Progress on Thermal Performance of Courtyard Buildings in Hot Humid Areas: A Review

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Abstract— **This literature review discusses the effect of design variables of courtyarded buildings, such as shape, orientation and shading devices of the courtyard, on thermal performance in hot humid climate. It is found that choosing appropriate shape of courtyard, taking the orientation into account and using good shading device can enhance the thermal performance in internal courtyard adjacent areas. In term of courtyard shape, central-close squared and U-shaped rectangular courtyards provide the optimum thermal performance compared with closed rectangular and U-shaped square courtyards, respectively. The courtyard orientation impact depends on the season, where during summer northern direction gives the optimum thermal performance due to high shading and wind speed, while during winter courtyard recommended to be oriented with an angle of 30o with respect to east to achieve high sunlit area. Last but least, the shading tools have a positive impact on thermal performance where using trees and vegetation show better performance compared with other types of roofing. However, having space between the roof of the courtyard and its opening level highly effect on the thermal performance. Further investigation on the effect courtyard walls material, size and number of openings, and material of courtyard roof shading on thermal comfort and energy consumption need be considered in future.**

Index Terms— **Courtyard, Design data, Hot-humid region, Thermal performance.**

I. INTRODUCTION

The courtyard can be defined as uncovered zone that is totally or partly surrounded by walls or buildings that gives privacy to the house and it has many purposes such as family gathering and safe play yard for children [1]. Courtyard is an ancient form within housing buildings that extended for more than 5000 years ago, it is traditionally related with the Middle East culture and it is found in different shapes. Then it is transferred to different cultures like Latin America and China [2]. In the past, courtyard housing was a popular form in hot-humid areas especially in China and India since it was more appropriate than another forms of buildings due to the people culture, and social conditions where it was considered as ideal shape for housing [3]. It was built by traditional method using traditional materials and the walls had large thickness but without any isolation and it had many windows [4]. Newly it started to be used as an element for sustainable buildings as passive cooling design strategies to minimize energy demands and reduce energy consumption [5, 6]. In addition, it can be a solution to reduce humidity through ventilation [5].

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In general, all the data design such as; shape, height, orientation, shading device, glazing thickness and ratio etc. had to take into account by designer due to their effect on thermal courtyard performance [7]. There are many studies reported to improve the performance of courtyard in residential building in different environments to achieve high thermal comfort but less information about courtyard buildings in warm-humid districts. Some of studies focused on the effect of courtyard shape on thermal performance in warm-humid areas and show that the optimum building shape in hot humid climate is open extended form to allow the air movement to achieve the thermal comfort [8]. Muhaisen and Gadi show that the thermal performance in deep courtyards is better than shallow one, and it is require less energy for cooling [9]. Muhaisen shows that optimum height for courtyard in hot humid zone is three stories [7], [10]. The literature also reports the effect of courtyard on enhancing air temperature in hot humid climate. A case study in Kuala Lumpur, Malaysia, investigated the effect of introducing the courtyard in terrace house and the results show that the courtyard housing is enhancing the thermal performance at internal zones since it reduces the temperature within the house [11]. Rajapaksha et al. explored the potential of a courtyard for passive cooling in a single story high mass residential building located in a warm humid climate. The effect of the courtyard for mass-air heat exchanges and thus lowering the daytime indoor air temperatures below the corresponding levels of shade ambient temperature is correlated with the indoor airflow pattern [12]. Toe discussed the passive cooling of an existing courtyard in Chinese house-shops in Melaka, Malaysia, and he found that the interior air temperature in adjusting areas of courtyard is lower by 5-6 °C during daytime, but at night it has same value for outdoor with the external doors and windows are closed. This indicates that thermal comfortability is enhanced [13]. A study introduced by Ghaffarianhoseini et al. to analyze the thermal performance on unshaded courtyard in Malaysia according to different design configurations including the orientation, height and albedo of wall enclosure, and using of vegetation. They concluded that selection of the courtyard's orientation leads to maximize the wind received and increase the amount of shade during daytime. Higher wall enclosure enhances the indoor thermal comfortability since it reduces the radiations and provides more shaded areas. Planting vegetation inside the courtyard increases the humidity and reduces the speed of wind but it provides better thermal comfort at certain periods of daytime [14].

This paper discusses design variables, namely: shape, orientation and shading devices, on thermal performance of courtyard in hot humid climate through a literature review. The discussion contains the future outlook in design process to achieve the optimum choice of design variables, the previous studies show the courtyard form is impact on thermal performance in internal adjusting zones. [15], [16]. The orientation of courtyard is important step in design process, it is a way to reduce of the direct sun exposure, where have to take into account the movement of sun from east to west, in addition to the wind direction [17]. The shading is considered an important solution to reduce the air temperature and enhance the thermal performance, therefore, shading devices in design process such as adding roof for courtyard [18] and using trees [19] have to be taken into account.

II. Design Variables Consideration on Thermal Performance of Courtyard in Hot Humid Climate

Building design is the most important factor influences the internal thermal of the buildings. The building's shape, arrangement, composition and spacing impact on the solar and wind factors [20]. Therefore, there are some variables in building design have to be considered such as:

A. The shape of courtyard

Yasa and Ok studied the optimum courtyard shape for fully enclosed courtyard in Antalya that has hot-humid climate using CFD software [15]. They evaluated the thermal performance in different courtyard building shapes. In their case study, they considered a courtyard with a dimension of 6 m × 6 m as reference model then increase the east–west side by a ratio of 1.5, 2, 2.5, 3 and 5 for the other models as shown in figure 1. The result shows that the optimum choice for the hot period during July (between the daily hours of 05:00 -19:08) is for the square courtyard, which shows the lowest solar radiation gain as depicted in Fig. 2.

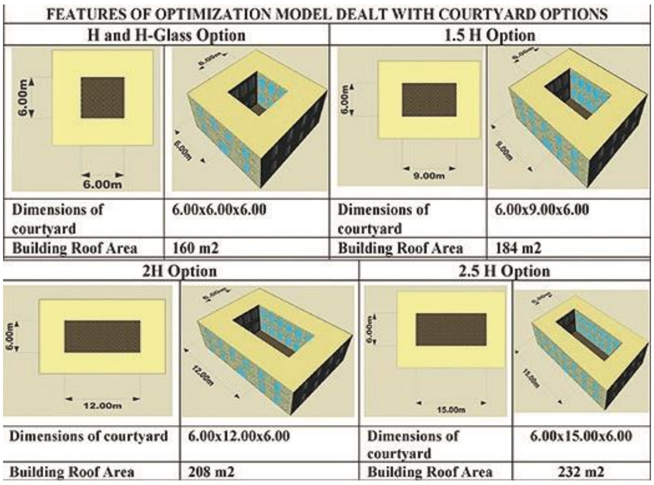


Fig. 1 Courtyard models at different dimensions [15].

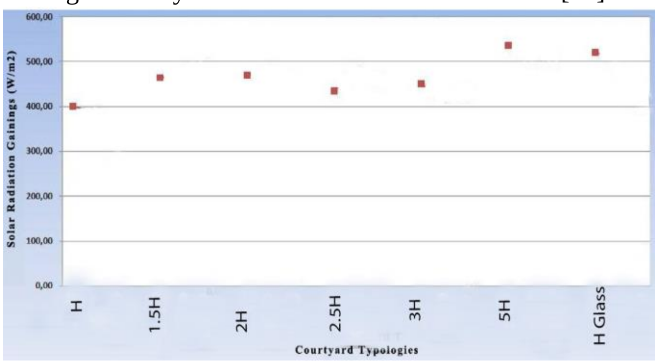


Fig. 2 The solar radiation gain amount of the courtyard ground on 21st July for all courtyard options in Antalya [15].

Almhafdy et al. reported a study on U-shape courtyard using CFD software in Malaysia [16]. They selected three models for simulation as shown in Fig. 3 and found that the cantilever and the side ratio of courtyard's walls directly effect on the wind velocity, and therefore, the thermal comfort is evaluated by the Predicted Mean Vote (PMV) index. In the square u-shaped courtyard with plan aspect ratio of (1:1) that facing the north, the result shows the air temperature from the opened side is less than the closed one. They found that the air temperature at the opening side is 32.4 ºC while at the closed side is the range of 32.8 ºC to 33.4 ºC, whereas the air velocity is within the range of 0.01 m/s to 2 m/s from the opening side of the courtyard toward the closed one. Moreover, they found that the PMV at the opening side is 1.4 while it is 1.6 to 2.8 in the other zones of courtyard as shown in Fig. 4 (a).

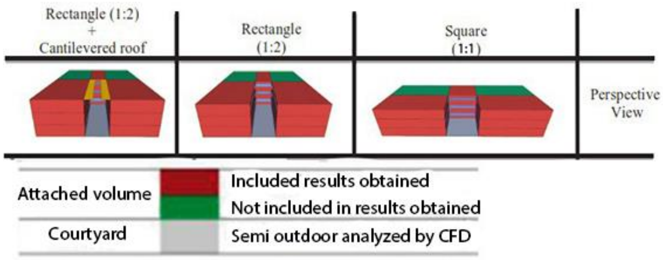
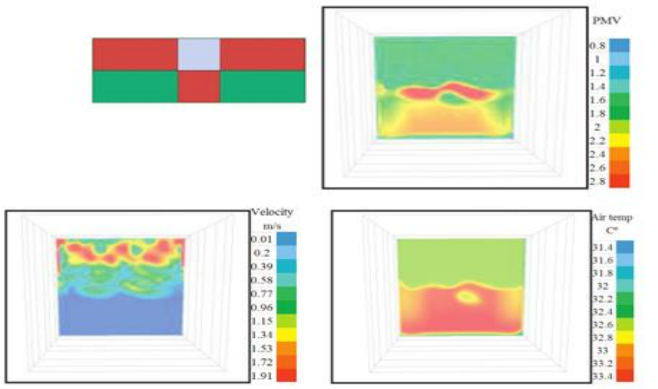
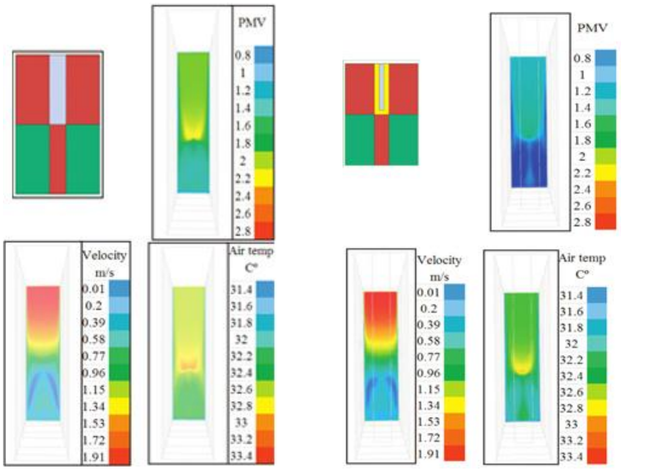


Fig. 3 U-shaped courtyard models [16].

In addition, the rectangle U-shaped courtyard with plan aspect ratio of (1:2) shows that the air temperature at the opening side is 32.6 ºC while at the opposite side is 32.4 ºC to 32 ºC, and they found that the air velocity is in the range of 0.01 m/s to 2 m/s from the opening side of courtyard to the closed one. The recorded PMV value close to the opening side was 1.2 to 2.2 while the rest area of the courtyard, the PMV results recorded with 1.2 to 1.6 as illustrated in Fig. 4(b). One can see that the (1:2) aspect ratio of courtyard shows slightly better performance in term of air temperature, airflow and PMV value compared to the 1:1 aspect ratio courtyard, indicating that rectangular shaped courtyard could be a better choice to reach a higher thermal comfort. However, in rectangular U-shaped courtyard of (1:2) aspect ratio with a cantilever roof that covers 60% of total top opening of the courtyard case, the results show better performance compared to the other cases for all parameters, indicating that the cantilever added to the courtyard of 1:2 aspect ratio has high impact on the thermal comfort as shown in Fig. 4(c).



(a)



(b) (c)

Fig. 4 Results of CFD simulation for U-shape courtyard with (a) plan aspect ratio of (1:1), (b) plan aspect ratio of (1:2) and (c) plan aspect ratio of (1:2) with cantilevered roof [16].

B. *Orientation of building*

The building orientation plays an important role on the thermal performance by reducing the exposed area to the direct solar radiation of the buildings cover, opaque walls and openings. Have to take into account the movement of sun with respect to latitude and the expected shading effect when the direction of buildings is selected [8]. The important goal of orienting the courtyard is to obtain the optimum performance for the courtyard regarding to sun. The optimum angle of orientation is measured when the courtyard has a maximum wall-shaded zone in summer and lesser in winter. Muhaisen studied the effect of courtyard orientation in buildings in different climates on the thermal performance [10], he investigated the changing of courtyard angle from 0^{o} with respect to east to 90^{o} toward north in 10^{o} steps from 7 am to 5 pm as shown in Fig. 5. He concluded that the maximum shaded zone for the building in hot-humid area during summer, particularly in Kuala-Lumpur, could be obtained when the courtyard direction extended along the north–south axis, whereas, in winter the greatest sunlit area is achieved at the angle of 30^{o} with respect to east as shown in Fig. 6. Ghaffarianhoseini et al. reported the effect of orientation of unshaded courtyard on thermal performance of buildings in hot-humid areas, particularly in Kuala Lumpur, using ENVI-met simulation software [14]. They studied five models for squared-shaped courtyards oriented toward west, north, south and east in addition to central courtyard as shown in Fig. 7. The impact of orientation of the courtyard on thermal performance has been investigated through parameters such as air temperature, wind speed and relative humidity. They found that the courtyards that facing north and east have a higher wind speed and lower air temperature especially from 10 am to 5 pm with nearly 0.5 ^{o}C of difference compared to the other models as shown in Fig. 8 (a) and (b), whereas these courtyards recorded the highest level of humidity as shown in Fig. 8 (c). The relatively high wind speed and low air temperature for north and east oriented courtyards are attributed to the fact that these courtyards are open to the northeast wind direction and receiving slightly more shading [14].

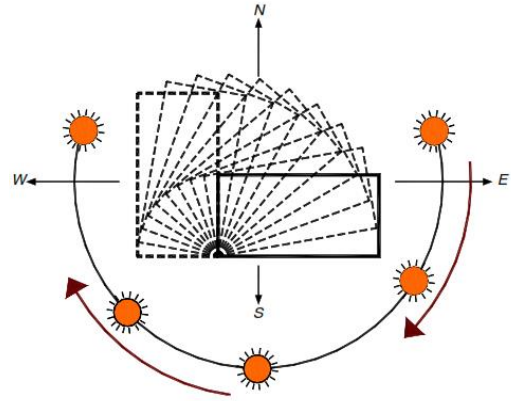
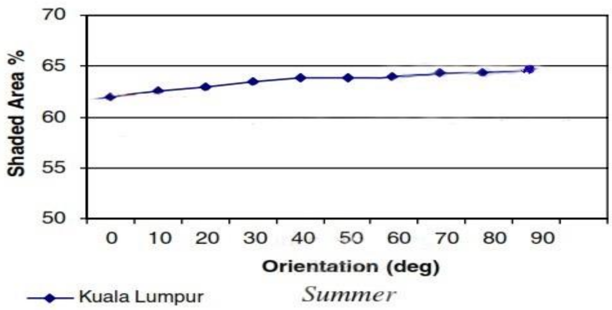
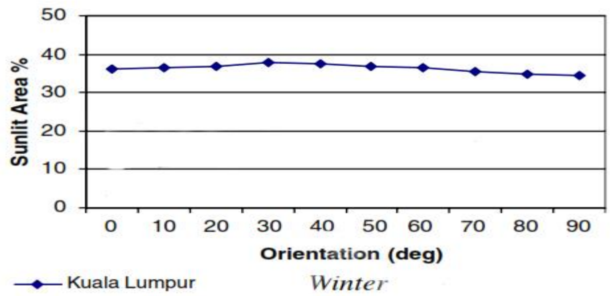


Fig. 5 changing the orientation of the courtyard from 0^{o} to 90^{o} in 10^{o} steps [10].



(a)



(b)

Fig. 6 Effect of changing the courtyard's orientation in Kuala Lumpur on (a) shaded area in summer and (b) sunlit area in winter [10].

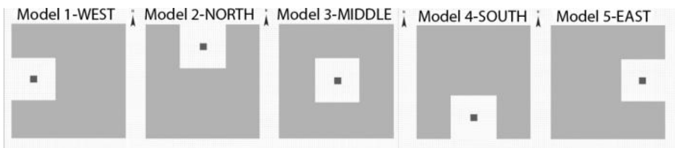
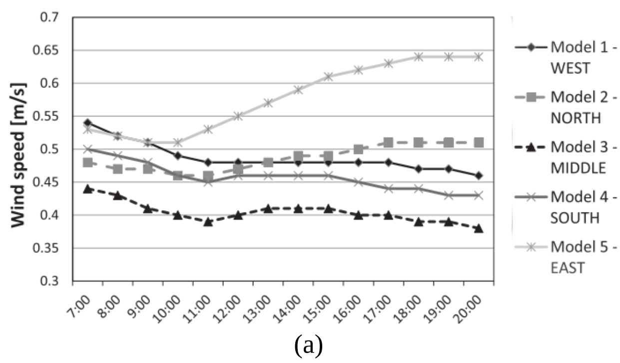
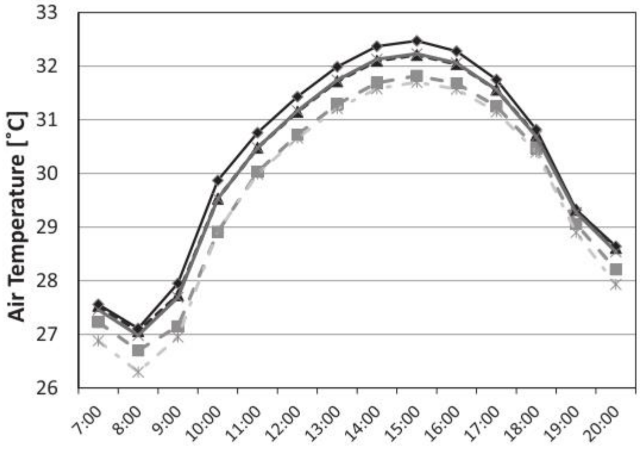


Fig. 7 The models of square-shaped courtyards in different orientations [14].



(a)



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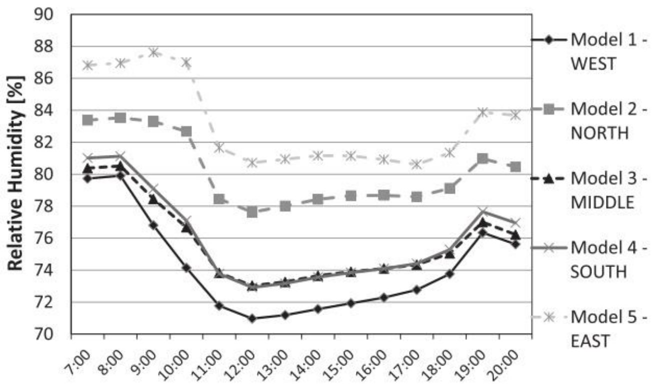

(c)

Fig. 8 Comparison of average of hourly (a) wind speed (b) ambient temperature and (c) relative humidity of different models [14].

C. Shading tools

The shading tools have a positive impact on thermal performance of buildings especially in hot climates. According to Al-Tamimi [21], selecting good shading tools increases the comfortable hours by 26% for unventilated buildings and 4.7% in ventilated conditions in hot-humid climate.

Using plants and trees

Makaremi *et al* studied two outdoor locations named as Space A and Space B at University Putra Malaysia campus to investigate the effect of shading device on thermal comfort by calculating the Physiologically Equivalent Temperature (PET) using software packaging Rayman based on data from objective measurement and subjective assessment [19]. The Space A is covered with translucent polycarbonate roofing whereas Space B is shaded with trees and plants within a courtyard surrounded by office buildings. In which PET value can be estimated by input data for the air temperature, wind speed, radiant temperature, cloud cover and humidity. The results of this study show that the PET values are more than comfort range limit of 30 °C for both locations during daytime. However, in translucent roofing case (Space A) without support of any shading from surroundings gives a minimum quantity of the comfort situation during the day, but the Space B that has trees and plants as shading gives better results of thermal performance than Space A as shown in Fig. 9.

The figure also illustrates that the PET value in Space A is higher than the Space B from 10 am to 4 pm with a deference of 12 °C above the acceptable comfort range that is assumed to be 34 °C. Moreover, Space B that is shaded with trees has better results where the PET values, from 9-11 am and 4-5 pm, are in acceptable range (PET < 34 °C) compared to Space A. In general, the study shows that the pergola surrounded by plants enhances the thermal performance in case B [19].

Using shaded roof

Sadafi et al. added shaded roof for courtyard in terrace house case to study its impact on absorbing heat and thermal situation of adjacent spaces in Malaysia using ECOTECT software [18]. They found that the solar gain is reduced when the courtyard is shaded and therefore enhances the thermal performance of the adjacent spaces. They also examined the effect of the shading surface height with respect to the opening at different heights of 25 cm, 50 cm and 100 cm to find out that the shading roof of 50 cm separation with the respect of house roof provides the lowest value of air temperature in the adjacent area as depicted in Fig. 10.

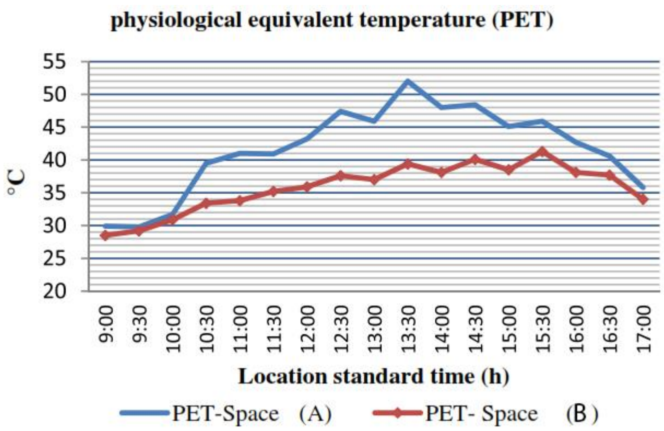

Fig. 9 the calculated PET for Space A and B [12].

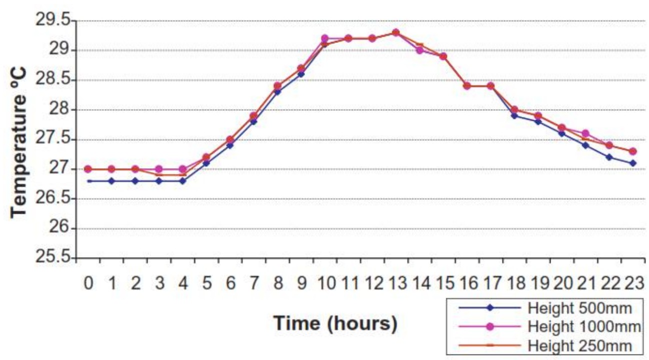

Fig. 10 temperature in adjacent area at different height for courtyard roof [18].

III. Conclusions

This paper discussed the effect of design variables on thermal performance of courtyarded buildings in hot humid climate through a literature review. The discussion basically focused on investigating the effect of courtyard shape, orientation and shading devices of courtyard on thermal performance, and it is concluded that choosing appropriate shape of courtyard, taking orientation into account and the good shading device can enhance the thermal performance in internal courtyard adjacent zones. This discussion provides a good future outlook in design process to achieve the optimum choice for design variables in hot-humid climates. The detailed conclusion is as follows:

i. The shape of courtyard is considered an important step in design process. In the case of fully enclosed courtyard, it is found that the optimum shape is the central squared courtyard since it shows the minimum solar radiation gain as a result of the large shade zone, thus, enhancing the comfort conditions.

ii. In case U-shaped courtyard that considered semi enclosed courtyard, it is found that the rectangle U-shaped courtyard of side ratio of 1:2 gives better performance compared to the squared U-shape courtyard of side ratio of 1:1.

iii. Using cantilever creates shading that reduces the air temperature value, which in turn enhances the thermal comfort.

iv. In hot humid climates the optimum orientation for building is when the courtyard extended along the north–south axis during summer due to the high shading obtained, whereas, during winter, the optimum orientation is at an angle of 30^o with respect to east because of high sunlit area achieved.

v. In hot-humid areas the courtyard facing West direction shows the worst orientation due to its low wind speed and high value of air temperature. Whereas, the best orientation for thermal performance is for courtyard facing North due to minimum air temperature and high wind speed.

vi. The shading tools have a positive impact on thermal performance for the adjacent zones of courtyard since it reduces solar gain. Using trees and vegetation show better performance in term of thermal performance compared to translucent roofing.

vii. Having space between the roof of the courtyard and its opening level relatively effect on the thermal performance, and it is found that 50 cm height for the roof provides the lowest air temperature value in two story terrace house in hot-humid climate.

Finally, the future studies must focus on the effect courtyard walls material, size and number of openings, and material of courtyard roof shading on thermal comfort and energy consumption.

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