

## ENERGY AND DAYLIGHTING PERFORMANCES OF HIGHLY GLAZED BUILDINGS

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### ABSTRACT

Glazed façades create indoor environment more attractive and pleasant but also let high solar and thermal gains in the buildings that lead to energy inefficiency. Hence, more attention needs to be given to the glazed component to improve the buildings' energy performance and indoor visual comfort. This study aims to provide insightful on the suitable selection of the glazed components for the office buildings. In this study, a number of simulations were performed, using EnergyPlus, for the office rooms with one and two exposure wall(s) in two different climates. Results were analysed and presented in terms of the energy demands for heating, cooling, fans and lightings and daylighting performance considering useful daylight illuminance (UDI) and discomfort glare.

### INTRODUCTION

In industrialized countries, approximately 40% of the primary energy is consumed by buildings only and they also responsible for about 36% of the energy related CO<sub>2</sub> emissions (Energy 2009). The energy demand in the buildings and associated issues are presumed to be continued to increase in the future because of a rapid continuous growth in the construction sector. Indian construction industry represents about 33% of electricity consumption (Tulsyan et al. 2013). Moreover, a new trend of constructing highly glazed façades modern office buildings, to provide high aesthetic value, has been observed that may also increase the HVAC energy demand (Aboulnaga 2006; Omar & Al-Ragom 2002). On the other hand, the glazed façades allow access to best quality natural light, view to outdoor as well as significant savings in lighting energy. However, inappropriately designed glazed façades may lead to indoor visual (Freewan 2014) and thermal discomfort as well as energy inefficiency in buildings. Various parameters, such as dimensions of glazed façade, thermal and optical properties of glazing, type and position of shadings as well as control strategies for shading and lighting are crucial and advised to be opted carefully to achieve energy efficiency and indoor visual comfort (Hee et al. 2015; Liu et al.

2015; Acosta et al. 2015; Goia et al. 2013). In recent past, several theoretical and experimental attempts have been made, around the world, to improve the energy, thermal and visual performances of the buildings through advanced alternatives of glazing and shadings (O'Brien et al. 2013; da Silva et al. 2012; Bellia et al. 2013; Tzempelikos & Shen 2013; Hammad & Abu-Hijleh 2010). Recently, significant lighting energy saving was estimated, just by tuning the occupancy set point controls for daylight, for an open-plan office areas on three typical floors in a 51-story building tower (Fernandes et al. 2014).

It is worth to be noted here that a higher energy efficiency and better indoor visual comfort can only be achieved simultaneously if the size of glazed façade, properties of shading and glazing, shading type and control strategies for lighting and shading are selected suitably (Nielsen et al. 2011; Shen & Tzempelikos 2012; Bellia et al. 2013; Shen & Tzempelikos 2013) and automatic controlled dynamic shading with controllable electric lightings are used (Tzempelikos & Athienitis 2007) in an integrated manner (Kim et al. 2007). Moreover, effective shading conditions can be achieved using the automatic dynamic shadings that are easier to operate and better in performance over fixed shadings (Nielsen et al. 2011; Freewan 2014). An uncertainty and sensitivity analysis showed that shade transmittance and the glazing type are the two parameters affect the energy and daylighting performance in the office building significantly (Shen & Tzempelikos 2013). Most of the past studies are limited to one exposure glazed façade and effect of internal roller shades and glazed area on the discomfort glare period and energy performance in Indian climatic conditioned have hardly been discussed previously.

Present study aims to study the effect of glazing and shading type on the energy and visual performance in the office buildings with one and two glazed exposers, having glazed area between 30% and 90%. Results presented in this study were obtained simulating a number of glazing options for a standard office room in cold and hot-dry climates.

## SIMULATION

### 2.1 Simulation tool

In this study, a whole building simulation software, EnergyPlus, promoted by the Building and Technology Program of the Energy Efficiency and Renewable Energy Office (Anon 2013), was used. The software has received a wider acceptance in the building energy analysis community. The tool calculates the energy demand in an integrating manner considering the effect of heating, cooling, lighting and many other building integrated renewable energy system (Bojić et al. 2012). The tool is capable for modelling the buildings solar irradiance, illuminance under different sky conditions, advanced fenestration systems, shading and lighting controls, and indoor illuminance maps (Seo et al. 2011). The EnergyPlus uses the split flux method to calculate the daylight at the interior after reflection from the interior surfaces (Anon 2013). The method is comparatively less accurate than the radiance/daysim programme. Despite some inaccuracies in the daylight results calculated by the split flux method (Tian et al. 2014), can still be used in this study as a great similarity was found between the internal illuminance obtained by the two different programmes with a maximum difference of 20% (Ramos & Ghisi 2010).

### 2.2 Climates

Two different climates i.e. cold climate of Shillong and hot-dry climate of Jodhpur were chosen for this study. Figure 1 presents the monthly variation of climatic parameters for these locations. The temperature in the cold climate remains below 20°C but reached close to 35°C in the hot-dry climate. The minimum, maximum and average values of horizontal global radiation for hot-dry and cold climates are 157, 329, 242 and 113, 233, 160 respectively.

### 2.3 Simulation model

Simulations were performed for a standard air-conditioned office room (4m × 4m × 3m) with one and two (exposures) glazed façades varying window to wall ratios, glazing and shading types. The glazed area is expressed in terms of window-to-wall ratio (WWR) for generalizing the results. The room was simulated for four major façade orientations for three different WWRs, i.e. 30%, 60% and 90%. These values of WWRs do not include the framing area. A frame of width 0.0572m was also taken into consideration during the simulations. The framing accounts for an extra 3.75%, 5.41% and 6.41% of the total wall area with the WWR 30%, 60% and 90%

respectively. The conductance and absorptance of the frame used in the simulations are 5.68 W/m<sup>2</sup>-K and 0.6 respectively. The interior surface reflectances of the floor, ceiling and walls are kept 30%, 70% and 60% respectively, normal values in the design of interiors. The room is assumed to be located at an intermediate floor in a multi-storey office building and only glazed façades were assumed to be exposed to outdoor environment.

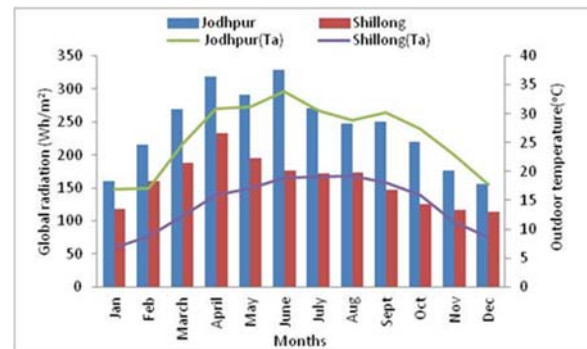


Figure 1. Global monthly averaged horizontal radiation and outdoor monthly dry bulb temperature for studied locations.

All the other opaque surfaces including ceilings and the floors were assumed to be adiabatic surfaces, attached to adjacent offices at the same indoor temperature. Therefore, there will not be any heat transfer through the internal adjacent surfaces. The heat transmittance coefficients (U-values) of the opaque portion, in the external wall were used as recommended by the energy conservation building code (ECBC 2009). The exterior surface absorptance of the external façade was taken as 0.6.

Table 1 Description of office room and internal gain

| PARAMETER                              | DESCRIPTION  |
|--|--|
| Climate                                | Hot-dry ( Jodhpur lat. 26° 17' N, long. 73°1'E)<br>Cold and cloudy (Shillong lat. 25° 34'N, long. 91°52'E) |
| Dimension of room                      | 4m ×4m ×3m   |
| WWR                                    | 30%, 60%,90%   |
| Shading type                           | Internal woven roller shade  |
| Internal gain                          |  |
| Equipment                              | 5.4 W/m <sup>2</sup>   |
| Lighting (daylight continuous dimming) | 11.8 W/m <sup>2</sup> (ECBC 2009)  |
| Personnel occupancy                    | 0.11 p/m <sup>2</sup> (office hours: 9am to 5pm) with sensible heat gain from each occupant is 76 W        |
| Daylight illuminance sensor point      | 1 (x=2m,y=2m)  |

The other characteristics of the office room are given in Table 1. A HVAC system that delivers the theoretical loads necessary to keep the temperature within the heating and cooling set point temperatures were used in the simulation. During office hours (9

am to 5 pm), the room temperature is assumed to be maintained at 22°C in winter and 24°C in summer. Heating and cooling temperature set points during non-office hours were also assumed to be at 18°C and 30°C respectively. An hourly time-series meteorological data used in this study is taken from(EnergyPlus 2015).

For office spaces, the minimum desirable work plane illuminance is set 500lx. One daylight photo sensor was assumed to be positioned at a work plane height of 0.8 m above the floor to control the artificial lighting. If the illuminance levels drop below this, artificial lighting switched on.

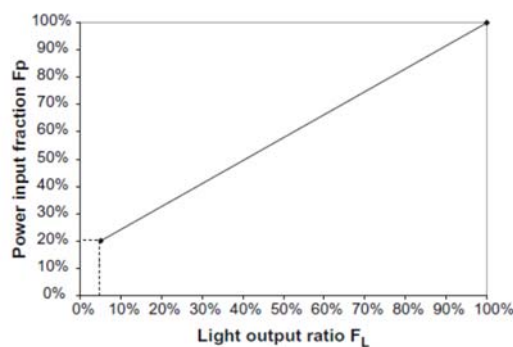


Figure 2. Correlation between light output ratio and power input fraction for an ideal operation of the high frequency dimming controls.

In this study, an ideal continuous dimming control system is assumed to be installed in the office to compensate the artificial lighting use with the daylight illuminance to reach the desirable value (i.e. 500lx) on the work plane(Bellia et al. 2013). The light output and the input power behaviour of dimming controls system, used in this study, is illustrated in Figure 2 (Li et al. 2010). The input power and output light relationship may vary for other ballasts available in the market and ballasts’ manufacturer (Doulos et al. 2008). Moreover, a solar radiation based shading control was used. The shading was assumed to be activated if solar radiation on the glazed façade exceeds 250W/m<sup>2</sup>. Properties of the two double pane glazing and five roller shade fabrics used in this study are given in Table 2 and 3.

#### 2.4 Evaluation criteria

Based on the simulations results, each shading alternative and its effect in relation to energy performance and indoor visual comfort were evaluated. The evaluations were performed on the basis of the total source energy demand of the office room, energy demands for heating, cooling, fans and lighting, discomfort glare index(DGI) and useful daylight illuminance (UDI). In this article energy performance is discussed for total source energy demands only. The UDI values were estimated and compared using the three bins suggested by Nabil

and Mardaljevic (A. Nabil 2006). However, the UDI presented in this article is the sum of all three bins. The maintained illuminance level for a work space should be higher than 500lx.

Table 2  
Glazing type and their solar optical and thermal properties.

| PARAMETERS                       | GLAZING      |                      |
|----------------------------------|--------------|----------------------|
|                                  | DG-I (Clear) | DG-II (low-e coated) |
| Visual transmittance( $\tau_v$ ) | 0.832        | 0.301                |
| Front/back visual reflectance    | 0.151        | 0.224                |
| Solar transmittance( $\tau_s$ )  | 0.795        | 0.109                |
| Front/back solar reflectance     | 0.142        | 0.398                |
| Front absorptance                | 0.035        | 0.41                 |
| Back absorptance                 | 0.029        | 0.083                |
| U-factor(W/m <sup>2</sup> -K)    | 2.677        | 1.616                |
| SHGC                             | 0.818        | 0.209                |

Note: All glazings have 12.7mm air gap between two panes

Table 3  
Properties and categories of shade fabrics

|                   | SHADE FABRIC |       |       |       |       |
|-------------------|--------------|-------|-------|-------|-------|
|                   | B            | C     | D     | E     | F     |
| Transmittance     | 50%          | 40%   | 30%   | 20%   | 10%   |
| Reflectance       | 20%          | 20%   | 20%   | 20%   | 20%   |
| Openness(average) | 45%          | 35%   | 25%   | 15%   | 5%    |
| Thickness(m)      | 0.005        | 0.005 | 0.005 | 0.005 | 0.005 |

## DISCUSSION AND RESULT ANALYSIS

Figures 3-9 show the energy and visual performance results for standard office room in cold and hot-dry climates. Figures 3 and 4 show the source energy demand estimated comparatively higher for the office with two glazing façades in both the climates. Irrespective of glazed area, glazed façade orientation, shading and glazing types, the energy consumption was estimated lowest in south facing office (except for 30% WWR with glazing DG-I, in this case north facing office show lowest energy demand) and highest in east facing office in the cold climate. In hot-dry climate, the lowest and highest energy demands were estimated for north and west facing offices respectively. Also, east façade office’s energy performance was estimated very close to west façade’s office performance. A significant variation in the energy demand can also be observed for other orientated offices when glazing DG-I is used. With glazing DG-II the difference is estimated comparatively much lower and even trivial in some cases (e.g. in façades offices with smaller glazed area).

The energy consumption increases significantly with glazed area irrespective of façade orientation and climate type and glazing type. If glazed area is increased from 30% to 90%, the energy consumptions of one and two façades offices can increase up to 51% and 54% respectively. The effect is seen significantly smaller for glazing DG-II. In

cold climate, for offices with one glazed façade the glazing DG-II shows energy demand approximately 17-60% lower than glazing DG-I.

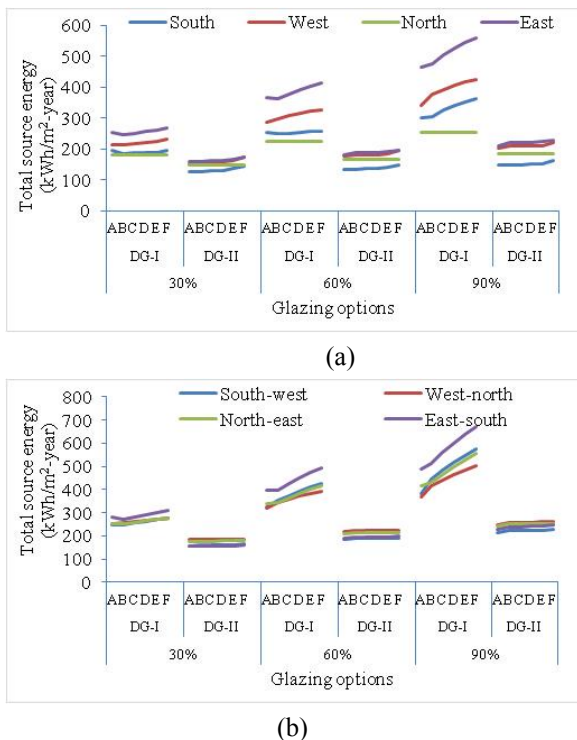


Figure 3 Source energy consumption in office a) with one glazed façade; b) two glazed façades in cold climate

The difference was estimated highest for east facing office and lowest for north façade. For two façade offices in the cold climate, the difference was estimated between 27-63% and highest was estimated for east and south glazed façades' office. In hot-dry climate, one and two glazed façades' offices with the glazing DG-I demand approximately 17-55% and 35-57% higher energy respectively. The higher energy demand with the glazing DG-I is clearly due to its higher thermal and solar transmittance values (see Table 2), which result in higher thermal and solar gain and eventually higher cooling demand especially in hot-dry climate. Moreover, for the glazing DG-I the energy demand also increases significantly with shading type in both the climates and for all façade orientations. However, variation can be observed very small or negligible for glazing DG-II despite the variation in the shading type. A significant variation in the energy demand with the glazing DG-I can also be seen in the Figures 3-4 by changing shading type from B to F. The energy demand increases with decrease in the shade transmittance, which seems to be unexpected. However, this increase in the energy demand can be explained as increase in the absorptance of the shading that can be revealed from Table 3.

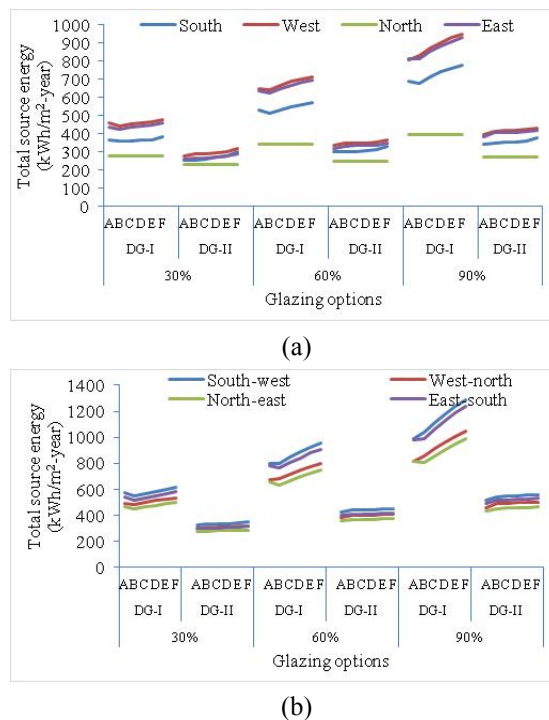


Figure 4 Source energy consumption in office a) with one glazed façade; b) with two glazed façades in hot-dry climate

The shade of lower transmittance absorbs higher solar radiation (see Figure 5 a representative example for 30% glazed area in the south oriented office in hot-dry climate) as a result of higher absorptance and eventually leads to higher cooling demand. In addition, a significant increase in the lighting energy consumption can be expected due to lower access to daylight (because of lower shade transmittance).

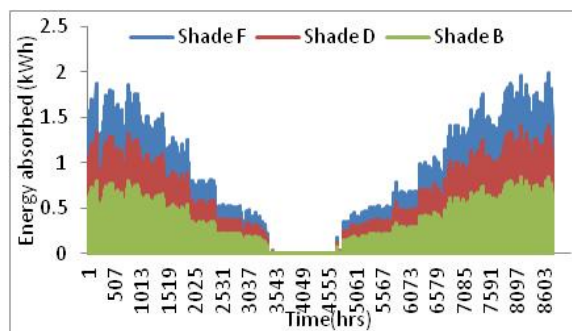


Figure 5 Solar radiation energy absorbed by three different shades in 30% glazed area on the south façade in hot-dry climate.

The variation in the energy demand with shading types for glazing DG-II is appear to be insignificant. The reason for this could be lower transmittance of the glazing, which already blocked most of the radiation and, therefore, a small amount of radiation reaches to the shading. In one façade office, a constant energy demand with respect to shading type can be observed in case of north facing office; this could be because shading is hardly activated, as the

total radiation on the north façade always remains below the set activation value of radiation for shading control.

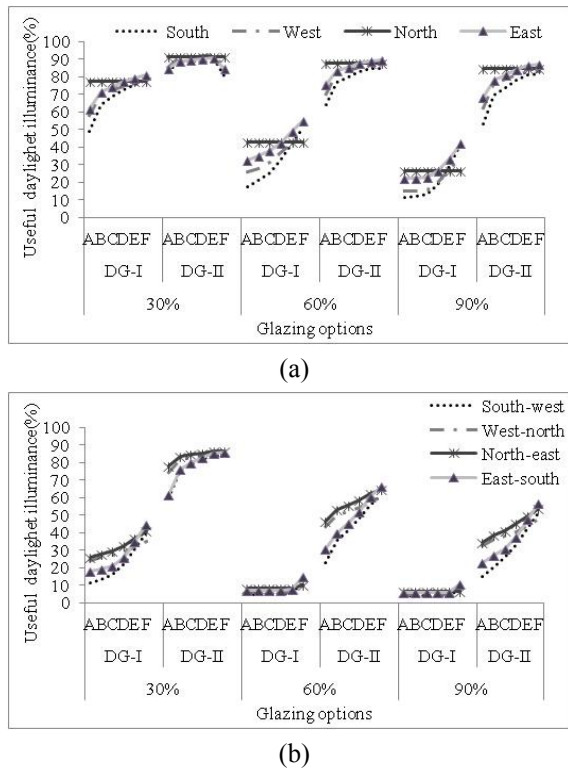


Figure 6 Variation in UDI in office with a) one; b) two glazed façade(s) in cold climate

Further, the visual performance in the office with different façade orientations and glazing options was assessed in terms of useful daylight illuminance (UDI) and discomfort glare index (DGI). The useful daylight illuminance and occurrence time for  $DGI(\leq 22)$  were estimated for office hours (9am to 5pm) only and are presented in Figures 6-9. Figures 6-7 show the variation in the UDI (100-2000) with variation in the glazing type, shading type, glazed area and façade orientations. It can be seen that UDI decreases with increasing glazed area and transmittance of glazing and shading irrespective of façade orientations. The UDI was estimated significantly higher for offices with one glazed façades. For one glazed façade offices in cold and hot-dry climates, the UDI values vary between 11 and 92%, and between 4 and 98% respectively. For two glazed façades offices, the UDI values reached up to 87% and 96% but also touches 4% and below in some cases. The UDI values were estimated higher for the glazing DG-II and lowest for bare glazing DG-I. In general, the UDI value significantly increases with low transmittance glazing and shadings, however, it decreases with increasing WWR.

It can also be observed that for 30% glazed area in one glazed façade offices with glazing DG-II, the UDI first increases with decreasing the shade

transmittance and then decreases for the shades of transmittance value below 20%. It could be because a major portion of the daylight is blocked by low transmittance glazing and further deployment of very low transmittance shading hardly allows natural light in to the room. In addition, the UDI remains unchanged with shading types for north façade offices.

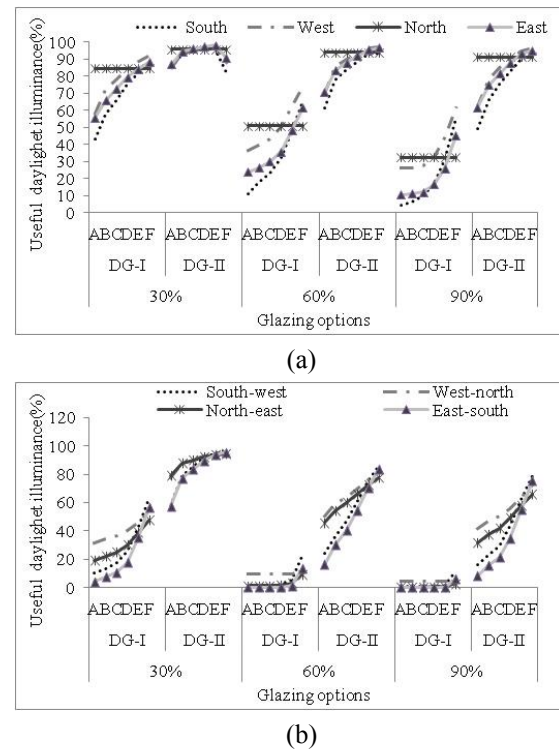
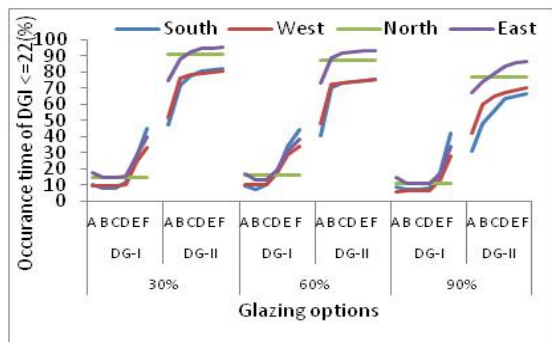


Figure 7 Variation in UDI in office with a) one ; b) two glazed façade(s) in hot-dry climate

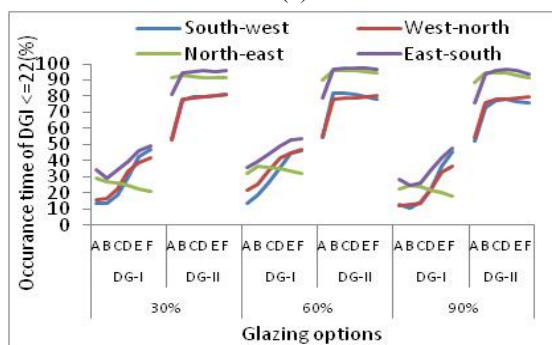
The stable behaviour could be explained by the lower value of radiation on the north façade than the set value used to control the roller shade. The UDI value remains below 20% especially for WWR of higher than 30% with glazing DG-I in two façades office, which indicates excessive access of daylight to indoor as a result of higher transmittance of glazing and larger glazed area. The illuminance values allowed by the glazing DG-I in 60% and 90% glazed façades' offices could be so high that even very low transmittance shade fabric is unable to lower the intensity effectively.

Discomfort glare is another matrix used to explain the quality of the indoor daylight. Figures 8-9 show the variation of acceptable discomfort glare index ( $\leq 22$ ) occurrence annual time in the office space with façade orientation, glazed area, glazing and shading types. The acceptable DGI occurrence increases significantly with decreasing transmittance of glazing and shading but decreases with increasing WWRs. For office with one glazed façade, the acceptable DGI occurrence vary between 6-95% and 4-99% in cold and hot-dry climates respectively. The values were estimated higher for glazing DG-II. For

two façades offices, the acceptable DGI occurrence time remains above 10% and 16% in cold and hot-dry climates respectively.



(a)



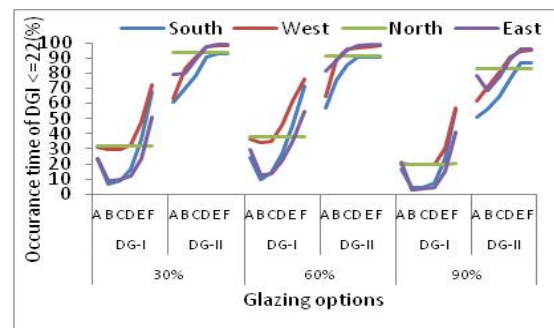
(b)

Figure 8 Occurrence of DGI ( $\leq 22$ ) in office with a) one; b) two glazed façade(s) in cold climate

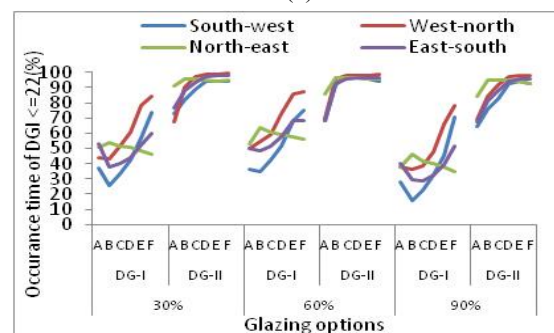
Moreover, the maximum acceptable DGI occurrence were estimated close to 95% and above in cold and hot-dry climates respectively. The values always estimated above 50% in both the climates with the glazing DG-II. It can also be observed that the value was estimated a bit higher for bare glazing (case A) than the shadings of transmittance above 40% in hot-dry climate. The effect is negligible in the cold climate. The reason could possibly be a comparatively higher background illuminance, which is inversely correlated to the DGI (Yun et al. 2014). With glazing DG-II, the acceptable DGI occurrence time first increases to a maximum value with decreasing the shade transmittance up to 30% and then becomes almost stable for lower value of shade transmittance. This could be due to lower values of source illuminance and background illuminance. Moreover, for north facing glazed façade, as expected DGI occurrence remains constant in one glazing façade offices, however, a negative behaviour can be seen in the two glazed façades offices. Overall, the acceptable DGI occurrence time can significantly be increased by selecting shadings of appropriate optical properties.

Results of this study are limited to cold and hot-dry climates and may vary in other climates as well as locations in the similar climates. Moreover, variations in the findings are expected with different

office geometries, shading effect from external nearby obstacles (e.g. buildings, trees etc.), the shading control strategies, types of shading devices, and functioning of lighting control devices, luminaires used in the buildings and office timings.



(a)



(b)

Figure 9 Occurrence of DGI ( $\leq 22$ ) in office with a) one; b) two glazed façade(s) in hot-dry climate.

Office holidays schedule may also have significant impact on the energy performance of the office, which has not been taken care in this study. In spite of these limitations, the current study can provide a very useful picture of how glazing components need to be designed to improve the energy and visual performances in office buildings. To address all of above limitations, a detailed study will be conducted further in the future.

## CONCLUSIONS

A number of combinations of glazing and shading were simulated for three WWRs, considering glazed opening in one and two façade(s) in a standard air-conditioned office room. The results were calculated for four major office orientations in two climates i.e. cold and hot-dry climates. Results show that the offices with one glazed façade perform better for both energy and indoor visual comfort viewpoint. Office with highly transparent glazing demands significantly high energy. In addition, energy demand increases with decreasing shade transmittance and the larger glazed area. For glazing DG-II, the energy demand was relatively seen stable with shade transmittance irrespective of façade orientations, glazed façades and climate type. The demands were

estimated below or close to 300 kWh/m<sup>2</sup>-year and below 500kWh/m<sup>2</sup>-year in the cold and hot-dry climates respectively. On the other hand energy demands for glazing DG-I were estimated roughly 20-60% higher than glazing DG-II. In addition, energy demand continuously increases on decreasing shade transmittance due to increased absorptance. However, UDI and acceptable DGI occurrence time increase significantly with decreasing shade transmittance irrespective of façade orientations and climate type. In general, findings of the study are equally beneficial to existing as well as the buildings at the planning stage. Building designers, energy consultants and owners can take the advantage of the study to improve the energy and indoor visual performances of the office buildings implementing at the design stages or at the time of modification in the in the existing buildings.

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