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Potential Thermal Impacts of Internal Courtyard in Terrace Houses: A Case Study in Tropical Climate

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Abstract: This study investigates the effects of introducing internal courtyard on thermal comfort performance of a case study terrace house in Kuala Lumpur Malaysia. The inclusion of an internal courtyard in building design is attributed to maximize the thermal interactions between the building and outdoor environment. However, different design details of the building composition will result in various climatic effects of internal courtyard. Based on computer simulations, the introduction of internal courtyard into a typical Malaysian terrace house will increase heat gain in the indoor spaces which do not have any openings to the outdoor environment except into the courtyard. In contrast spaces with openings to the outdoors as well as courtyard will experience better thermal conditions. The behavioral effects of the courtyard on indoor thermal condition is affected in relation with envelop openings. Since more solar radiation will penetrate in the house through the internal courtyard, sufficient and effective openings with suitable shading device as well as suitable material for its walls will help to improve the thermal condition in surrounding spaces of the courtyard.

Key words: Thermal comfort, terrace housing, internal courtyard, heat gain, tropical climate

INTRODUCTION

The concerns over global warming and need for reduction of high emission of greenhouse gases, demand the utilization of strategies for indoor climate modification in promoting comfortable indoor environment (Givoni, 1994). In warm humid tropics overheated building interior are common due to solar penetration through the buildings envelope and windows (Rajapaksha *et al*., 2003) and terrace houses as one of the most common typologies of residential buildings in Malaysia are also facing these problems. Because of the high density of the building blocks and the crowded dwellings a large number of buildings do not fulfill the requirements for thermally comfortable environment. So far many bioclimatic design strategies have been proposed in different studies and some of them are also used in practice (Budaiwi, 2006). One of the common strategies is to include internal courtyard in the house in order to introduce the out doors in to the heart of the buildings core as well as optimizing the climatic source. Solar radiation which received to the courtyard surfaces will affect the thermal performance of the building especially in areas adjacent to courtyard. The amount of heat gain through radiation depends on climatic condition, the time during the year and configuration of the courtyard (Muhaisen and Gadi, 2006). Moreover, thermal performance of courtyard building has been investigated by many researchers such as; Al-Hemiddi and Megren Al-Saud (2001), Rajapaksha *et al*. (2003), Ratti *et al*. (2003) and Muhaisen (2006). But normally mentioned studies have evaluated buildings as common bungalows without the limitation for land size and opening, in different countries (Japan, UK, Saudi Arabia). This study intended to investigate the influence and effectiveness of internal courtyard on thermal performance of terrace houses in Malaysia, in order to take the advantages and offer recommendations. To this end, ECOTECT software is used to simulate thermal and shading performance of the case study building. Ecotect is a powerful tool to simulate the environmental effects on building's internal condition. Similarly Al-Sallal (2007), Krüger and Dorigo (2008), Kharrufa and Adil (2008) and Alexandri and Jones (2008) have used this software to evaluate the required design configurations in their studies.

AMBIENT CLIMATE

The study area is located in Kuala Lumpur, which is situated at latitude 3° 7' above the equator and longitude 101° 33'. Being close to the equator, the hot and humid conditions are emphasized with heavy rain fall and sunshine throughout the year.

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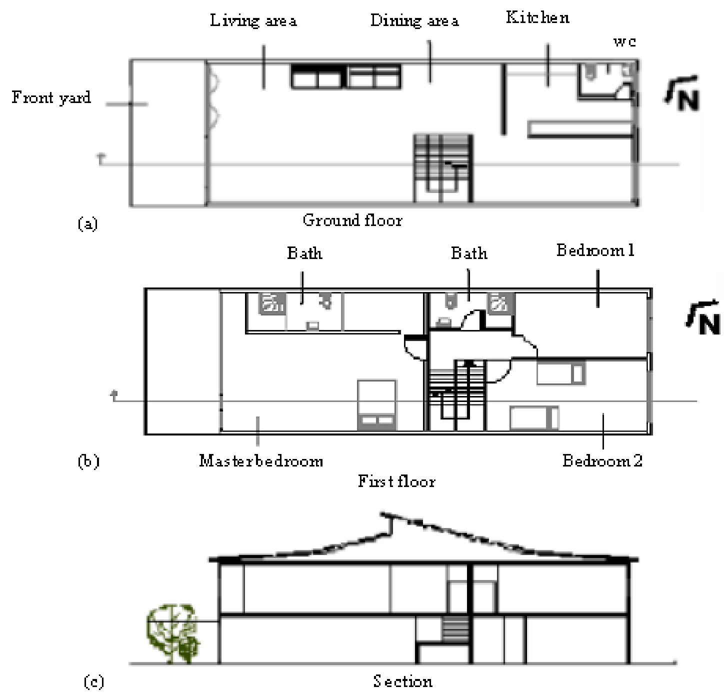

Fig. 1: Case study building, plans (a, b) and section (c)

It has a yearly mean temperature of about 27°C and relative humidity (RH) of 70 to 90% throughout the year (Sabarinah and Hyde, 2002). Moreover, the monthly mean of maximum temperatures values ranged from 33.5°C on March and April to 31.9°C on December, while monthly mean of minimum temperatures values ranged from 23.1°C on January to 24.3°C on May (Malaysian Metrological Service, 2007).

THERMAL MODELING TOOL

There are different computer tools for building thermal modeling with different simulation methods. ECOTECT is a complete building design and environmental analysis tool that covers the broad range of simulation and analysis functions, when it is required to truly understand how a building design will operate and perform (Marsh, 2003). It couples an intuitive 3D modeling interface with extensive solar, thermal, lighting, acoustic and cost analysis functions. ECOTECT is one of the few tools in which performance analysis is simple, accurate and most importantly, visually responsive. For analyzing the output ECOTECT use a wide range of informative graphing methods which can be saved as Metafiles, Bitmaps or animations. Tables of data can also be easily exported to; RADIANCE, POV Ray, VRML, AutoCAD DXF, EnergyPlus, AIOLOS, HTB2, CheNATH, ESP-r, ASCII Mod files and XML.

MODELING

A case study terrace house has been considered for modeling and evaluation of thermal condition (Fig. 1). The two stories of the house consist of:

- **Ground level:** This level is for family area of the house. The thermal zones were divided in to 5 zones: (1) the kitchen, (2) dining area, (3) living area, (4) utility, (5) the front yard which considered as out side zone.
- **First level:** This level is for bedrooms and bathrooms of the house and the created zones are for: (1) Master Bed room, (2) Bed room 1, (3) Bed room 2, (4) The staircase, (5) The Roof. The main bath room has been considered in the staircase zone and the other one in the master bedroom zone.

Materials: For Ecotect model materials for the building are either chosen from Ecotect library or created from user library (Table 1). The property values for these materials are calculated from Ecotect material property. The materials of the house are considered as follows:

PROCEDURE

First investigation for thermal performance of the house as it exists was conducted for three different months of the year (March, Jun and December) (mode A).

Table 1: Material description for the case study building

	Material description	U-Value (W m^{-2} k^{-1})	Admittance (W m^{-2} k^{-1})
Floor	100 mm thick suspended concrete floor plus ceramic tiles and plaster ceiling underneath.	2.90	5.21
Wall			
Internal	100 mm brick with 10 mm plaster either side.	2.72	4.32
External	130 mm brick with 10 mm plaster either side.	2.44	4.46
Roof	16 mm thick zinc metal deck roof with 150 mm air gap and 50 mm thick glass fibre insulation	0.13	1.00
Ceiling	10 mm suspended plaster board ceiling, plus 50 mm insulation, with remainder (150 mm) joists as air gap.	0.50	0.90
Door	40 mm thick hollow core plywood door.	2.98	0.65
Window	Single pane of glass with aluminum frame	5.00	5.00

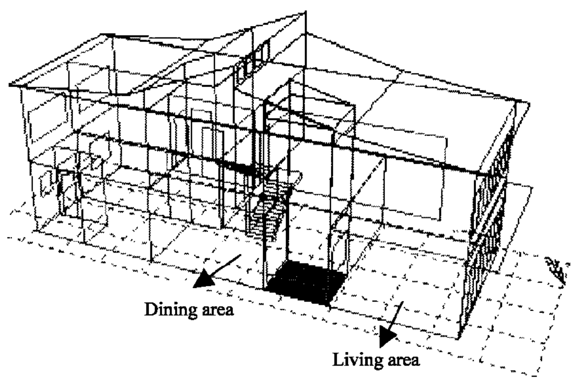

Fig. 2: Case study terrace house after introducing the courtyard

In the next step after investigating common typologies of terrace houses with courtyard, a rectangular shape courtyard with 2.2×2.5 m dimension, has been introduced in the house. Figure 2 shows the case study terrace house model after including the courtyard in the family area (Mode B). As could be seen, the court yard zone is adjacent to the living and dining zones.

The evaluation of thermal performance for the adjoining zones was repeated after introducing the courtyard.

RESULTS AND DISCUSSION

In mode A results showed that noon hours are normally critical times as higher internal temperatures are experienced during these hours according to the sun's beams angle and penetration in to the house.

According to temperature variations of the living area in mode B, introducing the internal courtyard in the house has distinctly affected the thermal conditions in this area. Figure 3 shows the comparison between temperature variations of living area for mode A and B. The temperature has decreased (less than 1°C) all the times after including the courtyard in March.

It is clear that after introducing the internal courtyard in this area the overall UA value has increased because of

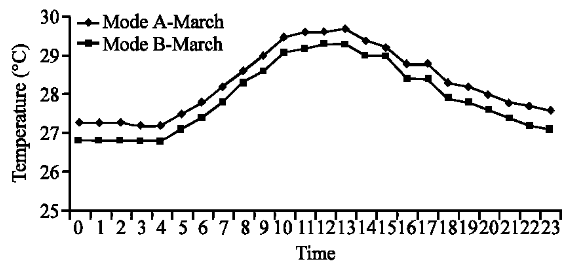

Fig. 3: Temperature difference between mode A and B in March

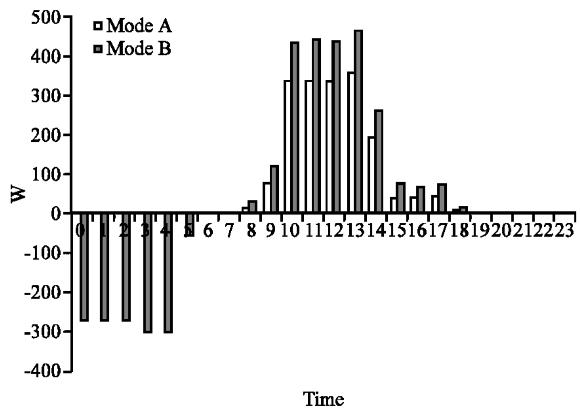

Fig. 4: Conduction gains difference of mode A and B for living area

the added windows (high U-value) to the walls adjacent to the courtyard, which will cause the temperature decrease. Figure 4 also displays the difference between hourly conduction heat gains of the living area in Mode A and B.

It is perceivable that although the conduction gains -including the window-have increased in mode B around noon hours, since the living zone is naturally ventilated; increasing ventilation and heat loss in morning hours will help for temperature decrease (Fig. 5). As could be seen conduction gains in living area has also decreased at morning hours in mode B, which shows the heat releasing through the windows at these hours.

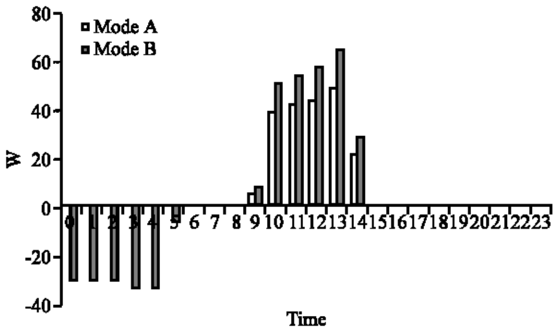

Fig. 5: Heat gain and loss through ventilation for mode A and B

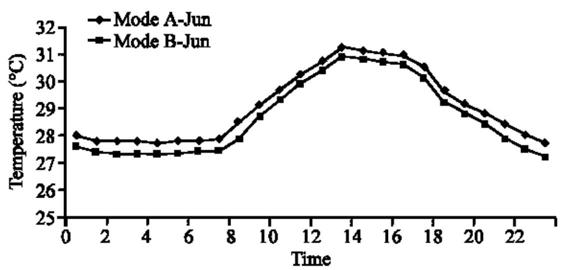

Fig. 6: Temperature difference between mode A and B for living area in Jun

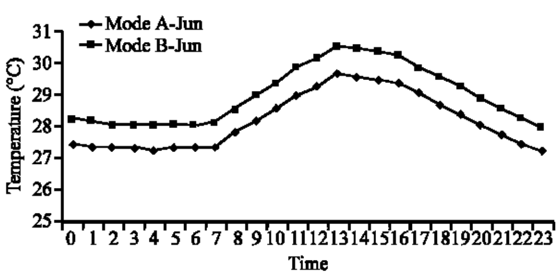

Fig. 7: Temperature difference between mode A and B for dining area in Jun

Figure 6 shows the temperature difference of Mode A and B in Jun. there is evidence that the temperature has decreased.

According to hourly heat gains analysis after introducing the courtyard the inter-zonal heat gains of the living area have increased so, in order to have a more accurate analysis thermal performance of dining area which is the adjacent zone to living area and courtyard has been considered. Figure 7 shows the temperature difference for dining area in mode A and B in Jun. As could be seen internal temperature in dining zone has increased all the times during the day and night after introducing the courtyard.

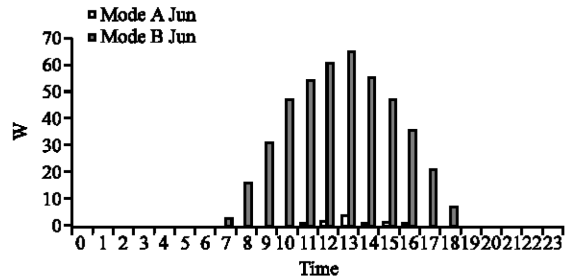

Fig. 8: Solar gains difference of dining area for mode A and B in Jun

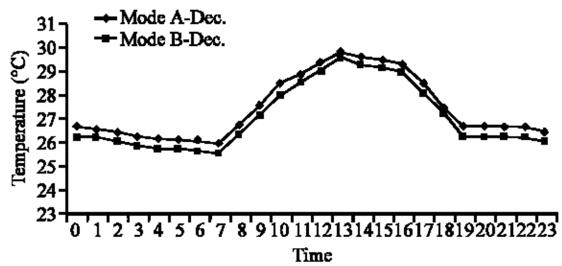

Fig. 9: Temperature difference between mode A and B in December for living area

Figure 8 shows the difference of solar gains in dining area for mode A and B. It is perceivable that dining area will receive much more solar heat after introducing the courtyard, from the window adjacent to the courtyard and since this zone does not have enough openings to release the heat, afterwards it will share its heat with its adjacent zones (living area) and cause the increase in inter-zonal heat gains of the living area.

The results for temperature variations of living area in December shows that the temperature has decreased in compare with Mode A again, while the temperature of the dining area has increased the same as two other months (March and Jun) (Fig. 9).

So it has been perceived that introducing the internal courtyard will somehow enhance the thermal condition of the living area by increasing natural ventilation and internal heat release through its windows. But as it will increase the solar heat gains of the dining area and since this zone does not have enough opening to release the heat, the temperature will increase in this zone and make it hotter. In return dining area will try to share this heat with living zone so will reduce the cooling effects of the courtyard in this area.

Shaded courtyard: In the next step a shading roof was considered for the courtyard in order to examine its effects on heat absorption of the fabrics and thermal conditions

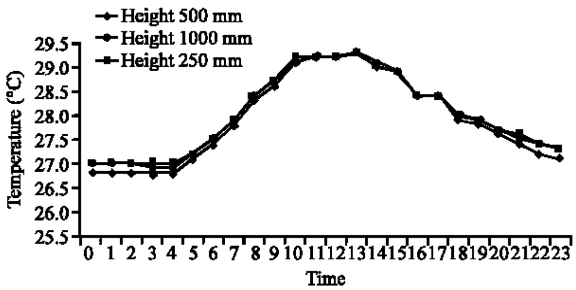

Fig. 10: Temperature difference for living area with different height for courtyard roof

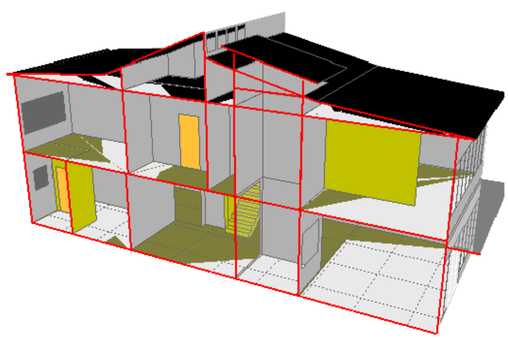

Fig. 11: Courtyard with roof

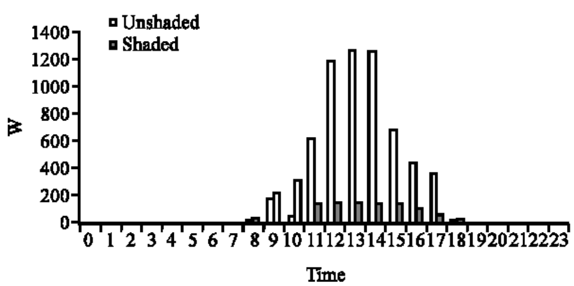

Fig. 12: Solar gains difference for courtyard with and without the shading roof

of the zones adjusted to it. After trying different heights for the shading roof (250, 500 and 1000 m) the height of 500 mm seemed more suitable for shading the courtyard area as well as letting the indoor hot air to be discharged into the sky. Figure 10 shows the temperature difference of the living area after testing different height for the shading roof. As could be seen living area will experienced lowest internal temperature when the roof has the height of 500 mm (Fig. 11).

According to thermal analysis, adding the shading roof for the courtyard will decrease the solar heat gains in this area (Fig. 12) which will accordingly cause the improvement in thermal condition of the adjacent zones.

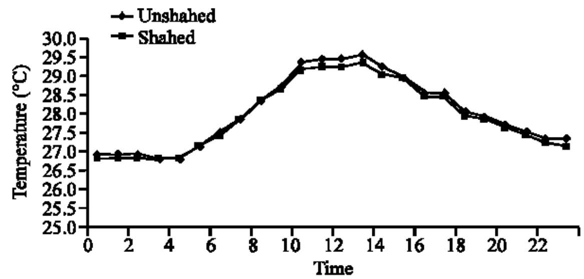

Fig. 13: Temperature difference for living area with shaded and unshaded courtyard in Jun

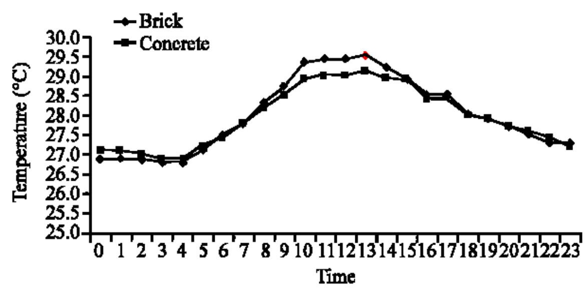

Fig. 14: Temperature difference of the living area after changing the material of the party walls with courtyard

Figure 13 displays the temperature difference of the living area for mode B and courtyard with shading roof in Jun. As could be seen added shading roof for the courtyard will change the thermal condition of the adjacent zones especially around noon and afternoon hours. The decrease in solar heat gains of the adjacent walls after including the roof for courtyard, could be the main reason.

Material: Next step is to analyze the thermal performance of the living area when the material of the walls surrounded the courtyard has been changed. Instead of common materials (brick and plaster: 110 mm brick with 10 mm plaster either side) with U-value of 2.62 w/m^2k, materials with lower U-Value (1.15 w/m^2k) were chosen (aeratedConcBlkPlaster: 10 mm aerated plus, 220 mm concrete block with 10 mm plaster inside).

Results shows changes in temperature variation of the living area, as Fig. 14 displays the temperature has decreased around noon hours which is considered as critical times, while in the morning and afternoon hours little increase in temperature is perceivable. Although the temperature still has its acceptable range (27 to 27.5°C). The reason is because of the increase in the width of the wall for second material which increased the effects of thermal mass. As this area is normally being used during the day hours it could be acceptable, while for the zones such as bedrooms which are used during night hours, lighter materials are preferable because of their short time lag which let the heat to disperse quickly to the outdoors and decrease the indoor temperature.

CONCLUSION

Including an internal courtyard in the terrace houses of tropical climate has significant effects on the thermal performance of indoor spaces specially the areas adjacent to the courtyard. The results obtained from computational analysis (Ecotect) revealed the potential thermal impacts of courtyard for passive cooling in double story terrace houses located in tropical climate. It has been explored that, since the zones adjacent to courtyard with suitable openings in two sides will be able to release the heat through natural ventilation, they will experience better thermal condition after introducing the courtyard. Whereas in the areas with openings just to the courtyard the penetrated heat through solar radiation will make the zone hotter. This extra heat tries to be released in the adjoining areas and increase their internal temperature. So considering the internal relations of the areas in courtyard housing seemed necessary. Also in order to lessen the influences of solar radiation which will penetrate in the house through the internal courtyard, suitable shading devices as well as suitable materials for its walls are suggested. More detailed studies on appropriate materials for different areas adjacent to the courtyard, in terrace houses of tropical climate seemed requisite.

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