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TROPICAL BUILDING DESIGN PRINCIPLES FOR COMFORTABLE INDOOR ENVIRONMENT

PRINSIP REKABENTUK BANGUNAN TROPIS UNTUK KESELESAAN LINGKUNGAN DALAMAN

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Abstract

It is a generally held view that, in tropical countries, traditional house is more sympathetic to the prevailing climate and provide comfortable interiors. This study analyses the above hypothesis for Tropical House in 'Taman Tropika' (TTH) Universiti Teknologi Malaysia (UTM), which was designed emplacing tropical design strategies.This house initiated good ventilation, which indicated indoor temperature similar with the outdoor condition. However, the architectural design solutions do not permit good passive cooling for thermal comfort for whole day. It is illustrated by the indoor temperature above the neutral temperature experienced during the day time. In this research, new tropical building principle has been suggested by adopting Taman Tropika house elements as alternative techniques for achieving passive cooling. The thermal comfort study in this research involved the use of field measurement and computer simulation using ECOTECT software. Validation of ECOTECT is done by comparing the computer simulation result with the field measurement. The results of the new tropical building principles illustrated that the indoor air temperature reduced by 3.5 ^{o}C and below the neutral temperature for comfort. The other important factor is that it can continuously maintain the comfortable condition during full day regardless of the available outside climate condition. This effect is significant toward improving the comfortable indoor environment of the tropical house.

Key words: Taman Tropika House, comfortable indoor environment, new tropical building design

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Abstrak

Secara umumnya telah wujud satu pandangan bahawa, di negara-negara tropika, rumah traditional adalah lebih bersimpati terhadap cuaca setempat serta menyediakan ruang dalaman yang selesa. Kajian ini menganalisa hipotesis diatas bagi Rumah Tropika di Taman Tropika (TTH) Universiti Teknologi Malaysia (UTM), yang dibina berdasarkan strategi rekabentuk tropika. Rumah ini menerapkan ciri-ciri pengudaraan yang bagus, yang mana telah menunjukkan suhu dalaman adalah sama dengan keadaan diluar. Namun, kaedah rekabentuk senibinanya tidak membenarkan penyejukan pasif bagi keselesaan terma pada siang hari. Ini telah ditunjukkan oleh suhu dalamannya yang melebihi paras suhu neutral yang dilalui sepanjang hari. Dalam kajian ini, prinsip rekabentuk tropika yang baru telah di cadangkan dengan mengambil kira elemen-elemen rumah tropika sebagai teknik alternatif untuk mencapai penyejukan pasif. Kajian keselesaan terma dalam kajian ini melibatkan pengukuran di lapangan dan simulasi berkomputer menggunakan perisian ECOTECT. Keputusan bagi prinsip bangunan tropika yang baru telah menunjukkan yang suhu udara dalaman dikurangkan sehingga 3.5°C dan kurang daripada suhu neutral untuk keselesaan. Faktor lain yang penting adalah ia boleh mengekalkan keadaan keselesaan secara berterusan pada hari penuh dengan tidak mengambilkira wujudnya keadaan iklim diluar. Kesan kajian adalah penting untuk memperbaiki keselesaan persekitaran dalaman di sebuah rumah tropika.

Kata kunci: Rumah Taman Tropika, keselesaan persekitaran dalaman, rekebentuk bangunan tropika yang baru

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LIST OF ABBREVIATIONS

ASHRAE	-	American Society of Heating, Refrigerating and Air Conditioning Engineers
AAC	-	Auto-claved Aerated Concrete
AMT	-	Annual Mean Temperature
CIBSE	-	Chartered Institution of Building Services Engineers
DBT	-	Dry Bulb Temperature
ET	-	Temperature Index
FR	-	Response Factor
MRT	-	Mean Radiant Temperatures.
NatHERS	-	National Housing Energy Rating Scheme
PMV	-	Predicted Mean Vote
RH	-	Relative Humidity
UTM	-	Universiti Teknologi Malaysia
WBGT	-	Wet Bulb Globe Temperature

LIST OF SYMBOLS

C	-	Celcius
dt	-	Temperature reduction
e	-	Emissivity
*P*a	-	The water vapor pressure
T_{amt}	-	Annual mean air temperature of the month
T_a	-	Mean air temperature of the month
T_c	-	Comfort temperature
T_n	-	Neutral temperature
T_o	-	Mean outdoor temperature for the month
v	-	Air velocity

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The Tropics regarded as a region where the human evolved and comfort has often been taken for granted, built environments are increasingly becoming issues of public concern. The tropical outdoor environment has been regarded as important as indoors in the life of the populace and which is remarkably evident in the vernacular architecture of the region. However, today many cities in the region experienced rapid urban growth often without much reference to the evolving urban environment. This tendency has put increased demand on the comfort requirements in the design of buildings. Comfortable out door spaces have a significant bearing on the comfort perception of the indoor ambience. The demand for comfort conditions in buildings are significantly increased as a result of exposure to uncomfortable outdoors (Ahmed, 2003). In the context of Malaysia, overheated outdoor environment of the city has contributed to a growing preference for a lower comfort temperature indoors. This in turn has put an immense pressure on the energy demand in the cities.

Local climate greatly affects the indoor thermal environment in buildings. In tropical climates, buildings are overheated during the day due to solar heat gain through the building envelope and solar penetration through windows (Rajapaksha, 2003). From a thermal comfort point of view it requires lowering of indoor daytime temperature below the outdoor temperature using building elements and by passive or active systems. Techniques for such thermal modification have been widely addressed (Givoni, 1994). From a thermal comfort point of view, climatic and physical factors other than air temperature are important. In outdoor conditions the radiant exchange of the human body with the environment is of special importance

due to exposure to solar radiation, the cold sky-vault, and warm and cool urban surfaces. The other factors influencing thermal comfort, air movements and humidity vary much more outdoors than indoors. There are, however, few studies has assessed the thermal comfort by calculation of the physiologically equivalent temperature (PET) (Johansson, 2006). A comfort index is determined by the environmental parameters that influencing thermal comfort: temperature, radiation, humidity and the wind speed.

The rational approach to thermal comfort seeks to explain the response of people to the thermal environment in terms of the physics and physiology of heat transfer. An 'index' of thermal comfort is developed which expresses the thermal state of the human body and in terms of the thermal environment (Johansson, 2006). Although the indices were based on the responses of subjects in constant-temperature conditions in climate chambers, it was hoped that such an index would express the response of people in variable conditions in daily life. In fact problems arise when rational indices are used to predict the thermal comfort of subjects from field surveys. Firstly the rational indices require knowledge of clothing insulation and metabolic rate which are difficult to estimate. Secondly they are no better than simpler indices at predicting the comfort vote (Humphreys and Nicol 2002) and the range of conditions which subjects find comfortable in field surveys is much wider than the rational indices predict. The reason for this has been the subject of considerable speculation and research, most of which have concentrated on the context in which field surveys are conducted. Nicol and Humphreys (1973) first suggested that this effect could be the result of a feedback between the comfort of the subjects and their behaviour and that they 'adapted' to the climatic conditions in which the field study was conducted.

Tropical House in Taman Tropika UTM was designed emplacing tropical design strategies of avoiding direct penetration of sunlight and applying natural ventilation. Without trapped hot air, the house experienced good indoor climate for thermal comfort (Ahmad 2001). Many visitors found the building provides good shelter during hot days, suggesting that indoor climate would be lower than the outdoor climate. However there is no evidence to justify the performance of this

building in term of its actual indoor climate and comfort condition that can be compared to establish thermal comfort condition as suggested by many researchers such as Md Rajeh (1989), Abdul Malik (1992) and Adnan (1997). The actual performance through this research can provide further improvements and directs in the advancement of knowledge and design appropriate within tropical climate. It is hypotheses that performance of Tropical House is similar or lower than outdoor environmental condition. This research will determine the justification of the hypothesis. The actual performance of the house can then provide new concepts, principles of passive design and help in the advancement of knowledge and design that is appropriate for tropical climate.

1.2 The Problem Statement

Hot humid tropical conditions in Malaysia affect the high temperature, and low air flow which affect on the comfortable indoor environment. Residential buildings are subject to significant cooling requirements due to high intensity of heat transient from building envelope. Tropical building design principle can significantly decrease air temperature in the rooms and large energy savings can be achieved.

An application of tropical building principle design reduces internal heat gain, high temperature in the room and make comfortable indoor environment. In hot humid climate, the problem emphasized by the fact that it is important to understand the solar radiation, temperature and wind profile outside buildings in order to achieve indoor thermal comfort.

1.3 Research Hypothesis

The hypothesis of this research is that a new tropical building roof, wall opening and landscape design principle will achieve the following:

- Decrease indoor air temperature compared with outdoor air temperature.

- Provide minimum temperature at thermal comfort temperature requirement.
- Determine the minimum temperature to predict the effectiveness of new tropical building design principle.

The term "new tropical building design principle" refers to best performance of building design principle which will decrease maximum indoor air temperature to obtain comfortable environment.

1.4 Research Questions

The following questions will be addressed in this study:

Q1. Does the use of tropical building design principle are effective in Taman Tropika House?

Q2. What is the influence of tropical design principles in Taman Tropika House with comfortable indoor environment?

Q3. What is the new tropical building design principle model to obtain maximum comfortable indoor environment under tropical climate condition in Malaysia?

Q4. Does the effective new tropical design principle at (Q3) achieve comfortable indoor environment in residential building?

Q5. What is the limitation of the new tropical design principle model to increase comfortable indoor environment in the residential building?

1.5 Research Objective

The main objective of this study is to assess and compare the impact of tropical building design principle for comfortable indoor environment in Malaysia residential building. Other specific objectives of the study are as follows:

- To identify and establish the effectiveness of existing tropical house design against actual outdoor condition
- To develop new tropical building design principles base on theoretical and actual building performance with scientific evidence

1.6 Scope and Limitations

The scope of this study is to evaluate the effectiveness of new tropical building design principle in Malaysia's residential building. The main focus is to determine the design parameters to achieve comfortable indoor environment. A single space room of prototype Malaysia traditional timber house (Taman Tropika UTM House) was selected for the experiment.

This study is entirely carried out using field measurement and Ecotect computer simulation program and thus bears the limitations of the simulation tool used. In the following chapter, a review on common research methods used by previous researches and justification for the selection of the present tool is discussed.

1.7 Importance of the Research

The out come of the study is expected to show that, the effectiveness of the new tropical building design principle will decrease air temperature for comfortable indoor environment. The study also expect to suggest that appropriate design decisions on tropical design principle can significantly reduce the heat gain in residential buildings in Malaysia. Apart from reduced air temperature, the use of new design principle has benefit on various other aspects as shown in figure 1.1 The most important aspect is the thermal environment and energy efficiency. Hence, findings of this study will enable and provide the building designer with wider range of options in selecting appropriate tropical building design strategy for achieving the balance between thermal environment and energy consumption.

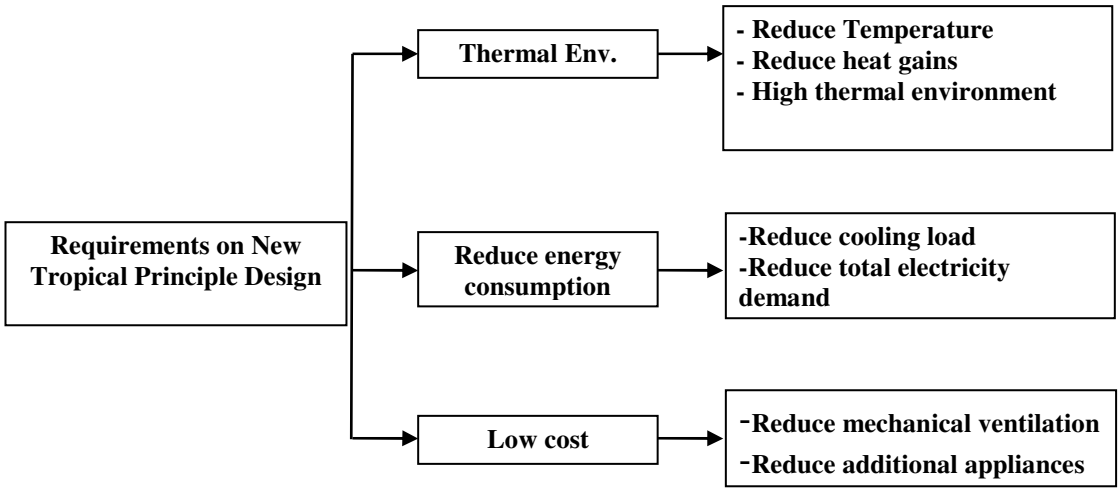

Figure 1.1 User requirements for new tropical building design principle

1.8 Organization of report

The report is divided into five chapters as summarized bellow.

Chapter one introduces the main issue of this research. This chapter discusses the research background, problem statements, hypothesis of the study, research questions, objective, scope and limitations of the study, importance of the research and the overall research structure.

Chapter two presents the literature review of tropical building design principle, indoor environment and thermal environment simulation. This chapter introduces an overview of tropical building design principle creating a comfortable indoor under Malaysia climate condition. All aspects of tropical design are discussed in this chapter with the intention of giving a review of roof and wall opening. The study also covers the concepts and work related to comfortable indoor environment that affect thermal environment especially comfort neutral temperature that have been carried out by other researchers. Finally, an appropriate computer simulation program is determined to analyse the performance of tropical design principles in relation to various design parameters.

Chapter three discusses the research design and the methodology implemented in tropical building design principle. The justification of selecting the

methodology for this study is also elaborated. The investigation conducted in this research was explained, including the field measurement and simulation method. The field experiment and simulation design method are discussed separately. Further, development of the base model, procedures, assumptions, limitations, condition and the overall setting-up of the field study and computer simulation are described. The reliability and validity of the methods, equipments and simulation procedures are also discussed. The estimation of the air temperature value for the research is also presented. Finally, the data analysis criterions are discussed, which is used to analyze the results of the experiment. Thorough analyses of the raw data collected from each type of study are discussed in the following chapter

Chapter four presents the results and analysis of field study, validation, configuration of tropical building design principle and performance of new tropical building design model. The principle findings of the field experiment and simulation are also summarized. The results of the research are analyzed as follows:

- Assess the field study and the validation of computer simulation of tropical building design principle in Taman Tropika House UTM
- Assess the configuration of tropical building design principle to achieve the minimum indoor air temperature.
- Assess the performance of new tropical building design principle under Malaysia climate condition.

Chapter five concludes the study by summarizing the major findings of the experiment. It also outlines the suggestions for future research on tropical building design principle especially on the area of limitations of this study.

CHAPTER 2

LITERATURE REVIEW

2.2 Tropical Building Design Principles

Generally the tropical zone is defined as the area of land and water between the Tropic of Cancer (latitude 23.5^{o} N) and the Tropic of Capricorn (latitude 23.5^{o} S). Occupying approximately forty percent of the land surface of the earth, the tropics are the home to almost half of the world's population. There are variations in climate within the tropic. However ninety percent of the tropical zones embody hot and humid climatic regions, whether permanent or seasonal. The remaining ten percent is desert like, and characterized as hot and dry climate (Baish, 1987). Local conditions may also differ substantially from the prevailing climate of a region, depending on the topography, the altitude and the surroundings, which may be either natural or built by humans. The presence of conditions like cold air pools, local wind, water bodies, urbanization, altitude and ground surface can all influence the local climate strongly (Gut et al., 1993). According to Gut et al. (1993) the main climatic factors affecting human comfort and relevant to construction are:

- air temperature, its extremes and the difference between day and night, and between summer and winter;
- humidity and precipitation;
- incoming and outgoing radiation,
- the influence of the sky condition, air movements and winds.

According to Gut et al. (1993) the main points to take into consideration when designing a tropical responsive building are:

- minimize heat gain during daytime and maximize heat loss at night in hot sea sons,
- minimize internal heat gain in the hot seasons;
- select the site according to microclimatic criteria;
- optimize the building structure (especially regarding thermal storage and time lag);
- control solar radiation;
- regulate air circulation.

Any building design for warm climatic conditions would attempt to exclude any of the above major heat loads arising due to the prevailing ambient temperature and the intensity of solar radiation. The interaction of solar radiation by the building is the source of maximum heat gain inside the building space. The natural way to cool a building, therefore, is to minimize the incident solar radiation, proper orientation of the building, adequate layout with respect to the neighbouring buildings and by using proper shading devices to help control the incident solar radiation on a building effectively. If ambient temperatures are higher than the room temperature, heat enters into the building by convection due to undesirable ventilation, which needs to be reduced to the minimum possible level. Incorporate these design principles into the design wherever possible. The tropical building principle are discussed thus include the elements of roof, wall, opening and landscape.

2.2.1 Tropical Roof Design Principles for Passive Cooling Strategy

A near vertical sun during the hottest hours of the day causes the roof to bear the greatest intensity of heat (Plumbe, 1987). The roofing should be tightly fixed and the material should insulate the building from both excessive heat and humidity. Big eaves are recommended as they create plenty of shade around the building and protect the outer walls from getting soaked (Duchein, 1988; Schüller, 2000). Pitched or sloping roofs are recommended, specially designed to stand the many and sudden tropical showers as well as the violent winds, from gusty to cyclonic. Metal roofs

made from aluminum, zinc, copper or stainless steel have the disadvantage of being very effective heat conductors, as well as possibly suffering from corrosion caused by contact with sulphur dioxide in the atmosphere (Duchein, 1988). Flat roofs are not advisable because of the risk of leaking during heavy rains (Karim, 1988). Flat roofs made of concrete with or without a false ceiling are often subject to cracking due to contraction and expansion (Plumbe, 1987). The construction of secondary roofs and facades, with a gap of several inches between the primary and secondary surfaces, to allow for ample airflow around the primary building, is very important. This prevents sunlight from shining on and directly heating the outside surfaces (Schüller, 2000). Thermal insulation or the construction of a false ceiling will have a similar positive effect. According to Agrawal (1974), a light roof colour to reflect unwanted summer heat may reduce the heat transmission into the building. The reflectance of a surface is a measure of the energy that is neither absorbed nor transmitted and is expressed as a ratio of the reflected energy to the total incident radiation energy. The roof tropical principle designs are discussed below.

a. Roof Solar Shaded

Appropriate external shading devices can control the amount of solar radiation admitted into the room, which could largely reduce cooling loads and improve indoor thermal comfort and day lighting quality. Bouchlaghem (2000) presented a computer model, which simulate the thermal performance of the building taking into account design variables related to the building envelope and optimize window-shading devices with optimization programs. Corrado (2004) evaluate the influence of the geometry of window-shading device system on the thermal performance. Liping (2007) study on facade designs to improve indoor thermal comfort for naturally ventilated buildings, especially for hot-humid climate. In addition, it is noticed that there are very few guidelines for facade designers of naturally ventilated buildings or for occupants with operation of individual control over their thermal environment for the hot-humid climate.

b. Roof Solar Reflection

According to Sharma (2003) if the external surfaces of the building are painted with such colours that reflect solar radiation (in order to have minimum absorption), but the emission in the long wave region is high, then the heat flux transmitted into the building is reduced considerably. For highly absorptive (low-solar reflectance) roofs, the difference between the surface and ambient air temperatures may be as high as 50°C (90°F), while for less absorptive (high-solar reflectance) roofs, such as white paint, the difference is only about 10°C (18°F). For this reason, "cool" roofs (which absorb little "insolation") are effective in reducing cooling energy use.

An alternative method is to provide a cover of deciduous plants or creepers. Because of the evaporation from the leaf surfaces, the temperature of such a cover will be lower than the daytime air temperature and at night it may even be lower than the sky temperature.

c. Roof Thermal Insulation

According Garde (2004) the major importance of good insulation of the roof in tropical climate is thickness and colour of insulation. In general, 5cm insulation is being used for red and blue tiled roofs, which is inadequate. Therefore, insulation thickness needs to be at least 8cm (the value for medium colours) and to use polystyrene as insulation rather than mineral wool. Mineral wool is fairly cheap but not very well adapted to tropical climates: it loses its thermal properties when it absorbs ambient humidity. In another experiment more than 3°C have been observed between a dwelling with a well insulated roof and with no insulation (Garde, 2004).

Palomo (1998) showed that a well designed and managed green roof could behave as a high quality insulation device in summer, reducing the heat flux through the roof. The parameters determine the role of the canopy as a shadowing device. The thickness of the soil layer, its apparent density, and its moisture content

determine the soil thermal diffusivity. It increases with the apparent density, and decreases with the soil moisture content.

f. Summary

The optimisation of the thermal performance of the roof was achieved through different levels of thermal mass, insulation, geometry of ceiling, external colour and levels of ventilation (attic). For both operation modes, the use of low absorptance values substantially reduced the cooling energy requirements (Parker *et al*., 1995) and the degree hours of discomfort. The use of ceiling insulation was also a determinant of thermal performance. It was the most effective element of improvement of roofs. Higher values of insulation showed no improvement. In fact, for higher mass cases, the effect was adverse, as the super insulation prevented heat dissipation at night. For both modes, the use of an attic roof ceiling improved performance. The higher levels of ventilation of the attic did not show much improvement in performance of the zone below, for either of the operation modes, unless no insulation or higher absorptance values were used.

2.2.2 Tropical Wall Design Principles for Passive Cooling Strategy

Today, buildings are required to have a high degree of thermal inertia so that the interior temperature and relative humidity remain reasonably stable and unaffected by fluctuations in exterior conditions. The design of wall is a potential for passive control of a building's indoor conditions by managing the transference of external outdoor temperature. Construction materials such as concrete, brick, cement block and other solid masonry materials are considered as having high thermal mass. However, high thermal mass materials are considered very effective against rapid heat transfer, which is mainly due to their properties to absorb heat from solar radiation at a much slower rate than lightweight materials with a low thermal mass. Lightweight materials of timber, steel and the various building wall materials absorb heat quickly and conversely cool down quickly. A composite construction wall may

be a compromise solution ideally suited to the local climatic conditions. From literature review it was found that there are four tropical designs factor for wall. They are wall solar shade, solar reflection, thermal material and thermal insulation.

a. Wall Solar Shade

The impact of solar protection of walls is of less importance than the solar protection of windows. Therefore, if a project is too expensive, the preferred initial source of economy is the wall protection. Garde (2004) highlighted that an overheating of 2ºC was observed in rooms with coloured concrete walls exposed to the solar radiation compared to rooms with no walls exposed. The most important surfaces to treat therefore are those most exposed to the sun that is to the east and west, and to a lesser extent, the northern and southern surfaces. The other surfaces could be granted dispensations, or else given less requirements (Garde, 2004).

b. Wall Solar Reflection

The use of reflective surfaces to avoid solar gains and the use of reflective insulation are the most effective means of improving attic performance. According to Rosangela (2002) the use of a white reflective surface indicated the best performance, and minimized the need for insulation. Also, the differences in wall types were almost equalised when white surfaces were tested. For the solar protection of the dark colored house wall of reflectance, it was recommended to put 10 cm insulation instead of the 6 cm. No insulation was planned for the solar protection of medium colored walls. A dispensation was granted over this point as well (Garde, 2004).

c. Wall Thickness

The variation in wall thickness makes a significant difference in the comfort performance of houses. Fuad H Mallick (1996) indicated rooms with thicker walls tend to be more comfortable. Comparison of temperature measurements in houses that have wall thicknesses ranging between 125 and 500 mm shows that rooms with thicker walls tend to be more comfortable, particularly in hot and dry period between March and June in Bangladesh. Houses which have thick walls and are on lower floors can be comfortable all year round as opposed to ones that are on top floors (Fuad H. Mallick, 1996). Thermal transmission in a certain material depends upon the thermal property (in this case the thermal conductivity) and the thickness of that material. The lower value thermal conductivity will have less thermal transmission. Similarly, the thicker insulation material will create less thermal transmission (Mahlia, 2007). From traditional knowledge, low-mass materials such as wood are considered appropriate for free-running operation in hot humid climates as their indoor temperature drops rapidly in the evening, when the winds usually subside. High-mass buildings cool down more slowly during the night, which is a feature to cause discomfort during sleep. Over a 24 hours period high-mass buildings can have more cumulative degree hours of discomfort, but on a daytime basis only they have far more advantages. The conclusion is that for free-running operation, if there is assisted ventilation at night, for most of the time high mass buildings can be more comfortable than low-mass ones (Rosangela, 2002).

d. Wall Thermal Insulation

Massing of the enclosing envelope is a parameter that is mostly related to the thickness and type of the construction material used and its ability to delay heat transfer through the building structure over a period of time. It is another important parameter in determining thermal performance of the building and hence the energy required to provide thermal comfort in the occupied space. Results indicate that insulation materials subject to high temperature have higher thermal conductivity and

therefore higher envelope cooling load with varying degrees depending on the type of insulation material.

According to Mahlia (2007) suggest that fiberglass–urethane is the most economic among other insulation materials. If we see the thermal conductivity, perlite has the highest thermal conductivity among the insulation materials. Higher the thermal conductivity of an insulation material means lower thermal resistance; therefore the thickest thickness is required to be used in order to get optimum thermal insulation. The thickness of insulation material is an important part in designing of building since thick insulation material will reduce the space of building significantly.

Thermal insulation is a major contributor and obvious practical and logical first step towards achieving energy efficiency especially in envelope-load dominated buildings located in sites with harsh climatic conditions. The thermal performance of building envelope is determined by the thermal properties of the materials used in its construction characterized by its ability to absorb or emit solar heat in addition to the overall U-value of the corresponding component including insulation. The placement of insulation material within the building component can affect its performance under transient heat flow. The best performance can be achieved by placing the insulating material close to the point of entry of heat flow. However, for practicality it is common to use insulation to the inside or between wall cavities (Al-Homoud, 2005).

e. Summary

The building wall is affected by all three heat transfer mechanisms; conduction, convection, and radiation. The incoming of solar radiation into the outer wall surface will converted to heat by absorption and transmitted into the building by conduction. At the same time, convective thermal transmission occurs from air outside of the building to the outer surface of the wall and the inner surface of the wall to the air inside of the building. It makes most portion of heat gains from the

outside of the building wall occurs by conduction through the building wall and by air leakage since the inner building area has lower temperature. In order to lower the heat flow from outside into inside building, insulation material is usually used. This material has a very low thermal conductivity. In this case, a suitable insulation material with its optimal thickness is necessary in order to have an economic cooling load system. The insulation thickness will increase the investment cost, but the cost of energy will decrease, until at one point the thickness of material is optimum and will contribute the highest overall cost savings.

2.2.3 Tropical Opening Design Principles

In traditional buildings designers place windows at certain points to create a current of air. Further, opening windows can reduce heat and humidity, but on the other hand the existence of windows can increase inside temperatures with solar penetration. East and west-facing walls and windows are the most important to shade, as solar heating is most intense on these orientations. Reduce unwanted morning and afternoon solar heat gain by minimizing or protecting extent of walls and windows facing east or west. Planting trees around the building is one way of controlling the temperature in repositories and keeping the sunlight out as well. A comprehensive list of shade giving trees is given in Gut *et al*.,(1993). Trees can also form a security risk providing easy access to windows as well as the roof. A simple way to reduce the heat-gain of the building is for the windows to catch the prevailing breezes. There are two factors used in determining the opening in tropical building; solar shade and size.

a. Solar Shade

Climate conscious design in the tropics must be attempted in order to prevent solar heat gain into the building. The primary design strategy implies that exploration of the shading potentials is to reduce the total heat gain through the wall openings. These strategies in broad term can be achieved by two means; natural devices and

sun control devices. The natural shading strategies are the means of shading the building with orientation of the sun and by the use of vegetation. Apart from the natural devices, sun control devices are used to exclude the unwanted solar radiation penetration into the building. The design, fixing location, effectiveness in terminating the direct sun and operational systems are attributes of the sun control devices. They can broadly divided into two; internal and external devices

Internal devices to control solar radiation can be categorized into two types; firstly, solar shading using blinds, louvers, drapers and screens which are other than the window glazing pane. Secondly, the use of special glazing without the use of external or internal shading devices. Compared to external devices, the internal solar shading devices are less effective, as they allow solar radiation to strike on the vertical surface of the building. They also permit the heat into the building.

External devices are projections attached to the building skin or an extension of the skin to eliminate unwanted solar heat. They are more effective as they intercept the solar radiation before it reaches the vertical surface of the building envelope. The obstructed heat is dissipated to the out side air. Thus, heat reduction is best achieved by excluding unwanted heat rather than removing it later.

The horizontal (overhang) and vertical (fins) devices are the two basic forms of external shading devices. The egg crate devices are combinations of the horizontal and vertical devices. Based on these basic forms, configuration of the external shading devices varies from structural projections in the form of cantilevered floor, recessed walls and shading devices using light weight materials. The form of horizontal and vertical fins and light shelves perform a similar function. Use of lightweight materials enabled to give more flexibility in operating solar shading. Configurations of operable shading device were able to change or adjusted to the changing patterns of sun's motion and the shading needs. Therefore, the performance of an operable device in eliminating the unwanted heat is better than a fixed device (Givoni, 1998). The fixed device needs no handling by the occupant and free of maintenance, while operable devices need frequent maintenance to keep them in good condition. Operable system is more useful in temperate and cold climates as it can be adjusted to get more favored solar heat during winter but obstruct the heat

gains during summer. In the tropics, it can be useful to control glare, daylight and solar heat gains. Advent of technology has enabled development of automatically controlled operable devices with solar sensors for efficient use.

Canopy and awnings are another form of external horizontal solar shading device, mostly used for high solar altitudes. Effectiveness of the canopy and the awning depends on; material used (thermal and optical transmittance, colour), geometry and fixing position and details (Dubois, 2001). Studies done by the same author indicated that the canopy or awning angles (to vertical surface) are also an important aspect in reducing building energy consumptions.

However, there are structural and architectural limits in designing external projections. Excessively long projections can be alternated with number of smaller projections at different heights and widths to obtain the same solar protection (Olgyay, 1957). In most cases, limitations were imposed based on structural and architectural reasons, than concerning on the energy implication.

b. Opening Size

Cross ventilation is of prime importance in humid tropical climates as well as the solar protection of the roof. As for these two projects, natural ventilation of dwellings is efficient during the hot and humid season. This is quite a good result because the main objective of the building design in tropical climates is to avoid the overheating of the indoor temperature by keeping it at least below the outdoor temperature. The comparison of the indoor air temperature shows a gap of more than 1.5 °C between the cross-ventilated dwelling and the other one (Garde, 2004). Prianto (2003) examined various types of louver to improved the comfort level by use of increased air velocity. Louver window at the ceiling height and floor level with angle of 45 degree achieve a comfortable condition under activities of 1 and 1.25 met. The modification on the ceiling height at balcony and the enlargement of opening dimension on façade has no significant effect on the indoor comfort level. Actually, for heavyweight construction types smaller opening areas provided better

performance also for free-running operation. Based on these simulations, a 50% value was set as a maximum window opening area in terms of wall area for dual mode operation (Rosangela, 2002).

c. Summary

Windows facing east or west should be protected by a sufficiently wide horizontal-shading device (such as wide eaves, verandah or pergola), a vertical shading device or the window should be small and placed high on the wall under the eave. External sun-shading devices are preferred to internal and interstitial shading devices. Aligning windows and doors should assist in maximising natural ventilation to allow for the capture of prevailing breezes and to allow cross-flow breezes in summer. Provide high-level ventilation through roof cavity space via roof vents. Choose window types that offer the best ventilation performance or alternatively look at design combinations that fit the situation

2.2.4 Use of Landscape Design Principles

The essence of landscape planning for passive cooling is to modify the aspects of air temperature, humidity, radiation and air movement in such a way as to bring existing or unpleasant conditions as closely as possible into the climatic conditions which are comfortable to specific persons on a precise site at a particular time. A well thought-out landscape design, incorporating hard and soft landscape elements, is expected to help control the microclimate and thereby significantly reduce the amount of heat gain in the house (Parker, 1981). The landscape elements, comprising various types of hard and soft material can absorber, re-radiate and act as thermal insulation.

a. Natural Solar Shade

Shading by trees and vegetation is a very effective method of cooling the ambient hot air and protecting the building from solar radiation. The solar radiation absorbed by the leaves is mainly utilized for photosynthesis and evaporative heat losses. A part of the solar radiation is stored as heat by the fluids in the plants or trees. The best place to plant shady trees is to be decided by observing which windows admit the most sunshine during peak hours in a single day in the hottest months. Usually east and west oriented windows and walls receive about 50% more sunshine than the north and south oriented windows/walls (Garde, 2004). Trees should be planted at positions determined by lines from the centres of the windows on the west or east walls toward the position of the sun at the designated hour and date. A major advantage of the use of vines and creepers in passive cooling strategy landscaping is their potential to cover a large portion of a building in a very short period. Consequently, they can be effectively utilized during the period required for the establishment of the trees and shrubs in the landscape. They are also useful in situations where there is limited ground space.

b. Ground Surface Treatment

In a region where surface temperatures of concrete can reach as high as 55°C (and metal up to 70°C), extreme care has been taken in the design and location of each hard landscape feature around the test house. Paved surfaces can absorb and re-radiate great quantities of heat. Any ground surface design should minimize the heat collector surfaces. Where paving is necessary it need to incorporate with intervening patterns of grass cover and shade by some form of architectural element, tree plantings or a combination of architectural elements and plant material (vines and creepers). The colour of the paved surfaces has a great deal to do with the heat absorption and re-radiation. Lighter colours with rough surface finishes were used to reduce glare. Overhead structures, both attached and unattached, have been used to reduce heat absorption and re-radiation from the horizontal (roof, driveway and pathways) and vertical (boundary walls, dwelling walls and openings) surfaces. Open

type wooden or aluminum structures were used to let breezes through and to support plant material, like vines, for additional cooling. Structures attached to the building have proved very helpful in reducing direct heat gain in the buildings (Bajwa, 1995).

c. Ground Thermal insulation

Because of the thermal storage capacity of earth, the daily and even the annual temperature fluctuation keeps on decreasing with increasing depth below the ground surface. At a depth of 15 m, the earth has a constant temperature of 10°C. The level of water table plays an important role here. In summer and particularly during the day, the ground temperature is much lower than the ambient air temperature. If a part of the building is earth bound, the building loses heat to the earth particularly, if the insulation levels are low. The most ancient dwellings were often dug into the ground or covered with earth to take advantage by transferring the heat to the deep earth (Rosangela, 2002). According to an experiment on two floor types by Rosangela (2002) experiment two floor types, suspended timber and concrete slab on ground, the on-ground type floor had superior performance. The explanation for the better performance of the on-ground type is directly related to the mass of the ground, which acts as a heat sink to the floor above. The first simulations for the un-insulated timber floor assumed a fully enclosed perimeter (with 0.4 m high under-floor space). For both free-running and conditioned operations, the concrete slab on ground performed better. The use of insulation (EPS or carpet) for the on-ground floor type decreased performance in both modes. This is to be expected as the insulation increasingly isolated the room from the mass of the ground.

f. Summary

In open spaces, solar radiation and wind must be considerably controlled to provide human thermal comfort to guarantee the use of these public spaces. Referring to the geometry, sun trajectory diagrams and solar masks, corresponding to the place latitude, must be known and taking into account. Shadowing areas by

constructed elements (pergolas, marquises or kiosks) or by the disposition of trees, together with the use of low absorbing or reflective surface materials, can minimize the problems provoked by excessive solar radiation first by the control of solar radiation that arrives directly on people and also by diminishing the environmental temperature. Materials employed and the buildings sizes affect the thermal comfort of indoor condition. The colors of the surrounding surfaces are also important due to its capacity to absorb different amounts of solar radiation. These amounts will be determined by the facility of radiation to reach these surfaces, considering the existing elements that reduce radiation, such as marquises, trees, etc. Surface colors and reflectivity and the surrounding materials diffusivity and effusively modify infrared radiation and therefore the comfort sensation for occupant. The greater the area covered by buildings and constructions, the greater impermeability will result from the relation between the paved soil and the naked but compacted soil. Impermeability is one of the elements that have influence on the reduction of the relative air humidity, on the infrared radiation increase, which results from the superficial temperature raise (Barlag A, Kuttler W. 1991).

2.3 Comfortable Indoor Environment

The number of indoor thermal comfort studies far outweighs the number performed outdoors (de Dear R. J, 2002), and those outdoor studies that do exist are usually premised on the assumption that indoor comfort standards are applicable outdoors. Predicted Mean Vote (PMV) is an indoor comfort model to equate thermal conditions with levels of physiological strain in human subjects. PMV predicts the thermal sensation of a person based on the six thermal comfort variables, parameterized into a heat-balance equation and outputting results on a scale from -3 to +3 (where -3 is cold, 0 is neutral, +3 is hot). The PMV index has been partially validated in a variety of indoor contexts (McIntyre DA., 1980; de Dear RJ, 1985) and a PMV value between ±1 is widely considered to be “thermally acceptable” (Fanger, 1970, ASHRAE, 2001). Based on Fanger’s, (1970) generalization that one PMV scale unit corresponds approximately to a change in temperature of 3ºC ($\Delta PMV/\Delta t = 1/3$) under mid-range clothing insulation and near-sedentary metabolic rate, the VDI

3787 (Spagnolo, 2003) guideline implies that a narrow band of ±1.5ºC around the neutral temperature circumscribes “thermal comfort”.

The PMV scale was developed to describe thermal discomfort, not thermal stress, therefore its relevance to conditions that vary greatly from neutrality, as many outdoor climatic conditions do, remains untested. The psychometric tool at the very core of thermal comfort research (including models like PMV) is the seven-point scale of thermal sensation, but its performance under more extreme outdoor climatic environments remains largely untested. The basis for using seven points and not more or less has been established in psychological studies (Miller GA., 1956 and Osgood CE, 1957), but it has been suggested (Wilkinson RT., 1974) that the experimentally determined optimum temperature in climate chamber studies may be subject to the “range effect”, where the optimum temperature is biased towards the mid-point of the range of temperatures to which the subjects are exposed, although there is no definitive experimental evidence for this hypothesis. An excellent review of the seven-point scale is given by McIntyre (1980).

The fact that the outdoor microclimate is generally assumed to be beyond architectural and mechanical control leads people to expect the conditions experienced outdoors to fall within a much wider range than the indoor climates experienced in their home or office and therefore, because of this expectation, the range of conditions that they would regard “acceptable” should also be considerably wider than in the indoor context. To date, many of the well-known outdoor environmental indices (e.g. AT (Steadman RG.1984); windchill (Siple PA, 1945); wet bulb globe temperature (WBGT) (ISO-7243., 1989) were developed to predict and warn against heat or cold stress, as distinct from thermal comfort. Conceptually we can regard the human thermal environment as a set of concentric “zones” with thermal preference at its centre, Ranked by a wider band of thermally comfortable conditions, which in turn may be Ranked by wider bands of acceptable thermal conditions, then uncomfortable, then moderately stressful, then stressful conditions, and finally, hazardous thermal environments.

2.3.1 Comfort Neutral Temperature

Nicol (2004) presented evidence that the comfort temperature in free-running buildings depends on the outdoor temperature. Humphreys (1978) have shown that for free-running buildings the relationship between comfort temperature T_c and outdoor temperature T_o is remarkably stable. The relationship for buildings which are heated or cooled is more complex, and less stable. It is less precise because when a building is heated or cooled the indoor temperature is decoupled from the outdoor temperature and the indoor temperature is more directly governed by the custom of the occupants (or their building services manager). This custom is not absolute as shown by the wide range of comfort temperatures for heated and cooled buildings. There is also a difference of some 2ºC in indoor comfort temperatures for heated and cooled buildings between the two databases according to Humphreys (1978) and de Dear and Brager (1998). Whilst it is not clear whether this is due to a change in preference over time or to other differences between the two databases, the preferred indoor temperature may need to be determined from time to time or between one group of people and another. It should be noted that this does not put the adaptive standard at a disadvantage vis-à-vis the rational indices. These also need to know of changes of clothing behaviour and working practices if they are to reflect changes in comfort temperatures.

Defining the range of conditions which will be found comfortable around the comfort temperature is problematic. The adaptive approach tells us that variability in indoor temperatures can be caused by actions taken to reduce discomfort, as well as those which are uncontrolled and therefore more likely to cause discomfort. Adaptive thermal comfort is therefore a function of the possibilities for change as well as the actual temperatures achieved. The width of the comfort 'zone' if measured purely in physical terms will therefore depend on the balance between these two types of action. In a situation where there was no possibility of changing clothing or activity and where air movement cannot be used, the comfort zone may be as narrow as 2ºC. In situations where these adaptive opportunities are available and appropriate the comfort zone may be considerably wider.

a. Comfort Temperature

The indoor design temperatures as described by international standards (ISO 7730 (ISO 7730, 1994) and ASHRAE 55-1981, ASHRAE 55-1992 take no account of climatic variations and people adaptive behaviour. For any task and use of the building, there is a recommended temperature that is assumed to apply irrespective of climate and people culture, way of life and kind of clothing, though with some recognition of difference between summer and winter.

Analysis of thermal comfort field studies have shown that indoor comfort temperature as felt by the occupants is function of mean outdoor temperature (Humphreys, 1978; Auliciem, 1981; Nicol, 1994)

This means that we can relate indoor comfort temperature to climate, region and seasons. For free running buildings and according to different surveys held under different climatic conditions, Humphreys (1978) has found that the comfort temperature can be obtained from the mean outdoor temperature with Eq. (1)

$$T_c=0.534T_o+11.9 \qquad (1)$$

Auliciems (1981) revised Humphreys equation by deleting some fields studies such those with children as the subjects, and adding more information from other studies not included by Humphreys. These revisions increased the database to 53 separate field studies in various climatic zones covering more countries and more climates. After combining the data for naturally ventilated buildings and air-conditioned buildings, the analysis led to an equation involving the outdoors air temperature (T_o) and the indoor air temperature (T_i), this resulting equation is [Eq. (2)]:

$$T_c=0.48T_i + 0.14T_o + 9.22 \qquad (2)$$

Auliciems (1986) has also proposed a single line for all buildings which covered the naturally ventilated buildings and air-conditioned buildings. This relation is given by Eq. (3)

$$T_c=0.31T^o + 17.6 \qquad (3)$$

Nicol has conducted several surveys under different climatic conditions. In a first survey in Pakistan (Nicol, 1996), he has established a relation between comfort temperature and outdoor temperature given by Eq. (4)

$$T_c=0.38T_o + 17.0 \qquad (4)$$

In a second survey in Pakistan (Nicol, 1996), he has found a second regression given by Eq. (5)

$$T_c=0.36T_o + 18.5 \qquad (5)$$

Those relations show clearly that the comfort temperature is related to the outdoor temperature and so to the climate. The difference between those relations confirms that there is no universal comfort temperature. Each community must have its own perception of the thermal comfort according to its climate, local culture and type of buildings.

b. Neutral Temperatures

Another interesting way of examining thermal sensation is through the use of neutral temperatures, i.e. the thermal conditions where people feel neither warm nor cool, but neutral (Nikolopoulou, 2005). This term was first introduced by Humphreys (1975), when he showed that variation of the neutral temperature is associated with the variation of the mean temperature (Humphreys, 1975).

Deciding what temperatures to provide in buildings is a complex problem. One way around this is to treat the process as a black box where the internal mechanisms of the relationship between comfort and the environment are less important than the outcomes. This is the approach taken by those who use field

surveys to investigate the problem. In the field all the variables are in action—people are free to change their clothes, their activity, their posture and when the building allows it, to change the temperature, air movement and even the humidity.

Nicol and Humphreys (1973) presented the results of field studies in the UK, India, Iraq and Singapore. The result shows that mean comfort vote changes little with the mean temperature experienced. Note that temperatures well above 30 ◦C are not considered uncomfortable in some cases. Subsequent work by Humphreys (1975) showed that the temperature which people find comfortable is closely related to the mean temperature they experience. In other words people find ways in which to make themselves comfortable in the conditions they normally experience: they *adapt* them behaviorally. Recent work by Humphreys and Nicol (2000) using data collected by deDear and Brager (1998) shows that, taking account of differences in the calculation of comfort temperatures, almost exactly matches these earlier findings.

This relationship enables building professionals to predict the temperature which will be comfortable in free-running buildings by calculation from the monthly mean outdoor temperature given by meteorological records. Results for Islamabad, Pakistan indicated the comfort temperature overlaid on the outdoor temperature to indicate the temperature differential which the building must achieve to remain comfortable indoors. In this case the building must be warmer than the outdoor mean in winter and cooler in summer, but by amounts which it might be possible to achieve by passive means (certainly in winter). A comfort *zone* within which temperatures are generally acceptable can be taken to extend some 2–3 ◦C either side of this optimum temperature.

c. Neutral Temperature Zone in Malaysia

The analytical method of evaluating the comfort zone for Malaysia have been studied by several authors (Rajeh, 1988; Abdul Malek and Young, 1993; Zain Ahmed, Sayigh and Othman, 1997; Abdul Rahman and Kannan, 1997, Hamdan,

2007), using the "Neutrality Temperature". This is the temperature at which the respondents in the various studies experienced neither warm or cool, which is a state of "neutral" or "comfortable". It is the mid point of the comfort zone, as an average value for many experimental subjects. There four factors that can combine together to produce different neutral temperature for the individual: thermal environment, level activity, thermal insulation of the clothing and physiological state of the individual. For adults the neutrality temperature ranges from 17°C to 30°C. The observed range of neutrality temperatures is therefore effectively 13 degree. But it is necessary to conclude that acclimatization also had an affect on the temperature required for thermal neutrality. Szokolay recommended the use of the annual mean temperature (AMT) for applied Auliciems's equation for Kuala Lumpur data (Rajeh, 1988). The comfort temperature or neutrality temperature can be predicted from the linier equation for naturally ventilated building as cited by Hamdan (2007):

$$T_n = 17.6 + 0.31 \times T_{amt} \qquad (6)$$

Where,

T_n = neutral temperature with$^{+/-}$ 2°K range

T_{amt} = annual mean air temperature of the month

The comparative comfort zone, using above equations and the annual mean air temperature of the month worked out from the climatic data for Malaysia weather data. This will give a general picture of the range of comfort zone for Malaysia. According to Szokolay (1997) with the range of the comfort zone is taken as 5°C, thermal comfort temperatures extends approximately about 2.5°C above and below the neutral temperature. While Humphrey's equation gives a good approximation of a single comfort temperature in free running buildings, the thermal comfort zone defined using solely this technique does not accommodate the influences of thermal comfort in hot and humid climates.

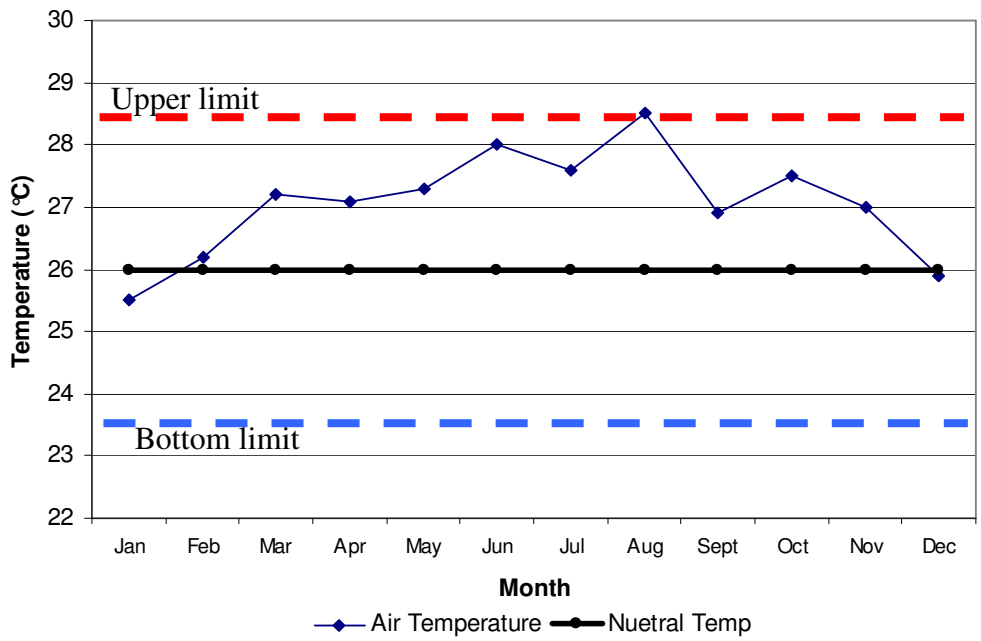

Figure 2.1: Neutral temperature range on the Ecotect monthly data

Daily climatic patterns in the tropics required climate conscious building design strategies to achieve thermal comfort. Outdoor temperature for monthly data is plotted in Figure 2.1. According to the fig.2.1 the outdoor air temperature reached to 28.5°C in August. The lowest temperature was reported as 25.5°C in January and the average temperature is about 27°C. According to Szokolay comfort formula, the neutral temperature needed to maintain at 26ºC. The single value resulted from this comparative study was confirmed with previous study. With the width of the comfort zone taken to be 5ºC (Szokolay, 1997), thermal comfort temperatures extends approximately about 2.5ºC above and below the neutral temperature. Taking the neutral temperature of 26ºC in free running building as an illustration, the upper limit of the comfort zone would then be 28.5ºC. This neutral temperature is for conditions without air movement.

2.4 Computer Simulation Study of Indoor Environment

Review of the above stated methods informed that simplified design and calculation is unreliable and does not represent real-world complexity. While field experiment requires complex and comprehensive procedure in methodology,

limitation in available equipment, limited budget and time consuming. Therefore, computer simulation is an alternative method for this study.

Over the past 50 years, literally hundreds of energy programmes have been developed, enhanced and applied in the building energy community. New design tools approach enable all simulation model being simulated under virtual condition. Computer simulation tools developed by scientist and researcher provide accurate result and the models in simulation adequately represent real-world complexity (Sonia, 2005). However they require extensive training, for learning on how to use them, preparing input, running and interpreting the result to the requirement of the research.

Technology and information today allow scientists and researchers to bring computer simulation tools to implementation in actual building design and construction (Kristensen, 2003; Garde F. et al, 2001; Shaviv E., 2000). Study from Garde F. et al (2001) demonstrates the methodology of the above methods. Firstly, identify the specifications needed to consider in the building design and complete the simulations for each specification. Then, implement the solutions on real projects and finally have the experiment validated.

2.4.1 Selection of Computer Simulation Software

Sonia (2005) recognizes the need for building simulation or performance tools that can be integrated into the building design process. The complexity of simulation tools created by scientists, who are more technically oriented, discourages architects or designers who are more visually oriented people to use them.

The selected computer simulation programme must provide a design tool that is user-friendly and easy-to-use. Sonia (2005) describes the following factors to be integrated into the programme:

a. Provide designers with a building performance tool that would aid in the design process.

b. Provide a front-end that supports AutoCAD so that the building information can be assigned to the drawings.

c. Develop a graphical user interface where the mode of output is both graphical and numerical.

d. Provide designers with building design information tool that requires the least amount of training and yet is very easy to learn and use.

e. Provide designers option to create their own custom databases of building components.

f. Allowing researchers to expand or further their study to widen perspective and scope (expandable design tools).

The purpose of this study is to understand the indoor environment on tropical climate in minimising the indoor temperature. The selected computer programme should be able to analyze thermal performance and simulate any possibility of tropical design strategy. Therefore, the computer simulation programme must fulfil the following criteria:

a. Provide required climate condition and weather data for the specified location of the study being carried out.

b. Provide detailed weather data input for hourly climate data (solar radiation, temperature, humidity, wind).

c. Provide editable modeling features, for example options in creating various generic building shapes and further modification it into building shape.

d. Provide thermal analysis that enables distribution of computation at required time-step.

2.4.2 Review of Thermal Simulation Software

Sonia (2005) explained those most available simulations programmes were originally developed by researchers to have extremely sophisticated analysis tools. It

requires significant amount of detailed information about the building and its context. The input requires mechanical engineering data that comes at the end of the design process and the output is largely numeric or text. It becomes difficult for architects to incorporate the analysis results during the process of designing. Building designers require energy analysis tools that are quick to use and produce result that are easy to understand. Gratia E (2004) believes that user interface tool for architects should be very user-friendly and uses visual language of architects based mainly on illustrations.

The comparative surveys of twenty major building energy simulation programme developed by Crawley, et al, (2005) became the reference of many researchers. Availability of the comparative analyses provides immediate information for researchers to have a quick view and precise assessment based on information provided by the programme developers in various categories such as general modeling features, building envelope and daylighting, climate data availability, validation and links to other programmes.

From the comparative survey, the following simulation programmes fulfil the required criteria of this research: ECOTECT, Energy Plus, e-QUEST, TRNSYS and IES <Virtual Environment> (IES <VE>). ECOTECT is the ideal simulation programme for this study that can fulfil all experiment requirements and can easily be integrated into the building design process. A generative design tool is suitable for complex and expendable models.

CHAPTER 3

METHODOLOGY

In order to achieve the objectives of the research, to test the research hypothesis and to answer the research questions that have been laid in chapter I, this research is divided into three main stages. Firstly, review and validation of the selected building simulation program to be used in the research. Secondly, method of the field study is described and finally, development of simplified model using tropical design principles. These methodologies were reviewed and selected for the purpose of this research.

3.1 Research Design

In order to achieve the research objectives, the following steps are suggested: preparing climate data, field measurement, ECOTECT software validation, simulation of Taman Tropika house model and indoor comfort analysis. In this study, the climate data of Malaysia with Kuala Lumpur weather data will be adopted for analysis. The weather data will be used to determine the trend of the monthly dry bulb temperature, wind speed and relative humidity available for thermal environment in Taman Tropika house at UTM skudai, Johor Bahru. Climate data consist of annual climate data and design day of dry bulb temperature of each month. The effect of tropical design principle for thermal environment is quite difficult to be determined by analytical means. The simplest means is to investigate by using computer simulations of both the climate data and buildings elements. The ECOTECT is the instrument that is used to model the thermal environment of the Taman Tropika house. The program is validated by comparison between field study

and ECOTECT simulation. This step will involve the testing of a modification the Taman Tropika house design principle in order to fulfill previous stated objective. Several elements of a Taman Tropika house principle design (roof, wall, opening, landscape) is built to a scale of 1:1. The testing of the models exclusively is divided several parts to ease the comparison between various modifications of thermal environment performances.

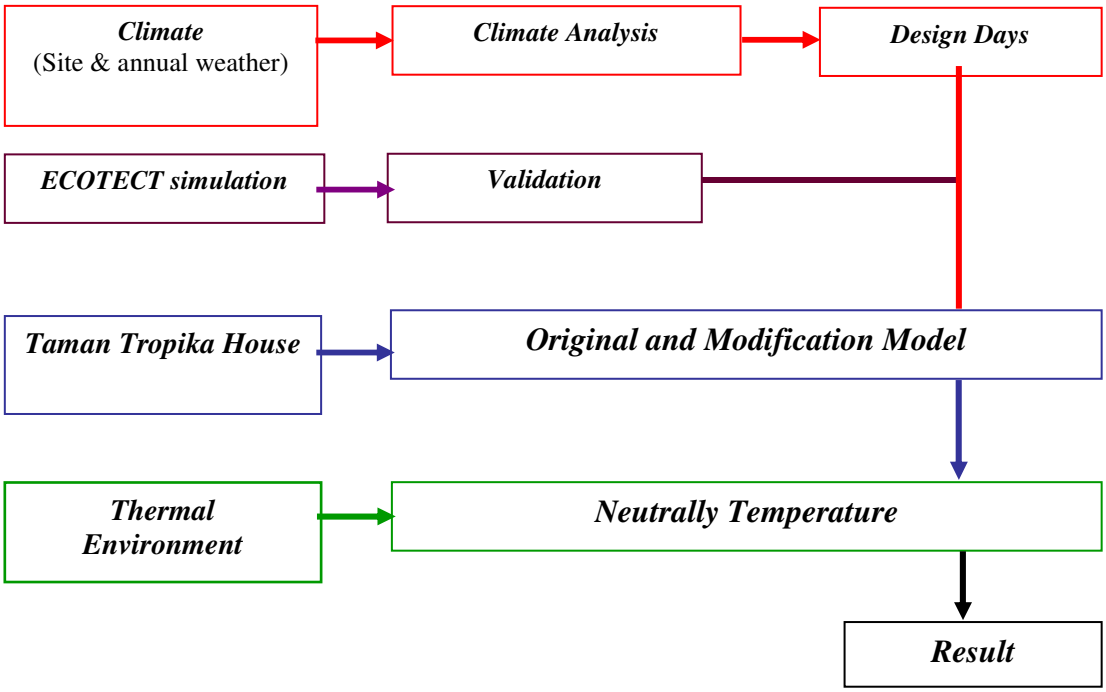

Figure 3.1: The research design

3.2 ECOTECT Simulation

The ECOTECT software is relatively unique amongst performance analysis tools as it is aimed primarily at architects and is intended for use during the earliest, conceptual stages of design. It integrates a relatively simple and intuitive 3D modeling interface with a range of analysis functions. These include, overshadowing and solar reflection; sun penetration and shading device design; solar access and photovoltaic/heat collection; hourly thermal comfort and monthly space loads; natural and artificial lighting levels; acoustic reflections and reverberation times; project cost and environmental impact.

The original ECOTECT software was written as a demonstration of some of the ideas presented in a PhD thesis by Andrew Marsh (2000). Its modeling and analysis capabilities can handle geometries of any size and complexity. Its main advantage is that it focuses on feedback during conceptual building design stages. The intention is to ease design process to create a truly low energy building. Analysis results can be mapped over building surfaces or displayed directly within spaces that generate them. It provides the designer the best chance of understanding exactly how their building response to the climate conditions.

It is an environmental design tool which couples an intuitive 3-dimensional modeling interface with extensive performance analysis functions covering shading, thermal, lighting, acoustic, energy, resource use and cost aspects. ECOTECT provides performance analysis which is simple, accurate, interactive and visually responsive (Crawley, et al, 2005). The most significant feature of ECOTECT is its interactive approach to performance analysis. Students are able to select different surface materials and very quickly compare the resulting changes to internal lighting levels, reverberation times, monthly heat loads and hourly internal temperatures at different times of the year. New windows can be added in order to see their effect on day lighting, thermal response and overall building costs. As the complexity of the model increases, it can also be exported to a range of application-specific tools for more detailed analysis. Formats currently supported include the RADIANCE radiosity-based lighting simulation package from Lawrence Berkley Laboratories; VRML for interactive 3D visualization; the DOE-2 and Energy-Plus thermal simulation tools from the US Department of Energy and a range of other applications such as POV-Ray, a freeware ray-tracing-based rendering tool.

The primary aim of ECOTECT software was to minimise the amount of application specific data that the designer has to input and make it as graphically intuitive and interactive as possible. This means that the designer uses a single application to generate the geometry of a building and assign material properties to each element. As the library is easily customised to select the most appropriate material for each element, material assignment is not a significant chore.

Once a model has been defined, the application itself is responsible for extracting all of the detailed information it requires for any particular analysis. This vastly reduces the load on the user, is relatively simple to derive and usually produces more accurate results than user-supplied data anyway. This approach does place a significant burden on the user interface, as this is the primary input mechanism and will dictate how the software is used. The ability to rapidly and interactively create or edit models was considered of paramount importance. Numerical accuracy is provided through direct entry input fields, object snap points and snap grids. However, most models do not require a high degree of precision, especially at the most formative stages. Thus, significant effort has been devoted to the interactive interface, resulting in the development of a new 3D cursor system for the manipulation of geometry in perspective projection.

3.2.1 ECOTECT Simulation Data Requirement

This section will outline the sequence of the simulation approach, from the required data and the construction of geometric models to the output of the results. One tool vital to any pre-design analysis provides for the visualization of climate data. This tool builds on the work of Murray Milne at UCLA in the development of *Climate Consultant* (Milne, 1992) and on Balcombe's *WeatherMaker*, a utility program for use with the Energy-10 design software (Balcombe, 1999). Using this tool, data can be viewed in a number of different ways, ranging from a monthly summary with wind roses after Szokolay (Szokolay, 1982), to simple hourly graphs, or even interactive 3-D surface plots. Hourly data can be imported from a wide range of file formats including TMY, TMY2, TRNSYS TRY files, Australian Bureau of Meteorology LST files, CSIRO and NatHERS climate data as well as ASHRAE WYEC2 format. Custom formats also can be defined and saved within the software. The tool also features a new form of wind analysis graph developed by the author to display speed simultaneously, direction and frequency over any date/time range. Wind speed is shown by the distance of each block from the graph centre

whilst frequency is indicated using coloured shading. Temperature, relative humidity and rainfall can also be overlaid on these graphs.

Additional research is currently underway to develop a methodology for rating the suitability of various design strategies to the specific climate data loaded. This will include an assessment and recommendation of shading periods, natural ventilation suitability, mass/insulation levels, glazing ratios and the most appropriate passive solar design techniques.

3.2.2 ECOTECT Simulation Geometric Modeling

One of the major challenges in the development of ECOTECT was to produce an interface within which geometric modeling could be as simple, loose and disposable as a traditional hand sketch, yet still be used for both general and detailed analysis. This required a departure from traditional CAD environments, which tend to concentrate on the drawing process rather than modeling - the lines that define an element only provide visual clues as to its architectural function. In ECOTECT, a relational modeling system is used in which the role of each element and its relationship to others is automatically derived from the way it is created. This means deriving the geometry and type of one element from the geometry and type of another, and storing the rules used. If the parameters of these rules are subsequently changed, or the parent element moved, the geometry of the child can be automatically updated.

It was, however, of fundamental importance to know the function of each element within the model. As a result, whenever elements are created, they are created as a particular type. For example, the user chooses to create a floor plane, or insert a window into a wall, a skylight into a ceiling, a partition within a zone, etc. The following is a list of the 12 basic element types defined in the application are; void, roof, floor, ceiling, wall, partition, window, panel, door, point, speaker and light. These type definitions imbue the model with an inherent knowledge base.

Surface areas and statistical data can easily be determined, for example, the ratio of north/south facing glass to floor area. Calculating the distances between doorways, and hence the adherence to fire codes, becomes relatively trivial. Knowing that an element is a roof plane yet has only a shallow incline, means that the properties of airflow and air-film resistance can be accurately modeled. It also eases material assignments as a large material library may contain over 100 materials, but only 8 internal partitions or 12 ceilings.

3.2.3 ECOTECT Simulation Analysis

The thermal analysis calculations were performed with the software ECOTECT v5.2 (Marsh, 2003). The model of a representative building type with southern orientation was constructed. The thermal modeling was based on a series of assumptions. The different rooms of each level were used either throughout the day, or for specific hours during the morning. These diurnal differences in the use of the house were represented with different schedules. The summer comfort band was set at 18 to 26 °C. The winter spaces (ground floor) were assumed with no ventilation apart from the air infiltration, while the summer spaces (upper floor) had natural ventilation. The infiltration rate for all the zones of the building was set at 1 air change per hour. All the thermal analysis calculations, which are presented, concern only the zones of the upper storey of the building.

3.2.4 ECOTECT Simulation Result

The very nature of the architectural design process is visual. This is especially true of the early stages of design where the building form itself is still being established. In addition to simply displaying results, ECOTECT attempts to relate the analysis directly back to the geometry. This is relatively simple in the case of solar and lighting calculation, however it is not always possible as some results can only be displayed as a graph. Where possible, however, graphs are displayed as separate interactive windows that automatically update to reflect changes in the

model. In some cases, changes in the graph can also automatically effect changes in the model. Many building analysis tools also provide very little visual feedback during calculations. This means that the process being undertaken is essentially hidden from the user, who has to trust in the fact that what is being modelled is correct. Mistakes in modeling that are not immediately visually apparent must be determined from a detailed examination of any output. Whilst the majority of calculations are not inherently visual, there are techniques that can be used to make them more so. For example, when using sampling or raytracing techniques, it is a simple matter for ECOTECT to display each point or ray as it is generated and tested. This acts to provide an indication of how the calculation is progressing as well as allowing the user to identify possible problems with the model by observing anomalies in the display. Such techniques have been implemented during surface area, volume, daylighting and acoustic calculations (Robert, 2002).

3.2.5 ECOTECT Simulation Limitation

In ECOTECT, all calculations are structured around a full set of basic assumptions and default values that can be changed at any time. Inexperienced users, or those requiring a quick result, need only specify whatever level of information they have at the time. As the design is gradually resolved, information that is more detailed is added to the model, making the results progressively more accurate. This makes the process of modeling far more responsive. There are, of course, issues relating to the validity of results based on default values. However, the same limitations are true of simplified manual and rule-of-thumb methods that are well understood and accounted for by most practitioners. Where accurate results are more critical, more information is provided. This allows the *designer* to control both the effort and accuracy required for a result, not the application developer.

3.3 Development of Tropical Principle Design

The existing Taman Tropical house at Universiti Teknologi Malaysia was designed using traditional Malay architecture and tropical design principles. Thus, there is a clear definition of architectural elements and can be categorized into three main zone. The top zone, which covers the roof element, the middle zone for wall and the bottom zone which is the floor. Thermal performance of the existing tropical house was measured and the results were used to develop a computer model to further determine the aspects of tropical design principles. The methodology of the field measurements is described in the following section. The new model is developed by modifying the configurations of roof, wall and openings, and the floor. The development of the simplified model is described in the following sections.

3.3.1 The Field Study of Comfortable Indoor Environment Simulation Model

The basic filed study model is a typical room configuration with overall size of 10m x 5m x 4m high. This size is to represent a single space room on field study. The field measurements were carried out using air temperature and humidity data loggers and surface temperature data loggers. The positions and the measured variables of the data loggers described in the following table (table 3.1). The building was neither occupied nor heated during this period. The measurements were collected for one-month period stating from 20 September to 20 October 2007.

Table 3.1. Description of data logger positions and measured variables installed at Taman Tropica UTM

No	Position & Description	Measured variable
1	Middle of the Space on the timber floor surface	Internal floor surface temperature
2	Middle of the Space, 1.7m from floor level	Internal air temperature & humidity at human body level
3	Middle of the space, 3m from floor level	Internal air temperature & humidity under the roof space
4	South wall, 1.7m from floor level	Internal wall surface temperature
5	South louvered wall, 1.7m from floor level	Internal louvered surface temperature
6	Outdoor space under shade, 3m from floor level, East, West, North & South	Outdoor air temperature and humidity

The indoor environmental studies conducted in the Taman Tropika building not only provided valuable insights on its thermal performance but also made it possible to compare the results with the computer model in which the dynamic thermal performance of the building was simulated with the real performance as recorded. Graphs displaying both the real and calculated data can be used to judge accuracy of the simulations and if discrepancy occurs, the relevant parameters can be adjusted.

When the weather data for the given region is available, simulations can be performed for different times of the year. It is also possible to test a model with the climatic data of other regions. Thus, it is possible to evaluate the effect of building materials and climatic factors on thermal comfort inside a given building. It is also possible to calculate the amount of energy required for space heating and cooling in order to maintain the ideal conditions for thermal comfort. The environmental performance of traditional materials against those of contemporary materials can be evaluated. Other parametric studies related to building form and orientation, window size, type and orientation can be performed.

The major different between the simulation model and pilot testing is the topography shape. The simulation consists of flat topography with building elevation (1m above ground) while the field study model consists of natural topography shape with an uneven surface. Therefore, the height between the natural ground and the raised floor of the building differed from 1.4m to 0.8m. A model created for thermal analysis is geometrically simplified since the relevant attributes here are the thermo-physical properties (such as U-values and thermal admittance values) of the building envelope and fenestrations.

Figure 3.2 A field measurement of Taman Tropika building at UTM.

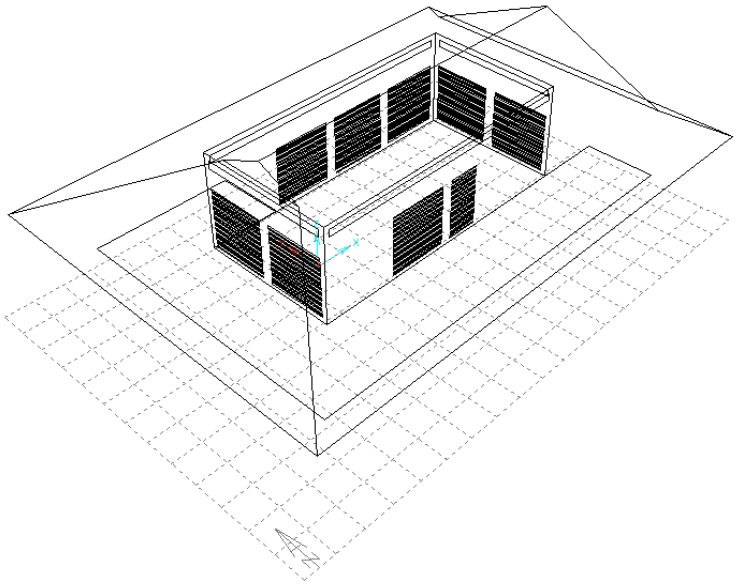

Figure 3.3 A 3D view of the thermal model of Taman Tropika building developed in ECOTECT v.5.20.

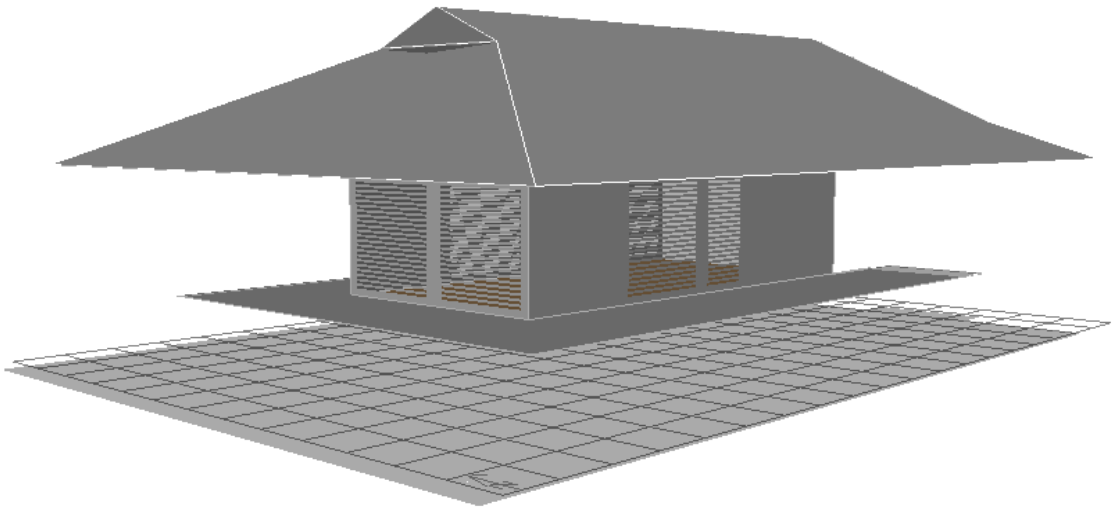

Figure 3.4 Captured view of the rendered thermal model with shade and shadows as calculated with ECOTECT v.5.20.

3.3.2 Modified Tropical Building Design Principle

The modified tropical building design principle are extension of the field study model described in section 3.3.1. In this stage, the basic tropical building models are modified physically into four alternative modifications. The modifications are performed at roof, wall, and opening and floor elements.

a. Roof modification

In this study, the shape of the roof model is assumed as similar with base case model. The aperture above the roof of tropical principle model is assumed effective in decreasing the indoor temperature, while the area below the window has no effect on air movement on the sitting plane. However, when considering the effect of roof design, several modifications were simulated: ceiling, roof color, insulation and thermal mass material (Table 3.2).

b. Wall modification

The basic wall of Taman Tropika construction is 0.05m thick timber material without external insulation and with natural color. Hence, the wall modification elements tested are insulation thickness and thermal mass (Table 3.2).

c. Opening modification

The opening of tropical design is an independent variable in this study. The main purpose of this study is to determine the optimizing of the opening design in terms of decrease air temperature and achieving comfort indoor temperature. The louvered opening are tested as to following sizes; 0.05 m, 0.1m, 0.2m (Table 3.2).

d. Floor modification

The base Taman Tropika model and the modified configurations with different floor elements will be used to investigate the objectives of the study. Further, the characteristics of the thermal models will be determined based on the types of floor variables to be investigated. Following parameters were used to determine the influence of floor element on the thermal performance of the tropical house; color, insulation and thermal mass (Table 3.2).

Table 3.2: The summary of building modification

No	Element			
	Roof	Wall	Opening	Floor
1	With Ceiling	Thin Insulation	Without louver	Light Color
2	High Pitch	Thick Insulation	No opening	Dark Color
3	Thin Insulation	Low U value	Small louver	Thin Insulation
4	Thick Insulation	High U Value		Thick Insulation
5	Low U value			
6	High U Value			
7	Light Color			
8	Dark Color			

CHAPTER 4

RESULT, ANALYSIS AND FINDING

This chapter evaluates the experiment and simulation results obtained for indoor environment for the Taman Tropika model. The evaluation on indoor environment is based on the air temperature and relative humidity from on site data. The indoor environment analysis is based on the thermal environment, which includes both air temperature and relative humidity. Further, in order to find the correlation between the air temperature and relative humidity component, both results are presented in the same graph as a function of tropical design principle models. The development of new tropical principle design configuration is established based on the main element designs (roof, wall, opening and floor) and their relationship between modified models and the base model of Taman Tropika house. Finally, the interpretations of the results on the application of the new tropical design principle on Taman Tropika house are discussed.

4.4 Field Study of Comfortable Indoor Environment

A field study using one model was measured and simulated for tropical principle design. The single room in the field study was 3.5 meter high, 5m width and 10m length, supported structurally by timber material. Data loggers were positioned at nine different points on indoor and at outdoor. In the Ecotect simulation, the following boundary condition area used: the material and thickness of the Taman Tropika house are based on the base model, while the climatic condition is set similar to the site climatic conditions. Sample graphs used for these studies are illustrated below.

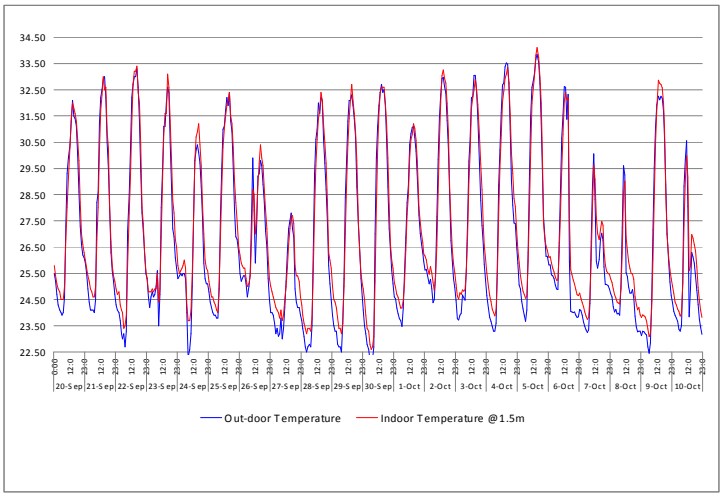

Figure 4.1 Comparison of internal and external temperature at 1.5m height from floor level - 20th September to 10th October at TTH.

4.4.1 Indoor Environment Results of Field Study Measurement

A typical diurnal variation of the mean indoor temperature against the outdoor temperature is illustrated in Figure 4.2. It can be observed that the Taman Tropika house temperatures were significantly below the outdoor in 09:00h until 14.00h. Peak ambient temperature (indoor temperature) of 31.79°C at 15:00h. Figure 4.2 showed that the indoor and outdoor humidity of Taman Tropika House. The outdoor humidity was generally lowest than the humidity in Taman Tropika house. Relative humidity in outdoor and indoor decrease start in 09:00h until 18:00h with similar pattern.

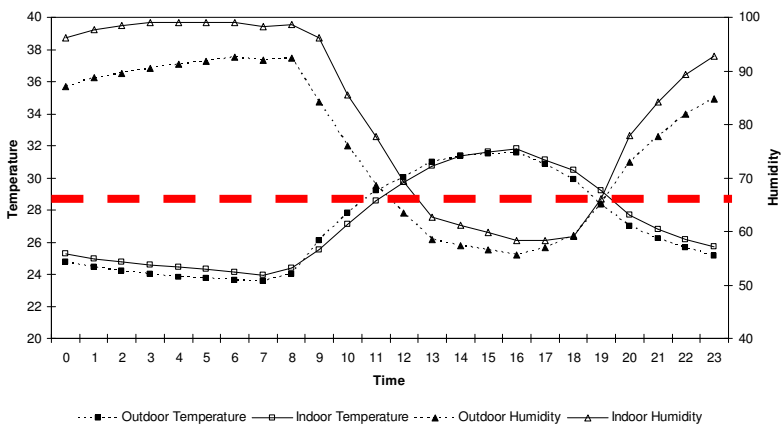

Figure 4.2: The average temperature and humidity in indoor and outdoor measurement

The indoor temperature was generally higher than the outdoor temperature during in the afternoon and the night. Indoor temperature increasing start in 14:00h and peak in 18:00h. The indoor humidity decrease but still high from 08:00h until 16:00h. Effectiveness for time to large temperature reduction in 10:00h until 12:00h. The measurement in 10 days showed the Taman Tropika house developed by tropical principle design impact for decreasing indoor temperature. Generally, temperature differences in mid day are 0.01°C-0.72°C for compare in outdoor and indoor. Taman Tropika house model potential to reduce heat gain base large different temperature for indoor and outdoor. Indoor temperature incident on the single room is evident at 15:00h on north oriented room façade (figure 4.2). A higher amount of indoor temperature is recorded compare to outdoor. The maximum indoor temperature (31.5°C) is above the neutral temperature.

4.4.2 Results Analysis of Field Study Measurement

A typical diurnal variation of the mean indoor Taman Tropika house temperature against the ambient temperature is illustrated in figure 4.2. It can be observed that the indoor temperatures were significantly below the ambient. This is representative of the pattern for all the tests undertaken. Typical values of peak indoor temperatures were between 25°C and 30°C compared with peak outdoor temperatures of 26°C-30.5°C. Corresponding average indoor temperature elevations ranged between 1°C and 0.5°C below outdoor temperature at 09:00h until 14:00h. The result illustrates the effectiveness of the principle of the tropical building design employed in this study and the need for the maximal temperature reduction to achieve upper limit of neutral temperature within the room. The use of main principle design or the use shaded roof and louvers opening (which would serve equally as main element design) is recommended. The study of the shaded roof and louvers opening base on previous research has shown promising results. It is possible to create a maximum indoor reduction of single room. The incorporation of a combined roof, wall, opening and floor element design can be increase temperature reduction in the single room. To obtain such a neutral temperature (28.5°C) inside the room should be extended the new tropical design based on field study.

These present results are similar to previous results where they were indicated that the increase of roof solar shaded will decrease the indoor temperature as discussed by Bouchlaghem (2000) and Corrado (2004). Bouchlaghem (2000) presented a computer model, which simulate the thermal performance of the building taking into account design variables related to the building envelope and optimize window-shading devices with optimization programs. According to Corrado (2004) the appropriate external shading devices can control the amount of solar radiation admitted into the room, which could largely reduce cooling loads and improve indoor thermal comfort by computer simulation. Finally, it is our opinion that tropical principle design seems to be feasible and viable and the opportunity to development new principle design for tropical climate.

4.4.3 Ecotect Validation of Field Study Simulation

Validation of the program was performed by comparing the measurement of field study with the Ecotect simulation. Figure 4.3 shows the comparison of measurement and simulation result. It shows that the agreement between the measurement and simulation is generally good. The average difference between the measurement and simulation for ambient temperature was 5%; the maximum difference was 9% for the cavity 07:00h of indoor temperature. This gives confidence in using the computer code to study the indoor temperature.

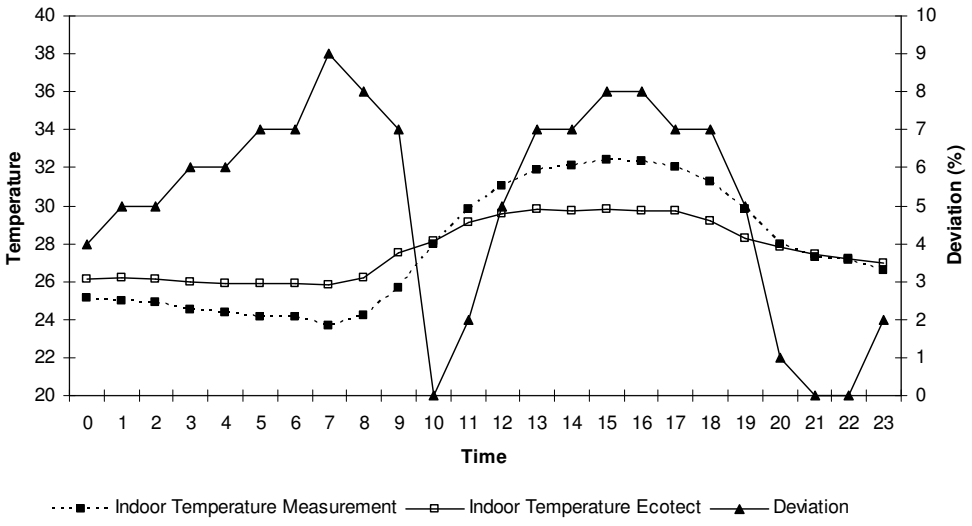

Figure 4.3: Comparing measurement and Ecotect simulation of field study on 19 September 2007

4.4.4 Finding and Conclusion of Field Study of Taman Tropika House

The results obtained from the measurement Taman Tropika house has illustrated that tropical principle if designed properly can maintain indoor temperatures consistently below the outdoor temperature in the morning. The maximum indoor temperature on the measurement and simulation is achieved at 16:00h. The indoor temperature profile also indicates similar trend against the outdoor temperature. This means the indoor temperature close with outdoor temperature can be achieved by maximize roof shading and louver opening on single space room. Figure 4.2 illustrates that the upper target neutral temperature (28°C) is obtained during one day average indoor temperature measurement and simulations except at 12:00h until 19:00h. The neutral temperature performance was achieved with modification of tropical building design principle studied. Better performance was obtained with a maximum temperature reduction within the single space room. The results do, however illustrate the desired effectiveness of the tropical principle model.

4.2 Modification of Tropical Building Design Principle Model in Selected Climate Condition

Developing the new tropical building design principle had been undertaken on selected climate condition (on 19 September) to same ambient conditions. It was simplify to make a comparison between field study and the different design principle configuration because of the same climatic conditions. However, general and subjective conclusions were formulated. Predictions of the impact of new tropical building principle configuration were performed for variety of main building design configuration (roof, wall, opening, floor). The influence of these variables on the indoor temperature performance is discussed below. An example of variation of new tropical building elements is given in figure 4.6, figure 4.7 and figure 4.8 shows that the indoor temperature of Taman Tropika model is changing along with the modification of tropical building elements. The ability of the modification tropical building elements to offer comfortable indoor environment is expressed by the air

temperature inside of the Taman Tropika model. The lower air temperature meaning more comfortable indoor environment.

4.2.1 Roof Modification

To evaluate the effect of roof tropical building element, several modifications were simulated: roof with ceiling, roof with big pitch, roof with insulation 0.04m and 0,1m, roof with u value 6 W/m^{2}K and 1 W/m^{2}K, roof with light color and dark color. In Figure 4.4, a comparison between indoor temperatures for Taman Tropika model is made, for different values of roof elements. The other building elements are similar with field study (wall, opening and floor). Under similar ambient conditions, the average temperatures obtained inside of the Taman Tropika house for eight modifications. It was found that average air temperatures decreased with used ceiling which is obvious as less radiation was absorbed by the room. In addition, temperature along the Taman Tropika house is at a maximum at the roof with material U value 6 as shown in figure 4.4.

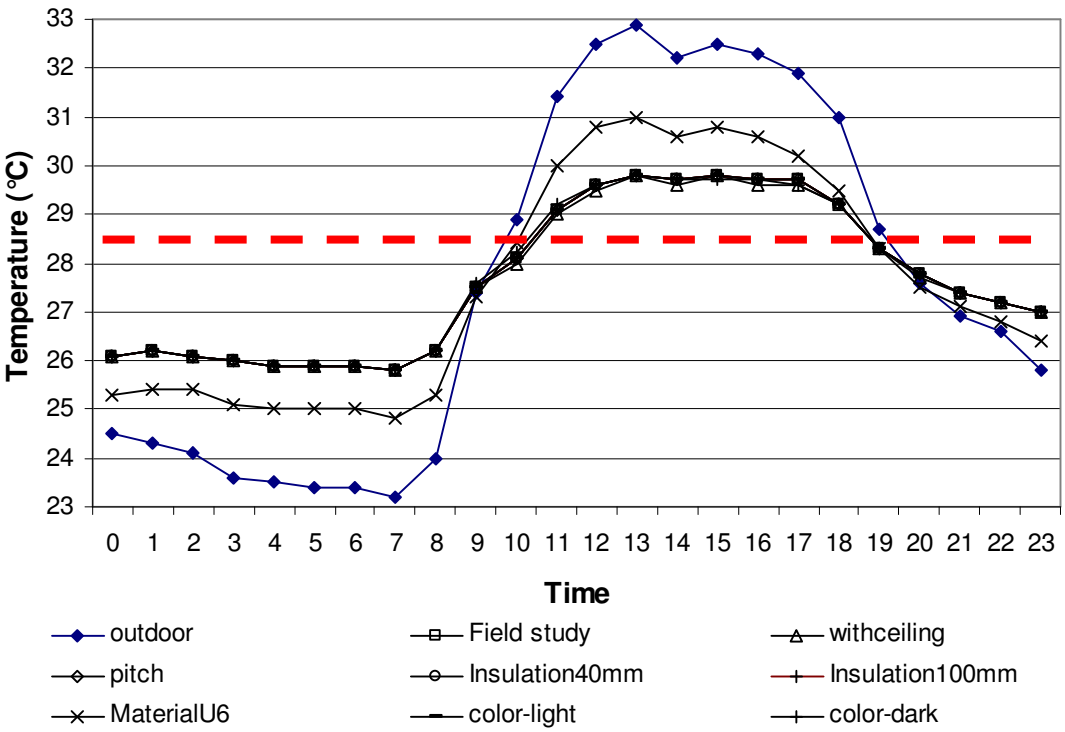

Figure 4.4: Indoor temperature in relation to roof modification

Figure 4.5 illustrates the temperature differences obtained by the roof modification. The maximum temperature difference during one day was about 3.2°C. The U value of roof material influences quantity of solar radiation absorbed by the roof and makes temperature difference between the indoor and outdoor condition greater and consequently air temperature inside of the single room rises.

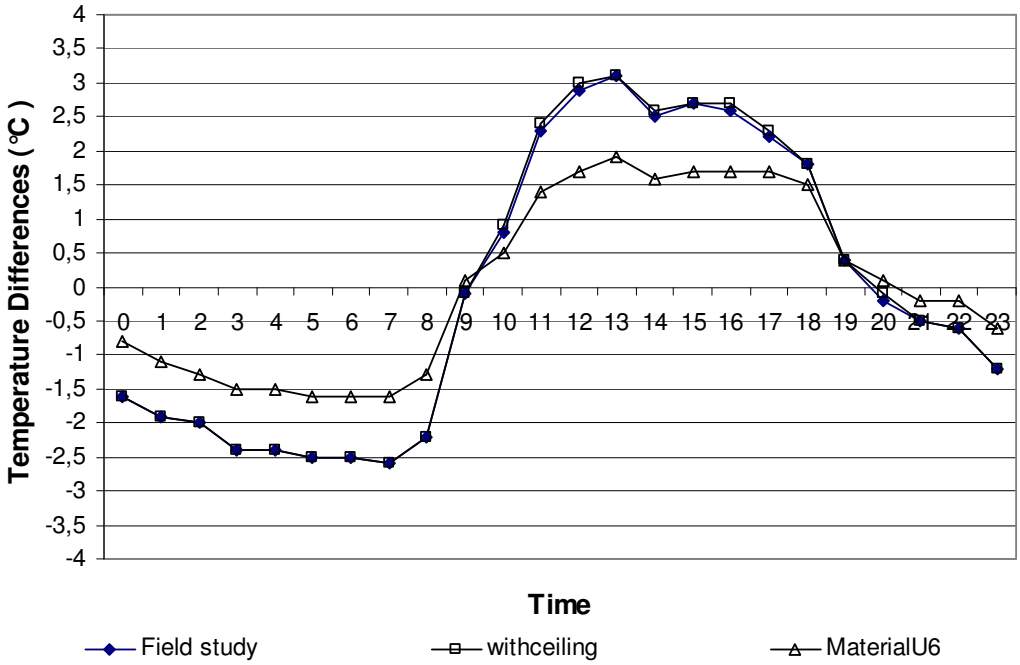

Figure 4.5: Temperature differences in relation to roof modification

In Figure 4.5, a comparison between indoor temperatures for roof modifications is made, for different parameters of ceiling and material. As can be seen, temperature differences increases with the use of ceiling, to achieve a lower indoor temperature through the single room. The profile of the indoor temperature incident on the roof modification showed on figure 4.4. Hence, when the roof with ceiling is lower value of indoor temperature, the neutral temperature component is lower as compared to the indoor temperature which is uncomfortable condition.

The present results are consistent with the previous results by Mathews (1996) and Parker *et al*. (1995). In fact, according to previous research (Mathews, 1996) a ceiling was again found to have the greatest energy saving potential with respective savings of 62%, 61%, 23% and 39% for the polystyrene, the clay brick, the asbestos and the particle board houses. It is therefore suggested that all new low-cost houses be supplied with insulation integrated ceilings. Parker *et al*. (1995)

investigated the use of an attic roof ceiling improved performance. For conditioned spaces the use of ceiling was the most effective element of improvement of roofs.

4.2.2 Wall modification

To evaluate the effect of wall elements on indoor temperature, several modifications were simulated: wall with insulation 0.04m and 0.1m, wall with high U value (3 W/m^{2}K) and wall with light color, which correspond to roof, opening and floor similar with field study. Figure 4.6 show the indoor temperatures at the middle of the single room of Taman Tropika house for five different modifications. It was found that indoor temperatures decreased with increased U value of the wall. In fact, those previous researchers regarded the fact that big U value will cool the inner surface of the wall leading to decreased temperature of the room.

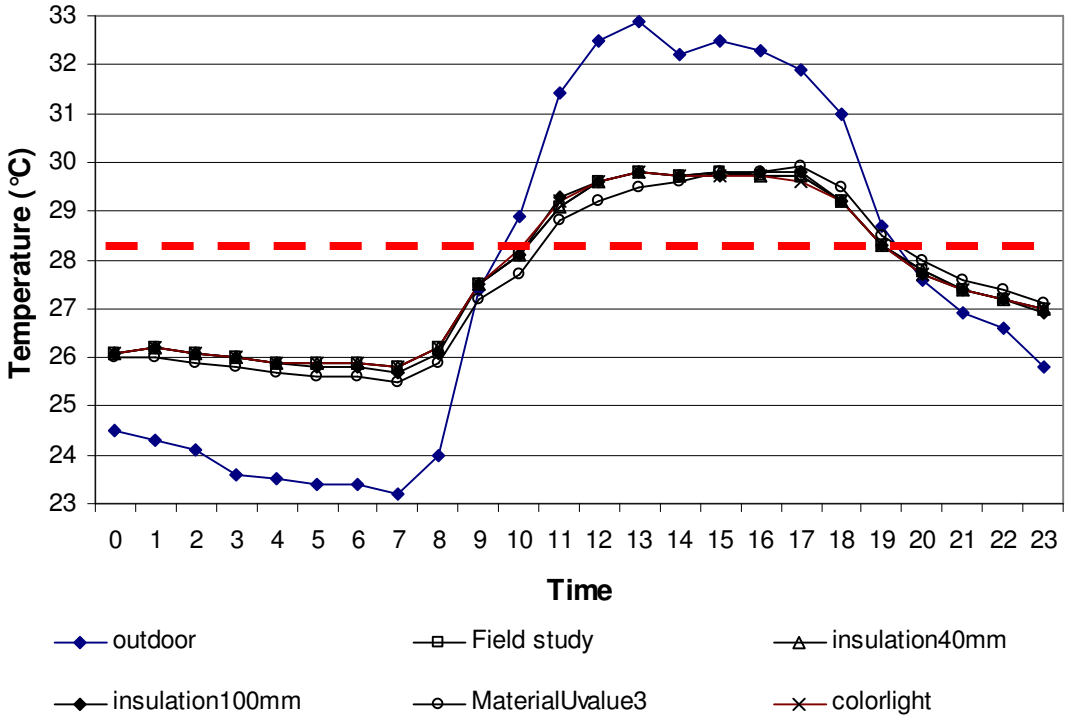

Figure 4.6: Indoor temperature in relation to wall modification

Figure 4.7 shows the simulation results of the temperature different produced by the wall modification. It can be seen that the temperature differences increased with U value material of 3W/m^{2}K. Figure 4.7 show the comparison of temperature difference in the field study, wall U value 3W/m^{2}K (maximum reduction) and wall

with light color (minimum reduction). This showed that a wall modification with a U value 3W/m^{2}K was able to provide 0.1°C cooler than field study. Therefore, large U value of wall material is recommended.

Figures 4.7 illustrates that the similar indoor temperature are obtained on wall modification. However, on U value 3, average indoor temperature indicated a lowest value. This can be explained that on U value 3, the wall reduce solar radiation; therefore the indoor temperature values are low. This indicates, with the decrease of indoor temperature, the target neutral temperature levels still were not achieved compared to the minimum temperature values at 11:00h until 17:00h.

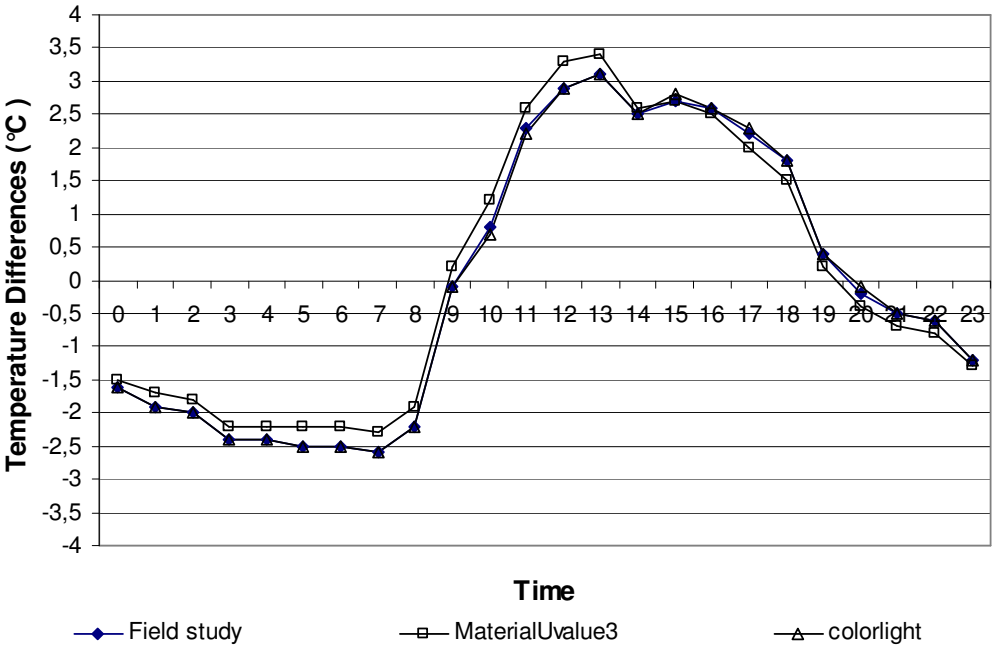

Figure 4.7: Temperature differences in relation to wall modification

The comparison of present study agrees with Rosangela (2002), Garde (2004), Al-Homoud (2005) and Mallick (1996). The present results showed that temperature reduction due to light color wall and big U value wall effects were significant. Rosangela (2002) investigated the use of a white reflective surface indicated the best performance, and minimized the need for insulation. Garde (2004) used a medium colored wall for solar protection reflectance. It was recommended to put no insulation instead of the one originally planned. According to Al-Homoud (2005) the thermal performance of building envelope is determined by the thermal properties of the materials used in its construction characterized by its ability to

absorb or emit solar heat in addition to the overall U-value of the corresponding component including insulation. Mallick (1996) indicated rooms with thicker walls but high u value tend to be more comfortable. Similarly, the thicker insulation material is the less thermal transmission will be (Mahlia, 2007). Accordin to Rosangela (2002) the most of the time high mass buildings can be more comfortable than low-mass ones

4.2.3 Opening modification

In field study, the louver of the Taman Tropika house is used as a ventilation controller. A combined opening modification between full opening (100% open), no opening (close) and small louvers (0.05m) should be solved for same field study design elements (roof, wall, floor). Figure 4.8 show the indoor temperature and outdoor temperature of the Taman Tropika house with different sizes of opening. Generally, decrease the opening size decreased the indoor temperature, which is a consequence of the large opening impact decreased indoor temperature similar with outdoor temperature. Further, closed opening with good insulation and wall material make indoor temperature cooler than outdoor temperature.

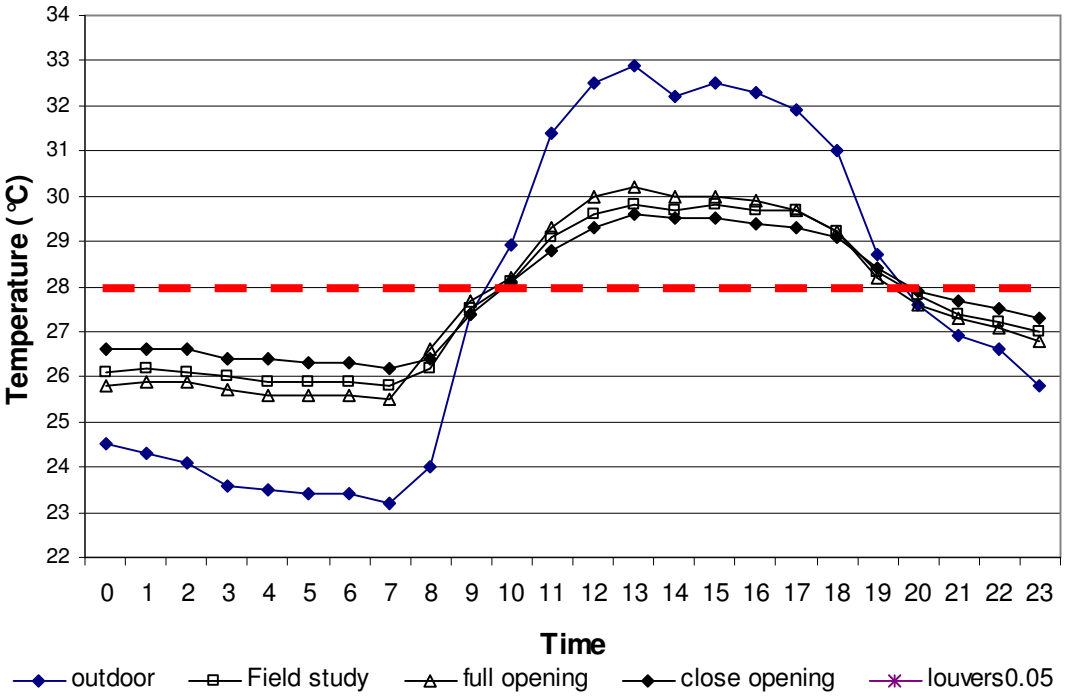

Figure 4.8: Indoor temperature in relation to the opening modifications

However, as shown in figure 4.8, the temperature differences increased with reducing opening size of the Taman Tropika model. Thus, the amount of indoor temperature by no opening would be lower than that full opening. Therefore, to anticipate the heat gain by the user (human body and equipment), the size opening of the Taman Tropika should be 0.1m of louvers size. Figure 4.8 shows that the average indoor temperature was achieved for each correspondence opening modification and the upper target of neutral temperature (28.5°C) during all day except at 11:00h until 18:00. The close opening modification indoor temperature profile indicated lesser than the field study indoor temperature profile.

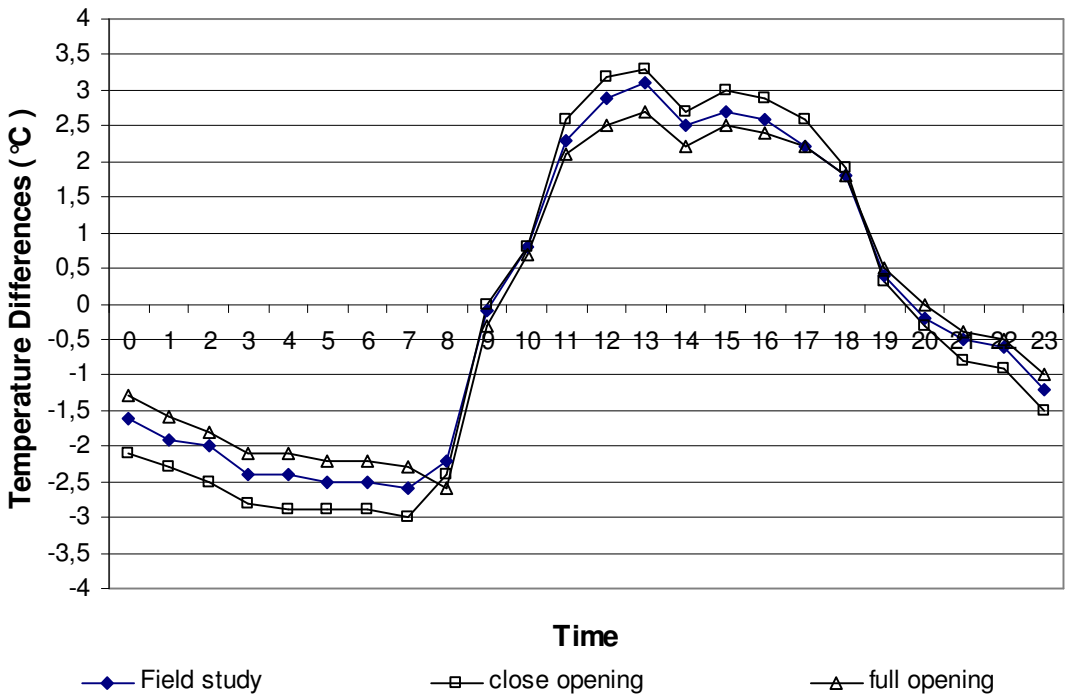

Figure 4.9: Temperature differences in relation to the opening modification

From figure 4.9, it is clear that temperature reduction up when the opening size is minimal. Therefore, the results are similar with Rosangela (2002) and Prianto (2003), there is no need of a much large opening for the climatic conditions considered. Opening type and size should be chosen in accordance with the building passive cooling (lesser than outdoor temperature) for diurnal building operation small opening are advisable while for the building day operation, louver opening type should be adopted. Prianto (2003) examined various types of louver has significant effect on the indoor comfort level. According to Rosangela (2002) the

type smaller opening area for heavyweight construction provided better performance of indoor temperature.

4.2.4 Floor modification

The effect of floor modification was analyzed by performing simulations for floor color and floor insulation. Figure 4.10 show indoor temperature profiles for different floor modification, as well as modification results with a floor with light color. Floor modification does not change significantly the indoor temperature and temperature differences, the maximum being obtained at 15:00h.

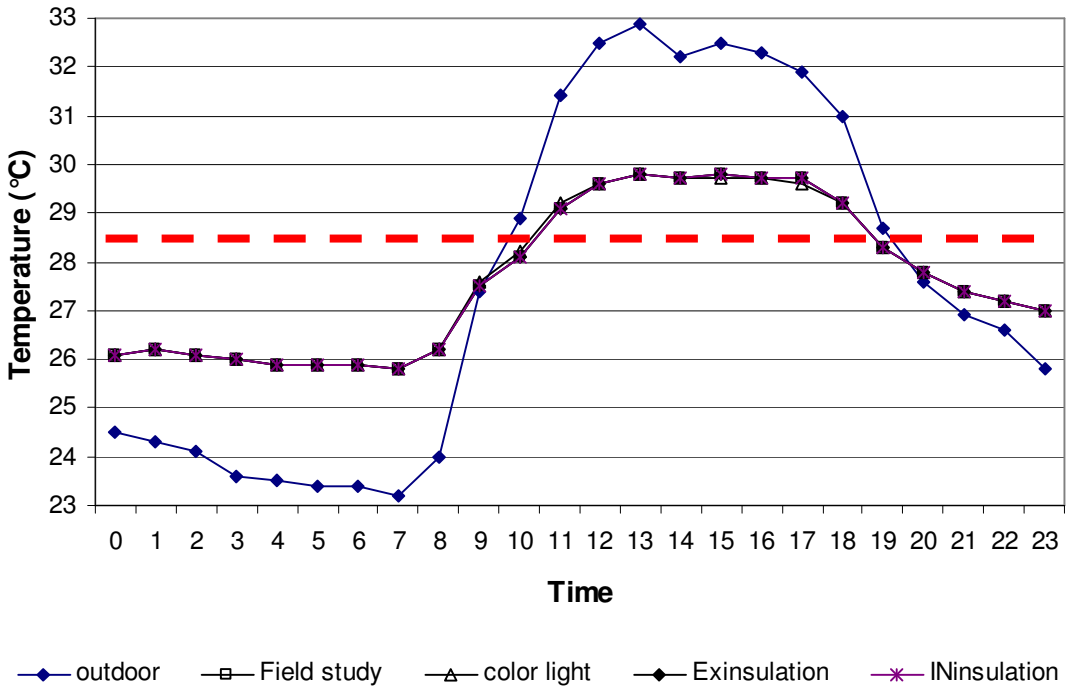

Figure 4.10: Indoor temperature in relation to the floor modification

Figure 4.11 show plot of temperature differences at different floor modification values. Similarly, higher temperature difference at floor with light color caused the small temperature differences. By changing the floor color from solar absorption 0.7 to 0.1 the temperature difference derived in the single room is increased to the maximum value of 3.1°C at 13:00h. The maximum temperature in floor modification was still above the minimum target of neutral temperature. This is mainly due to the highest temperature into the building during mid day.

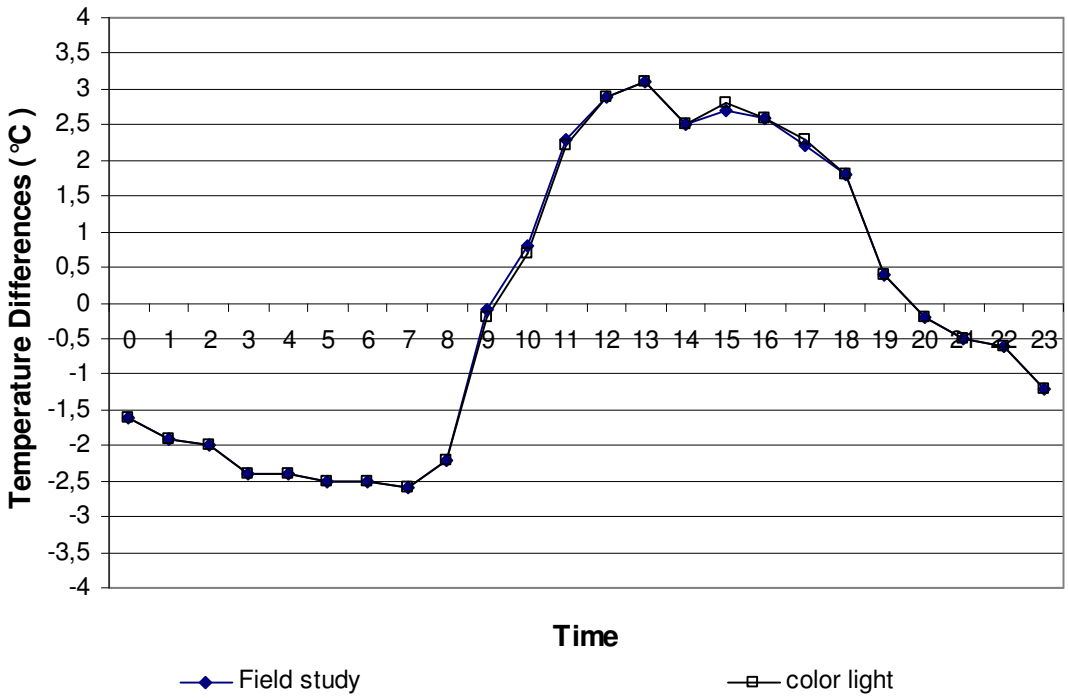

Figure 4.11: Temperature differences in relation to the floor modification

Figure 4.11 shows the color light of floor have significant impact to reduce indoor temperature. The present result is similar with previous study by Bajwa (1995) which the colour of floor surfaces has a great deal to do with the heat absorption and re-radiation. Lighter colour with rough surface finishes were used to reduce direct heat gain in the buildings (Bajwa, 1995).

4.2.5 Selected modification model

The discussion of the results of this simulation modification are referred to the field study configuration, model A (roof with ceiling, small roof u value, roof with insulation, big wall u value, wall with insulation, wall color light, opening louvers 0.1m), model B (roof with ceiling and small u value, wall with large u value and light color, opening louvers 0.1m) and model C (roof with ceiling and small u value, wall with large u value and light color, opening louvers 0.05m). All models used the floor material. For the purpose of comparative analysis on the effect of the new principle design (model A, model B, model C), the basic model (field study)

indoor temperature and temperature difference values were used to determine the deviation of values at the proposed configurations.

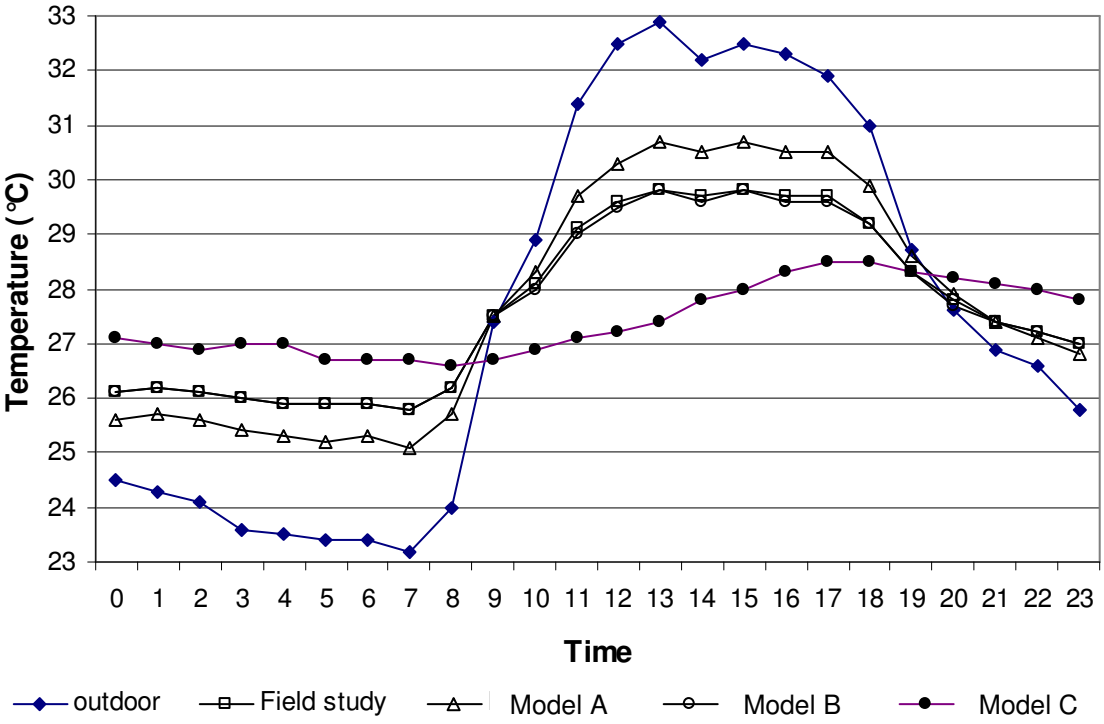

Figure 4.12: Indoor temperature in relation to the proposed model

The indoor temperature data shows that at proposed C the temperature value is the lowest in mid day (27.1°C until 28.5°C). The highest temperature reduction effect is recorded at model C of the big U value wall and decreases towards the increase of the ratio opening. The average indoor temperature of proposed A, B and C for the south oriented house are shown in figure 4.12. The minimum indoor temperature was obtained in proposed C. Results on the average temperature were obtained at similar profile of the three rooms. The results showed significant temperature reduction which the indoor average temperature values obtained neutral temperature (27.4°C) was less than upper limit neutral temperature (28.5°C).

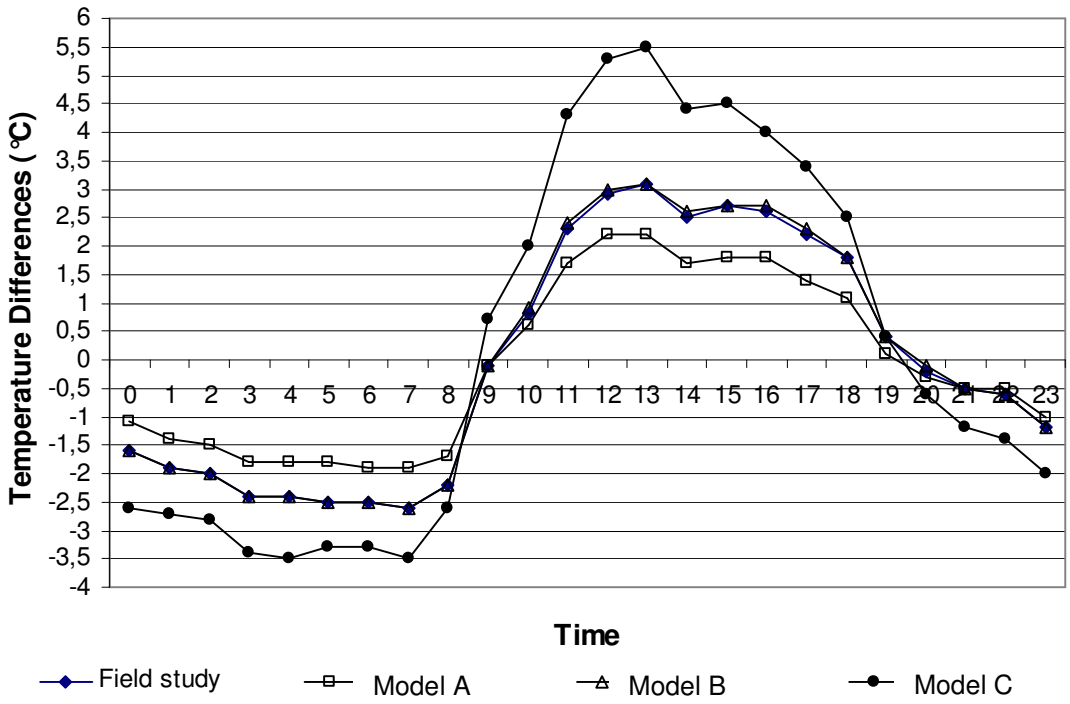

Figure 4.13: Temperature differences in relation to the proposed model

Figure 4.13 illustrate effectiveness of each selected proposed model in temperature reduction for the selected climate condition (19 September). The temperature reduction value increases significant at model B and C. This situation is reversed at the model A. The temperature reduction obtained from the proposed model A shows that maximum temperature reduction achieve in the night and maximum temperature addition during the day time. The average air velocity pattern on the field study and proposed B is similar profile. The results indicated that the maximum temperature reduction (5.5°C) through the model C. The maximum temperature reduction was obtained during 13:00h for model C. The effects of model C on different climate condition (orientation and design days) will be simulated to show the thermal environment performance of the new tropical building design.

4.3. Performance of New Tropical Building Design

The primary purpose of the new tropical building designs to main building elements for improvement passive cooling strategy. The performance of proposed B as new tropical building design was obtained at hourly condition during one year for four main cardinal orientations (north, south, east and west). The indoor temperature was analyzed as a function of new tropical building design for four design days (17 March, 19 June, 19 September and 4 December).

4.3.1 Orientation

The average indoor temperature on respective orientations showed that the west (27.65°C) received the higher amount of indoor temperature than the other orientations (figure 4.14). Hence, the orientation of Taman Tropika house affected the amount of indoor temperature. The values obtained for the average indoor temperature of the Taman Tropika house model on the west orientation indicated a highest indoor temperature (30.7°C) at 17:00h. The average indoor temperature values obtained at 12 hour on west orientation was 28.43°C, 28.36°C on south orientation and 28.35°C on North and East orientation. The profile of the indoor temperature into the house indicated a reduction when the orientation is changed from west to east. Figure 4.14 illustrate the profile of the indoor temperature for new tropical building design models on all orientations. Further, the indoor temperature is generally high during the afternoon compare with in the night. However, the indoor temperature of the all selected models is higher during the afternoon hours than in the morning on all oriented aperture. Although north and east orientations indicated the lower indoor temperature in the afternoon compare on south and west orientations.

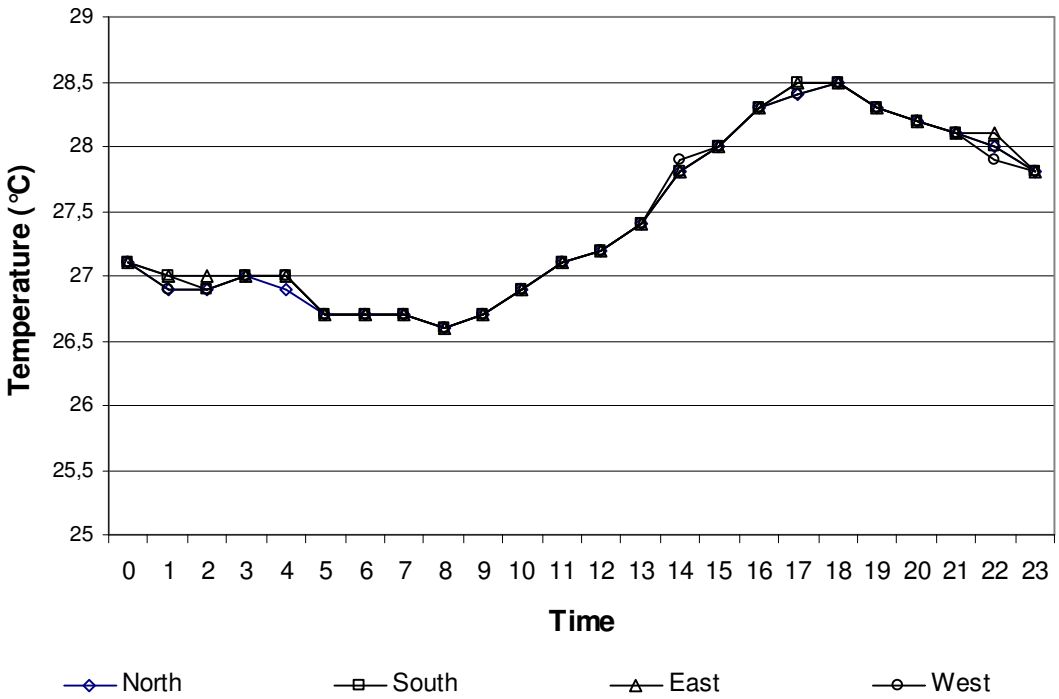

Figure 4.14: The indoor temperature in the new tropical building design on north, south, east and west orientations

The average indoor temperature received on the north orientation is lower than the other orientations in night (0.01°C) and higher in day (0.01°C). In comparison, the average of indoor temperature on north orientation received 27.4°C in the night less than the other orientations. Comparatively, the day obtained average indoor temperature 27.3°C on the north orientation less than the other orientation. The mean reduction of indoor temperature on respective orientations showed that the north received the comfortable than south, east and west orientation. In comparison, the north indicated less than the other orientations in terms of temperature reduction through the single room on monthly data. On all orientations, they represent the same condition as the reduction in air temperature pattern. Figure 4.14 shows that the air temperature in the room, which ranged between 26.9°C and 28.5°C, was more within the neutral temperature. The air temperature in the occupant zone of all orientations was higher especially at 16:00h until 18:00h.

4.3.2 Design Days

The effects of hourly variations of selected design day on the dry bulb temperature were assessed with respect to the new tropical building design. This enables us to understand the condition of time component on the overall indoor temperature of the building. The analysis is done based on four days: 17 March, 19 June, 19 September, 4 December as design days. Hence, during 17 March and 19 September the sun rotates closer to the tropical region and have peak air temperatures while on 19 June and 4 December the sun rotates furthest from the tropical region. The average indoor temperatures were obtained for each hour on the selected days. The profile of the indoor temperature in the new tropical building design model exhibited a steep gradient on 17 March and 19 June than in 19 September and 4 December. Further, on 19 June achieved a maximum of indoor temperature is 29.5°C at 18:00h and a minimum is 27.5 at 08:00h. The profile pattern of indoor temperature is reduction on 4 December with the maximum of indoor temperature 28°C and minimum 26.5°C. But on 17 March, the profile of indoor temperature exhibited fluctuated curve than on the other three days. This is mainly due to the impact of ambient temperature.

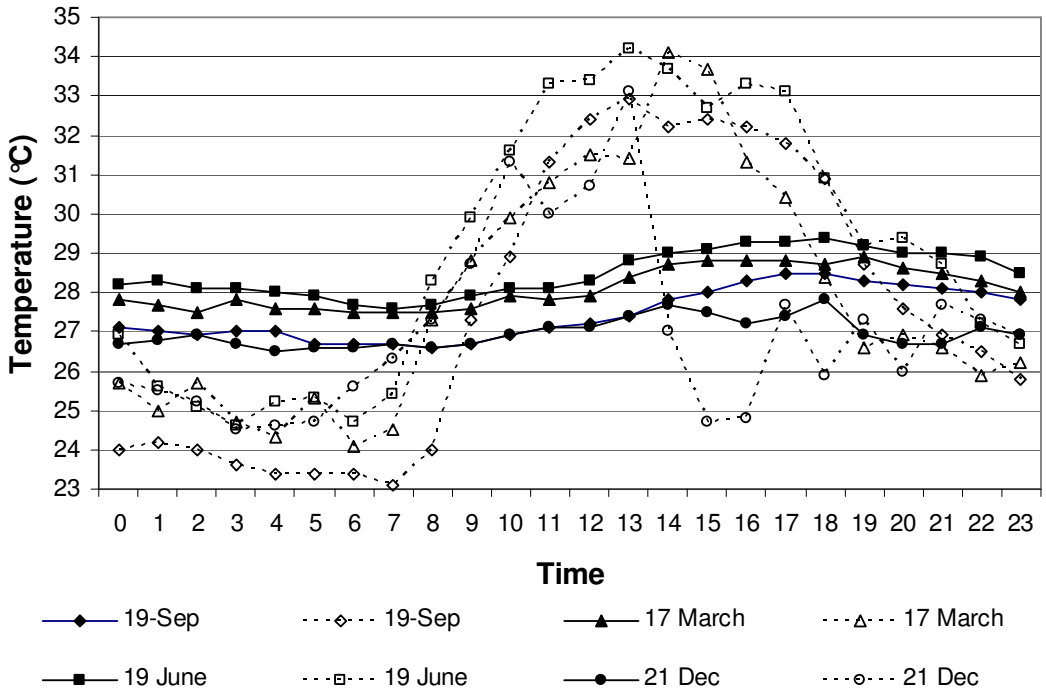

Figure 4.15: The indoor temperature in the new tropical building design on respectively day

The average indoor temperatures on the new tropical building design are evident on 19 June, 19 September and 4 December on north-south orientation (figure 4.10). A high amount of the indoor temperature in the model occurs at 18:00 on the correspondence dates. However, on 17 March, it exhibits the maximum incident values at 19:00h. On 19 September can increase the indoor temperature reduction into the new tropical building until 5.5°C during the day. On 4 December and 17 March the graph exhibits that, a new tropical building model can increasing the temperature reduction at mid day when the sun is at higher altitudes.

4.3.3 Findings of the Performance of New Tropical Building Model

Figure 4.11 until figure 4.14 illustrate effectiveness of proposed new tropical building model in rising indoor temperature reduction for the respective orientation and design days. The calculations were compared to indoor temperature on the new tropical building design model on respective orientations. The north, south, east and west orientations had similar profile of the relationship between the new tropical building design model and the increasing indoor temperature reduction. The north and east orientation air flow rate profile indicates a lower gradient than the south and west profile. This implies that on the south and west orientation, the use new tropical building design had a lesser impact on the amount of indoor temperature reduction than on the north and east orientation. The indoor temperature profile for all orientations indicated about 0.1°C reduction at mid day. The east orientation indicated the maximum reduction percentage than other orientations. The effects of new tropical building design on the average indoor temperature were assessed for each hour on the selected design days (17 March, 19 June, 19 September and 4 December).The maximum average indoor temperature reduction on all respectively days can be achieved by new tropical building model on 19 September at 13:00h (5.5°C). Further, on 19 September received average of indoor temperature reduction compared to all other days. The indoor temperature profile showed a similar pattern for all respective days.

The results, analysis and findings of the simulation exercise are done to determine the influence of the new tropical building design for hourly conditions and orientations in term of indoor temperature were presented in this chapter. The analysis of the above performance variables were carried out in annual monthly data for east, west, north and south orientations. The results of indoor temperature and comfort neutral temperature value were plotted against house model and orientation in the same graph. Similarly, absolute target neutral temperature was also based against house model in the same discussion. It enabled us to understand the influence of house model on the correspondence orientations, dates and hours. The hourly average results of indoor temperature were also analyzed for the respective orientations. This gave overall view of the influence of different house model and orientation on the patterns of temperature value variation throughout the day. This chapter has analyzed the results obtained for the proposed house model and house orientation for improved thermal comfort.

Comparison of the average indoor temperature on field study and new tropical building model indicated that new tropical building obtained the minimum air temperature and within upper limit of neutral temperature. According to figure 4.12 and figure 4.14, the new tropical building achieved below target of neutral temperature for thermal comfort under the selected climate condition. The average air temperature on field study indicated above of neutral temperature for mid day. However, the field study can significantly decrease indoor temperature below 30°C. Further, new tropical building decreased the average air temperature up to 2°C on respective conditions. The new tropical building design provides the optimum indoor comfortable. It enabled us to understand the influence of tropical principle design components on the overall indoor comfortable. The results showed that ceiling, material and opening were main contributors on improving indoor comfortable. The results revealed that the use of ceiling, wall material with $3W/m^2K$ U value and the use of small louvers as opening were the three important aspects towards building's indoor comfortable environment.

CHAPTER 5

CONCLUSION

The findings of the research have been presented and discussed in the previous chapter. This final chapter will conclude the overall findings of the report. The application of the research findings are also discussed in relation to the aims and objectives of the report as set in Chapter 1. Finally, further work related to this study will be suggested in this chapter in order to strengthen and compliment this report.

5.1 Review of Study Objectives and Research Questions

As stated in Chapter 1, the main aim of this study is to assess and compare the impact of tropical building design principle for comfortable indoor environment in Malaysia residential building. Other specific objectives of the study are as follows:

- To identify and establish the effectiveness of existing tropical house design against actual outdoor condition
- To develop new tropical building design principles base on theoretical and actual building performance with scientific evidence

The hypothesis of this research is that a new tropical building design principle will achieve the following:

- Decrease indoor air temperature compare with outdoor air temperature.
- Provide minimum comfort index at thermal comfort temperature requirement.

- Thus, decrease and provide minimum comfort index to predict the effectiveness of new tropical building design principle.

The term “new tropical building design principle” refers to best performance of building design principle which will decrease maximum indoor air temperature to obtain comfortable environment.

The following questions will be addressed in this study:

Q1. Does the use tropical building design principle effective in Taman Tropika House?

Q2. What are the tropical design principles influences in achieving comfortable indoor environment in Taman Tropika House?

Q3. What is the new tropical building design principle to obtain maximum comfortable indoor environment under Malaysian climate conditions?

Q4. What is the limitation of the new tropical design principle model to increase comfortable indoor environment in the residential building?

5.2 Research Conclusion

This section attempts to conclude the research by summarizing the major findings of the study and answering the research questions as stated. They are as follows:

5.2.1 Comfortable Indoor Environment of Field Study

a. The air temperature in the existing Taman Tropika house is similar compare to outdoor temperature. The results were compared for the neutral temperature and received higher than upper limit of neutral temperature.

b. Simulations of the Taman Tropika house were developed to predict the air temperature under similar condition of the existing building. Observations on the

indoor temperature revealed that this simulation in good agreement with field measurement result.

c. Based on the measurement and simulation results, significant impact on indoor temperature is above the neutral temperature for selected conditions. The investigation of the indoor temperature also showed that this house on all correspondence months experienced the temperature value of an uncomfortable condition. Generally, the Taman Tropika house received the highest indoor temperature in the afternoon. Increase of outdoor temperature on the annual month data also resulted in the increase of indoor temperature values of the thermal comfort. Therefore, it is important to consider the indoor temperature in existing house especially in the afternoon times with respect to outdoor conditions.

5.2.2 Modification of Tropical Building Design Principle

a. The study indicated that the proposed new tropical building design achieved the minimum indoor temperature. The modifications were done to roof structure, wall component, opening and floor to achieve minimum indoor temperature. Hence, it can be concluded, that for an indoor comfortable house, the Taman Tropika building modification can be used to develop the appropriate design of tropical building design and provide lower than neutral temperature.

b. The simulation results comparing different roof modification indicate that the roof with ceiling provide indoor temperature lower than the other roof modification on hourly data. This is above the upper limit neutral temperature for thermal comfort. In the case of the roof with ceiling, the lowest indoor temperature of 29.6°C on maxima peak time (19 September) was achieved.

c. The air temperature values indicated lower value in the U value and color wall modification compared to another wall modification house models. Considering

the material attributes to develop this the Taman Tropika model; therefore the study suggest that wall material with high U value and light color wall are required to achieve maximum temperature reduction.

d. The indoor temperature on opening modification indicated minima indoor temperature in the small percentage opening size. Differently, it experienced highest maximum temperature reduction compared to the other opening modification. Influence of the opening size indicated a decrease opening size in indoor temperature and has significant impact on the comfortable condition.

e. Simulation of the Taman Tropika house with floor modification on light color resulted in better indoor temperature performance than the other floor modifications. This implies that changing floor color surface had an impact to indoor temperature reduction. These results can be combined with another building modification to obtain the optimum thermal comfort house model.

5.2.3 New Tropical Building Design Principle

a. The relationship between the thermal comfort and the proposed tropical building were determined based on the assumptions of the indoor temperature and temperature reduction on the selected climate condition. The optimum proposed model suggested that the proposed model C can be achieved best proposed model as the new tropical building.

b. Hourly data in comfort condition had more impact on the amount of the indoor temperature and temperature reduction received inside the new tropical building house. Hence, the results indicated that in the afternoon, the new tropical building has upper limit of neutral comfortable temperature and minima temperature reduction.

c. The comfortable condition on new tropical building was obtained on the north orientation. It showed the lowest indoor temperature and highest temperature reduction. However, comparison with all orientations indicates that when considering only the indoor air temperature, all orientation can become thermally comfortable on proposed model C. Thus for low rise buildings impact of orientation is minimum.

Table 5.1: Influence of proposed tropical building design for indoor temperature

Time	outdoor	Field study	Model A	Model B	Model C
0	24,5	26,1	25,6	26,1	27,1
1	24,3	26,2	25,7	26,2	27
2	24,1	26,1	25,6	26,1	26,9
3	23,6	26	25,4	26	27
4	23,5	25,9	25,3	25,9	27
5	23,4	25,9	25,2	25,9	26,7
6	23,4	25,9	25,3	25,9	26,7
7	23,2	25,8	25,1	25,8	26,7
8	24	26,2	25,7	26,2	26,6
9	27,4	27,5	27,5	27,5	26,7
10	28,9	28,1	28,3	28	26,9
11	31,4	29,1	29,7	29	27,1
12	32,5	29,6	30,3	29,5	27,2
13	32,9	29,8	30,7	29,8	27,4
14	32,2	29,7	30,5	29,6	27,8
15	32,5	29,8	30,7	29,8	28
16	32,3	29,7	30,5	29,6	28,3
17	31,9	29,7	30,5	29,6	28,5
18	31	29,2	29,9	29,2	28,5
19	28,7	28,3	28,6	28,3	28,3
20	27,6	27,8	27,9	27,7	28,2
21	26,9	27,4	27,4	27,4	28,1
22	26,6	27,2	27,1	27,2	28
23	25,8	27	26,8	27	27,8

d. The hourly data of the new tropical building model showed the maximum air temperature and temperature reduction on different peak temperature days. Increase of outdoor temperature on mid day until the afternoon time increased the indoor temperature in new tropical building but still close with upper limit of neutral temperature. The constant air temperature obtained contributes to effective comfortable condition on different peak design day.

f. Also the results of monthly data indicated that indoor air temperatures are lower on new tropical building than the field study for all respectively conditions with high U value and small louver opening size (0.05m).

5.3 Suggestions for Further Research

This research has revealed two significant findings. Firstly, the introduction of the Taman Tropika House is significantly produced thermally comfortable house in the morning. It can maintain the indoor temperature similar with outdoor temperature but still above for thermal neutral temperature for comfort (28.5°C) in single space room. Secondly, the new tropical building design experienced minimum thermal comfort inside the rooms. As a result the internal thermal comfort performance of the new tropical building cool condition. Some of the area even achieved air temperature below 28.5°C. However, the introduction of the new tropical building design roof solar shade, wall material and louver opening at the house increases and further improve the thermal comfort condition.

This study has suggested that how a simple tropical building principle house strategy can be effectively used to reduce the air temperature and increase comfortable condition. The new tropical building design strategies require simple and rational modifications in material of the wall and window openings. However, several areas of study need further investigation, to develop the knowledge of the tropical building design strategies in Malaysia and regions with design of similar climates. Therefore, it is recommended that future research could look further into this area in order to strengthen and compliment this research.

The following are some suggestions:

a. Investigation on the effectiveness of the wall material. Apart from higher U value of wall material, the other factors need to be investigated are; the combining between several local material.

b. Further investigations are required to determine the effects of the new tropical building strategy on different room size on various building forms.
c. Further study and analysis on existing Malaysia house typology should be carried out to give a better indication on the indoor thermal comfort performance. Hence, a better comparison on the performance can be carried out.

Finally, it can be acknowledged that this work is a significant contribution by the researcher towards providing indoor comfortable house. It is hoped that it can induce good design solution that is not impossible in term of its low cost towards providing better comfort and more beneficial to the user.

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APPENDIX

Paper Submitted to ***9th SENVAR & 2nd ISESEE 2008*** International Seminar. Universiti Teknologi MARA (UiTM), Shah Alam, Malaysia on 1-3 December 2008

Title: Thermal Performance of Prototype Malaysian Traditional Timber House

THERMAL PERFORMANCE OF PROTOTYPE MALAYSIAN TRADITIONAL TIMBER HOUSE

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ABSTRACT

It is a generally held view that, in tropical countries, traditional house is more sympathetic to the prevailing climate and provide comfortable interiors. This paper analyses the above hypothesis for Taman Tropika House (TTH) in Universiti Teknologi Malaysia (UTM), which was designed emplacing tropical design strategies. The analysis of actual performance of the house can provide information on the effectiveness of applying principle of passive design that is appropriate for tropical climate. Empirical studies have been performed and internal and external air temperatures were measured. The internal data were collected in three zones; roof zone, middle zone enclosed with walls and the elevated floor surface. This study uses the neutrality temperature as a base to determine the thermal performance of the TTH. The upper and lower limits of the comfort zone without air movement were 28.5ºC and 23.5 ^{o}C respectively. Results show that the TTH architectural design solutions do not permit good passive cooling for thermal comfort during the whole day. The elevated floor effectively maintained the surface temperature within the comfort range for the most of the hours of the day.

Keywords: Taman Tropica House, traditional design principles, thermal performance

1.0 INTRODUCTION

Local climate greatly affects the indoor thermal environment in buildings. In tropical climates, buildings are overheated during the day due to solar heat gain through the building envelope and solar penetration through windows. From a thermal comfort point of view, it requires lowering of indoor daytime temperature below the outdoor temperature using building elements and by passive or active systems. Techniques for such thermal modification have been widely addressed in traditional building technology. Traditional building techniques utilized the environmental challenges and responds to achieve comfortable indoor environments. This subject has been dealt with by a number of researchers (Koenigsberger et. al, 1973; Evans, M. 1980). It can be argued that environmental performance of a traditional house also largely depends on the surrounding environment. The random layout, the natural setting, the use of local building materials and the lack of physical barriers give the village (kampong) an informal and open atmosphere compared to present urban and sub-urban environments. Direct application of traditional design principle to contemporary designs indicated adverse results on the environmental performance of the building (Ahmad, 2005). If traditional architecture works well when blending with nature, the question arises whether these traditional design principles are responsive with harsher environment that we experience today?

A comparative study between traditional Malay house and modern low cost house by Jones P. J, et.al (1993) indicated that both house types had 2.5^{o} C higher internal temperatures than the external temperatures during the day time. Further, at night the traditional house cooled rapidly near to external temperatures compared to the modern low cost house, which retained the temperature 2.5^{o} C higher than the external temperature throughout the night. However, different architectural elements of traditional house; roof, wall, opening and floor, need to be explored to determine the influence on the thermal performance. Thus, design principles implemented in traditional architecture can be applied in improving the current architecture. Thereby, present study set out to investigate the thermal performance of a timber house designed using traditional tropical architectural principles.

This paper discusses the results of a field measurement on the thermal performance of traditional Malay house in hot and humid climate. The experiment was carried out at the Tropical House in Taman Tropika UTM which was designed emplacing tropical design strategies, traditional Malay design concept and use of local material. Many visitors found the building provides good shelter during hot days, suggesting that indoor climate would be lower than the outdoor climate. However, there is no evidence to justify the performance of this building in term of its actual indoor climate and comfort condition that can be compared to establish thermal comfort condition as suggested by many researchers such as Md Rajeh (1989), Abdul Malik (1992) and Adnan (1997). Evaluation of actual performance through this research can provide further improvements and advancement of knowledge and design appropriate within tropical climate. It is hypotheses that performance of Taman Tropika House is similar or lower than outdoor environmental condition. This paper will determine the justification of the hypothesis.

2.0 METHODOLOGY

2.1 Taman Tropika House at UTM (TTH)

The basic field study is a timber house with a post and lintel structure raised on wooden stilts and a typical room configuration with overall size of 10m length and 5m width. The wall plate is about 3m and the ridge plate at the center of the roof is about 4.2m high from the floor surface. This TTH represents a single space room without internal partitions. The house is surrounded by lush landscaping and the longitudinal axis of the house is oriented east- west.

As the traditional Malay house, the TTH has architectural elements that can be categorized into three main zones. The top zone, which covers the roof element, the middle zone for wall and the bottom zone which is the elevated floor space above the natural ground level (figure 1). The roof is the most important building envelope component providing shelter from external climatic forces, such as solar radiation, rain and wind. Its performance will depend on the form, construction and material. The roof form at TTH is similar to the ‘bumbung lima’ (limas) or a hipped roof with Dutch gable ends. The Dutch gable is decorated with ventilation panels to extract the heated air outdoors. Timber frames are used as roof structure covered with clay tile and timber panels underside of the tiles. The eave of the roof extends about 2.8m from the external wall thus controls the solar penetration even at low solar angles.

The middle zone is enclosed with 25mm thick wooden horizontal louvered panels and 12mm thick solid timber walls. The wooden horizontal louvered panels cover 80% of the wall area and positioned in all four cardinal orientations. The ventilation gaps between the horizontal louvers are about 25mm and each panel is about 2.9m high from floor surface. The design intentions of these horizontal louver panels are to provide cross ventilation while the openings are closed and for night ventilation. This will reduce the effect of warm air in the room.

The floor is constructed with 25mm and 150mm wide wooden stripes. The height between the natural ground and the raised floor of the building differed from 1.4m to 0.8m. An elevated floor can influence on two distinct thermal criterions, provide good airflow under the floor space and avoid direct heat transfer from the ground. However, the effectiveness of these horizontal louvers and the elevated floor in reducing the internal air temperatures needs to be explored before applying them in contemporary architectural design. .

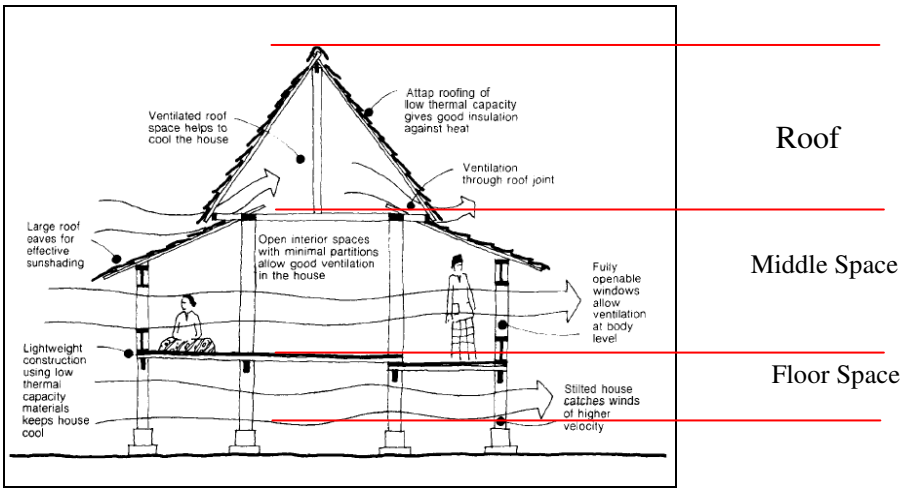

Figure 1: Typical cross section of a Traditional Malay House (Source: Yuan, Lim Jee 1987)

2.2 Instrumentation

The physical measurements were carried out using air temperature and humidity data loggers and surface temperature data loggers. The temperatures for both internal and external were recorded at every 10 minutes. The data were averaged for every hour to obtain the hourly values. The positions and the measured variables of the data loggers are described in table 1. The building was unoccupied during this period. The measurements were collected for one-month period starting from 20 September to 10 October 2007.

Table 1: Description of data logger positions and measured variables installed at Taman Tropika UTM

No	Position & Description	Measured variable
1	Middle of the Space on the timber floor surface	Internal floor surface temperature
2	Middle of the Space, 1.5m from floor level	Internal air temperature & humidity at human body level
3	Middle of the space, 3m from floor level	Internal air temperature & humidity under the roof space
4	Outdoor weather station	Outdoor air temperature

Figure 2: Physical data collection at interior and the exterior views of TTH

The analytical method of evaluating the comfort zone for Malaysia have been studied by several authors (Rajeh, 1988, Jones, P. J, 1993), using the "Neutrality Temperature". This study uses the neutrality temperature as a base to determine the thermal performance of the taman tropika house. In various studies, neutrality temperature is defined as the temperature that gives a thermal experience neither warm nor cool, which is a state of "neutral" or "comfortable". It is the mid point of the comfort zone, as an average value for many experimental subjects. According to Auliciems, A. and S. Szokolay (1997) with the range of the comfort zone is taken as 5°C, thermal comfort temperatures extends approximately about 2.5°C above and below the neutral temperature. According to Szokolay comfort formula, the neutral temperature needed to maintain at 26ºC. With the width of the comfort zone taken to be 5ºC (Auliciems, A. and S. Szokolay, 1997), thermal comfort temperatures extends approximately about 2.5ºC above and below the neutral temperature. Taking the neutral temperature of 26ºC in free running building, the upper and lower limits of the comfort zone would then be 28.5ºC and 23.5 ºC respectively. This neutral temperature is for conditions without air movement.

3.0 RESULTS AND ANALYSIS

3.1 Comparison of Internal and External Temperature

The purpose of this paper is to discuss the influence of the tropical design strategies on the thermal performance of the taman tropika house at UTM. The results are analysed by comparing the internal and external temperatures of the three zones identified, namely, top zone covered by the roof element, middle zone enclosed by the wall element and the elevated floor space. Figure 3 & 4 illustrate the results of the internal temperatures obtained at 1.5m and 3m height from the floor level over the period of three weeks. This period was taken in order to establish the trend of the temperature over a period longer than a day (24 hours). The external and internal air

temperatures did not vary very much during the three week period and therefore any 24-hour period selected would be representative.

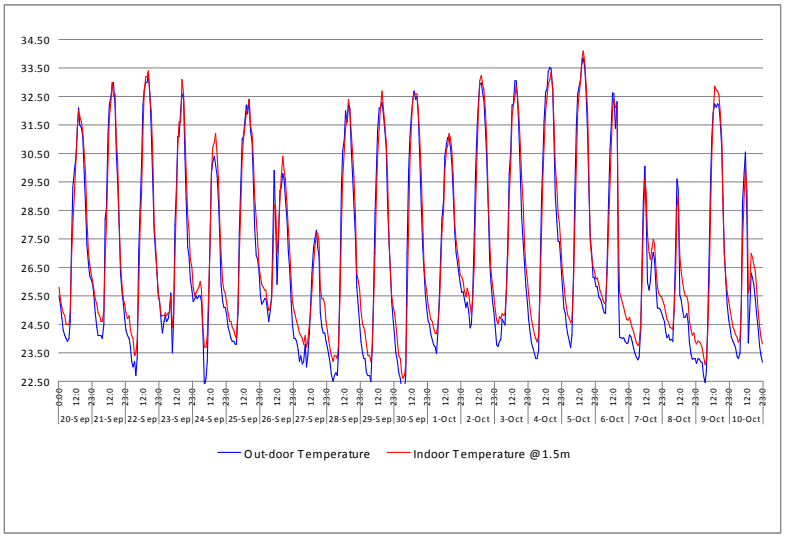

Figure 3: Comparison of internal and external temperature at 1.5m height from floor level - 20th September to 10th October at TTH

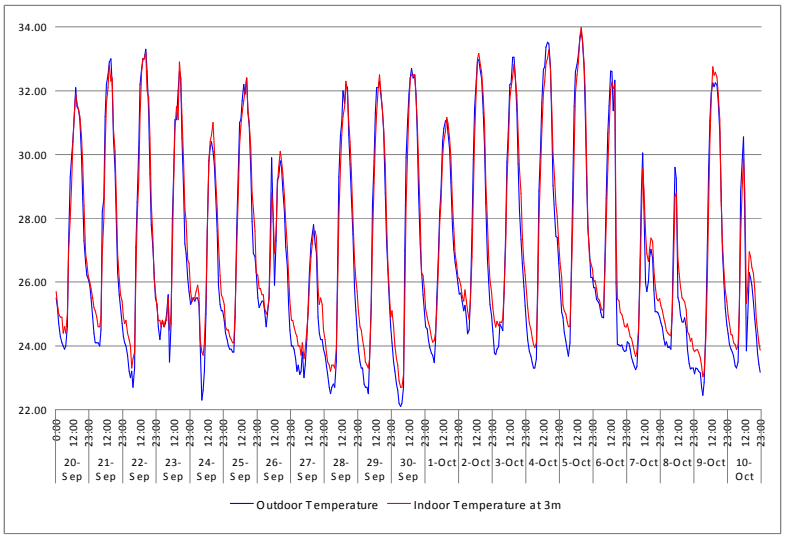

Figure 4: Comparison of external and internal air temperature at 3m height from floor level - 20th September to 10th October at TTH

The internal surface temperature of the raised floor was measured and the results are illustrated in figure 5. The internal floor surface temperature showed higher value during night time, while lower value during daytime compared to the external temperature. This pattern was consistent throughout the measured experiment days. Therefore two dates are selected to compare the external and internal temperatures of the physical measurement.

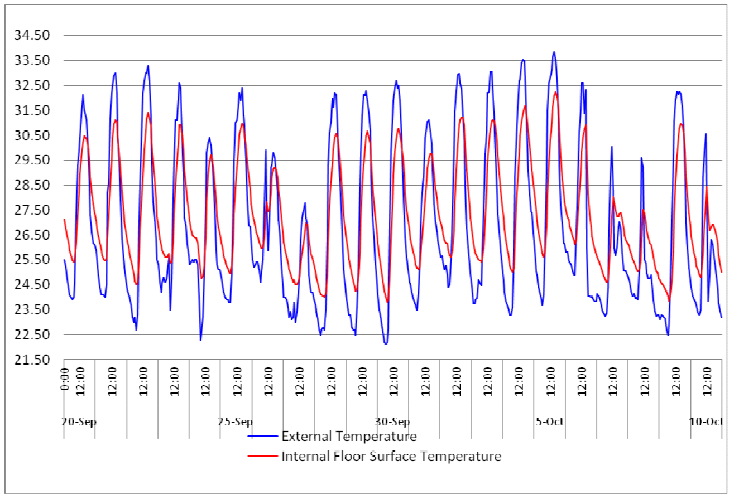

Figure 5: Comparison of external and internal air temperature and indoor floor surface temperature at 1.4m height from natural ground level - 20th September to 10th October at TTH

The reveiw of maximum and minimum temperature data on each day indicated that the air temperature vary little between the day and night. External, internal and surface maximum and minimum temperature resulted an average 8.2 °C, 7.9°C and 5.3°C temperature differences respectively. The comparatively smaller temperature differences indicates that building envelope cannot cool down sufficiently at night therefore use of lightweight construction is recommended.

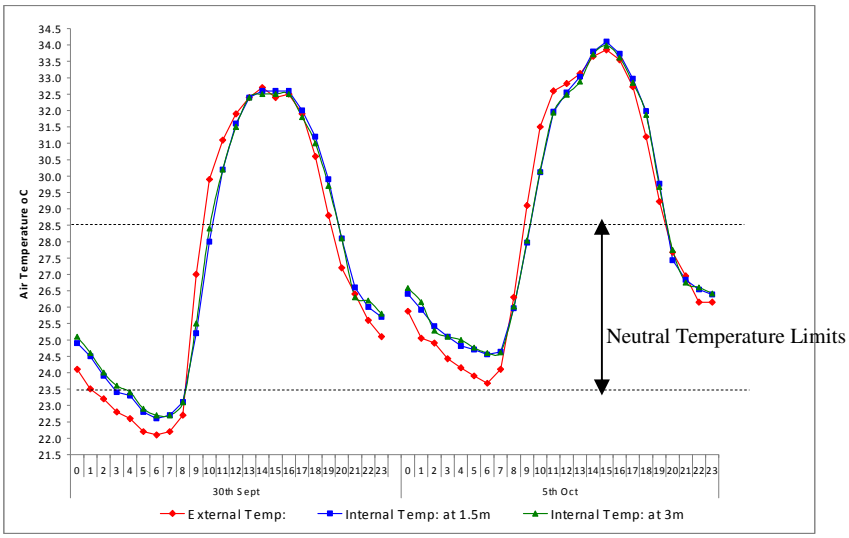

Figure 6: The external and internal temperature profile for the selected days

As illustrated in figure 6, 30th September and 5th October were selected to analyse the internal and external temperatures. These two days were selected as they indicated the minimum and maximum external temperatures respectively, during the experiment period. The external and internal temperatures illustrate a similar pattern during day and night time. Similarly, the roof zone (3m height) and middle zone

(1.5m height) of the internal space indicated insignificant temperature difference. This may be due to the exposed nature with louvers of the external walls of the TTH. This means that the effect of the wall design for cross ventilation with louvers had influence on the internal temperature to be similar as the external temperature during the day time. Further, the roof does not include any insulation materials. Therefore the heat transfer through the roof element is high. It is important to reflect or re-radiate the heat to outdoors as much as possible before entering to the space inside. Thus, the use of insulation material is inevitable with the roofing material. Use of dark colour surfaces for roof, wall, louvers and the floor also may have influenced on the high internal temperature.

The external maximum temperatures were recorded as 32.7^{0}C (14:00hr) and 33.85^{0}C (15:00hr) on 30th September and 5th October respectively. The maximum internal temperatures at 1.5m height were recorded as 32.6^{0}C (14:00-16:00hrs) and 34.1^{0}C (15:00hr) on respective days. The internal temperature recorded above the comfort range (28.5^{0}C) between 10:00-19:00hrs on both days. This emphasises that during daytime TTH is uncomfortable with louvered openings.

The minimum external and internal temperatures were indicated at 6:00 AM on both days. On 30th September, the minimum internal temperature indicated below the comfort limits at 1.5m height between 3:00 – 8:00 AM. Although, the internal temperature increased above the external temperature during night hours (between 20:00 to 07:00 hours), the house is under comfort range between 20:00 hours at night to 9:00 hour next morning. Thus, uses of louvers are inadequate to control the hot air during daytime although it may control the glare and direct radiation. But during night time the louvers may help to reduce the internal air temperature through stack effect. Hence, the design principles for cross ventilation need to rethink considering the time of day and especially in areas with minimum ventilation. Further, the results emphasise the importance of the use of night ventilation in hot and humid climate.

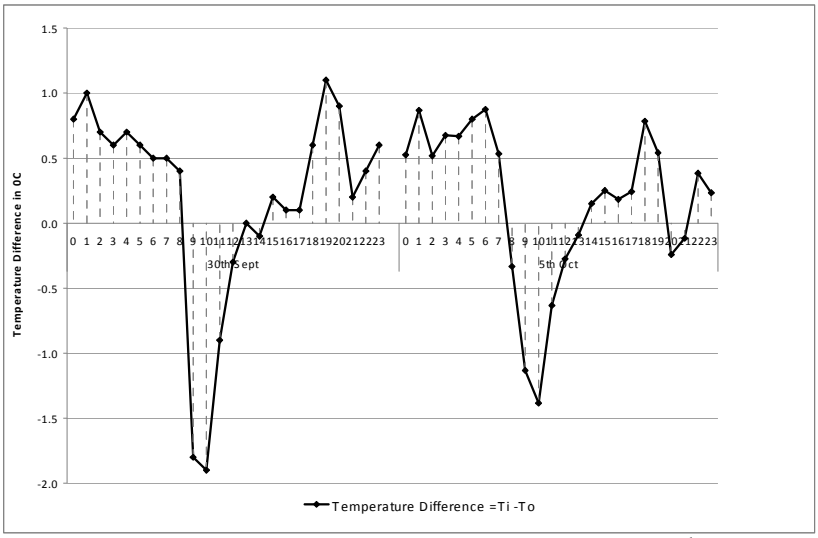

Figure 7: Internal to External air temperature difference on 30th September and 5th October at TTH

Figure 7 illustrates the differences obtained by comparing the internal and external temperatures. Positive values means the external is cooler than the internal temperatures, while negative value means the external is hotter than the internal

temperatures. The maximum difference between internal and external air temperatures is within 3 degree and this transpires during daytime. Night-time temperature difference is less compared to the daytime temperature difference. The temperature differences between internal and external are relatively very small. This is due to lightweight and low thermal capacity materials used for construction.

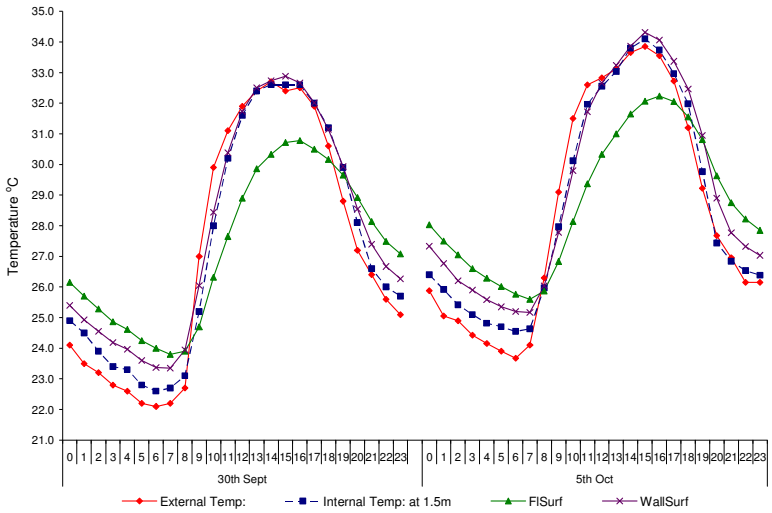

Figure 8: Comparison of floor and wall surface temperature with internal and external air temperature

The surface temperatures of the floor and wall were measured to understand the influence of the heat towards achieving a comfortable interior. According to a study conducted by Zhang, L et. al (1998), to achieve internal air temperature within 21-23°C, the floor surface temperature need to maintain within 26-30°C. The reradiated heat from the floor surface is high compared to the wall surface during night time (figure. 8). Both surface temperatures indicated a higher value compared to internal and external air temperatures in the night. During the daytime the internal wall surface temperature measured higher temperature than the floor surface temperature. The maximum external temperature was indicated at 14:00 and 15:00 hours on respective days. However, the maximum internal floor surface temperatures were measured at 16:00 hour on both days. This means the thermal lag properties of the material used at TTH are low. Use of light weight materials at TTH has reduced the amount of heat stored by the wall.

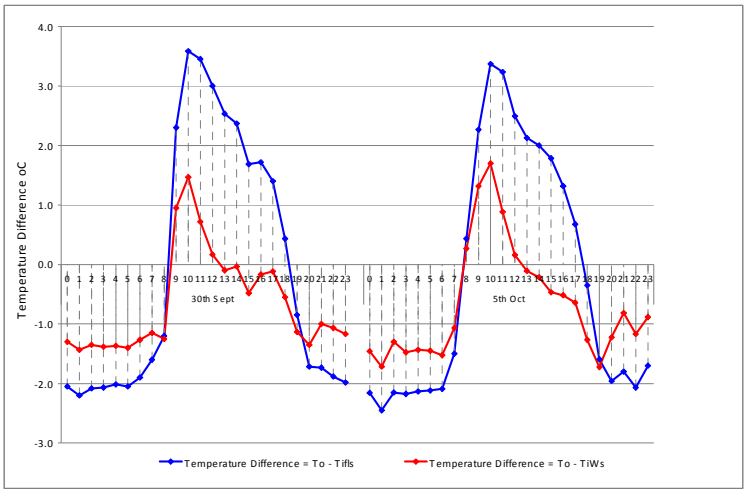

Figure 9: Comparison of temperature differences between external air temperatures and internal surface temperature

The difference between external and internal wall and floor surfaces temperatures are illustrated in figure 9. Positive values indicate that internal surface temperature is cooler than the external temperatures, while negative values means the internal surface temperatures are hotter than the external temperatures. According to figure 9, the temperature difference between floor surface and internal air temperature is higher compared to the wall surface and internal air temperature. Smaller the temperature difference higher the amount of heat transferred through the material. Further, figure 9 illustrated that wall surface temperature is lower than the outdoor temperature (T_o>T_{iWs}) from 9:00AM to 12:00 noon and 8:00AM to 12:00 noon on respective days. Thus, over 80% of hours of the day, the internal surface temperature of the wall is higher than the outdoor temperature. Internal floor surface temperature indicated a lower value (T_o>T_{iFs}) compared to outdoor temperature during 9:00AM to 18:00PM and 8:00AM to 17:00PM on respective days. This means the internal floor surface temperature measured high over 60% of hours within a day. This indicates that the reradiating temperature from the wall surface influence on the internal air temperature compared to the reradiating temperature from the floor surface, especially during the daytime. The use of 12mm thick timber as wall element had little effect on reducing the heat transfer from outside to inside during daytime compared to 25mm thick timber floor. Further, the dark coloured surfaces of the wall also reflected poorly and allow more heat gains. The elevated floor reduced the heat gains from the floor surface to the interior during daytime. However, the stored heat from the floor influenced the indoor air temperature to be higher than the external air temperature during the night time.

4.0 CONCLUSION

The results of the physical measurements of the air temperatures of the existing Taman Tropika house proved that the internal air temperature is similar to the external temperature. The results were compared for the neutral temperature and received higher than upper limit of neutral temperature for comfort zone. This is due to the low maximum and minimum temperature difference experienced in the warm humid zone and due to the use of lightweight materials for construction. The TTH is

within the comfort range during late night time and in the morning hours when the external environment is cooler, while during the daytime the air temperatures were above the comfort range. During the day time, efficiency of the roof, wall and louvered panels are low in order to reduce the internal air temperature than the external air temperature at TTH. Louvered panels provide required night ventilation to bring the temperature within comfort range at night. However, the design principles for cross ventilation need to rethink considering the time of day and especially in areas with minimum ventilation.

The elevated floor reduced the heat gains from the floor surface to the interior during daytime. However, the stored heat from the floor influenced the indoor air temperature to be higher than the external air temperature during the night time. The heat gain from the floor surface enabled to maintain the internal temperature within the comfort temperatures.

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