CHEMICAL ENGINEERING TRANSACTIONS

VOL. 106, 2023

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Peck Loo Kiew, Hon Huin Chin
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ISBN 979-12-81206-05-2; **ISSN** 2283-9216

DOI: 10.3303/CET23106051

The Exploration of Energy Efficient Material for Shading Devices in Tropical Climates

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In recent years, extreme weather events lead to reducing the supply of renewable energy sources, which contributes to the global energy crisis. Due to the long hours and high intensity of solar radiation during the day, buildings require a large amount of energy to lower the indoor air temperature in Malaysia. Shading devices are an important strategy for reducing building cooling loads. The form and materials of shading devices are two crucial factors that affect their effectiveness. This study aims to explore the potential of construction materials used for shading devices in improving the energy efficiency of these devices through a case study conducted in a northwest-facing room located on the campus of Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia. To explore energy-efficient materials for shading devices, the building can be modelled using EnergyPlus building simulation software and OpenStudio software. By employing these tools, the indoor air temperature can be calculated for different materials of shading devices during the spring equinox, summer solstice, autumnal equinox, and winter solstice. The indoor air temperature can be reduced by up to 2.8 °C when using concrete shading devices compared with no shading devices. The results indicate that implementing shading devices in tropical regions can significantly reduce indoor air temperatures and improve energy efficiency. However, among the three commonly used materials for shading devices in Malaysia, their impact on enhancing energy efficiency is minimal, with wood resulting in the lowest indoor air temperatures.

1. Introduction

Both the energy crisis and global warming have been prominent challenges faced by developed and developing countries since the 1970s. The construction industry accounts for over 40% of global energy consumption and contributes to a significant amount of greenhouse gas emissions (Lin et al., 2021). Hence, reducing energy consumption in the building sector becomes crucial. An essential aspect of this effort is improving energy efficiency, which plays a significant role in reducing greenhouse gas emissions (Rong and Lahdelma, 2016). Therefore, achieving energy savings by enhancing the energy efficiency of buildings remains a top priority worldwide (Chel and Kaushik, 2018). Thus, a fundamental question for the sustainable development of the building industry is how to improve energy efficiency.

Shading devices are widely recognized as effective passive strategies in buildings, as they can enhance thermal comfort indoors and reduce energy consumption (Alwetaishi et al., 2021). There have been numerous previous studies on shading devices. Research has found that shading device systems in summer can reduce the heat gain entering the interior by 38.7% (Evangelisti et al., 2020). The impact of shading devices is influenced by several factors, such as the sun's path, the direction of the building and the proper use of shading devices (Rana et al., 2022). A study introduces the use of horizontal sun shading devices and reveals that the distance and tilt angle of shading devices are significant for controlling solar radiation in Hong Kong (Liu et al., 2019). Research conducted in Cyprus has revealed that the implementation of overhang shading devices during the hot summer months can lead to a remarkable 50% reduction in energy demand, while simultaneously enhancing thermal comfort by 20% (Ogbeba and Hoskara, 2019). In hot regions, the utilization of overhang shading devices is widespread due to their effectiveness in significantly reducing energy consumption (Kirimtat et al., 2019). The above studies have focused on exploring the impact of the type of shading device on the effects of shading devices without considering the energy-saving potential of the materials used for shading devices. There's a

Paper Received: 11 June 2023; Revised: 07 August 2023; Accepted: 19 August 2023
Please cite this article as: Peng J., Aziz T.I.S.T., Leng P.C., 2023, The Exploration of Energy Efficient Material for Shading Devices in Tropical Climates, Chemical Engineering Transactions, 106, 301-306 DOI:10.3303/CET23106051

study has found that the application of exterior shading devices can dramatically reduce the cooling load on buildings in hot climates. In general, exterior shading devices are more energy efficient compared to interior shading devices. However, if appropriate materials are used for internal shading, the reduction in cooling load achieved by internal shading can be comparable to that of external shading (Ye et al., 2016). This example effectively demonstrates the potential of materials used for shading devices to improve energy efficiency. Many researchers use simulation tools for energy efficiency studies, and EnergyPlus is a widely used simulation tool in the field (Kirimtat et al., 2016).

EnergyPlus is widely used for building energy consumption prediction to explore factors that influence energy-efficient buildings. A study developed a building model using a combined simulation of EnergyPlus and CONTAM and evaluated the impact of strategies based on this model on indoor pollutant concentrations and energy usage in the Trondheim Office Building in Norway (Justo Alonso et al., 2022). A study investigates the impact of Vertical Greenery Systems (VGS) on building energy efficiency by utilizing EnergyPlus (Dahanayake and Chow, 2017). A study has benchmarked the energy efficiency of 400 housing blocks using the EnergyPlus simulation tool (Shabunko et al., 2018).

In tropical regions, buildings often experience overheating due to high temperatures, humidity, and intense solar radiation. Air conditioning is commonly employed as a conventional mechanical method to regulate the thermal conditions inside buildings. In tropical regions, the largest energy consumption in any building is typically attributed to air conditioning (Shahdan et al., 2018). Therefore, reducing indoor temperatures is crucial for improving energy efficiency in tropical region buildings. This study explores the potential of materials to improve the energy efficiency of shading devices by comparing their effectiveness in reducing indoor temperatures. Simulation modelling is an advanced and straightforward method to accomplish the task of finding suitable shading elements to improve energy efficiency.

A great deal of previous research has focused on exploring the effect of shading device type on the energy efficiency of shading devices. Without designing new types of shading devices, it is no longer meaningful to continue to study the impact of shading device types on improving the performance of shading devices. In this context, this study provides a new way of thinking to further improve the energy-saving effect of shading devices by comparing the energy-saving potential of three widely used materials for shading devices. The objective of this study is twofold, first to fill this research gap by exploring the potential of materials used for shading devices to enhance the performance of shading devices, second to explore energy-efficient materials that can be used for shading devices in the tropical regions by comparing indoor air temperatures while using several commonly used materials for shading devices. The results will also provide some insights for future research on enhancing the effectiveness of shading devices.

2. Methodology

In this study, different materials were used for shading devices to examine their impact on indoor and outdoor temperatures, with the aim of exploring energy-efficient materials for shading devices. The building is located within the Universiti Teknologi Malaysia (UTM) campus in Johor Bahru, Malaysia which is described in detail in the subsequent section. Summer solstice, winter solstice and autumn equinox were taken into account when studying the effect of the sun's position on the shadows of buildings (Rana et al., 2022). Considering the impact of the sun’s path on the duration of sunshine and the rainy and dry seasons in Malaysia, in this study, the indoor air temperatures of shading devices using different materials are simulated for four particular days: the spring equinox, the summer solstice, the autumn equinox and the winter solstice.

2.1 Research flow

In the study, EnergyPlus simulation software was utilized in conjunction with SketchUp and OpenStudio software. SketchUp was used for drawing and creating the geometric shapes of the model, while OpenStudio was employed to modify model properties such as construction and materials. And, EnergyPlus is used to calculate indoor and outdoor temperatures to evaluate the energy-saving potential of each material. As shown in Figure 1, the geometry of the model was drawn and created in SketchUp based on the geometric data of the selected building, and after finishing the drawing of the model, the structural and material data of the building were set up in OpenStudio by entering the model's location information and weather data. Secondly, various materials used for shading devices such as wood, concrete and aluminium were changed in OpenStudio and the model with different materials was imported into EnergyPlus to simulate the indoor and outdoor air temperatures. Finally, the outdoor air temperature and indoor air temperature of the test area were compared and analysed when different materials were used to evaluate the energy-saving potential of the different materials.

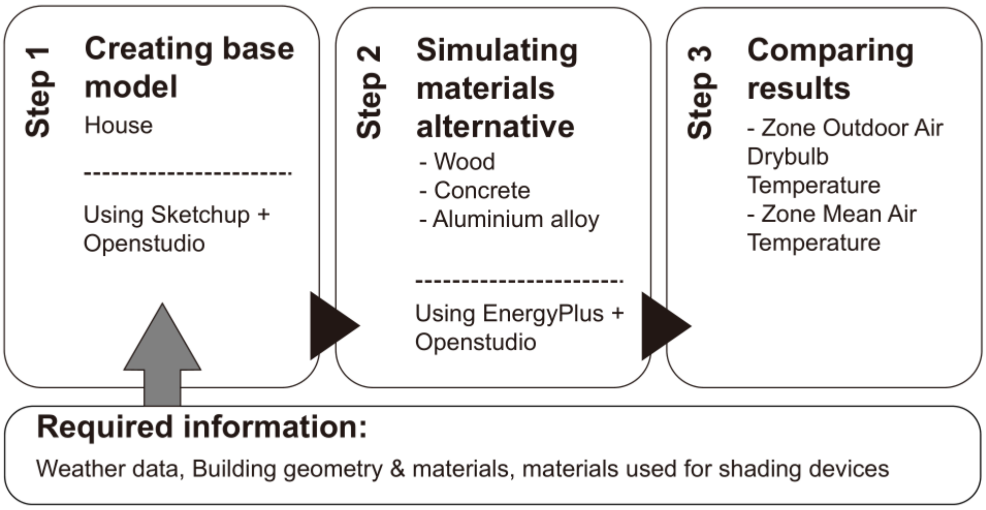

Figure 1: Research flowchart

2.2 Case study

The building situated on Universiti Teknologi Malaysia (UTM) campus was simulated using the EnergyPlus-OpenStudio plugin. The test room is situated on the fourth floor of a four-story office building within the campus of Universiti Teknologi Malaysia in Johor Bahru, Malaysia. The simplified building model used for this simulation is shown in Figure 2. Weather data for Johor Bahru is currently unavailable in the selected software. In this simulation project, the weather file utilized is sourced from Singapore, as it is the closest available location in the selected software to Johor Bahru. The choice is based on the similarity in climate between these two areas. The selected office has two windows. There is a fixed window facing the corridor, and there is an operable window facing the northwest direction, at an angle of 135°.

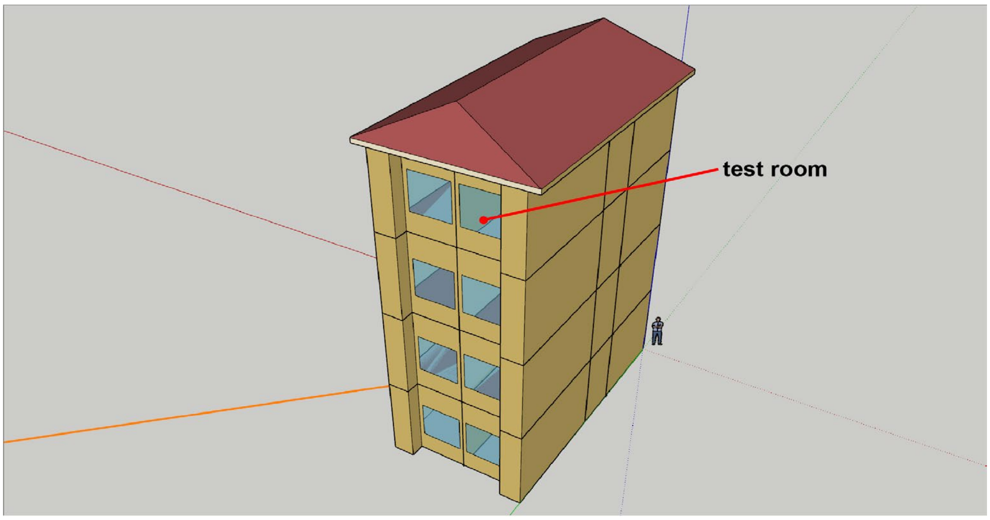

Figure 2: A three-dimensional SketchUp model of the building under study

In general, the four-story office building is constructed with reinforced concrete beams and columns. The office ceiling features mineral fibre ceiling tiles, and the ceiling height measures 3.75 m. The operable window in the office has dimensions of 1.70 m × 1.70 m, while the fixed window facing the corridor measures 1.20 m × 1.20 m. Both windows consist of single-pane transparent glass with aluminium alloy frames. Additionally, the door is a solid wood door with dimensions of 1.00 m × 2.10 m. The construction of each component and the thermal properties of the materials used in each construction layer are shown in Table 1, while the remaining values are kept at their default settings.

Table 1: Materials and their thermal properties in the case study

Element	Material	Thickness (mm)	Thermal conductivity (W/m·K)	Density (kg/m³)	Specific heat (J/kg·K)
Wall	gypsum plaster	12	0.42	1,200	837
	brick	75	0.721	1,700	800
	gypsum plaster	12	0.42	1,200	837
Floor	reinforce concrete	100	2.6	2,500	750
	mineral fibre tiles	16	0.052	280	840
Roof	gypsum plasterboard	10	0.16	950	840
	fibreglass insulation	50	0.05	36	840
	clay roof tile	15	0.84	1,900	800
Ceiling	mineral fibre tiles	16	0.052	280	840
	reinforce concrete	100	2.6	2,500	750
	fibreglass insulation	25	0.05	36	840
Door	hardwood	25	0.158	721	1,255
Windows	single glass in an aluminium frame	3	0.9	-	-

2.3 Shading device model and simulation parameters

To explore energy-efficient materials for shading devices, this study selected several commonly used materials for shading devices in Malaysia, namely wood, aluminium, and concrete. The parameters of the materials considered for shading devices in this study are shown in Table 2. The shading device type used for testing in this study is the horizontal overhang, with a horizontal distance-to-window height ratio of 0.5.

Table 2: Properties of shading devices modelled

Materials	Thickness (mm)	Thermal conductivity (W/m·K)	Density (kg/m³)	Specific heat (J/kg·K)
Wood	25	0.12	500	2,300
Aluminium	5	150	2,700	896
Concrete	50	0.5	2,400	1,050

3. Results and discussion

The following results focus on the indoor temperature under the proposed materials for shading devices. The test room exhibited a relatively small temperature variation throughout the year, with a daily indoor air temperature range of 27.7 °C to 35.3 °C, as shown in Figure 3. Under these indoor temperature conditions, occupants may feel uncomfortably hot, leading to increased cooling loads and energy consumption in the building. To streamline the experimental data and improve the accuracy of the results, the subsequent findings will specifically examine the hourly variations of indoor air temperature on four particular days: the spring equinox, summer solstice, autumn equinox, and winter solstice. This approach will provide a more focused analysis of the impact of different materials used in sun shading devices on indoor thermal conditions throughout the course of these days. These results will compare the indoor air temperature without shading devices and with the implementation of overhang shading devices using different materials.

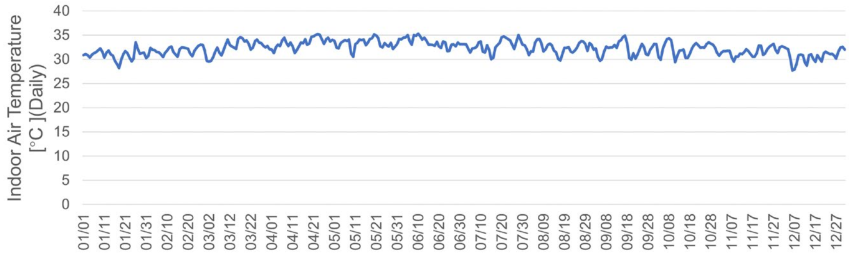

Figure 3: The annual indoor air temperature of the test room (Daily)

Based on the observation that the most widely used material for shading devices on the UTM campus is concrete. Figure 4 compares the hourly indoor air temperatures between not using shading devices and using concrete shading devices for these four days. From the graph, it can be found that during the four days, the indoor air temperature increased significantly from 8 am each day and reached its maximum at 6 pm each day, which coincided with the school's working hours. Moreover, the indoor air temperature decreased considerably when the concrete shading device was used, compared to the time without the shading device. And, the fluctuation range of indoor air temperature is significantly reduced after implementing concrete shading devices, varying between 28.3 ºC to 35.3 ºC. Figure 5 illustrates the hourly temperature difference between not using shading devices and using concrete shading devices for these four days. The maximum temperature difference all occurs between 5 pm and 7 pm, where the largest temperature difference is recorded during the summer solstice, reaching up to 2.8 ºC.

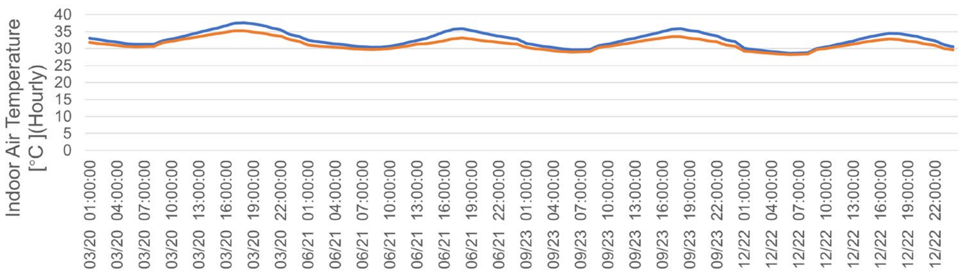

Figure 4: Hourly indoor air temperature without the using shading devices and using concrete shading devices

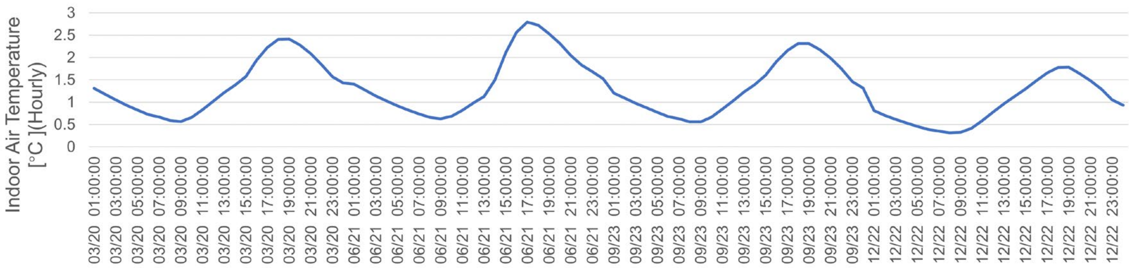

Figure 5: Hourly difference in indoor air temperature between not using shading devices and using concrete shading devices

As shown in Figure 6, there is not much variation in indoor air temperature when using aluminium, concrete, and wood as materials for shading devices. However, when wood is used as a material for shading devices, the indoor air temperature is always lower compared to using aluminium panels and concrete.

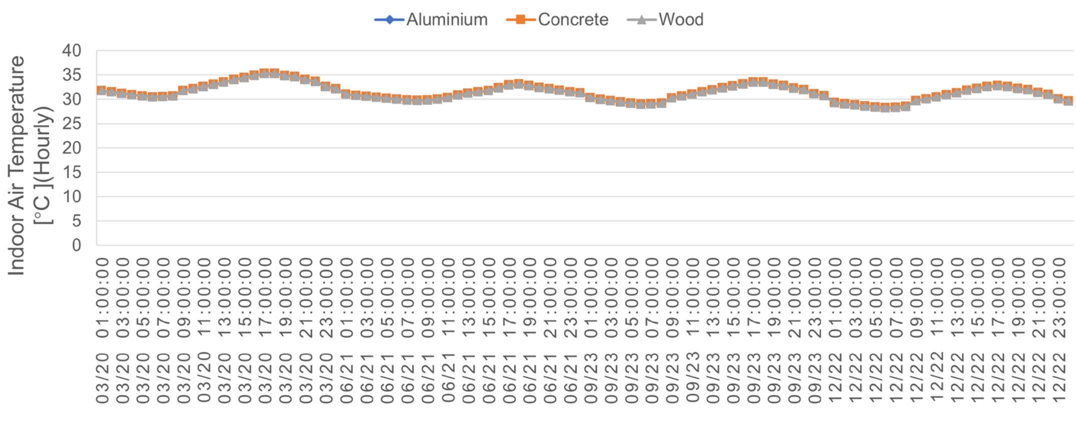

Figure 6: Hourly indoor air temperature for different materials of shading devices

4. Conclusions

From this study, it can be observed that shading devices can significantly reduce indoor air temperature in tropical regions, thereby reducing building cooling loads and improving energy efficiency. The common construction materials used for shading devices in Malaysia have minimal impact on improving energy efficiency. However, as for the three most commonly used shading materials investigated in this study, their impact on enhancing energy efficiency is minimal, with wood as the most notable in reducing indoor air temperatures compared to using aluminium and concrete. The accuracy of the indoor air temperatures calculated by this simulation software was not examined in this study. The real surroundings of the selected buildings were not fully reproduced in the modelling. All these limitations may lead to a decrease in the accuracy of the results of this study. In future work, the accuracy of the model can be adjusted and improved by field measurement of the indoor air temperatures of the selected rooms and comparing them with the indoor air temperatures calculated by the simulation. Based on the results of this study, future research related to enhancing the performance of shading devices could focus on enhancing wood shading devices, such as adding high-reflectivity materials to the surface of wood shading devices or exploring ways to reduce the thermal conductivity of wood shading devices.

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