Engineered Science
DOI: https://dx.doi.org/10.30919/es1309

A Comparative Analysis of Variables Affecting Heat Gain Through Louvers Shape and Wall by Evaluating the Overall Thermal Transfer Value (OTTV)

Winai Mankhatitham,[1] Phadungsak Rattanadecho[2] and Ratthasak Prommas[3,*]

Abstract

The selection of sun louvers is essential for effectively preventing heat from entering buildings. The shapes of sun louvers are not for beauty or effectiveness in preventing heat transfer through walls and building voids. This study compared the heat prevention properties among three types of sun louvers: a straight shape (I-shape), a curve shape (C-shape), and an overturning V-shape (Λ-shape) by simulating installation in the testing room of 72,000 mm and then comparing the values of heat transfer through the walls and windows of a room without a sun louver (Type A) and rooms with three types of sun louvers (Type B, C, and D). The purpose was to reach a conclusion about which sun louver is effective for sun protection and which direction is best for preventing heat from buildings. The summary shows that sun louver Type D (Λ -shape) provides the best shading effectiveness in the south (S) with Overall Thermal transfer value (OTTV) = 54.57 W/m^2 and Shading Coefficient (SC) = 0.291 and is helpful for architects and engineers in selecting sun louvers suitable for buildings based on energy saving and sustainability concepts.

Keywords: Overall Thermal transfer value; Sun louver; Shading coefficient; Shading divide
Received: 13 March 2024; Revised: 25 November 2024; Accepted: 10 October 2024.
Article type: Research article.

1. Introduction

Designing a building to suit the environment and climate is a top priority for designers. The concept of using a nature-dependent system called '*Passive Design*' is a concept for saving energy and increasing the comfort zone for building users for buildings in hot and humid climates.[1,2] The amount of solar radiation is high during the daytime, and it transfers heat through the building walls and roofs, causing cumulative heat inside the buildings. According to the survey of energy consumption in commercial buildings, air conditioners in shopping malls, hotels, hospitals, offices, and educational institutions consume up to 84% of the total electricity consumption to cool the indoor temperature.[3] Therefore, the effective use of shading that is suitable for the direction of the sun acting on the earth's surface is a good device for solving the problem of heat transfer through walls.[4]

The popular shapes of sun louvers are in various forms, and basic geometric shapes are used in design and development.[5] According to the survey of shading fins, the basic shape design is in straight and curved shapes before further developing into other shapes such as L-shape, horizontal I-shape, C-shape, and Z-shape, *etc*.[6] The shape of sun louvers is an important factor for preventing solar radiation,[7] and suitable shapes can provide good shading for preventing solar radiation from directly contacting building surfaces or windows.[8] There are six important parameters: angles of rotation, shading ratio, fin spacing, distance from the wall, fin width, and fin angles of

[1] *Rattanakosin College for Sustainable Energy and Environment (RCSEE), Rajamangala University of Technology Rattanakosin, 96 Moo 3, Phutthamonthon Sai 5 Rd. Salaya, Phutthamonthon, Nakhon Pathom, 73170, Thailand*
[2] *Center of Excellence in Electromagnetic Energy Utilization in Engineering (CEEE) Department of Mechanical Engineering, Faculty of Engineering Thammasat University (Rangsit Campus), 99 Moo 18, Klong Luang, Pathum Thani, 12120, Thailand*
[3] *Department of Mechanical engineering, Faculty of Engineering, Rajamangala University of Technology Rattanakosin, 96 Moo 3, Phutthamonthon Sai 5 Rd. Salaya, Phutthamonthon, Nakhon Pathom, 73170, Thailand*
**Email:* ratthasak.pro@rmutr.ac.th (R. Prommas)

inclination.[9] Regarding heat evaluation, the overall thermal transfer value (OTTV) is one of the indicators of building performance for evaluating heat gain flowing through building walls, according to ASHRAE 90-75 (1975). In Thailand, energy conservation is governed by laws such as the Energy Conservation Promotion B.E. 2535 (1992) and the Ministerial Regulation Prescribing Type or Size of Building and Standard, Criteria, and Procedure in Designing Building for Energy Conservation B.E. 2552 (2009), which address issues related to heat gain through walls.

The purpose of this presentation is to analyze the sun protection performance of 3 types of sunscreens, namely, straight shape (I-shape), curved shape (C-shape), and overturning V-shape (Λ-shape), by studying the size, proportion, and spacing of sub-panels and comparing the thermal protection efficacy of the sunshades. The study involved the computation of the OTTV of the building wall in eight different orientations and the examination of the factors influencing heat energy transmission. In order to mitigate heat radiation from contact with the building envelope, it is imperative to consider the judicious selection of the sun shade's configuration. It is important to refrain from obstructing the external perspective and visual attractiveness of the architectural enclosure. Public education institutions will use the research findings as design guidelines to prevent heat from entering their buildings. This emphasizes general building construction standards and the selection of locally available materials that are inexpensive, lightweight, and simple to implement.

The concept is to control heat gain so as not to overflow through the building according to the criteria because overflowing heat gain causes waste energy consumption in the building. For an educational building, the heat must not exceed 50 W/m^2 through the building walls and 15 W/m^2 through the roof.[10] The most critical parameters affecting the amount of heat in the building are the shading coefficient (SC) and the direction of the opening, which are essential variables in controlling the amount of heat in the building.[11-13]

The concept of designing sunshade panels aims to mitigate heat transfer via the building frame. There are several important factors to consider, including the direction in which the building wall receives sunlight and the fact that the sun's rays acting on the building wall will have different effects on heat transfer. For example, Sheng Liu *et al*. studied the design of sun louvers on opaque walls of residential buildings in eight directions, and they also studied the inclining angles of vertical and horizontal panels in different projection lengths. They found that a sun louver on an opaque wall in the west could save energy by more than 8%, indicating that fixing a sun louver to cover the whole wall, both opaque walls and voids, can save energy in the building.[14] The Earth's orbit around the Sun causes a change in the angle of sunlight in both the azimuth and the ultimate. The altitude varies throughout the year. Therefore, the design concept of adjustable-angle sunshade panels has been developed and used more widely. The research results show the higher efficiency of the sunshade panel in preventing heat radiation from entering the building. Aviruch Bhatia *et al.* calculated the equivalent solar heat gain coefficient through windows with fixed and dynamic shading. The researchers found that adding an adjustable-angled shading device to the windows decreased their solar heat gain coefficient (SHGC). This reduction in energy consumption was between 0.11% and 7.57%.[15-20] However, using adjustable sun louvers will require construction costs. Government buildings or those with budgetary constraints might not find the installation and maintenance suitable for the evaluation of total heat transfer through building envelopes (OTTV). Outdoor factors such as air temperature must be taken into account. Period Heat transfer is influenced by the sun's angle on the building's wall and the quantity of solar radiation it emits. Variables of the building factors include wall material, glass, roof, shading coefficient, shade area, wall paint, thermal conductivity, heat reflection value of the material, *etc*. All of the above variables are important in evaluating OTTV values. The variables with the most significant effect on heat transfer into the building are the window-to-wall ratio (WWR) and the SC.[21-26]

2. Methods

The research methodology of this study focused on sun louver models affecting OTTV through the building envelope in 8 directions under the simulating conditions of a prototype room and building location. The study area was located in Bangkok, Thailand, and the climate data in 2023 were used for the evaluation, as described below (Fig. 1). The researcher will experiment with the Building Energy Code (BEC) scheme. The measurement period is December. The outside air temperature is recorded at 32 °C. The window area is 6,589 mm^2. The tilt angle is 0°, and the sunshade overhang is 1,500 mm. The humidity and wind speed are not taken into consideration.

2.1 Virtual simulated classroom

The virtual classroom used for evaluating heat transfer through the walls was simulated with the Autodesk Revit program. The dimensions of the simulated classroom were 8,000 × 9,000 × 3,000 mm, providing 72,000 mm of usable area in the Bangkok location (Fig. 2). The window's area was

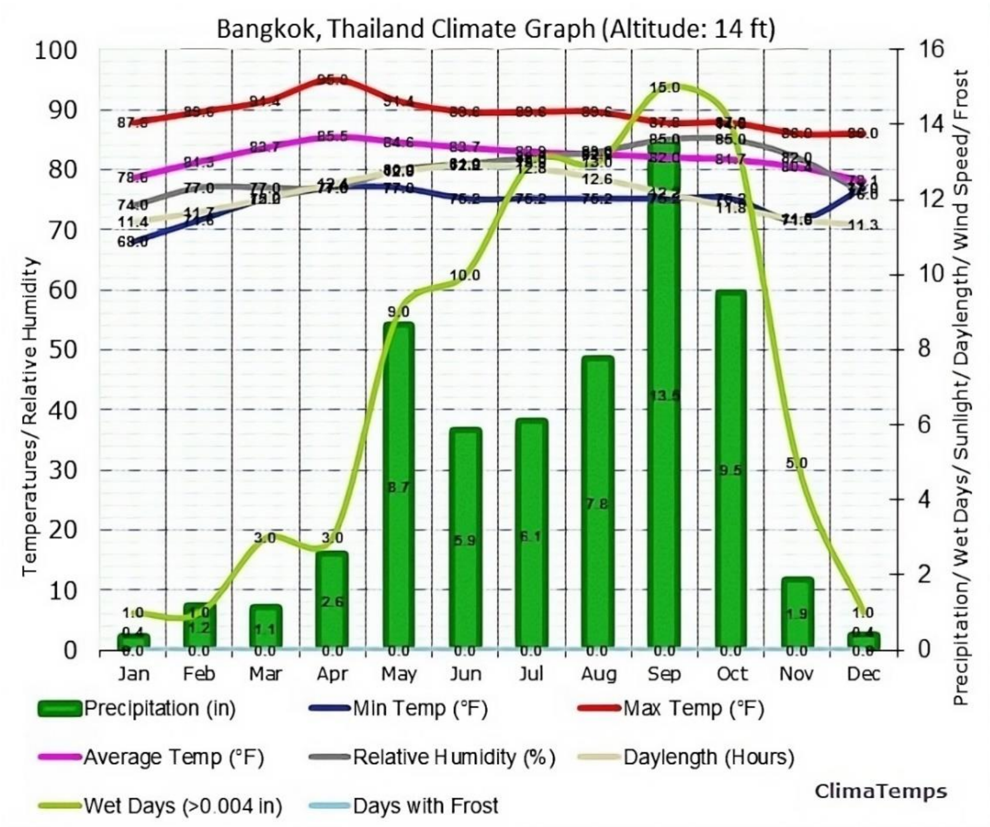

Fig. 1 Shows the climate in Bangkok, Thailand, 2023. (Data source: Https://www.climate.top/thailand/bangkok/graphs/).

6,589 mm^2 with 60 WWR of the void to total window wall ratio and 90 WWR of the void to total door wall. The floor was laid with 300 x 300 mm ceramic tiles. The walls were built with lightweight concrete with 70 mm thickness, the voids were made of clear glass with 6 mm thickness, the concrete slab roof was 100 mm thick and padded with 75 mm thickness fiberglass insulation, the gypsum board ceiling was 9 mm thickness (Table 1), the sun shading device on the window was with 1,500 mm projection length of concrete fins, and the sun shading device on the door was with 1,500 mm projection length of concrete fins (Fig. 3).

Table 1. Material properties of the tested classroom.

Types	Description	U Value (W/m^2)
Exterior Wall	Light Weight Concreate 70 mm Plaster 15 mm 2 sides	1.55
Window	Clear glass 6 mm	5.52
Roof	Concreate Slab 100 mm Fiberglass Insulation 75 mm Gypsum board 9 mm	1.61

2.2 Overall thermal transfer value

The concept of evaluating heat energy flowing through buildings has been around for more than 45 years. Later, different rules and regulations have been developed continuously. As the current building's appearance and characteristics are more beautiful and complicated, the main principle for evaluating heat gain through walls is implemented with 3 important components: opaque walls, voids, and roof. To evaluate the OTTV of each external wall, the following equation (1) is used.

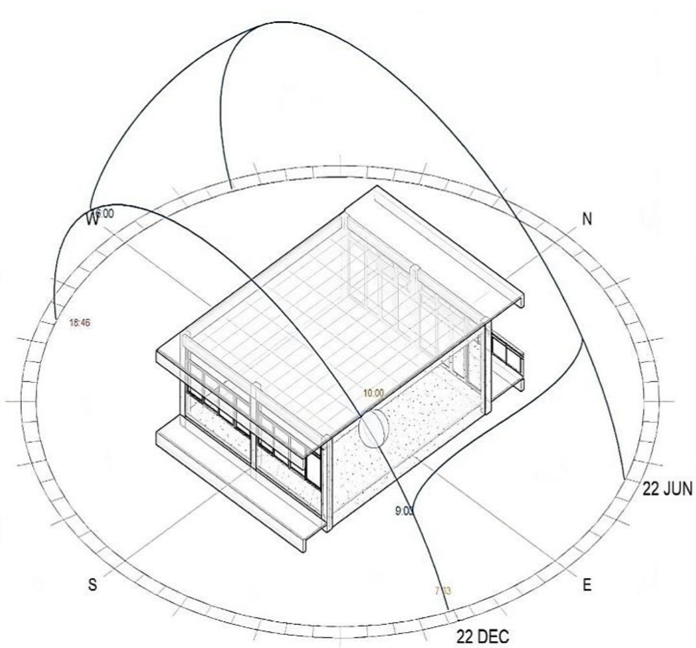

Fig. 2 The display of 3D classroom simulation through the Autodesk Revit.

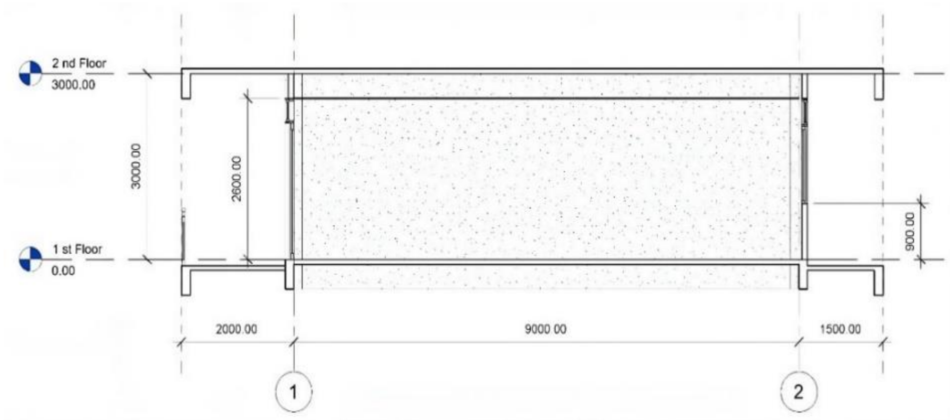

Fig. 3 The section view of the classroom without sun louvers.

$$OTTV = (Uw)(1 - WWR)(TDeq) + (Uf)(WWR)(\Delta T) + (WWR)(SHGC)(SC)(ESR) \quad (1)$$

where $OTTV$ is the overall thermal transfer value of a wall (W/m^{2}K), U_w is the thermal transmittance of the opaque part of a wall, U_f is thermal transmittance of the opaque part of a fenestration, WWR is the window-to-wall ratio, ΔT is temperature difference between exterior and interior design conditions (°C), TD_{eq} is equivalent temperature difference for the opaque part of a wall, SHGC is solar the heat gain coefficient, SC is shading coefficient, and ESR is the effective solar radiation (W/m^2).

The following Equation (2) is used to evaluate the OTTV of the average external wall of the whole building.

$$OTTV = \frac{(Aw1)(OTTV1)+(Aw2)(OTTV2)+\ldots+(Awi)(OTTVi)}{Aw1+Aw2+\ldots+Awi} \quad (2)$$

To evaluate heat gain through voids, apart from considering heat gain through voids, the consideration should be on solar the heat gain coefficient (SHGC) of glass or translucent walls and the SC of the external sun shading devices. The SC is the ratio of solar heat through windows to solar heat through 3 mm thickness glass without sun louvers. Normally, windows of general buildings consist of glass parts and sun shading devices. Therefore, the shading coefficients of glass and shading devices were calculated by using the following Equation (3).

$$SC = (SC_1)(SC_{2)} \quad (3)$$

The shading coefficient of glass (SC_1) is determined by the manufacturer, so the evaluation was on sunlight acting with glass at 45 from the right angle. On the other hand, the shading coefficient of a shading device (SC_2) depends on each type of shading device. The shading coefficient was calculated from 2 factors: 1) Beam shading coefficient (SC_s) and 2) Diffuse shading coefficient (SC_d) according to the following equation.

$$SC_2 = (SC_s)(SC_d) \quad (4)$$

Regarding the evaluation of heat gain through the roof, the equation was similar to the equation for evaluating heat gain through the wall but different on the angle of inclination and space under the roof. To evaluate heat gain through the roof, the following equation (4) was used.

$$RTTV = \frac{(Ar1)(RTTV1)+(Ar2)(RTTV2)+\ldots+(Ari)(RTTVi)}{Ar1+Ar2+\ldots+Ari} \quad (5)$$

The Q value was used to express all heat gain through the building. This value was calculated from the relationship between heat transfer coefficient, total area exposed to sunlight, and equivalent temperature difference between external and internal parts of the building, as in the following equation.

$$Q = (U)(A)(\Delta T) \quad (6)$$

The calculation for heat gain transferred through windows is similar to the calculation for heat gain through opaque walls but with additional variables, *i.e.*, solar heat gain coefficient (SHGC), shading coefficient (SC), and effective solar radiation (ESR).

$$Qtr = (Uf)(WWR)(\Delta T) + (WWR)(SHGC)(SC)(ESR) \quad (7)$$

2.3 Shapes of sun louvers and parameters

The shapes of the tested sun louvers were of three types: a straight shape (I-shape), a curved shape (C-shape), and an inverted V-shape (Λ-shape) (Fig. 4). The researchers identified a range of materials for the louver section. 1) Lightweight 2) Reasonable pricing. 3) Low maintenance 4) Installation is simple. 5) Thermal conductivity coefficient, 6) Thickness, and 7) Weight. As a result, there are five categories of materials to consider: 1) Aluminum sheet, 2) Fiberboard, and 3) Synthetic Wood Board. 4) Gray Glass, and 5) Cement Board. According to Table 2.

Table 2 shows that aluminum sheets are more suited for use as a material for testing louvers than other materials since they are lightweight, easy to install, low maintenance, and widely available.[27] Although aluminum sheets have higher thermal conductivity than other materials, they are just 1.30 mm thick, weigh 0.85 kg/m, and do not retain heat. This enables quicker

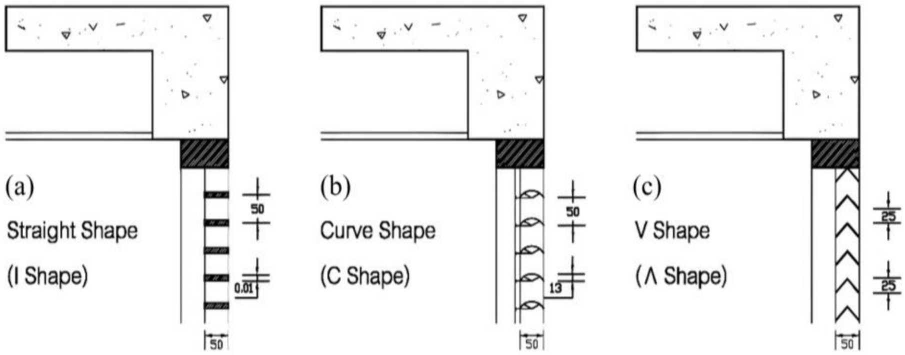

Fig. 4 The section views three types of sun louvers: (a) Straight shape, (b) Curve shape, and (c) V shape.

Table 2. Comparative of different materials for louvers.

Sr. No	Materials / Specific	Aluminum Sheet	Fiber Board	Artificial Wood	Grey Glass	Cement Board
1	Lightweight	Best	Good	Good	Good	Fair
2	Inexpensive	Good	Good	Good	Good	Good
3	Low Maintenance	Good	Good	Good	Good	Good
4	Simple to implement	Best	Good	Good	Good	Fair
5	Thermal Conductivity (W/mK)	211	0.052	0.135	1.053	0.398
6	Thickness (mm)	1.50	10.00	12.00	6.00	16.00
7	Weight (kg/m)	0.85	1.25	1.30	1.50	2.90

heat dissipation than other materials, including all louvers. Furthermore, because no sections come into contact with the building walls, pouring aluminum fins into the structure does not affect its thermal conductivity.

To test the shading efficiency of three types of sun louvers, the selected shading panels were 50 mm wide with the distance between panels at 25-50 mm, the distance to the window at 1,500 mm, vertical shadow angle in the south at 10.00 a.m. and 48° (Fig. 5).

3. Results and discussion

The value of thermal energy moved through the building wall is calculated using the OTTV theory based on Equation (1) and the BEC, which the Department of Renewable Energy Development and Conservation has validated. This ensures that the data obtained are accurate and satisfy the appropriate requirements. The thermal energy must be evaluated using the solid wall area (UW), the void area (UF), and the SC, with the calculation date set to December 22 (Winter Solstice) because this is when the angle of sunlight in Thailand has the lowest slope angle of the year, which is considered the most critical period. The temperature difference between the room and the inside is around 5 °C (ΔT). The evaluation phase will decide the building's use hours, which will be 9:00 a.m. to 5:00 p.m. on the south side, where the lowest HAS (Horizontal shadow angle) of 5.80° and VSA (Vertical shadow angle) of 22.8° were observed at 5:00 p.m.

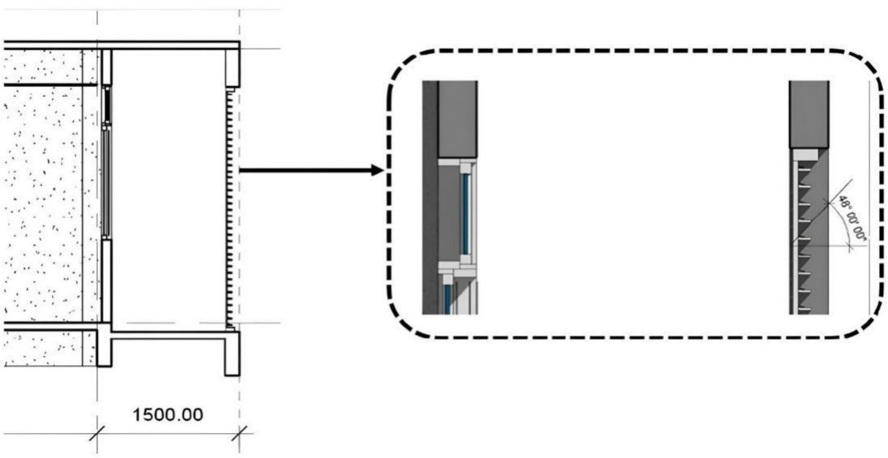

Fig. 5 The display of distance expansion of the sun louvers.

Table 3. The energy efficiency of the test room without the sun louver is Type A (None Louver).

Type	Value	Orientation							
		N	NE	E	SE	S	SW	W	NW
A (None Louver)	SC_s	0.092	0.194	0.334	0.336	0.299	0.449	0.412	0.235
	SC_d	0.908	0.766	0.566	0.474	0.455	0.523	0.588	0.765
	SC	1.000	0.960	0.900	0.810	0.755	0.972	1.000	1.000
	Qop	280.69	311.19	330.43	339.71	340.33	333.60	320.78	303.20
	Qtr	968.59	1070.61	1128.96	1097.61	1045.63	1266.04	1196.86	1072.61
	ESR	185.06	215.84	244.53	263.14	267.41	256.82	234.58	207.62
	OTTV (W/m^2K)	83.78	92.67	97.87	96.39	92.95	107.28	101.78	92.27

Table 4. The energy efficiency of the test room with the sun louver is Type B (I-shape Louver).

Type	Value	Orientation							
		N	NE	E	SE	S	SW	W	NW
B (I-Louver)	SC_s	0.092	0.181	0.288	0.319	0.109	0.334	0.341	0.215
	SC_d	0.751	0.630	0.461	0.394	0.264	0.404	0.486	0.633
	SC	0.843	0.811	0.748	0.713	0.373	0.738	0.828	0.848
	Qop	280.69	311.19	330.43	339.71	340.34	333.61	320.78	303.21
	Qtr	834.05	922.42	958.78	980.62	575.16	989.14	1010.32	926.94
	ESR	185.06	215.84	244.53	263.14	267.41	256.82	234.58	207.62
	OTTV (W/m^2K)	74.76	82.73	86.46	88.55	61.40	88.71	89.27	82.50

Table 5. The energy efficiency of the test room with the sun louver is Type C (C-shape Louver).

Type	Value	Orientation							
		N	NE	E	SE	S	SW	W	NW
C (C-Louver)	SC_s	0.093	0.179	0.278	0.314	0.107	0.324	0.331	0.212
	SC_d	0.719	0.604	0.442	0.379	0.246	0.386	0.466	0.606
	SC	0.812	0.783	0.720	0.693	0.353	0.710	0.797	0.819
	Qop	280.69	311.19	330.43	339.71	340.34	333.61	320.78	303.21
	Qtr	807.74	893.96	926.55	955.49	550.91	956.39	976.92	899.23
	ESR	185.06	215.84	244.53	263.14	267.41	256.82	234.58	207.62
	OTTV (W/m^2K)	73.00	80.82	84.30	86.86	59.77	86.51	87.03	80.64

Table 6. The energy efficiency of the test room with the sun louver is Type D (Λ-shape Louver).

Type	Value	Orientation							
		N	NE	E	SE	S	SW	W	NW
D (Λ-shape Louver)	SC_s	0.092	0.173	0.252	0.292	0.105	0.296	0.297	0.204
	SC_d	0.616	0.514	0.376	0.322	0.186	0.324	0.398	0.519
	SC	0.708	0.687	0.628	0.614	0.291	0.620	0.695	0.723
	Qop	280.69	311.19	330.43	339.71	340.34	333.61	320.78	303.21
	Qtr	718.69	798.75	822.90	860.51	473.29	849.69	866.94	807.35
	ESR	185.06	215.84	244.53	263.14	267.41	256.82	234.58	207.62
	OTTV (W/m^2K)	67.02	74.44	77.35	80.49	54.57	79.36	79.65	74.48

The study used four simulation models: 1) A room without fixing a sun louver at the external part of the building (Type A); 2) A room fixed with a straight shape (I-shape) sun louver (Type B); 3) A room fixed with a curve shape (C-shape) sun louver (Type C); and 4) A room fixed with an overturning V-shape (Λ-shape) sun louver (Type D). Then the directions were set for evaluating heat gain through walls with windows in eight directions: North (N), Northeast (NE), East (E), Southeast (SE), South (S), Southwest (SW), West (W), and Northwest (NW), all together in thirty-two directions in total. The evaluation results are presented in the Q-value of walls, SC of sun louvers, and OTTV of each direction, as shown in

Tables 3-6 (WWR = 0.36).

The ESR refers to the total radiation incident on a wall at a specific degree of inclination, dispersing in various directions while accounting for the wall's angle of inclination in a building. The vertical wall of a building forms a 90° angle of inclination with the ground surface. In contrast, the wall on the horizontal plane (or flat roof) possesses an inclination angle of 0°. The analysis of heat energy by the OTTV method will show the heat energy through the building in eight directions and show the variables that affect the heat energy.

3.1 SC of sun louver

According to the effectiveness comparison of the window sun louver in the simulated building of 6,589 mm^2, the comparison was performed between windows with the upper 1,500 mm projection length of the reinforced concrete fins without a sun louver (Type A) and three types of windows fixed with sun louvers (Type B, Type C, and Type D) respectively in eight directions. The results from calculating equation (4) to find the shading coefficients of the 4 types showed that the SCs (solar beam) were lowest in the north (N) at about 0.092-0.093,[28] whereas they were highest in the southwest (SW) at about 0.449.[29] This finding indicates that the horizontal reinforced concrete overhang with a 1,500 mm projection length has the best shading performance in the north (N).

The SC_d (diffuse) of the window without fixing a sun louver (Type A) was highest in the north (N) at about 0.908, whereas the SC_d was lowest in the south (S) at about 0.455. However, when the windows were fixed with three types of sun louvers, the SC_d were significantly lower at 0.264 for the Type B sun louver, 0.246 for the Type C sun louver, and 0.186 for the Type B sun louver, resulting in SC reducing by about 42%, 46%, and 60%, respectively. This indicates that the sun louver has a significant effect on diffusing, and the Λ-shape of the sun louver (Type D) is more effective in preventing solar diffusing than the other types. Regarding the eight directions of the sun louvers, it was found that the SC in the south (S) was the lowest, indicating that the effectiveness of the Λ-shape sun louver (Type D) is higher than the other types. The SC of the other direction was at a good level, reducing SC by about 20%-25% compared to the window without a sun louver,[30] as shown in Figs. 6-9.

3.2 Shading and heat flow through transparent window

The effectiveness of sun louvers was compared among Type A, Type B, Type C, and Type D to find the shading effectiveness of the sun louvers with the lowest SC by considering the shading areas appearing on the windows and the heat transfer through the window (Qtr).

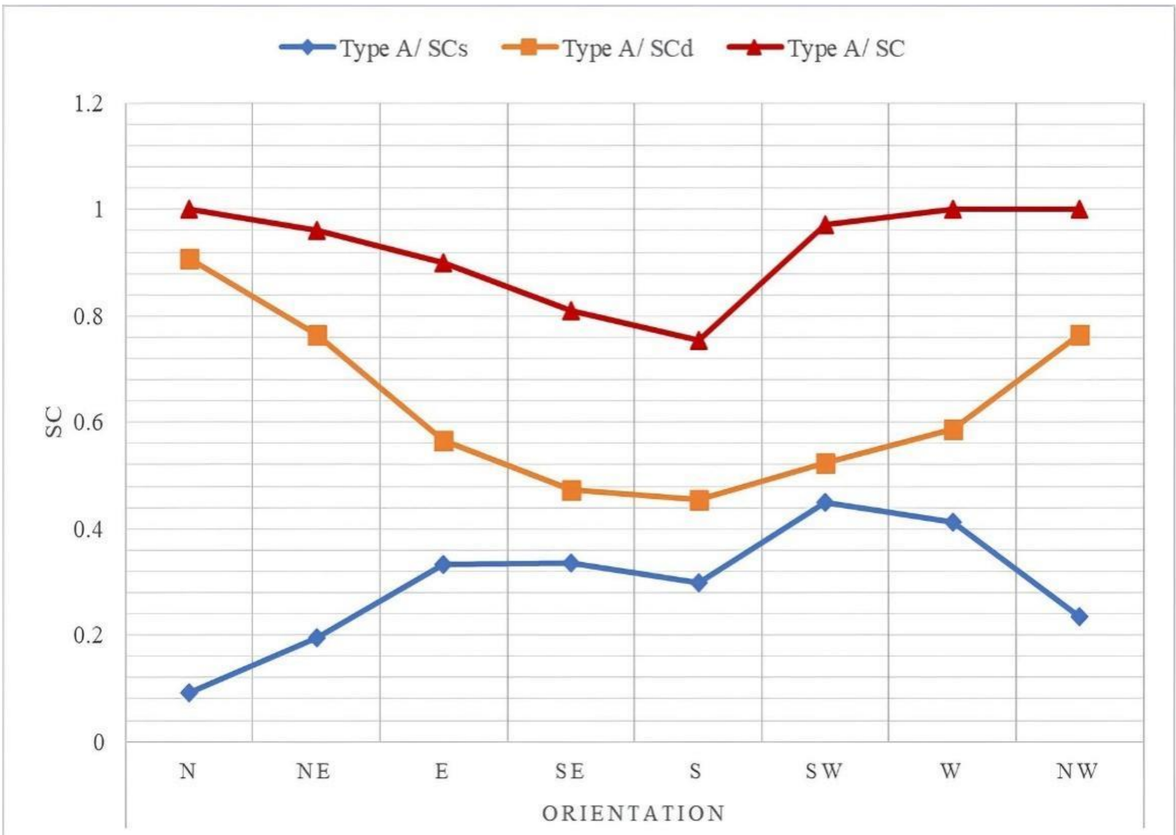

Fig. 6 The SC of the test room without the sun louver Type A (None Louver).

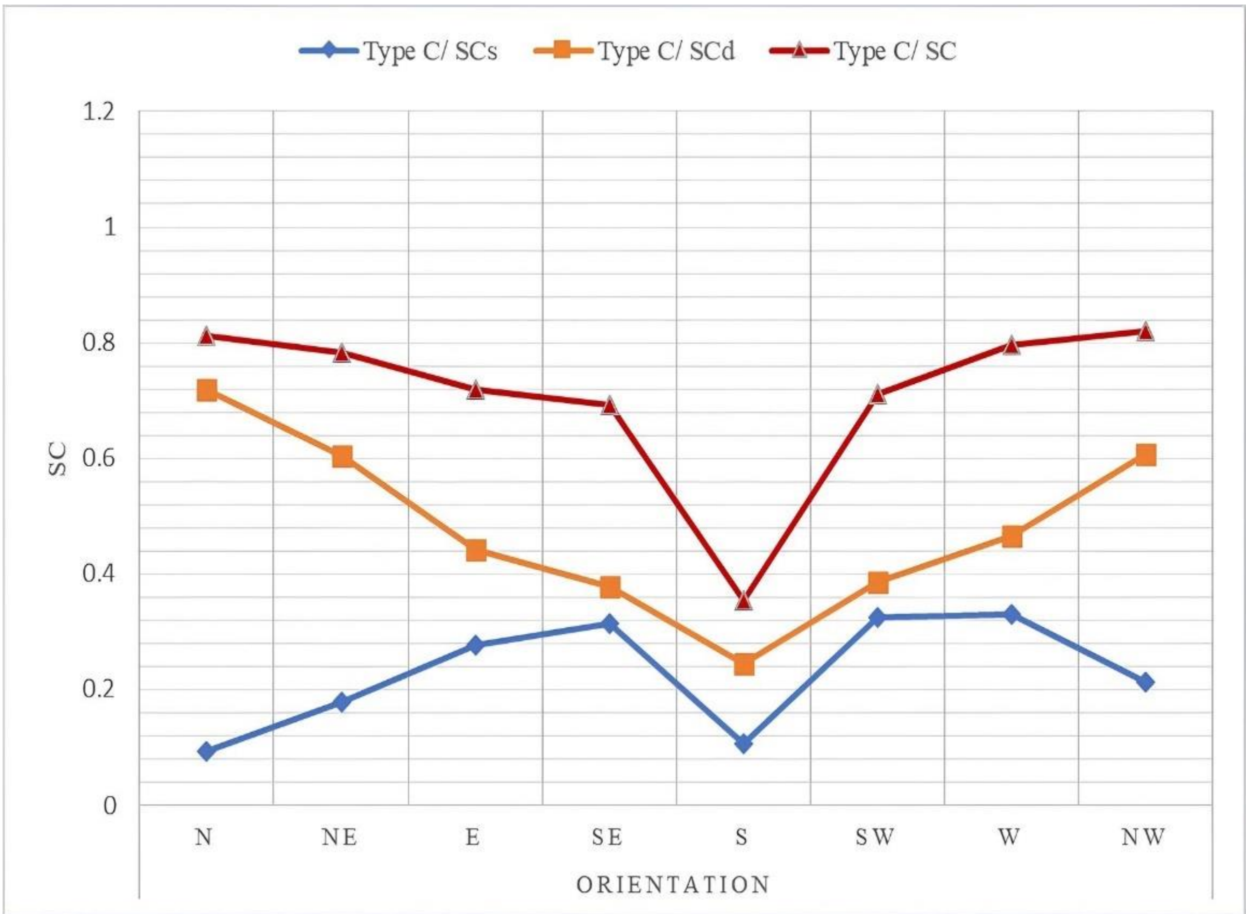

Fig. 7 The SC of the test room with the sun louver Type B (I-shape Louver).

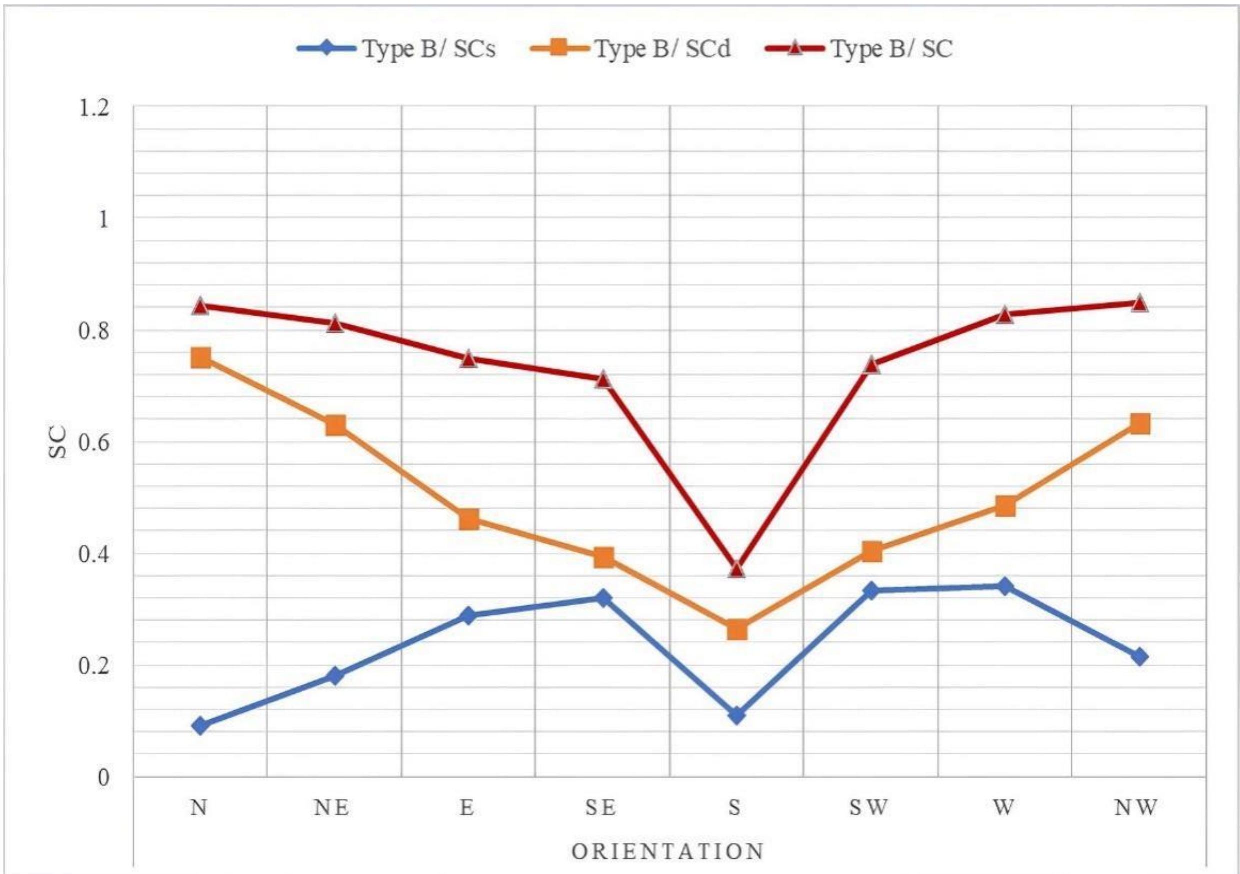

Fig. 8 The SC of the test room with the sun louver Type C (C-shape Louver).

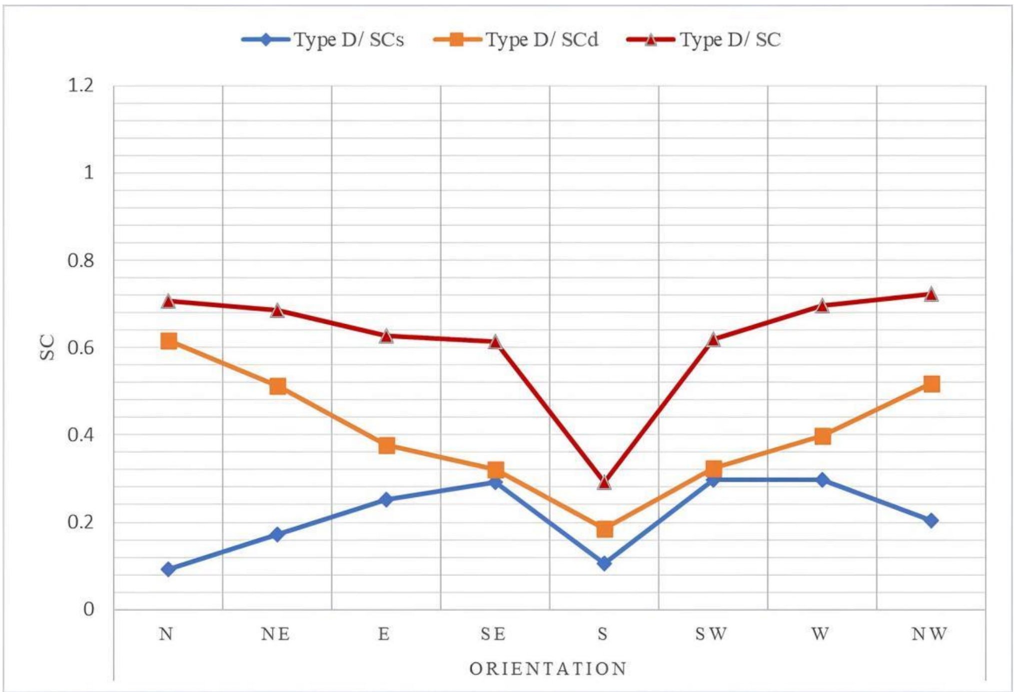

Fig. 9 The SC of the test room with the sun louver Type D (Λ-shape Louver).

3.2.1 Shading area

This refers to the area shaded vertically by all types of sun louvers and through the window. Each type of sun louver has a different form, as shown in Fig. 3. According to Table 7, the vertical sun louver Type D has more shading area than the other types, and its 45° inclination can cause more shading area, resulting in a reduction of heat gain through glass.

3.2.2 Heat flow through transparent (Qtr)

This varied according to the building direction in association with ESR, calculated by the equation (7). Fig. 10 shows the heat gain through the window of the room in Type A with none louver had nearly similar values in each direction. However, when the sun louvers were fixed at the windows, the heat gain reduced noticeably in the rooms Type B, Type C, and Type D. In the south (S), heat gain reduced lower than in the other direction, especially in the room Type D with heat gain at 473.29 W compared to the room Type A in the south. It was found that the sun louver Type D can reduce heat energy up to 45%.

Table 7. The shading area of each sun louver type on the window.

TYPE	Window Area (mm^2)	None Shading Area (mm^2)	Shading Area (mm^2)	Ratio (%)
B	6,586	5,256	1,332	20.22
C	6,586	4,815	1,771	26.89
D	6,586	3,069	3,517	53.40

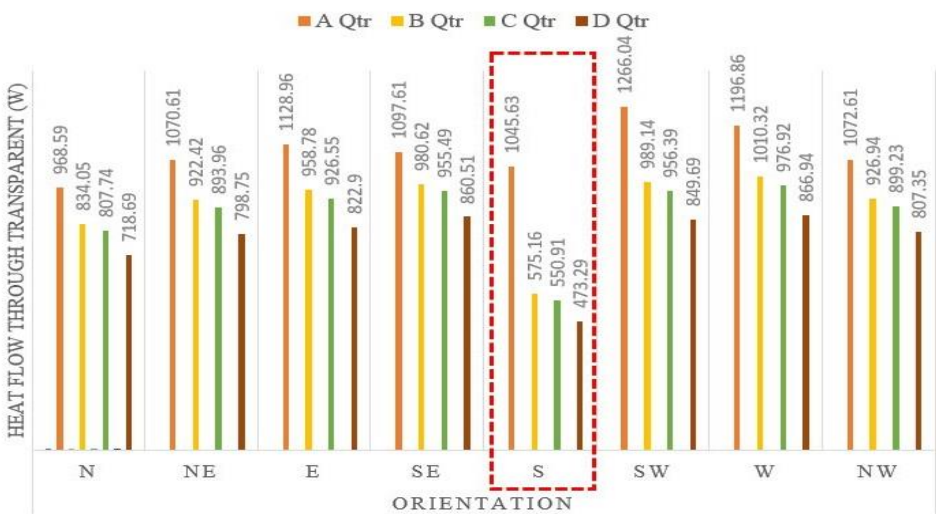

Fig. 10 Heat flow through the windows of the classroom in 4 types.

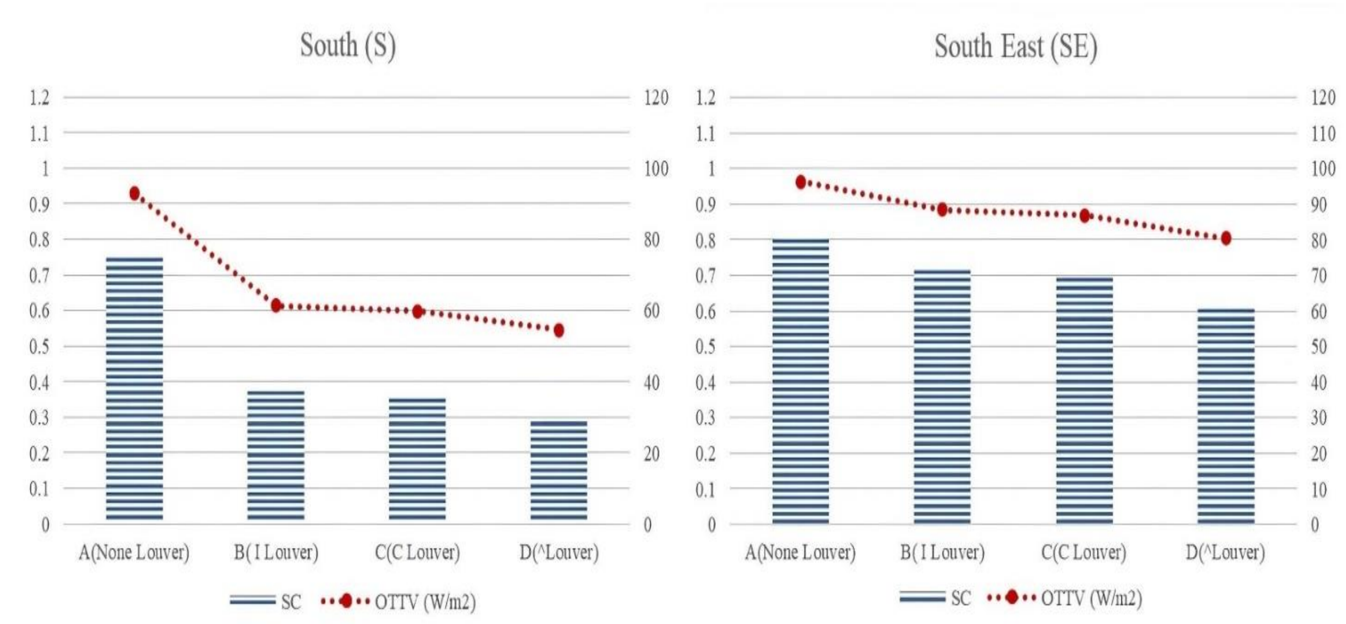

Fig. 11 Relationship between OTTV and SC in the south (S) and the southeast (SE).

3.3 Relationship between OTTV and SC

The difference between the three types of sun louvers caused different shading on the walls and the windows of the simulated building. According to Table 7, The shading effectiveness of the sun louver Type D is affected by reducing SC and Qtr (heat flow through the transparent). Therefore, when evaluating the OTTV of each wall in eight directions, it was found that all three types of sun louvers had OTTV in the south (S) lower than in the other directions. The sun louver Type D had OTTV = 54.57 W/m^2 and SC = 0.291, which were lower than those in Type B and Type C. Figs. 11-14 show the results of the statistical tests by using a correlation and scatter diagram between Qtr and OTTV in eight directions.[31] The trend of the point distribution rises upward to the right in a straight alignment. Both values have a linear positive relationship. The correlation coefficient R^2 = 0.973 indicates that such a relationship is congruent and associated. This relationship finding can be used in designing and optimizing the OTTV of the building with the same characteristics, as shown in Fig. 15.

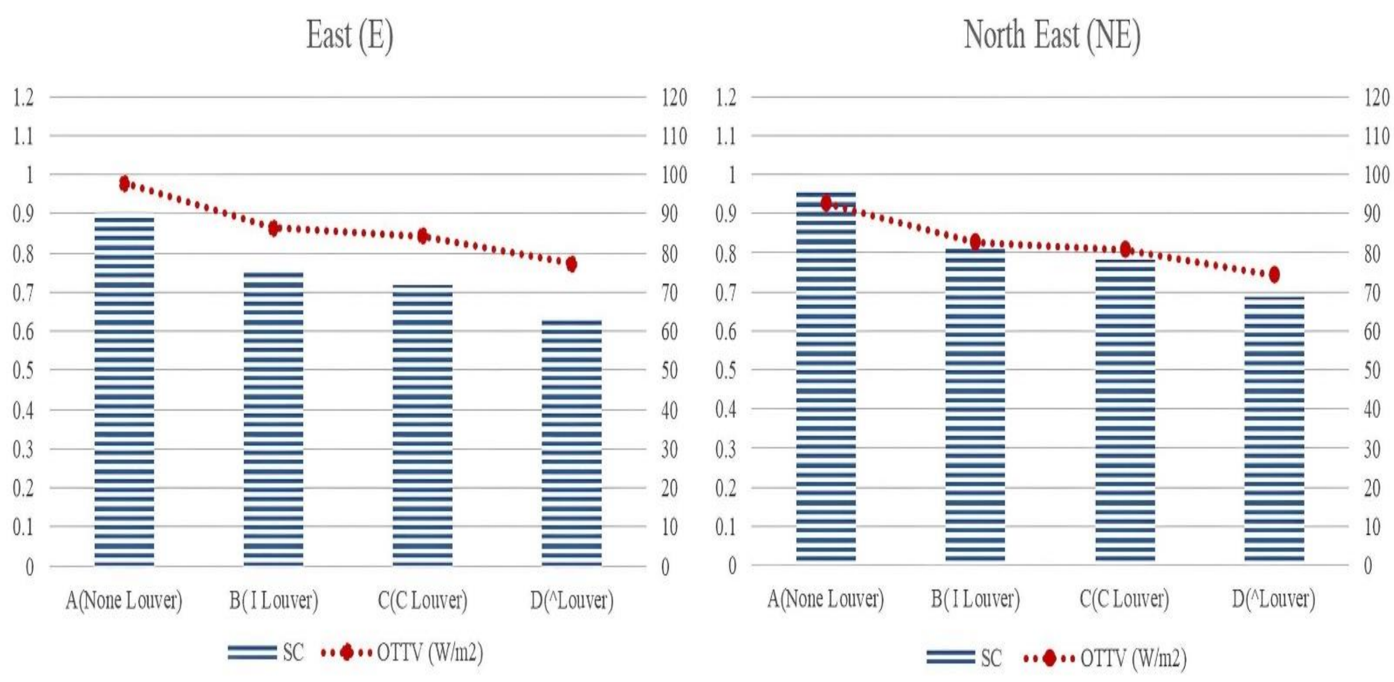

Fig. 12 Relationship between OTTV and SC in the east (E) and the northeast (NE).

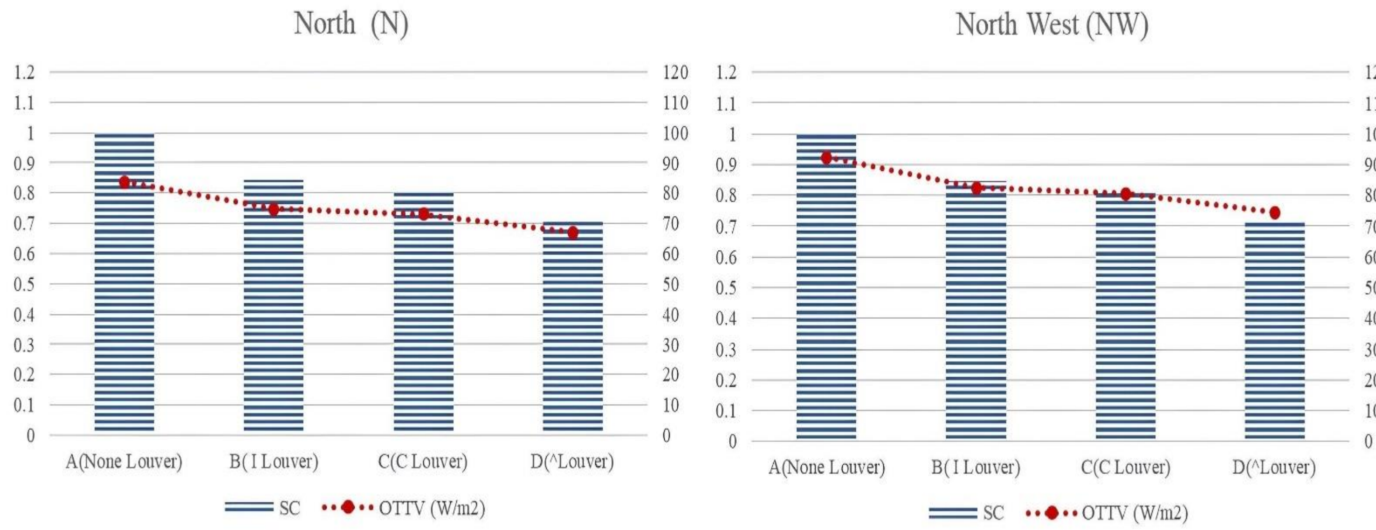

Fig. 13 Relationship between OTTV and SC in the north (N) and the northwest (NW).

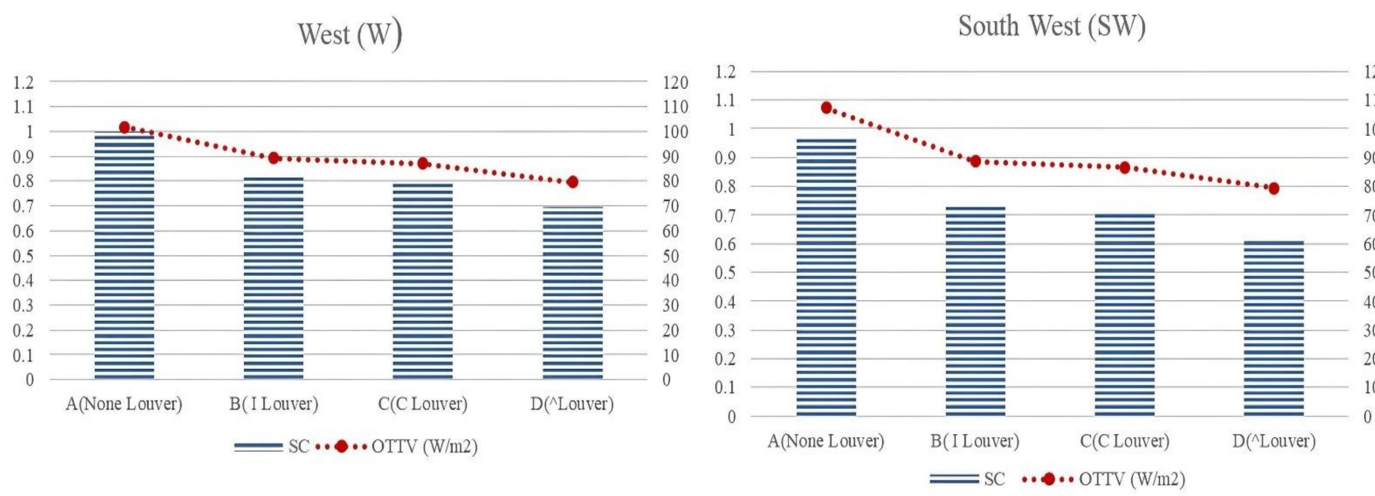

Fig. 14 Relationship between OTTV and SC in the west (W) and the southwest (SW).

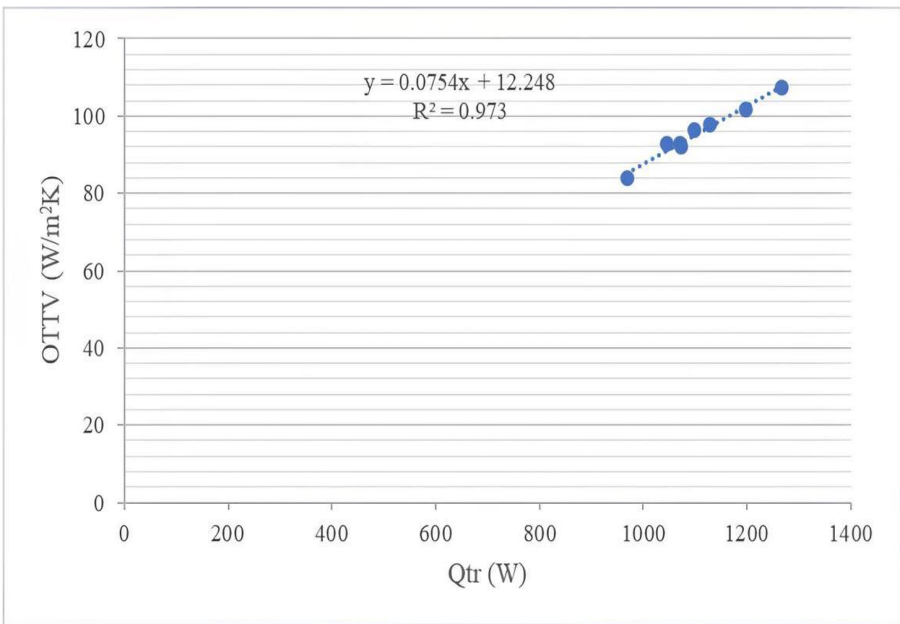

Fig. 15 Correlation on a scatter diagram between Qtr (W) and OTTV (W/m^2K).

4. Conclusion

At present, different shapes of sun louvers influence architectural design because they look beautiful and modern, giving the building a distinctive identity. Using suitable sun louvers helps save energy in the building, and the building owner can save on electricity costs.[32] At the same time, this aligns with the Ministry of Energy's energy conservation measures in Thailand, which limit the heat flow through walls to no more than 50 W/m^2, and the heat flow through building roofs to no more than 15 W/m^2.

The comparison of the three types of louvers reveals that type D louvers have the highest heat protection performance, making them appropriate for use in public school buildings or structures that have limited construction budgets since they employ locally accessible materials. Its affordable pricing makes it suitable for common commercial applications. Unlike an adjustable shade device, it is simple to install and requires low maintenance because it lacks a control mechanism. The experiment concluded that the Type D louver outperforms the Type B and Type C louvers in terms of heat protection performance. However, the design, distance, and installation location must be carefully considered, as the louver's inverted V-shape may obscure the building's exterior view and affect the amount of lighting in the room. Adding a shading area to prevent heat from passing through the windows will also decrease the outside light entering the classroom. The initial solution is for the designer or building owner to improve the classroom environment by selecting bright or light colors, such as white or light grey, to achieve a high luminance value. A light color enhances the room's luminosity, reducing the lighting electricity consumption while increasing visual comfort.

Acknowledgment

The authors are pleased to acknowledge the Thailand Science Research and Innovation Fundamental Fund for the fiscal year 2024 and National Research Council of Thailand (Grant Number N42A650197)

Conflict of Interest

There is no conflict of interest.

Supporting Information

Not applicable.

Nomenclature

OTTV Overall Thermal Transfer Value (W/m^{2}K)
U*w* Thermal transmittance of the opaque part of a wall
U*f* Thermal transmittance of the opaque part of a fenestration
WWR Window-to-wall ratio
ΔT Temperature difference between exterior and interior design conditions (°C)
TD*eq* Equivalent temperature difference for the opaque part of a wall
SHGC Solar the heat gain coefficient
ESR Effective Solar Radiation (W/m^2)
A*w* Area of opaque wall (m^2)
A*r* Area of roof (m^2)
SC Shading coefficient (dimensionless)
SC1 Shading coefficient of glass
SC2 Shading coefficient of shading device
SC*s* Direct solar beam
SC*d* Diffuse solar
Q Heat gain through building
Qop Heat Flow through Opaque Wall (W)
Qtr Heat Flow through Transparent (W)
U*r* Thermal transmittance of roof (W/m^{2}K)
U*w* Thermal transmittance of opaque wall (W/m^{2}K)

References

[1] S. Subhashini, K. Thirumaran, A passive design solution to enhance thermal comfort in an educational building in the warm humid climatic zone of Madurai, *Journal of Building Engineering*, 2018, **18**, 395-407, doi: 10.1016/j.jobe.2018.04.014.

[2] L. Lan, W. Tushar, K. Otto, C. Yuen, K. L. Wood, Thermal comfort improvement of naturally ventilated patient wards in Singapore, *Energy and Buildings*, 2017, **154**, 499-512, doi: 10.1016/j.enbuild.2017.07.080.

[3] Z. Li, W. Gao, Energy use and consumption of Thailand's commercial buildings in 2010, *Environmental Science and Engineering*, 2014, **61**, 64-68, doi: 10.7763/IPCBEE.

[4] J. Zhao, Y. Du, Multi-objective optimization design for windows and shading configuration considering energy consumption and thermal comfort: a case study for office building in different climatic regions of China, *Solar Energy*, 2020, **206**, 997-1017, doi: 10.1016/j.solener.2020.05.090.

[5] S. M. Al-Masrani, K. M. Al-Obaidi, N. A. Zalin, M. A. Isma, Design optimisation of solar shading systems for tropical office buildings: Challenges and future trends, *Solar Energy*, 2018, **170**, 849-872, doi: 10.1016/j.solener.2018.04.047.

[6] N. Heidari Matin, A. Eydgahi, Technologies used in responsive facade systems: a comparative study, *Intelligent Buildings International*, 2022, **14**, 54-73, doi: 10.1080/17508975.2019.1577213.

[7] D. Lee, Y. H. Cho, J. H. Jo, Assessment of control strategy of adaptive façades for heating, cooling, lighting energy conservation and glare prevention, *Energy and Buildings*, 2021, **235**, 110739, doi: 10.1016/j.enbuild.2021.110739.

[8] A. Mohammed, M. A. U. R. Tariq, A. W. M. Ng, Z. Zaheer, S. Sadeq, M. Mohammed, H. Mehdizadeh-Rad, Reducing the cooling loads of buildings using shading devices: a case study in Darwin, *Sustainability*, 2022, **14**, 3775, doi: 10.3390/su14073775.

[9] G. Chiesa, A. Acquaviva, M. Grosso, L. Bottaccioli, M.

Floridia, E. Pristeri, E. Sanna, Parametric optimization of window-to-wall ratio for passive buildings adopting A scripting methodology to dynamic-energy simulation, *Sustainability*, 2019, **11**, 3078, doi: 10.3390/su11113078.

[10] P. Chiradeja, S. Thongsuk, S. Ananwattanaporn, A. Ngaopitakkul, Renovation of an academic building's envelope, lighting, and air conditioning system according to Thailand building energy code for energy consumption reduction, *Sustainability*, 2023, **15**, 15298, doi:10.3390/su152115298.

[11] L. Kusumawati, E. Setyowati, A. B. Purnomo, Practical-empirical modeling on envelope design towards sustainability in tropical architecture, *Sustainability*, 2021, **13**, 2959, doi: 10.3390/su13052959.

[12] A. S. Bachrun, T. Z. Ming, A. Cinthya, Building envelope component to control thermal indoor environment in sustainable building: a review, *Sinergi*, 2019, **23**, 79-98, doi: 10.22441/sinergi.2019.2.001.

[13] C. Kohler, Y. Shukla, R. Rawal, Calculating the effect of external shading on the solar heat gain coefficient of windows, 2017.

[14] S. Liu, Y. T. Kwok, K. K. L. Lau, P. W. Chan, E. Ng, Investigating the energy saving potential of applying shading panels on opaque façades: a case study for residential buildings in HongKong, *Energy and Buildings*, 2019, **193**, 78-91, doi: 10.1016/j.enbuild.2019.03.044.

[15] A. Bhatia, S. A. R. Sangireddy, V. Garg, An approach to calculate the equivalent solar heat gain coefficient of glass windows with fixed and dynamic shading in tropical climates, *Journal of Building Engineering*, 2019, **22**, 90-100, doi: 10.1016/j.jobe.2018.11.008.

[16] S. M. Al-Masrani, K. M. Al-Obaidi, Dynamic shading systems: a review of design parameters, platforms and evaluation strategies, *Automation in Construction*, 2019, **102**, 195-216, doi: 10.1016/j.autcon.2019.01.014.

[17] S. M. Hosseini, M. Mohammadi, T. Schröder, O. Guerra-Santin, Integrating interactive kinetic façade design with colored glass to improve daylight performance based on occupants' position, *Journal of Building Engineering*, 2020, **31**, 101404, doi: 10.1016/j.jobe.2020.101404.

[18] S. Nazari, P. K. MirzaMohammadi, B. Sajadi, P. Pilehchi Ha, S. Talatahari, P. Sareh, Designing energy-efficient and visually-thermally comfortable shading systems for office buildings in a cooling-dominant climate, *Energy Reports*, 2023, **10**, 3863-3881, doi: 10.1016/j.egyr.2023.10.062.

[19] I. Shah, B. Soh, C. Lim, S.-K. Lau, A. Ghahramani, Thermal transfer and temperature reductions from shading systems on opaque facades: Quantifying the impacts of influential factors, *Energy and Buildings*, 2023, **278**, 112604, doi: 10.1016/j.enbuild.2022.112604.

[20] N. Pringsakul, R. Prommas, P. R. Kaewpengkrow, Analysis of waste optical fiber cables for converting to fuel through pyrolysis, *Chiang Mai Journal of Science*, 2023, **50**, e2023006, doi:10.12982/CMJS.2023.006.

[21] C. E. Hagentoft, S. Pallin, A conceptual model for how to design for building envelope characteristics. Impact of thermal comfort intervals and thermal mass on commercial buildings in U.S. climates, *Journal of Building Engineering*, 2021, **35**, 101994, doi: 10.1016/j.jobe.2020.101994.

[22] W. K. Alhuwayil, M. Abdul Mujeebu, A. M. M. Algarny, Impact of external shading strategy on energy performance of multi-story hotel building in hot-humid climate, *Energy*, 2019, **169**, 1166-1174, doi: 10.1016/j.energy.2018.12.069.

[23] J. Cho, C. Yoo, Y. Kim, Viability of exterior shading devices for high-rise residential buildings: case study for cooling energy saving and economic feasibility analysis, *Energy and Buildings*, 2014, **82**, 771-785, doi: 10.1016/j.enbuild.2014.07.092.

[24] K. Riniardi, N. W. Priyomarsono, J. Rilatupa, re-designing facade of kadin tower building (application of retrofit programme with OTTV), *Materials Science and Engineering*, 2019, **508**, 012028, doi: 10.1088/1757-899x/508/1/012028.

[25] D. Nonthiworawong, P. Rattanadecho, R. Prommas, Energy and exergy analysis of low-cooling in building by using light-vent pipe, *Science & Technology Asia*, 2019, **24**, 41-53. doi: 10.14456/scitechasia.2019.5.

[26] M. Murzyn-Kupisz, J. Działek, Cultural heritage in building and enhancing social capital, *Journal of Cultural Heritage Management and Sustainable Development*, 2013, **3**, 35-54, doi: 10.1108/20441261311317392.

[27] A. Levinskytė, R. Bliūdžius, R. Kapačiūnas, The comparison of a numerical and empirical calculation of thermal transmittance of ventilated facade with different heat-conductive connections, *Journal of Sustainable Architecture and Civil Engineering*, 2018, **23**, 39-48, doi: 10.5755/j01.sace.23.2.21204.

[28] A. Atiz, Comparison of three different solar collectors integrated with geothermal source for electricity and hydrogen production, *International Journal of Hydrogen Energy*, 2020, **45**, 31651-31666, doi: 10.1016/j.ijhydene.2020.08.236.

[29] T. Potrč Obrecht, M. Premrov, V. Žegarac Leskovar, Influence of the orientation on the optimal glazing size for passive houses in different European climates (for non-cardinal directions), *Solar Energy*, 2019, **189**, 15-25, doi: 10.1016/j.solener.2019.07.037.

[30] S. G. Koç, S. Maçka Kalfa, The effects of shading devices on office building energy performance in Mediterranean climate regions, *Journal of Building Engineering*, 2021, **44**, 102653, doi: 10.1016/j.jobe.2021.102653.

[31] M. Chihib, E. Salmerón-Manzano, F. Manzano-Agugliaro, Benchmarking energy use at university of Almeria (spain), *Sustainability*, 2020, **12**, 1336, doi: 10.3390/su12041336.

[32] Y. Lu, P. Li, Y. P. Lee, X. Song, An integrated decision-making framework for existing building retrofits based on energy simulation and cost-benefit analysis, *Journal of Building Engineering*, 2021, **43**, 103200, doi: 10.1016/j.jobe.2021.103200.

Publisher's Note: Engineered Science Publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Open Access