External shading devices for energy efficient building

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Abstract. External shading devices on a building façade is an important passive design strategy as they reduce solar radiation. Although studies have proven the benefits of external shading devices, many are designed solely for aesthetic purposes without fully considering its high potential to reduce solar radiation and glare. Furthermore, explorations into shading devices by the design team are mostly left too late in the design development phases. Hence, the paper looks into the effectiveness of external shading devices on a building towards more energy efficient building. The study aims to analyse the effects of various configurations of external shading devices towards the energy consumption of a case study building based on computer simulations. This study uses Building Information Modelling (BIM) through Autodesk Revit software as simulation tool. The constant variables for the simulation are the orientation of the building, types of glazing used by the building and the internal loads of the building. Whereas, the manipulated variable is the types of shading device used. The data were sorted according to the categories and translated into a chart. Analysis of the findings indicate that shading devices with different configurations show significant results in the energy consumption and the best configuration is the egg-crate shading devices. The study recommends that the consideration for shading device as a passive design strategy needs to be developed at the early stage of the building design.

1. Introduction

Energy efficiency is now recognised as one of the fastest and suitable approaches to reduce any energy related emissions associated with, air pollution, global warming and climate change [1]. Buildings are expected to achieve energy efficient status by most nations, which could be achieved through active or passive design strategies. The biggest percentage of energy consumption for any building in hot-humid climate is for air conditioning followed by artificial lighting [2]. Besides enhancing the aesthetic appearance to the buildings, shading devices on the building facades help to minimise energy consumption in the building. Several researchers have conducted studies on improvements and impact of shading devices on the building energy consumption where several types of passive design strategies can be implemented.

Numerous strategies can be applied to minimise energy consumption in a building such as better OTTV values for walls and external shading devices. A study in Hong Kong reported that an energy efficient envelope design could save as much as 35% of total the cooling demands [3]. Another study in Malaysia confirmed that high-rise office buildings use 46% of total energy use for cooling [4]. External shading devices can either be made of building materials or living plants and could reduce the indoor cooling load by 30% [5]. This study also confirmed that shading devices are more effective to reduce cooling energy load compared with the use of high performance glazing [5]. Even for plant based external shading, a study in Penang with vertical green system showed a façade surface temperature reduction of up to 6.4°C [6].

Shading devices, which is a component of a building envelope, performs a crucial role to give positive influences towards energy efficiency in buildings [7, 8]. Generally, shading devices are used to protect inner spaces from direct solar gain through openings, windows and large glazed surfaces.
Different climatic region needs different configuration of shading devices. Buildings in hot-humid climate need to reduce solar radiation and sunlight penetration into the building. On the other hand, for cold climate, it is critical to let the sunlight enter into the building or the envelope material absorb the solar radiation to keep the warmth within the building especially in winter.

2. Problem Statement
Shading of buildings as a means to reduce energy consumption needs careful consideration. Numerous studies explored the use of shading devices, for example between 10% and 11.3% of energy savings can be expected from the benefit of external shading devices in hot and humid climates [9, 10]. However, most shading devices are designed for aesthetic purposes rather than their energy savings potentials. Designers mostly ignore findings on the importance of shading devices as they leave the analysis too late in the design development phases. Shading devices need careful consideration at the early design stage especially for facades with high window to wall ratio [11, 12].

This paper aims to study the effectiveness of external shading devices for more energy efficient building in the hot-humid climate of Malaysia. This paper analyses the effects of various configurations of external shading devices towards the energy consumption of a school building based BIM simulations. The significance of this research is to understand through how the various configurations of external shading devices can contribute to lessen cooling energy consumption.

3. Methodology
This paper employs the quantitative approach for data collection through Autodesk Revit Building Information Modelling (BIM) simulations. Published articles on studies into shading devices and energy savings potentials have explored other simulation tools besides Revit [13, 14, 15, 16] with encouraging results. Simulations were conducted to gather accurate values of the energy consumption of a case study building based on various configurations of external shading devices. Through the simulations outputs, the readings collected through the simulation are reliable primary data collection. The detailed information of the methodology is discussed in this section.

3.1. Building Information Modelling (BIM) Simulation through Revit
To determine the effectiveness of the external shading devices, a strategy was introduced based on Building Information Modelling (BIM) simulations using the validated Revit software. BIM is a smart 3D modelling process that provides an integrated and comprehensive architectural, engineering, and construction (AEC) tools for more proficient planning, design, construction, and operation management of buildings and infrastructure for architects, engineers and construction managers [17]. This technology enhances decision-making and performance across the building and infrastructure lifecycle.

The case study selected for the simulation is a 3-storey school building located in Shah Alam, Malaysia. Table 1 shows the total floor areas of air-conditioned and non-air-conditioned spaces. The ground floor houses several classrooms, conference rooms, cafeteria and other mechanical and technical rooms. The first floor has several classrooms, drafting room, library, computer labs, and administration office while the second-floor houses classrooms, media room and administration office (Figure 1-3).

For this simulation, seven shading device models are considered as variants, which include the basic forms of shading devices that are typically used in buildings. The behaviours of the shading provided by these models demonstrate the influence of each configuration of shading device on the cooling loads of the building, which would lead to the understanding of the devices efficiency.
Table 1. Total air-conditioned and non-air-conditioned floor areas.

| Floor level   | Total A/C floor area (m²) | Total non A/C floor area (m²) |
|---------------|----------------------------|------------------------------|
| Ground floor  | 1386.08                    | 130.02                       |
| First floor   | 1320.35                    | 334.84                       |
| Second floor  | 1462.22                    | 203.97                       |
| Total         | 4168.65                    | 668.83                       |

As shown in Table 2, the options of external shading devices are:

i. No shading device
ii. Horizontal single panel shading device
iii. Horizontal double panel shading device
iv. Horizontal inclined double panel shading device
v. Horizontal louvers shading device
vi. Vertical fins shading device
vii. Vertical slanted fins shading device
viii. Egg-crate shading device

The depth of the size and the material of these shading devices were fixed for the simulation as different types of material and sizes of the shading could cause inconsistencies in the result.

Table 2. Eight types of external shading devices used in the simulations.
In this simulation, several variables were selected to ensure the most effective result. The following variables remain constant to make sure that the results are accurate and reliable on all categories:

i. Internal loads of the building
ii. Orientation of the building
iii. Type of glazing

The dependent variables are the types of shading devices. The efficiency of the external shading devices was determined according to their capability to reduce the cooling load of the building in comparison with the base case condition without any shading on the facade. The less energy needed to reduce the cooling load indicates the more efficient external shading device.

3.2. Simulation Process

The simulation process involves the application of several steps to ensure that the process is clearly well thought and reliable results can be achieved. The details of the process for the first variable, which is the base case (walls without any shading devices) then followed by other types of shading devices, are as follows:

Step 1: Model/draw of the building, which includes the floor plans, elevation and section in scale of 1:500. The total floor area for air-conditioned space is 4168.64 m² and the total floor area for non-air-conditioned space is 668.83 m².

Step 2: Choose the orientation, location, date and weather data. The orientation of the building is as shown in Figures 1-3 and the building is located in Shah Alam, Malaysia and the month for the simulation is March.

Step 3: Choose the building materials from the library or add materials. These materials must be constant for all simulation since different types of material might affect the results.

Step 4: Run the simulation for energy efficiency based on façade without any shading device (Table 2 option 1) as base case study. Record the results.

Step 5: Apply the second type of shading device (Table 2 option 2) onto the building and record the results.

Step 6: Repeat step 5 with applying different types of shading devices (Table 2 options 3 –8) onto the building and record the results.

Step 7: Repeat steps 2 – 6 with different month, namely September.

Step 8: Tabulate the results and translate them into a bar chart. Discuss and analyse the results.

| Table 3. Parameters and conditions used in the simulation. |
|----------------------------------------------------------|
| Month of simulation                                      | March and September |
| Orientation                                              | North-South         |
| Total floor area                                          | 4837.48 m²          |
| Storey                                                   | Three storeys       |
| Shading configurations                                   | Eight types of shading configuration |
| Simulation for                                            | Monthly energy consumption for cooling load |
| Location                                                 | Shah Alam, Selangor |
4. Results

The results from the simulation through Revit software are collected and interpreted into a table and bar charts for ease of reference and comparisons. The results are then analysed to get the findings and later concluded. Some recommendations are introduced based on the findings at the end of the report. Table 4 shows all the results for simulations on the types of shading devices applied on the wall facades.

Table 4. Electricity consumption for cooling system for the school building in March and September 2017

| Types of shading devices        | Electricity used for cooling (kWh) in March | Electricity used for cooling (kWh) in Sept | % of reduction in Sept from March |
|---------------------------------|-------------------------------------------|-------------------------------------------|----------------------------------|
| None (base case)                | 45,337                                    | 42,898                                    | 5.38                             |
| Horizontal single panel         | 43,882                                    | 41,392                                    | 8.70                             |
| Horizontal double panel         | 33,433                                    | 31,491                                    | 30.54                            |
| Horizontal inclined double panel| 32,204                                    | 29,542                                    | 34.84                            |
| Horizontal louvers              | 40,725                                    | 38,399                                    | 15.30                            |
| Vertical fins                   | 41,808                                    | 39,259                                    | 13.41                            |
| Vertical slanted fins           | 40,000                                    | 37,476                                    | 17.34                            |
| Egg-crate                       | 25,475                                    | 22,834                                    | 49.63                            |

Table 4 highlights the comparison of cooling energy consumption for the school in March and September. Table 4 shows the most effective shading device for March is the egg-crate shading device as it reduces the energy consumption for cooling from 45,337.67 kWh to 25,475.75 kWh. In March, the total energy saved by installation of egg-crate shading devices is 19,861.92 kWh. The second most efficient shading device for March is the horizontal inclined double panel, while the least efficient shading device is horizontal single panel, which only save about 1,455.09 kWh of electricity.

Table 4 also indicates the cooling energy used for the school in September where the egg-crate shading device is still the most effective shading device with a 49.63% reduction in cooling energy consumption from the March base case of no shading (Table 4). The least effective is the horizontal single-panel shading device with only an 8.7% reduction in cooling energy consumption from the March base case of no shading installed.

Generally, from Figure 4 we can see a similar pattern of energy consumption for March and September, although all devices perform incrementally better in September. From both months of simulations, the most effective shading device is the egg-crate shading device since it consumes the lowest energy for cooling system for the school.
The results of this study are in agreement with published work on shading devices. A simulation study in Milan during summer showed a 20% reduction in energy consumption [13] when shading devices were installed on the building. A simulation study in South Korea on external shading devices also revealed that the experimental shading device with angled slats gave the most efficient performance and offers better views from indoors [14]. The effects of louvered shading devices on building energy consumption were studied across Mexico, Cairo, Lisbon, Madrid and London [15] using TRYNSYS and EES simulation tools. The results showed that the external louvered shading devices provided comfortable indoor conditions and led to significant energy savings compared with a building without shading devices. However, the significance of this study is that the exploration into egg crate shading devices proved to be more effective than other types of shading devices studied earlier.

5. Conclusion
In conclusion, this paper has achieved its objective which is to analyse the effects of various configurations of external shading devices towards the energy consumption of the building based on computer simulations. The BIM simulation clearly shows that the egg-crate shading device is the best solution for hot-humid climate area where it combines both horizontal and vertical shading devices. For hot-humid climate region, it is crucial to keep the building shaded from sunlight to minimise heat penetration into the building. All the tested shading devices give impact on the energy consumption of the building according to the types of shading device installed onto the building facades. This study can be further explored by varying the orientations and the building form, the size or depth of the shading devices as well as the materials of the shading devices as different types of materials have different thermal insulation. As a recommendation, it is important to take into consideration the design criteria of each shading devices prior to its application on the façade of the building. External shading devices will act as a passive design strategy for the building thus, planning for this at the early phase of the design is very important.

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