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Reducing The Energy Cost of Buildings Using Shading Plates: Experimental and Numerical Study

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ABSTRACT

The amount of carbon emission pumped into the atmosphere has led to a rise in global temperature. Rapid urbanization increased the use of air conditioners, resulting in the urban heat island effect. The use of environmentally friendly methods in reducing energy consumption for buildings is needed now more than ever. This study aims to evaluate the cooling load of a prototype by installing a shading plate above its roof at a height of 0.67m. A wooden panel with an attached aluminium sheet is used as a shading plate, 2m by 0.9m. The prototype with a dimension of 0.80m (L) x 0.50m (W) x 0.97m (H) is a scaled-down model of the guardhouse located near Block E, UCSI University. Along with the shading plate, the prototype is placed nearby the guardhouse to validate the actual guardhouse's exact condition. The shadow acts as an insulator to the prototype. There were two devices used for data collection; a VELOCICALC thermometer to measure the air velocity and air temperature and an infrared thermometer to measure the profile temperature of the room walls, roof, and floor. To ensure the prototype is adequately ventilated, it was placed 20 cm above the floor using red bricks from 9 a.m. to 5 p.m, a maximum temperature reduction of 4.5°C when the shading plate thoroughly shades the room. A total of 14.5% electricity cost can be reduced monthly when the guardhouse is fully shaded from 11 a.m. to 2 p.m. In contrast, both the actual guardhouse and the prototype model can receive full sunlight from 11 a.m. to 5 p.m., while from early morning till 11 a.m., the guardhouse is fully shaded by the UCSI Block E building.

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1. Introduction

The concern of reducing carbon footprint or being more sustainably efficient has become an important topic today [2-4]. Thermal insulation plays an important role in a hot and humid country to reduce dwellings' energy consumption and cooling load [1]. The increase in the human population has increased the number of homes needed. Being in a tropical region that is constantly hot and humid, installing air conditioning is a must for comfort purposes [5]. The rise in carbon emission from various industries that have caused the increase of surrounding temperature has led to increased air conditioning usage, leading to consuming more fuel for electricity generation, which raises more greenhouse gases being pumped into the atmosphere [6]. Insulating materials such as Rockwool, Polyethylene Aluminium Single Bubble (PASB), and Expanded Polystyrene Foam (EPS) with the thickness of 50 mm to 100 mm are widely used due to their low cost and low thermal conductivity [7-10]. The use of awnings has also shown a sound reduction in indoor temperature as it acts as an insulating layer with a good amount of air circulation beneath it [11].

Heating, ventilating, and air conditioning plays an essential role in providing an optimum temperature to the surrounding to maximize the productivity and comfort level of the occupant. Intelligent buildings are built to improve overall efficiency [12-13]. The increase in electrical appliances usage has driven up the demand for more energy. Hence, power plants need to increase the power output, i.e., burn more fossil fuel, which is one of the significant contributors to climate change. Being in a comfortable location ensures the productivity of a person stays high. However, if the building is poorly insulated, especially the roof where most heat enters, unnecessary waste in energy is bound to happen [14].

The use of the Vertical Greenery System in reducing the building temperature has seen a seasonal cooling energy saving of almost 30% [15]. The primary reasons behind the thermal performance of buildings are related to the building architecture design, such as roof type and material, the orientation of the roof and insulation beneath it, building material, and glazing. In hot weather zones, the shading of building in the sense of roof and façade will aid in reducing the cooling load during the hot season [1].

One of the critical potentials to reduce carbon emission and generate more sustainable energy is installing solar panels [16]. Approximately 3,850,000 exajoules (One exajoule, EJ = 1018J) per year of total solar energy absorbed by the Earth's atmosphere, lands, and oceans [17]. The total energy used by humans in 1 year is 4.6 x1020 J which can obtain from the sun in 1 hour [18]. Solar energy is a renewable energy source as no pollution is generated from harnessing its energy [19-22]. Energy demand is a vast sector that is drastically increasing throughout the world. With the growing human population and people migrating to urban areas, the demand for clean energy is more than ever [23]. Most of the electricity generation worldwide is from the burning of fossil fuels, which emits enormous greenhouse gases into the atmosphere [24].

The objective of the study is to evaluate how shade cast by shading the roof will affect the temperature and building cooling load. This research was performed through simulations and experiments to determine how much the prototype's temperature can reduce when the shading panels fully shade the prototype. The main focuses are solar irradiance, air velocity, and air temperature inside the room and outdoor surroundings. It will compare with an actual room, i.e., a guardhouse without any shading throughout the day. The current methods used to reduce heat flux in the building are applied beneath the roof. Those materials could be Rockwool, Polyethylene Aluminium Single Bubble (PASB), Glasswool, spray form insulations. Besides solar panels, reflective wall paint and creeping plants could be the thermal reduction method. Not only do these methods require a complex installation, but they are harmful to human health over a long exposure, and improper disposal methods are considered upon the end of their lifecycle. However, by shading an entire building during peak hours, i.e., 11 a.m. to 2 p.m., the heat flux rate can be reduced, which aids in decreasing electricity consumption during peak hours.

2. Methodology
2.1 Experimental Setup

The experimental setup consists of a 1:3 ratio prototype model of the actual guardhouse, as shown in Figure 1 and Figure 2. The prototype was built to compare temperature differences when the shading plate casts a shadow on the room model.

(a) (b)

Fig. 1. Right side (a) and left side (b) view of the prototype model

UCSI Block E building open car park has experimented upon completing the prototype construction and the shading plate. It was near Block E guardhouse and an ideal location to receive sunlight throughout the day.

Fig. 2. UCSI Block E guardhouse

Table 1 shows the dimensions of the guardhouse and prototype model:

Table 1
The geometry of the prototype model and guardhouse

Components	Dimension (mm)	Material
Guardhouse	2400 x 1500 x 2900	Metal
Prototype model	800 x 500 x 970	Balsa wood

The room model has four walls and a roof while placing it on four bricks with the floor left open for air ventilation purposes, as shown in Figure 1. The room model for this study is made from Balsa wood, and Table 2 [25] are the specifications:

Table 2
Balsa wood specifications [31]

Property	Value	Units
Thermal Conductivity	0.050	W/(m.K)
Specific heat	1.420	kJ/kg.K
Density	178	kg/m^3
Elastic Modulus	0.175	GPa
Poisson ratio	0.290	-

The shading plate is made of a 1 mm aluminium sheet, placed on a 3 mm Balsa wood to shade the room model. Aluminium is used due to its high efficiency in reflecting the sunlight and heat instead of absorbing them [26]. It is vertically installed at 0.67 m above the room model, as shown in Figure 1, and the dimensions of the shading plate are 2.00 m x 0.90 m. Extra caution is required when handling the aluminium sheet due to its sharp edges.

2.2 Simulation

SketchUp software simulation was used to determine a strategic location that receives good sunlight to experiment. Then, the prototype model with the shading plate was designed using this software to determine when the shading plate will fully shade the room model. SketchUp software aids in determining the sun's orientation throughout the year. Hence, an optimum height and size of the shading plate can be designed to ensure the prototype stays partially and fully shaded during the peak hours of the day. Also, more time can be saved through this software as there is no need to track the sun's orientation physically throughout the year. Optimum dimensions of the shading plate can also be confirmed through SketchUp; hence there is no need to waste more materials through the fabrication process. The shadow analysis features in SketchUp were used to determine the sun's orientation throughout the year. Furthermore, the size of the shading plate was designed to ensure the casted shadow is at least partially shade the room during peak hours of the day, i.e., from 11 a.m. to 2 p.m.

Figure 3 shows the design and dimensions of the scaled-down model in SketchUp. The air velocity and air temperature of the walls and surrounding temperature were determined. Data for all of them were collected from 9 a.m. to 5 p.m. during clear skies and hot sun throughout the day.

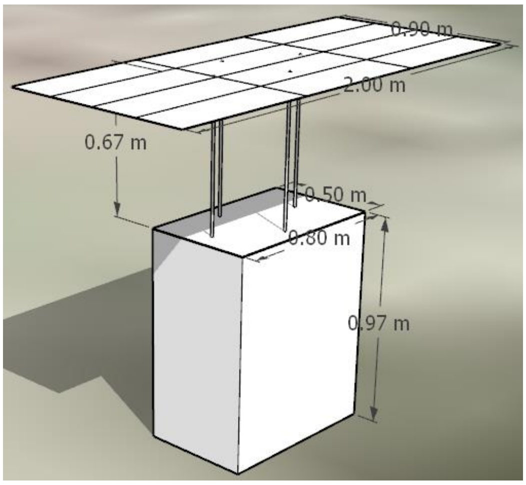


Fig. 3. Dimensions of the prototype model with shading plate

The measuring instruments used in this research are Infrared Thermometer and a TSI VELOCICALC multi-function ventilation meter, as shown in Figure 4 and Figure 5. Both devices were used to measure the inner and outer air temperature and inner and outer air velocity of the room model and guardhouse from 9 a.m. to 5 p.m. The Infrared Thermometer was used to measure the temperature profile.

Fig. 4. TSI VELOCICALC meter

Fig. 5. Infrared thermometer

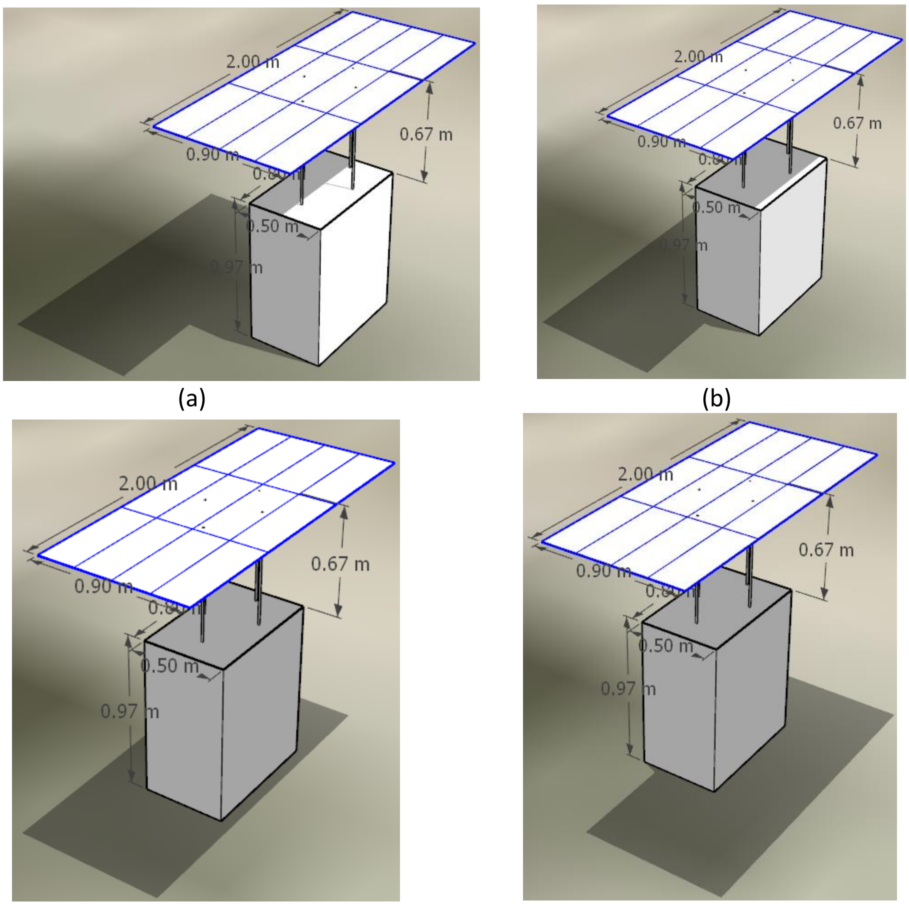
3. Results and Discussion

This research aims to evaluate how effective the shade cast by a shading plate is in lowering the temperature of the prototype. A prototype model made from Balsa wood was constructed, with a shading plate almost twice the model's size installed about 0.67 m above its roof. The shading plate consists of a 1 mm thick aluminium sheet placed on a 3 mm thickness of Balsa wood due to the aluminium sheet not being rigid. Figure 6 shows the simulation data on how the shade cast by the shading plate on the prototype would look from 11 a.m. to 2 p.m. and Figure 7 shows the experimental data collected every hour, from 9 a.m. to 5 p.m., for a total of 30 days.

3.1 Simulation Result

Before proceeding with the experimental result, a simulated version of the prototype model with the shading plate has been modelled using SketchUp software to find the optimum shade of the plate to the room model that falls between 11 a.m. to 2 p.m., shown in Figure 6. The reason to provide the

SketchUp result from 11 a.m. to 2 p.m. is to show the outcome of shade cast by the shading plate on the room during peak hours.



(a) (b)

(c) (d)

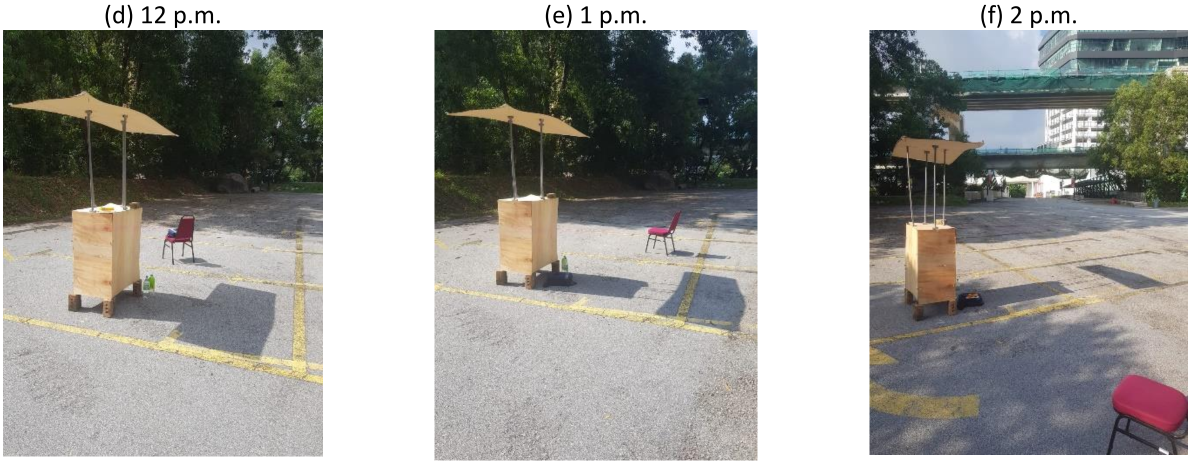
Fig. 6. Shading cast on the prototype model at the peak hours, (a) 11 a.m. (b) 12 p.m. (c) 1 p.m. (d) 2 p.m.

3.2 Field Result

Figure 7 shows the experimental result on how the shading panel can shade the room model from 9 a.m. to 5 p.m., and Figure 8 shows the temperature distribution results from 9 a.m. to 5 p.m.

(a) 9 a.m. (b) 10 a.m. (c) 11 a.m.

(d) 12 p.m. (e) 1 p.m. (f) 2 p.m.



(g) 3 p.m. (h) 4 p.m. (i) 5 p.m.

Fig. 7. Experimental result of the shade cast from shading panel on the prototype model from 9 a.m. to 5 p.m.

The average difference in air temperature reduction between the inside of the prototype model and outdoor surroundings ranges from 1.9°C to 4.5°C during the peak hour, from 11 a.m. to 2 p.m., as shown in Figure 8.

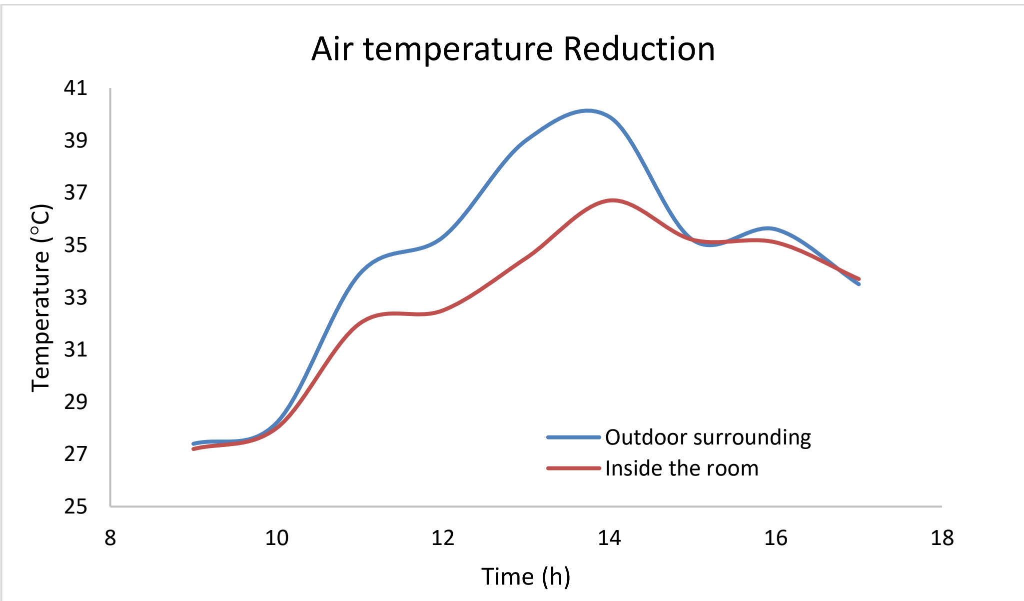


Fig. 8. The air temperature difference between outdoor surroundings and inside the prototype model

As the shading plate was installed flat above the room model, no shade was cast from 9 a.m. to 11 a.m. and from 2 p.m. to 5 p.m. However, the prototype model receives a partial shade after 11 a.m., and it is fully shaded till 2 p.m. as shown in Figure 7 and the air temperature inside the room model reduces up to 4.5°C.

As shown in Figure 9 and Figure 10, the recorded wall temperatures are highest at 2 p.m., due to the shade starting to be away from the room since there is no insulation fitted within the walls of the room model.

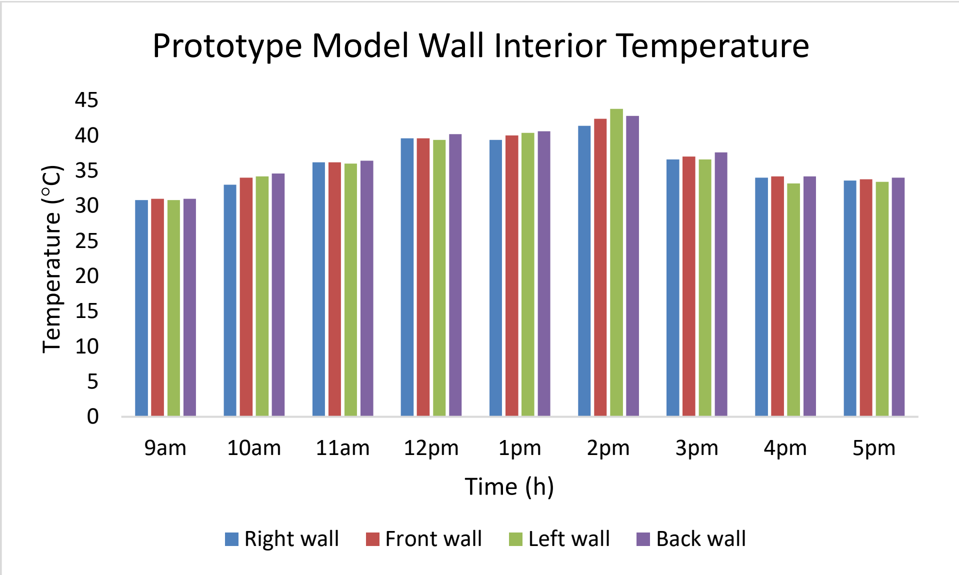


Fig. 9. Prototype model wall interior temperature

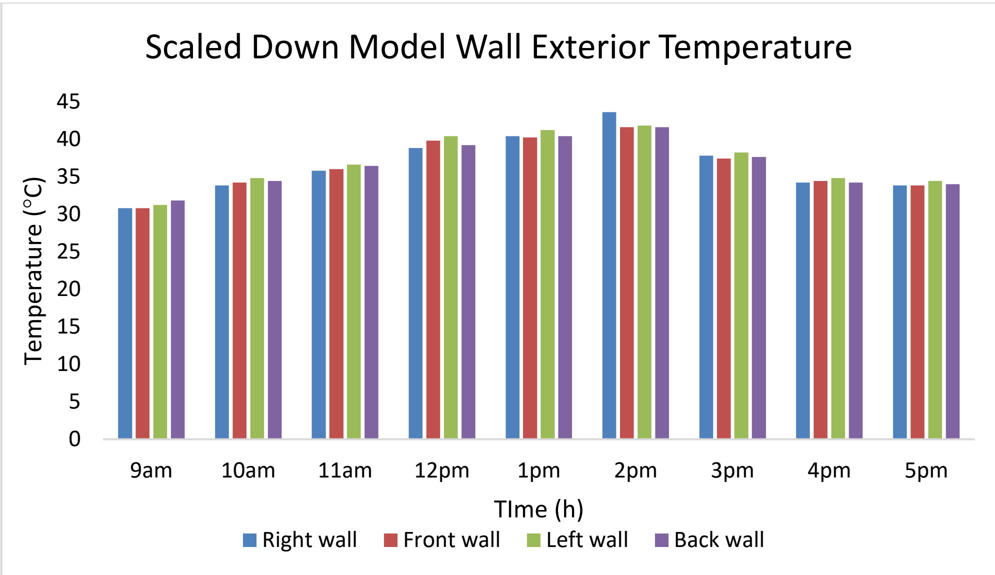


Fig. 10. Prototype model wall exterior temperature

Temperature data was collected from the room model compared with the actual guardhouse wall temperatures. Figure 11 and Figure 12 show the guardhouse wall temperatures, and the highest temperature is at 2 p.m. as well.

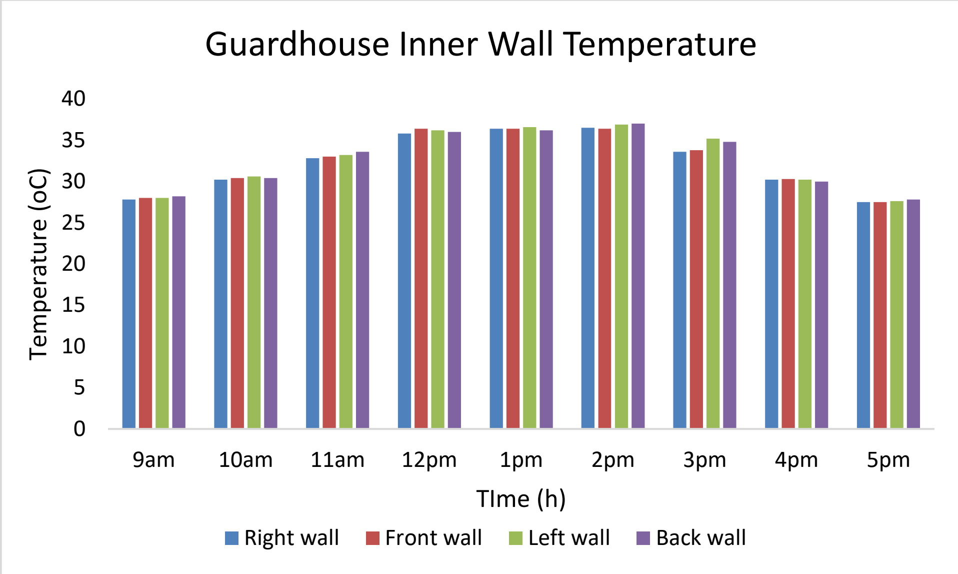


Fig. 11. Guardhouse Wall Inner Temperature

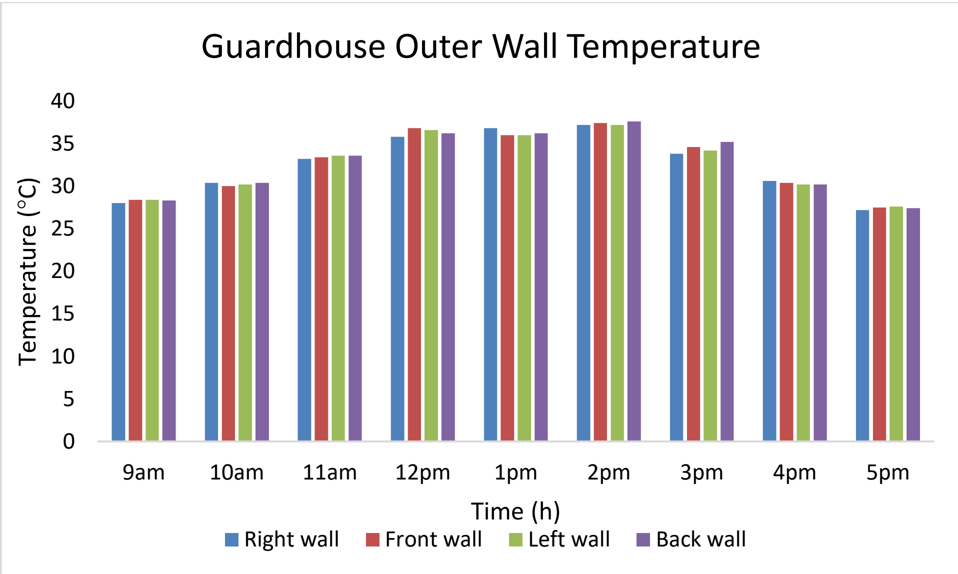


Fig. 12. Guardhouse Wall Outer Temperature

The wall temperatures of the guardhouse and the scaled-down model in Figures 9, 10, 11, and 12 are at their highest at 2 p.m. The recorded temperatures of the guardhouse are lower than the temperatures of the prototype model, and it is due to the presence of air conditioning inside the guardhouse. The main goal of the present study is to reduce the usage of the air conditioner unit by applying the shade of the panel above the room.

3.5 Power Consumption Analysis

The air conditioner installed in the guardhouse is Daikin 1.0 HP air conditioner, which uses 0.52 kW/h [27], as shown in Figure 13. The assumption of no environmental or weather factor may have caused the air conditioner to consume more or less power. If a shading panel were to be installed on the guardhouse, it would thoroughly shade it from 11 a.m. to 2 p.m., which is 3 hours. Hence the air conditioner can be turned off to reduce its power consumption.

FTKM-T Series	
Indoor	FTKM25TVMM
Outdoor	RKM25TVMM
Specifications / Model name	
Type	
Horsepower (hp)	1.0
Refrigerant	
Rated Cooling Capacity (Btu/h) (Min-Max)	8,500 (4,100-12,300)
Rated Power Consumption (W) (Min-Max)	520 (185-920)
Rated Running Current (A)	2.6
CSPF (Wh/Wh)	7.40
Energy Rating	

Fig. 13. 1.0 HP Daikin Air Conditioner (Airflow n.d.)

Table 3 would show the reduction in monthly power consumption if a shading plate were to be installed above the roof of the guardhouse. This calculation assumed the air conditioner runs 18 hours a day and 30 days a month.

Table 3
Energy consumption

Method	Monthly power consumption (kWh)	Monthly power reduction (kWh)	Percentage monthly power reduction (%)
Without shading	280.80	-	-
With shading plate	234.0	46.8	20

Table 4 shows the cost for electricity bill is calculated based on the tariff given by Tenaga National Berhad, which is 21.80 cents/kWh for the first 200kWh and 33.40 cents/kWh for the next 100 kWh.

Table 4
Monthly electricity cost saving of the guardhouse

Method	Monthly power consumption (kWh)	Monthly Electricity cost (RM)	Monthly saving (RM)	Percentage monthly saving (%)
Without shading	280.80	70.58	-	-
One layer	234.0	60.38	10.20	14.5

Based on the power assumption for the 1.0 HP Daikin air conditioner, the data presents an average power reduction of 46.8 kWh if the shading plate thoroughly shades the guardhouse from 11 a.m. to 2 p.m. A total of 14.5% can be reduced monthly on the electricity cost and reduction in 20% of power consumption if the guardhouse is fully shaded from 11 a.m. to 2 p.m.

4. Conclusions

The shading plate played very important role; is it helps to reduce the temperature during the peak hours by 4.5°C, while this reduction considers very high based on the condition of the experiment, as the prototype has been fabricated from the wood and there is no air movement inside the room, this could heat the room to be same as the environment temperature. However, with this technique of the temperature has reduced inside the room to 11.2% and this will lead to reduce the energy consumption. The best result was achieved at 1 p.m. when the shading plate fully shaded the room, and the air temperature inside the room was 34.5°C vs surrounding was 39°C. The aim of this study is to find the optimum hight of the shading plate above the room to cover the room most of the time during the day. The experimental and numerical result using SketchUp software shows the room could be fully shade during the peak hours, which are at 1 p.m. and 2 p.m., while partially shading at 11 a.m. and 12 p.m., by installing the shading plate about 2 m above the room and this shading could help to reduce the energy consumption inside the room by 14.5% per month, without considering the air movement inside the room. SketchUp software has been used in this research, primarily to determine on the orientation of the sun throughout the year. This could help to save the time by running the experiment through the entire year to evaluate the position of the sun, physically. The optimum size of the shading plate for the prototype was also determined using shadow analysis feature, to ensure the prototype is fully shaded during the peak hours i.e., 11 a.m. to 2 p.m.

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References

[1] Odeh, Saad. "Thermal performance of dwellings with rooftop pv panels and pv/thermal collectors." *Energies* 11, no. 7 (2018): 1879. https://doi.org/10.3390/en11071879
[2] Muhieldeen, Mohammed W., Lim Chong Lye, Mohammed Sameer Sharaf Kassim, Wah Yen Tey, and Kah Hou Teng. "The Optimum Thickness of Rockwool as Roof Thermal Insulation: An Experimental and Numerical Study." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 89, no. 1 (2022): 77-91. https://doi.org/10.37934/arfmts.89.1.7791
[3] Muhieldeen, M., N. M. Adam, E. Salleh, S. G. Tang, and Q. J. Kwong. "Student behaviour that leads to energy abuse: case study at a teaching institution in Malaysia." In *International Seminar in Sustainable Environment and Architecture (9th SENVAR+ 2ND ISESEE 2008: Humanity and Technology)*. Uitm Shah Alam, (2008): 1–7.
[4] Muhieldeen, M. W., N. M. Adam, Elias Salleh, S. H. Tang, and H. Ghezavati. "CFD simulation on use of polyethylene single bubble to reduce radiant heat on lecture hall." (2009): 3–6.
[5] Muhieldeen, M. W., Danson Loi, A. Vishnuvarthan, L. Paramanandam, Wong Mun Fai, Barrathan Arthimoorthy, Yeo Chuan Wei, Latchumanan Kanesskumar, and Gabriel Koh. "Combined Ventilation Methods in a Large Scale Warehouse Building to Reduce Indoor Air Temperature." *American Journal of Energy and Power Engineering* 2, no. 5 (2015): 74-78.
[6] Muhieldeen, M. W., and Y. C. Kuang. "Saving energy costs by combining air-conditioning and aircirculation using CFD to achieve thermal comfort in the building." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 58, no. 1 (2019): 84-99.
[7] Muhieldeen, M. W., N. M. Adam, and B. H. Salman. "Experimental and numerical studies of reducing cooling load of lecture hall." *Energy and Buildings* 89 (2015): 163-169. https://doi.org/10.1016/j.enbuild.2014.12.026
[8] Muhieldeen, Mohammed W., Q. Y. Wong, Ummi Zulaikha Abd Rahman, and Wah Yen Tey. "Energy Saving by Applying Different Wall Thermal Insulations on a Room at Malaysian Institution." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 65, no. 1 (2020): 130-139.
[9] Muhieldeen, Mohammed W., Lim Chong Lye, M. S. S. Kassim, Tey Wah Yen, and K. H. Teng. "Effect of Rockwool Insulation on Room Temperature Distribution." *Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer* 3, no. 1 (2021): 9-15.
[10] Muhieldeen, Mohammed W., Lim Zhen Yang, Lim Chong Lye, and Nor Mariah Adam. "Analysis of Optimum Thickness of Glass Wool Roof Thermal Insulation Performance." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 76, no. 3 (2020): 1-11. https://doi.org/10.37934/arfmts.76.3.111
[11] Muhieldeen, M. W., Y. R. Lim, Sunil Govinda, and Wah Yen Tey. "Investigation of the Effect of Awning using Sunlight Sensor to Reduce Cooling Load in the Room." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 67, no. 1 (2020): 136-145.

[12] Kirankumar, Gorantla, Saboor Shaik, and Ashok Babu Putta Ranga Talanki Setty. "Thermal and energy saving analysis by using tinted double window glass combinations for heat gain in buildings." *International Energy Journal* 18, no. 2 (2018): 215 – 230.
[13] Wu, Wei, Harrison M. Skye, and Piotr A. Domanski. "Selecting HVAC systems to achieve comfortable and cost-effective residential net-zero energy buildings." *Applied energy* 212 (2018): 577-591. https://doi.org/10.1016/j.apenergy.2017.12.046
[14] Dominguez, Anthony, Jan Kleissl, and Jeffrey C. Luvall. "Effects of solar photovoltaic panels on roof heat transfer." *Solar Energy* 85, no. 9 (2011): 2244-2255. https://doi.org/10.1016/j.solener.2011.06.010
[15] Perini, Katia, Marc Ottelé, A. L. A. Fraaij, E. M. Haas, and Rossana Raiteri. "Vertical greening systems and the effect on air flow and temperature on the building envelope." *Building and environment* 46, no. 11 (2011): 2287-2294. https://doi.org/10.1016/j.buildenv.2011.05.009
[16] Pazheri, Faisal Rahiman, Electrical Inspectorate, and N H Malik. "Applications of Solar Electricity." April (2015)
[17] Hayat, Muhammad Badar, Danish Ali, Keitumetse Cathrine Monyake, Lana Alagha, and Niaz Ahmed. "Solar energy—A look into power generation, challenges, and a solar-powered future." *International Journal of Energy Research* 43, no. 3 (2019): 1049-1067. https://doi.org/10.1002/er.4252
[18] Inganäs, Olle, and Villy Sundström. "Solar energy for electricity and fuels." *Ambio* 45, no. 1 (2016): 15-23. https://doi.org/10.1007/s13280-015-0729-6
[19] Shukla, A. K. "Turning sunlight into electricity." *Resonance* 16, no. 12 (2011): 1294-1302. https://doi.org/10.1007/s12045-011-0146-5
[20] Kannan, N., and D. Vakeesan. "Sun based vitality for future world: a survey." *Exam Clean Sustain Energy* 62 (2016): 1092-1105. https://doi.org/10.1016/j.rser.2016.05.022
[21] Yang, Junnan, Xiaoyuan Li, Wei Peng, Fabian Wagner, and Denise L. Mauzerall. "Climate, air quality and human health benefits of various solar photovoltaic deployment scenarios in China in 2030." *Environmental Research Letters* 13, no. 6 (2018): 064002. https://doi.org/10.1088/1748-9326/aabe99
[22] Kabir, Ehsanul, Pawan Kumar, Sandeep Kumar, Adedeji A. Adelodun, and Ki-Hyun Kim. "Solar energy: Potential and future prospects." *Renewable and Sustainable Energy Reviews* 82 (2018): 894-900. https://doi.org/10.1016/j.rser.2017.09.094
[23] Beck, Silke, and Martin Mahony. "The IPCC and the new map of science and politics." *Wiley Interdisciplinary Reviews: Climate Change* 9, no. 6 (2018): e547. https://doi.org/10.1002/wcc.547
[24] Dyrstad, Jan Morten, Anders Skonhoft, Magnus Quist Christensen, and Eirik Theie Ødegaard. "Does economic growth eat up environmental improvements? Electricity production and fossil fuel emission in OECD countries 1980–2014." *Energy policy* 125 (2019): 103-109. https://doi.org/10.1016/j.enpol.2018.10.051
[25] Yu, Ziqing, and Aixi Zhou. "Fiber reinforced polymer composite structures in fire: modeling and validation." *Mechanics of Advanced Materials and Structures* 20, no. 5 (2013): 361-372. https://doi.org/10.1080/15376494.2011.627639
[26] Setiawan, Eko Adhi, and Khairiah Dewi. "Impact of two types flat reflector materials on solar panel characteristics." *Science* 2 (2013): 188-199. https://doi.org/10.14716/ijtech.v4i2.108
[27] Airflow, Coanda. "R32 Inverter Wall Mounted".