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COURTYARD CONFIGURATION STRATEGY TO REDUCE AIR TEMPERATURE IN MALAYSIAN UNIVERSITY CAMPUS

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Abstract

A Courtyard is an open space that is partly or completely surrounded by building walls. It acts as a microclimate modifier as it not only allows sunlight into the building but also helps to protect occupants from outdoor harsh conditions by reducing air temperature of its surrounding environment. Malaysia hot and humid climate is characterised by a high temperature, humidity and abundant of rainfall throughout the year. A courtyard design that is tailored to Malaysia climatic conditions could help improve thermal comfort of building occupants. The aim of this study is to identify factors that influence the reduction of air temperature within the courtyard for thermal improvement and to recommended strategies for hot and humid climate courtyard design. The study employed a quantitative approach. The investigations were conducted using ENVI-met simulation software, focused on the three courtyard factors that could influence the reduction of ambient air temperature, namely the orientation, shape and height, and vegetation. Results show that the three factors influence the improvement of shading effect within the courtyard, thus reduce the ambient air temperature reading for better occupant thermal comfort. In hot and humid climate countries such as Malaysia, shading effects are very important since the region is exposed to direct sunlight as the sun path is mostly overhead between 11:00 and 15:00. Hence, courtyard design strategies must be wisely considered during the early design stage using credible simulated findings.

Keywords: Courtyard; Microclimate modifier; Hot and humid climate; Air temperature; Thermal comfort

1.0 INTRODUCTION

University campus is one of the important learning centres where students improve themselves as a person by producing creativity and gain knowledge for their future career. Thus, providing a comfortable surrounding environment for students are paramount in this investigation. However, in today's modern world, certain courtyards are merely been designed for aesthetic improvement. Their designs are often complained as not functional enough to provide occupants with the minimum thermal comfort they need. It is speculated that reason is due to the lack of knowledge and understanding among designers of what constitutes a good design of courtyard that could lead to the significant reduction of ambient air temperature. In the context of the university campus where many courtyards are generally seen, reducing the outdoor air temperature through good courtyard design is compulsory. It will help improve students' thermal comfort passively thus help them be more focused on learning, and keep them live in satisfaction. In the previous years, there has been a growing attention of designing courtyard for the microclimatic improvement of outdoor spaces. From previous studies, it can be concluded that designers from different climates would propose different courtyard design strategies to improve the thermal comfort of the building occupants (Makaremi et al., 2012). Despite the type of buildings, a successful courtyard design could be achieved if proper initiatives are taken during the preliminary design stages. Previous studies proved that good courtyard design strategies that are tailored to climatic conditions could significantly improve occupants' thermal comfort. Thus, the objectives of this study are, i) to analyse elements of courtyard design that could influence air temperature reduction, and ii) to recommend a combination of courtyard design strategies for Malaysian hot and humid climate.

2.0 LITERATURE STUDY

A Courtyard is defined as an outdoor or semi-outdoor area, often enclosed by building walls, and is exposed to the sky. It is a common architectural feature that has been used in many parts of the world for thousands of years. It is regularly served as a major gathering area as well as for gardening, playing, working sleeping, and cooking. There are also some cases where the courtyard is used as a place for animals keeping (Edwards et al., 2006). Surrounded by paved indoor spaces, numerous plants, water bodies, shading elements, colonnades and arcades, they all played an essential character for human social and working life (Sadafi et al., 2011).

2.1 Courtyard Configuration

Courtyard designs or layouts are not fixed. There are a number of different courtyard layouts. The very basic ones, commonly found in many buildings around the world, are square and rectangle. Besides, circular or curvilinear layouts are also quite common. Throughout times, the basic configurations have evolved and improved not only for its aesthetic but also to respond to numerous ever-changing environmental conditions. Courtyard with Y, U, T, and L layouts can now commonly be found (Das, 2006).

2.2 Courtyard Orientation

Numerous research showed that the orientation of a courtyard played a significant role for the shading effects (Cantón et al., 2014; Berkovic, Yezioro, & Bitan, 2012). During the preliminary design stage of a courtyard, consideration of the orientation and location are very important. Solar radiation and penetration onto the internal envelope mainly influenced the thermal performance of the courtyard, depending on the sun's position and geometrical parameters of the courtyard. It is argued that each climatic region has its own strategies to take full advantage of the passive solar potentials, to avoid the cause of discomfort thus help maximise comfort. This includes the strategies of courtyard placement and sun orientation as they help contribute to the desired amount of shading within a building. A thorough consideration of shading within a building is crucially needed to overcome issues of solar heat gain or radiation (Alnaser & Flanagan, 2007).

2.3 Courtyard Height

The courtyard height is defined as the height of the enclosure walls that surround the courtyard. Different climatic regions need different courtyard heights to achieve maximum thermal comfort potential. A suitable courtyard height is needed as it could create the appropriate amount of shade as well as it allows the desired amount of light into the building. For example, in a hot region where the sun is typically high overhead in the sky, the design of the courtyard must be deep to avoid direct solar radiation and insolation, thus generate more shade from the wall to reduce the temperature within the area (Ghaffarianhoseini, Berardi, &

Ghaffarianhoseini, 2015). In the meantime, a courtyard in cold climate needs lower walls to permit enough solar penetration with low altitude to reach into internal spaces of a building (Muhaisen, 2006).

2.4 Vegetation

Ernest and Ford stated that the use of bio-climatic features such as vegetation is extremely recommended to improve courtyard thermal performance (Ernest & Ford, 2012). For example, a case study conducted in Israel has proven that the application of grass and trees could improve thermal comfort through daytime cooling results of Predicted Mean Vote (PMV) range between 1.5 and 2.5 based on different landscape treatments (Shashua-bar, Pearlmutter, & Erell, 2009). Moreover, a study in Saudi Arabia also claimed that the outdoor air temperature could be reduced by 4ºC when the outdoor courtyard is covered with trees during daytime (Al-Hemiddi & Megren Al-Saud, 2001).

2.5 Summary

Findings from the literature review conclude that the courtyard configuration, orientation, and height as well as the application of vegetation within the courtyard could influence the reduction of air temperature. They help to provide shades within the courtyard, thus increase comfort level of the occupants. Acknowledging this, therefore, this study investigates the influencing factors combinations, and to recommend the best design strategies for hot and humid courtyard – specifically in Malaysia.

3.0 METHODOLOGY

3.1 Research Design, Instrument and Procedure

The study employed a quantitative approach to achieve the aim and objectives. Data were collected from various primary and secondary sources. Primary data were sourced from observation and ENVI-met simulations, whilst secondary data were sourced from online websites, journals, and books. ENVI-met simulation software was used in the study to carry out the parametric environment study according to the surrounding variables. ENVI-met is a holistic three-dimensional non-hydrostatic model for the simulation of surface-plant-air interactions not only limited to but very often used to simulate urban environments and to assess the effects of green architecture visions. It is designed for microscale with a typical horizontal resolution from 0.5 to 5 metres and a typical time frame of 24 to 48 hours with a time step of 1 to 5 seconds. This resolution allows analysis of small-scale interactions between individual buildings, surfaces, and plants (Bruse, 2014).

Table 1. ENVI-met simulations parameters (Source: Ghaffarianhoseini, Berardi, & Ghaffarianhoseini, 2015)

Parameters		Input
Location		Kuala Lumpur, Malaysia (Latitude 3º 7´ N, Longitude 101º 33´ E)
Simulation day and duration		23rd June (hot day), 12 hours (from 8:00 am to 8:00 pm)
Grid size		80 × 80 × 30
Soil data	Initial temperature, upper layer (0-20 cm)	28 °C
	Initial temperature, middle layer (20-50 cm)	26 °C
	Initial temperature, deep layer (>50 cm)	24 °C
	Relative humidity, upper layer (0-20 cm)	88 %
	Relative humidity, middle layer (20-50 cm)	90 %
	Relative humidity, deep layer (>50 cm)	93 %

Table 1 above lists all the ENVI-met simulations parameters used in the study. It followed the specifications specified by Ghaffarianhoseini, Berardi, and Ghaffarianhoseini in 2015. A case study was conducted within a small university campus building that has a courtyard in Malaysia known as Universiti Kuala Lumpur. All the parametric analyses were carried out based on its location – Kuala Lumpur, a hot and humid climate region near the equator (3º8' N, 101º42' E). The mean of air temperature in Kuala Lumpur is 27 ºC, where the mean of the maximum and minimum readings are ranged between 31.9ºC to 33.5ºC and 23.1ºC to 24.3ºC respectively (Sadafi, Salleh, Haw & Jaafar, 2011).

4.0 RESULTS AND DISCUSSION

4.1 Courtyard Orientation Influence on Air Temperature

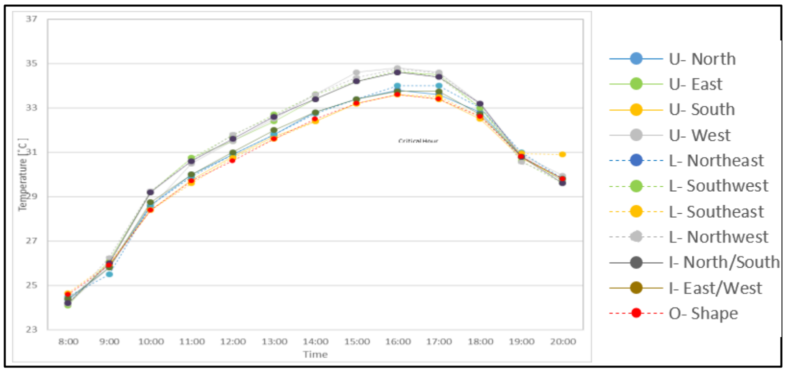

Figure 1. Comparison of air temperature results in all courtyards. (Source: Author)

11 models with different types of shapes (O-shaped, U-shaped, L-shaped, and I-shaped) which facing different orientations were simulated to identify the most recommended courtyard configuration in Kuala Lumpur, Malaysia. Figure 1 above shows that the courtyard models facing the South and the North have lower air temperature readings compared with the models facing the East and the West. The results were expected as the courtyards oriented to the South and the North were the most shaded and protected from direct sunlight from the East in the morning and the West sun in the afternoon. Based on the results, the top three courtyard models with the lowest air temperature readings were U-south, O-shaped, and L-Southeast courtyard models respectively.

4.2 Courtyard Height Influence on Air Temperature

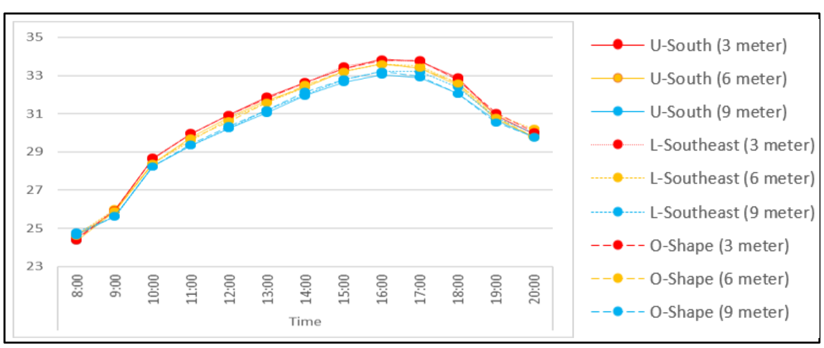

Figure 2. Comparison of air temperature results in all courtyards

The top three courtyard models with the lowest air temperature readings namely U-south, O-shaped, and L-Southeast courtyard models were tested with three different wall heights - 3 metres, 6 metres, and 9 metres. The walls width were fixed to the similar original dimension of 18 metres. The air temperature results were then recorded. Figure 2 above shows that the three courtyard shapes produced similar temperature pattern with variations in the air temperature readings as they responded to the variances in wall height. From the record, the highest wall height (9 metres) gives more positive result compared with the lowest wall height (3 metres) with the temperature difference of approximately 1 ºC. The results show that as the wall height of courtyard increases, direct sun penetration and air temperature decreases, which agrees with other published findings (Taleghani et al., 2014; Berkovic, Tezioro, & Bitan, 2012).

4.3 Vegetation Influence on Air Temperature

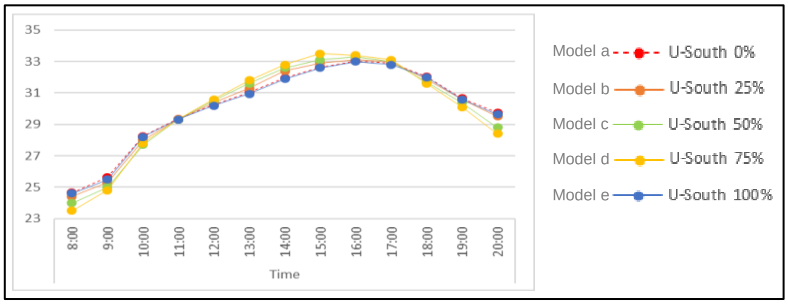

Figure 3. Comparison of air temperature results in all courtyards

Previous studies proved that when the sun is almost above the building and the shade is minimal, the adoption of greeneries in the courtyard may help decrease the ambient air temperature (Zango et al., 2017). In the context of the study, the U-South courtyard with 9 metres walls height was simulated with five different greeneries configurations. The five courtyard models were named as bare ground (model a), 25% covered by trees (model b), 50% covered by trees (model c), 75% covered by greeneries (model d) and 100% covered by grass (model e). Figure 3 above shows the influence of vegetation to reduce air temperature were clearly enhanced during the morning (8:00 – 9:00) and evening hours (19:00 – 20:00). During the hours, the air temperature reading decreases as the percentage of area covered by trees (model b and c) increases, whilst on the other hand, model a and e did not have a significant impact on the thermal performance. However, it is seen that between 12:00 and 17:00, model a and e achieved the lowest air temperature readings. The findings proved similar results to the previous studies.

5.0 CONCLUSION AND FUTURE WORKS

Table 2. The recommended courtyard design strategies (Source: Author)

Rank	Courtyard Strategy	Description	Air Temperature at 16:00
1	U-South (9m) (25%)	Semi-enclosed courtyard (U-shape)	32.8 °C
		Opening facing South	
		9 metres wall height	
		25% vegetation	
2	O-Shape (9m) (25%)	Fully-enclosed courtyard (O-shape)	33.1 °C
		9 metres wall height	
		25% vegetation	
3	U-North (9m) (25%)	Semi-enclosed courtyard (U-shape)	33.9 °C
		Opening facing North	

		9 metres wall height	
		25% vegetation	

In conclusion, controlling the amount of solar radiation that penetrating a courtyard is very crucial in a tropical hot and humid climate context. In the early design stage, it is important to select a proper courtyard location and to determine its best orientation and height as they can lead to the maximisation of shading, thus improves the thermal comfort of occupants. Table 2 above summarised the three recommended courtyard design strategies for hot and humid climate region. The recommendations are made based on the air temperature reading at the most critical hour of 16:00. Based on the simulation findings, the U-shape and O-shape courtyards are the most recommended shapes to be adopted in the hot and humid region. The courtyards should be oriented to the South and North, to avoid the direct sun penetration from the East and West. Moreover, the amount of shade within a courtyard is very important as it could further help reduce the air temperature. To achieve the adequate amount of shade, higher courtyard walls of at least 9 metres high is recommended as it could provide more shades covering up larger courtyard area as compared to the lower ones. Besides, the implementation of vegetation such as trees of at least 25% of courtyard ground coverage is also highly recommended to significantly reduce the surrounding air temperature. However, careful placement of vegetation within a courtyard is required as it could also give a negative impact on the building thermal performance. For instance, the presence of too many trees could hinder the wind from entering the courtyard, thus lead to the increase in air temperature. It is suggested that future studies could look into studying the thermal condition of the shaded courtyard. A study on the impact of courtyard design towards the indoor thermal performance of the surrounding building could also be conducted.

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