
Medium light work (i.e. house work, machine tool work)	2.0	116
Steady medium work (i.e. jackhammer, social dancing)	3.0	175

2.4.3 Determination of comfort criteria

Air temperature and temperature of the immediate surroundings, humidity and speed of airflow in the local environment all modify the manner in which thermal comfort is experienced. For given values of aforementioned variables, thermal comfort level may be determined. Thermal comfort level can be defined in term of range of operative temperature and also by PMV and PPD index.

2.4.3.1 Operative temperature

When calculating the indoor thermal climate, operative temperature (T_o) can be used as a simple measure for the heat loss from a person (Christensen, 2008) and also used to determine the temperature limit of the comfort zone. A range of operative temperature provides an acceptable thermal environmental condition. In determining operative temperature, mean radiant temperature is seems to be a significant factor, especially in buildings which the envelopes are exposed to a strong solar radiation where conventional indoor temperature and humidity control cannot guarantee indoor comfort (Atmaca et al., 2007). Note that, the mean radiant temperature has significant effects to the changes of operative temperature in dependence on the location. In addition, operative temperature is also time variable since indoor surface temperature is changing during the day depending on the outdoor climatic condition (Zmrhal & Drkal, 2007).

Operative temperature can be defined as the temperature of a uniform, isothermal 'black' enclosure in which man would exchange heat by radiation and convection at the same rate as in the given non-uniform environment; or can simply defined as the average of mean radiant temperature and dry bulb temperature weighted by their respective transfer coefficients (Auliciems & Szokolay, 2007). Hence, operative temperature can be expressed in the following equation:

$$T_o = \frac{h_c T_a + h_r T_{mrt}}{h_c + h_r} \tag{2.3}$$

Where;

h_c = convection coefficient

h_r = radiation coefficient

T_a = air temperature (dry bulb temperature)

T_{mrt} = mean radiant temperature

This index integrates the effect of air temperature and radiation, but ignores humidity and air movement (as the effect of humidity is small and indoor air movement negligible).

In addition, for occupants engaged in near sedentary physical activity, not in direct sunlight, and not exposed to air velocities greater than 0.2 m/s, a simple calculation of operative temperature which can give acceptable accuracy result is expressed by the following equation:

$$T_o = \frac{T_a + T_{mrt}}{2} \tag{2.4}$$

2.4.3.2 Predicted Mean Vote (PMV)

A model named Predicted Mean Vote model was developed in 1970 which combines the six thermal comfort parameters into an index that can be used to predict thermal comfort level. PMV can be precisely determined if both environmental and individual parameters are correctly measured and only for steady-state conditions or minor fluctuations of variables. PMV index is derived on the basis of experimental conditions which are near thermal neutrality or slightly discomfort. The index provides a score that corresponds to ASHRAE thermal sensation scale (see Figure 2.5) and represents the average thermal sensation felt by a large group of people in a space (Fanger, 1970; ASHRAE, 2001; Charles, 2003).

-3	-2	-1	0	1	2	3
cold	cool	slightly cool	neutral	slightly warm	warm	hot

Figure 2.5: ASHRAE scale of thermal sensation

In defining the conditions for comfort, ASHRAE offers three classes of comfort as goals or criteria for performance. These classes (A, B and C) differ in the allowable PMV range and PPD as well. Obviously, the C class have larger percentage of dissatisfied people and offers a wider boundary of allowable thermal condition than the A class. The three classes of thermal comfort are given in the Table 2.5 below:

Table 2.5: Three classes of acceptable thermal environment for general comfort (source: ASHRAE, 2004)

Comfort Class	PMV Range	PPD
A	-0.2 <PMV< +0.2	<6
B	-0.5 <PMV< +0.5	<10
C	-0.7 <PMV< +0.7	<15

2.4.3.3 Predicted Percentage Dissatisfied (PPD)

The quality of the thermal environment may be expressed by the PPD index, which is related to the PMV index. It is based on the assumption that people voting -3, -2, +2 or +3 from the thermal sensation scale are dissatisfied with the current environment.

Even if the indoor thermal condition is maintained in accordance to the PMV model, there will be some dissatisfaction feelings amongst occupants. When PMV is equal to 0, PPD of 5% is reflected to the dissatisfaction of occupants with the thermal environment. While PMV range of ±0.5 correspond to 10% of dissatisfaction.

Dissatisfied is defined as ‘A vote outside the central three categories of ASHRAE or similar scales. A vote within the three central categories is referred as satisfaction with the thermal environment, and this is called as thermal acceptability. Thermal acceptability is defined as ‘Any condition in which 80% or more of the people express satisfaction with a given environment’ (ASHRAE, 1993; Ismail, 2007).

Unlike PMV, which gives the average response of a large group of people, PPD is indicative of the range of individual responses (Ismail, 2007). The maximum/minimum value of PMV are at ±2, since the more the PMV deviates from zero, the more PPD increases, in a semi-logarithmic manner (Abdullah, 2007).

The relationship between PMV and PPD is shown in Figure 2.6 below:

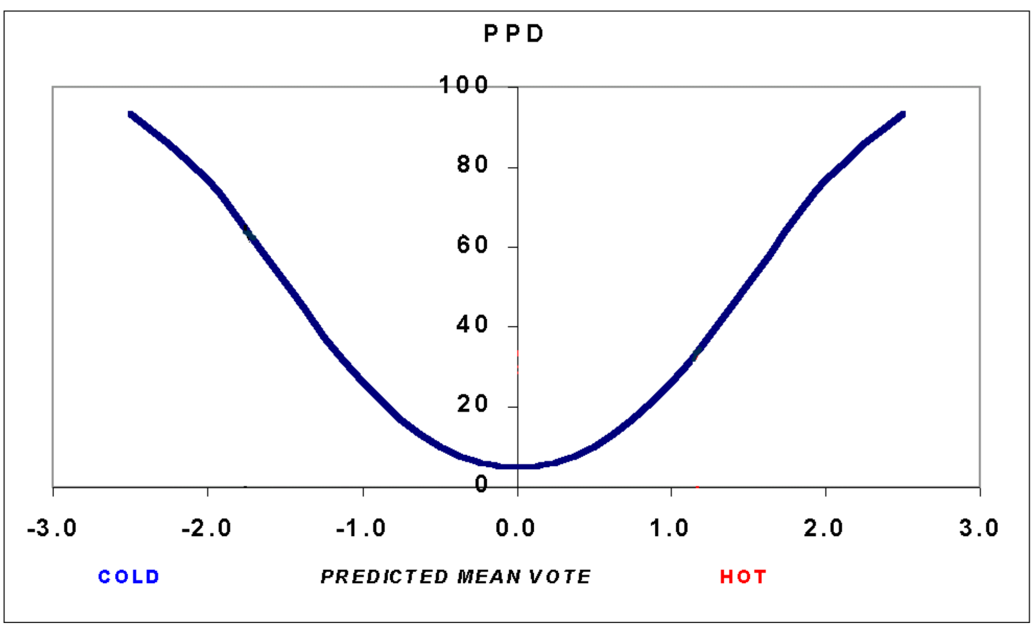

Figure 2.6: Percentage of people dissatisfied as a function of mean vote
(Source:Lyons et al., 2000)

REFERENCE

Abdullah, A. H. (2007). *A Study on Thermal Environmental Performance in Atria in the Tropics with Special Reference to Malaysia*. Unpublished PhD thesis. Heriot-Watt University.

Abdullah, A. H., & Wang, F. (2005). Effect of water spray and blinds on indoor thermal environment in an atrium in tropical climate. *The Proceedings of Asean Postgraduate Seminar in Built Environment* (pp. 79–87). Faculty of Built Environment, University Malaya, Kuala Lumpur, Malaysia.

Adam, E. A., & Agib, A. R. A. (2001). *Compressed Stabilised Earth Block Manufacture in Sudan*. Paris, France: UNESCO.

Al-homoud, M. S. (1997). Optimum thermal design of office buildings. *International Journal of Energy Research*, *21*(February), 941–957.

Al-Tamimi, N. A. M., Fadzil, S. F. S., & Harun, W. M. W. (2011). The Effects of Orientation, Ventilation, and Varied WWR on the Thermal Performance of Residential Rooms in the Tropics. *Journal of Sustainable Development*, *4*(2), 142–149.

Allen, E. (1995). *How buildings work: The natural order of architecture* (2nd editio.). New York: Oxford University Press.

Andamon, M. M. (2006). Thermal Comfort and Building Energy Consumption in the Philippine Context. *PLEA 2006 - The 23rd Conference on Passive and Low Energy Architecture* (pp. 6–8). Geneva, Switzerland.

Aprita, Y. D. (2004). Optimize the Percentage of Opening Area due to Thermal Comfort in Hot Humid Residential (Using Eco House as Model Simulation). *SENVAR5 - The 5th International Seminar on Sustainable Environmental Architecture* (pp. 1–10).

Arnold, D. (1999). The evolution of modern office buildings and air conditioning. *ASHRAE Journal*, 40–54.

Artmann, N. (2008). *Cooling of the building structure by night-time ventilation*. Aalborg University.

ASHRAE. (1992). *Thermal Environmental Conditions for Human Occupancy*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASHRAE. (1993). *ASHRAE Handbook - 1993 Fundamentals*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASHRAE. (2001). *Thermal Comfort in ASHRAE Handbook* (pp. 8.1–8.29). Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASHRAE. (2004). *Thermal Environmental Conditions for Human Occupancy*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Atmaca, I., Kaynakli, O., & Yigit, A. (2007). Effects of radiant temperature on thermal comfort. *Building and Environment*, *42*, 3210–3220.

Attia, S., Beltrán, L., Herde, A. De, & Hensen, J. (2009). " Architect friendly ": A comparison of ten different building performance simulation tools. *Eleventh International IBPSA Conference* (pp. 204–211). Glasgow, Scotland.

Augenbroe, G. (2004). Trends in building simulation. *Advanced building simulation* (p. 4). New York: Spon Press.

Auliciems, A., & Szokolay, S. V. (2007). *Thermal comfort* (2nd editio.). PLEA: Passive and Low Energy Architecture International with association with Department of Architecture, The University of Queensland.

Aun, A. C. S. (2009). *GREEN BUILDING INDEX – MS1525*.

Baker, N. V. (1987). *Passive and low energy building design for tropical island climates*. Pall Mall, London: The Commonwealth Secretariat.

Balaras, C. A. (1996). The role of thermal mass on the cooling load of buildings. An ovrview of computational methods. *Energy and Buildings*, *24*(1-10).

Bland, D. W. (2011). *In-pkane cyclic shear shear performance of interlocking compressed earth block walls*. Master thesis. California Polytechnic State University.

Blondeau, P., Sperandio, M., & Allard, F. (1997). Night ventilation for building cooling in summer. *Solar Energy*, *61*(327-335).

Breesch, H., Brossaer, A., & Janssens, A. (2005). Passive cooling in a low-energy office building. *Solar Energy*, *79*(6), 682–696.

Breesch, Hilde, & Janssens, A. (2007). Reliable Design of Natural Night Ventilation Using Building Simulation.

Butler, T. (2008). *Design in a simulation environment*. Master thesis. Georgia Institute of Technology.

Chadderton, D. V. (1991). *Building Services Engineering*. London: Chapman & Hall.

Charles, K. E. (2003). *Fanger ' s Thermal Comfort and Draught Models*. Ottawa, Canada.

Chirarattananon, S., & Taveekun, J. (2004). An OTTV-based energy estimation model for commercial buildings in Thailand. *Energy and Buildings*, *36*, 680–689.

Chow, D. H. C. (2010). *Material for Energy Efficiency and Thermal Comfort in Commercial Buildings*. (M. R. Hall, Ed.). Woodhead Publishing.

Chowdhury, A. A., Rasul, M. G., & Khan, M. M. K. (2008). Thermal-comfort analysis and simulation for various low-energy cooling-technologies applied to an office building in a subtropical climate. *Applied Energy*, *85*, 449–462.

Christensen, J. E. (2008). A method for more specific simulation of operative temperature in thermal analysis programmes. *Building Physics - 8th Nordic Symposium* (pp. 551–558).

Clifford, G. E. (1992). *Modern Heating and Ventilating Systems Design*. Prentice-Hall.

Cohen, R. R., Davies, R. M., & Standevan, M. A. (1992). Natural ventilation design for a concert hall, air infiltration centre. *17th AIVC Conference* (pp. 468–475).

Compressed Earth Blocks:Standards. (1998). Brussel, Belgium: CDI and CRATerre-EAG.

Crawley, D. B., Hand, J. W., Kummert, M., & Griffith, B. T. (2005). Contrasting the capabilities of building energy performance simulation programs. *Ninth International IBPSA Conference* (pp. 231–238).

Daghigh, R., Adam, N. M., & Sahari, B. B. (2009). Ventilation Parameters and Thermal Comfort of Naturally and Mechanically Ventilated Offices. *Indoor and Built Environment*, *18*(2), 113–122.

Daghigh, R., Adam, N. M., Sopian, K., & Sahari, B. B. (2009). Thermal comfort of an air-conditioned office through different windows-door opening arrangements. *Building Services Engineering Research and Technology*, *30*(1), 49–63.

Darus, A.Z.M., Hashim, N.A (2012). Sustainable Building in Malaysia: The Development of Sustainable Building Rating System, Sustainable Development - Education, Bussiness and Management -Architecture and Building Construction - Agriculture and Food Security. InTech. Retrieved from http://www.intechopen.com/books/sustainable-development-education-business-and-management-architecture-and-building-construction-agriculture-and-food-security/sustainable-building-in-malaysia-the-development-of-sustainable-building-rating-system

Degelman, L. (2010). Simulation and uncertainty: Weather prediction. In A. M. Malkawi & G. Augenbroe (Eds.), *Advanced building simulation* (p. 61). New York: Spon Press.

Department of Statistic (2010). *Population Distribution and Basic Demographic Characteristic Report*. Retrieved on July 20, 2011 from http://www.statistics.gov.my/portal/index.

Economic Transformation Programme. (2010). Chapter 6: Powering the Malaysian economy with oil, gas and energy. *Economic Transformation Programme: A roadmap for Malaysia*. Retrieved on May 19, 2011 from http://etp.pemandu.gov.my/upload/etp_handbook_chapter_6_oil_gas_and_energy.pdf

Egan, M. D. (1975). *Concepts in Thermal Comfort*. Englewood Cliffs, New Jersey: Prentice-Hall.

Ellis, M. W., & Mathews, E. H. (2002). Needs and trends in building and HVAC system design tools. *Building and Environment*, *37*(5), 461–470.

Energy Commission. (2009). *Annual Report*. Retrieved on May 19. 2011 from http://www.st.gov.my/v4/

Etheridge, D. W. (2000). Unsteady flow effects due to fluctuating wind pressures in natural ventilation design-instanteneous flow rates. *Building and Environment*, *35*, 321–337.

Fanger, P. O. (1970). *Thermal Comfort*. Copenhagen: Danish Technical Press.

Fanger, P. O. (1972). *Thermal comfort, analysis and applications in environmental engineering*. New York: McGraw-Hill.

Finn, D., Connolly, D., & Kenny, P. (2007). Sensitivity analysis of a maritime located night ventilated library building. *Solar Energy*, *81*(6), 697–710.

Gagge, A. P., Burton, A. C., & Bazett, H. C. (1941). A practical system of units for the description of the heat exchange of man with his environment. *Science*, *94*(2445), 428–430.

Geros, V., Santamouris, M., Tsangrasoulis, A., & Guarracino, G. (1999). Experimental evaluation of night ventlation phenomena. *Energy and Buildings*, *29*(2), 141–154.

Gezer, N. A. (2003). *The effects of construction materials on thermal comfort in residential buildings: An analysis using Ecotect 5.0*. The Middle East Technical University.

Givoni, B. (1998). Effectiveness of mass and night ventilation in lowering the indoor daytime temperatures. Part I: 1993 experimental periods. *Energy and Buildings*, *28*(1), 25–32.

Gratia, E, Bruyère, I., & De Herde, A. (2004). How to use natural ventilation to cool narrow office buildings. *Building and Environment*, *39*(10), 1157–1170.

Gratia, Elisabeth, & Herde, A. De. (2003). Design of Low Energy Office Buildings. *Elsevier, Energy and Buildings*, *35*, 473–491.

Guillaud, H., Joffroy, T., & Odul, P. (1995). *Compressed Earth Blocks: Manual of Design and Construction*. Retrieved from http://www.gate-international.org/documents/publications/webdocs/pdfs/g09c2e.pdf

Hacker, J. N., Saulles, T. P. De, Minson, A. J., & Holmes, M. J. (2008). Embodied and operational carbon dioxide emissions from housing : A case study on the effects of thermal mass and climate change. *Energy and Buildings*, *40*, 375–384.

Hensen, J. L. M., Lamberts, R., & Negrao, C. O. R. (2002). A view of energy and building performance simulation at the start of the third millenium. *Journal of Energy and Buildings*, *34*, 853–855.

Hidayat , M. S. (2004). Pembangunan Program Tropic untuk Simulasi Pembolehubah Bumbung Terhadap Keselesaan Dalaman di Malaysia. PhD Thesis. Universiti Teknologi Malaysia.

Huang, Y. J., & Deringer, J. J. (2007). Status of energy efficient building codes in Asia. The Asia Business Council, Hong Kong SAR. Retrieved from http://www.climateworks.org/download/status-of-energy-efficient-building-codes-in-asia-june-2009

Hui, S. C. M. (1997). Overall Thermal Transfer Value (OTTV): How to Improve Its Control in Hong Kong. *Proceedings of the One-day Symposium on Building, Energy and Environment* (pp. 12–1 to 12–11).

Hussein, I. (2009). Field Study on Thermal Comfort in Malaysia. *European Journal of Scientific Research*, *37*(1), 134–152.

Ismail, L. H. (2007). *An Evaluation of Bioclimatic High Rise Office Buildings in a Tropical Climate: Energy Consumption and Users' Satisfaction in Selected Office Buildings in Malaysia*. PhD thesis. University of Liverpool.

ISO 7730. (1994). *Moderate thermal environments: Determination of the PMV and PPD indices and specifications for thermal comfort*. Organisation for Standardisation.

Judkoff, R., Wortman, D., O'Doherty, B., & Burch, J. (2008). *A methodology for validating building energy analysis simulations*. Colorado. Retrieved from http://www.osti.gov/bridge

Koenigsberger, O. H., Ingersoll, T. G., Mayhew, A., & Szolkolay, S. V. (1973). *Manual of Tropical Housing and Building. Part 1: Climatic Design*. London: Longman.

Kohn, A. E., & Katz, P. (2002). *Building Type Basics for Office Buildings*. (Stephen A. Kliment, Ed.). New York: John Wiley & Sons.

Kolokotroni, M., & Aronis, A. (1999). Cooling-energy reduction in air-conditioned offices by using night ventilation. *Applied Energy*, *63*, 241–253.

Kolokotroni, M., Web, B. C., & Hayes, S. D. (1998). Summer cooling with night ventilation for office buildings in moderate climates. *Energy and Buildings*, *27*(3), 231–237.

Kreider, J. F. (2002). *Heating and cooling of building design for efficiency* (2nd edition). New York: McGraw-Hill.

Kubota, T., Chyee, D. T. H., & Ahmad, S. (2008). The effects of night ventilation technique on indoor thermal environment for residential buildings in hot-humid climate of Malaysia. *Energy and Buildings*.

Lam, J. C., & Hui, S. C. M. (1996). A review of building energy standards and implications for Hong Kong. *Building Research and Information*, *24*(3).

Lyons, P., Arasteh, D., & Huizenga, C. (2000). Window Performance for Human Thermal Comfort. *ASHRAE Winter Meeting*. Dallas, Texas.

Malaysia Meteorological Department. (2010). General climate of Malaysia. Retrieved on August 28, 2010 from http://www.met.gov.my/index.php?option=com_content&task=view&id=75&Itemid=1089&limit=1&limitstart=0

Marsh, A. J. (1997). *Performance analysis and conceptual design*. University of Western Australia.

Marsh, A. J. (2003). Ecotect and EnergyPlus. *Building Energy Simulation User News*, *24*(6), 2–3.

Marsh, A. J. (2008). Fitting a spatial analysis grid. *Natural Frequency Journal*. Retrieved from http://naturalfrequency.com/articles/analysisgrid

McHaney, R. (2009). *Understanding computer simulation* (p. 10). Roger McHaney & Ventus Publishing. Retrieved from http://www.bookboon.com

McQuiston, F. C. (2004). *Heating, ventilating and air conditioning: Analysis and design* (6th edition.). John Wiley & Sons.

MS 1525. (2007). *Code of practice on energy efficiency and use of renewable energy for non-residential buildings* (p. 29). Department of Standards Malaysia.

Mui, K. W., & Wong, L. T. (2007). Neutral temperature in subtropical climates - A field survey in air-conditioned offices. *Building and Environment*, *42*, 699–706.

Nasly, M. A., Yassin, A. A. M., Zakaria, Z., & Abdullah, K. (2009). Compressed Stabilised Earth as Load Bearing Interlocking Block. *Conservation and Susainability, RCER'09* (pp. 274–282).

Ng, B. H., & Akasah, Z. A. (2011). An Overview of Malaysia Green Technology Corporation Office Building: A Showcase Energy-Efficient Building Project in Malaysia. *Journal of Sustainable Development*, *4*(5), 212–228.

Nicol, F. (2004). Adaptive thermal comfort standards in the hot-humid tropics. *Energy and Buildings*, *36*(7), 628–637.

Ossen, D. R. (2008). *Tropical building design principles for comfortable indoor environment*.

Parson, K. (2010). Thermal comfort in buildings. In M. R. Hall (Ed.), *Materials for energy efficiency and thermal comfort in building* (pp. 127–147). Washington, DC: Woodhead Publishing.

Pfafferott, J., Herkel, S., & Jaschke, M. (2003). Design of passive cooling by night ventilation: evaluation of a parametric model and building simulation with measurements. *Energy and Buildings*, *35*(11), 1129–1143.

Rahman, I. A. (2005). *Malaysia Building Energy Estimation*. PhD thesis. University of Manchester.

Raman, M. (2009). Mitigating climate change: What America's building industry must do. *Design Intelligence*. Retrieved from http://www.di.net/articles/archieve/3097/

Razman, R. (2010). Thermal and structural properties of compressed earth brick. *Proceedings of the International Postgraduate Cnference on Engineering (IPCE 2010)*.

Reardon, C. (2010). Technical manual: Thermal mass. Retrieved July 17, 2011, from http://www.yourhome.gov.au/technical/fs49.html

Reddy, B. V. V., & Jagadish, K. S. (2003). Embodied energy of common and alternative building materials and technologies. *Energy and Buildings*, *35*, 129–137.

Ruyssevelt, P., & Batholemew, D. (1997). Stimulating simulation, computer tools in building services. *Building Services Journal*.

Sabarinah, S. A. (2002). A review on interior comfort conditions in Malaysia. *ANZAScA COnference 2002*. The University of Queensland, Brisbane, Australia.

Saidur, R., Hasanuzzaman, M., Hasan, M. M., & Masjuki, H. H. (2009). Overall thermal transfer value of residential buildings in Malaysia. *Journal of Applied Sciences*, *9*(11), 2130–2136.

Santamouris, M., & Wouters, P. (2006). *Building ventilation*. UK: The State of the Art, Earth Scan.

Sonia, P., & Valerian, M. (2005). Development of an integrated building design information interface. *Ninth International IBPSA Conference* (pp. 969–976). Montreal, Canada.

Square One Research. (2008). Ecotect software tool 5.60 (manual). Retrieved from http://www.squ1.com

Unver, R. (2004). Prediction of Building Envelope in the Design Stage: An Application for Office Building. *Building and Environment*, *39*, 143–152.

Vijayalaxmi, J. (2010). Concept of Overall Thermal Transfer Value (OTTV) in Design of Building Envelope to Achieve Energy Efficiency. *International Journal of Thermal & Environmental Engineering*, *1*(2), 75–80.

Walker, P. J. (1999). Bond Characteristics of Earth Block Masonry. *Journal of Materials in Civil Engineering*, *11*(3), 249–256.

Wang, Z., Yi, L., & Gao, F. (2009). Night ventilation control strategies in office buildings. *Solar Energy*, *83*(10), 1902–1913.

Wong, N. H. (2004). *Thermal performance of façade materials and design and the impacts on indoor and outdoor environment*.

Yin, H., Cong, Z., Ahmed, A., Tumwesigye, E., & Menzel, K. (2010). Building performance analysis based on modelling and simulation. *Proceedings of the International Conference on Computing in Civil and Building Engineering*.

Zain, Z., Taib, M. N., Mohd, S., & Baki, S. (2007). Hot and humid climate : prospect for thermal comfort in residential building, *209*, 261–268.

Zmrhal, V., & Drkal, F. (2007). Using energy simulation to operative temperature evaluation. *Proceedings: Building Simulation* (pp. 878–885).