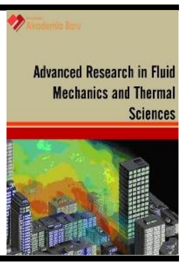
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Investigation of the Effect of Awning using Sunlight Sensor to Reduce Cooling Load in the Room

Open Access

M.W. Muhieldeen[1,*], Y.R. Lim[1,♣], Sunil Govinda[2], Wah Yen Tey[1]

[1] Faculty of Engineering, Technology and Built Environment, Mechanical Engineering, UCSI University, Cheras, Malaysia
[2] Faculty of Engineering, Technology and Built Environment, Electrical and Electronics Engineering, UCSI University, Cheras, Malaysia

ARTICLE INFO

Article history:
Received 26 September 2019
Received in revised form 1 November 2019
Accepted 1 November 2019
Available online 15 March 2020

ABSTRACT

In this paper, the potential of a motorized awning, coupled with sunlight sensor, attached to the window, in reducing the cooling load of a wooden room is investigated experimentally. The wooden room was built with a scaled down dimension according to a classroom in UCSI College that has a window facing approximately true East, hence fully exposed to the morning sun. A Light Dependent Resistor (LDR) was installed at the bottom of the window to detect the presence of sunlight hitting the window. The LDR then gives a signal to the microcontroller Arduino Uno 3 which controls the servo motor to lift or lower down the awning to block sunlight. The constructed system is then able to change the angle of awning periodically to provide constant shading to the window. A manual mode was also constructed to allow users to override and control the awning with satisfaction and flexibility. An experiment was conducted on the wooden room on both cases with and without awning, from 9am to 3pm daily. The surrounding temperature measurements were taken with an anemometer while surface temperatures were taken with an Infrared thermometer. Results showed that a potential reduction of average temperature and cooling load of 0.47 ºC and 1.86 kW for the room with awning installed. Moreover, the projected monthly operation savings was RM 114 for 120 operation hours.

Keywords:
Motorized Awning; Sun Light Sensor; Saving Energy; Cooling Load

1. Introduction

Many researchers have done multiple different studies and development of external awnings and high-performance windows, along with their effect on cooling load, including the works of Juanico [1], Luo *et al.,* [2], Muhieldeen, *et al.,* [3], Hammad and Abu-Hijleh [4], Lee, *et al.,* [5], Arce *et al.,* [6], Farrington *et al.,* [7], Samaan *et al.,* [8], Winther *et al.,* [9], Ghodsieh & Nadooshan [10], Muhieldeen and Kuang [11], Muhieldeen *et al.,* [12] and Salman *et al.,* [13].

However, the effectiveness of the awning in reducing direct insulation was not maximized due to it being fixed. Wong and Istiadji [14] investigated the effects of external awnings on temperature as

[*] *Corresponding author.*
E-mail address: al-gailani@ucsiuniversity.edu.my (M.W. Muhieldeen)
[♣] *Corresponding author.*
E-mail address: limmyyingran@gmail.com (Y.R. Lim)

well. The investigation demonstrated a reduction of indoor temperature of 0.6 – 0.88°C with a horizontal awning implemented. Al-Tamimi & Syed Fadzil [15] carried out a study of the potential of awnings in the reduction of temperature in high-rise buildings in Penang, Malaysia. Among the horizontal, vertical and egg-crate awnings, the findings showed that in unventilated rooms the egg-crate awning had a significant impact on the indoor temperature, with a maximum reduction of 5.1 °C. Wong and Li [16] investigated the effectiveness of awnings on the consumption of cooling energy for windows on the East and West façade in Singapore. A 30 cm horizontal awning was applied to the window. The results showed a 2.6 – 3.2 % of savings on cooling load. The savings increased to 5.9 – 7.0 % when the depth of the awning was 60 cm.

Arifin and Denan [17] analysed the relationship of indoor air temperature with various external awnings in Malaysia. The awnings included in the analysis were vertical awning, horizontal awning and egg-crate awning. The location of the analysis was set at Klang Valley, Kuala Lumpur and the duration were seven days, from 13 to 20 February 2014, 1:00 pm. The analysis returned a positive result in reducing room temperature with awnings installed, with egg-crate awning achieving the lowest average indoor temperature, at 30°C. Rabczak *et al.,* [18] investigated the influence of awning on cooling energy demand of a building in Lublin Providence, Poland. The results demonstrated an approximate of 4% of reduction of annual cooling demand when simple blinds are attached on the windows at an angle of 45°.

Gomez-Munoz and Porta-Gandara [19] proposed a mathematical model to analyze the relationship between external awnings and external walls. The setting of the study was in Northwestern Mexico, where it is hot and dry. The authors proposed a shading device design incorporating awnings and external walls. Results displayed that the method is reliable in creating an increased size of shadow on the façade to completely obstruct solar radiation onto the window with optimal parameter relations between the shading devices. With the current setup, in the Summer Solstice, the design achieved a 45% reduction of direct solar insolation. Gusdorf *et al.,* [20] conducted an experiment to investigate the savings of cooling energy that an external awning can save. The awnings were manually operated and angled at 55° and the experiment was conducted from August to September 2010. Results proved a total saving of 3.186 kWh/day and 30% of net reduction of cooling load. Dubois *et al.,* [21] studied the impact of the geometry of seasonal awning on the heating and cooling loads in an office room with 30% glazing-to-wall-ratio. The result returned a decent amount of energy saving of 12 kWh/m^2-year can be obtained by employing simple awning during summer. The implementation of light dependent resistors in sensing systems are common and permits light to be a variable for several light-related investigations such as night lamp controllers [22–24]. The objective of this paper is to evaluate the potential reduction of cooling load in a room with and without an automated awning experimentally.

2. Methodology

2.1 Test Room

The design of the test room was based on one of the classrooms in UCSI College Kuala Lumpur, with its window facing approximately true East, as shown in Fig. 1. The approximate dimension of the designated classroom was (4.8 x 3.2 x 3.2) m and the window was (2.6 x 1.6) m. For this project, the test room was scaled down to (1.2 x 0.8 x 0.8) m with a window of (0.65 x 0.4) m, centered. Acrylic was used as the substitute material for the window as it is widely available in the market and share the opacity of reinforced glass. On the other hand, the dimension of the awning was (0.65 x 0.308) m, and made with a 2 mm thick plywood, so that it is light and would not cause extra load to the servo motor. The awning was attached to the window using door hinges that enables single-degree of freedom movements. The required tools and materials to build the test room, along with the measuring equipment are listed in Table 1.

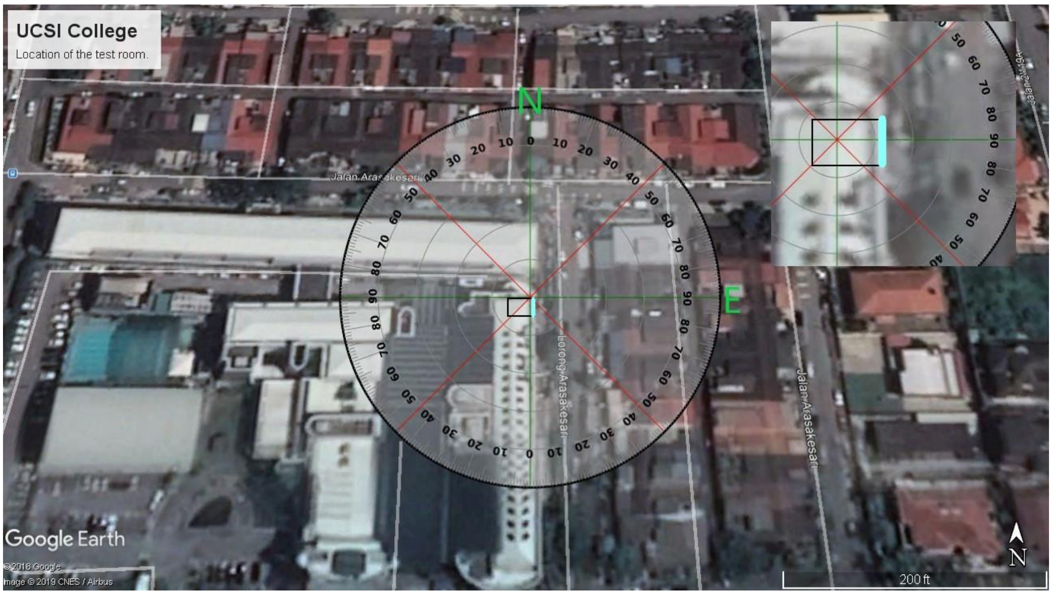


Fig. 1. Location of the classroom in UCSI College, Kuala Lumpur

Table 1
Tools, materials and devices

Materials and apparatus	Quantity	Function
Plywood (122 x 244 x 0.9) cm	2	Walls of the room
5mm screws	1 packet/50	To hold the room together
Acrylic board (A2 and 1.5 mm thick)	1	The window of the test room
L-shaped metal brackets	33	Used with 5mm screws
Small door hinge	2	To connect awning with window
Electrical Jigsaw	1	To cut the plywood
Power drill	1	To drill holes
Electric screwdriver	1	To install brackets
Sandpaper	1	Smoothen cut edges
F-clamps	4	To hold the plywood during woodworking
Safety gloves	1	Safety precautions
Epoxy	1	To adhere the acrylic to the plywood
IR thermometer	1	To measure surface temperature
Anemometer	2	To measure surrounding temperature

2.2 Sensing System

The sensing system of this project was adapted from the studies by Jung *et al.,* [25]. The system aims to detect the presence of sunlight using a simple light dependent resistor and control the awning by lifting or lowering it to a suitable angle, thus providing a constant shade to the window. The basic working principle and interaction of the electrical components are based on it. In addition, the servo motor was installed on top of the test room model to raise and lower the awning, granting a smooth control, while the LDR was installed at the bottom part of the window. Fig. **2** shows the schematic diagram of the sensing system. Three major parts of sub-systems are designed to receive different input parameters that can be manipulated. R2 is the potentiometer where the pin of the wiper is connected to A0 pin on the Uno 3 as an analog input to detect varying resistance. The Uno 3 then manipulates this value and sends a PWM to the servo motor through pin D8, thus allowing the user to manually control the awning by turning the knob of the potentiometer. Referring to Fig. **2**, PH2 represents the LDR, coupled with a 10k Ohm resistor connected in series, with an analog signal input connected to A1 pin of the Uno 3. As the varying amount of sunlight hits the LDR, it exhibits different resistance and in accordance to the voltage divider rule, the analog signal at A1 determines the amount of voltage drop the circuit receives. On the other hand, S1 represents an "on-off" switch that is connected to Ground on one end, and pin D9 on the other. Such connection of the switch enables the microcontroller to accept a digital signal of 1 or 0, which literally deduces the On or Off state.

Conclusively, the system accepts two modes of inputs, the LDR and the potentiometer, and produces only one output, which is the servo motor. The schematic diagram is then converted to a Printed Circuit Board (PCB) layout using DipTrace and fabricated. The PCB layout is shown in Fig. **3**.

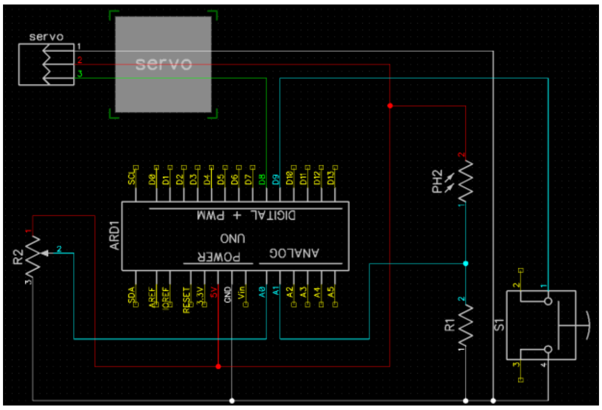


Fig. 2. Schematic diagram

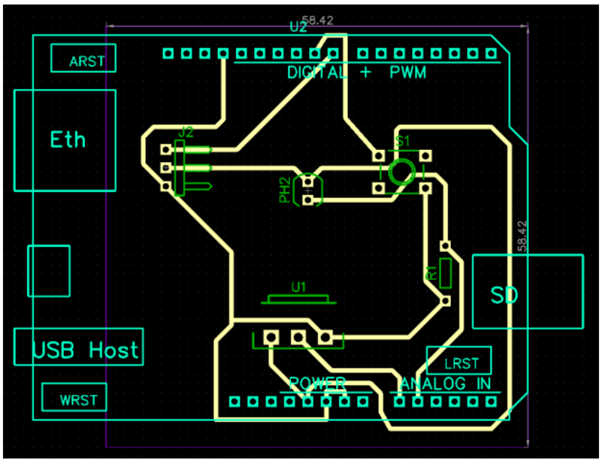


Fig. 3. PCB layout

2.3 Experimental Setup

Fig. **4** shows the final product of the test room, installed with the sensing system and awning. Data on the surface temperature of the awning and window, and the surrounding temperature of inside and outside the test room is collected daily from (9 am to 3 pm) for the whole month of March 2019. Measuring devices were mentioned in Table 1

Tools, materials and devices

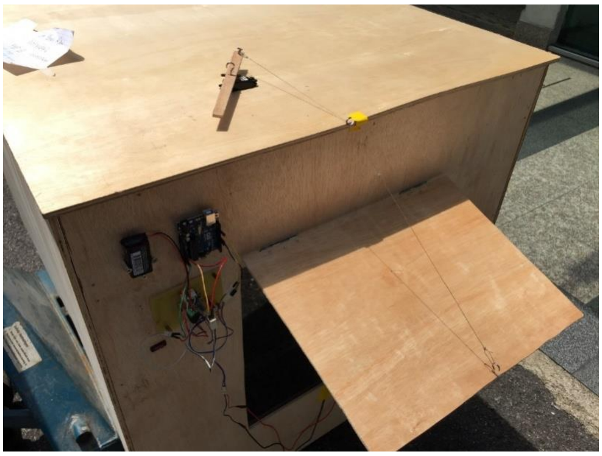


Fig. 4. Final product of the test room

3. Results

3.1 Experimental Result

Fig. **5** shows the graph of average outdoor temperature. The temperature increases from 36.6°C at 9am as the sun changes its position and by 1 pm, the temperature rose to 43.1°C, which totals to a growth of 6.5°C. At 9 am, the distance from the sun is further than that at 1pm, which results in the sun rays or solar radiation to travel a further distance through the atmosphere, before hitting the test room model [26]. Therefore, occurs the loss of heat and reduction in surrounding temperature at morning hours. It is also noteworthy that the peak of the graph is at 1300 hours (1 pm) as oppose to 12 pm (noon). According to Trenberth *et al.,* [26], higher levels of solar radiation is absorbed by the surface of the Earth, i.e. buildings and the ground as compared to the atmosphere, and the slow absorption process takes about one or two hours. The temperature at noon is higher than that in the morning, but in the afternoon, 1 pm in this study, as the heat is released from the Earth, the heat combined with the solar radiation develops a temperature profile higher than noon, thus explains the peak of this curve. As the day moves into the afternoon, the temperature drops to 41.8°C at 1500 hours (3 pm), hence the decline in the graph, after the peak.

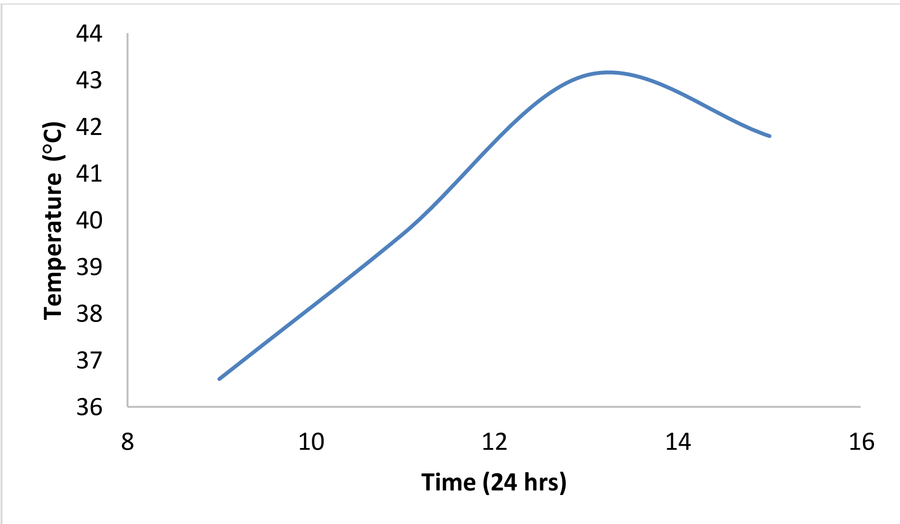


Fig. 5. Average outdoor temperature

It is illustrated in Fig. **6** that the graph of outer surface temperature of the window (acrylic) shows different trends for the case of with and without awning installed. Both cases show a similar decline from 1300 hour to 1500 hour, which was mainly due to the position of the sun that was then above the test room model. This resulted the absence of direct solar insulation to the outer surface of the window, thus the reduction of temperature for both cases. Still, a constant gap was still present between the two cases, with the difference being 1.1°C at 1500 hour. In the morning hours from 0900 hours to about 1100 hours, the window without awning shows an enormous growth, with temperature reaching 43.2°C at 1100 hours, a shocking difference of 2.9°C as compared to the other trend. This would be caused by the absence of awning, whereby sun rays directly hit the surface of the window, on top of the absorbed heat by the window. Looking at the test room with awning however, since the window was constantly shaded, the increment of the surface temperature was swift but constant.

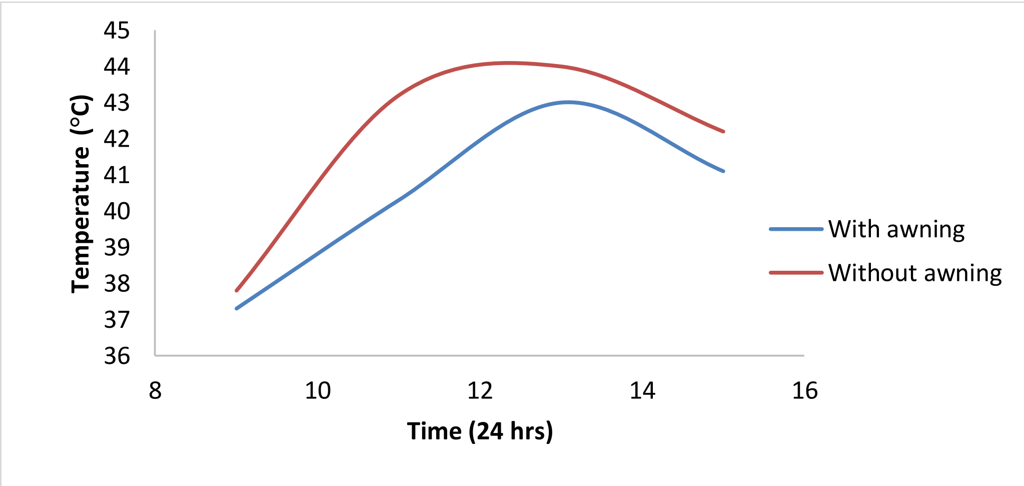


Fig. 6. Outer Surface Temperature of the Window with and Without Awning

Fig. **7** shows the graph of indoor temperatures of the test room model in both cases, with and without awning. It can be observed that both cases exhibit similar curves and trends which is an accelerated growth from 0900 (9 am) hours to 1300 hours (1 pm) and a decline from therein onwards to the 1500-hour (3 pm) point. The temperature trend of the test room model without awning has been constantly shadowing the temperature profile of the test room model with awning. From 0900 hours to 1200 hours the trends showed an almost constant difference in temperature difference, with 0.5°C at 0900 and 0.4°C at 1100 hours respectively. By 1300 hours, the temperature of the room without awning has peaked at 41.3°C, as compared to the temperature of the room with awning, at 40.7°C. This peak has the most difference, of 0.6°C among the whole trend. Both trends start to converge after 1300 hour and ended with a temperature difference of 0.4°C. To sum up, the implementation of an awning to the test room model demonstrates an effective reduction in temperature along the experiment time period, especially during the morning hours when the sun rays are hitting the window.

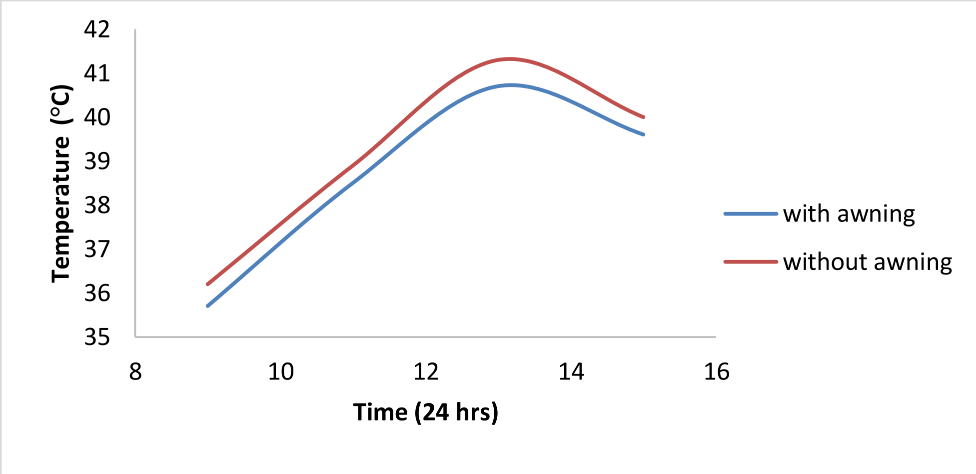


Fig. 7. Indoor Temperature of The Test Room Model with and Without Awning

Fig. **8** illustrates the combined trends of outdoor temperatures and indoor temperatures, with and without awning. It is easily understood that all three trends had a constant and accelerated increment of temperature during the morning hours, however the indoor temperatures diverge from the outdoor temperature from 1300 hours onwards. It can be deduced that the temperature difference of the test room model with awning installed reached a peak of 1.5°C at 1300 hours, while the case of without awning only contributes to a 0.9°C of reduction at the same hour. This justified that the awning is a great shading device in reducing temperature and the cooling load of a room. In addition, looking at the climbing trend of both indoor temperatures, the indoor temperature trend with installed awning can be constantly below the case of without awning due to it is constantly shaded by the moving awning.

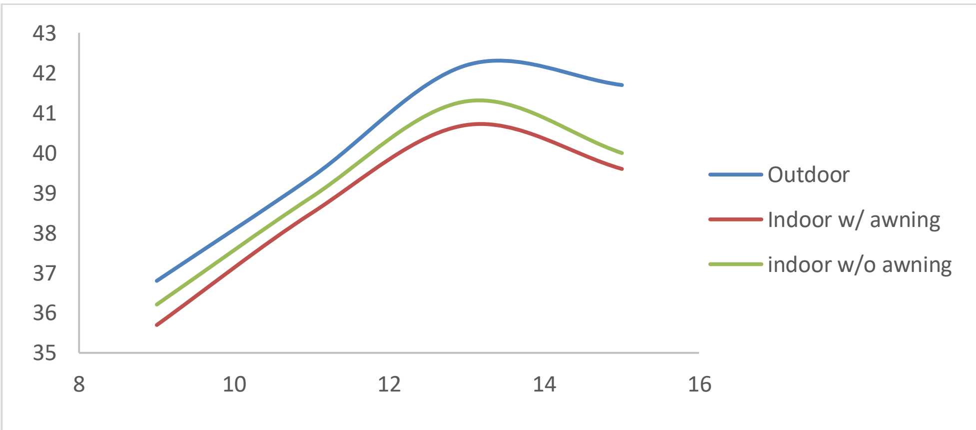


Fig. 8. Outdoor Temperature and Indoor Temperature with Awning

3.2 Cooling Load Analysis

Table 2 summarizes the cooling load, temperature reduction and peak reductions. It is noticeable that the average temperature of the case with awning is 38.63°C, which is equivalent to a 0.47°C difference as compared to the case of without awning. The table also shows that the peak temperature reached by the test room with awning is 0.6°C lesser than the test room without awning. Looking at the cooling load of both cases, it is clear that the test room with awnings installed produces a 31% reduction of cooling load. Results for the experimental methods are acceptable as they display similar peaks and trends of outdoor and indoor temperature as mentioned by Wong and Li [16] and Arifin and Denan [17].

Table 2
Temperature reduction and cooling load

Case	Average Temperature (°C)	Average Temperature reduction (°C)	Peak Temperature (°C)	Cooling load (kW)	Peak cooling load (kW)
Without awning	39.1	-	41.3	5.993	5.421
With awning	38.63	0.47	40.7	4.132	4.653

3.3 Cost Analysis

It is assumed that the room operates for the duration of 6 hours from 9 am to 3 pm daily, 20 working days in a month. Table 3 summarizes the energy consumption for each case and the percentage of reduction. It shows that the test room model with awning implemented contributes to a 1.86 kW of cooling load reduction, thus 223.32 kWh reduction of monthly energy consumption, which equals to a 31.05 % of reduction per month.

Table 3
Energy consumption

Case	Cooling load (kW)	Monthly Energy Consumption (kWh)	Monthly Energy Reduction (kWh)	Percentage of Reduction (%)
Without awning	5.993	719.16	-	-
With awning	4.132	495.84	223.32	31.05

On the other hand, Table 4 shows the calculated electricity cost for both cases, referred to the tariff by Tenaga Nasional Berhad Malaysia. The commercial tariff for low voltage usage is 43.5 cents per kWh for the first 200 kWh and 50.9 cents per kWh for 201 kWh onwards [27]. It is clear that the installation of the awning will introduce a 32.6 % of monthly savings due to the reduction of cooling load.

Table 4
Electricity consumption

Case	Monthly Electricity Cost (RM)	Monthly Savings (RM)	Percentage of Savings (%)
Without awning	351.25	-	-
With awning	237.58	113.67	32.36

4. Conclusions

An experimental study on the potential of an automated awning coupled with a light sensor to reduce the cooling load inside a test room (1.2 x 0.8 x 0.8) m. The results suggested that a potential reduction of the average temperature and cooling load with the installation of awning to the window of the room was 0.47°C and 1.86 kW. It is therefore justified that an added awning to the window of the room can reduce the cooling load of a room. Moreover, calculation of cost estimated a monthly saving of RM113.67 based on the tariff by Tenaga Nasional Berhad. It is therefore clear to say that the objectives of this research have been achieved.

References

[1] Juanicó, Luis E. "A new design of configurable solar awning for managing cooling and heating loads." *Energy and Buildings* 41, no. 12 (2009): 1381-1385.
[2] Luo, Songqin, Hongqiang Li, Yingjie Mao, and Changzhi Yang. "Experimental research on a novel sun shading & solar energy collecting coupling device for inpatient building in hot summer and cold winter climate zone in China." *Applied Thermal Engineering* 142 (2018): 89-99.
[3] 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.
[4] Hammad, Fawwaz, and Bassam Abu-Hijleh. "The energy savings potential of using dynamic external louvers in an office building." *Energy and Buildings* 42, no. 10 (2010): 1888-1895.
[5] Lee, E. S., D. L. DiBartolomeo, and S. E. Selkowitz. "Thermal and daylighting performance of an automated venetian blind and lighting system in a full-scale private office." *Energy and buildings* 29, no. 1 (1998): 47-63.
[6] Arce, Pablo, Cecilia Castellón, Albert Castell, and Luisa F. Cabeza. "Use of microencapsulated PCM in buildings and the effect of adding awnings." *Energy and Buildings* 44 (2012): 88-93.
[7] Farrington, Robert B., John P. Rugh, and Greg D. Barber. *Effect of solar-reflective glazing on fuel economy, tailpipe emissions, and thermal comfort*. No. 2000-01-2694. SAE Technical Paper, 2000.
[8] Samaan, Mina Michel, Osama Farag, and Magdi Khalil. "Using simulation tools for optimizing cooling loads and daylighting levels in Egyptian campus buildings." *HBRC journal* 14, no. 1 (2018): 79-92.
[9] Winther, Frederik V., Mingzhe Liu, Per Heiselberg, and Rasmus L. Jensen. "Experimental And Numerical Analysis Of Modelling Of Solar Shading." *Energy Procedia* 132 (2017): 472-477.
[10] Ghodsieh S. and Nadooshan A. A. "The Impact of Awning on Consuming for Cooling and Heating Energies at A Residential Construction," *Indian J. Fundam. Appl. Life Sci.* 6 (2016): 91–101.
[11] Muhieldeen, M. W., and Y. C. Kuang. "Saving Energy Costs by Combining Air-Conditioning and Air-Circulation 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.
[12] 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).
[13] Salman, B. H., M. Z. Hamzah, J. Purbolaksono, J. I. Inayat-Hussain, H. A. Mohammed, and M. W. Muhieldeen. "Determination of correlation functions of the oxide scale growth and the temperature increase." *Engineering Failure Analysis* 18, no. 8 (2011): 2260-2271.
[14] Hien, Wong Nyuk, and Agustinus Djoko Istiadji. "Effects of external shading devices on daylighting and natural ventilation." In *Proceedings of the 8th International IBPSA Conference, Eindhoven, The Netherlands*, pp. 475-482. 2003.
[15] Al-Tamimi, Nedhal A., and Sharifah Fairuz Syed Fadzil. "The potential of shading devices for temperature reduction in high-rise residential buildings in the tropics." *Procedia Engineering* 21 (2011): 273-282.
[16] Wong, N. H., and S. Li. "A study of the effectiveness of passive climate control in naturally ventilated residential buildings in Singapore." *Building and Environment* 42, no. 3 (2007): 1395-1405.
[17] Arifin, Nor Azah, and Zuraini Denan. "An analysis of indoor air temperature and relative humidity in office room with various external shading devices in Malaysia." *Procedia-Social and Behavioral Sciences* 179 (2015): 290-296.
[18] Rabczak, Sławomir, Maria Bukowska, Danuta Proszak-Miąsik, and Krzysztof Nowak. "Influence of Shading on Cooling Energy Demand." In *IOP Conference Series: Materials Science and Engineering*, vol. 245, no. 5, p. 052046. IOP Publishing, 2017.
[19] Gómez-Muñoz, Victor M., and Miguel Angel Porta-Gándara. "Simplified architectural method for the solar control optimization of awnings and external walls in houses in hot and dry climates." *Renewable Energy* 28, no. 1 (2003): 111-127.
[20] Gusdorf, John, M. M. Armstrong, Frank Szadkowski, and Jeremy Sager. "Summer Shading Performance of Awnings at the Canadian Center for Housing Technology." *Natl. Res. Counc. Canada* (2011).
[21] Dubois, Marie-Claude. "The Design of Seasonal Awning for Low Cooling and Heating Loads in Offices." In *5th Symposium on Building Physics in the Nordic Countries, August 24-26, Goeborg (Sweden), Chalmers University of Technology, Goeborg* 2 (1999): 505–512.
[22] Govinda, K., Udit Mishra, and Apurv Ekansh. "Night Lamp Controller." *Int. J. Sci. Res. Dev.* 2 (2014): 238–241.
[23] Salim, Ghassan Maan, Hashimah Ismail, Niranjan Debnath, and A. Nadya. "Optimal light power consumption using LDR sensor." In *2015 IEEE International Symposium on Robotics and Intelligent Sensors (IRIS),* pp. 144-148. IEEE, 2015.
[24] Tharamuttam, Jerin Kuriakose, and Andrew Keong Ng. "Design and development of an automatic solar tracker." *Energy Procedia* 143 (2017): 629-634.

[25] Jung, Woojin, Taehoon Hong, Jeongyoon Oh, Hyuna Kang, and Minhyun Lee. "Development of a prototype for multi-function smart window by integrating photovoltaic blinds and ventilation system." *Building and Environment* 149 (2019): 366-378.

[26] Trenberth, Kevin E., John T. Fasullo, and Jeffrey Kiehl. "Earth's global energy budget." *Bulletin of the American Meteorological Society* 90, no. 3 (2009): 311-324.

[27] Tenaga Nasional Berhad Malaysia, "Pricing & Tariffs," TNB, Janaury 1, 2014. https://www.tnb.com.my/commercial-industrial/pricing-tariffs1.