THE EFFECT OF GLAZED FENESTRATION AREA AND NATURAL VENTILATION ON THERMAL PERFORMANCE IN RESIDENTIAL BUILDINGS IN TROPICAL REGION

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ABSTRACT

Building orientation is a significant design consideration, mainly with regard to solar radiation and wind. In predominantly hot humid regions like Malaysia which receives sunlight all year around, buildings should be oriented to minimize solar gain and maximize natural ventilation (NV). This paper describes an investigation into the effect of building orientation in view of solar radiation absorptance of exterior wall, varied area ratio of glazed window to wall and the effect of natural ventilation on the thermal performance for residential building in tropical region. The FAJAR BAKTI building (postgraduate student residential building) which is oriented in the east west directions, and a located in USM Campus, Penang. The selected case study are two rooms, the first one is facing east direction while the other faced west. The differences in in/out door air temperature and air velocity of both rooms have been measured from the field directly using the comprehensive datalogger BABUC/M, this data have been analyzed and investigated. The results shows that east windows have more obvious effect on increasing indoor air temperature than west windows, that is applicable for ventilated or unventilated rooms.

Keywords: Fenestration; Natural ventilation; Thermal performance; Orientation; Tropical region

1.0 INTRODUCTION

Architecturally, the hot and humid region is one of the hardest climates to ameliorate through design. This is due to the high humidity and daytime temperatures that result in high indoor temperatures exceeding the ASHRAE summertime comfort upper limit of 26°C for most of the year (Sabarinah Sh. Ahmed, 2008). Glazed building’s facade imposes itself as an icon for the developing cities. This large area of glazing in each facade needs protection against overheating and sun glare in tropical region, especially when it faces east or west direction.

In Malaysia for example, east and west façade expostulate to direct sun radiation every morning and evening, while north façade faces sun radiation during May, Jun Jul and Aug, and south façade faces it during Nov, Dec, Jan and Feb. Therefore building orientation, particularly in tropical region should be seriously considered according to its interaction with solar radiation as well as wind direction. (Givoni, 1994) has reported that, in hot humid regions the provision of effective cross ventilation under the local wind direction is the major factor that may affect the building’s orientation. Air movements inside a building depend not only on external wind velocity, but also largely on the architectural parameters. Architectural means for achieving this aim include
conventional design elements such as position and orientation of building, roof shape, balcony configuration, type and location of windows, partition and furniture arrangement.

2.0 CLIMATE RESPONSIVE DESIGN STRATEGIES IN HOT AND HUMID CLIMATE

Climate responsive design of buildings is important not only because of the comfort and energy saving implications for its users, but also because it helps preserve valuable resources in our planet (La Roche, P., Liggett, R., 2001). Unfortunately, new building envelope designs are developed to meet the client's requirements without much concern to the local climate and with no objective to conserve energy. This has undoubtedly disregarded the climate as a design determinant in building envelope design process. As a result, these have contributed to an overall poor thermal performance of the buildings which became more dependent on artificial means to provide comfortable thermal environment at high energy consumption.

2.1 Local Climate Condition

The monitored building is located at University Science Malaysia campus, Penang. Local latitude is 5.35 N and longitude is 100.30 E. The local climate of the location is belong to Malaysian tropical climate, uniformly high temperatures, high humidity and abundant rainfall throughout the year. It has a diurnal temperature range of minimum 23–27°C and maximum 30–34°C, with a mean annual RH value of 84%.

According to 10-Day Agromet Bulletin, issued by Malaysian Meteorological Department (MMD, 2009) for the month of March 2009 shows that, typical solar radiation falling onto Penang Island is more than 6.1 kWh/m² per day. Since at present, this energy cannot be explored efficiently, it creates discomfort and becomes a problem that needs to be extracted from the building space.

2.2 Impact of Envelopes Design on Thermal Performance

Building envelope is one of the most important components with respect to total heat gain of whole building and overall heat transfer coefficient determines heat gain through the building envelope. An analysis of the building energy consumption in Hong Kong, Singapore, Saudi Arabia for example gives a result that, the building envelope design accounts for 36%, 25%, 43% of the peak cooling load respectively (Lam and Li, 1999) (Grace Cheok, 2008) (Al-Najem, 2002).

In despite of the availability of many experimental and numerical research studies have been conducted in some tropical warm and humid climates such as China, Taiwan, Singapore, Saudi Arabia, India, Indonesia, Thailand and Malaysia to investigate the impact of building envelope in internal thermal performance or its impact energy consumption, there is only a limited amount of research literature on building envelope fenestrations through the climate responsive design requirements to achieve energy-efficient building in hot and humid climate. In this paper, the relevant literature in the above aspects will be reviewed.

2.3 Influence of Varied Orientation

Selecting the most optimal building orientation is one of the critical energy efficient design decisions that could have impact on building envelope energy performance, as it can be used to minimise the direct sun radiation into the buildings through windows, building openings as well as external opaque walls. It will be most affected considering full glazed building. (S. F. Syed Fadzil et al, 2004) studied the effect of direct sunlight penetration and daylight distribution in a building.
with 12 bays of continuous orientation located in Penang (Tropical climate). The results indicated that the best bay with the least sunlight penetration is with orientation 0° and the worst is with 240°; those with orientations 30°, 180°, 330°, 60°, 90°, 300°, 150°, 120°, 210° and 270° are the next one’s ranking them in order. In this context, the bay with the least direct sunlight penetration is considered the best as it receives the least heat gain thus reducing the cooling load and saving energy. It is also the best bay with regard to minimum glare problems. (Dirk Rilling et al, 2007), reported a study which investigated the impact of changes in orientation and insulation appliances, they showed up to 43% lower cooling load. Results have also indicated a positive impact in the consumption of electrical power. However the case studies are applied on two different designs of residential buildings located in Malacca, Malaysia. (Joseph C. Lam et al, 2003) reported a study which investigated the impact of the façade’s surfaces orientation on the intensity of the direct and indirect solar radiation. The results showed that the north has the lowest solar intensity which varies from 43.6 W/m² in October to 65.5 W/ m² in July. Solar intensity on the east and west surfaces is similar, the 6-month mean solar intensity is 86.1 and 89.6 W/ m² for the east and west surfaces, respectively. The 6-month mean intensity on the south surface is 74.5 W/ m² somewhere between the north and the east/west.

2.4 Influence of Natural Ventilation NY

Natural ventilation is the intentional flow of outdoor air through an enclosure under the influence of wind and thermal pressures through controllable openings. It can effectively control temperature particularly in hot and humid climate. Temperature control by natural ventilation is often the only means of providing cooling when mechanical air-conditioning is not available (Tony Rofail, 2006). Natural ventilation in this work defined as the increase in building thermal performance due to an increase in natural air movement as a passive cooling strategy. In a tropical climate the improvement in comfort by NV range between 9% and 41% (Kuala Lumpur in April). In a temperate climate the improvements vary between 8% and 56%. The results showed that NV has a good potential in tropical and temperate climates (M. Haase et al, 2008).

2.5 Influence of Glassed Fenestration Systems

Windows, doors, and skylights have a significant impact on the thermal performance of the building envelope. Windows can also have a strong influence on the use, productivity, and comfort of the people who occupy the building. Study reported by (Jinghua Yu, 2006) shows that heat gain through the exterior window accounts for 25-28% of the total heat gain, adding to the infiltration, it is up to 40 % (Yang and Yu 2002) in hot summer and cold winter zone. Glazed windows are becoming an important component of contemporary architecture. They allow natural light, offer a visual communication with outdoors, reduce a structural load and enhance aesthetic appearance of buildings. With many benefits that the glazed windows do offer to the occupants and the designers, they are not free of introducing problems if they are not properly selected. Many parameters in fenestration system are important when thermal performance is evaluated. However, two parameters evaluated for thermal performance for this study:

- Impact of Window to Wall Ratio (WWR)
- Impact of natural ventilation
3.0 METHODOLOGY AND THE CASE STUDY

3.1 Methodology

The methods used in this study included conducting at 10 minutes intervals monitoring of the temperature, measuring the air velocities; using data logger, i.e. BABUC/M. A series of continuous environmental data measurements were undertaken in Fajar building during the highest month of average temperature and solar radiation in Penang, i.e. (6th to 31st March). The building consists of four storeys (the topmost floor chosen as the shading is similar and no effects of outdoor shading like trees were found), and functions as a student dormitory complex. Two rooms at Fajar dormitories were used for this study, the first facing East (E1) orientation and the second West (W1) orientation (refer to Fig. 1,2 and 3) as the typical worst case orientation scenario in the tropics in terms of direct solar radiation in the morning and afternoon hours. The overall floor area for each room is 12.9 m², the building is oriented in such case that openings have mainly exposure to east and west direction, the window-to-wall ratio (WWR: net glazing area to gross exterior wall area) of both rooms is 50% and all windows include steel grades.

For analyzing the effect of glazed area, the performance of E1 and W1 in terms of air temperatures were monitored in relation to outdoor air temperatures T_o. The existing WWR of 50% were compared with 0% (ie covering up the whole glazed area with polystyrene foam boards) with no influence of natural ventilation (ie windows and doors closed).

For studying the effect of natural ventilation the same E1 and W1 rooms were used and this time all windows and doors were opened. WWR of 50% were compared to WWR of 25%. Data on selected days were taken for graphs and analysis.
3.2 Physical Specifications of the Building:

- **External walls (from inside to outside)**
  - 20mm Plaster
  - 110mm Clay brick
  - 20mm Plaster
- **Internal walls**
  - 20mm Plaster
  - 100mm Block concrete
  - 20mm Plaster
- **Roof (from inside to outside)**
  - 10mm Hanging ceiling
  - 0–2400mm Air Gap (Attic)
  - 0.6mm Aluminum Foil
  - 50mm Clay Tiles

4.0 RESULTS AND FINDINGS

4.1 Effect of Windows Orientation on Thermal Performance With Considering to WWR and NV

In considering the orientation of a building, the main issue is the orientation of the windows. The potential of the solar penetration through windows in hot climate, and its effect on the elevation of the indoor temperature, depends greatly on the orientation of the windows (Givoni, 1994). The net effect of the window system in building envelope design depends on the window orientation, window wall ratio WWR and weather conditions.
4.1.1 Unventilated Rooms with WWR = 50%

In this analysis, different designs of window system are taken into consideration in order to observe the interaction of the heat gains and/or loss and the depending thermal comfort. The result (Fig. 4) shows that east windows have more obvious effect on increasing indoor air temperature than west windows for the whole time of the day. That is applicable for ventilated or unventilated rooms. With no ventilation, the maximum, average and minimum differences in in/outdoor temperature for western rooms were $+5.6^\circ\text{C}$, $+2.4^\circ\text{C}$ and $-1.7^\circ\text{C}$ respectively, while it was $+3.9^\circ\text{C}$, $+0.63^\circ\text{C}$ and $-2.9^\circ\text{C}$ respectively, that means the average air temperature in east room is more by $1.78^\circ\text{C}$ than the recorded in west room. The peak temperature in east room was $35.17^\circ\text{C}$ occurred at 9:20am, while it was $32.20^\circ\text{C}$ in the west room at 5:30pm.

4.1.2 Ventilated Rooms with WWR = 50%

In hot and humid regions where the diurnal temperature range is small, constant daytime ventilation across the skin, either naturally or mechanically, may not provide thermal comfort without additional assistance. In many cases, daytime ventilation alone cannot keep indoor temperatures below those of the outdoors (Givoni, 1981). The results (Fig. 5) shows that with applying natural ventilation NV, the temperature in both rooms slightly decreased, but the eastern room remain hotter than eastern. the maximum, average and minimum differences in in/outdoor temperature for eastern room were $+3.5^\circ\text{C}$, $+0.66^\circ\text{C}$ and $-2^\circ\text{C}$, while it was $+2.9^\circ\text{C}$, $+0.45^\circ\text{C}$ and $-2.6^\circ\text{C}$ for the western room, that means the average time of keeping east and west room below $28.6^\circ\text{C}$ are 41.7% and 57% respectively.

Figure 4: In/out door temperature for a typical day, unventilated rooms with WWR= 50%
4.1.3 Ventilated Rooms With WWR = 25%

Change east and west area ratio of window to wall from 50 to 25%, and applying cross ventilation strategy, significant decrease in indoor air temperature in both rooms occurred, that is because of the reduction in the total solar radiation coming through window. The result (Fig. 6) shows that, the peak temperature in east and west room became closer to each other i.e. 29.82°C and 29.27°C respectively. the maximum, average and minimum differences in in/outdoor temperature for eastern rooms were +2.6°C, +1°C and -2°C, while it was +2°C +0.5°C and -3.1°C for western room, that means 80% of the time, indoor air temperature for both rooms will be below 28.6°C.

4.1.4 Opaque Wall/Unventilated Room With WWR = 0%

In this case, the windows are fully covered. At day and night time the average temperatures inside both rooms are similar, within or less than 0.5°C difference. In another hand the difference in day and night temperature for both rooms is about 2°C, however, it reached 7°C in existing case (WWR=50%, unventilated).This is due to the avoidances in solar gain through the glazed windows. The result in (Fig. 7) shows that, the maximum, average and minimum differences in in/outdoor temperature for eastern rooms were +6°C, +1.3°C and -4°C, while it was +5.7°C,+0.67°C and -5°C. This big difference in in/outside temperature occurred because of the thermal insulated envelope, and indicates that the building is able to protect from the intense heat from outside.

4.2 Effect of Natural Ventilation on Thermal Performance

(Sabarinah Sh. Ahmad, et al, 2007) reported that, the comfort band for Malaysia for all building types is between 23.6 and 28.6°C. (Zainazlan Md Zain et al, 2007) suggested that, the occurrence of thermal comfort can be achieved below 28.69°C. Fig. 4.5 shows that without air flow, there is no count of temperature below the neutral temperature while about 80% of the day time occurrence below 28.6°C with considering WWR=30%. An air flow of 0.7 m/s will give reduction in temperature from 29.5°C to 27.6°C, and rise to indoor thermal comfort, While an air flow if less than 0.2 m/s would not be as effective.
Figure 6: In/out door temperature for two typical rooms, ventilated rooms with WWR= 25%

Figure 7: In/out door temperature for two typical rooms, ventilated rooms with WWR= 0%

Figure 8: The effect of natural ventilation in reduction air temperature.
5.0 CONCLUSION

Good selection for windows orientation, optimal size of the glass and applying natural ventilation system, can reduce the negative effect of solar radiation in increasing indoor air temperature. The main findings of this paper are summarized as follows:

1. According to climate condition and field measurements, the existing scenario for the case study shows in table 5.1 that, east orientation is more sensitive to solar radiation. The east rooms are always hotter than those in west direction. And even by applying natural ventilation, changing WWR or not, the average differences in in/out door air temperature in east rooms is higher, comparing with west rooms. Thus, the percentage time of being the room temperature below the recommended level in tropical region -i.e. 28.6°C- in east room is less than the west, under all conditions. Unless with WWR=25% they are almost same.

2. More care should be taken in the primary stage of design to avoid any opening in east or west direction, unless there is need for that. In this case, intensive consideration should be taken for the following variables:
   - Using thermal insulation for the exterior walls with less U value.
   - Select a proper shading devices.
   - Select a type of glass that have small U value, to minimize solar penetration.

3. Based on the above results, it can be concluded that, in general, thermal comfort can be improved by applying natural ventilation and WWR=25%. Thus, the needs for applying mechanical ventilation is necessary to improve occupants thermal comfort.

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