Energy Efficient Fenestration for Daylighting Application in Thailand

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Abstract

Combinations of side-window parameters are proposed which produce less energy consumption in Thai commercial buildings. A generic reference building is generated by using DOE-2, a building energy simulation program, using Thailand's weather data. The base case of the office building model includes both the typical energy consumption characteristics and the daylight factor at various room depths. In the daylighting case, lighting integrated with stepped dimming devices is considered as an energy saving option compared with the conventional lighting system. The daylighting application using stepped dimming devices is recommended to reduce artificial lighting energy and electricity consumption of the Thammasat hospital building. Results of parameterization study and combinations of window properties, window-to-wall ratios, and external shadings give recommendations for energy efficient fenestration design. Finally, daylighting application in the Thammasat hospital can reduce annual electricity consumption by 2.3% with a payback period of 2.82 years and an internal rate of return of 43.8%, revealing a high potential for daylight utilization in Thailand.

Keywords: Daylighting, fenestration, lighting integration, generic reference buildings, building energy simulation.

1. Introduction

New office buildings in Thailand are constructed to comply with the 1992 Energy Conservation Promotion (ECP) Act [1]. Limitations of window height and low shading coefficient (*SC*) to meet the Overall Thermal Transfer Value (OTTV) result in high artificial lighting power density. There is abundant natural daylight in Thailand, the potential of which has been reported [2]. However, real application is often overlooked because the effect of the sun's radiant energy on cooling load of the air-conditioning system is still questionable.

The Lumen method is considered as a good daylighting calculation method [3]. Because of its manual calculation, detail analyses are often simplified. The daylight factor curves from DOE-2 daylight processor are used [4] for creating an energy efficient daylighting design of different *WWR*s, room types and orientations. Most previous works focused on daylighting potential but energy efficient side-window design was rarely investigated.

This paper aims to assess and figure out parameters effecting energy consumption in buildings utilizing daylighting through a generic reference office building. Combinations of window glazing types, *WWR*s and external shading devices to achieve optimum energy consumption are proposed taking into account Thailand's weather data [5]. A case study of Thammasat hospital to achieve daylighting utilization was investigated in the office zones of the hospital buildings.

2. The Generic Reference Building (GRB)

The use of a generic reference building (GRB) is necessary in order to investigate the thermal effect of parameterization. A 20-storey office building of two daylit zones was modeled for DOE-2 simulation [6]. (see Fig. 1). The building dimension is 24.5m × 40.5m with a 14.5m × 14.5m non-air-conditioned service core. The floor-to-ceiling height is 2.5m with conventional concrete-block wall design. The type of window is strip-window of aluminum frame without overhang with *WWR* of 0.42 and single tinted glazing with *SC* of 0.69. Uniform electric lighting without daylighting is usually applied in Thai commercial buildings. Recessed fluorescent lamps with luminaires are typical characteristics. The average value of lighting power density is 17.22 W/m^2. The office equipment load is 16 W/m^2 and the occupancy density is 11 m^2/person. The air-conditioning system is a constant volume type with a set-point temperature of 24.5°C. Chillers are water-cooled centrifugal type with a COP of 3.22 and annual service hours of 2,772 hrs.

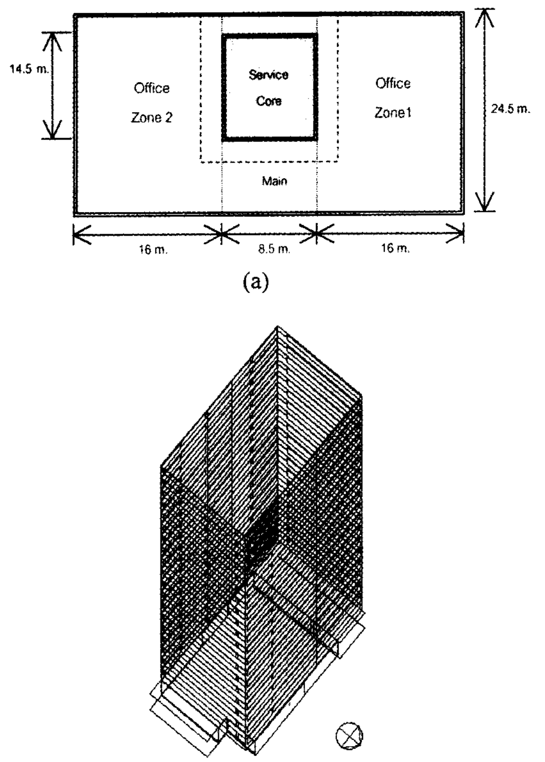


Figure 1. Generic reference office building (a) Floor plan (b) 3D view.

Results of DOE-2 simulation agree with the audit reports of the Department of Energy Development and Promotion [7] (DEDP) and give an energy consumption of 204.2 kWh/m^2-yr (52% for air-conditioning system, 27% for equipment load, and 21% for lighting load). The GRB in the base case is simulated to reflect energy performance and daylighting potential of the commercial buildings in Thailand [8].

3. The GRB's Daylighting Reference Case

Without daylighting the Lumen method gives the average illuminance of electric lighting on work plane of 546 to 764 lux. According to Illumination Engineering Society [9] (IES). standards the space illuminances comply with the standards. When daylight is allowed to enter the space, DOE-2 daylighting program will calculate hourly daylight illuminance taking into account the current sun-position and cloud cover presented in the weather file. Figure 2 shows results of simulation of the base case in which electric lighting is unnecessary in the daylighting reference case at a distance less than 10.5 m from windows, but glare is too high especially for a few meters from the window. In case of controlling glare, the interior movable-shading device is set to automatically deploy window shading devices to satisfy the maximum specified glare index.

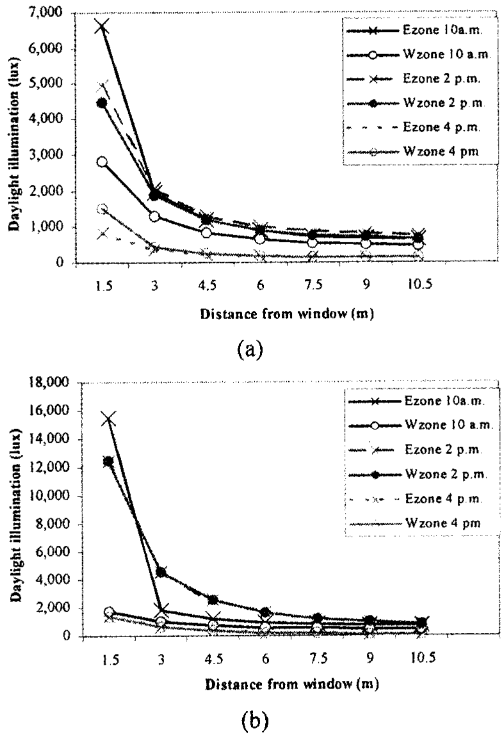


Figure 2. Daylight illuminance at distances from window (a) April (b) November.

To simulate the energy saving from daylighting the DOE-2 program requires input data for BUILDING-LOCATION, WINDOWS and SPACE-CONDITION commands as shown in Table 1. For an urban area and tropical climate location of the building, recommended by the DOE-2 manual, the value of moisture and particulate pollutant indices are 1.3 and 0.12 respectively. The tinted glass with a *SC* value of 0.69 in the GRB is converted to a GLASS-TYPE-CODE (G-T-C) value of 1205. In the SPACE-CONDITIONS variable, the three-stepped light dimming system is chosen. Maximum glare index is 22, recommended by the DOE-2 for general office work. In addition, the depth and the target lux level must be specified.

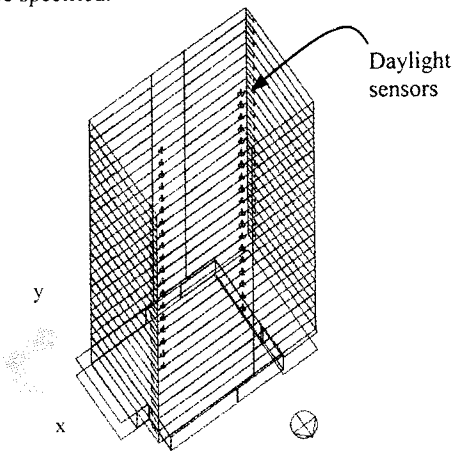


Figure 3. Location of daylight sensors.

Figure 2 shows that at 10 to 10.5m from window, daylight alone provides illuminance of 200 to 600 lux. The values suggest that electric light should be integrated to daylight and daylight sensors are placed at this depth. The daylit fraction of the space is about 70% and daylight sensors are placed at x =12.3 m, y (depth) = 10 m and z (height above floor) = 0.75 m in office zones from the 2nd –19th floors as shown in Fig. 3.

4. Daylighting Application

4.1 Window-to-Wall Ratio (WWR)

Tall and narrow windows give a deeper daylighting zone and a better open view but high glare if they face south, east or west and are more likely to create light/dark contrast [10]. For the same window area, a wider window at a higher level provides more daylight illumination and high level of minimum daylight factor. Building designers often recommend the latter because of less glare and preference of the occupant for a wider window. Figure 4 illustrates parameterization of *WWR* values and the change of energy consumption of the building run by DOE-2. The higher the *WWR*, the more is the electric-lighting saving from daylighting. For the generic reference building with a *WWR* of 0.43, 30% of electric lighting, 4.3% of electric cooling, and 7.6% of total electricity consumption are saved annually from the daylighting application.

Table 1. Description of keyword values for DOE-2 simulation.

Daylighting commands	Keyword values
Building location	
Atmospheric moisture	1.30
Atmospheric turbidity	0.12
Glass type	
Glass type code	1205
Space conditions	
Daylighting	YES
Target lux	500
Sensor location	(12.3, 10, 0.75)
Lighting control system	STEPPED
Lighting control steps	3
Maximum glare index	22
Ratio of dimming area	0.8
Interior visible light reflectance	
Floor	0.2
Wall	0.5
Ceiling	0.7

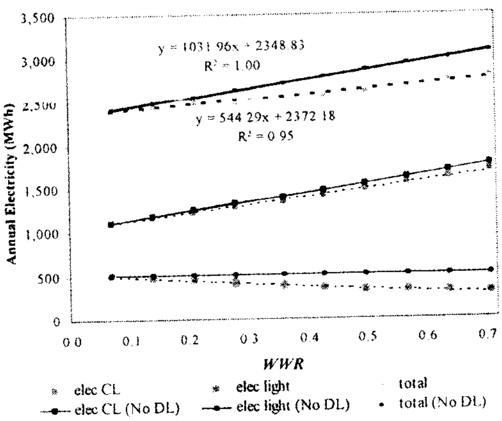


Figure 4. Annual electric consumption at various window-to-wall ratios.

4.2 Window Glazing

The DOE-2 program contains a window library covering common glazings, which are available in the market as well as experimental electrochromic (EC) glazing. In this study parameterizations are performed by varying one-by-one the glazing type covering 28 single-pane glazings in clear, tinted, reflective, low-e and

EC types, as shown in Table 2. The glazing properties such as T_{vis}, RF_{vis}, T_{sol}, RF_{sol}, U_f and SC are important parameters in daylighting design [11]. For instance high T_{vis} glazings are typically appropriate in daylighting design but if T_{vis} is too high the SC value must be high and allow high solar cooling load.

Table 2. Summary of DOE-2 glazing properties.

G-T-C	Window type	SC	T_{vis}	Remark
10xx[a]	Clear	1.0	0.89	-
12xx[b]	Tinted	0.71	0.57	-
1400	Reflective	0.23	0.08	-
1418	Reflective	0.58	0.33	-
14xx[c]	Reflective	0.35	0.16	-
1602	Low-e	0.84	0.81	-
1800	Absorbed EC	0.98	0.85	Bleached
1801	Absorbed EC	0.36	0.13	Colored
1802	Reflective EC	0.85	0.82	Bleached
1803	Reflective EC	0.34	0.16	Colored

Note: *a*, *b*, *c* represent 1001-1003, 1201-1201 and 1400-1418 respectively.

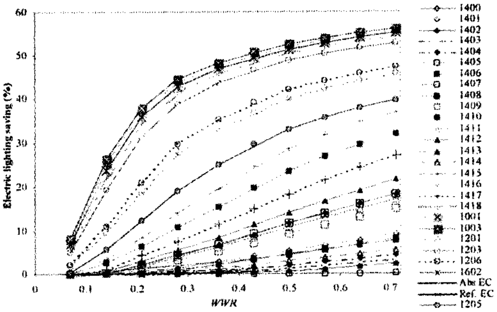


Figure 5. Annual electric lighting saving of different glazings.

Table 3. Summary of electric lighting savings.

WWR	Electric lighting saving	Glazing type	G-T-C
> 0.50	> 50%	Clear, EC, Low-e	1001, 1801,1602
> 0.50	40-50%	Tinted	1201, 1203, 1206
> 0.50	< 40%	Reflective	1400-1418
< 0.50	30-50%	Clear, EC, Low-e, tinted	1001, 1801,1602, 1203

Simulation results show that the daylighting application saves the largest electric lighting in the case of clear glazings followed by EC, tinted and reflective glazings respectively (see Fig. 5) and Table 3.

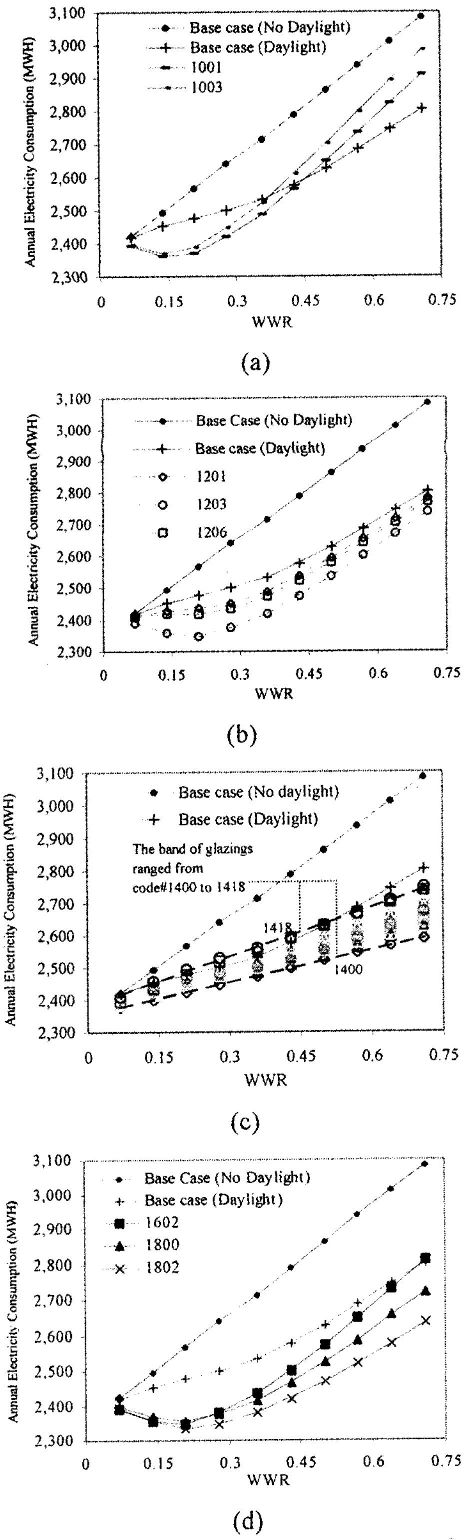
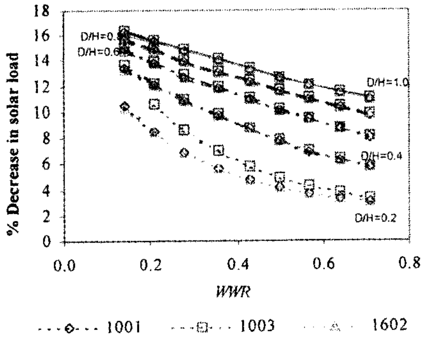


Figure 6. Annual electricity consumption of different glazings.

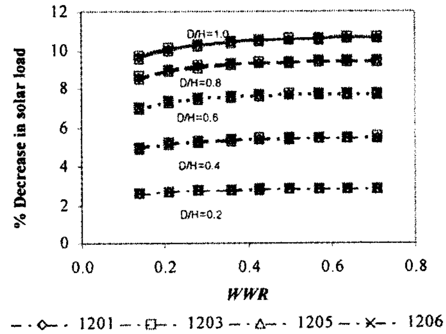
However, total electricity consumption reduction from daylighting application is shown in Fig. 6 where the penalty of using too high *WWR* and too high *SC* glazing is pointed out. Figure 6 illustrates that the reflective EC glazing of code#1802 shows the largest savings for each value of *WWR*s. At *WWR*<0.5, electric saving of EC glazing is larger than low-e, tinted, clear and reflective glazings. When *WWR*>0.5, electric saving of EC glazing is larger than reflective, tinted, low-e and clear glazings. It is clearly shown that, at *WWR* less than 0.5, high T_{vis} glazings increase energy savings, but for the *WWR* greater than 0.5, the *SC* value must be paid more attention than the T_{vis}. The saving in the base case having *WWR* of 0.43 is increased by 4% if T_{vis} increases from 0.43 to 0.75, i.e. changed from gray tinted glazing of code#1205 to green tinted glazing of code#1203.

4.3 The External Shading

Simulation results of the daylighting case with overhangs in the south windows and setbacks in the east and west windows are shown in Fig. 7. It shows parameterization of shading devices with depth to window height (*D/H*) ratios of 0.2, 0.4, 0.6, 0.8, 1.0 for glazings of G-T-C code# 1001, #1003, #1201, #1203, #1205, #1206, #1400, #1418, #1602, #1800 and #1802. It reveals that external shading devices reduce solar cooling load by 2-18% depending on *WWR*s and glazing materials.



(a)



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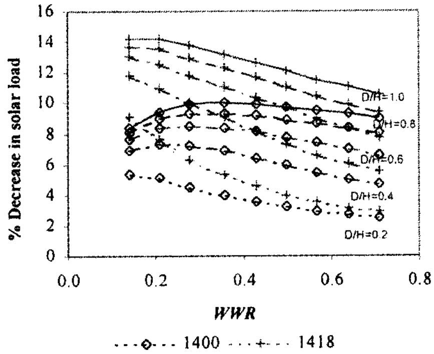

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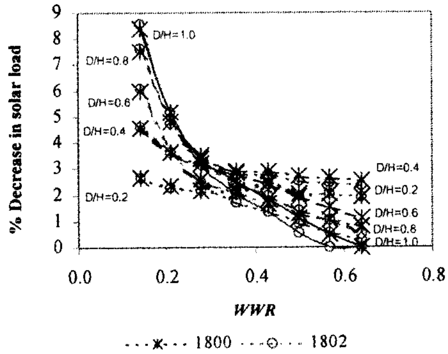


(d)

Figure 7. Percentage of decrease in solar load with shadings for various *WWR*s, glazings and *D/H*s.

However, the percentage decreases in solar load for EC glazing decrease sharply by 1-10% with increasing shading depth. Because T_{vis} property of the EC glazing is set to adjust as close as possible to the illuminance set point, increasing D/H ratio changes EC glazing from a colored state to a bleached state for more T_{vis}.

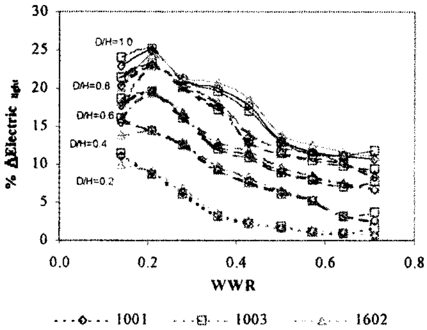
The percentage difference of electric lighting, $\Delta Elec_{light}$, describes the effect of external shading devices on the electric lighting reduction in the daylighting application. A high $\Delta Elec_{light}$ value means high effect of the device on the electric lighting i.e. more electric light to substitute for the obstructed natural daylight. The percentage difference between electric lighting with external shading and electric lighting without shading devices is determined from the following equation.

$$\Delta Elec_{light}(\%) = \frac{(E_{shade} - E_{w/o\,shade}) \times 100}{E_{w/o\,shade}} \qquad (1)$$

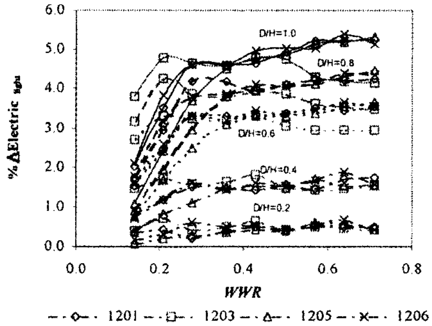
Where $\Delta Elec_{light}$ is the percentage difference of electric lighting between building with external shading and without external shading, E_{shade} is electric lighting with external shading devices, and $E_{w/o\ shade}$ is electric lighting without external shading devices.

Results of the study shows that there are four consequences of external shading devices obstructing the daylight (see Fig. 8). The parameterization results of 11 representative glazings in the range of $0.14<WWR<0.71$ and $0.2<D/H<1.0$ are as follows:

(1) Increasing in *WWR*s decreases the effect of external shadings. External shadings for high SC glazings code# 1001, #1003 and #1602 reduce lighting savings by 2-25% compared to the case without shadings, see Fig. 8a.
(2) External shadings have small effect on lighting savings. External shadings for tinted glazings such as code# 1201, #1203, #1205 and #1206 have less effect on lighting savings, about 1-6% saving changes (see Fig 8b).
(3) External shadings have high effects on electric lighting saving. The reflective glazing code#1400 is highly affected by external shadings as savings reduce rapidly from 0-16% without daylight recovering from increasing *WWR*s (see Fig. 8c).
(4) External shadings reduce lighting savings. Lighting savings from EC glazings are independent of *WWR*s but are decreased with high-depth external shadings from 1-13% (see Fig. 8d).



(a)



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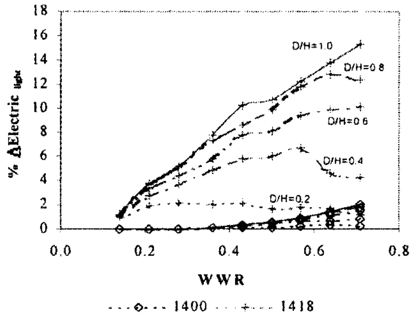

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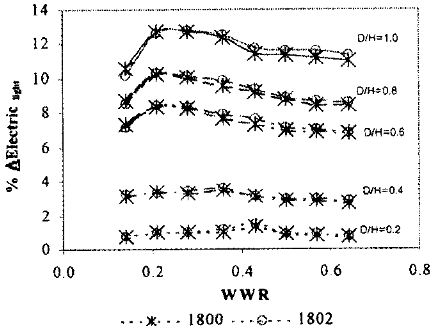


(d)

Figure 8. Percentage difference between electric lighting with external shading and without shading devices.

The percentage difference of annual electricity consumption of the GRB building with external shadings and without external shadings is determined from the following equation.

$$\Delta Elec_{\text{total}}\ (\%) = \frac{(E_{\text{tot, shade}} - E_{\text{tot, w/o shade}}) \times 100}{E_{\text{tot, w/o shade}}} \quad (2)$$

Where $\Delta Elec_{\text{total}}$ is the percentage difference of annual electricity consumption between buildings with external shadings and without external shadings, $E_{\text{tot, shade}}$ is the annual electricity consumption with external shadings, and $E_{\text{tot, w/o shade}}$ is the annual electricity consumption without external shadings.

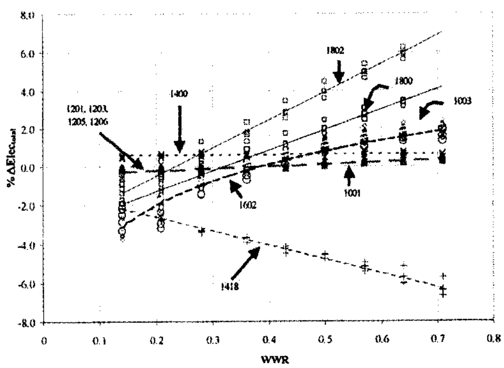


Figure 9. Percentage difference of annual electricity consumption between buildings with external shading and without shading.

Equation (2) suggests that when $\Delta Elec_{\text{total}} > 0$, external shadings reduce annual electricity consumption, i.e. promoting energy savings. When $\Delta Elec_{\text{total}} = 0$, external shadings do not affect the annual electricity consumption and when $\Delta Elec_{\text{total}} < 0$ external shadings increase the total electricity consumption.

Increasing the *D/H* ratio for clear (code#1001 and #1003), low-e (code#1602) and EC (code#1800 and #1802) glazings results in significant reductions in annual electricity consumption (see Fig. 9). In clear, low-e and absorbed EC glazing, the electricity saving with external shading starts at a *WWR* value between 0.3 and 0.4. The low *SC* reflective (code#1400) and tinted glazings code#1201, #1203, #1205 and #1206 do not affect electricity consumption with increasing *WWRs* or *D/H* ratios. The high *SC* reflective glazing, i.e. code#1418, increases annual electricity consumption at any *WWR* and *D/H* ratios, because its low T_{vis} is insensitive to increasing *WWR* (see Fig. 8c) and its high *SC* value is sensitive to solar load (see Fig. 7c) and *WWR*.

4.4 Electric Energy Savings and Economic Analysis

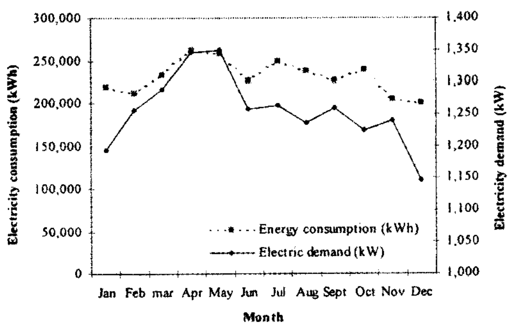


Figure 10. Energy consumption of the GRB.

According to electric tariffs in Thailand, electricity bills differ from types and sizes of businesses. Because the generic reference office building shows a minimum 15-minute integrated demand of 1000-1200 kW and the energy demand of 3 consecutive months less than 250,000 kWh (see Fig. 10), it is categorized as a medium enterprise consumer.

The stepped dimming method of fluorescent lamps (FLs) is to completely turn off a portion of lamps when the level of daylight exceeds a pre-defined limit. The 3-stepped-dimming lighting system consists of three components: 1) the photo sensor, 2) electronic controller and 3) FLs. When the existing FLs and luminaire arrangement in Fig. 11 is used, 135 lamps are dimmed (70% of the office area × 64 luminaires × 3 lamps per luminaire). Typically, an electronic controller is able to support 1000W, thus 5 controllers are required in each zone (Philips Electronics, 2000). Table 4 provides estimated investment costs of 3-stepped dimming devices and Table 5 is the estimated costs of fenestration materials for five different *WWR*s.

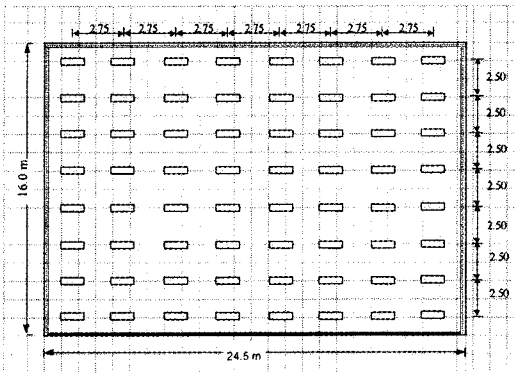


Figure 11. Plan view of uniform arrangement of recessed fluorescent lamps in the office GRB.

Table 4. Costs of 3-stepped dimming devices.

Item	Quantity used	Cost/unit (Baht)	Total cost (Baht)
Controller	190	10,400	1,976,000
Photo sensor	38	2,630	99,940
Sensor cable	300	500	15,000
Installation	5,130	40 Baht/lamp	205,200
Total investment			2,386,140

Source: Phillips Electronics (Thailand) Ltd.

Table 5. Investment costs of glazing materials.

G-T-C	1001	12xx	1400	1602	18xx
Cost(Baht/m^2)	197	305	1,047	2197	2600
Cost (10^6 Baht)					
WWR=0.43	0.54	0.84	2.89	6.06	6.89
WWR=0.50	0.64	0.98	3.37	7.07	8.04
WWR=0.57	0.73	1.12	3.85	8.08	9.19
WWR=0.64	0.82	1.26	4.33	9.09	10.4
WWR=0.71	0.91	1.40	4.82	10.2	11.5

Note: The 12xx stands for code#1201, #1203, #1205 and 18xx stands for code #1800 and #1802.

Results of energy saving analysis show that daylighting application can save 10-15% of annual electric energy when proper glazings are installed on a building of *WWR* > 0.50. In the same case, if there are external shading devices of any depth attached to the window, annual electric energy savings increase about 1-6% compared to the case without shading. Therefore, economic analyses of the five best glazing options from Table 5 with external shading devices for *WWRs* of 0.43, 0.50, 0.57, 0.64 and 0.71 are studied to determine economic attractiveness of each option. The average simple payback periods and internal rates of return (IRRs) of five *WWR*s for eight glazing materials are shown in Fig. 12.

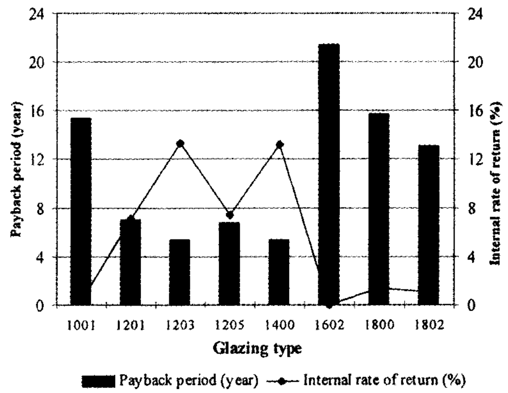


Figure 12. Simple payback periods and IRRs of window glazings.

From the economic point of view, the two best options are glazing using code#1203 and #1400 with payback periods of 5.3 and 5.4 years and IRRs of 13.3 and 13.2% respectively. For all glazing types, an increase in *WWR* decreases the payback periods.

5. The Case Study of Thammasat Hospital

Lighting power density reduction can be achieved through reducing the number of lamps per luminaire, and using the low-loss and electronic ballasts. The daylighting application is a good option for electric lighting reduction. This study analyses daylighting application in the office areas through the existing fenestration design of the treatment & accident building on the 3^{rd}-6^{th} floors where the annual working hours are 2,380 hours per year. The building's *WWR* is 0.38 and the fenestration is tinted glazing with *SC* of 0.75, T_{vis} of 0.60 and a *U*-value of 5.2 W/m^2°C. There are external shading devices of *D/H*=1.33 and internal venetian blind (see Fig. 13). It is assumed that occupants adjust the venetian blinds to reduce the window *SC* value to (0.6) x (0.75) = 0.45 and a visible transmittance reduce T_{vis} to (0.6) x (0.35) = 0.21 (recommended by DOE-2 program for diffusive white translucent drape). The study of Thammasat hospital is focused on daylighting application in office zones using 3-stepped dimming devices at the target lux of 430.

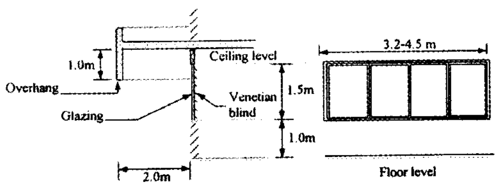


Figure 13. The fenestration of the office floors of treatment & accident building.

5.1 The Existing Electric Lighting System of the Daylit Zones

The present electric lighting specification effects the capability of daylighting application. To determine the existing lux level, trial measurements of electric lux level in perimeter zones are conducted. Table 6 shows lighting power intensity and illumination. The illumination of specific daylit zones are shown in Fig. 14.

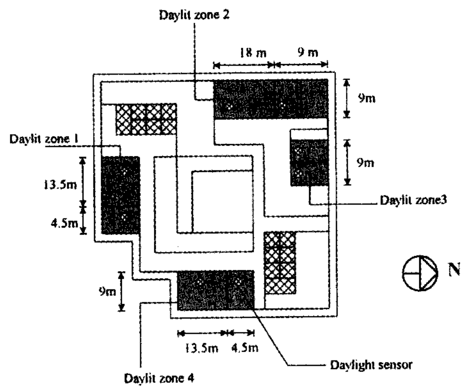
The shading areas in Fig. 14 indicate the daylit zones for daylighting application. It illustrates that some perimeter zones are divided into small rooms and the interior partitions obstruct the natural daylight (see daylit zone 2 of floor#4, #5 and #6). However in the daylighting simulation, these partitions are removed to leave empty space between windows and the daylighting sensors.

5.2 Daylighting Simulation

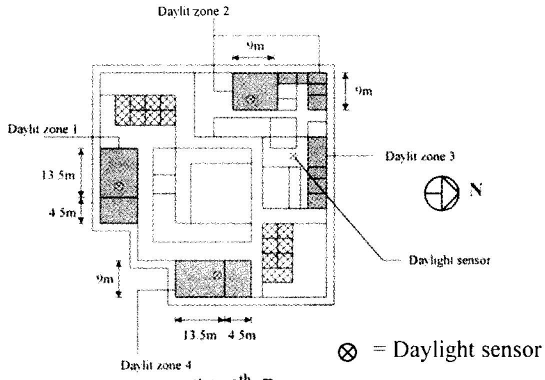
At the present time, occupants in the treatment & accident building utilize interior venetian blinds as a glare-controlling tool and as another direct daylight protection device. However, interior shading devices obstruct daylight. To investigate the significant of the interior-shading device, energy savings from daylighting application in the present-window case, utilizing interior shading devices, and in the bare-window case are simulated by DOE-2 as shown in Table 7.

Table 6. The lighting power intensity.

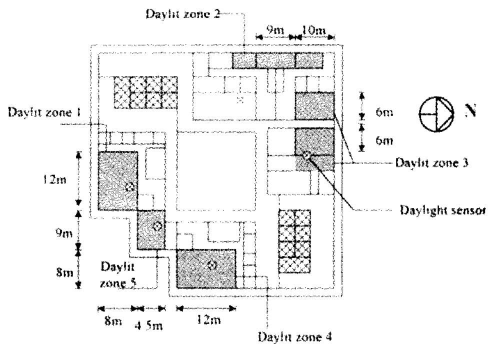
Floor#	W/m^2	Illumination (lux)
3	15.18	300-700
4	11.63	250-700
5	15.30	550-650
6	17.44	550-650
Average	14.90	367-675



(a) 3^{rd} floor.



(b) 4^{th} floor.



(c) 5^{th} and 6^{th} floor

Figure 14. The daylit zones and window system.

Table 7. Energy savings from daylighting applications.

	Energy consumption (MWh)	
	Present window application	Bare-window application
No daylighting	5,141.0	5,402.1
Daylighting case	5,092.2	5,289.4
Glare-control case	-	5,280.2
Energy saving	48.8	112.7 to 121.9

Results of simulation shown in Table 7, are energy savings of the 3-stepped dimming lighting system in office zones on the 3^{rd}, 4^{th}, 5^{th} and 6^{th} floors. The daylighting commands and keyword values are similar to that shown in Table 1 except the specific properties of glazing and target lux of 430. The positions of reference points are shown as daylight sensors in Fig. 14. For daylighting case, the bare-window application does not have shading devices to obstruct any daylight but in the present window application, the existing *SC* and T_{vis} are reduced by 60% and 35%, respectively. To solve glare-problem in the bare-window, daylighting performance in the specific zones was investigated and it was found that daylit zone#2 of the 3^{rd}, 4^{th}, 5^{th} and 6^{th} floors had high glare index. The percentage of hours with too high glare is greater than 10% of total annual working hours, i.e. 238 hours/year. By using interior shading devices only in the daylit zone#2, annual energy consumption is 5,280.2 MWh and energy saving increases up to 121.9 MWh per year (see the glare-control case in Table 7). The electric lighting savings, average daylight illuminance, average glare index, and percentages of hours with too high glare are shown in Table 8.

Thus total annual electricity saving from daylighting application in this building is 121,900 kWh/year which accounts for 2.3% of the total electricity consumption. For the area utilizing daylighting, electric saving is 24.42 kWh/m^2·year (121,900 kWh/year/4,991.52 m^2). From Table 9 the electricity consumption in the base case is 227,148 kWh per year or 227,148 kWh/4,991.52 m^2 = 45.51 kWh/m^2·year. Therefore, the daylighting application can save 53.7% of electric energy in the office zones.

The number of 40-W lamps on the 3^{rd} floor is (610.55 m^2×15.18 W/m^2)/(40 W/lamp) = 231 lamps, on the 4^{th} floor is 195 lamps, on the 5^{th} floor is 373 lamps, and on the 6^{th} floor is 425 lamps. Since the electronic controller is able to support up to 1000W, the required equipment quantity and the total cost are calculated and shown in Table 10.

In 2001, a non-profit organization like Thammasat hospital, falls into schedule 6 of the electric tariff of Thailand where the nominal rate of energy charge used in this study is 2.1412 Baht /kWh. By assuming a nominal interest rate of 12% and a life-span of 10 years, a payback period of 2.82 years and the IRR of 43.8% are determined indicating a highly attractive economic option.

Table 8. The results of daylighting application in the bare-window case.

Daylit zone	% Lighting reduction	Avg. daylight Illum. (lux)	Avg. glare index	% Hour with too high glare
Floor 3				
DL zone 1	61.3	429.0	10.2	0
DL zone 2	54.2	328.9	15.6	0
DL zone 3	35.9	226.2	10.5	0
DL zone 4	49.9	702.7	0	0
Floor 4				
DL zone 1	37.7	853.3	15.7	0
DL zone 2	63.8	401.1	17.3	0
DL zone 3	53.6	415.1	17.8	4
DL zone 4	59.4	943.1	8	0
Floor 5				
DL zone 1	53.6	712.0	15.7	4
DL zone 2	13	122.4	14.7	0
DL zone 3	41.2	227.7	8	0
DL zone 4	25.0	146.8	8	0
Floor 6				
DL zone 1	68.8	539.9	14	0
DL zone 2	16.5	134.6	16.2	0
DL zone 3	40.9	221	8.8	0
DL zone 4	23.9	142.9	8.9	0
DL zone 5	71.8	704.4	17.8	5.2

Table 9. Annual electricity consumption for the 3rd, 4th, 5th and 6th floors.

Floor	Area (m^2)	Daylighting area		Base case kWh/year
		(m^2)	%	
3rd	796.30	610.55	86.72	42814
4th	1,427.52	672.68	47.12	37843
5th	1,383.85	975.23	70.47	79405
6th	1,383.85	975.23	70.47	67086
Total	**4,991.52**	**3,233.69**	**64.78**	**227,148**

Table 10. Total investment costs.

Item	Quantity used	Cost per unit (Baht)	Total cost (Baht)
Controller	49	10,400	509,600
Photo sensor	24	2,630	63,120
Sensor cable	45	500	22,500
Material cost	595,220 Baht		

Source: Philips Electronics (Thailand) Ltd, (2000).

6. Conclusions

Daylighting application has high potential in Thailand. The utilization of energy efficient fenestration in the generic reference building results in electric lighting saving up to 50% and total electric energy saving up to 15%. From the economic point of view, green-colored tinted glazing of high T_{vis} and *SC* of 0.71 is the best glazing option, followed by the reflective glazing of the lowest *SC*, and the bronze-colored tinted glazing having T_{vis} of 0.53 and *SC* of 0.71. The two best glazing options with *WWR*>0.5 and external shading of any depth can save 15-20% of electric energy with payback periods of 5.3 to 5.4 years and IRRs of 13.2 to 13.3%.

A case study of daylighting applications in Thammasat hospital on the office floors of the treatment & accident building shows that daylighting has a high potential in total electric savings. The modification of internal partitions in perimeter zones and proper utilization of interior shading devices can reduce total electric consumption by 2.3% with an attractive IRR of 43.8% and a payback period of 2.82 years. However, this study assumes, at the indicated position of the reference points, daylighting area is 80-100% of the total daylit area. Increasing or decreasing in daylighting area can effect the total energy savings.

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8. Nomenclature

$\Delta Elec_{light}$	=	Percentage difference of electric lighting
$\Delta Elec_{total}$	=	Percentage difference of total electricity
COP	=	Coefficient of performance
DEDP	=	Department of Energy Development and Promotion
D/H	=	Overhang depth to window height ratio
EC	=	Electrochromic, a coating that makes the glazing more absorbing or more reflecting as the voltage applied to glazing changes.
ECP	=	Energy Conservation Promotion
FLs	=	Fluorescent lamps
GRB	=	Generic Reference Building
G-T-C	=	Glass Type Code
IES	=	Illumination Engineering Society
IRR	=	Internal rate of return (%)
NEPO	=	National Energy Policy Office
OTTV	=	Overall Thermal Transfer Value (W/m^2)
PBP	=	Payback period (years)
RF_{sol}	=	Solar reflectance
RF_{vis}	=	Visible light reflectance
SC	=	Shading coefficient

T_{sol} = Solar transmittance
T_{vis} = Visible light transmittance
U_f = Heat transfer coefficient of glazin W/m^2°C)
WWR = Window-to-wall ratio

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