ENERGY EFFICIENT DESIGN OF SIDE-WINDOW FOR DAYLIGHTING APPLICATION IN THAILAND

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ABSTRACT

The combinations of parameter effecting optimum energy consumption and good open view for designing side-window of office buildings are proposed. A generic reference building (GRB) is generated by using DOE2.1E, a building energy simulation program, under Thailand's weather data. The base case of the office building model includes both the typical energy consumption characteristics and the daylight factor (DF) at various room depths. In the daylighting case, integrating the daylight with step dimming devices is considered for energy saving compared with the conventional lighting system. Results of parameterization and combinations on window properties, window-to-wall ratios (*WWR*), and external shadings give recommendations for energy efficient daylighting design.

INTRODUCTION

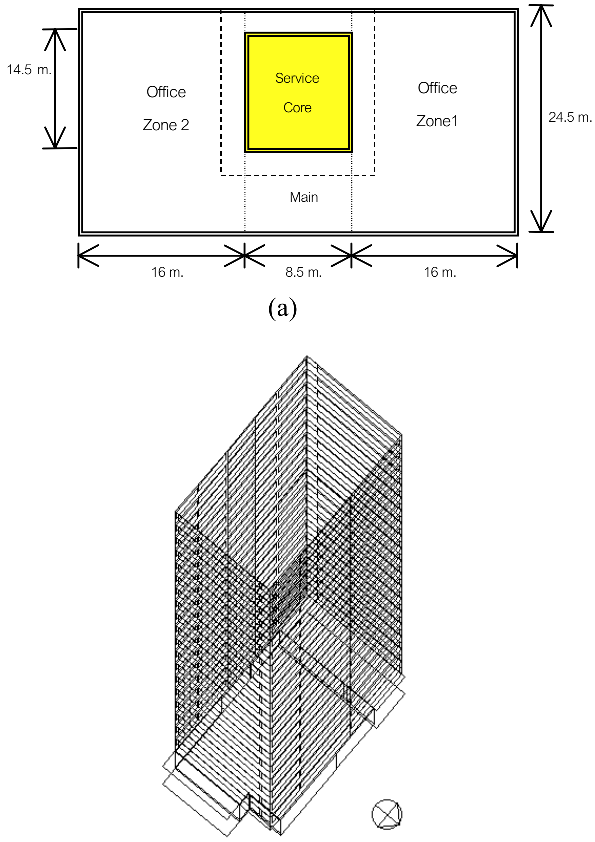
New office buildings in Thailand have been constructed to comply with the 1992 Energy Conservation and Promotion (ECP) Act[1]. Limitations of window height and lower shading coefficient (*SC*) to meet the Overall Thermal Transfer Value (OTTV) result in high artificial lighting power. Though the high potential of daylighting application for energy efficient lighting in Thailand is noticed and reported[2], real application is often looked over 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 (DF) curves from DOE-2 daylight processor were proposed[4] for energy efficient daylighting design of different *WWR*s, room types and orientations. Most previous works focused on daylighting potential but energy efficient window design was rarely investigated.

This paper investigates the parameters effecting energy consumption in building 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 under Thailand's weather data[5].

THE GENERIC REFERENCE BUILDING

The use of generic reference building (GRB) is necessary in order to investigate the thermal effect of parameterization. A 20-storey office building of two daylit zones has been 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. Floor-to-ceiling height is 2.5m with conventional concrete-block walling design.



(a)

(b)

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

Window is strip-window of aluminum frame without overhang with *WWR* of 0.42 and single tinted glass 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 (LPD) is 17.22 W/m^2. The office equipment load is 16 W/m^2 and the occupancy density is 11 m^2/person. 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 with annual service hours of 2,772 hrs.

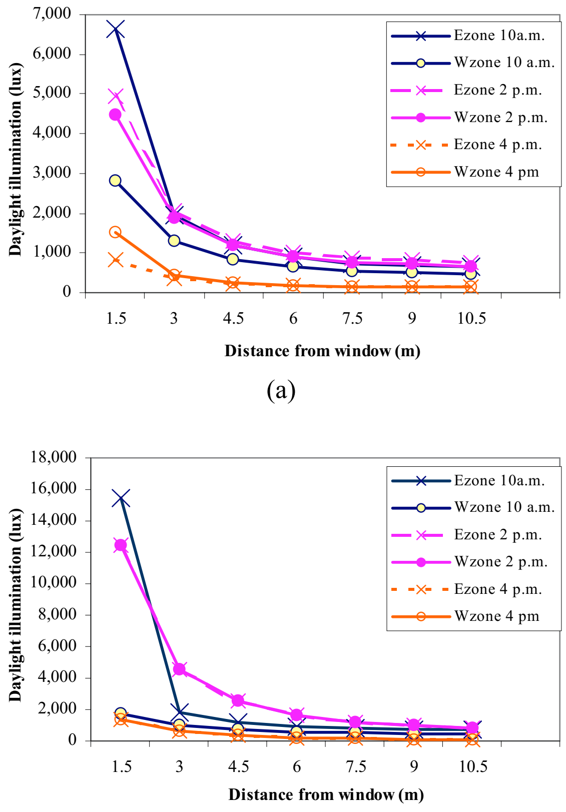
Results of simulation agree with the audit reports of Department of Energy Development and Promotion[7] (DEDP) and give energy consumption of 204.2 kWh/m^2-yr (52% for air-conditioning system, 27% for equipment load, and 21% for lighting load). The GRB in the base case is simulated to reflect energy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

DAYLIGHTING REFERENCE CASE

Without daylighting Lumen method gives the average illuminance of electric lighting on work plane of 130-510 lux. According to Illumination Engineering Society[9] (IES) standards the space illuminance complies with the standards. If daylight is allowed to enter the space, it will light up at each point of the room depth as shown in Fig. 2. It is noticeable that with the typical window and room characteristics, daylighting potential is very high.

Figure 2 shows that at the distance less than 10.5 m from windows, electric lighting is unnecessary in the base case but glare must be too high especially for a few meters from the window. In case of controlling glare, the reference case is set a probability to control glare to be 0.5 where the program will automatically deploy window shading devices to satisfy the maximum specified glare index.

To simulate the energy saving from daylighting the DOE-2 program requires input data in BUILDING-LOCATION, WINDOWS and SPACE-CONDITION variables as shown in Table 1. Tropical and urban location give values of atmospheric moisture and atmospheric turbidity of 1.30 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, in the direction of occupant's view to east and west for the east and west office zones respectively. In addition, the depth and the target lux level must be specified.



(b)

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

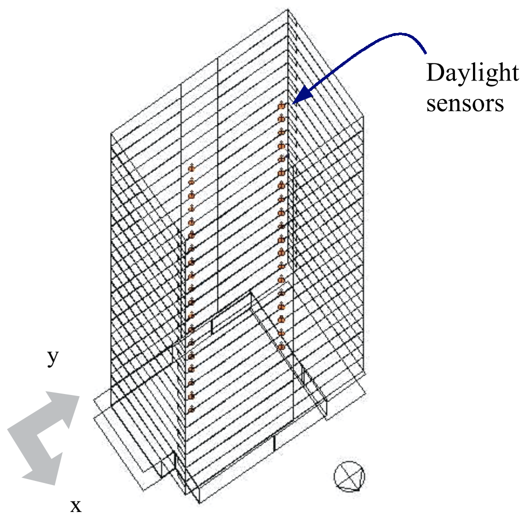


Figure 3. Location of daylight sensors.

Figure 2 shows that at 10-10.5m from window, daylight solely provides 200-600 lux illuminance. The values suggest that at this depth electric light should be integrated to daylight and daylight sensors are placed here. 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.

Table 1. Daylighting commands and keyword values.

DAYLIGHTING COMMANDS AND KEYWORDS	KEYWORD VALUE
BUILDING LOCATION	
ATM-MOISTURE	1.30
ATM-TURBIDITY	0.12
GLASS-TYPE	
GLASS-TYPE-CODE	1205
SPACE-CONDITIONS	
DAYLIGHTING	YES
LIGHT-SET-POINT1	500 (LUX)
LIGHT-REF-POINT1	(12.3, 10, 0.75)
LIGHT-CTRL-TYPE1	STEP
LIGHT-CTRL-STEPS	3
MAX-GLARE	22
LIGHT-CTRL-PROB	0.5
ZONE-FRACTION1	0.8
VIEW-AZIMUTH	180
INSIDE-VIS-REFL	
FLOOR	0.2
WALL	0.5
CEILING	0.7

WINDOW-TO-WALL RATIO

Tall and narrow windows give deeper daylighting zone and better open view but high glare if they face south, east or west and are more likely to create light/dark contrast. Of the same area, the wider window at high level provides more daylight illumination and higher minimum daylight factor. Building designers often recommend the latter one because of less glaring and preference of the occupant for the wider opening.

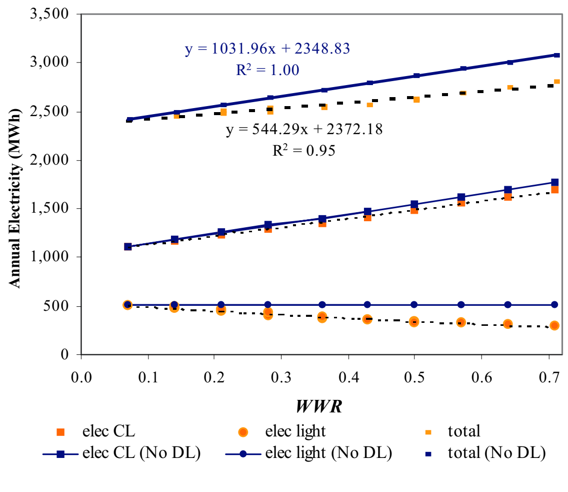


Figure 4. Annual electric consumption at various window-to-wall ratios.

Typical heights of windows in Thailand which vary from 1.0 - 1.2 m do not suggest any daylighting application for energy saving.

Figure 4 illustrates parameterizations of window heights that result in different *WWR* values and the change of energy consumption of the building.

The higher the *WWR*, the more is the electric-lighting saving from daylighting. For the generic reference building with a *WWR* of 0.43, 20% of electric lighting, 4% of electric cooling, and 10% of total electric consumption are saved annually.

WINDOW GLAZING

Solar properties such as T_{vis}, R_{vis}, T_{sol}, RF_{sol}, U and *SC* are important parameters in daylighting design. Glazings with a high T_{vis} appear relatively clear and provide sufficient daylight but they can create glare problems and allow too high solar cooling load. Glazings with low T_{vis} are properly and oftenly used in highly glare-sensitive conditions, but they can create gloomy interiors and are unsuitable for many daylighting applications[10]. Usually high T_{vis} glazings have higher *SC* (high solar cooling load) values than that of the reflective coated one.

Table 2. DOE-2 glazing properties.

G-T-C	WINDOW	U-SI	SC	T_{sol}	RF_{sol}	T_{vis}	RF_{vis}
1001	CLEAR	6.17	0.95	0.77	0.07	0.88	0.08
1003	LOW IRON	6.22	1.04	0.89	0.08	0.91	0.08
1201	BRONZE	6.17	0.71	0.48	0.05	0.53	0.06
1203	GREEN	6.17	0.71	0.49	0.06	0.75	0.07
1205	GREY	6.17	0.69	0.46	0.05	0.43	0.05
1206	BLUE	6.17	0.71	0.48	0.05	0.57	0.06
1400	CLEAR-L	4.90	0.23	0.07	0.34	0.08	0.41
1401	CLEAR-M	5.11	0.29	0.11	0.27	0.14	0.31
1402	CLEAR-H	5.41	0.36	0.16	0.22	0.2	0.25
1403	TINT-L	4.93	0.26	0.04	0.15	0.05	0.17
1404	TINT-M	5.11	0.29	0.06	0.13	0.09	0.14
1405	TINT-H	5.29	0.34	0.1	0.11	0.1	0.11
1406	CLEAR-L	5.44	0.35	0.15	0.22	0.2	0.23
1407	CLEAR-H	5.5	0.45	0.24	0.16	0.3	0.16
1408	TINT-L	4.93	0.26	0.04	0.13	0.05	0.09
1409	TINT-M	5.05	0.33	0.1	0.11	0.13	0.1
1410	TINT-H	5.5	0.4	0.15	0.09	0.18	0.08
1411	CLEAR-L	4.99	0.29	0.11	0.25	0.13	0.28
1412	CLEAR-M	5.23	0.37	0.17	0.2	0.19	0.21
1413	CLEAR-H	5.35	0.41	0.2	0.16	0.22	0.17
1414	TINT-L	4.99	0.29	0.07	0.13	0.08	0.13
1415	TINT-M	5.23	0.34	0.1	0.1	0.11	0.1
1416	TINT-H	5.35	0.37	0.12	0.09	0.13	0.09
1417	CLEAR	6.12	0.58	0.43	0.31	0.33	0.45
1418	TINT	6.12	0.53	0.3	0.14	0.25	0.18
1602	LOW-E .2	4.27	0.84	0.38	0.09	0.81	0.11
1800	Abs EC	6.17	0.98	0.81	0.09	0.85	0.1
1801	Abs EC	6.17	0.36	0.11	0.18	0.13	0.08
1802	ref EC	6.17	0.85	0.69	0.17	0.82	0.11
1803	ref EC	6.17	0.34	0.1	0.22	0.16	0.07

DOE-2 program contains window library covering common available glazings as well as experimental electrochromic (EC) glazing. In this study varying the G-T-C, shown in Table 2, electric savings from single pane window of clear, tinted, reflective, low-e and EC are simulated. The one-by-one parameterization of glazing properties such as T_{vis} or *SC* may not reflect real aspect because each of glazing treatments such as reflective coatings, heavy tints, reflective retrofit film or EC owns unique values of U_f, T_{vis}, R_{vis}, *SC*, etc. Table 2 provides properties of glazing used in the simulation. The second digit of G-T-C indicates glazing type; 0 = clear/low-iron, 2 = tinted but no coating, 4 = reflective coating, 6 = low-e coating, and 8 = electrochromic glass.

Results of simulations 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.

It is obviously shown in Fig. 6 that both reflective and absorbed EC glass give lowest annual energy consumption especially for $0.28 < WWR < 0.57$. However, the EC glazing shows similar performance to reflective glass at $WWR > 0.57$. Low-e glazing performance is similar to reflective glazing at $WWR > 0.43$ and less effective than tinted and all reflective glazings at $WWR > 0.60$. For all tinted glasses of the same *SC*, code#1203 has the highest value in T_{vis} showing the best energy saving option. The code#1205 is the worst option of tinted glass. Clear glass with code#1001 seems to be good for daylighting application at low *WWR*.

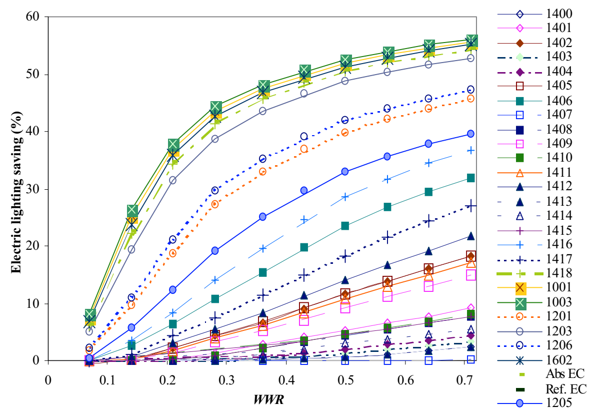


Figure 5. Electric lighting vs. WWRs of different glazings.

Reflective glasses of code#1400-1418 show a wide range of performance. Figure 6 shows the performance between clear glazing and reflective EC at $WWR > 0.5$ but lower than clear glazing at $WWR < 0.3$.

The code #1400 is the best reflective glazing option for reducing annual energy consumption, see Fig. 7, because of the lowest *SC* value. The code#1418 is the third best option for electric lighting reduction, see Fig. 8, but the *SC* value higher than code#1400 by 57% makes it the least effective option for annual electric energy reduction.

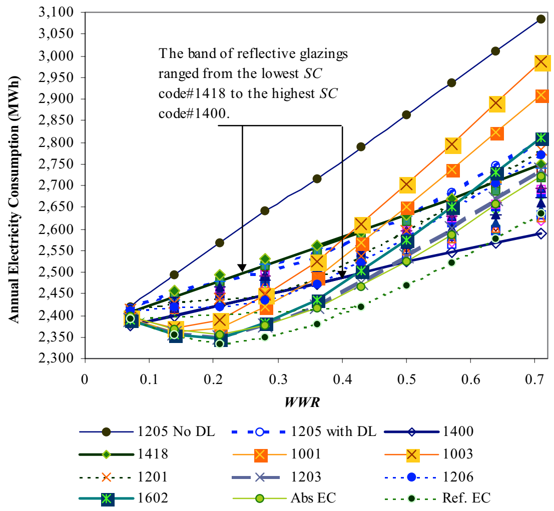


Figure 6. Annual electricity consumption of different glazings at various WWRs.

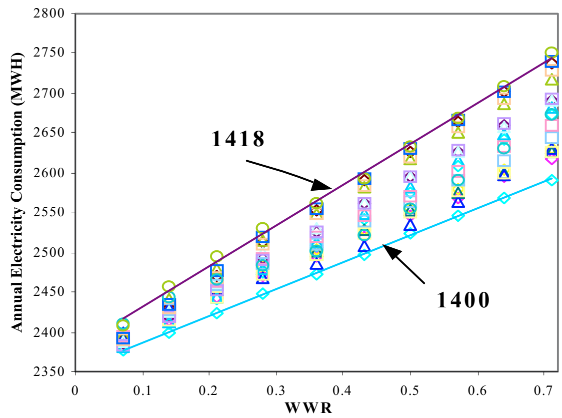


Figure 7. Annual electricity consumption of reflective glazings.

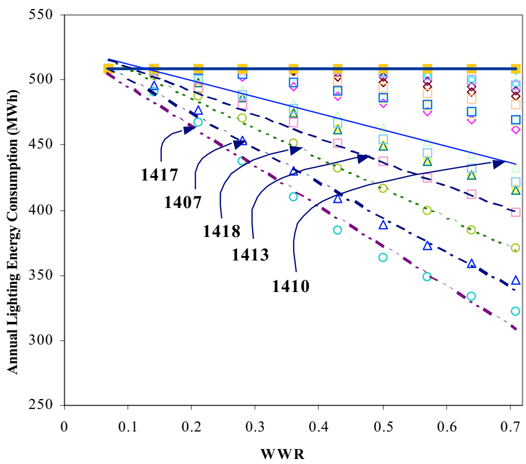


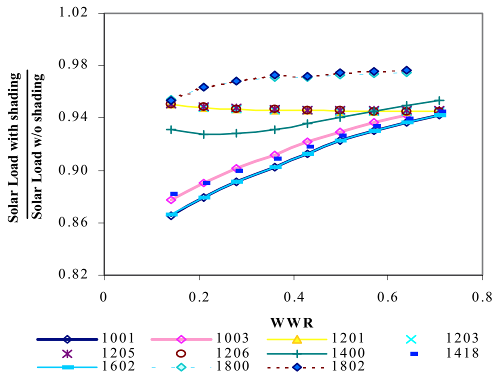
Figure 8. Annual lighting energy consumption of reflective glazings.

EXTERNAL SHADING

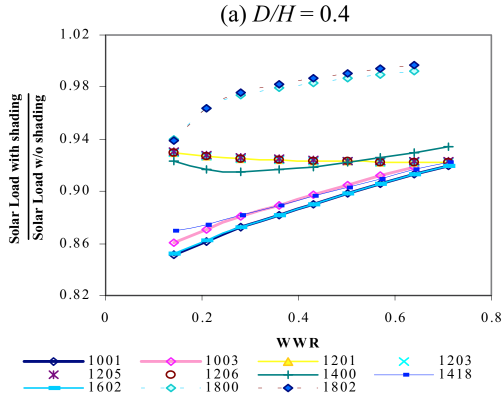
Simulation of the daylighting case with overhangs in the south windows and setbacks in the east and west windows are shown in Fig. 9 (a)-(d). The parameterizations of shading devices with depth to window height (*D/H*) ratios of 0.4, 0.6, 0.8, 1.0 show that external shading devices reduce solar cooling load by 10-18% depending on *WWR*s and glazing materials.

The graphs in Fig. 9 can be divided into three groups: 1) the high *SC* glazing, 2) the low *SC* reflective glazing and tinted glazing, and 3) the electrochromic groups. At the same *D/H* ratio, high *SC* glazings such as code#1001, 1003, 1418 and 1602 are more sensitive to external shading than other glazings as they show the lowest ratio of solar loads. Moreover for high *SC* glazing, the higher the *D/H* ratio the lower is the solar load. Low *SC* reflective code#1400 is more sensitive to solar load than tinted glazing but at the high *D/H* ratio it performs similar to tinted glazings. Tinted glazings make *WWR* insensitive to solar load but it is sensitive to *D/H* ratio as it changes a wide range of solar load varying from 3-10%.

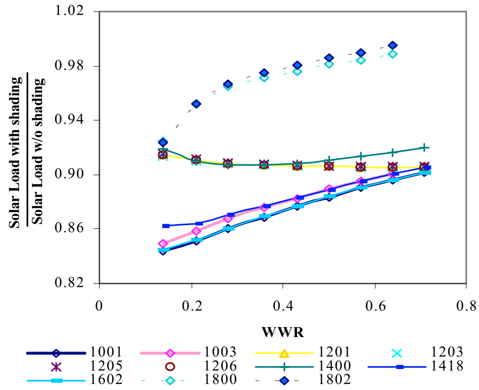
The EC group acts so different from the other groups as it increases solar load with increasing in shading depth. Because T_{vis} of EC glazing is set to adjust as close as possible to the illuminance set point, increasing *D/H* ratio changes EC glazing from the colored state to bleached state for more T_{vis}.



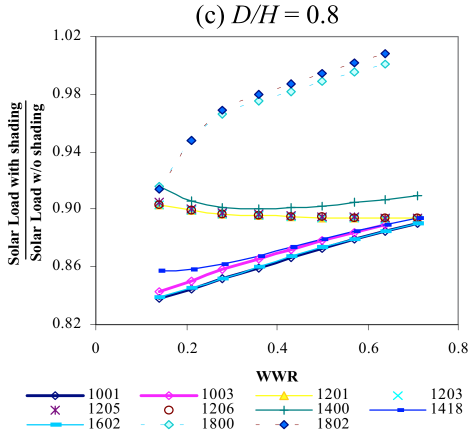
(a) *D/H* = 0.4



(b) *D/H* = 0.6



(c) *D/H* = 0.8



(d) *D/H* = 1.0

Figure 9. Ratio of solar load with shading to solar load without shading at various *WWR*s and *D/H*s.

The percentage difference between electric lighting with external shading and electric lighting without shading is determined from the following equation.

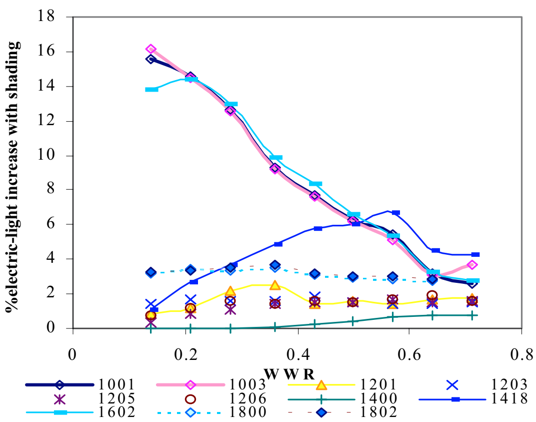
$$\Delta Elec_{\text{light}}\,(\%) = \frac{(E_{\text{shade}} - E_{\text{w/o shade}}) \times 100}{E_{\text{w/o shade}}} \qquad (1)$$

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

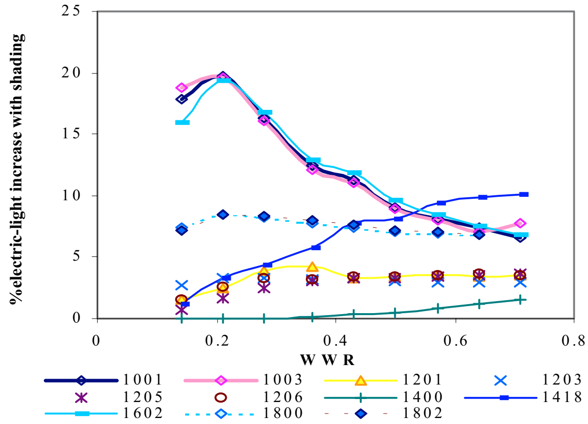
Varying *D/H* ratios results in the percent difference between 2-25% for clear and low-e glazings, 2-15% for high *SC* reflective glazings, 0-5% for low *SC* reflective and tinted glazings and 1-14% for electrochromic glazings. The percent differences increase when *D/H* ratios increase, see Fig. 10.

The percentage difference of electric lighting also depends on *WWR*. Clear and low-e glazings at low *WWR* increase electric lighting by 25%, however it decreases as *WWR* increases. The rapid decreasing in the percent difference of these kinds of glazings indicates that they are very depended on both external shading device and *WWR*.

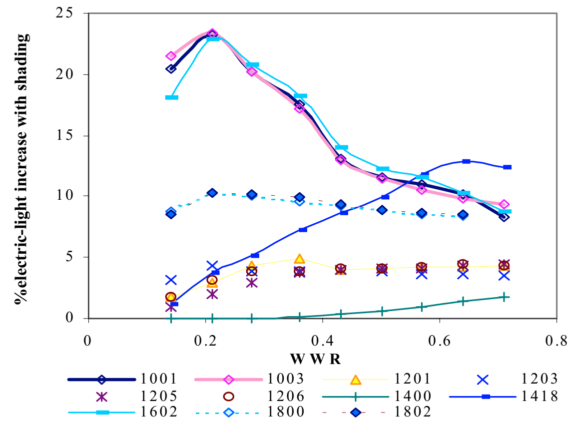
Usually, increasing in window heights which results in increasing in *WWR* values must recover the loss of daylight from increasing external shading depth. However, in the case of reflective glazings the percent difference of electric lighting with and without external shading increases as *WWR* increases. This means that external shadings have higher effects on the percentage difference than *WWR* values.



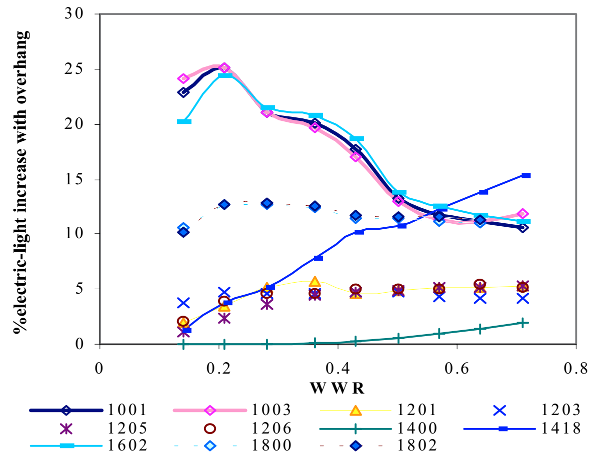
(a) *D/H* = 0.4



(b) *D/H* = 0.6



(c) *D/H* = 0.8



(d) *D/H* = 1.0

Figure 10. Electric savings between electric lighting with external shading and without shading.

Percent differences of electric lighting for tinted glazings are consistent with *WWR* but vary with *D/H* ratio by 2-5%. Like the tinted glazings, percent differences of electric lighting of electrochromic glazings do not change much with *WWR*. However, increasing in *D/H* ratio increase percent differences by 1 to 12%, see Fig. 10.

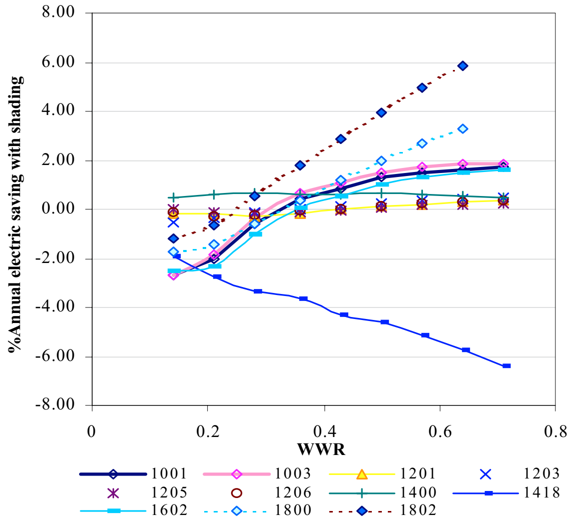
The percentage difference between annual electric consumption with external shadings and without external shadings is determined from the following equation.

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

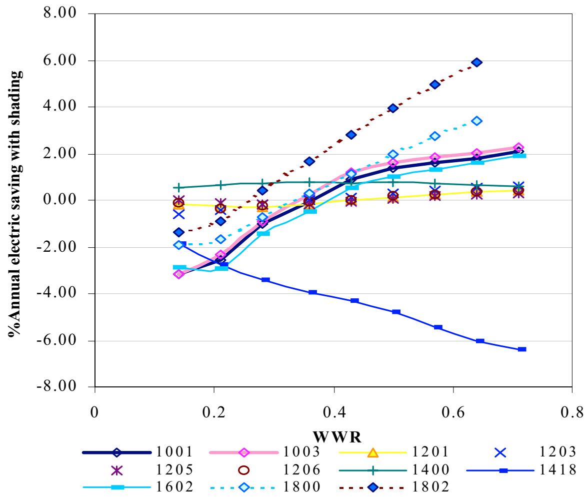
where $\Delta Elec_{\text{ total}}$ is percentage difference between annual electric with external shading and without external shading, $E_{\text{tot,shade}}$ is annual electric with external shading, and $E_{\text{tot,w/o shade}}$ is annual electric without external shading.

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

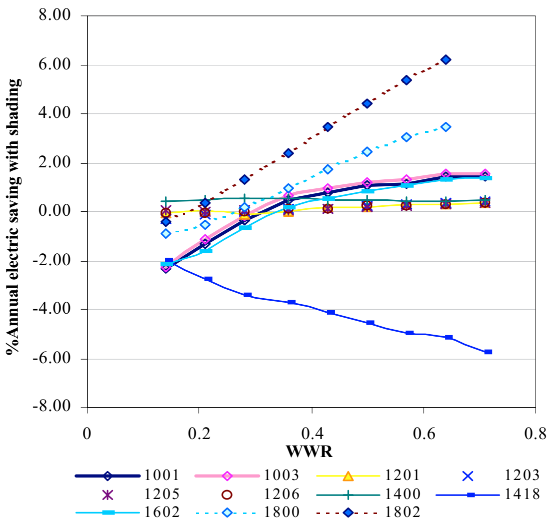
Increasing in *D/H* ratio for the case of clear, low-e and EC glazings results in significant reducing in annual electricity consumption. In clear, low-e and absorbed EC glazing, electrical saving with external shading starts at a *WWR* value in between 0.3 and 0.4. Low *SC* reflective and tinted glazings do not change electricity consumption with increasing *WWR* or *D/H* ratio. The high *SC* reflective glazing obviously always increases annual electricity consumption at any *WWR* and *D/H* ratio.



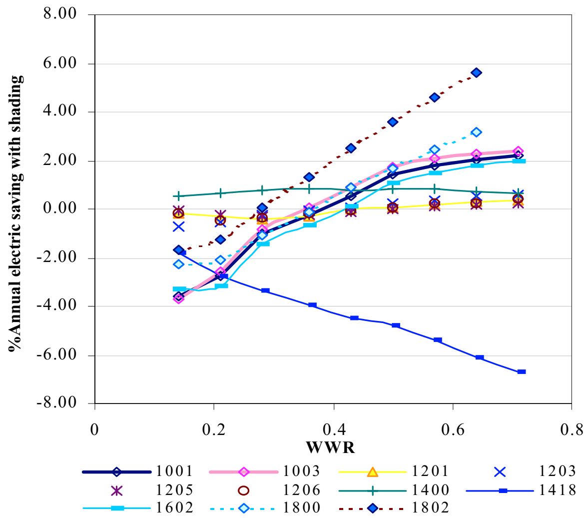
(b) *D/H* = 0.6



(c) *D/H* = 0.8



(a) *D/H* = 0.4



(d) *D/H* = 1.0

Figure 11. Percentage difference between annual electricity with external shading and without shading.

CONCLUSIONS

Results of the analysis show that the high *SC* with high T_{vis} glazing is the best option for electric lighting reduction in daylighting application. The highest percent reduction is clear, low-e, EC and tinted glazings where $T_{vis} > 0.75$. For the glazing types of GRB, daylighting save electric lighting energy by 50% at $WWR > 0.5$. If the total electricity consumption is considered, the three best options are 1) EC glazings, 2) reflective glazings of $0.4 < SC < 0.6$ and $0.2 < T_{vis} < 0.3$, and 3) single tinted glazing with *SC* of 0.71 and T_{vis} of 0.75. The reduction in annual electricity consumption is only 15% compared to the base case.

Application of external shading devices in south, east and west facades results in solar cooling load reduction and electric lighting addition. However, the annual electric saving depends on glazing types, *WWR*s and *D/H* ratios. If $\Delta Elec_{total} > 0$, external shadings option saves more annual electricity than the cases without shadings by 1 to 6%. There are no energy savings in the daylighting case with shading devices, especially for the high *SC* but low T_{vis} glazing such as reflective code#1418.

ACKNOWLEDGEMENT

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