IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

International Journal of Sustainable Development and Planning
Vol. 17, No. 6, October, 2022, pp. 1705-1712
Journal homepage: http://iieta.org/journals/ijsdp

Comparative Study on Performance of Wind-Catcher Shading Device and Other Types of Shading Device on Residential Houses in Tropics

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https://doi.org/10.18280/ijsdp.170603

Received: 13 April 2022
Accepted: 15 September 2022

Keywords:
external shading devices, indoor thermal comfort, tropic climate, wind-catcher shading device

ABSTRACT

The optimal shading system plays a significant role in a sustainable environment in controlling the amount of excessive sunlight and reducing the thermal discomfort of occupants. External shading device requires many design considerations such as solar altitude, control strategies, and aesthetics to control solar gain, improve the visual environment and reduce glare. Proper external shading design can reduce cooling energy consumption and prevent an overheated indoor environment. This paper focuses on the performance of the Wind-Catcher shading device on the residential house in a hot and humid climate. This study focused on the effect of using Wind-Catcher shading devices on indoor thermal comfort. It proposes solar shading and wind catching design and its performance compared to other types of external shading devices. One of the residential houses in a hot and humid climate is taken as the representative study house of the research. The theoretical and analytical approach will analyze three types of shading devices, such as overhang, box-type shading devices, and wind-catcher shading devices, to validate and compare the shading magnitude amount. The result indicates that the Wind-Catcher shading significantly reduces thermal discomfort hours and allows moderate wind flow into the room rather than other shading types.

1. INTRODUCTION

1.1 Background study

Eliminating indoor thermal discomfort while receiving enough sunlight by installing proper external shading devices regaining interest in environmentally friendly building design. Well-designed shading devices can partially benefit from reducing heat loads in natural daylight, reducing glare the occupant's preference, and providing visual relief [1]. Building surfaces directly exposed to sunlight, such as windows, walls, and roofs, can admit heat and increase the energy needed for cooling. Whether direct or indirect sunlight, the building surfaces on which the sun's rays fall must be protected to avoid the inflow of heat [2]. Excessive solar gain causes an increase in indoor air temperature, consequently contributing to cooling load in the summer. Therefore, using appropriate shading devices reduces excessive solar gain and improves indoor climatic conditions while energy savings in the building can be achieved [3].

The basic function of the shading device is to intercept the sun rays before intruding on the building interior. However, an improper shading design can also block the view out, and eventually, it can affect the aesthetics of the building negatively [4]. The effective shading device design will depend on the solar orientation of a particular building façade. For example, the horizontal overhangs are very effective at shading south-facing windows when the sun angles are high. However, it is ineffective at blocking low afternoon sun from a west-facing window in the summer [5]. Thus, the design consideration of external shading devices needs special attention. The movable or adjustable design excludes solar radiation during overheated periods and admits it during underheated periods [6]. External shading devices have been utilized extensively in tropics residential buildings to control the amount of daylight entering buildings. In hot and humid region, daylighting in building should be carefully designed as there is problem such as heat gain. Thus, small openings and shading devices are considered the main features of the building to control excessive penetration of direct sunlight [7].

Among the components of the building, the envelope is the window component, whose overall heat transfer coefficient is normally five times greater than any other components and is responsible for about 60% of the total energy consumption of the building [8]. Therefore, external solar shading has become an important system for optimizing and controlling solar radiation entering indoor space to improve indoor thermal comfort and reduce energy consumption. However, design consideration of external shading device should be carefully taken into account as the unproper shading can also have negative effects, including weakened winter solar gain and increased electricity consumption for lighting. In this framework, overhang, box type shading devices which are the basic form of external shading devices mostly used in the tropics, and the new proposed wind-catcher shading device, will be studied comparatively to understand the shading performance on the building surface area.

1.2 External shading devices design

The design of shading devices should be carefully taken into consideration because its thermal evaluation demands an extensive understanding of the mechanics of the sun's position and the sun path diagram. In tropical climates, building designers should keep solar radiation away from the transparent elements of the building's envelope. As all facades receive solar radiation from different angles all year round, each orientation should be designed separately. The most sun-exposed surface of the building, especially in a tropical climate, the south orientation surface faces strong sunlight in the summertime. The altitude of the sun path, which depends on the location of the desired country, also varies with the seasons of the year. Detailed sun direction calculations should be done for different time zone and seasons changes to understand the different impact of shading by external shading device of the whole year.

2. CLIMATE OF PROPOSED SITE AREA

2.1 Origins of site area

The previous research is related to using local building materials to achieve indoor thermal comfort. In this study, the emphasis will be on the same target area as the previous study because it targets the same purpose of achieving optimal indoor thermal comfort in a hot and humid climate. The site area was in Dala, Yangon Township, Myanmar, with a hot and humid climate. According to the city's urbanization, the sub-urban area is developing into an urban standard of living. The Republic of the Union of Myanmar, formerly known as Burma, which is one of the Southeast Asia countries. Myanmar is bordered by Bangladesh and India to its northwest, China to its northeast, Laos and Thailand to its east and southeast, and the Andaman Sea and the Bay of Bengal to its south and southwest.

Yangon was the capital city of the Republic of the Union of Myanmar from 1948 to 2006, and nowadays, it is the main central commercial city in Myanmar [9]. As Yangon is the CBD area, it has become the main growing city in Figure 1. The population in Yangon is also dramatically increasing from 30 years ago, with the population increasing yearly to approximately 6.2 million in 2017.

Source - Yangon Information

Figure 1. Yangon city 2017

By 2040, the city is expected to become a megacity with 10 million inhabitants, according to the Yangon Vision 2040 [10]. It is suggested that the increasing population can lead to high demand for energy consumption in Yangon. Many researchers nowadays aim to solve the issue using sustainable and energy-saving methods [11]. The study area is a suburban area, and within a few years, it is estimated that the target area will be more developed into an urban standard living zone after the connection bridge between the Yangon downtown area and Dala township is built, as in Figure 2 [12].

Source - Yangon Expansion

Figure 2. Construction of a new bridge between Dala and Yangon

2.2 Local climate condition

Dala City, Yangon township, lies 27m above sea level and has a tropical climate. The microclimate of the site area is classified as a Tropical savanna climate (Aw) with dry-winter characteristics of average monthly precipitation by the Koppen-Geiger system [13]. Myanmar has three kinds of seasons: the hot, dry inter-monsoon season (mid-February to mid-May), the rainy southwest monsoon (mid-May to late October), and the cool, relatively dry northeast monsoon (late October to mid-February). In winter, there is much less rainfall than in summer. The average annual temperature in Dala is 27.3℃, and the rainfall amount annually averages 2374 mm. April is the hottest month of the year, which averages around 30.4℃. In January, the average temperature is 24.9℃, the lowest average temperature of the whole year. The driest month is January, with 6.58 mm of rain. Most precipitation falls in August, with 676.75 mm of rainfall [14].

2.3 Observation of sun path in proposed area

To properly design shading devices, it is necessary to understand the altitude and azimuth angles of the sun. For the study of shading area, the azimuth and altitude angle of the sun direction for the whole year is needed to focus on detail. The target area has three seasons: summer, rainy, and winter. Depending on the seasons, the altitude angle of the sun also differs. Generally, the summer sun's altitude angle is higher than in winter. The solar altitude of the chosen site area is generally described in the paper [15]. Figure 3 shows the solar altitude angle of summer and winter sunlight falling on the southern elevation of the window.

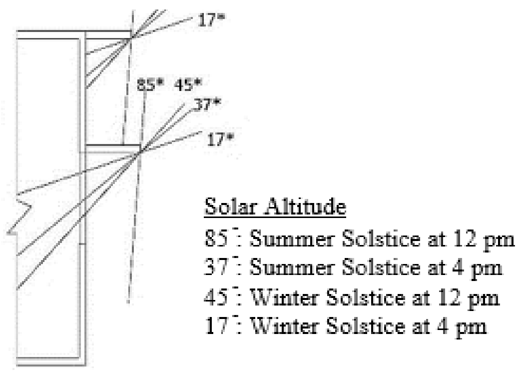
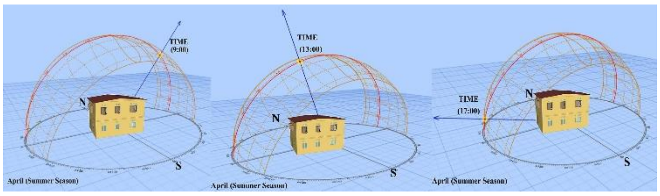
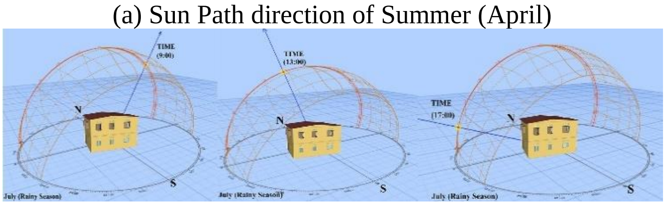


Figure 3. Solar altitude on window section of the south elevation wall

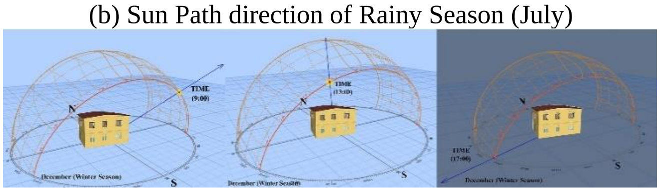
Depending on the three seasons of Myanmar: the hot season, the rainy season, and the cool season, the shading device design will be considered for the adaptation to all kinds of seasons. Thus, the representative month will be chosen with the hottest month, heavy rainfall month, and coolest month, such as summer as April, Rainy season as July, and winter as December. The representative time of the day is defined as 9 am (the morning solar radiation), 1 pm (the afternoon solar radiation), and 5 pm (the sunset solar radiation). These three sets of time will be acquired in the above three chosen months, as shown in Figure 4.



(a) Sun Path direction of Summer (April)



(b) Sun Path direction of Rainy Season (July)



(c) Sun Path direction of Winter (December)

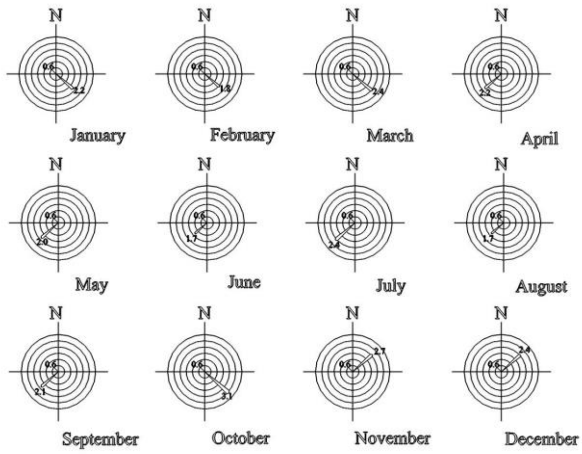
Figure 4. Sun path of three seasons

Table 1. Sun angle of three seasons

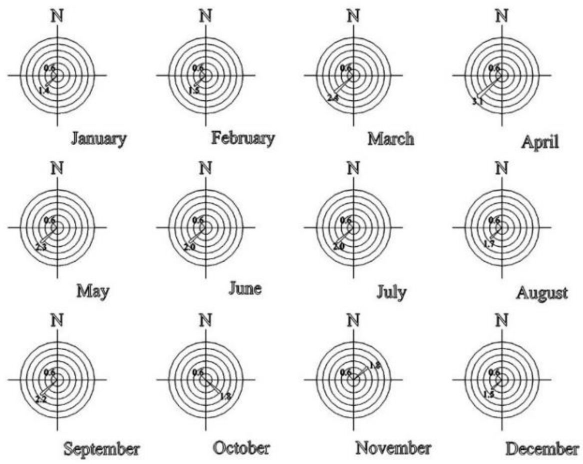
Season	Time	Altitude	Azimuth
Summer	9:00	44.38°	92.77°
	10:00	58.7	98.43
	11:00	72.6	111.66
	12:00	82.88	168.96
	13:00	75.05°	243.81°
	14:00	61.32	259.62
	15:00	47.07	266.42
	16:00	32.73	271.05
	17:00	18.44°	275.03°
Rainy Season	9:00	44.7°	75.96°
	10:00	58.6	75.93
	11:00	72.5	71.32
	12:00	84.52	82.25
	13:00	77.57°	294.75°
	14:00	57.01	284.86
	15:00	43.06	283.71
	16:00	15.43	284.73
	17:00	22.32°	286.86°
Winter	9:00	30.49°	130.96°
	10:00	44.67	148.97
	11:00	47.38	159.32
	12:00	50.01	179.86
	13:00	47.43°	200.39°
	14:00	40.48	217
	15:00	25.57	228.89
	16:00	19.17	237.26
	17:00	6.78°	243.22°

Depending on the solar azimuth and altitude angle, the sunlight falling into the interior of the room varies from morning to evening. Thus, the sun angle changes with time are observed in detail to design an optimal external shading device, as seen in Table 1. The proposed building is facing east orientation.

By analyzing the above data in the table, it is found that the altitude of the sun angle is highest during the summer and rainy seasons. Therefore, as for the house facing the Southeast orientation, in summer, most sunlight will be received from the North and the South orientation, while the winter sunlight will be received from the South orientation. The study site receives an average temperature around 34℃ with strong sunlight in summer and in winter around 24℃. An external shading device design will be built to adjust the sun's orientation while keeping the house's optimal indoor thermal comfort.



(a) Monthly Mean Wind Speed and Direction (mph) at (09:30) hrs



(b) Monthly Mean Wind Speed and Direction (mph) at (18:30) hrs

Figure 5. Monthly Mean Wind Speed and Direction (mph) (2006-2015)

2.4 Wind speed and direction

For summer, the wind speed is generally about 2.079 mph (0.93 m/s), the rainy season averages around 1.925 mph (3.09 m/s) to 2.325 mph (1.04 m/s), and in the winter season, the wind speed ranges around 1.55 mph (0.69 m/s) to 2.275 mph

(1.02 m/s). According to the Bio Climate Chart of Yangon, generally, the wind blows from the Southwest direction. Mostly the South wind blows in March and June while the wind blows from the North direction in winter. The monthly mean wind speed and direction from 2006 to 2015 are shown in Figure 5.

3. METHODOLOGY

Most of the research involving building physics environmental simulation methods is the norm. However, in this framework, the study of external shading devices' effects on indoor air temperature will be conducted by quantitative analysis. Originally, the shading configurations that minimize solar exposure for the South and North orientated windows are installed with a 20.3 cm overhang length in the study house. The present condition of the shading area is not enough to keep indoor thermal comfort. Thus, three types of external devices will be compared by simplifying equation formulations for different shading areas covering on windows of a southwest - orientated wall.

In three seasons, the shading area falling on the window surface will be calculated from the morning at 9 am to the evening at 5 pm. Each period's resulting shading area will be analyzed and evaluated its effectiveness. And then, by summing all shading areas fallen on the window, the total shading area will be divided by the window façade area. The calculated result is the shading area magnitude ratio of the shading device. Each result of shading devices will make a comparison to suggest better types of shading device design which have advantages in maintaining optimal indoor thermal comfort in a hot and humid climate.

3.1 Typology of shading devices

Shading devices can block direct solar radiation and reduce the influence of indirect illumination: diffuse sky radiation and the ground level. A shading device can be divided into internal shading and external shading.

- Internal shading devices are generally used in the window's inner façade, which can be adjustable. Interior elements can be blinds, curtains, and others.
- The external shading device is the shading element installed at the exterior façade of the building. It can reduce thermal energy effectively to anticipate and reduce radiation before glass surfaces. There are two types of external shading devices: fixed and adjustable devices.

There are several types of external shading device designs. In this study, three types of design will be studied in detail.

(1) Horizontal shading devices (overhang)

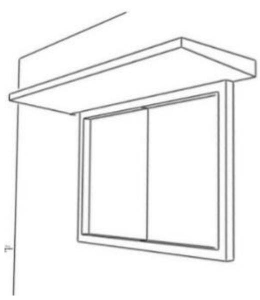


Figure 6. Horizontal shading device

As shown in Figure 6, this type of shading is useful for building facades where the sun's rays are at a high angle of incidence where the sun appears high in the sky. It is specially designed for northern or southern facades of a building with a higher latitude of the summer mid-day sun. However, depending on the orientation of the building, overhang shading is the inefficiency of strong sunlight entering from the side directly into the room.

(2) Combined shading device (box type shading)

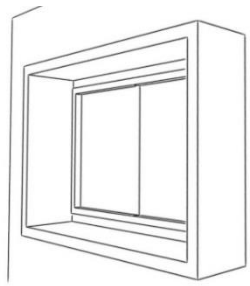


Figure 7. Combined shading device

As in Figure 7, a combined shading device is used for conditions where different times of the year warrant different shading needs. It has vertical and horizontal orientation options and has more potential than overhang shading. The box-type shading device allows better yearly performance, reducing incident solar radiation on the window and decreasing artificial lighting consumption. The drawback is that it can somehow prevent wind direction which entering the room.

(3) Wind-catcher shading device

Figure 8. Wind-catcher shading device

A wind-Catcher shading device is a proposed design for this study. Most shading devices emphasize reducing direct solar radiation and avoiding trapping heat in the room. Obtaining indoor thermal comfort, air temperature, and wind velocity play an important role. This design is considered not only for reducing direct solar radiation but also for receiving cool wind. The idea was inspired by a traditional wind catcher called "Malqaf," used in Egypt to create natural ventilation in buildings. Moreover, the Wind-Catcher shading device is adjustable, as shown in Figure 8.

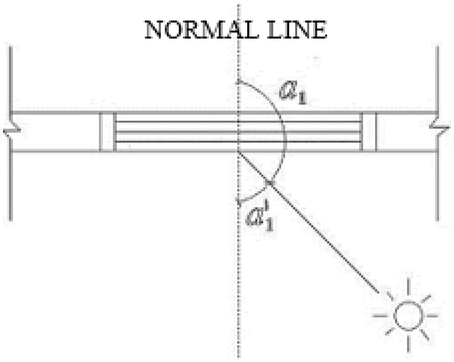
Depending on the sun and wind flow movement, the shutter can adjust easily by moving 180°. The 45° angle between the shutter and the wall will allow catching cold breeze air to enter the room while the body of the shutter is providing to block direct sun rays. The shutter material will be used local material called "*Dani*." In a previous paper [16], it can be found the properties of *Dani* local material and its effect on enhancing indoor thermal comfort. As the *Dani* material is made from dry palm leaves, unlike other shutter materials such as metal, plastic, or concrete, it has the potential to absorb sunlight and reduce transmission indoors. Wind can also easily flow through the little gap of the *Dani* Surface shutter. The advantage of using *Dani* material on shading devices is that it is low cost, flexible to fold, environmental-friendly and suitable to use in a hot and humid climate.

4. QUANTITATIVE ANALYSIS OF SHADING AREA

4.1 Shading principle

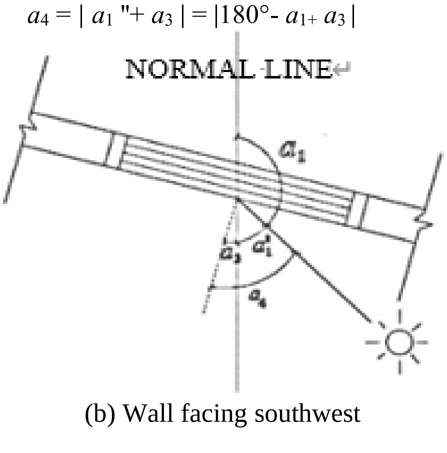
The external overhang shading device, whose configuration and installation position are similar to the single inclined canopy with the highest efficiency factor value. The shading principle for the horizontal shading system is the same for the eave and corridor. The shading area calculation method of this study references the paper on shading area covering southerly orientated windows calculation method [17]. The orientation for a south-facing wall has three conditions. They are the wall facing directly south as in Eq. (1), facing Southwest, as in Eq. (2), and facing Southeast, as in Eq. (3) as shown in Figure 9 [17]. The equations of a4 for the wall orientated directly south, Southwest, and Southeast are expressed as follows.

$$a_4 = |a_1'| = |180° - a_1| \tag{1}$$



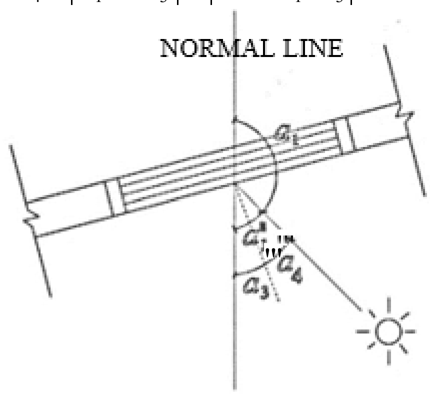
(a) Wall facing directly south

$$a_4 = |a_1'' + a_3| = |180° - a_1 + a_3| \tag{2}$$



(b) Wall facing southwest

$$a_4 = |a_1''' - a_3| = |180° - a_1 - a_3| \tag{3}$$



(c) Wall facing southeast

Figure 9. Wall facing orientation

where, a_1 is solar azimuth, a_3 is wall azimuth that the angle between the wall-normal line and local longitude; a_4 is the angle between the wall-normal line and the projection line of solar ray on the ground plane. By the trigonometric function, the wall orientation, and the angle between the wall-normal line and vertical projection line of the solar ray, the tangent b_1 is formulated as Eq. (4) as in Figure 10.

$$\tan b_1 = \frac{\tan a_2}{\cos a_4} \tag{4}$$

where,

b_1: the angle between the wall-normal line and the vertical sunlight projection

a_2: solar altitude

a_4: angle between wall-normal line and projection line of solar rays on the ground plane

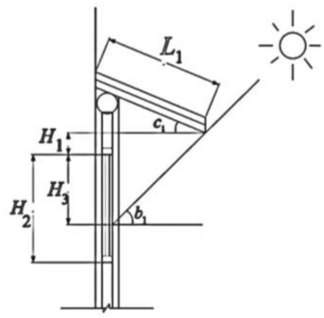


Figure 10. Schematic of window shaded by overhang

After calculating window orientation and the angle of sunray fall onto the window, the shading height H_3, generated by the overhang, will be formulated as Eq. (5), which results in input in the calculation of shading area.

$$H_3 = L_1 \times \cos c_1 \times \tan b_1 - H_1 \tag{5}$$

where,

H_3: Shading Height

L_1: The depth of the overhang

c_1: The inclined angle of the overhang

b_1: The angle between the wall-normal line and the vertical sunlight projection

H_1: The height from the bottom edge of overhang to the top edge of the window

When $H_3 < H_2$, the height of the shading surface area is less than the height of the window surface area, and the shading area covering the windows (SHA), as in Figure 11, will be formulated as follows Eq. (6).

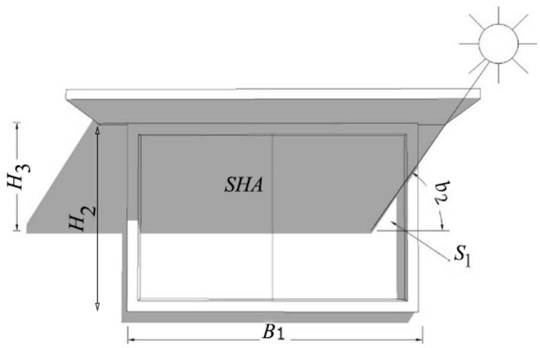


Figure 11. Schematic of shadow area coverage

$$\begin{aligned} SHA &= B_1 \times H_3 - S_1 \\ &= B_1 \times H_3 - \left(H_3 \times \frac{H_3}{\tan b_2} \times \frac{1}{2}\right) \\ &= B_1 \times H_3 - \left(H_3 \times \frac{H_3}{\frac{\tan a_2}{\cos(90° - |180° - a_1 + a_3|)}} \times \frac{1}{2}\right) \end{aligned} \tag{6}$$

where,

SHA: Shading Area
B_1: Length of window
H_3: Shading Height
S_1: Unshaded Area
b_2: Inclined angle of solar radiation and the bottom edge of the shaded area
a_1: Solar azimuth
a_2: solar altitude
a_3: Wall azimuth that the angle between the wall normal line and local longitude

However, when $H_3 > H_2$, the height of the shading surface area is greater than the height of the window surface area, and the shading area covering the windows (*SHA*) should be formulated as follows Eq. (7).

$$SHA = B_1 \times H_2 - \left(H_3 \times \frac{H_3}{\frac{\tan a_2}{\cos(90° - |180° - a_1 + a_3|)}} \times \frac{1}{2}\right) \tag{7}$$

where, H_2: Length of window.

The shading magnitude ratio is formulated with the result of the shading area divided by the Window surface area as in Eq. (8).

$$\text{SMR} = \frac{\text{Shading Area on Window}}{\text{Window Area}} \tag{8}$$

5. RESULT AND DISCUSSION

In this research, the study house is oriented in the Southeast direction. Additionally, the windows on the south side wall compare different shading devices, as shown in Figure 12. The reason is the layout of bedrooms and a living room are generally on the south side of the house in study area. According to the previous study, sunlight enters from the south side of the room, leading to a heat trap that raises the occupant's discomfort. The climate of the target area is normally high in air temperature and generally ranges around 21℃, even in winter. Therefore, controlling moderate cooling and heating loads is necessary for the tropics. Thus, the window orientation is calculated as the wall facing the Southeast orientation equation as described in Eq. (2).

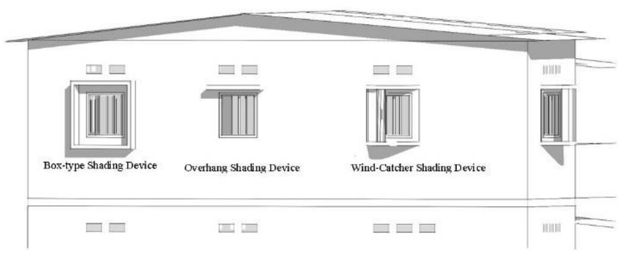
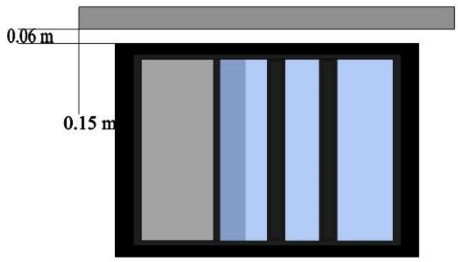
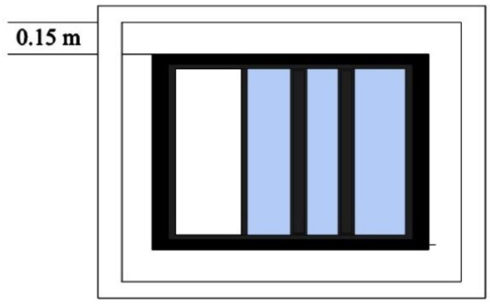


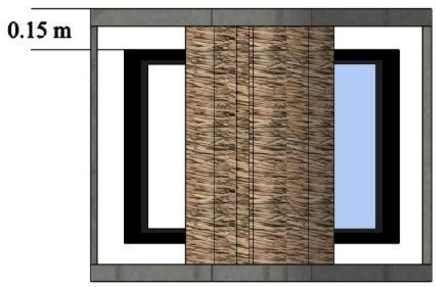
Figure 12. Comparison of sun shading devices



(a) Overhang shading device



(b) Box-type shading device



(c) Wind-catcher shading device

Figure 13. Representative types of shading devices

The selective representative types of shading devices of this framework, as shown in Figure 13, are (a) Overhang Shading Device, (b) Box-Type Shading Device, and (c) Wind-Catcher Shading Device. The depth of the shading devices is 0.36 m, and the distance between the top of the window and the bottom of the shading device is 0.15 m. The window size is the width of 1.2 m × the height of 0.8 m; the total window area is 0.96

m^2. The fallen shading area on the window differs depending on the time and season of the year as the change of sun path direction. Besides this, different types of shading devices' areas are calculated by the equations above for dawn to dusk. One representative day for each season has been chosen to make a comparison of three shading devices in each season.

5.1 Comparison of shading device

(1) Shading devices performance on summer

It is found that in summer, among the three types of shading devices, box-type and Wind-Catcher shading devices offer only a slight difference in magnitude of shading area on the facade of the wall. In summer, the target area has high solar radiation intensity, and enough sun penetration coverage is necessary for windows. The study window surface area is 0.96 m^2, and it is found that except for overhang shading devices, the rest offer enough shading in the afternoon. The shading Magnitude ratio is formulated to be seen as the result of the shading area falling on the window surface area. The nearer the ratio, 1 means full shading of the window.

The shading magnitude ratio is resulted by dividing the shading area on the window surface area by the window surface area. According to the graph in Figure 14, the mid-day time, the amount of shading area by the Wind-Catcher is a little bit higher than others, meaning the coverage on the window surface gave almost enough shading. It can be found that all three types of shading device in summer reaches the shading ratio nearer 1, which happen when the sun is at its highest position during the afternoon time. Generally, analysis shows that the performance of the Box-type shading device and Wind-Catcher shading device has only slightly different conditions for the whole day. However, the Wind-Catcher shading device gives stable shading magnitude for almost the day.

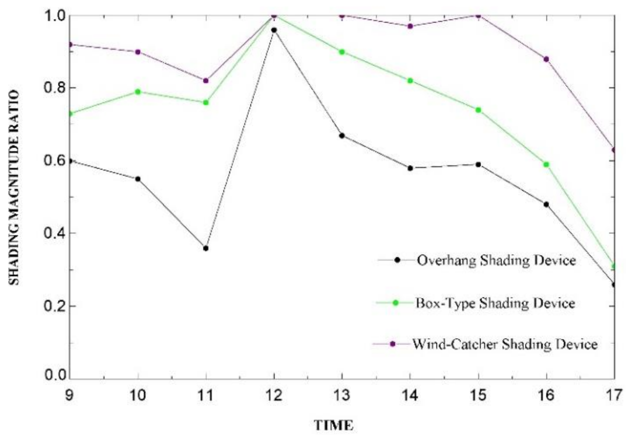


Figure 14. Comparison of shading magnitude ratio of three types of shading device (summer)

(2) Shading devices performance in rainy season

Figure 15 shows that in the morning period from 9 am-noon, the shading ratio of the three shading devices has the same pace at different distances. Among them, the Wind-Catcher shading device rises to ratio one, giving full shading in the afternoon. In the rainy season, the performance of the Wind-Catcher shading device shows its potential in comparison with other types. However, the intensity of sunlight during the daytime of the rainy season is not as high as in summer. Though the rainy season, on some sunny days, the shading of the window should emphasize having enough shading in critical daytime. In all aspects, Wind-Catcher Shading Device offers the most enough shading for the whole day.

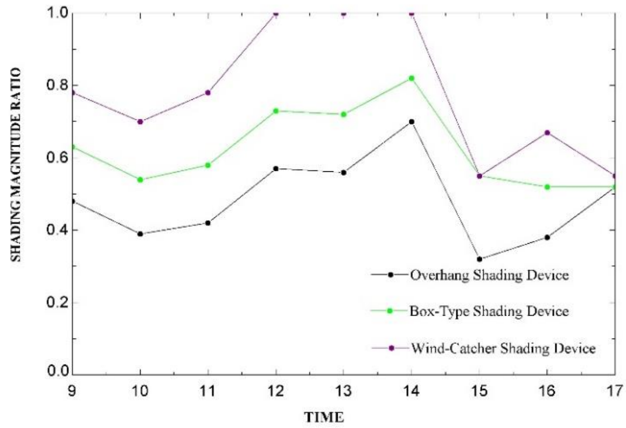


Figure 15. Comparison of shading magnitude ratio of three types of shading device (rainy season)

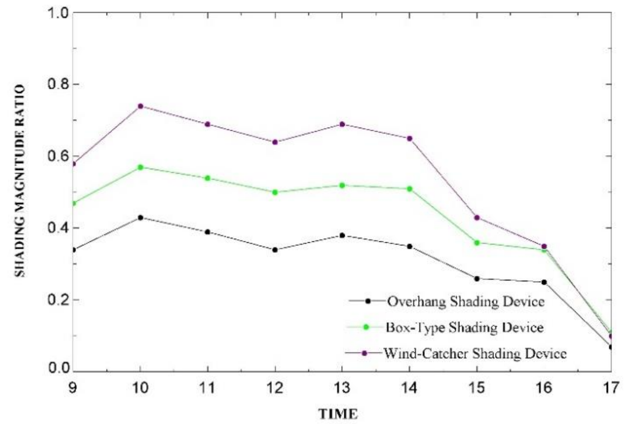


Figure 16. Comparison of shading magnitude ratio of three types of shading device (winter)

(3) Shading devices performance in winter

In winter, the sun rotates in the southern path at a low altitude, and the shading area of the shading device results lower than the shading area of other seasons. As seen in Figure 16, even the performance of the Wind-Catcher shading device is only nearer the ratio of 0.8, while the rest ranges the shading magnitude ratio of 0.6 and 0.4. As the winter solstice falls on the Southern side, the South facade wall receives the most sunlight in winter. On the other point, morning sunlight must pass into the room to reduce the cooling load of the room in winter. In the target area of winter, the early morning and the evening gets colder than in the daytime. So, getting full shading of the window for the whole day is unnecessary. The shading magnitude ratio also provides a satisfying result of the Wind-Catcher shading device, which maintains the stable amount of required shading in the diurnal time.

6. CONCLUSIONS

The paper focused on the performance of three types of shading devices and their effect on protecting direct sun rays entering the room to avoid heat traps. Originally, the target study house's windows are provided with an overhang shading device, and the occupants felt uncomfortable at the daytime peak. In addition, occupants in that area prefer natural ventilation more than the air-conditioning system. Surprisingly, it is found that the indoor air temperature is higher than the outdoor air temperature in the daytime, according to the previous measurement data. The reason is that the occupants try to close the windows when the strong sun ray falls into the room, which leads to an increased heat load released from the glazing of the window. This type of house requires allowing cool breeze air into the room while blocking the sunlight. The idea for the Wind-Catcher shading device is based on solving this issue which can do both functions.

The box-type shading device also offers enough shading, like the Wind-Catcher shading device. However, the side shading boundary around the window will prevent wind direction from flowing inside the room. The potential point of the Wind-Catcher shading device is that the shutter is movable around 180℃ and can adjust to the occupant's preferable condition at any time in any season. The above theoretical validation and result showed that the proposed Wind-Catcher Shading device performs well on the Southern façade wall at three seasons. The merit of this device is environmentally friendly, favorable aesthetic, and reasonable price as the material of the shading device is made from the local material called "Dani" which is made from palm leaves. Plam leaves "Dani" material is low thermal conductivity and was originally used as roofing material in traditional houses of the study area. It has the advantages of less maintenance and is suitable for all seasons.

In this framework, the effective shading performance of shading devices is studied, and the results show that the Wind-Catcher shading device is the most recommendable type among the three types of shading devices. Although the shading performance of the shading device is mainly focused on this study, the wind flow calculation of the wind-catcher shading device will be done in further study to understand ventilation improvement. To conclude, the Wind-Catcher shading device is appropriate to install at North, South, East, and West facing windows as the adjustable shutter design can prevent strong sunlight from different angle of the sun in whole day. Therefore, it is recommended that a Wind-Catcher shading device is suitable to install as an external shading device to increase shading area and indoor thermal comfort in residential houses, especially in the tropic area.

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NOMENCLATURE

mph	Mile per hour (wind speed unit)
m/s	Meter per second (wind speed unit)
SHA	Shading Area on the window, m^2
SMR	Shading Magnitude ratio