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Optimizing Benefits of Multiple-Slat Shading Device and High Performance Glazing on High-Rise Buildings

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Abstract: The climate of Thailand is hot and humid and air-conditioning for thermal comfort is used in all tall buildings. Buildings with curtained walling are perceived to possess specific aesthetic value by many developers. As a consequence, such buildings cannot accommodate external shading device. In order to reduce transmission of solar radiation into such building, heat reflective glazing has been popularly used. Inadvertently, the building is subject to high cooling load from high heat gain through the curtained walling. However, as Thailand is located near the equator. For a northern or a southern façade, an exterior horizontal shading device can effectively shade radiation of the sun beam from a window below it while allowing skylight to enter the window to give a soft natural daylight in the room. The use of multiple-slat, sufficiently spaced horizontal shading device on the exterior of a facade on appropriately sized window will allow sufficient view out through the window, enables application of daylighting and reduces cooling load. This paper presents results of a study on the use of such shading device on windows under different combinations of glazing types, ratios of window area to wall area, and with un-insulated and insulated wall. When diffuse daylight from sky is used for daylighting, glazing that allows more daylight penetration is shown to offer a monetary worth of savings on electric lighting over its cost, and the cost of air-conditioning energy when the value of the ratio of window to wall ratio falls within certain range. The net benefit can be optimized at an appropriate ratio of window to wall area. When wall insulation is applied, the benefit is even enhanced at lower range of window to wall area.

Keywords: glazing performance, daylighting, window to wall ratio, wall insulation, multiple-slat shading device.

1. Introduction

Thailand is located in a tropical zone in between latitudes of 5° 37'N and 20° 27'N, where beam radiation of the sun on the north and south facades can be effectively shaded. In cooled buildings, energy performing building envelope that allows minimum heat gain but allows daylight to be utilized could help reduce energy consumption of the building.

Large glazed windows are popular features in the present trend of building design in Thailand. Heat gain through these large windows can lead to excessive heat gain and other thermal problems for such buildings. In Thailand, efficient lighting is heavily promoted through Demand-side Management Program and through programs conducted under the Energy Conservation Promotion Act (ECP Act). However, consulting engineers and architects commonly recommend that dark heat reflective (coated) glazing be used to reduce solar heat gain. These practices reduce daylight illumination in building interior that leads to fully electric lighting which in turn imposes a significant thermal load on the building, [1] (Chirarattananon, 2006).

The popular glazing type for commercial buildings two decades ago were mostly dark tinted, i.e. the dark grey type. In the last decade, coated glazing that heavily reflects and absorbs solar radiation has been popularly used. Different types of coating are now available. Insulating glass (of more than one layer) is now widely available and is being increasingly used. Spectrally selective coating and low-emissivity coating are also applied to enhance optical and thermal performance of glazing. Safety regulation requires that glazing used on tall buildings be laminated and shatter-proof. Glazing offers lower thermal performance than that of a normal opaque wall. However, windows allow a view from a confined space and offer an opportunity for daylighting. The type and relative size of glazing used on a windowed wall that allows daylight to be utilized in the peripheral space cost effectively, where good thermal and visual comfort in such space are achievable, are climate dependent. However, solar radiation that encompasses visible radiation, particularly direct or beam radiation from the sun, must also be appropriately shaded to avoid excessive heat gain and visual glare.

This paper briefly reviews literatures on daylighting through glazed windows. Selected results from a study on energy audit and a study on revision of the Building Energy Code of Thailand are described (Section 2). Section 3 gives an outline of the features and capabilities a computer program that has been developed by our team and describes details of two room models and of the sky luminance model used with our computer program to simulate the situation of energy use in the daylighted rooms due to air-conditioning and supplemental electric lighting. Section 4 presents the results of simulation that include the extent of daylight penetration, total cooling and supplemental electric lighting energy, and life cycle costs.

2. A Brief Review of LITERATURES and the Situation of Windows and LIGHTING Energy

2.1 A Brief Review of Literatures

Daylighting is the planned use of natural light in buildings to provide full or supplemental lighting for building interior. However, the amount of sunlight admitted into a building should be well controlled. Daylighting in air-conditioned buildings in tropical regions under the requirement of visual comfort, thermal comfort, energy conservation, and the constraints of varying skylight and sunlight condition poses a real challenge that still awaits a satisfactory solution (IEA, 2000) [2]. In such application, daylight is transmitted optically through multiple layers of glazing system. The absorbed radiation energy is transferred to the air-conditioned interior space through thermal transfer. These optical and thermal components should be considered separately as well as the treatment for the beam and diffuse component of solar radiation. Three important properties of glazing are relevant: thermal transmittance (U-factor), solar heat gain coefficient (SHGC) which is the indicator of heat gain due to solar radiation, and visible light transmission (T_v).

Three types of commercial glazing are used: clear, tinted, and coated. Clear glass comprises silica of low impurity. Tinted glass is clear glass with a controlled amount of impurity to render the desirable color. Coated glazing includes reflective glazing with thin layers of metals or metallic oxides on the surface of the glass. Some coatings render high or lower transmittance of radiation depending on the wavelength of light they are subjected to. In hot climate, Clarke et al. (1998) [3] recommended that glazing of low thermal transmittance and high visible transmittance such as double layer glazing with low emissivity coating on surface 2 be used.

Krati et al. (2005) [4] used DOE-2.1E to study application of clear, blue, gray and reflective coated double glazing, with visible transmittances ranging from 0.073 (reflective tint) to 0.781 (clear), under climate conditions in the US. It was found that window visible transmittance and window area had significant impact on energy saving from daylighting as increasing glazing transmittance or window area contributed to greater daylight illuminance as well as greater heat gain.

Shading devices are used to prevent beam radiation from the sun to enter a space, but to utilize an exterior shading device requires more thought and innovation than to utilize most other devices introduced to achieve energy conservation. The following points should be considered, Wulfinghoff, 1999, [5]: shading effectiveness, effect on view through the window, and heat gain.

2.2 Glazed Windows and Lighting Energy

In Thailand, a law called Energy Conservation Promotion Act (ECP Act) was enforced in 1992, and a Bye-law that required all buildings having electric peak demand above 1000 kW, called designated buildings (DBs), to conduct energy audit and to submit energy audit reports to a designated government department. The department compiles information from the audit reports into a database coded Energy Audit Base 5. There are over 1,550 entries pertaining to over 1,550 individual DBs in this database. Table 1 shows the size of window area to total wall area for DBs that are classified into eight categories, extracted from the database.

While glazed windows allowed a view out to the exterior, solar radiation and heat are also gained into such air-conditioned buildings. However, the present building design practice does not take advantage of daylight that accompanies solar radiation. Commercial buildings rely totally on electric lighting. Table 2 shows the extent of lighting energy used in DBs. Electric lighting contributes directly to electricity consumption and indirectly by contributing to the cooling load of the air-conditioning system of a building.

It has been reported that daylight illuminance from the sky on any vertical façade exceeds 5 klux and 10 klux at frequencies of 90% and 80% respectively, Chirarattananon et al. [6]. A revised Bye-law of the ECP Act accredits daylighting from the use of daylight through windows as follows [7]. The row(s) of luminaries designed to serve a space along the row(s) of window(s) at a distance of 1.5 times the window height is excluded from the required restriction on lighting power density of the building if

1) the row(s) of luminaries is separately switched from the rest of the space, and

2) the product of visible transmittance of the glazing and the shading coefficient of the external shading device exceeds 0.3, and

3) the value of visible transmittance of the glazing exceeds the value of its solar heat gain coefficient.

Table 1. Ratio of window area to total wall area.

Building category	Ratio of glazed window area to wall area (%)		
	Minimum	Maximum	Mean
Office	10	90	29
Hotel	10	80	29
Hospital	13	77	26
Department store	13	76	22
Education	14	86	26
Condominium	13	25	20
Hyper market	11	51	20
Miscellaneous	12	72	32

Table 2 Electric lighting energy use in designated buildings.

Building category	Light energy/area, $kWhm^{-2}.Y^{-1}$			Light energy/total energy, (%)
	Minimum	Maximum	Mean	
Office	4.8	94.5	12.9	22
Hotel	20.7	38.2	27.0	19
Hospital	11.0	32.9	24.1	22
Department store	13.6	163.5	56.2	22
Education	11.4	171.4	11.1	32
Condominium	2.6	135.9	12.2	22
Hyper market	7.5	176.2	84.8	24
Miscellaneous	3.5	82.9	26.0	20

Opaque wall sections are allowed to intersperse glazed windows. Width of wall section(s) of up to the window width is allowed. Figure 1 illustrates the configuration of windows with interspersing wall section(s), height of window above work plane, and the location of the row of luminaries serving the space. The conditions above ensure that there is sufficient daylight illuminance on the work plane when electric lighting serving the space is turned off and that solar heat gain does not exceed heat from electric lighting, were the luminaries to be turned off.

3. Computer Simulation of Daylighted Rooms

Two identical room models, one with a windowed wall that faces north and the other one with a windowed wall that faces south, are used in computer simulation that assumes electric lights are turned off for the areas that are daylight-illuminated to a set level.

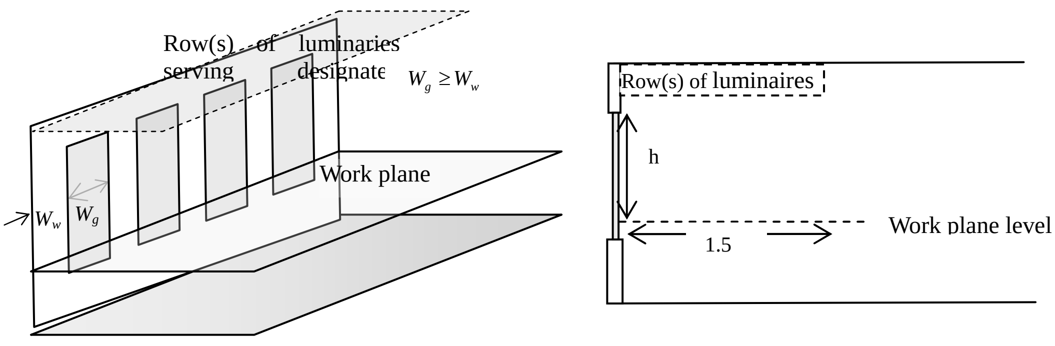


Figure 1. Configuration of an accredited daylighted space.

3.1 The BESim Program

A computer program called BESim was used in the calculation that utilizes beam and sky illuminance and irradiance measurements taken at a station near Bangkok. Development of the computer program was initiated earlier, as a part of research on heat transfer through roof.

The program requires setting up of a main rectangular coordinate that is referenced to the cardinal directions. The position of each flat interior surface in a room, such as the panes of glazing and interspersing opaque wall sections, is defined with respect to the main coordinate. The program first calculates the values of view factors between all surfaces in each enclosed zone created by a user. It utilizes the method of Hien and Chirarattananon (2005) [8] in the calculation of view factors. The view factors between surfaces are stored for use in calculation of thermal radiation transfer between surfaces in the zone and flux transfer calculation for the electric light and daylight from the sky on diffuse surfaces in the zone

For daylight calculation, BESim first calculates the direction of solar vector using given information on time. It then calculates part of daylight beam from the sun that is not shaded by the shading devices that enters the glazing pane into the room and traced its reflections until the reflected illuminance becomes negligible. For the diffuse daylight from the sky, it calculates contribution of light flux from a sky patch on to a small subsection of each given surface as direct sky component. It uses flux transfer method to calculate the reflected components. Configuration factors are used in the calculation of contribution of light flux from subsections of surfaces to a given point on a work plane, where the work plane can be an imaginary plane above the floor. In the present version, BESim uses the ASRC-CIE sky luminance and sky irradiance models that utilizes CIE clear and turbid clear sky model, partly cloudy and cloudy sky models [9].

BESim uses finite difference method for calculation of dynamic conduction heat transfer through a wall. Both convective and radiative heat transfer from a wall surface are calculated using the principle of energy balance. The room can be cooled or naturally ventilated.

3.2 The Room Models

Figure 2 shows the configuration of the use of multiple-slat shading device on the exterior of a room. The windowed wall faces north or south. The height of the wall from the floor to the window sill is 0.85 m. The glazed window of height 1.8 m extends from the window sill to the ceiling. A multiple-slat shading device is used to shade out beam radiation. There are six slats. The distance between a pair of slats is 0.3 m. The width of each slat is chosen so that a slat extends from the window sufficiently to shade out beam radiation from the sun. For Bangkok, the appropriate width of a slat is approximately 0.195 m.

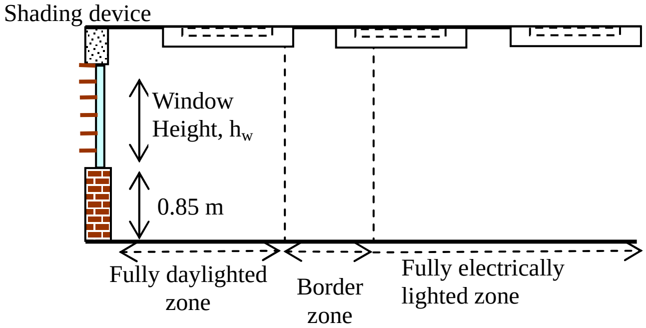


Figure 2. The configuration of the shaded exterior of the room model.

Figure 3 shows a perspective view of the interior of one room model. The two models used are identical, but oriented in opposite directions. Each room has a length from the windowed wall to the back of 20 m, and a width of 10 m. Interspersing panes of glass and opaque brick wall sections are located above the brick wall and extend to the ceiling. In the simulations that are to be described, the width of each glass pane and the width of each opaque brick wall section are adjusted so that the ratio of the total glazed area to the total wall area (including the brick wall based on the floor) equals the required value of the ratio of window area to wall area (WWR). Fifty four standard fluorescent lamps, each with a standard magnetic ballast, are installed on the ceiling. Six lamps spaced equally apart at 1.67 m form a row along the width of the room. Nine rows of such lamps are spaced 2.25 m apart along the length of the room. The reflectance values of the surfaces are: ceiling 0.7, walls 0.5, and floor 0.3.

The WWR is varied by adjusting the width of the glass panes and the width of the opaque sections so that WWR will assume 4 values. At each value of WWR, four types of glazing are used. Additionally, one set of simulation runs are made for un-insulated walls and another set for insulated walls.

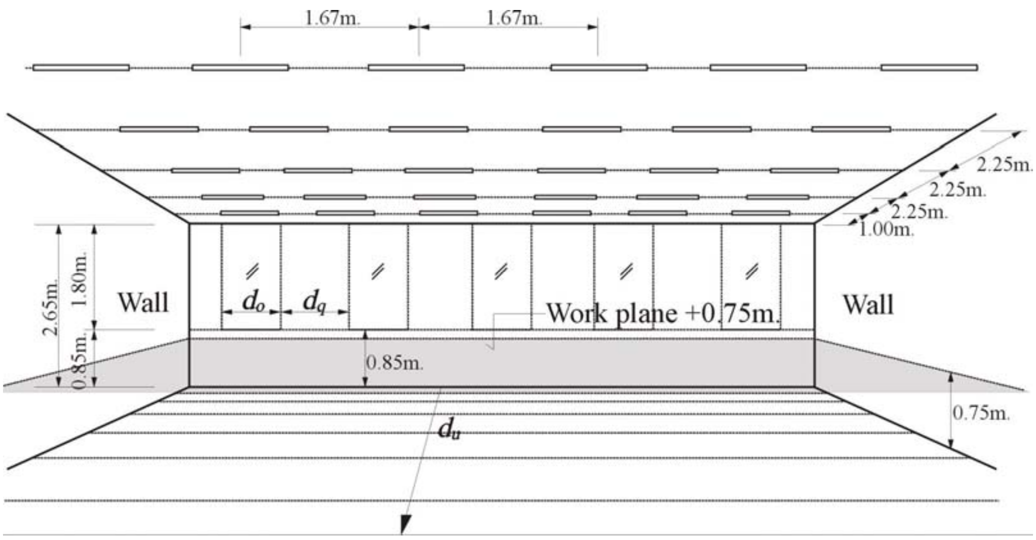


Figure 3. A perspective view of the interior of the room model.

Table 3. Properties of the four types of glazing.

Type	Thickness, mm	Visible ray		Solar radiation			Front emittance	Back emittance	Solar heat gain coefficient	U-Value, $Wm^{-2}K$
		Reflectance	Transmittance	Reflectance	Transmittance	Absorptance				
NGRN-CLR	12.38	0.12	0.67	0.06	0.26	0.67	0.85	0.82	0.40	4.63
GRN-LE	12.38	0.14	0.63	0.09	0.19	0.72	0.85	0.18	0.27	2.68
GRN-IGU	30.38	0.16	0.55	0.24	0.16	0.61	0.82	0.82	0.22	2.57
HR-GRN	12.38	0.22	0.12	0.12	0.03	0.85	0.85	0.84	0.20	4.63

GRN-CLR = laminated green (tinted) and clear,
GRN-LE = laminated green and clear with low emissivity hard coat on the interior facing surface,
GRN-IGU = green and IGU with low-emissivity coating on the surface of clear glass in the gap,
HR-GRN = heat reflective green and green.

Table 3 shows the properties of the four types of glazing. Heat reflective glazing and low-E glazing are coated glasses. All glass types are laminated as required by the building regulation (since 2003) on buildings taller than 23 m. The basic thickness of each glass layer is 6 mm. The width of the bonding layer is 0.38 mm, and the gas layer of the insulating glass unit (IGU) is 12 mm.

The room models with interspersing glass panes and opaque sections comprise a relatively large number of sections. This together with the use of six exterior shading slats per glass pane that require calculation of shading of beam radiation, led to relatively long computation time for each set of input data of daylight illuminance, solar irradiance, and ambient condition. Therefore, only a set of hourly data of the 19th, 20th, and 21st of March, June, September, and December 2000, totalling 12 days, was used in the simulation runs.

4. Results and Discussion

BESim was run to simulate the use of the room during normal office hours of 0800 - 1700 (Figures 2 and 3). Even though beam radiation from the sun is effectively shaded off by the multiple-slat shading system shown in Figure 2, daylight from sky can penetrate at up to a certain depth into the room interior. In general, increasing the value of WWR (that is increasing the size of glazed window) leads to an increasing penetration of daylight with an accompanying heat gain. The relative gain of daylight and heat through the glazing and through the whole wall are related to the properties of each type of glazing, as well as the properties of wall.

The scheme of simulation and arrangement in this study that leads information used in the presentation of benefits and costs of various glazing options under each value of WWR comprises three steps. Each run of BESim produces values of daylight illuminance on specified points on the specified work plane, values of heat flux from and temperature on each section of the wall in each room. These results are used as follows.

Step One: determination of daylight penetration and lighting arrangement.

For a given value of WWR and a given type of glazing, BESim produces values of daylight illuminance on specified point(s) in the work plane. A plot of daylight illuminance for points at 1, 2, 3,…, 12 m from the window along a line near the middle of the room from 0600 - 1900 hours on 19 March is shown in Figure 4.

The daylight data used pertain to the year 2000. For the given day, daylight illuminance at 0600 and at 1900 is negligible. It was decided that the room model would be illuminated to a general lighting level of 300 lux. Earlier calculation shows that 54 luminaires each housing a standard fluorescent lamp installed in 9 rows along the length of the room, with each row comprising 6 luminaires equally spaced along the width of the room (as described in Section 3.2), could be used to serve the space in the room. It was then decided that the depth of daylight penetration (d_u in Figure 3) is the depth at which daylight illuminance reaches 150 lux or over between 0800 - 1700, daytime office hours. The rows of luminaires serving the space between this depth and the windows could be turned off. Next to the daylighted zone is the border zone (Figure 2) that is jointly illuminated by daylight and electric light. As a part of this step, the number of rows of lamps beyond the penetration depth required are determined as shown in Table 4 for the cases considered. During the winter period (of 13 weeks), the daylength is shorter and it is assumed that an additional row of lamps may be required to be turned "on" for some days, or periods.

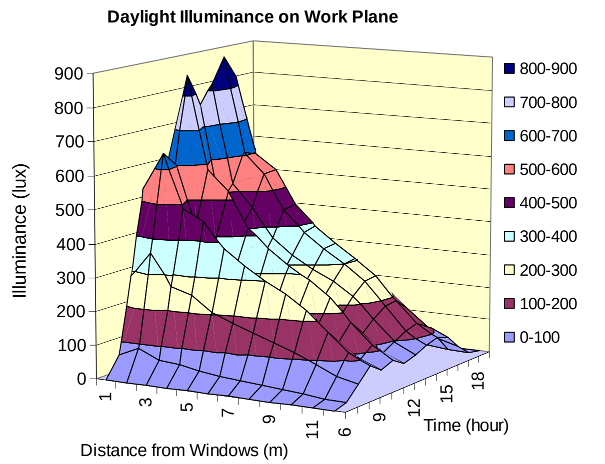


Figure 4. A plot of daylight illuminance on points along a line on a work plane during 600 to 1900 hours on 19 March 2000.

It is noted that for each WWR level of daylight illuminance from the use of clearer glasses at a given depth are comparable. For these types of glazing, the depth of penetration reaches up to 12 m at WWR of 0.68. Penetration depth for heat reflective glazing reaches only 2 m.

Step Two: determination of savings of electric lighting energy (ELE saved), total heat gain through exterior wall, cooling energy, and temperature of wall surface.

Table 5 shows savings of electric lighting calculated from the data in Table 4, where it is assumed that the room is used 5 days per week, and there are 13 weeks in the winter period and 39 weeks in other periods. A set of one lamp and one ballast requires 36 W from the lamp and 11 W from the ballast. For each room, the total lighting energy required if electric lighting is used between 0800 and 1700 for the entire year is 5,939 kWh/Y per room. The number of rows of lamps that are supposedly turned off are used to calculate saving of electric lighting energy (ELE in Table 5). It is assumed that electric power supplied to lamps that are turned on contributes entirely to cooling load of the air-conditioner.

Table 4. The penetration depth and rows of lamps required.

Glazing type	DL depth and No. of rows	WWR 0.0	0.2	0.4	0.68
GRN-CLR	DL depth, m	0	7	11	12
	No. rows, W	9	6	4.5	4.5
	No. rows, O	9	5.5	4	4
GRN-LE	DL depth, m	0	6	10.5	11.5
	No. rows, W	9	6.5	5	4.5
	No. rows, O	9	6	4.5	4
GRN-IGU	DL depth, m	0	5.5	10	11
	No. rows, W	9	7	5	4.5
	No. rows, O	9	6.5	4.5	4
HR-GRN	DL depth, m	0	0	1	2
	No. rows, W	9	9	9	8
	No. rows, O	9	9	9	8

Note DL depth = daylight penetration depth,
No. rows, W = number of rows of electric lamps required to be "on" during winter period,
No. rows, O = number of rows of electric lamps required to be "on" during other periods.

The ceiling and the walls on the eastern and western facades are insulated to an unrealistic level with glass fiber insulation of 1m in thickness. Heat gain through the southern wall in Table 5 is calculated as the average daily value of *load to cooling coil* from the 12 days used in the simulation and then multiplied by the total number of working days in a year to get the annual value. The residual loads from heat gain through the ceiling and through walls on eastern and western facades are discounted from the load to the cooling coil. The value of heat gain through wall in Table 5 is the resultant annual cooling load from the southern wall only. Figure 5a shows plots of cooling load as sensed by the cooling coil due to heat gain through the exposed south wall, labeled 'Heat through wall, kWh_{th}' in Table 5, as function of WWR. Each graph appears quite linear as would be expected, that heat gain through the opaque part of a wall composition is independent of heat gain through the glazing.

Cooling energy, *CL En*, is calculated from

$$CL\ En = \frac{Heat\ gain\ through\ wall + electric\ lighting\ energy}{COP},$$

and *COP* = coefficient of performance of the air-conditioning system. Here it is taken as 3.0. Higher cooling energy occurs in the cases that heat reflective glazing is used.

The surface temperature of each wall and each glazing section at each hour is given by BESim for each of the 12 days of simulation runs. Higher values of surface temperatures are obtained from the surface of glazing sections and are shown in the table as Max T_{fs}. The last row in Table 5 shows the value of the maximum of the average surface temperature of all sections of a wall from the simulation runs among all hours of 12 days of each case. The higher values for each glazing type are obtained at higher ration of glazed area, or higher values of WWR. These temperature values affect thermal comfort condition for a person situated sufficiently close to the windowed wall.

Step Three: determination of total energy use and benefits and costs of each glazing.

Total energy use

Total energy is calculated as

Total energy = lighting energy (LE) + cooling energy (CL En).

Lighting energy is obtained as the difference between the value of reference total electric lighting energy, when no daylight is utilized, and the value of electric lighting energy (ELE) saved in Table 5. Figure 5b shows the pattern of variation of total energy with WWR corresponding to each type of glazing.

Energy performances of walls with GRN-CLR, GRN-LE, and GRN-IGU types of glazing are all clearly much superior to that of HR-GRN glazing. Walls with insulation are also superior to those without insulation. The benefit of insulation declines with increasing value of WWR in each case. The striking common feature of the first three types of glazing is that total energy declines as the size of WWR increases as daylight penetrates deeper and is utilized to replace electric light. However, when the window size increases beyond a point, heat gain through the window starts to overwhelm benefit obtained fro m daylighting. For the first three types of glazing, there is a distinct point of

Table 5. Lighting electricity saved, heat gain through wall, cooling energy and wall temperatures.

Glazing type	Item	WWR 0.0 Un-Ins	0.0 Ins	0.2 Un-Ins	0.2 Ins	0.4 Un-Ins	0.4 Ins	0.68 Un-Ins	0.68 Ins
GRN-CLR	ELE saved, kWh/Y	0	0	2227	2227	3217	3217	3217	3217
	Heat through wall, kWh_{th}/Y	3853	628.2	5758	3067	7336	5370	9701	8675
	Cooling energy, kWh/Y	3264	2189	3157	2260	3353	2697	4141	3799
	Max T_{fs}, C	33.0	25.8	48.9	48.9	49.1	49.1	49.4	49.4
	Max Av T_s, C	32.9	25.8	39.0	35.1	39.0	35.4	46.7	46.7
GRN-LE	ELE saved, kWh/Y	0	0	1897	1897	2887	2887	3217	3217
	Heat through wall, kWh_{th}/Y	3853	628.2	5411	2642	6671	4616	8464	7401
	Cooling energy, kWh/Y	3264	2189	3151	2228	3241	2556	3729	3374
	Max T_{fs}, C	33.0	25.8	55.8	55.8	55.9	55.9	56.0	56.0
	Max Av T, C	32.9	25.8	41.4	37.6	41.7	41.7	51.8	51.8
GRN-IGU	ELE saved, kWh/Y	0	0	1567	1567	2887	2887	3217	3217
	Heat through wall, kWh_{th}/Y	3853	628.2	5312	2603	6470	4435	8104	7060
	Cooling energy, kWh/Y	3264	2189	3228	2325	3174	2496	3609	3261
	Max T_{fs}, C	33.0	25.8	45.4	45.3	45.6	45.5	45.7	45.7
	Max Av T_s, C	32.9	25.8	38.1	34.1	38.2	34.3	44.4	44.4
HR-GRN	ELE saved, kWh/Y	0	0	0	0	0	0	247.5	247.5
	Heat through wall, kWh_{th}/Y	3853	628.2	5722	2969	7284	5258	9476	7060
	Cooling energy, kWh/Y	3264	2189	3887	2969	4408	3732	5056	4710
	Max T_{fs}, C	33.0	25.8	53.7	53.6	53.9	53.8	54.1	54.0
	Max Av T_s, C	32.9	25.8	40.7	36.8	40.9	37.2	50.6	50.6

GRN-CLR = laminated green (tinted) and clear,
GRN-LE = laminated green and clear with low emissivity hard coat on the interior facing surface,
GRN-IGU = green and IGU with low-emissivity coating on the surface of clear glass in the gap,
HR-GRN = heat reflective green and green.
Un-Ins = un-insulated
Ins = insulated.

minimum for each type. GRN-CLR glazing with insulated walls offers the lowest energy consumption of 5414 kWh/Y at the value of WWR of 0.38, obtained from its trend line. This value is lower than the reference annual electric lighting energy. To get accurate trend lines and more accurate estimates of the point and value of minimum for a given case, more simulations with values of WWR near the minimum of each case should be run.

Benefits and Costs

In order to calculate the benefits and costs of different types of glazing, the material cost of each type of glazing and the cost of brick wall, polystyrene insulation, and labor appearing in Table 6 will be used. Reference values for use in the net present value analysis are: life 25 years, discount rate of 8%, present worth factor 10.675, and electricity cost 3 Bahts per kWh.

The present value of electricity cost and savings at the given discount rate and given life of walls are added to the cost of wall, all calculated based on per unit area of wall. The total life cycle cost of cooling energy and wall coat on net present value basis appears in Figure 6a. The value of cooling energy for each wall and glazing type at each WWR appears larger than the material and labor cost. Even though the costs are not linear with respect to the value of WWR, each line appears to be orderly. The lines for set of combination of glazing wall and un-insulated walls is distinct the lines from the corresponding set of insulated walls. Among each set, there is an orderly rank among the wall with different types of glazing. For example, the insulated wall with GRN-CLR glazing has the lowest cost followed by walls with GRN-LE, GRN-IGU, and HR-GRN respectively for each value of WWR.

Based on the above costs, the costs of glazed walls per unit area at different values of WWR are shown in Table 7. Figure 6b shows corresponding sets of graphs of wall and cooling energy costs discounted with savings from present values of electric lighting energy, all based on per unit area of each wall and grazing combination. The pattern of all graphs appear to be similar to those in Figure 5. Those cases with GRN-CLR, GRN-LE, and GRN-IGU are clearly superior to ones with HR-GRN grazing. The main points are that insulation reduces the Net Present Value (NPV) costs in all cases. Grazing that offers high visible transmittance and reasonable optical performance enables more daylight to be utilized culminating in lower costs. The combination of laminated green and clear grazing without any coating is superior to all in this set. Furthermore, these appears to be a distinct value of WWR at which the NPV of each grazing and wall combination reaches a minimum. The minimum cost for each of these cases is close to or lower than the material and labor costs.

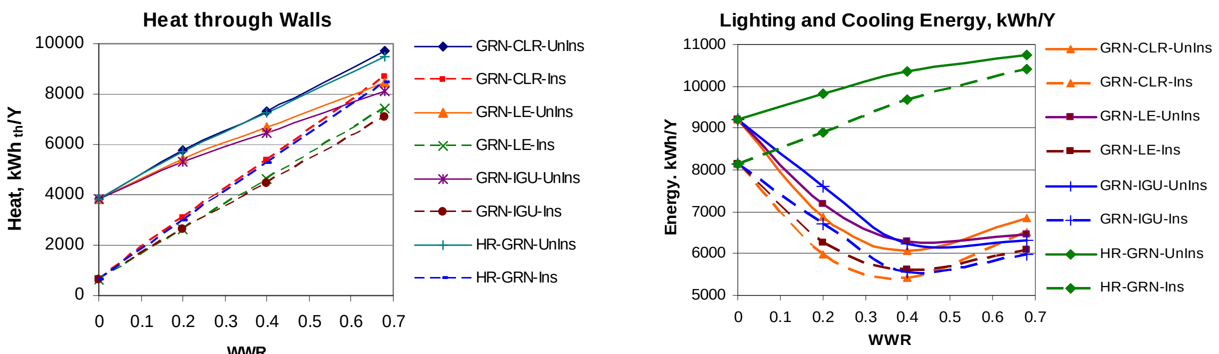
Table 6. Material and labor costs of brick, insulation, a nd different types of laminated glazing.

Item	Concrete	Insulation	GRN-CLR	GRN-LE	GRN-IGU	HR-GRN
Material, Bm^{-2}	464	197.5	2000	3000	4000	2500
Labor	100		100	100	100	100

Note The cost of each type glazing is given as 'list price' by a manufacturer for laminated glazing.

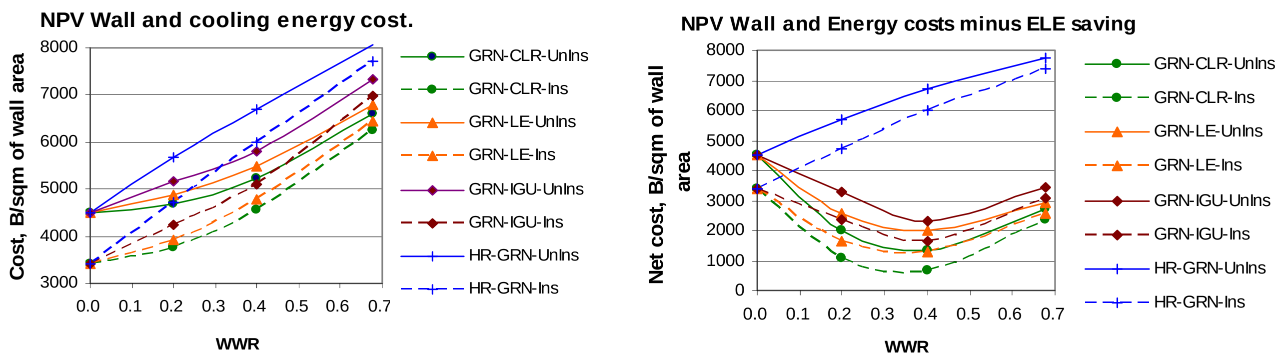
Table 7. Total cost of walls with different types of glazing, Bm^{-2}.

	WWR							
Type of glazing	0.0		0.2		0.4		0.68	
	Un-Ins	Ins	Un-Ins	Ins	Un-Ins	Ins	Un-Ins	Ins
GRN-CLR	564	761.5	871.2	1029.2	1178.4	1296.9	1607.3	1670.7
GRN-LE	564	761.5	1071.2	1229.2	1578.4	1696.9	2286.6	2349.9
GRN-IGU	564	761.5	1271.2	1429.2	1978.4	2096.9	2965.8	3029.2
HR-GRN	564	761.5	971.2	1129.2	1378.4	1496.9	1947.0	2010.3



a) Heat through wall as sensed by cooling coil, kWh_{th}/Y b) Electric lighting and cooling energy, kWh/Y

Figure 5. Heat through wall and total energy as function of WWR for each wall combination.



a) NPV of material and cooling energy cost of each wall. b) NPV of material and cooling energy discounted by saving of electric lighting energy.

Figure 6. NPV of material and cooling energy cost without and with discount from saving of electric lighting

5. Conclusion

Glazing contributes a substantial part of walling in buildings. In new building construction, post-tensioned flooring has been a popularly feature because its use leads to shortened construction time and to avoidance of beam or allowing lighter beams to be used. However, this type of flooring necessitates the use of light wall. Consequently, curtained walling has proliferated. In air-conditioned buildings, heat reflective glazing has been popularly used in the belief that it could effectively reflects solar radiation and thus also reflecting thermal energy that accompanies it. Unfortunately, such glazing allows low transmission of visible radiation and absorbs a substantial part of solar radiation. The requirement by law that allows only laminated glazing to be used on high-rise buildings indirectly encourages the use of high performance glazing. This paper shows that if properly planned and such high performance glazing is used, daylight could be used to great advantage that such glazing can even be considered an investment that offer net positive value.

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