Passive Cooling Strategy in Designing Public Assembly Building

(A Design Typology for the Taoist Academic Centre in Tropical Climate)

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ABSTRACT
Passive cooling strategy is a key element of sustainable building. Its optimum performance and potential benefit can be realized with careful and meticulous design. As a design option for public assembly spaces, however, passive cooling strategy is seldom given a fair consideration as compared to the mechanical cooling approach, especially in the tropical climate where high humidity prevails. This paper presents an extensive study on the technological aspects of vernacular architecture in Malaysia, particularly on the efficiencies and limitations of the passive house design, in order to explore the workable sustainable architecture prototype for public assembly spaces in the tropical climate. With the lessons learnt from the vernacular architecture, the design typology for a Taoist Academic Centre (TAC) was proposed. By adopting an integrated environmental design approach which involved performance analysis through computational studies, the design scheme was tested and modified to achieve the optimum spatial and environmental outcome. Ultimately, the paper aims to demonstrate that modern tropical architecture prototype is possible to be developed from vernacular architecture, and the proposed prototype will not only respond well to the local climates, but is able to accommodate different cultural contents.

Keywords: *Thermal comfort, tropical climate, Malay house, passive design*

1.0 Introduction

All built developments, from the smallest to largest, make a long-term impact, either on the communities they house or in the surrounding neighbourhoods. Where they are, how well designed and built the structures are, and how well knitted into the fabric of existing or new communities, are factors that can affect the lives of people and for future generations. Public assembly spaces (i.e. churches, meeting halls, school classrooms etc.), in particular, have a considerable influence on the urban culture and city life. These spaces not only ensure a physical link between buildings and land uses in order to keep afloat the marketing, manufacturing, administrative, and transportation activities of the cities, but also facilitate a link amongst people, facilities, communication and interaction - thereby serving to bind together the social order of local community by creating a locale for social interaction (Gencel and Velibeyoglu, 2006).

Following the increase of awareness on global warming and energy dependence in the built environment, building sustainability is increasingly being emphasized around the world. Occupants are now more conscious about the importance of sustainability for a better quality of life (Jamaludin et al., 2014). Public assembly spaces are no exception in fulfilling their contribution to the society in respect to sustainability. At the building stage, the social benefits of sustainability focus on ensuring occupants' health, comfort, and satisfaction. Studies show that building environment can have negative impacts on the occupants. These impacts include illness (Brightman and Moss, 2001; Fisk, 2002), absenteeism (Milton et al., 2000), discomfort (Heerwagen et al, 1991; Wyon, 1996; Leaman and Bordass, 2001), stress (Heerwagen, 2000), and distractions (Leaman and Bordass, 2001), resulting from poor indoor air quality, thermal conditioning, lighting, and specific aspects of interior space design (i.e. materials selections, furnishings, and personnel densities). Reducing these problems through sustainable design can improve occupant's overall health and performance. Buildings also contain features and attributes that can create positive psychological and social experiences. Emerging evidence shows that certain sustainable building features, such as access to daylight and views (Leather et al., 1998), and connection to nature (Ulrich, 1984; Clearwater and Coss, 1990), are likely to generate positive states of wellbeing and health.

Passive cooling strategies, such as thermal mass, external shading, building orientation, cross ventilation, and better insulation in buildings, are the key elements of sustainable building. With less reliance on mechanical system to maintain comfortable internal temperatures, passive design building has become synonymous with quality, comfort, and ultra-low energy buildings that require less energy for space heating and cooling (Wimmer et al., 2013). Extensive research on passive house design in temperate climates has been carried out in the last two decades and remarkable improvements have been achieved with regards to the energy performance of buildings. In contrast, there are far less documentation and examples available for the tropical climates. As pointed out by Groenhout and Partridge (2010), it is relatively easy to achieve energy efficient climate control through passive measures alone for most or even all of the year in temperate climates. But much more challenges associated with elevated external temperatures, such as higher humidity for much of the year, significantly more direct solar radiation, and the lower diurnal temperature variation, are to be expected in the tropical climates. In the case of public assembly spaces, the challenges of achieving comfort conditions are further compounded by the high occupant density, and intermittent or infrequent usage as they have very different occupancy and space loads, compared to more conventional spaces. As a consequence, attempts to achieve building comfort in tropical climates, particularly for those public assembly spaces, are mainly through improved mechanical cooling.

However, it is believed that the optimum performance and potential benefit of passive cooling strategy can be achieved with careful and meticulous design. A good building design can decrease power consumption, saves money, and contribute to the reduction of greenhouse gas emissions. A bioclimatic design that is based on local climate, aimed at providing thermal and visual comfort, as well as making use of solar energy and other environmental sources can even provide a comfortable environment, given the passive features & design. Research suggests that bioclimatic buildings use 5 to 6 times less energy than conventional buildings over their lifetime, through the use of the buildings' microclimate, form and fabric, rather than through the use of efficient mechanical equipment (Jones, 1998). In fact, using natural phenomena to reach indoor comfort has been well known since the early eras. The vernacular architecture of the Malay *kampong* house has responded with such phenomena with good solutioning for tropical climate region. It realizes the optimum comfortable indoor temperature throughout most days of the year by equating the volume adopted, with the different natural elements forces of the sun, atmosphere, biosphere, and climate, which are commonly known as passive design strategies. Since the vernacular architecture has been recognized as a climate responsive approach that accomplishes sustainability in human environment (Choi and Yu, 2013), building for sustainability may need to reconsider these pre-industrial times' design techniques and principles, so as to draw a deeper insight on quality of life in built environment in present day.

It is with this aim that the study is conducted, by undertaking a case study to propose and optimize the design of a public assembly space – Taoist Academic Centre (TAC) – with the use of passive design strategy extracted from the vernacular architecture – a typical Malay *kampong* house. By further assessing the efficiency and limitation of the passive cooling strategies for hot and humid climates, the study aims to prove that modern tropical architecture prototype is possible to be developed from the vernacular architecture, and this prototype will not only respond well to the local climates, but also able to accommodate different cultural contents. Ultimately, the findings from this study functions as an input to the real project that takes place in Sri Kembangan, Kuala Lumpur.

2.0 Methodology

The study started with the analysis of local climate, by using the Ecotect software, to identify the thermal comfort zone to be achieved in the architecture design at later stage. Then, the simulation was done to a typical traditional Malay *kampong* house, to identify the embedded environmental design strategies. Based on the preceding analysis, the prototype of TAC was developed to form the basic module for the design of the mentioned real life project.

2.1 Tropical Climate Study

The actual project will be taking place in Sri Kembangan – a town located 20km from the centre of Kuala Lumpur. The zone setting and other thermal properties for local climate analysis were based on the one that is applicable to Kuala Lumpur. Figure 1 shows the location of the actual project. The dimensions of the site measures 290m by 280m, with a small lake in the centre. Four corners of the site are connected by public roads, with the North/South Highway situated in the southern part of the site.

Figure 1: Site plan for the project

2.2 Malay Kampong House Simulation

There are three approaches which are commonly adopted in the study of thermal performance for building envelopes: (i) through calculation with a formula, in Grigoletti et al. (2008); (ii) through field measurement, in Healthcote (2007); and (iii) computer simulations. For current day study, the simulation of a typical Malay *kampong* house was carried out to identify the details of its climatic responses.

Through literature review, it was found that most of the traditional Malay *kampong* houses share the same strategies in attaining the optimal climatic control:

(i) allowing adequate ventilation for cooling and reduction of humidity;

(ii) using low thermal capacity building materials, so not a lot of heat is transmitted into the building;

(iii) controlling direct solar radiation;

(iv) controlling glare from the open skies and surroundings;

(v) protecting against heavy rain; and

(vi) assuring adequate natural vegetation in the surroundings to provide a cooler microclimate. As such, a simplified model of the typical Malay *kampong* house, with the following conditions, was constructed to capture the essence of its design strategies:
  - The house is elevated 1500mm above ground.
  - The interior space is sub-divided into three rooms, and are connected with doors. The height of the rooms is 3000mm from ground which is 1500mm above 1st floor.
  - The high pitch roof has opening on both gable ends; this is common features for Malay house.
  - There is no ceiling; the roof space and the room space is one high volume of space.
  - There are two zones assigned, the room zone includes the roof space, and the ground zone, which is the elevated space below the room.
  - The materials used are mainly timber – for walls and roof.

- The façade has large openings, using void instead of windows from the software.
- Overhangs are 1500mm all round.
- The longer elevation are facing north south orientation.
- The date chosen is on 21st March, Equinox, where the Sun is directly above the equator and shortest distance to Earth.

Both the model zoning views are shown in Figure 2 and Figure 3, respectively.

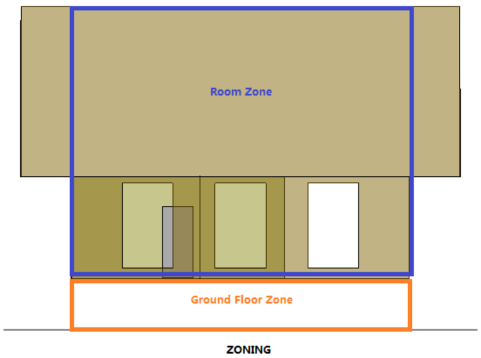

Figure 2: Malay house Ecotect model zoning

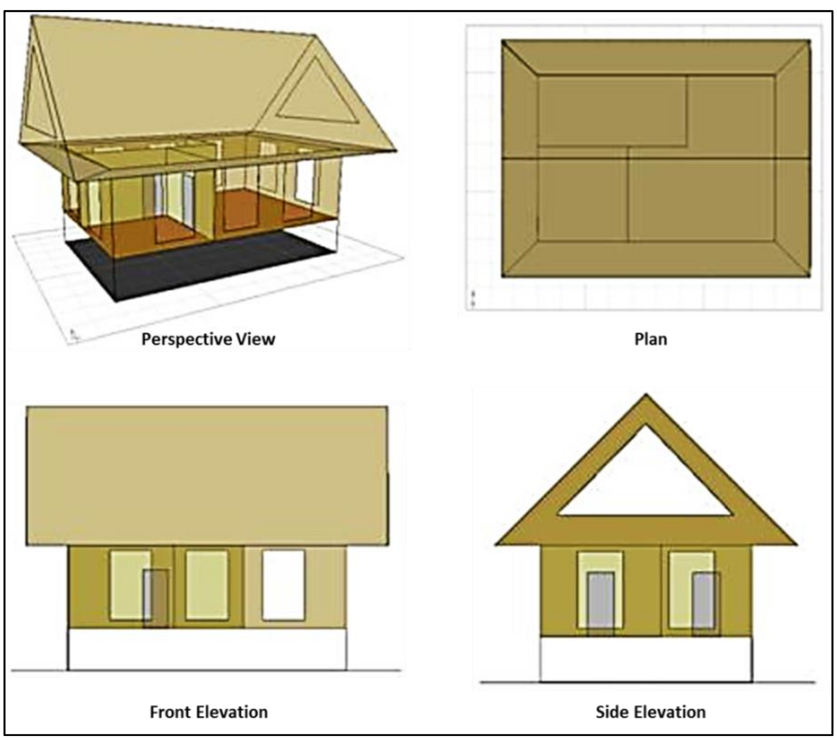

Figure 3: Malay house Ecotect model views

2.3 Proposed Prototype Design – The Concept of Eco-Pavilion

Based on the results from the preceding analysis, the concept of Eco-pavilion was proposed as an initiator towards sustainable public assembly building in tropical climate. Conceptually, the Eco-pavilion is a reflection of the passive cooling strategies found in Malay *kampong* house that considers the issues of space, internal circulation, cross ventilation, and numbers of openings, but proposes for the reverse of space functions within the house. Three models of TAC were simulated and their thermal performance was compared.

3.0 Results and Discussion

3.1 Local Climate Analysis

The results of local climate analysis are shown in Figure 4, while the other important points are summarized as follow:

- The average temperature in Kuala Lumpur, Malaysia is 27.5 °C (82 °F).
- The range of average monthly temperatures is 1 °C.
- The warmest average max/ high temperature is 33 °C (91 °F) in February, March, April, May & June.
- The coolest average min/ low temperature are 22 °C (72 °F) in January, February, July, September & December.
- Kuala Lumpur receives on average 2409 mm (94.8 in) of precipitation annually or 201 mm (7.9 in) each month.
- There are 202 days annually on which greater than 0.1 mm (0.004 in) of precipitation (rain, sleet, snow or hail) occurs or 17 days on an average month.
- The month with the driest weather is July when on balance 102 mm (4.0 in) of rain, sleet, hail or snow falls across 11 days.
- The month with the wettest weather is April when on balance 279 mm (11.0 in) of rain, sleet, hail or snow falls across 21 days.
- Mean relative humidity for an average year is recorded as 62.6% and on a monthly basis, it ranges from 58% in March, to 66% in May & November.
- There is an average range of hours of sunshine in Kuala Lumpur of between 4.9 hours per day in November and 7.4 hours per day in February.
- On balance, there are 2228 sunshine hours annually and approximately 6.1 sunlight hours for each day.

Please note: The green-coloured belt shown in Figure 4 is the thermal comfort zone for Kuala Lumpur, which ranges from 20 – 25°C for environmental designers. It is, thus, important to achieve this range in the proposed prototype design.

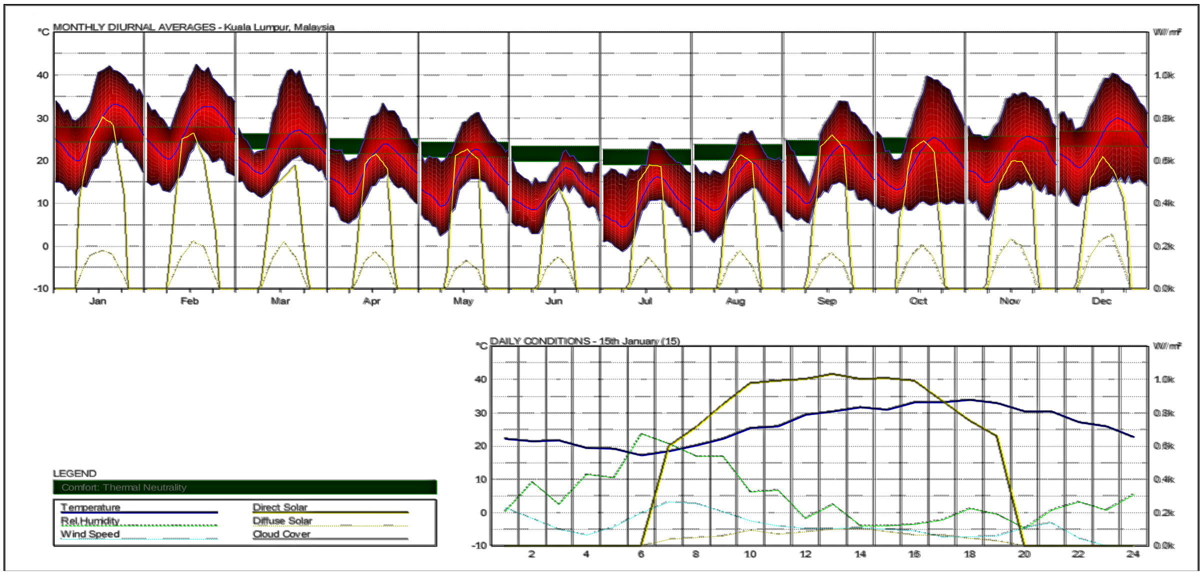

Figure 4: Monthly Diurnal Average – Kuala Lumpur

3.2 Ecotect Analysis of Malay *Kampong* House

Amongst the analysis to be undertaken are solar exposure, daylight analysis, insolation analysis, and thermal comfort analysis.

3.2.1 Solar Exposure

Figure 5 shows the average daily solar exposure of the model. The direct solar exposure average daily from 0900hr – 1800hr ranges from 400 – 640W/m^2 for the whole year. In January, the radiation reaches as high as 792.1W/m^2 at 1300hr, which is the highest throughout the year. This indicates that the room receives tremendous solar exposure in the day. The shading graph, as depicted in Figure 6, indicates that the shading of the Malay *kampong* house in Jan, Feb, Mar, Oct, Nov, and Dec are insufficient from 0900hr – 1800hr. For example, in January, the shading is 0% for most of the time within the respective period.

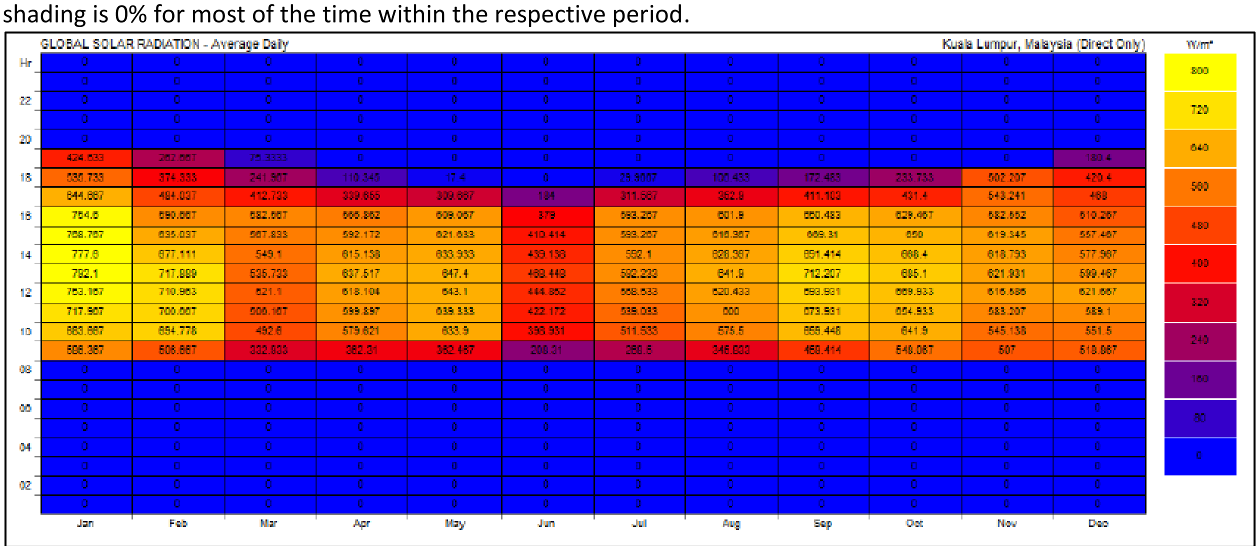

Figure 5: Malay *kampong* house global solar radiation – average daily

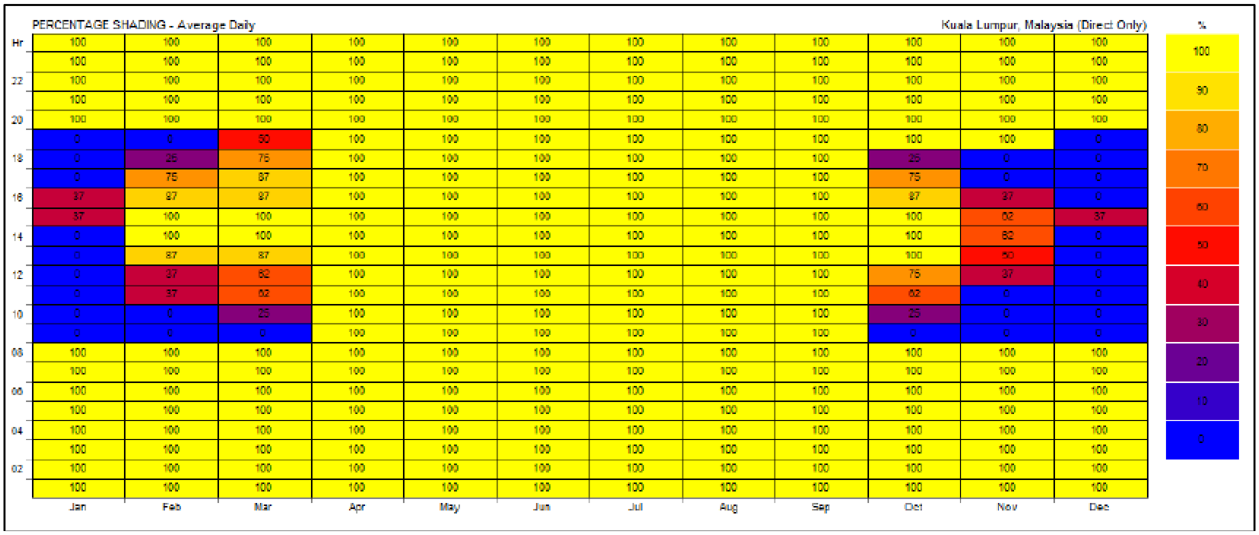

Figure 6: Malay *kampong* house percentage shading – average daily

3.2.2 Daylight Analysis

The daylight analysis is carried out at two levels – 1500mm (ground floor zone) and 3000mm above ground (room zone). The following results are presented: (i) daylight factor; (ii) day-lighting level; (iii) internal reflection; and (iv) sky component (Please refer to Table 1 on Summary of Daylight Analysis). The daylight factor for ground floor has an average value of 48.95% while the average value at room level is 66.45%. The amount of daylight that enters the room is about 1.5 times that of ground level. The day-lighting level is up to 4160.51lux for ground floor and 5648.00lux for room level, which indicates that the amount of daylight is immense. As for comparison, the required day-lighting is about 320lux for normal office activities. As there is intense daylight in the day, the amount of daylight reflected internally for ground floor is 10.89% while the room space is 25.18%. The room has higher percentage because it has relatively more daylight and enclosed by walls. In terms of sky component, the daylight in room and ground floor is 41.24% and 38.05%, respectively. Overall, the daylight level is high and together with daylight brings in heat and radiation to internal space.

Table 1: Summary of daylight analysis

Daylight analysis	**Room zone (3000mm above ground)**	**Ground level zone (1500mm above ground)**
Daylight factor	66.45%	48.95%
Daylighting level	5648.00 lux	4160.51 lux
Internal reflection	25.18%	10.89%
Sky component	41.24%	38.05%

3.2.3 Insolation Analysis

This section looks at the insolation effect and radiation from the vegetation around the building. It includes sky factor and photo-synthetically active radiation (PAR), which is the total radiation, percentage visible sky, and plant radiation. The average daily PAR for the ground floor and room zone is almost similar, which is 3.60 MJ/m2/d and 3.79MJ/m2/d, respectively. The average daily total is 2368.45Wh (ground floor zone) and 2495.40Wh (room zone). Although the room zone are exposed to more radiation, the difference is only 129.95 Wh, due maily to the effects of vegetation around the house on ground level.

Table 2: Summary of insolation analysis

Insolation analysis	**Room zone (3000mm above ground)**	**Ground level zone (1500mm above ground)**
PAR	3.79MJ/m^2/d	3.60MJ/m^2/d
Average daily total	2495.40Wh	2368.45Wh

3.2.4 Thermal Comfort Analysis

The mean radiant temperature is high, with 32.50°C in the ground floor zone and 35.83°C in the room zone. The results are beyond the ideal range of thermal comfort (25.5ºC – 28°C). This renders the house to a relatively high discomfort level in the day. The Predicted Mean Vote (PMV) index shows the mean response of a large group of people according to the ASHRAE thermal sensation scale. Based on this scale, both ground floor (2.6 PMV) and room zones (3.6 PMV) are considered warm and hot. Another indicator – Predicted Percentage Dissatisfied (PPD) – also indicates that over 95% of the occupants are dissatisfied staying in the house. Further study on the hourly temperature found that the temperature of the room zone increases beyond 30°C at 1130hr to 40°C at 1430hr, and decreases back to 30°C at 1600hr, in which the temperature in this period is totally above the thermal comfort level. The temperatuer of the room zone is much higher than the outdoor temperature as heat trapped within four walls, while the ground floor zone is generally within the thermal comfort zone, with the highest temperature in the same period is 28°C, due to vegetation on ground, no walls nor partition, and the air flow freely through the space. The main heat gain is from Direct Solar. The rate of hourly heat gain for the ground floor zone is faster. However, the values at ground zone is only 7200W, peak at 1200hr then decreases to 4800W at 1330hr and slightly rise to 5000W at 1500hr and then continue to decrease. The room zone, on the other hand, it takes a longer time to increase, and the gain goes beyond 100,000W at 1700hr. This means a lot of heat is trapped in the room zone between 1300 – 1500 hrs. Heat gain is 14 time more in room zone.

As shown in Table 3, the ground floor zone loses heat through fabric (58%) and inter-zone (35.90%), while gains heat from solar (67.9%) and internal (15.0%). The room zone loses heat through fabric (86.5%) and gains from solar (87.00%). Room zone highest heat gain value 18400W/m^2 and ground zone highest heat gain 2400W/m^2, which is 7.6 times more in room zone.

Table 3: Results of pasive gain breakdown

Category	Ground floor zone		Room zone	
	Losses	Gains	Losses	Gains
FABRIC	58.50%	6.40%	86.50%	4.90%
SOL-AIR	0.00%	0.00%	0.00%	5.00%
SOLAR	0.00%	67.90%	0.00%	87.00%
VENTILATION	6.20%	0.80%	6.70%	0.40%
INTERNAL	0.00%	15.00%	0.00%	1.60%
INTER-ZONAL	35.30%	10.00%	6.80%	1.10%

The result appears to coincide with the field measurement by Hassan and Ramli (2010) in which the thermal comfort of the room space is not satisfactory. The simulation shows that the ground floor zone open space of the Malay house performed better than the room zone due to:

- The ground space is open and allows for cross ventilation while the room above is enclosed with walls. Even though the openings are able to facilitate cross ventilation, it is not as good compared to the ground. The room zone is not comfortable to stay in from 1100 – 1800hrs.
- The ground level has two layers of protection against the sun, the first layer is the roof and the second layer is the room directly above. The heat reaching the ground space is greatly reduced. Also since the ground space is open with vegetation, ventilation is possible, together with green, heat will be absorbed or flushed away.

3.3 Development of Eco-Pavilion – An Ideal Model Formation

The simulation results show that space within the comfort zone is the elevated space below the room (ground floor level). As such, the house can be conceptually made climatically responsive by reversing its functions, which is making use of the ground level space as functional rooms while leaving the 1st floor as an open pavilion. The features of the Eco-pavilion are summarized as follow (Please refer to Figure 7):

- An elevated space at ground level. The space is of multifunctional use. It can be used as an open space, similar to the Malay traditional house, or to be used for various functions. Rooms, office, canteen and so on can be at the ground level.
- Around the ground level, an interstitial space is developed on four sides to serve as a climatic buffer zone.
- Above the ground floor is the open deck or "pavilion deck". This deck will be primarily used as open deck for human activities; no physical rooms will be built here.
- The eco-pavilion is in a basic form of a square or circle, the size and dimension can vary according to functions. This basic unit will be in modular construction and will be above to comply with the geometrical layout requirements of fengshui.
- The module is flexible and expandable according to the site conditions. It follows the modular principles of the Malay house discussed earlier.
- The rooms are encouraged to stay open, although they can be enclosed by windows and bi-fold doors.

Since the main heat gain is from solar (67.9%) at ground level, it is crucial to design a buffer element to reduce the external heat. The Eco-pavilion with the primary functions located at ground level has two major climatic buffer zones: (i) roof buffer zone; and (ii) wall buffer zone. The roof buffer consists of the open terrace above plus the roof with overhang. The roof will be installed with solar panels and gutter that collect rainwater. The absorption of solar energy reduces the impact of the sun to the space below. This means the room space at ground level has double layer protection (Figure 8). Wall buffer integrates the ideas of interstitial space and added an addition of 2m corridor on four sides around the ground level. The external envelope can be in the form of green walls, or water curtain as main features.

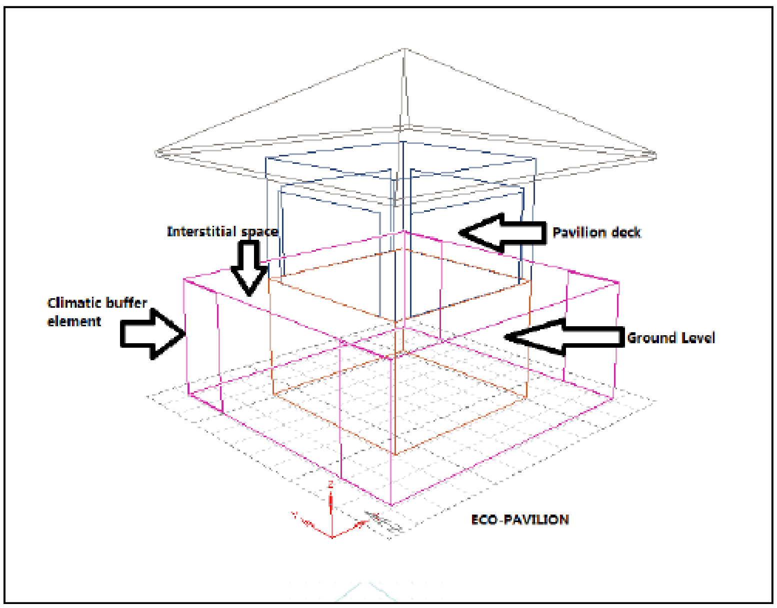

Figure 7: Eco-Pavilion model

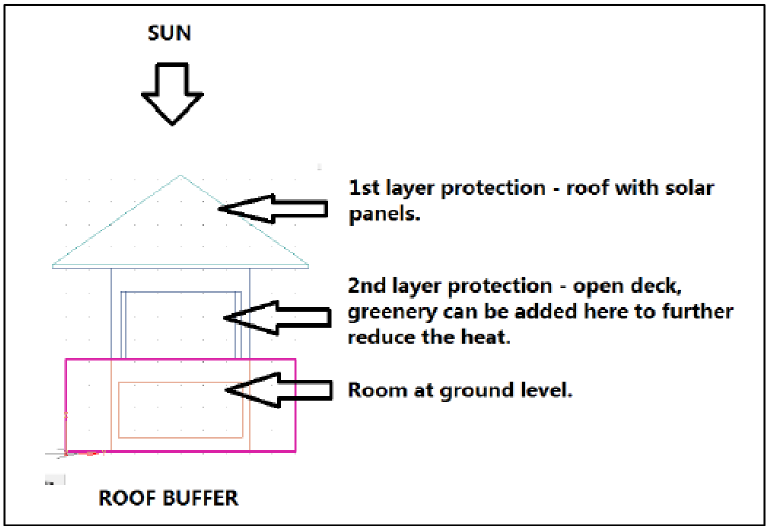

Figure 8: Eo-Paviliion roof buffer

An ideal model was developed based on the analysis of Malay *kampong* house. The computational studies found that the reversed functional arrangement, i.e. with the room at ground floor, terrace above, water curtain at the site, together with greenery around will form the most ideal scenario (Figure 9). Further analysis was conducted to investigate the performance of such ideal model. The hourly temperature graph was tabulated (Figure 10), which shows that the temperatures are within comfort band, in which the hottest hour is at 1600hr (26.80^{o}C).

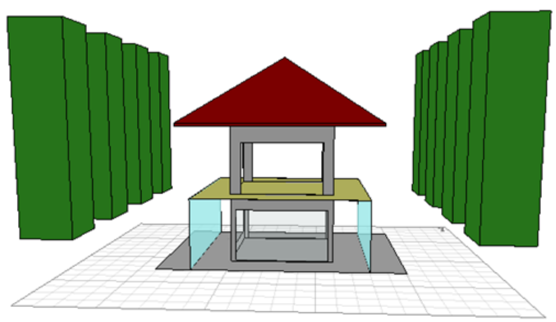

Figure 9: Ideal Model

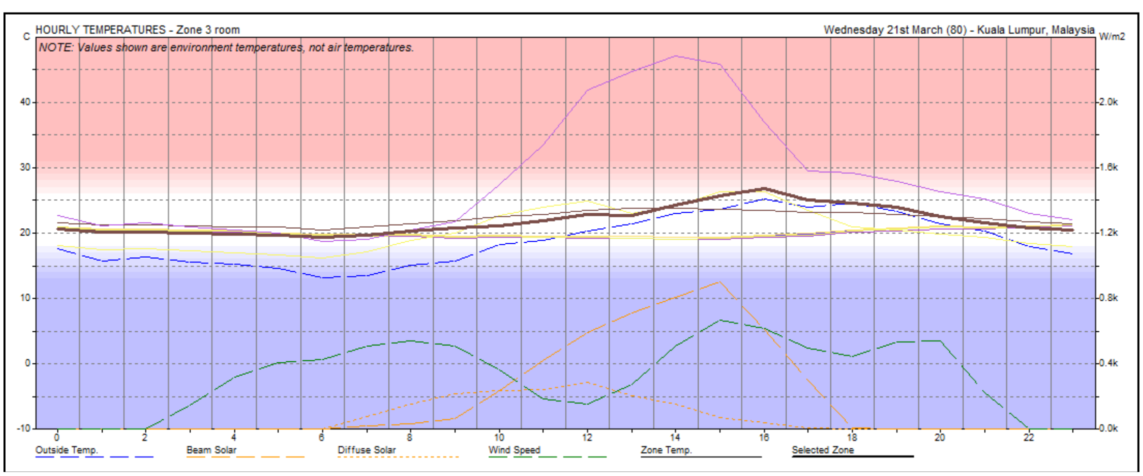

Figure 10: Hourly Temperatures, Zone 3 (Room) – Ideal Eco-Pavilion

The overall results are satisfactory. The model provides good thermal comfort conditions for a dual mode function. A few major characteristics of the eco-pavilion are:

- The ideal pavilion model with water curtain and plants offer the most suitable model for the tropics.
- The room space at the ground level performs better than the traditional Malay house;
- The deck space above open with full ventilation is suitable for other tropical activities in open air. Trees allow the open deck above for longer hour's usage in afternoon.
- The double space usage is suitable for activities in the tropics, for those activities required enclosed space use the room on ground level, for those in open use the open deck above. This is in line with the tropical living. Hence the model offers a dual mode operation in different times of the day.
- The Eco-pavilion as a basic unit is flexible in spatial arrangement for site planning
- The structure of the pavilion can be designed for modular construction easily.
- This unit will be the basic unit for the design and site planning of the project. A permutation and combination of the basic unit will form the overall design of the project.

3.4 Development of TAC

The basic building form of the TAC is derived from the preceding analysis, using the proposed Eco-pavilion concept as a base unit, forming clusters of pavilions in a structured manner. An open courtyard is in the centre, while on both sides of the courtyards nestled the eco-pavilions; the meditation pavilion is in the north, which is the enlarged version of the eco-pavilion; the main entrance hall is in the south (Figure 11). Landscaping is designed around the pavilions according to the climatic analysis, to provide the required thermal comfort environment. Earth mount are built around the perimeter of the site with trees on top to shield away from the traffic as well as for visual screen.

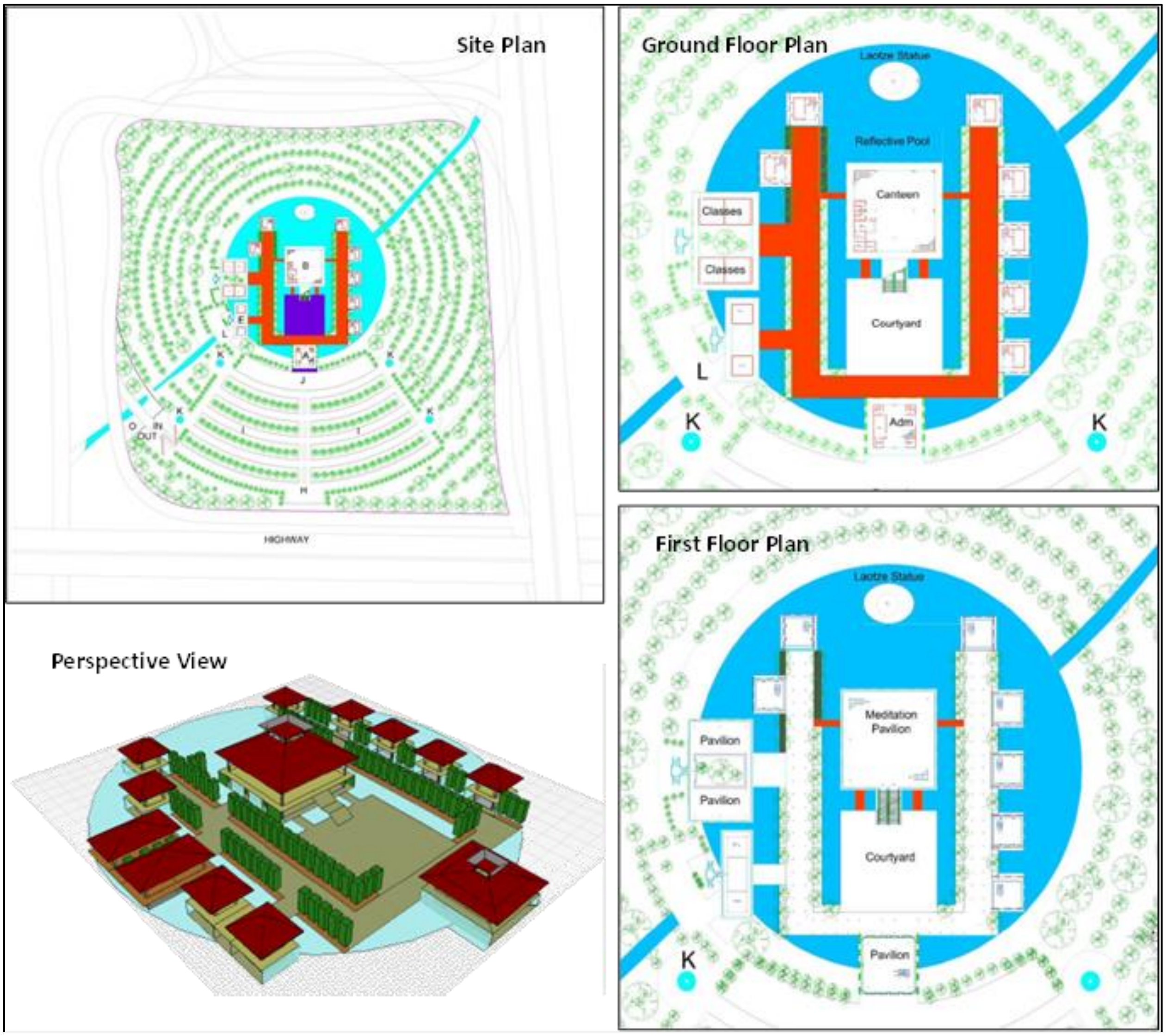

Figure 11: Different views of TAC project

Evolving from the ideal Eco-pavilion, some of the buildings need to increase in size to accommodate the architecture program. For example, the meditation hall and canteen need to accommodate 300 people; the classroom pavilion require four classes; and the entrance pavilion need a larger scale. Each of the building blocks is developed from the variants of the ideal Eco-pavilion, and tested using Ecotect. The meditation hall located at the first floor has temperature almost beyond the thermal comfort zone at 15:00hr (Please refer to Figure 12). However, there is no issue with regards to the thermal comfort of the occupants because the meditation activities are conducted only from 0500 – 1000hr and from 1800 – 2300hr, in which these are the period where the first floor is having a comfortable temperature variant.

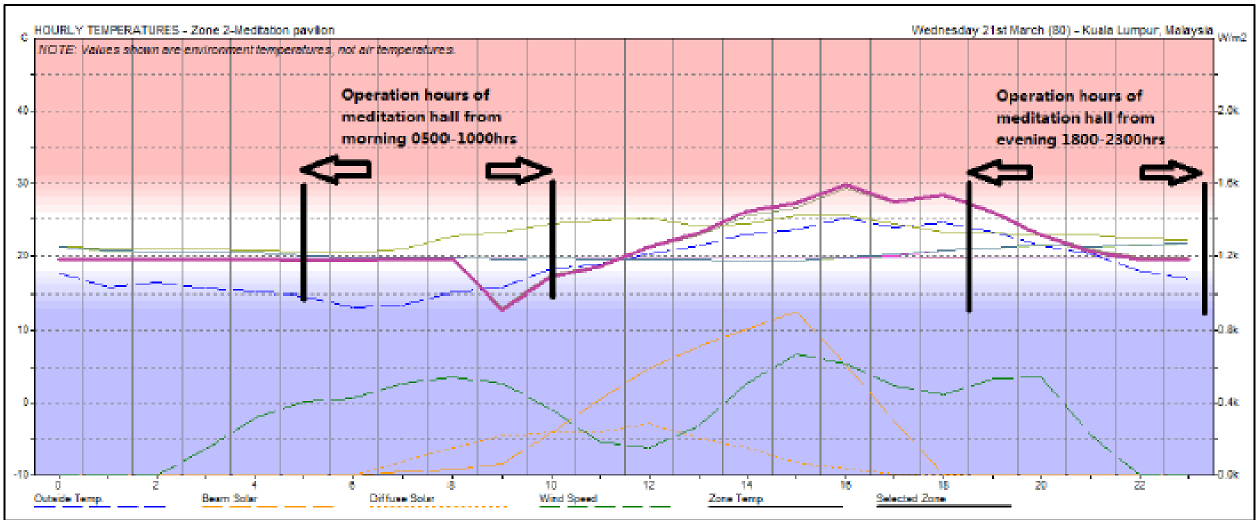

Figure 12: Hourly temperature – meditation pavilion

The canteen is located at the ground floor (Figure 13). Since the estimated daily usage of the canteen is about 20 people, it is possible to operate in natural ventilation mode. The Mean Radiant Temperature (MRP) for 20 people is 27.79°C, which is well within the comfort band. If there is enough air flow, the comfort requirement can be met, since 80 – 90% of the heat gain and loss is through ventilation (Table 4); hence, a demarcation of space near the perimeter of the building with maximum opening can be allocated for normal daily usage where air flow is enhanced (Figure 14).

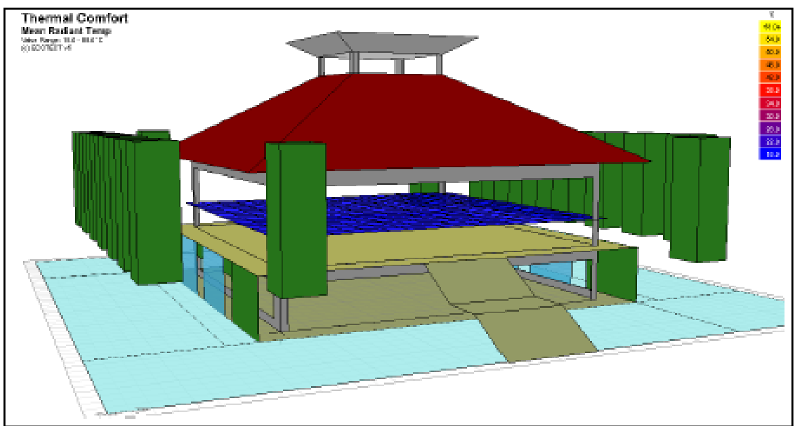

Figure 13: Location of the canteen and meditation pavilion

Table 4: Gains breakdown graph – Canteen

Category	Losses	Gains
FABRIC	2.70%	0.70%
SOL-AIR	0.00%	0.00%
SOLAR	0.00%	5.70%
VENTILATION	96.90%	85.60%
INTERNAL	0.00%	7.70%
INTER-ZONAL	0.40%	0.30%

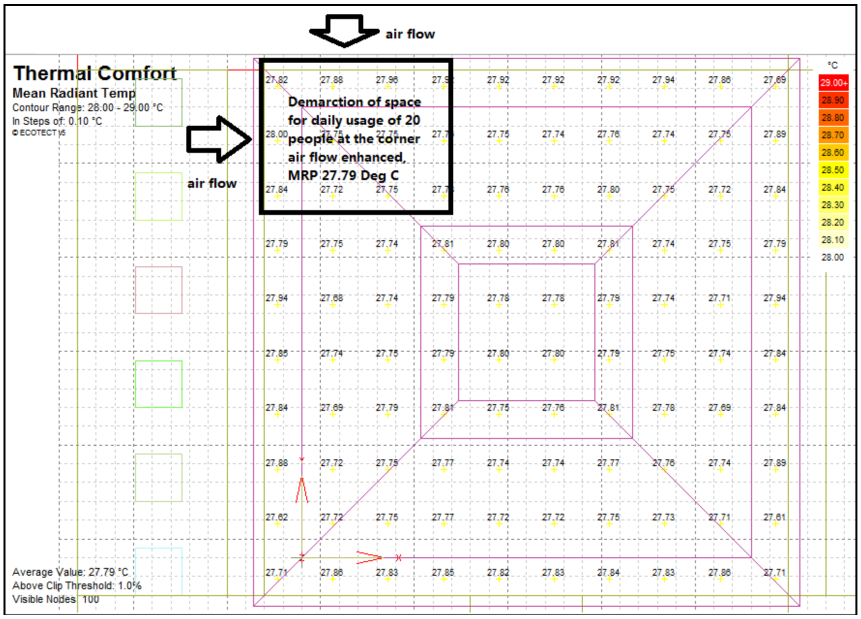

Figure 14: Demarcation area for 20 people in the canteen daily usage

Ceiling fans will be installed and used when necessary, to generate a required air velocity of 2m/s. Air-conditions will be installed but will only be used during festival seasons. As the hourly temperature increases beyond 28°C around 1600hr, air conditioning is recommended in festivals which operate from 1500 – 1800hrs. Other times of the day will be using mechanical fans. This mixed mode system will keep the overall temperature below 26°C throughout the day and is ideal for activities of 300 people (Figure 15).

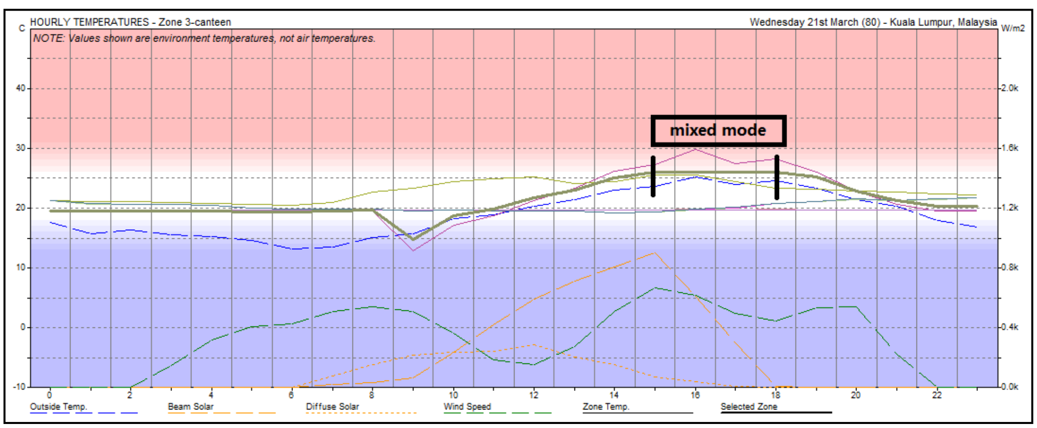

Figure 15: Hourly temperature – with mixed mode operation for canteen

The four classrooms are a combination of two eco-pavilions separated by landscaping (Figure 16 and Figure 17). The principle remains the same – the ground floor is used as classrooms with open deck above for outdoor activities for the students in the morning, evening or at night. Each classroom is estimated to accommodate 20 students and is designed using natural ventilation. The operational hours are from 0900 – 2200hrs. The main entrance is oriented to face north/south. Trees planted on both sides of the classes help to provide shades to the classroom on ground floor, and first floor, as sunrays may penetrate quite extensively.

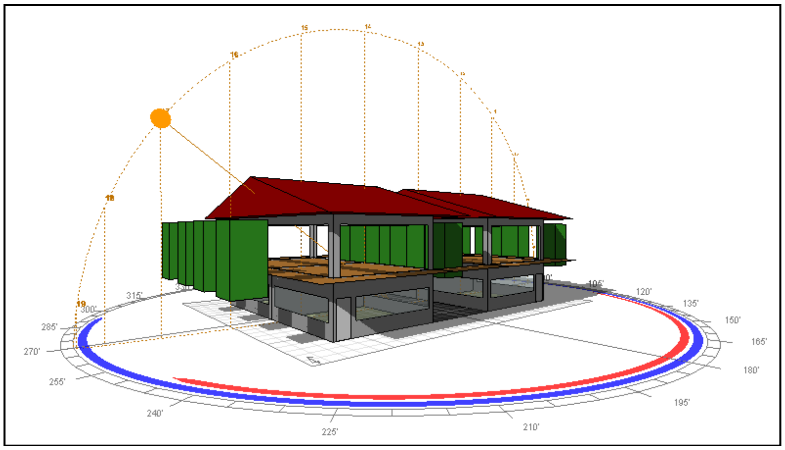

Figure 16: Classrooms shading

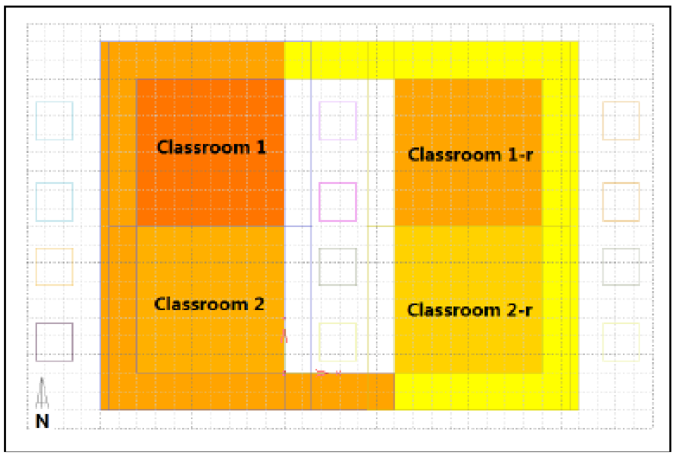

Figure 17: Classroom layout

The hourly temperature in the class room is within the comfort band, where the highest is recorded at 25.10°C at 1600hr (Figure 18, 19, 20 and 21). The solar gain can be further reduced by having a green roof pavilion on top of the classroom and more green walls to the external wall of the classrooms. More trees can be planted around the classrooms as trees are a good buffer for solar heat and provide good learning environment for the children. With more trees and green to reduce solar heat gain, mechanical fans will be recommended to generate air flow; the rate recommended is 2m/s. Since the classrooms are not facing one another, the exposed wall can open fully when classes are on. As heat also losses through fabric, (over 30% for all classrooms), cavity walls between classrooms is recommended so that heat will escape instead of transferring from one zone to another. Time schedule of the classes is important. As heat is also generated from internal activities and to avoid high outdoor temperature, it is better to arrange the classes in the morning, evening or at night, when the outdoor temperature is lower. The hourly temperature graph indicated that the good time schedule for classes is from 0700 – 1100hr and from 1800hr onwards. In general, it is believed that with the above recommendations, naturally ventilated classrooms are possible, however, air conditions will still be installed and on standby, to cater to classes conducted outside of the recommended schedule.

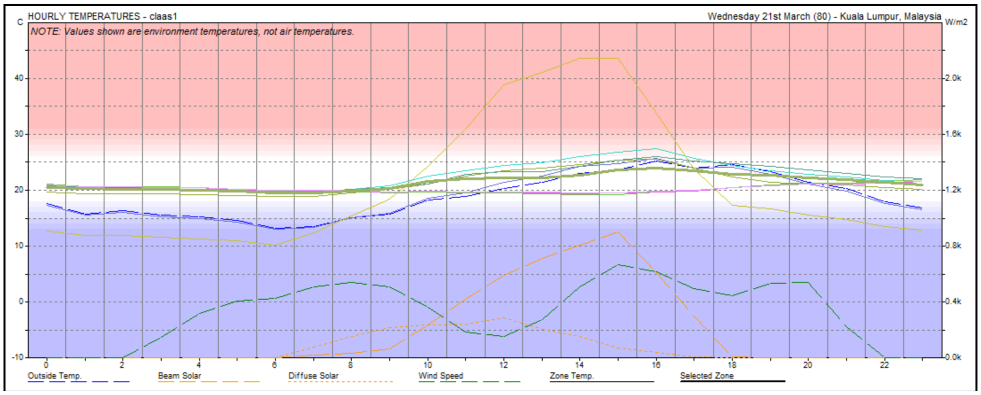

Figure 18: Hourly temperature – Classroom 1

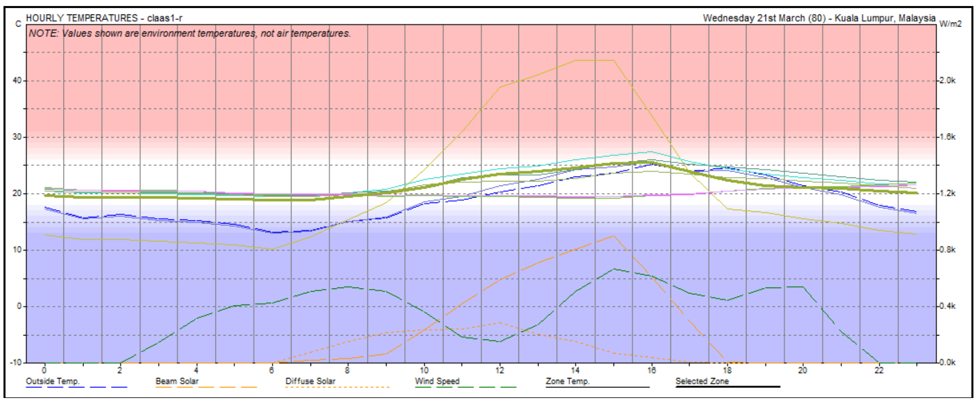

Figure 19: Hourly temperature – Classroom 1-r

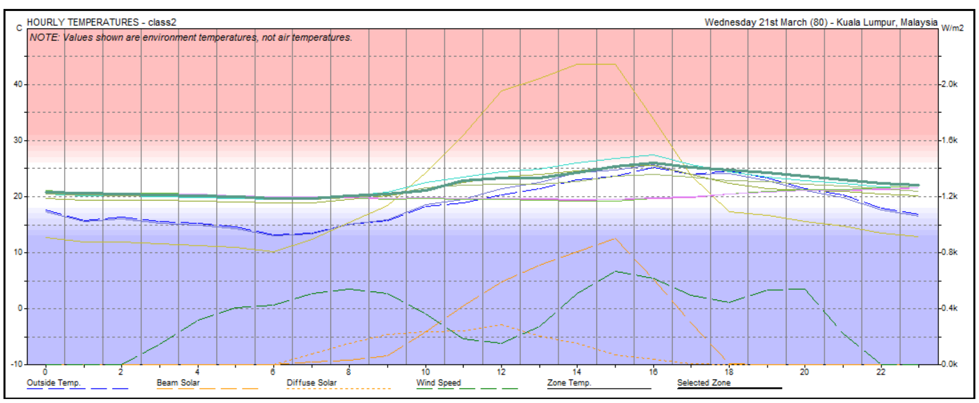

Figure 20: Hourly temperature – Classroom 2

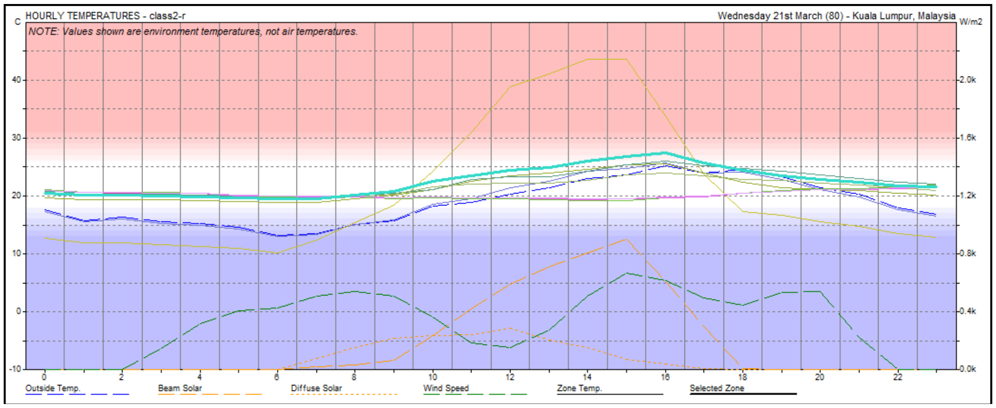

Figure 21: Hourly Temperature – Classroom 2-r

The office block is mainly for reception and general administration. The orientation is the same as the meditation hall – east/west oriented, with the front and back facing the rising and setting sun. It is designed to accommodate 10 persons in natural ventilation mode. The principle is the same as the eco-pavilion where all functional activities are below, with water curtain and plants at both sides. Unlike other building blocks that have full openings on four sides, the office is open on two sides due to internal partitions of rooms (Figure 22). This helps to reduce daylight and insulation and maintain MRT at 24°C but the resulting PPD and PMV are not satisfactory due to the internal room blockage. Human activities are the main heat generator. When air is saturated, humidity increases and thus PPD and PMV values also increase, causing occupants to feel uncomfortable in. It is, thus, necessary to increase air flow in the office to flush out the heat and humidity generated from human activities (main heat gain). Mechanical fans are recommended for air velocity above 2m/s. As the hourly temperature falls within good comfort temperature range throughout the day, air condition is not necessary (Figure 23). Localized air conditions zone is recommended for working areas with auto-sensors that turn on the air condition when indoor temperature increases beyond 28°C. Task lighting is also recommended for office.

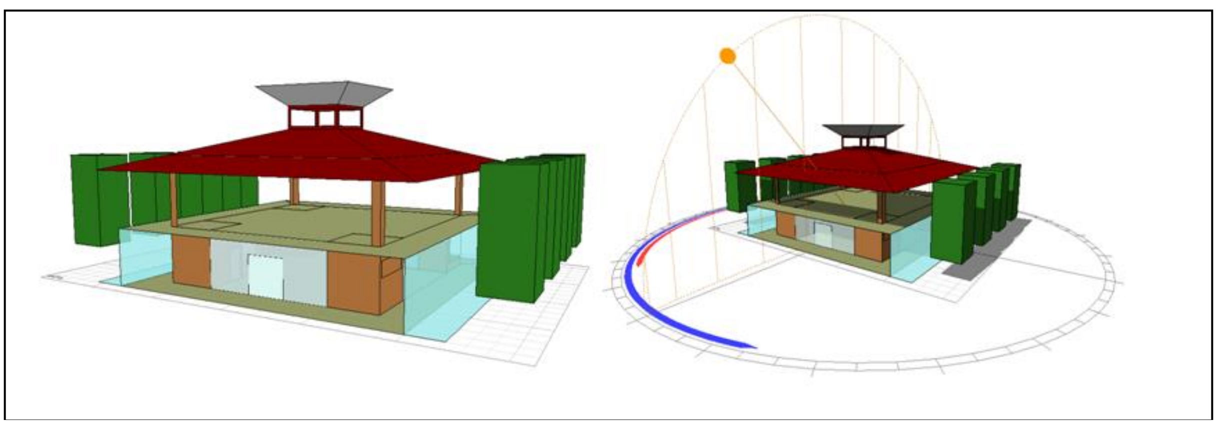

Figure 22: Administration office with sun path diagram

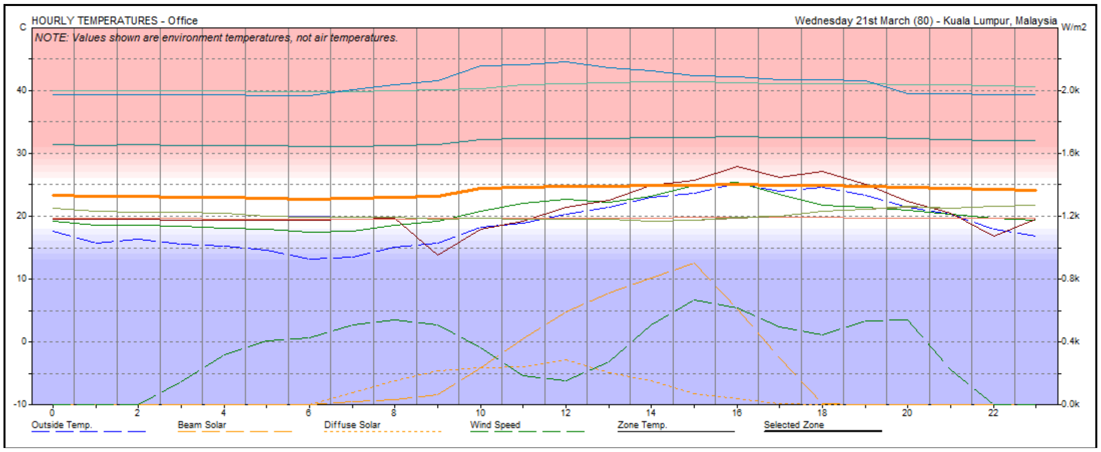

Figure 23: Hourly temperatures – Office

Table 5, 6, and 7 summarize the results of daylight factors, daily insulation, and thermal comfort of all the eco-pavilion building blocks, respectively. The daylight factor for the meditation hall pavilion is high (12.30%) due to the open deck that allows for daylighting penetration (Table 5). For other building blocks, the values range from 2% to 4%. The lux level is sufficient for normal designated activities except for administration office, and hence, task lighting is recommended. The internally reflected daylight in low (1.5 – 7%), while the externally reflected daylight is negligible. Sky component is highest in Ideal Eco-pavilion (5.5%). Overall, the daylight works well in all building blocks.

Table 5: Summary of lighting analysis

Building Block	Daylight Factor (%)	Daylight Level (lux)	Internally Reflected (%)	Externally Reflected (%)	Sky Component (%)
Ideal eco-pavilion	11.50	1000.00	5.00	1.90	5.50
Meditation canteen	4.00	330.00	2.90	0.60	3.60
Meditation hall pavilion	12.30	1000.00	7.60	1.50	3.00
Classroom CR1	3.50	330.00	1.90	0.60	1.50
Classroom CR2	3.70	340.00	1.95	0.60	1.80
Classroom CR1-r	4.60	420.00	3.30	0.44	1.60
Classroom CR2-r	4.80	450.00	3.60	0.50	2.20
Administration office	2.00	60.00	1.50	0.90	0.70

The average daily insulation penetrating into the functional space is low, with total daily up below 400Wh (Table 6). The outdoor values sometimes went up to more than 4000Wh, this means the proposed models able to reduce outdoor insulation up to 10 times. All building blocks are well shaded (over 90%) with minimum solar exposure.

Table 6: Summary of insolation analysis

Building Block	Average Daily PAR $MJ/m^2/d$	Average Daily Total Wh	Diffuse Fraction (%)	Average % Exposure	Average % Shading
Ideal eco-pavilion	0.65	390.00	0.07	0.80	99.50
Meditation canteen	0.43	257.00	0.01	0.00	100.00
Meditation hall pavilion	0.50	310.00	0.03	3.30	97.40
Classroom CR1	0.46	263.00	0.01	0.00	99.00
Classroom CR2	0.46	279.00	0.01	0.00	99.00
Classroom CR1-r	0.47	300.00	0.01	0.00	100.00
Classroom CR2-r	0.48	310.00	0.01	0.00	100.00

Administration office	0.43	253.00	0.00	0.01	99.00

While the spatial comfort of the ideal eco-pavilion works well (MRT=23.6°C, PMV=-0.8, PPD=17) and thus no air flow is needed for thermal comfort, other building blocks such as canteen, classrooms CR1-r, and classroom CR2-r, are having MRT above the recommended temperature of 23.5 – 28.5°C, which is 29.32°C, 28.9°C, and 29.6°C, respectively (Table 7). This is due to the large space and indoor activities that generate heat. It is noted that these high temperatures all occurred at 1600hr of the day, which is the hottest hour of the day and is considered as the "critical design hour". In other pavilions, the MRTs are within the recommended range.

Table 7: Summary of thermal comfort analysis

Building Block	**MRT (°C)**	**PMV**	**PPD**	**Recommended Air Velocity (m/s)**	**Solar Gain (Watt)**
Ideal eco-pavilion	23.60	-0.80	17.00	0.00	6.50
Meditation canteen	29.32	3.82	100.00	2.00	0.85
Meditation hall pavilion	22.15	2.67	96.50	2.00	7.5
Classroom CR1	25.50	3.25	99.74	2.00	0.15
Classroom CR2	26.40	3.40	99.92	2.00	0.16
Classroom CR1-r	28.90	3.82	100.00	2.00	0.17
Classroom CR2-r	29.60	3.99	100.00	2.00	0.17
Administration office	24.30	3.14	99.50	2.00	0.00

Two notable results for thermal comfort are the Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD). Except for the ideal eco-pavilion, all building blocks are having high PMV and PPD, indicating that there is a high level of dissatisfaction. However, such values cannnot be interpreted literally because there are a few crucial factors to be considered in order to evaluate these values correctly.

First and foremost, te Ecotect worked on full operation hours. For example, in the case of meditation hall, in reality, activities normally happen in the morning from 0500-1000hrs and evening after 1800hrs. However, in Ecotect, it assumes operations from 0800 to 1800hrs, the software is not able to break into two periods. Interestingly, even when separate simulations were conducted, the results are the same. Therefore, Ecotect is simulating 300 people using the meditation hall from morning till night, with the heat of the Sun and activities throughout the day, the PPD and PMV naturally will be high. To evaluate if the thermal comfort works, the schedule of operations is an important consideration. A more realistic solution to this is to study the hourly temperature graph, identify the temperature range and relate it to the schedule of activities. Taking the same meditation hall as example, morning activities (0500-1000hrs) is at temperatures 13-20°C and evening is at temperature reduced from 28.3 to 19.5 °C. In addition, as the simulation had identified that the main heat loss is through ventilation and recommeded air velocity of 2 m/s, hence, mechanical fans are recommended to generate the required air flow to achieve the desired comfort.

In order to investigate further the thermal comfort conditions, the Olgyay's bioclimatic chart (Figure 24) was adopted. Using meditation hall, taking temperature at 1800hr, DBT 24.6°C (outdoor), radiation at centre of the hall is 0.480MJ/m2/d, converting it to Wh/m^2, 0.48x277.78Wh/m2/d=133Wh/m2 (1MJ=277.78Wh), if air velocity is increased to 2m/s, as recommended by Ecotect, the extend of thermal comfort zone will increase. Air flow rate is therefore an important design strategy for thermal comfort. However, the air flow needs to be geneated by mechanical means with maximum open space shaded by trees. Since the prevailing winds in Kuala Lumpur is not as predictable and the site is blocked by buildings around, the prevailing wind analysis is not included in this study and it is taken as additional bonus on top of other design solutions.

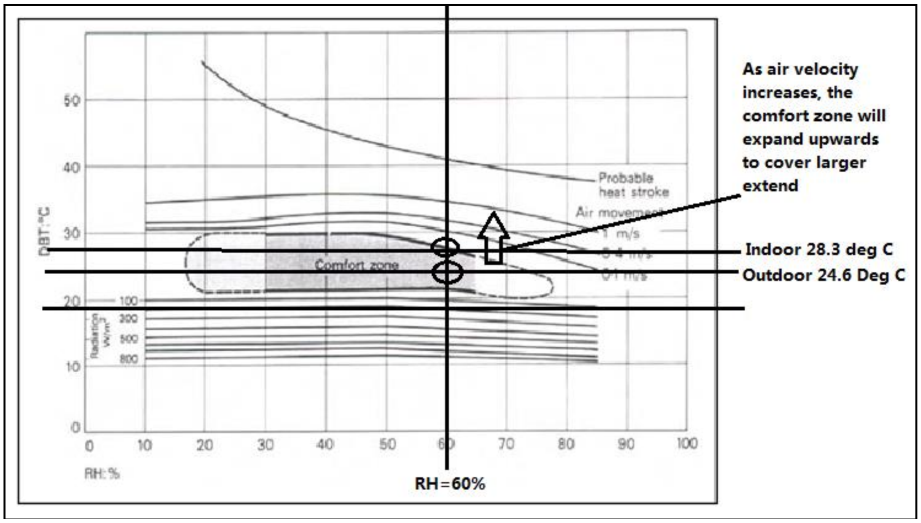

Figure 24: Olgyay's Bioclimatic Chart

According to Szokolay (1997), factors that influence thermal comfort are:

- Human factors – clothing, cultures, behavious, MET rate, activities;
- Climatic factors – MRT, Dry bulb temperature, relative humidity, air speed(wind), rainfall, radiations, evaporations, greenery;
- Building factor – materials, thermal insulation, colour, openings on facades, shadings thermal mass, dehumification, orientation, rain protection, location, ventilation in the buildings, landscaping and vegetation. Manage sufficient indoor daylight and reduce outdoor insolation;

Realizing that it is difficult to predict human factors, the proposed design solutions fully emphasize on the climatic and building factors by:

- Analysing the microclimate and develop the principles of tropical design;
- Developing a new architecture hybrid as a result of analyses on climatic and tropical built forms;
- Taking full advantage of the site by converting the deserted pool into reflective landscape pool, this will help to cool the environment;
- Simulations based on the local weather was made, and according to the simulation ourcome, recommendation made; and
- Extensive landscaping to cover the open space of the site, making it into gardens.

As such, the strategies and solutions proposed for the TAC are:

- To create roof and wall buffer zones, the buffer zones can be in the form of green walls, water curtain and trees;
- To have maximum façade opening possible;
- To schedule the operation hours based on the hourly temperature of the day;
- Plants as landscaping are used outside each of the building and to cover the remaining of the site;
- Making use of the existing pond and convert it into a reflective pool, locate the building block on the pool, surrounded by water elements;
- As ventilation is the main heat loss medium, besides façade openings, mechanical fans are recommended to generate air flow at minimum speed of 2m/s. This will increase the extend of the comfort zone; and
- In specific case, activities which are set up during the hottest hour (1600hrs), mixed mode systems will be used. Air condition can operate for a few hours until the temperature drops, then revert back to mechanical fans or natural ventilation.

4.0 Conclusion

Occupants' comfort and health are of utmost importance in sustainable building design. The indoor thermal environment should be designed to maintain maximum human productivity and performance. The present building design is said to have lost its build form identity in terms of rainforest and tropical landscape. This is largely due to planning patterns and construction systems, which through the process adopting planning laws, building codes, and regulations borrowed from the West - that promotes heavy weight construction using bricks and reinforced concrete as the main materials has forbidden building development based on traditional concepts. Apart from that, the practicing building construction method which is derived from systems used since the 1800s (the period of Industrial Revolution in Europe) is outdated. It is unlikely taking environmental concern as a primary consideration. Therefore, it is important to continuously sustain the fundamental nature of climate understanding into contemporary building design solution. With detailed research involving various disciplines such as mathematics, engineering, material, sociology and anthropology, coupled with the case study on traditional Malay *kampong* house, this would potentially give rise to concept planning of modern day housing and commercial developments.

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