The potential of shading devices for temperature reduction in high-rise residential buildings in the tropics

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Abstract

The present study focuses on the effect of shading devices on the indoor temperature of high-rise residential buildings in the hot–humid climate of Malaysia. Several methods can be employed to improve indoor thermal environment, including using a reflective glazing system, using light colors for external surfaces, and using the appropriate thermal properties of external walls and roofs. However, before using any of these methods, it is important to have an optimum shading device to reduce the solar radiation absorption that leads to an overheated indoor environment and an increase in cooling energy loads. Therefore, the main objective of the current paper is to find the extent of a building’s solar heat gain and, consequently, the indoor air temperature that is influenced by the external shading devices. A computerized simulation tool (IES<VE>) is used to carry out the investigation, taking Penang as the empirical background of the hot–humid climate. The results indicate that egg-crate shading has a significant impact on decreasing discomfort hours compared with other shading types.

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1. Introduction

In Malaysia, building surfaces exposed to the sun such as windows, walls, and roofs can admit heat from solar radiation, leading to an increase in the amount of energy needed for cooling purposes. To avoid the inflow of heat, whether direct or indirect, the surfaces on which the sun’s rays fall must be protected. Emphasis must be given to shading devices because glazed windows are the main components which allow the penetration of incoming heat and consequently increases the risk of overheating [1].
Therefore, the main objective of the present study is to determine the optimum external shading devices to reduce incoming heat and consequently reduce the risk of overheating which substantially contributes to energy consumption.

The design of shading devices can be quite complex because its thermal evaluation demands extensive understanding of the mechanics of the sun’s position and sun path diagrams. In tropical climates, however, building designers should keep solar radiation away from the transparent elements of the building’s envelope. Figure 1 shows that all facades receive solar radiation from different angles all year round and that each orientation must be designed separately.

| Nomenclature               | Description                                      |
|---------------------------|--------------------------------------------------|
| IES<VE>                   | Integrated Environmental Solutions Virtual Environment software |
| MMD                       | Malaysian Meteorological Department              |
| NS                        | No Shading case                                  |
| BC                        | Base Case                                        |
| VS                        | Vertical Shading case                            |
| HS                        | Horizontal Shading case                          |
| EC                        | Egg-crate Shading case                           |
| NV                        | Natural Ventilation                              |

2. Previous Studies

Previous studies investigated the effect of shading devices and their impact on daylight quantity and distribution [2–4], energy use [5–7], and human comfort and perception [1, 8]. However, there is a lack of information on their effect on several types of indoor air temperature, especially when considering natural ventilation conditions during daytime and nighttime separately. Corrado reported that the appropriate external shading devices can control the amount of solar radiation admitted into a room, which could largely reduce cooling loads and improve indoor thermal comfort [9]. Each face of a building requires a different shading treatment because sunlight strikes each side from different angles. Exterior systems are typically known to be more effective than interior systems in blocking solar heat gain.

In 2007, Wong and Li [10] studied the effectiveness of window shading devices on cooling energy consumption for east and west windows in Singapore. The study shows that 2.62%–3.24% of the energy cooling load can be saved by applying a simple 30 cm-deep horizontal shading device to the window. When the depth of the window shading device is 60 cm, 5.85%–7.06% of the cooling load could be saved. When the depth of the shading reaches 90 cm, the cooling load of the room is reduced by 8.27%–10.13%. However, Wong and Li’s study considered only east and west orientations, and did not take into account other parameters such as the width of the openings, height of the openings, horizontal shadow angle, and vertical shadow angle. The previous study by Yu on a high-rise residential building in Taiwan [11] indicated that envelope shading is the best strategy to decrease cooling energy consumption, which achieved savings of 11.3% on electric consumption.

In Singapore, Wong Nyuk [12] studied the effects of shading devices on temperature. The study shows that horizontal shading devices reduce indoor temperature by 0.61 to 0.88 °C. The vertical shading device reduces the temperature by 0.98 °C in another study by Yang and Hwang [13], who investigated the influences of external shading on energy savings in a Taiwanese building. The study by Yang and Hwang
showed that direct air conditioning power consumption readings indicate an average savings of 25% if external shading is properly installed.

On the other hand, Tzempelikos and other researchers reported that shading devices can lead to big energy savings when they are applied in combination with the appropriate glass type, enabling them to modify the thermal effect of windows to a great extent [14–15].

3. LOCAL CLIMATE CONDITION OF PENANG, MALAYSIA

Penang is an island located north of Peninsular Malaysia at its west coast. Its local latitude is 5.35° N and its longitude is 100.30° E. The local climate is hot–humid tropical characterized by uniformly high temperatures, high humidity, and abundant rainfall throughout the year. According to the Malaysian Meteorological Department [16], Malaysia has a diurnal temperature range at a minimum of 23–27 °C and a maximum of 30–34 °C. Thus, there is no particular hot or cold season. Annual rainfall is evenly distributed throughout the year, and relative humidity ranges from 74% to 86%, although September to November may be considered the wettest months. Figure 2 shows the maximum, minimum, and average dry bulb temperatures and average relative humidity for the Penang area, where the present case study is located.

According to the 10-Day Agromet Bulletin, MMD [16] showed that some places in Penang have the highest daily solar radiation of more than 6.1 kWh/m2 per day. At present, this energy cannot be explored efficiently, thus creating discomfort and becoming a heat gain problem that needs to be removed from the building space

4. METHODOLOGY

Environmental simulation method is the norm in any research involving building physics [11, 17–19]. For the purpose of investigating the effects of external shading devices on indoor air temperature, the present study used computer modeling techniques that have been widely promoted as an effective and reliable tool to optimize the design process for buildings. However, to carry out successful computerized building simulations, accurate and reasonable input data for the buildings and climate are essential [20].
To enhance accuracy of the simulation, several studies suggested that simulated results must be compared with measured data and several input parameters affecting the simulation discrepancies were tuned [21–22]. This procedure is usually known as the calibration of the simulation model.

To calibrate the building simulation, IES<VE> simulation results were compared with fieldwork data. The methodology was pursued in three phases. The first phase was the data collection from the field. The second phase was the verification and validation process, which included a model of the external shading device similar to the real one used in a residential unit. The results of the field measurement were then compared with those of the simulations. The last stage involved simulating the five proposed models (Figure 3). The width of the various investigated shading devices was fixed at 600 mm, as recommended by many studies conducted in the tropics, taking into account day lighting and aesthetic considerations, as well as the view angle requirements from the internal spaces [23].

The effect of shading devices on indoor air temperature was investigated annually in terms of the following:

- The min, max, and mean annual air temperatures.
- The number of hours that indoor air temperature recorded annually (365 * 24 hrs = 8760 hrs) was predicted to be below the upper limit of comfortable temperature in Malaysia, i.e., 28.6 °C

4.1. The base case model

The View condominium (Figure 4) is located at the Gelugor District, Penang, Malaysia. The residential scheme consists of two towers (A and B), each tower 29 stories high with three units on each floor. The two towers are connected by a sky bridge at the 14th floor, and have a total of 164 units each. The floor area of each unit is approximately 184 m². The View’s residential design was selected for this study because it exemplifies the trend of modern residential design, which has a façade mostly made of...
glass, in contrast to the energy-efficient building designs in the tropics. To investigate the effects of external shading devices on indoor air temperature, a southwest-oriented room (R1) located in the ninth floor of the tower (A) is selected, as shown in Figure 5.

4.2. Fieldwork

Environmental field data were collected at 10-minute intervals by monitoring the indoor/outdoor temperature, MRT, and air velocity using a data logger, i.e., BABUC/M. A series of continuous environmental data measurements was undertaken in Room R1 for the period between April 7 and 29, 2009. The collected data were used for calibration purposes to ensure the validity and the reliability of the developed simulation model. The data collected were in two different conditions: unventilated (with windows closed) and naturally ventilated (with windows open).

4.3. Thermal modeling tool

Many computational applications have been developed to support the energy and environmental performance of buildings [24]. The thermal performance of the building was investigated using the Integrated Environmental Solutions Virtual Environment software (IES-VEVersion 6.1.0.1), which is a well-established tool for analyzing the dynamic responses of a building based on the hourly input of weather data [25].

Virtual Environment (IES) consists of different modules, and each module performs specific calculations such as “Apachesim” for thermal simulation, “Radiance” for lighting simulation, “Mechanical” for mechanical simulation, and “SunCast” for solar shading analysis. Only three modules of the package were used to carry out the investigation, namely, ModelIT, SunCast, and Apache.

The full building model was constructed as shown in Figure 6. However, to reduce modeling complexity and closely exemplify the base case in high-rise building, with floors above and below, two complete units were modeled for both levels (upper and lower the base case unit).
5. RESULTS AND DISCUSSION

5.1. Calibrating the base case model

The simulation output was compared with the fieldwork results for the indoor/outdoor temperature pattern for two consecutive days in the selected room (R1) under ventilated and unventilated conditions. Statistical analysis for the present study was carried out between the field measurement readings and the simulation results IES<VE> of the indoor/outdoor air temperature for the room in different ventilation conditions and dates using SPSS v.16. Results showed that the Pearson correlation test between the simulated indoor air temperature (Ti) in the unventilated and ventilated room R1 with the field readings were 93% and 91%, respectively. Thus, the results proved the validity and reliability of IES<VE> for use...
in further simulations for building envelope modifications.

5.2. Annual thermal performance of varied shading devices

Further simulations to investigate the effect of shading devices, as shown in Figure 3, were carried out under ventilated and unventilated conditions. Simulation output are shown in Figures 7 and 8, which rank the annual effect of varied shading devices on indoor temperature behavior from worst to best. Alternatively, Tables 1 and 2 show the improvement in indoor conditions based on the number of comfort hours in the varied types of shading used in unventilated and ventilated rooms, respectively. Overall, the results showed that in unventilated rooms, the egg crate has a significant impact on reducing indoor air temperature. The results in Figures 7 and 8 show that a maximum reduction of 5.1 and 1.4 °C in indoor temperature could be achieved by adding egg crate shading devices to un-shaded windows in unventilated and ventilated rooms, respectively. However, the average annual reductions of temperature under the same conditions were 1.3 and 0.4 °C in unventilated and ventilated rooms, respectively.

The effect of shading devices may vary during daytime and nighttime. Tables 1 and 2 separate the two distinct periods for comparison, and show the number of comfort hours with the indoor air temperature and the percentages to the total annual hours in unventilated and ventilated rooms, respectively. In an unventilated room, adding egg-crate shading could result in an increase in the number of hours with temperatures less than 28.6 °C from 1821 to 3947 hours, respectively, with an improvement of 117%. In this case, the annual percentage of the full day that To and Ti (in NS and EC cases) were found to be less than Tc were 68%, 20.8%, and 45%, respectively. In the absence of NV, there was not much difference in the percentage of comfort hours achieved by vertical and horizontal shading devices in the annual full day, daytime, or nighttime period. However, the maximum improvement in indoor conditions was achieved using the egg-crate shading type.

![Fig. 7. Annual min, max, and mean temperatures with varied shading devices in an unventilated room](image7)

![Fig. 8. Annual min, max, and mean temperatures with varied shading devices in a ventilated room](image8)
Table 1. Annual effect of shading system on improving indoor temperature in an unventilated room

| Code | Shading System | Number of Hours < 28.6 °C | % hours of Tc/year |
|------|----------------|---------------------------|--------------------|
|      |                | Full Day                  | Daytime            | Nighttime           |
|      |                |                           |                    |                    |
| NS   | No Shading     | 1821                      | 683                | 1138               | 20.8% | 15.6% | 26.0% |
| BC   | Base Case      | 3135                      | 1098               | 2037               | 35.8% | 25.1% | 46.5% |
| VS   | Ver. Shading   | 3171                      | 1135               | 2036               | 36.2% | 25.9% | 46.5% |
| HS   | Hrz. Shading   | 3319                      | 1184               | 2135               | 37.9% | 27.0% | 48.7% |
| EC   | Egg Crate      | 3947                      | 1408               | 2539               | 45.1% | 32.1% | 58.0% |
| T_o  |                | 5969                      | 2366               | 3603               | 68.1% | 54.0% | 82.3% |

Table 2. Annual effect of shading system on improving indoor temperature in a ventilated room

| Code | Shading System | Number of Hours < 28.6 °C (Tc) | % hours of Tc/year |
|------|----------------|---------------------------------|--------------------|
|      |                | Full Day                        | Daytime            | Nighttime           |
|      |                |                                 |                    |                    |
| NS   | No Shading     | 5295                           | 1674               | 3621               | 60.4% | 38.2% | 82.7% |
| BC   | Base Case      | 5619                           | 1850               | 3769               | 64.1% | 42.2% | 86.1% |
| VS   | Ver. Shading   | 5655                           | 1877               | 3778               | 64.6% | 42.9% | 86.3% |
| HS   | Hrz. Shading   | 5848                           | 1995               | 3853               | 66.8% | 45.5% | 88.0% |
| EC   | Egg Crate      | 5868                           | 1949               | 3919               | 67.0% | 44.5% | 89.5% |
| T_o  |                | 5969                           | 2366               | 3603               | 68.1% | 54.0% | 82.3% |

On the other hand, in ventilated rooms, little improvement on comfort duration was recorded compared with unventilated rooms. In this case, the results showed no difference in the effect of both egg-crate and horizontal devices on improving the annual number of comfort hours, which were about 66.8% and 67%, respectively. The figures also show the thermal performance of varied shading types during daytime and nighttime separately. The results indicated that the egg crate has a significant impact on decreasing the annual discomfort hours during daytime.

6. Conclusion

External shading devices such as overhangs, louvers, and egg crates should be encouraged as architectural elements to protect building envelopes and occupants from solar radiation in Penang, which has the highest radiation level in Malaysia. Shading devices in both ventilated and unventilated rooms have a significant impact on improving internal thermal conditions. However, egg-crate devices are the best in reducing indoor air temperature and decreasing the number of discomfort hours because of their
configuration (i.e., combination of overhangs and fins devices), which avoids solar radiation from varied sun angles. Therefore, comparing the rooms EC with the rooms BC, the improvement in the number of the comfortable hours (i.e., less than 28.6 °C) was found to be 26% and 4.7% in unventilated and ventilated conditions, respectively. Consequently, egg crate has a more positive impact in slowing down the daily solar heat gain in a tropical climate.

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