A Study of Optimal Energy Consumption Measures for Building Façades with a Parametric Combination of Blinds, Lighting and HVAC Systems

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Abstract

This paper investigates the indoor light environment, lighting energy consumption and total energy including annual HVAC system in temperate and temperate monsoon climate zones. In certain areas, annual temperature variation is very extreme therefore a high thermal insulating performance for glazing systems is required to minimize the effects of outdoor temperature changes on the indoor temperature.

To obtain a variable solar heat gain coefficient value for annual energy performance, single and double skin façade systems were examined for this study and 18 cases considering blind type, ventilation and installing places were set to compare the effectiveness of each. Lighting energy consumption was also investigated using dimming control, high efficient lamp, and blind control throughout an entire year. With the calculation results from the target building as a baseline, we performed the calculation 992 times with a combination of energy saving measures, and total primary energy of lighting and HVAC ranging from 282kWh/m² year to 372kWh/m² year.

Keywords: simulation; u-value; g-value; building energy; blinds

1. Introduction

1.1 Background

Temperate climate zones are typically characterized by high temperatures with high humidity in summer and low outdoor temperatures in winter. For this reason, a high thermal insulating performance for walls and glazing systems is required to minimize the effects of outdoor temperature changes on the indoor temperature. However, solar radiation occurs all year round regardless of the outside air temperature and can be one of the important factors in maintaining a correct indoor thermal environment when blocked in summer, and let through actively in winter. A window maximizes the solar heat gain within a building in winter, but the net result is an increase in cooling load in summer, presenting a considerable risk to be avoided as much as possible. However, because it is not possible to change the façade of a building every season, solar radiation is normally controlled with subsystems such as blinds.

Besides this, additional consideration should be given to the proper amount of light influx into the indoor area when designing building façades. Here, the proper amount of light is vital and should be able to be manipulated to take full advantage of daylight without causing a glare phenomenon by direct solar radiation. Glare induces visual discomfort, which is directly related to productivity because most modern offices are equipped with computers and monitors to work with. Daylight serves as a method to reduce energy consumption from artificial lighting. While building owners and occupants typically prefer to have a spacious open area, most consultants or engineers may suggest a proper window-to-wall ratio (hereinafter, WWR) from the viewpoint of energy consumption. As a result, all glass curtain walls or building façade systems with maximum WWR are still being installed primarily in office buildings.

In other words, the most ideal façade must ensure a spacious openness and reduce the amount of solar heat gain in summer while maximizing it in winter. Also, it should prevent the glare phenomenon while accepting daylight. A double skin façade (hereinafter, DSF) is regarded as the only method to meet these requirements. Under the assumption of adequate controlling, it is more appropriate for the thermal environment rather than a single skin façade (hereinafter, SSF), leading to energy saving and the
operation expansion of natural ventilation\textsuperscript{5,6}. However, in terms of light environment, a DSF is known to have about thirty to forty percent lower effective light transmittance as compared to a SSF, which is just a theoretical issue and can be varied with the type of glazing system and a combination of blinds.

1.2 Purpose of Paper

In this paper, a more thorough consideration is given to the issues above. In the following paragraphs, for office buildings in monsoon climates, we describe an introduction to a number of methods to develop building façades, lighting and HVAC systems to minimize the annual heating, cooling and lighting energy consumption of the buildings depending on the combination of glazing systems and blinds. The building façade system consists of a combination of DSF, SSF, various types of glass and blinds. The lighting system is tailored with varying types of artificial light sources and dimming control and the HVAC system with night ventilation. Further, a comparison of energy consumption is done on the primary energy equivalent values.

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2. Combinations of Shades and Façade Systems

2.1 Overview of the Target Building

The target building examined in this study is an office building with 43 stories above ground and 8 stories underground completed in 2007, located at 37 degrees northern latitude, in the center of Seoul, Korea, in a temperate climate zone. As shown in the floor section of Fig.1.(b), the typical floor has a floor height of 4.2 m and ceiling height of 2.9 m. In particular, the building where the ceiling surface contacting with the window is tilted obliquely, Fig.1.(b), was designed to maximize the introduction of daylight and a roller blind with a SSF applied was installed as an internal shade.

2.2 Combinations

In this section, we derived a SHGC (Solar Heat Gain Coefficient, hereafter, g-value) and a glazing heat transmission coefficient (hereafter, u-value) using a combination of glazing systems and shades that has been applied to actual buildings. The WWR is 0.7 in this building and shades were classified into DSF and SSF and installed internally and externally.

Fig.2. shows a simplified diagram of cases studied. In this study, a total of 18 cases were investigated and the overview and features of each case are presented in Table 1. In the case of a SSF, its position has been mainly investigated. Ventilation and sealing of a cavity and varying shade angle inside the cavity were constituted for a combination. The shade angle is 0\textdegree, 60\textdegree for g-value calculations. However, case 11 to 13 follow the angles in the table.
separated by sealing and ventilation. For ventilation, the flow of outdoor and indoor air was reflected and the width of the opening was set to 100 mm. The conductive coefficient of glass is 1.4 W/m$^2$·K and the insolation is 783 W/m$^2$.

Fig. 3. shows a diagram used for calculating a combination of glazing and shades, and Table 2. represents specifications and boundary conditions applied to calculate g-values and u-values.

2.4 Calculation Results of g-values and u-values

Fig. 4. illustrates the calculation results of g-values at solar incident angles of 0° (upper black) and 60° (lower red). Compared to case 14 which was applied to the actual target building, in case 3 and case 5 to case 9, g-values were found to be relatively improved regardless of the shade angle control. The main specifications for each case are as follows.

- Case 3: SSF + exterior shade
- Case 5: DSF + cavity shade + cavity sealing
- Case 6: DSF + cavity shade + cavity outdoor air ventilation
- Case 7: DSF + cavity shade + cavity indoor air ventilation
- Case 8: SSF + no shade + solar protection glazing
- Case 9: SSF + internal shade + solar protection glazing

Fig. 5. shows u-values for each case of winter. In the figure, the result from case 7 was excluded because the risk of condensation was high in this case. Except for case 5, u-values from most cases appeared to be relatively high compared to case 14.

In summer, DSF's using different ventilation systems (non-ventilation: case 5, ventilated from outdoors: case 6, ventilated from indoors: case 7) do not show big differences. Cases 6 and 7, i.e. ventilated DSF using outdoor or indoor air, can achieve similar results as external shading systems (case 3). The non-ventilated DSF system (case 5) results in a 0.11 g-value like case 9, solar protection glazing with internal shading system. Under the single aspect of solar protection, solar protection glazing will be more cost-effective than a DSF system with respect to construction and maintenance.
In winter, cavity ventilation with indoor air should be prevented due to a high condensation risk. The U-values vary from 0.9 to 1.3, the cavity ventilation reduces the thermal insulation of the façade. Thus, the flexible, lockable exterior skin layer will be profitable in winter.

Findings from the analysis could be summarized as follows:
A) In the case of the double skin with a cavity shading system façade (low-e glazing with internal shading roller blinds), the g-value could be reduced to 0.07 from 0.29 in the specific conditions; if the cavity is ventilated with outdoor air or indoor air in clear sky and daytime.
A) In the case of the solar protection glazing (g-value: 0.19) with an internal venetian shading system, the g-value can be reduced to 0.11.
In winter, a double skin façade without cavity ventilation and with an internal shading system is advantageous due to a high g-value and a low u-value.

3. Illumination and Solar Incident Angle
3.1 Illumination of the Target Building
The indoor illumination of the target building was investigated. The reason we studied not only the thermal environmental factors such as g-values and u-values of glazing systems but also the indoor illumination was that it was meaningless to apply the results from the thermal environment only to actual buildings. However, a roller screen was installed as an internal shade in the target building, but in the simulation, a venetian blind was applied to find out illumination by shade angle.

![Fig.6. Result of Indoor Illumination](image)

Fig.6. shows the results from the input value of a solar incident angle at noon on March 21 in Seoul (52.5°) under a clear sky. The shade angle of 75° or higher represents an interval where direct solar radiation is perfectly blocked while 0° means the blind is in a horizontal state. Assuming the illumination criterion of an office to be 500lx, the light environment showed best at a shade-angle of 60°. When it was set to 30° or lower, it was likely to cause a glare phenomenon. In this manner, we investigated indoor illumination by daylight for each season. In winter, because solar incident angles were low, we could obtain results which met the illumination criterion in the interval of a shade angle of 60° or lower. But it was also found that we needed measures against a glare phenomenon. In summer, the risk of the glare phenomenon was relatively minimal due to high solar incident angles. But, consideration should be given to the setting of shade angle to secure standard indoor illumination.

3.2 Solar Incident Angle
Since a building façade is highly dependent on solar transmittance, we examined the solar position over time relative to the position of the target building$. The problem with this is that the calculation algorithm in ISO 15099 is based on the 2D solar position (only nominal incident) from -90° to 90° in front of the façade, however the real solar position has a 3D position with solar altitude and azimuth. In principle, the solar transmittance to the interior will be varied according to the solar altitude, azimuth and façade orientation. For the assessment of the façade quality, the steady-state calculation of ISO 15099 may be sufficient; however, in the case of a transient situation with a weather file and a specific shading device angle, it is not clear which solar angle is comparable to the 2D solar angle used in the ISO calculation algorithm.

For the analysis of solar incident angles, the Meteonorm weather data of Seoul (KR-Seoul-471080. tm2) provided by TRNSYS was used. Table 3. represents monthly averages of radiation on the vertical surface of a building in Seoul during business hours (08h to 18h).

Table 3. Monthly Average of Vertical Radiation (W/m$^2$)

| Month | South | West | North | East |
|-------|-------|------|-------|------|
| Jan.  | 293.36| 130.20| 58.48 | 122.71|
| Feb.  | 319.81| 159.35| 81.18 | 182.41|
| Mar.  | 292.42| 188.02| 103.77| 220.70|
| Apr.  | 261.21| 217.83| 120.09| 232.83|
| May   | 189.11| 200.10| 127.37| 216.28|
| Jun.  | 167.19| 187.01| 128.25| 212.35|
| Jul.  | 145.38| 157.10| 114.65| 171.22|
| Aug.  | 171.44| 160.52| 111.75| 171.52|
| Sep.  | 251.32| 184.98| 101.64| 190.62|
| Oct.  | 286.37| 163.81| 92.58 | 185.53|
| Nov.  | 272.43| 138.49| 67.74 | 131.43|
| Dec.  | 248.26| 117.50| 55.42 | 105.85|

4. Lighting Energy Consumption
4.1 Calculation Conditions
Based on the calculation results of a combination of glazing systems and blinds discussed above, the annual lighting energy consumption of the target building was calculated. WIS was also used for simulation and the value of cloud cover was used for Standard Weather Data (Seoul) published in the Korean Solar Energy Society. Artificial lighting consumption was assumed to be 10W/m$^2$, and overall efficiency of the lighting system to be 90 percent on the basis of the median illumination of the real space.

Further, in the calculation conditions, a dimming control which begins to spread into office buildings, 60 percent lighting, and 100 percent lighting were specified to obtain results under various conditions. The operation time of lighting was set to 08 to 18h on a 5-day workweek.
4.2 Calculation Results of Lighting Energy

In each type of glazing, low-e and solar protection glazing, and a venetian and roller blind with varying angle were applied to constitute 8 cases (A to H). Table 4. and Table 5. represent the calculation results of the annual lighting energy consumption from a single and double skin façade. When a dimming lighting control was installed in a SSF, the annual lighting energy consumption of case B in which low-e glazing was used and the angle of a venetian blind was controlled to Cut-off, appeared to be 7.96kWh/m²/year, showing the best performance. The position of a dimming sensor is in the middle of a workspace. However, in case A with low-e glazing and a roller blind applied, the lighting energy consumption was found to be 24.65kWh/m²/year, showing the lowest energy efficiency.

With dimming control on a DSF, the case showed the best performance consuming 10.07kWh/m²/year lighting energy when low-e glazing was used along with a venetian blind angle of 0° and cut-off control. Further, like a SSF, when applying a roller blind, annual lighting energy consumption was found to be 25.15kWh/m²/year, while solar protection glazing and venetian blind cut-off control are found to be 23.65kWh/m²/year, appearing as a disadvantageous combination.

Annual lighting energy consumption in a SSF decreased by about 25 percent compared to a DSF in all cases. This is because the amount of solar transmittance by a DSF decreased. And the energy consumption in SSF was about 46 percent less, showing the biggest difference in case G by 'solar protection glazing + venetian blind + shade angle cut-off control'. That is, calculation results revealed that the DSF with solar protection glazing was advantageous in terms of g-value and u-value but disadvantageous for lighting energy.

The angle of the venetian blind was set to an annually fixed value; however, the lighting energy consumption was the least mostly during cut-off control. Also, a shade angle of 0° was found undesirable as a control alternative since direct solar radiation from the outside could not be sufficiently blocked during the period of low solar altitude. The application of a roller blind also appeared to be disadvantageous due to its low solar transmittance.

In the case of a 'SSF + solar protection glazing + venetian blind Cut-off control', the lighting energy consumption increased about 15 to 30 percent compared to low-e glazing. But when taking the thermal performance factors such as g-value and u-value into consideration, it seems that an additional consideration should be given.

Last, in the case of artificial lighting, the energy consumption varied considerably with dimming control, 60 percent lighting and 100 percent lighting. In practice, most offices use 100 percent lighting annually so it seems that it is necessary to build a control system to realize proper illumination.

5. Total Energy Consumption

5.1 Simulation Model of the Target Building

We developed a simulation model on the target building mentioned above. Using TRNSYS17, the plan was divided into six zones for computational convenience, after being simplified as shown in Fig.7. A SSF with low-e glazing and internal roller blind were applied with a u-value of 1.4W/m²K, and a g-value of 0.59.

Table 4. Calculation Results of the Annual Lighting Energy Consumption from a Single Skin Façade

| No. | Glazing  | Solar shading                        | Continuous Dimming $Q_L$ [kWh/m²/year] | 60% lighting on $Q_L$ [kWh/m²/year] | 100% lighting on $Q_L$ [kWh/m²/year] |
|-----|----------|--------------------------------------|----------------------------------------|-------------------------------------|---------------------------------------|
| 1   | Low-e    | Roller blind, permanently activated  | 24.65                                  | 15.6                                | 26.1                                  |
| 2   | Low-e    | Venetian blinds: closed              | 12.39                                  | 15.6                                | 26.1                                  |
| 3   | Low-e    | Venetian blinds: cut-off             | 7.96                                   | 15.6                                | 26.1                                  |
| 4   | Low-e    | Venetian blinds: 0°                  | 7.96                                   | 15.6                                | 26.1                                  |
| 5   | Low-e    | Venetian blinds: 30°                 | 8.57                                   | 15.6                                | 26.1                                  |
| 6   | Low-e    | Venetian blinds: 45°                 | 9.22                                   | 15.6                                | 26.1                                  |
| 7   | Low-e    | Venetian blinds: 60°                 | 11.54                                  | 15.6                                | 26.1                                  |
| 8   | Solar protect | Venetian blinds: cut-off          | 12.59                                  | 15.6                                | 26.1                                  |

Table 5. Calculation Results of the Annual Lighting Energy Consumption from a Double Skin Façade

| No. | Glazing  | Solar shading                        | Continuous Dimming $Q_L$ [kWh/m²/year] | 60% lighting on $Q_L$ [kWh/m²/year] | 100% lighting on $Q_L$ [kWh/m²/year] |
|-----|----------|--------------------------------------|----------------------------------------|-------------------------------------|---------------------------------------|
| 1   | Low-e    | Venetian blinds: closed              | 13.89                                  | 15.6                                | 26.1                                  |
| 2   | Low-e    | Venetian blinds: cut-off             | 10.07                                  | 15.6                                | 26.1                                  |
| 3   | Low-e    | Venetian blinds: 0°                  | 10.07                                  | 15.6                                | 26.1                                  |
| 4   | Low-e    | Venetian blinds: 30°                 | 10.71                                  | 15.6                                | 26.1                                  |
| 5   | Low-e    | Venetian blinds: 45°                 | 11.58                                  | 15.6                                | 26.1                                  |
| 6   | Low-e    | Venetian blinds: 60°                 | 13.57                                  | 15.6                                | 26.1                                  |
| 7   | Solar protect | Venetian blinds: cut-off            | 23.65                                  | 15.6                                | 26.1                                  |
| 8   | Low-e    | Roller blind permanently activated   | 25.15                                  | 15.6                                | 26.1                                  |
The resulting values were displayed in net, end and primary energy, respectively. The primary energy resulted in 293 kWh/m² year, the value to be used as a baseline later in determining an optimal combination. Table 6. represents the system efficiency and primary energy conversion factors applied in Korea. Fig. 8. shows the energy consumption per unit area for heating, cooling, lighting, and ventilation. For a large primary energy conversion factor of electricity, the primary energy demand was more than twice as large as the end energy. The cooling demand of net energy accounted for 46 percent of the total, and 23 percent after being converted to primary energy. In contrast, the proportion of lighting energy was 27 percent of net energy, but increased to 41 percent in primary energy, showing the largest proportion.

5.2 Effects of Boundary Conditions

In this case, we investigated how energy consumption would change with varying parameter values set by the boundary conditions because the boundary conditions were merely numerical values subject to change according to design and operating conditions. We altered the parameter values for the factors of the number of people per unit area, heat gain of OA equipment, air change per hour (hereinafter, ACH), and temperature set-point of the air-conditioning on which 48 combinations were examined. The parameter values added to each factor are as follows.

- Number of people per unit area: 0.1/m², 0.2/m²
- Heat gain of OA equipment: 0.14 W/m², 0.23 W/m²
- Air change per hour: 0.15 ACH, 0.6 ACH
- Cooling temperature set-point: 24°C, 26°C
- Heating temperature set-point: 20°C, 22°C

From the results in Fig. 9., it was found that annual primary energy consumption ranged from the minimum, 282 kWh/m² year, to the maximum, 372 kWh/m² year, corresponding to 4 percent less and 27 percent more, respectively, than 293 kWh/m² year, the value calculated earlier from the default parameter conditions. The largest change occurred in energy consumption and a change of 2°C in cooling temperature in summer requiring larger energy consumption than in winter. Also, ACH was shown to have the greatest effect on heating energy consumption as well as the number of people per unit area on cooling energy consumption.

5.3 Energy Efficiency Measures

In the next step, the impacts of different energy efficiency measures are investigated. The measures considered for the target building are as follows.

- Measure 1: Double Skin Façade
  The double skin façade has a 300 mm cavity and openings in the top and down position (height of openings: 300 mm) of the exterior skin layer. The baseline has no cavity ventilation. It has a cavity shading device with a 45° shading angle. The interior glazing is low-e glazing, like the existing glazing of the single skin façade, while 4 mm clear glass is used for the glazing of the exterior skin layer.

- Measure 2: Solar Protection Glazing
  Solar protection glazing (hereafter, Insulation Gl.) is applied instead of low-e glazing.

- Measure 3: Position of Shading Device
  For the single skin façade, the shading position cannot be changed in a high-rise building (fixed as an internal shading), but it can be varied in the case of the double skin façade for winter (internal shading) and for summer conditions (cavity shading), if the façade has
two shading devices.

- **Measure 4: Lamp Efficiency**
  The lamp efficiency is varied from the existing 19W/m² year (Efficiency of Lamp: Low) to 10W/m² year (Efficiency of Lamp: High)

- **Measure 5: Daylight Use**
  In the baseline case (without dimming), the artificial lighting is assumed to be always turned on during operation time. For the case of "daylight use" the calculated artificial lighting is applied for the lighting energy demand, as well as for the heating and cooling energy demand.

- **Measure 6/7: Shading Angle Control in Summer and Winter**
  Three different shading angles (cut-off, 45°, roller blinds) are chosen for the parameter study, because 30° and 60° shading angles show similar results, whereas 45° and 0° cannot be applied in practice due to glare problems.

- **Measure 8: Summer and Winter Definition for Change of Shading Control**
  In the baseline case, summer is defined in the modeling if the prevailing outdoor temperature continuously exceeds 10°C for 24 hours. The optional value is 14°C.

- **Measure 9: Night Ventilation**
  Night ventilation can work as a free cooling system, if the night air temperature is lower than the indoor temperature. The baseline is without night ventilation and the optional case is 2 ACH during non-operation time.

- **Measure 10: HVAC System Efficiency**
  The efficiencies of the baseline system are that the boiler COP is 0.9, the chiller for cooling is COP 4.5, and the heating and cooling transport loss is 50 percent. The optional variant systems are: Boiler COP is 0.9, cooling COP is 6.3 and transport loss is 30 percent.

- **Measure 11: Phase Change Material**
  Phase change material (hereinafter, PCM) can reduce the cooling energy demand as well as the peak demand for cooling power. A PCM with a melting point of 27°C is applied at the entire ceiling area of the south, east and west zone.

6. Evaluation of Optimal Measures through Parametric Studies

6.1 Parameter Combinations

With the calculation results from the target building as a baseline, we performed the calculation 992 times with the combination of energy saving measures presented previously. Measure 3 is not varied for the single skin façade, while measure 2 is not varied for the case of a double skin façade. In the case of solar protection glazing, shading angle control is diversified only in two cases (cut-off and roller). Fig.10. shows the parameter combinations of DSF.

### 6.2 Calculation Results and Discussion

Table 7. shows the first five levels of classification of all 992 results under baseline conditions. The first five levels were determined on sensitive parameter for energy demand through the 992 results. The first influence factor for the primary energy demand is the efficiency of the lamps, followed by the HVAC system efficiency. The façade properties or the use of daylight appear as the third influence factors. Only in the case of highly efficient lamps combined with the existing cooling system efficiency, will the choice of SSF or DSF have an impact on energy efficiency; otherwise, the use of daylight has a greater influence than the construction of the façade. This is reasonable because the double skin façade with cavity shading mainly reduces the cooling energy demand. If the cooling system is not efficient, then it has more influence on the total energy demand. Likewise, if the lamp is not efficient, then it requires more lighting energy, thus the utilization of daylight is more efficient than measures for saving cooling energy. Assuming high HVAC system efficiency, the variable shading position is more important than the decision in favor of SSF or DSF. If dimming is applied, the use of venetian blinds is more efficient compared to roller blinds, even in summer. Without dimming, the roller blinds can save more cooling energy in summer than venetian blinds because roller blinds are more efficient than venetian blinds for solar incidence protection. A DSF with low system efficiency, without dimming and without variable shading position, will have a lower performance than a SSF grouped with dimming and venetian blinds.

The difference between the most optimized group (high efficient lamp and system, dimming, variable shading position in DSF, venetian shading: 179 kWh/m² year) and the most inefficient group (inefficient lamp and system, without dimming: 282 kWh/m² year).
Table 7. Calculation Results of Five Levels under Baseline Conditions

| Parameter 1 | Lamp efficiency: high |
| --- | --- |
| Parameter 2 | System efficiency: high |
| Parameter 3 | Without dimming control |
| Parameter 4 | Two shading devices |
| Primary energy demand [kWh/m²/year] | Single shading device | Two shading devices | Single shading device | Two shading devices |
| No. of samples | n=88 | n=12 | n=56 | n=32 |
| SSF | 205 | 193 | 194 | 182 |
| DSF | n=36 | n=12 | n=24 | n=12 |
| Cut-off | Shading: summer |
| 45°, roller | Roller | 45°, cut-off | Roller | 45°, cut-off |
| No. of samples | n=88 | n=36 | n=56 | n=36 |

is 103 kWh/m² year, which is about 37 percent of the total primary energy demand of the inefficient group. For the quantitative assessment of important individual measures and the combination of several measures, the energy demands of some representative combinations are compared to the baseline. The important single measures are chosen from the above analysis: efficiency of lamps, efficiency of system, dimming and different façade types (SSF with venetian blinds and solar protection glazing, DSF with variable shading).

The application of efficient lamps alone can reduce the total primary energy demand by 20 percent. Increasing the COP of the cooling system from 4.5 to 6.3 and decreasing transport losses from 50 percent to 30 percent of the net energy demand will reduce the primary energy demand by 7 to 11 percent on average, either as a single measure or as a combined measure applied in addition to other measures. In contrast to both measures, dimming as a stand-alone measure cannot increase the total energy efficiency. It can increase the total performance by 5 or 6 percent only as a combined measure along with the venetian blinds in the cut-off mode or at a 45° shading angle. This is logical because daylight cannot be used if a shading system like an existing roller blind blocks out the light transmittance.

7. Conclusions

This study showed what the target building conditions are. Our conclusions can be stated as follows, but it should not be forgotten that the results could vary for different design parameters such as latitude, climate, glazing type, number of people per unit area, temperature set-point of cooling and heating etc.

- In the case of a DSF with a cavity shading system, the g-value can be reduced 0.07 -from 0.29 in the given situation- if the cavity is ventilated with outdoor air or indoor air.
- In winter, because of the low solar incident angles, the illumination criterion in the interval of a shade angle of 60° or lower. In summer, the risk of the glare problem was relatively minimal due to high solar incident angles.
- With dimming control on a DSF, it showed the best performance consuming 10.07 kWh/m² year lighting energy when low-e glazing was used along with a venetian blind angle of 0° and cut-off control.
- The lighting energy consumption in a SSF was about 46 percent less by 'solar protection glazing + venetian blind + shade angle cut-off control' and was most useful.
- The application of efficient lamps reduces the total primary energy demand by 20 percent. And increasing the COP of the cooling system and decreasing transport losses of the net energy demand reduces the primary energy demand 7 to 11 percent on average.

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