A Comparative Study of Passive Design Features/Elements in Malaysia and Passive House Criteria in the Tropics

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Abstract: In tropical climates, buildings gain solar heat and penetration through building envelope and glazing, resulting in overheating and thermal discomfort of the occupants. The conventional solution is to use electro-mechanical cooling system in buildings which raises energy demands and leads to ecological loading. In order to mitigate the energy consumption spent on cooling load, natural ventilation and heat avoidance techniques have been extensively researched in Malaysia. A passive building design strategy is a method that can protect dwellers from the influence of external thermal discomfort and prevent the elimination of versatile vernacular architecture. Yet, previous studies have not compared the strategies to the principles of passive house (PH) in a systematic, solitary research. Therefore, this paper reviews, accumulates, and compares studies on passive design features/elements in Malaysia and those of the passive house criteria in the tropics. The findings verified that the passive house principles are applicable in the tropical climate. Similarities and/or differences in terms of achieving thermal comfort and energy reduction between the passive house and those found from the studies on passive design features and strategies were identified.

Keywords: Passive Design, Passive House, Thermal Comfort, Tropical Climates.

1. INTRODUCTION

In the tropical region, passive cooling components are the features that serve to engage dominant winds for vernacular houses. However, ignorance of these features to design contemporary house is essential (Al-Tamimi & Fadzil, 2011; Tantasavasdi, Srebric, & Chen, 2001). According to La Roche (2001), the significance of a climate-responsive building design is contributed by its thermal comfort and ability to save energy consumption, which in turn, sustains the precious resources in our mother earth. Nevertheless, new building designs have been developed with the aim to fulfil client’s requirements while disregarding the local climate and energy conservation, resulting in the facilities’ overall poor thermal performances. To render these buildings a comfortable thermal environment, the occupants thus must depend on artificial means at high rate of energy consumption (Al-Tamimi, Fadzil, & Harun, 2011). Given these points, this paper reviews the studies on passive design features (or elements) and compares them with the criteria of passive houses in a tropical climate.

2. METHOD OF STUDY

Nearly forty journal papers and conference papers on the subject of passive design strategies in tropical climates, thermal comfort, and vernacular elements/features were reviewed. All the existing strategies/features were alienated into three complementary categories, each comprising the different types of elements that perform relative passive design/techniques. The purpose was to compare these aspects with the passive house principles. Related studies from Passipedia as the International Passive House (PH) database were accessed, and full-length articles were drawn by securing membership with International Passive House Association (iPHA). The passive houses in the tropics, including one passive house located in Jakarta, Indonesia, have been recently analysed and tested using dynamic simulations. All the articles
obtained from the Passipedia databases were reviewed and summarised in this study.

3. REVIEW OF STUDIES ON PASSIVE DESIGN FEATURES/STRATEGIES

3.1 THERMAL COMFORT REQUIREMENTS

Thermal comfort is defined by ASHRAE as the “condition of mind which expresses satisfaction with the thermal environment” (Heating, Refrigerating, Engineers, & Institute, 2004). Thermal comfort has a significant implication on the health, psychology, and productivity of the working population who form the foundation of a country’s economy (Latha, Darshana, & Venugopal, 2015). In tropical climates, buildings gain solar heat and penetration through building envelope and glazing. Hence, they become overheated during the day (Rajapaksha, Nagai, & Okumiya, 2003). Studies in Malaysia particularly have found that indoor thermal comfort is approached when (i) the temperature is between 25.5°C and 28°C, (ii) the relative humidity of the air is between 40% to 60%, and (iii) the maximum air flow is between 0.3 and 0.5 m/s (for a naturally-ventilated environment) (Al-Tamimi & Fadzil, 2011). Other studies Zain, Taib, and Baki (2007); and Ahmad and Szokolay (2007) noted 28.69°C to be the indoor temperature that could result in thermal comfort. Nevertheless, the standard indoor environment design guideline for Malaysian climate published by Department of Standards Malaysia (Code of Practice on Energy Efficiency and Use of Renewable Energy, 2007) recommends an indoor temperature of 23°C to 26°C.

3.2 PASSIVE DESIGN STRATEGIES IN THE TROPICAL CLIMATE

The purpose of adopting passive design techniques in the tropics is to avoid solar heat gain and optimise natural ventilation by engaging the dominant wind and providing adequate daylight (Zaki, Nawawi, & Ahmad, 2007). A building envelope is a separator from the external environment and a protective layer shielding from climatic factors the influence the building directly (Givoni, 1976). Blocking off radiation of the sun causes less absorption and heat transmission, leading thus to natural cooling (Ali, 2012).

3.3 HEAT AVOIDANCE TECHNIQUES

Heat avoidance is applied to buildings as complementary techniques to increase thermal comfort (Aflaki, Mahyuddin, Awad, & Baharum, 2015). The following eight key designs have been adopted to prevent a building’s exposure to the sun in the tropics:

3.3.1 BUILDING ORIENTATION

Several studies have proved that the essential key to energy-efficiency building design is choosing the best orientation for the building. A building’s orientation affects it energy performance hence ability to meet the occupants’ thermal comfort requirement (Al-Najem, 2002; ÇAKIR, 2006; Fairuz Syed Fadzil & Sia, 2004; Manioglu & Yilmaz, 2006). As suggested by Thomas and Garnham (2007), building orientation should be specified in terms of solar angle and dominant wind direction. One example is the proposed affordable housing design by Rahman, Md, Al-Obaidi, Ismail, and Mui (2013) (Fig.2), a structure that spans a built-up area longer than the conventional existing building with a 10-meter wide frontage and 6.7-meter building depth. Another study in Singapore also shows that the north-south orientation is the best positioning for buildings in the tropics (Wong & Li, 2007).

Fig. 1: Building orientation in tropical climate, Source: La Roche (2001), retrieved by Aflaki, Mahyuddin, and Mahmoud Awad (2012).

Fig. 2: A proposed affordable housing design, Source: (Rahman et al., 2013).
3.3.2 BUILDING FORM/SHAPE OF ARCHITECTURAL PLAN

Notable studies have found that a building plan layout that is rectangle in shape with lengths facing north and south is able to avoid solar radiation and heat gain from the east and west (Halwatura & Jayasinghe, 2007; Konya, 1980; Tombazis & Preuss, 2001). Another study carried out in Putrajaya and UTM campus was based on modified ASHRAE thermal sensation scale, and the study found that a layout surrounded by buildings (shown in Fig. 3) is the most comfortable because it is protected from direct solar radiation and thus has lower ambient temperature (Md Din et al., 2014).

Fig. 3: Types of building layout, Source: Retrieved by Md Din et al. (2014)

3.3.3 SHADING

In the tropics where skylight is voluminous and the sun transverses in all directions, providing shading for both glass and opaque surfaces in windows, balanced with daylight strategies, was found to significantly improve the thermal comfort inside the buildings (Latha et al., 2015). Another strategy is to include shading elements on the east and west sides on the upper part of openings (Aflaki et al., 2015). In Mughal architecture particularly, verandas and lattice screens are the features that provide cooler internal spaces (Ali, 2012). Toe and Kubota (2015) recommended constant low roof eaves alongside a window top and strategically locating planting broadleaf trees that are taller than a building’s height. These building features existing in other climates could be useful for application in the tropics but only with scientific analysis to ensure their effectiveness. In one study, a KOMTAR solar penetration analysis showed that the depth of a horizontal shades design should be based on the appropriate sun path. The orientation, planning, and calculation of a shading device are also noted by Fairuz Syed Fadzil and Sia (2004) to be crucial if an energy-saving and environmental-friendly design is targeted.

3.3.4 MATERIALS/COLOURS

Internal thermal comfort is also dependent on building materials specifications, ambient temperature, and humidity (Hyde, 2013). A review by Latha et al. (2015) identified certain materials with good thermal properties that can enhance thermal comfort—such as vacuum insulation panel, phase change materials, aerated autoclaved concrete/autoclaved cellular concrete, and polymer skin. These properties are potentially suitable to be incorporated into the various components of a building envelope. Façades painted in light colours or reflective paints have also been verified to reduce building heat gain by reflecting the solar radiation year-round, particularly for buildings located in warm and temperate climates (Costanzo, Evola, Gagliano, Marletta, & Nocera, 2013; Kokogiannakis, Tuohy, & Darkwa, 2012; Synnefa, Santamouris, & Akbari, 2007; Wang, Kendrick, Ogden, & Maxted, 2008). A cool roof was also found to reduce daily heat gain (Hernández-Pérez et al., 2014).

3.3.5 WINDOW CHARACTERISTICS

The energy performance of a building depends on the building envelop particularly the window (Hee et al., 2015). Research findings of Bülow-Hübe (2001) reported by Lee, Jung, Park, Lee, and Yoon (2013) showed that window is responsible for 20–40% wasted energy in a building. Even though the existence of window is to allow daylight into the buildings, a minimum size of window limits the heat gain or heat loss. Al-Tamimi et al. (2011) found that window position, an optimum glass size, and the use of natural ventilation system should be appropriately selected so that it can mitigate the negative impact of solar radiation on heat gain. Thermal properties, optical properties, window sizing, window orientation, region of
employment, costs, and optimization are the criteria of window characteristics (Al-Tamimi et al., 2011). Window glazing can improve the penetration system through its optical and thermal characteristics, such as thickness, coat, colour, and gap filler between panes, which determine the glazing thermal performance and daylight aspects. Thermal comfort can be enhanced by natural ventilation application and a window wall ratio of 25% (Al-Tamimi et al., 2011). Whereas Zaki, Nawawi, and Ahmad (2012) revealed that the small-sized openings should be designed on the east and west sides, where the radiation is received twice as north-south elevations. In another study, Hee et al. (2015) examined the advantage of using photovoltaic (PV) glazing on thermal and visual comfort apart from its function as source of electricity.

3.3.6 VEGETATION SURROUNDING/INSIDE BUILDING

Vegetation surrounding building is a traditional time-tested and proven heat avoidance technique. Indirect evaporative cooling by vegetation has shown a promising performance in improving thermal comfort within building and therefore, such a strategy can be applied in tropical climates to provide shading for buildings, roofs, and the surrounding areas (Fig. 4) (Aflaki et al., 2015; Latha et al., 2015). Toe and Kubota (2015) found that when applied at a terraced house, the vegetation and unpaved ground surface in the adjacent area (as seen for a vernacular house) can mitigate ambient air temperature and moderate the amount of urban heat island intensity of the surrounding area, particularly during night-time. Another technique that affects the thermal performance of adjacent rooms is an internal courtyard (Sadafi, Salleh, Haw, & Jaafar, 2011).

3.3.7 INSULATION

Installing insulation in external walls is a significant heat avoidance technique. Thick walls consisting of low thermal conductivity materials are proposed to achieve a low-heat conductivity at a longer time (Halwatura & Jayasinghe, 2007; Sadineni, Madala, & Boehm, 2011; Yıldız & Arsan, 2011). Another study by Abaza (2002) attested the importance of thermal insulation in conjunction with the impact of other building elements on outdoor air flow to optimise the building thermal performance. Therefore, using thicker construction on external walls alongside east and west can prevent larger solar heat gain (Wong & Li, 2007). Apart from the walls, a thermally insulated roof/ceiling can also moderate large amount of solar heat gain regarding solar altitude at noon in the tropics and low-rise building form (Toe & Kubota, 2015).

3.3.8 DAYLIGHTING

As Rahman et al. (2013) pointed out, the dependence of artificial lighting can be mitigated by designing a longer façade that faces along the north-south side of the buildings. Mettanant and Chaiwiwatworakul (2014) also concluded that natural daylighting via broad windows can maintain the required indoor illuminance for a building in the tropics and thus can save the energy from artificial lighting. Munaaim, AL-Obaidi, Ismail, and Rahman (2014) considered a fibre optic daylighting system as an innovative, sustainable, and green technology that provides interior lighting for buildings in tropical climates. Nonetheless, it is shown that the fibre optic daylighting system has no significant effect on relative humidity and that adopting such strategy can increase an internal room temperature by 2°C (Munaaima, AL-Obaidib, Ismaile, & Abd, 2015). In the temperate climate countries, the modification of roof construction, attic, and ceiling enabled the employment of consistent high amount of daylight from the roof (AL-Obaidib, Ismail, & Abdul Rahman, 2013). This strategy resulted in Innovative Roofing System (IRS) which reduces indoor air temperature and main radiant temperature in a landed building (3-m height) without insulation while providing a high level of natural light (AL-Obaidi, Ismail, & Abdul Rahman, 2014a; AL-Obaidib et al., 2013). Nevertheless, the option of using several skylight roofing systems was found to be inappropriate for direct application in Malaysia (AL-Obaidi, Ismail, & Abdul Rahman, 2014c).

Fig. 5: The innovative roof structure, Source: AL-Obaidib et al. (2013).
3.4 PASSIVE COOLING TECHNIQUES

Zaki et al. (2012) stated that passive cooling is an innovative architectural way of building design to attain climate responsiveness in the region because such a strategy maintains sustainable indoor thermal comfort conditions naturally. Cook (1989) referred passive cooling to any architectural technique that prevents external heat while simultaneously shifting indoor heat to natural heat sink. According to Cook, the five main various methods of passive cooling are radiative cooling, evaporative cooling, heat avoidance, earth coupling, and ventilative cooling (Aflaki et al., 2012; Al-Obaidi, Ismail, & Abdul Rahman, 2014b; Geetha & Velraj, 2012; Ismail & Abdul Rahman, 2010; Kamal, 2012). Cross ventilation and stack ventilation systems have been mostly applied in vernacular architecture because these strategies can lead to maximum air movement into the indoor environment hence cool the building and comfort the occupants.

Another ventilation system named stack ventilation can perform as vertical flow of air. This system works when cool air is heated by human activities and the operation of home appliances/devices, and the resultant warm air escalates through the vertical architectural element/s and released from the building (Fig. 8). Nonetheless, the effectiveness of stack ventilation essentially depends on the apertures height variations and the difference between indoor and outdoor ambient temperature of a building. Sanusi, Shao, and Ibrahim (2012) investigated the passive ground cooling technology in hot and humid countries, where the ground can be used to absorb the heat from the building in order to produce cooler indoor air. The experiment found that the greatest temperature reduction was within the pipe buried at 1-m depth underground (Sanusi et al., 2012). According to Labs and Cook (1989), the sabotaging of building slabs’ conduction and convection in an earth-coupled building can thermally unify the indoor spaces into the subsoil. This system therefore is applicable in a moderate climate where earth temperature meets the comfort zone standard (Aflaki et al., 2012).

3.5 ELEMENTS AND TECHNIQUES ON THE APPLICATION OF NATURAL VENTILATION

Natural ventilation as defined by Al-Tamimi et al. (2011) is the intended current of outdoor air through apertures that can mitigate the heat and remove relevant humidity by taking the wind and thermal pressures into account in the tropical climate. Latha et al. (2015) stated that the application of natural ventilation in buildings has become a phenomenon due to energy requirement, indoor air quality, and environmental concerns associated with mechanically-ventilated buildings. The usage of building space plays a major role in thermal comfort and the energy usage of the building. In a tropical region like Malaysia, natural ventilation is the best strategy to remove the heat trapped in an indoor environment. Aflaki, Mahyuuddin, Mahmoud Awad, et al. (2014) noted that the amount of air flow into a building is subject to the architectural features/elements that provoke the outdoor wind inside the building. Review of formal studies has shown that the most essential architectural features regarding natural ventilation are building orientation and layout, windows and apertures orientation and size, and several vernacular devices. Several strategies were found to be the most effective for achieving natural ventilation, including the various louver shapes and angles in openings, window-wall ratio (WWR), and window-floor ratio (WFR), and openings of different forms for optimum pressure discrepancy (Aflaki, Mahyuuddin, Mahmoud Awad, et al., 2014; Fung & Lee, 2015).

Air wells allow the stack effect process to take place and encourage air flow into the building so that the existing indoor hot air will be exchanged with fresh and cool air. This measure works by taking fresh air through the opening in building façade, discharging the warm air through the vertical duct from the basement up to the roof level in buildings (Jafarian, Jaaifar, Haseli, & Taheri, 2010; Khanal & Lei, 2011). Alternatively, small-scale buildings can utilize chimneys and stack air ducts while large-scale buildings apply atrium (larger air well) to pledge ample wind flow and velocity to approach thermal comfort standards (Aflaki et al., 2012; Aflaki, Mahyuuddin, Manteghi, & Baharum, 2014; Latha et al., 2015; Moosavi, Mahyuuddin, Ab Ghafar, & Azzam Ismail, 2014). Double skin façade and double-skin roof (Fig.7) are effective strategies in passive design to curb heat gain into buildings in order to mitigate the reflective glass walls’ conduction via protection (Aflaki et al., 2012; Allard & Ghiaus, 2012; Zingre, Wan,
In addition, to achieve daylighting and natural ventilation during the night, proper location and accurate size of windows are considerable. Several other strategies can also reduce the cooling load in buildings, for example, replacement of fixed-glass windows with operable or adjustable louvered windows, and application of full-height windows or upper ventilating apertures to optimize its function in both ways (Aflaki, Mahyuddin, Manteghi, et al., 2014; Schulze & Eicker, 2013). Notable studies in Malaysia (Jamaludin, Hussein, Ariffin, & Keumala, 2014; Kubota, Chyee, & Ahmad, 2009) have shown that compared to day-time and full-time ventilation, night-time ventilation is the better strategy to cool down a building. Building corridors can significantly direct and transfer air flow through some building parts. Transferring outdoor wind to indoor environment by corridors is another strategy to ensure maximum ventilation in a building (Aflaki et al., 2012; Mohamed, Prasad, & Tahir, 2008). A narrow-width floor layout, on the other hand, is more effective to invite more air flow to a building (Tombazis & Preuss, 2001). Another study (Aflaki, Mahyuddin, Manteghi, et al., 2014) demonstrated that the speed of indoor wind velocity at a unit on the thirteenth floor is higher than that on the third floor, indicating thus that building height affects indoor air temperature and wind velocity directly.

3.6 PASSIVE HOUSE IN THE TROPICS

A passive house is defined by passive house institute (established in Germany) as providing thermal comfort in a building entirely by fresh air post-heating or post-cooling regarding good indoor air quality requirement without the additional usage of recirculated air (Feist, 2007). In a tropical climate, A passive house has been investigated in terms of dynamic simulations set (as the study conducted in Singapore), parametric studies in tropical climate comprise compactness (different ratios of exterior surface and enclosed volume from values typical for high-rise buildings to those typical for small single-family homes), insulation for wall, roof and floor, air infiltration through cracks and leakages, heat and humidity recovery of ventilation, glazing type, window area and orientation, absorption of coefficient of exterior surfaces, and heat capacity. The standard features of a tropical passive house include a very sealed building, average thermal insulation (with thickness of 10–15 cm), reflective light colours or additional thermal insulation as an alternative, windows fixed shading elements, low-emissivity double-glazed windows, and mechanical ventilation with energy recovery ("Passive Houses in tropical climates," 2014). Few of these principles, including interior insulation, although have been applied in cold climates, are applicable for the construction type in the tropics ("Passive Houses in tropical climates," 2014). In order to optimize energy efficiency and thermal comfort in the tropical regions, a cooling and dehumidification system should adopt a sensible heat ratio to the respective requirements. Unnecessary energy consumption will be the result of utilizing a regular air-handler at an approximate air temperature of 15 °C and an individual dehumidifier ("Passive Houses in tropical climates," 2014).

4. DISCUSSION

Prior studies have repetitively noted the importance of heat avoidance techniques and passive cooling in the tropical climate of Malaysia because these elements can have significant impact on energy reduction. For certain buildings, some passive features and strategies were found to be applicable, for instance, solar chimney, stack air duct, double skin façade, and double skin roof. A passive
house has demonstrated a solid guideline that can be followed for mitigating energy consumption on cooling demand while meeting the occupants’ thermal comfort. Results from the comparison suggest that the application of a passive house’s principles can be applied to render significant cooling load reduction for the buildings in the tropics. This is because amount of solar radiation heat gain is reduced by wall and roof insulation and by double-glazing windows. Window shading, which plays a great role in heat avoidance, is also considered a principle of a passive house. Table 1 below presents the similarities and differences of both groups.

Table 1: A Comparison of Passive Design Strategies/Features in Malaysia and Passive House Criteria in the Tropics.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>1</td>
<td>Building orientation</td>
<td>Rectangular building form alongside East-West</td>
<td>Not specified</td>
</tr>
<tr>
<td>2</td>
<td>Building form/layout</td>
<td>Shallow floor plan design</td>
<td>Compactness Fix shading devices for windows</td>
</tr>
<tr>
<td>3</td>
<td>Shadings</td>
<td>Sun shading devices over apertures to increases day-lighting and ventilation; and low roof eaves at approximately the window height level</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Materials</td>
<td>Facades with high sun reflexion (i.e. white colour exterior painting on the wall); and Lightweight party walls for optimum thermal mass of building structures</td>
<td>Reflective cool colours; absorption of coefficient of exterior surfaces, and heat capacity</td>
</tr>
<tr>
<td>5</td>
<td>Window characteristics</td>
<td>Orientation, sizing and glazing type</td>
<td>Glazing type, frame type, window area and orientation</td>
</tr>
<tr>
<td>6</td>
<td>Vegetation</td>
<td>Vegetation surrounding the building Small internal vegetated courtyard with pitched roof; and planting broadleaf tall trees at strategic location</td>
<td>Not specified</td>
</tr>
<tr>
<td>7</td>
<td>Insulation</td>
<td>Thermal insulation under the roof or over the ceiling</td>
<td>Thermal Insulation for wall, roof and floor (Moderate Level)</td>
</tr>
<tr>
<td>8</td>
<td>Daylighting</td>
<td>North-South façade, window glazing, fibre optic, and innovative roofing system</td>
<td>Window area and orientation</td>
</tr>
<tr>
<td>9</td>
<td>Air well design</td>
<td>Solar chimney, stack air duct, double skin façade, and double skin roof</td>
<td>Not specified</td>
</tr>
<tr>
<td>10</td>
<td>Ventilation openings/apertures</td>
<td>Night ventilation through open windows during night-time; and full-height windows or upper ventilation openings</td>
<td>Mechanical ventilation and dehumidification system with energy recovery</td>
</tr>
<tr>
<td>11</td>
<td>Building corridors</td>
<td>Shallow floor plan with long corridors</td>
<td>Not specified</td>
</tr>
<tr>
<td>12</td>
<td>Passive ground cooling</td>
<td>Ground cooling pipes and earth-coupled buildings</td>
<td>Not specified</td>
</tr>
</tbody>
</table>

5. CONCLUSION

Various studies on passive design strategies have been analysed and synthesised into this solitary paper. It can be verified that the passive house principles are applicable in the tropical climate. This paper also identified similarities and/or differences in terms of the approaches to achieving thermal comfort and energy reduction between a passive house and those found from contemporary studies on the climate-responsive buildings in the tropics. From the findings by Passive House Institute on the features of a passive house in the tropics, some aspects can be suggested for building designs in the same region. These aspects include wall and roof insulation, low-emissivity double-glazed windows, and strategic window orientation, reflective light colours on façade, and shading devices. In future studies, all these strategies can be tested and verified by available computer simulation software in the market, for instance, Passive House Planning Package (PHPP) software.

6. REFERENCES

and ventilation openings in tropical climates, Energy and Buildings.


ÇAKIR, Ç. (2006), Assessing thermal comfort conditions; A case study on the metu faculty of Architecture Building, MIDDLE EAST TECHNICAL UNIVERSITY.


Fung, Y., & Lee, W. (2015), Identifying the most influential parameter affecting natural ventilation performance in high-rise high-density residential buildings,
Indoor and Built Environment, 24(6), 803-812.


Ismail, M., & Abdul Rahman, A. (2010), Comparison of different hybrid turbine ventilator (HTV) application strategies to improve the indoor thermal comfort.


Konya, A. (1980), Design Primer for Hot Climates, Design Primer for Hot Climates.


Mohamed, M., Prasad, D., & Tahir, M. M. (2008), A study on balcony and its potential as an element of ventilation


Schulze, T., & Eicker, U. (2013), Controlled natural ventilation for energy efficient buildings, Energy and Buildings, 56(0), 221-232.


