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Table of Contents

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A Study of Vertical Shading Devices for Daylighting on East Façade of Buildings in Tropical Region

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Abstract—**This paper reports a simulation study on the application of shading devices for daylighting on the east façade of the building in the tropical region. BESim was applied as the simulation program to calculate illuminance on the workplane and cooling energy consumption. Multiple vertical shading devices with an additional horizontal slat were used to improve the energy efficiency of the building. On another case, instead of the shading application, wall insulation was utilized in order to minimize the heat gain. The determination of proper vertical slat angle, daylight penetration depth, lighting arrangement, energy consumption, and payback period are the specific objectives of this study. It was found that the energy consumption, combination of lighting and air conditioner, could be saved 42% by the application of daylighting. Roughly, it was achieved by 40% area of window relative to the wall on the large room. The additional cost of shading devices and insulation would recover less than two years.**

Keywords-daylighting; vertical shading; energy saving

I. INTRODUCTION

Chirarattananon stated that air conditioner (for cooling) and electric lighting typically accounted for 60% and 20%, respectively, of the electricity consumption of a commercial building in Thailand [1]. One of the solutions to achieve the energy efficiency in the building is by occupying daylighting system. Daylighting is the planned use of natural daylight from the sun during the day which can substitute artificial light.

Natural light could be classified by its source, i.e., which are directly from the sun, the sky, and the surrounding. The direct light from the sun, also known as beam light, is avoided due to its high intensity of solar radiation. The diffuse light, which is from the sky and surrounding, is preferred in tropics.

Commonly, shading is categorized into internal and external shading devices. The application of internal shading devices is widely used in the commercial buildings. The benefit of this shading device is providing privacy, easy for maintenance, and hard to be degraded by the environment. The weakness of this shading device is when it is placed in the room, the solar radiation has already passed through the glazing before it can be intercepted. The other issue is once this shading is installed, the occupants tend to shut it. The room will be fully lighted by the lamps. Thus, the use of daylighting system will vanish. Therefore, to solve these problems, the application of external shading devices is needed.

For utilization of daylight through the window, researchers suggest to use south or north facade. It is easier to block the beam light and to prevent the glare. Thus, the different method should be occupied to gain the daylight potency on the east or west façade.

Most of the experiments of shading devices were taken place in the high-latitude region [2-5]. There are several aspects determining the application of daylighting, such as the fenestration optical properties, surroundings, orientation of the facades, room characteristics, and climate. Therefore, the results from this region cannot be implemented exactly to the tropics.

Though it was not in tropics, the study which is relevance about vertical shading was conducted by Alzoubi and Al-zoubi [6]. The authors used artificial lighting as the energy consumption in the building to analyze the shading performance. The Lightscape simulation program was occupied by them.

This research has a purpose to minimize the energy consumption on the east façade by the utilization of daylight in the building. This simulation study comprises several steps. Section 2 will explain the scheme of this study whereas section 3 will give a description of BESim, the room configuration, and step of this study. Section 4 will describe the results following with the discussion of them. Finally, this simulation study will be concluded on section 5.

II. SCHEME

This study scheme was the office building with general lighting illuminance 300 lux. BESim simulation program was used to quantify the illuminance on the workplane and the cooling load in the building. The study was started by determining the slat angle which could shade beam light properly. With the slat angle configuration result, the daylight penetration depth and lighting arrangement would be determined. The variation of a window to wall ratio (WWR) was applied in this step. The next step was calculating the

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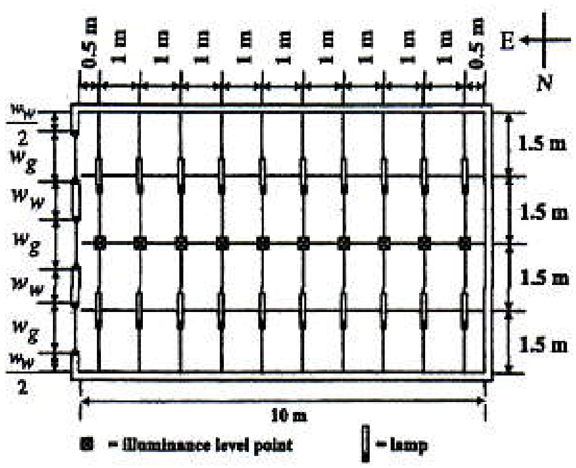

Figure 1. Top view of room model without shading devices

energy consumption from air conditioner and lighting. The comparison between the additional initial cost of installation shading and insulation with the annual cost saving became the financial consideration by using payback period.

The working time is 2340 hours/year, consisting of five days a week for 52 weeks in a year. It is started from 08.00 – 17.00. BESim uses 9 points of time to represent nine hours of working duration time for every simulation day. In this study, BESim occupies the meteorological data taken from Asian Institute of Technology (AIT) station, located 13.7^0 N of latitude and 100.6^0 E of longitude. It is 12-day data in the year 2000, which are 19th, 20th, and 21st of March, June, September, and December.

III. METHODS

A. BESim Description

This study used the BESim simulation program to calculate the illuminance and the energy consumption due to the cooling load on the building. BESim used measurement of the meteorological data, beam and sky illuminance with irradiance, as the input data. Ray tracing method has been coded in this computer program to calculate the beam light whereas the diffuse one was by flux transfer. The energy balance has been utilized to obtain the dynamic conduction heat transfer through the wall. The calculation method can be obtained from Chirarattananon [7].

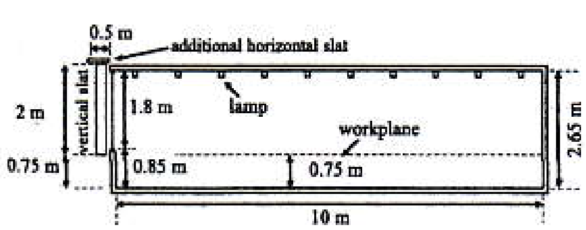

Figure 2. Side view of room model with shading devices

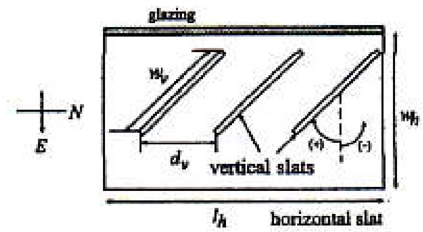

Figure 3. Horizontal cross-section of shading and glazing

B. Room Model Description

Considering the application of shading device on the office building, dimension of the room 6 m x 10 m x 2.65 m was preferred. The wall consists of brick and cement with thickness 0.075 m. A 0.05 m-thick polystyrene was used as the wall insulation. The eastern façade of the room comprised a glazed window that extends 0.85 m from the floor by 1.8 m to reach the ceiling. The glazing with thickness 12.38 mm comprised a green tinted glass that is laminated with a clear glass. The window width w_g and wall intersperse w_w could be adjusted so that it was fulfill several scenarios by using different window size. The reflectance of the floor, wall, and ceiling, which was 0.3, 0.5, and 0.7, was applied. The workplane height was 0.75 m from the floor.

The practical reason of choosing the shading configuration becomes the consideration. For eastern façade which mainly facing the low-altitude angle of the sun, the vertical slats is the better than horizontal one. Since it was movable, the additional horizontal part of shading as the supporting device could become additional horizontal slat, which could shade the beam light on the noon time.

For each window size, the number of vertical slats was varied but the additional horizontal shading device was fixed. For WWR 0.2, 0.4, and 0.68, it used 15, 21, and 31 vertical slats respectively. The ratio of width to the distance between two slats w_v/d_v was 1.5 where the width of vertical slats w_v was 0.3 m. The length of the additional horizontal slat l_h was 6.4 m with 0.5 m for its width w_h. The diffuse reflectance of these devices is 0.7.

TABLE I. GLAZING PROPERTY DATA

Properties		Value
Visible ray	Reflectance	0.12
	Transmittance	0.67
Solar radiation	Reflectance	0.06
	Transmittance	0.26
	Absorptance	0.67
Front emittance		0.85
Back emittance		0.82
Solar heat gain coefficient		0.40
U-value ($Wm^{-2}K$)		4.63

TABLE II. INCREMENTAL COST

Material plus labor	WWR			
	0.0	*0.2*	*0.4*	*0.68*
Insulation (THB)	3,149	2,519	1,889	1,008
Shading devices (THB)	0	8,395	10,872	15,000

1 THB = 0.0321027 USD on 18th November 2011

Window to wall ratio (WWR) is the ratio between window area to the total wall area, including the window itself. For example, the wall area on the east exposure is 15.9 m^2 so that for WWR 0.2, the window size must be 3.2 m^2.

The use of 20 lamps, 47 Watt for each lamp, was desired to fulfill scheme of this study to maintain general lighting illuminance standard, 300 lux. Next, the lamps were turned on all or only some of them related to the scenarios without or with daylight. There were 10 rows of lamps, with two lamps for each row. Each row located at the same distance from the window with the points of illuminance on the workplane.

C. Determination of Proper Shading Configuration

The scenario in this part was by justifying the proper shading slat due to its angle ψ , -45^0 or 45^0. The comparison of the illuminance on each case was analyzed to decide the better slat angle for particular time. WWR 0.68 was used in this step. The less of illuminance received by the workplane near the window, the better shading performance it would be.

D. Determination of Daylight Penetration Depth and Lighting Arrangement

After obtaining the proper angle due to certain period of time, the investigation of daylight penetration depth was conducted. Daylight penetration depth is the distance from the window which the illuminance on the workplane is higher than the border line illuminance. For general lighting, 300 lux with lamp configuration stated on the previous subchapter, the illuminance on the border line was 125 lux. Border line is the transition line between daylight and artificial light application.

The scenario in this step was by varying the façade into the different window to wall ratio. WWR 0, 0.2, 0.4, 0.68 were used in this step.

E. Determination Energy Consumption

The energy consumption in this study consisted of air conditioner and lighting. For air conditioner, the load comes from the exterior and interior. The external cooling load is from the heat transfer from exterior to the interior due to conduction, convection, and solar radiation. In this research, the source of internal cooling load was heat from lighting. It was assumed 100 % of electrical energy of lighting became heat. To convert the cooling load which was in the thermal energy into electrical energy unit, coefficient of performance (COP) of the air conditioner system was used. COP describes how much heat that can be extracted from the interior for each unit of electric energy. The unit of thermal energy is kWh_{th} whereas for the electric energy is kWh. For example, if total cooling energy consumption due to external and internal cooling load is 1000 kWh_{th} with COP is 2.5, the electrical energy consumption for this air conditioner system will be 400 kWh. The total energy consumption can be described mathematically as the following equations.

$$E_a = [(CCL \div COP) + LL]\, n_h \quad (1)$$

$$CCL = CCL_{external} + CCL_{internal} \quad (2)$$

Where:

E_a = Annual Electrical Energy Consumption (kWh/year)

CCL = Cooling Coil Load (kW_{th})

LP = Lighting Load (kW)

n_h = Nominal of Operating Hour (h)

COP = Coefficient of Performance of AC System

To achieve the energy saving and comparison between the application of shading devices, insulation, and daylighting, several cases have been used as the scenario in this step. These cases are as follows.

- the façade without shading devices, without insulation, and without daylighting (reference case)
- the façade with shading devices, without insulation and with daylighting (alternative case 1)
- the façade with shading devices, with insulation and with daylighting (alternative case 2)

F. Determination of Payback Period

The energy and finance were considered in this study. To obtain the saving, the subtraction between the reference case with the others was applied. By multiplying the electricity cost, 3 Baht/kWh, the cost saving could be calculated. Payback period method was occupied to quantify the return of the incremental initial cost, which was the additional cost due to applying shading devices and insulation, based on the annual cost saving. The incremental cost is shown on Table 2.

$$PP = IC \div CS_a \quad (3)$$

Where:

PP = Payback Period (Year)

IC = Incremental Cost (THB)

CS_a = Annual Cost Saving (THB/Year)

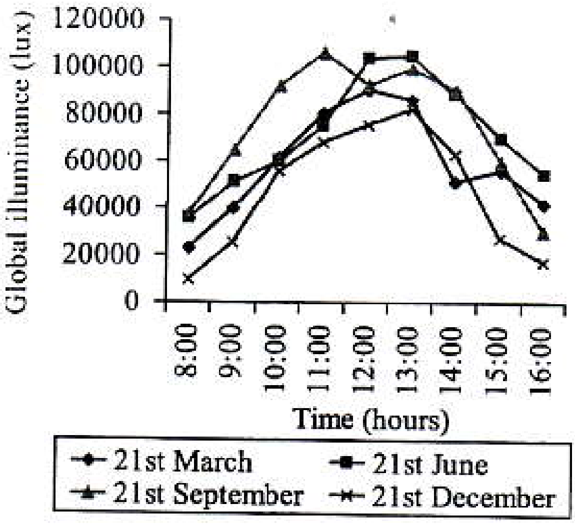

Figure 4. Global illuminance as function of time

IV. RESULTS AND DISCUSSION

A. Slat Angle Analysis

Sky ratio is the ratio of diffuse solar radiation from the sky to the global solar radiation. This ratio describes the sky condition. For sky ratio ≤ 0.3, the sky is clear whereas for that of $0.38 <$ to < 0.8, it is classified as the partly cloudy condition. Meanwhile, the cloudy sky is occurred when the sky ratio ≥ 0.8. From the simulation results shown on Figure 4, the illuminance on the workplane has the relationship with the sky ratio. When the sky ratio is decreasing, the illuminance on the workplane is increasing.

On March, even though it is cloudy at 09:00, there is high illuminance on -45^0 of slat angle at 1.5 meter from the window. It is different with 45^0 at the same time. Thus, it is not happened due to the sky condition. It is because of the geometry of the shading devices, façade, and sun position. There is some amount of beam light falling on point, 2.5 meter from the window. The December result exhibits that -45^0 of slat angle has better performance than that of 45^0. From this result, the slat angle -45^0 could be applied for March, September, and December whereas for June, that of 45^0 would be preferred. This configuration is used for the next subchapter.

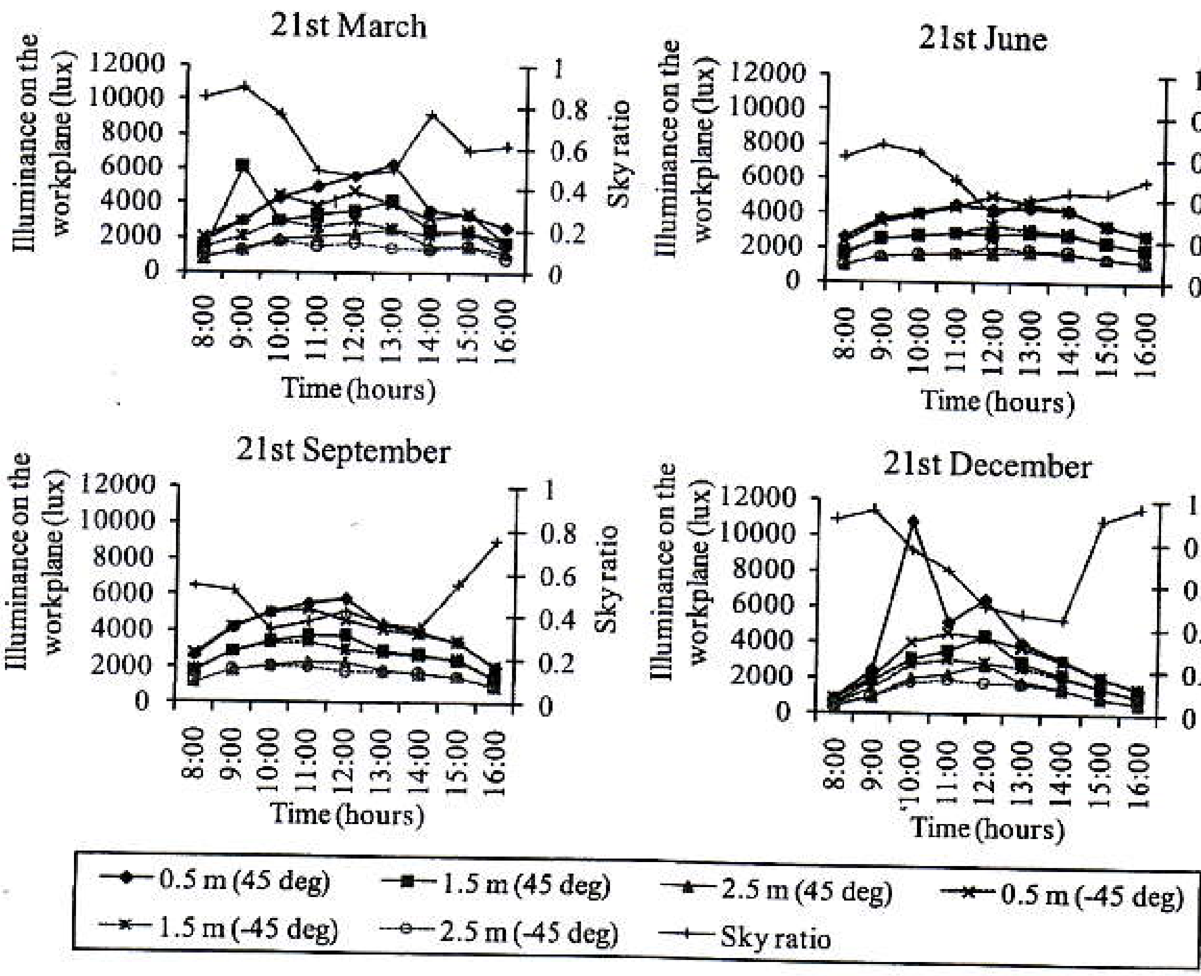

Figure 5. Illuminance on the workplane and sky ratio as function of time of WWR 0.68

TABLE III. DAYLIGHT PENETRATION DEPTH AND LAMP REQUIRED

Period	Parameter	WWR			
		0.0	*0.2*	*0.4*	*0.68*
March, June, September	DL depth (m)	0	4.5	6.5	7.5
	Number of lamps	20	12	8	6
December	DL depth (m)	0	2.5	3.5	4.5
	Number of lamps	20	16	14	12

B. *Daylight Penetration Depth and Lighting Arrangement*

Table 3 exhibits the daylight penetration depth and the number of lamps needed to maintain the illuminance on the workplane. It shows that by the increasing of window size, the daylight penetration depth will increase and it will decrease the amount of lamp. The ratio of change of daylight penetration depth from 0.4 to 0.68 is less than 0.2 to 0.4. Despite keeping increasing the window size, the daylight penetration depth would not increase significantly. The illuminance on the workplane at 08.00 on 21st March becomes the lowest illuminance comparing to June, and September. However, December case has been separated because the difference of daylight penetration is significant with the three other months. Figure 4 illustrates the global illuminance for each particular day. The global illuminance for 21st December is the least of the others. Thus, this might be the reason for the shallow daylight penetration depth for December.

Figure 6 illustrates the relationship between distance from the window and the illuminance level on it. From this particular day, 21st March which is used as an example, the illuminance tends to decrease significantly on the several points near the window. Roughly, on WWR 0.2, the illuminance at 1.5 meter from the window is half of the illuminance at 0.5 meter from the window. Meanwhile for the same condition, on WWR 0.4 and 0.68, the illuminance reduces 40% and 25% respectively. By applying wide window, the illuminance drop will be less near the window. However, by the increasing of distance from the window, the illuminance drop of the wide window will be higher than that of the narrow one.

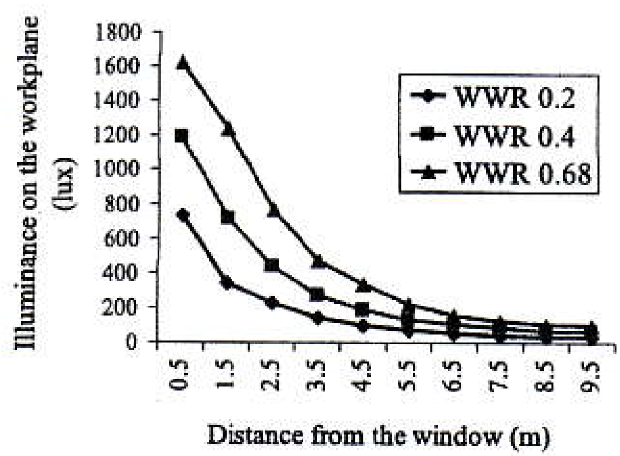

Figure 6. Illuminance on the workplane as function of distance from the window at 08:00 on 21st March

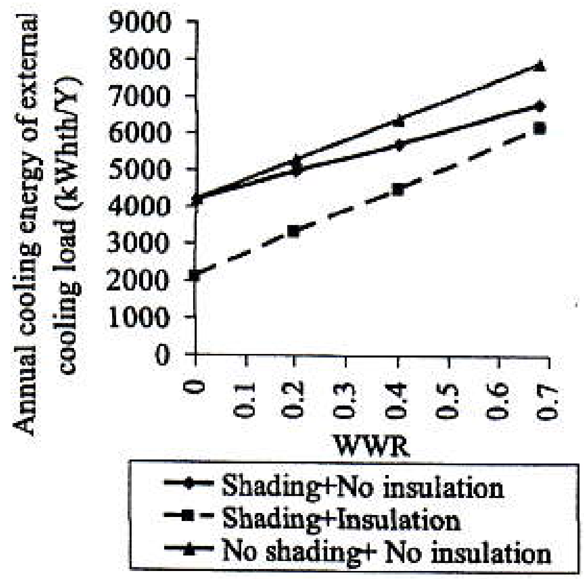

Figure 7. Annual cooling energy consumption of external cooling load as function of WWR

C. *Energy Consumption*

The wider the window, the more cooling load occurs from exterior to the room shown on Figure 7. The insulated wall gives better performance than that of without insulation. However, the benefit of this insulation keeps reducing since the decreasing of wall area.

Figure 8 expresses the annual energy consumption of several scenarios. The energy consumption consists of air conditioner and lighting. By utilizing daylight, the electric consumption of lighting can be reduced. For WWR more than

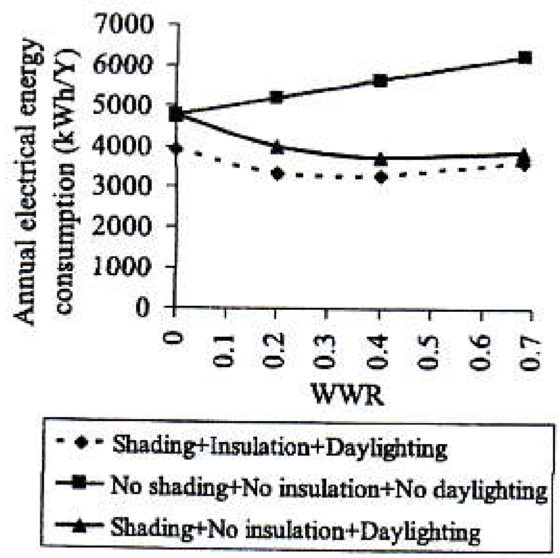

Figure 8. Annual electrical energy consumption due to WWR

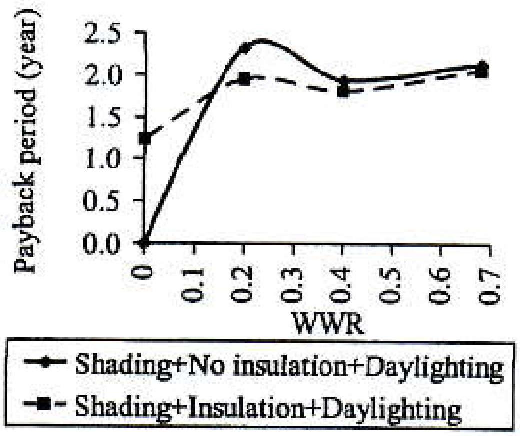

Figure 9. Payback period due to WWR

approximately 0.4, the energy consumption keeps increasing. The heat gain overwhelms the benefit from lighting energy saving. As a function of window size, the insulation gives more energy saving. After employing daylight with shading devices and wall insulation, the energy consumption for the building can be minimized until 3.25 MWh/Y at WWR 0.4 roughly. Before improvement, which is without using daylighting, shading devices, and wall insulation, its energy consumption is 5.62 MWh/Y. Thus, the energy consumption can be saved up to 42 %.

D. *Payback Period*

The payback period for applying the application of daylight by using shading devices and insulation can be seen in Figure 9. Since there is no additional cost on WWR 0 for no insulation case, the payback period become zero. The return of investment on WWR 0.2 is longer than that of WWR 0.4 despite less additional cost. For WWR 0.68, the high cost saving come with high investment so that its payback period is higher than WWR 0.4. Overall, by installing the insulation, the return of investment becomes faster than that of without insulation which is less than 2 years.

V. Conclusions

From this study, the vertical shading devices with additional horizontal slat have been sufficient for daylight utilization. The slat angle -45^0 for March, September, and December and that of 45^0 for June are satisfied for shading the direct solar radiation. This slat configuration has influenced the lighting energy consumption by the variation of daylight penetration depth. As the function of window to wall ratio (WWR), the application of these shading devices integrated with wall insulation has achieved the lowest energy among the other cases. After applying daylighting with shading devices and wall insulation, the energy consumption, which is combination of lighting and air conditioner, could be saved 42%. Roughly, it was achieved by WWR 0.4 for the large room. The additional cost of shading devices and insulation would recover less than two years.

Acknowledgment

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