Sensitivity Analysis of Influential Design Parameters for South Oriented Glazed Façade Office

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ABSTRACT

Buildings are accountable around 30-40% of global energy consumption. The modern designs of building with significantly large size of glazed façade are trending and liked by the owner and designers. However, their energy and indoor visual performances are required to be investigated thoroughly. This study assessed the most significant design parameters for south glazed façade office in composite climate of Amritsar in India. The influential parameters have been identified through uncertainty and sensitivity analysis for energy and indoor visual performances. The WWR, ASR, Gt and ST have been identified major and common design parameters that influence the performance of buildings. However, their contributions vary with the performance parameters.

Keywords: Sensitivity analysis, Uncertainty, Energy consumption, Indoor visual comfort, Glazed façade, Roller shade

NONMENCLATURE

Abbreviations	
UDI HVAC	Useful daylight illuminance Heating, ventilation and air conditioning
Symbols	
μ	Mean
σ	Standard deviation
U	Coefficient of variance

1. INTRODUCTION

Buildings currently consume approximately 30-40% of overall global final energy consumption[1]. Furthermore, in 2010, the building sector's direct GHG emissions and indirect CO² emissions were estimated to be around 6.4 percent and 12 percent, respectively[2]. The Indian construction sector, in particular, consumes approximately 30% of total electricity consumption[3]. Furthermore, the building sector's electricity demand, consumption, and GHG emissions will grow at a faster rate in the future due to increased demand for conditioned floor space. Therefore, various approaches to reducing energy consumption in buildings are being tested and employed[4–6].

Further, increasing trend of glazed façade has been observed recently in order to provide an appealing aesthetic and modernize looks to the building. However, excessive use of glass increases the risk of energy inefficiency in overall building operation. Even in low-energy buildings, glazed components can account for up to 40% of heat losses[7]. As a result, appropriately designed glazed facades may result in significant energy savings and provide an opportunity to improve building energy efficiency. Recently, many researchers have focused their research on exploring energy efficient and improving indoor visual comfort options by employing different types of glazing and shading options[8–11]. The internal roller shade is one that has been the interests of particularly in cold climates. However, the exhaustive research on significant parameters hardly has been explored yet for composite climate[12-15].

Moreover, the complexity of modern building designs makes it difficult to elaborate and formulate a

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decision making problem, as well as to solve it. Inappropriate design parameter values can lead to high energy inefficiency, indoor visual and thermal discomfort[15],[16].

Several methods have been proposed to help building engineers choose design parameters. Uncertainty and sensitivity analyses of design parameters, as well as building energy performance optimization, are among the methods proposed[17]. Many building energy researchers have used sensitivity analysis to rank the most influential parameters[18–22].

In this study, glazed facade with dynamic interior roller shade integrated glazed facade has been chosen as the research object from among commonly used dynamic shading devices for the uncertainty and sensitivity analyses. In northern hemisphere, south facade is second surface in the building after roof, which receives maximum direct radiation and influences energy performance of the building greatly. Also, the glared components in the south façade are used to take advantage of the natural light to illuminate indoor naturally and eliminate artificial indoor lighting. However, receiving natural light in appropriately and in controlled manner depends on various design parameters and cannot be selected randomly. In this study efforts have been made to explore the impact of individual design parameters on the energy and visual performance parameters to fix them appropriately. So, in-silico research has been done for the climate of Amritsar, India. These discrete solutions have been used in a two-step procedure to arrive at the best glazed facade design choice.

2. MATERIAL AND METHODS

2.1 Uncertainty and sensitivity analysis

The Monte Carlo (MC) method is commonly used to assess the uncertainty in design parameters. For better coverage of all parts of the factor distribution of input variables, the LHS strategy is used to stratify the samples in this study[23]. The LHS divides the range of each input parameter into m equally likely intervals (m>2). Every interval has at least one random observation. Furthermore. the number of recommended executions (n) is 3/2 the number of total input variables (p). The values of the variation coefficient () can be represented graphically by a histogram or a frequency plot. The coefficient of variation represents the standard deviation to the mean of results. For assessing complex problems of heat transfer and energy in buildings, the variance-based extended FAST method is preferred. The extended FAST is a highly effective variance-based method with a fast convergence. The extended FAST method is an improved version of the traditional FAST method[24]. Using the same set of samples, the extended FAST method can estimate two different sensitivity indices (Si and STi) for each input variable. The first-order and total-effect sensitivity indices are expressed as follows for input variables X1, X2,..., Xk:

$$S_{i} = \frac{V[E(Y/X_{i} = \widetilde{X}_{i})]}{V(Y)}$$
(1)

$$S_{Ti} = \frac{E[V(Y/X_{-i})]}{V(Y)} = 1 - \frac{V[E(Y/X_{-i})]}{V(Y)}$$
(2)

The first-order sensitivity index expresses the uncertainty effect of the input variable on the output results. The total-effect sensitivity index is the sum of all sensitivity indices, including first-order and higher-order indices, for the investigated parameters. The extended FAST method was used in this study to generate a sample set of input variables for sensitivity analysis in SimLab2.2[25]. A lower value of the first-order sensitivity index does not imply that the value of the input variable will be fixed anywhere within the given range. As a result, calculating the total-effect sensitivity index is recommended for determining the values of input variables. Infinitesimal total-effect sensitivity index values for the input variables indicate that the variables have no effect on the output.

2.2 Climate of the study location

Amritsar (latitude: 31° 22' N, longitude: 74° 31'E), the second most populous city in the Indian state Punjab, has been chosen as a case study location. The city is located 217 km northwest of the state capital Chandigarh and 455 km northwest of the national capital New Delhi. Figures depict the minimum, maximum, and mean monthly dry bulb temperature and daily solar radiation values for the study location[26]. The city is classified as composite climate by the Indian National Building Code (NBC) (Bureau of Indian Standard 2016).

2.3 Building energy simulation tool

EnergyPlus is, a software for whole-building energy simulation[27], used to simulate a dynamic glazed facade integrated building in this study. The tool incorporates the best features and capabilities of two older building energy simulation programmes, DOE-2 and BLAST[27]. The EnergyPlus simulation tool is advanced and capable of modeling the cooling, lighting, heating, ventilation, and other energy flows, as well as the effect of integrating renewable energy systems (e.g., solar PV, solar water heater) in the building. The split flux method in the tool[28] is used to estimate the daylight distribution at the work plane. Externally generated input variable values from SimLab 2.2 have been used in the EnergyPlus tool for parametric run with the help of the jEplus 1.6 tool[29].



Fig. 1. Dry bulb temperature of the study location



Fig. 2. Global horizontal radiation of the study location

2.4 Input parameters

A standard room of $16m^2$ was assumed to be located on an intermediate floor of a multi-story office building for the purposes of the analyses. Only the south glazed facade is assumed to be exposed to the outside environment. All other surfaces, such as the floor, roof, and walls, are assumed to be opaque and adiabatic. These surfaces are shared with adjacent similar office rooms, which are assumed to be kept at the same temperature. The other input values used in the simulation are listed in Table 1.

Table 1. Input values for simulation

Parameter	Unit	Value	Ref.
Glazed frame conductivity	W/m²-K	[13]	
Glazed frame surface	[-]	0.6	[13]
absorbance			
U-value of opaque external	W/m²-K	0.352	[31]
surface			
Opaque external surface's	[-]	0.6	[13]
absorbance			
Work plane illumination	[lux]	500	[31]
HVAC COP	[-]	3.5	[24]
Efficiency of electric heater	[-]	1	[13]
Sensible heat gain	W/m ²	5.4	[13]
Equipment load factor	W	76	[24]
Occupant density	p/m ²	0.11	[24]
artificial light load	W/m ²	11.8	[31]
DGI set point	[-]	22	[24]

The energy consumption in the associated ideal continuous dimmer used in this study is as specified in Ref. [30]. The floor of the office room was divided into a grid of 10x10 points to create a daylight illuminance map. The room is assumed to be air-conditioned, with the indoor air temperature maintained at 24°C in the summer and 22°C in the winter, between 9:00 a.m. and 5:00 p.m. (office hours). Non-office hours cooling and heating temperatures have been set at 30°C and 18°C in summer and winter, respectively. The daylight glare index (DGI) is one of the most widely used indices in the literature. The index is affected by the size and location of the luminance of the glare source (glazed component), the occupant's view direction, and the luminance of the background[24].

Hopkinson's[32] method is used to estimate the DGI in the EnergyPlus tool. The method used to calculate the DGI is described in ref. [28]. If the source is visible to the occupant sitting in the normal position at the work desk, the glare is estimated in the form of DGI. In this study, the DGI was estimated using the view angle facing the glazed facade in all simulated cases. Many factors affect the energy and indoor visual performance of glazed facade office buildings. These include glazing thermo-optical properties, glazing size, dynamic shading thermo-optical properties, artificial lighting and shading deployment control strategies[33], office room aspect ratio, interior surface absorbance, and glazed facade orientation. The properties of the ten different glazings used in the simulation are taken from Ref. [24]. The shading properties and other design parameters are used in the Table 2.

 Table 2 Detail of selected input design variables

Building design	Symbo	Uni	Range	Distributi
parameter	I	t		on type
Office room aspect ratio	ASR	[-]	[0.5-1.5]	Uniform
Window-to-wall ratio	WWR	[-]	[0.05-0.9]	Uniform
Absorbance of wall surface	Aw	[-]	[0.2-0.8]	Uniform
Absorbance of floor surface	Af	[-]	[0.2-0.8]	Uniform
Absorbance of ceiling surface	Ar	[-]	[0.2-0.8]	Uniform
Material transmittance of	ST	[-]	[0.05-0.5]	Uniform
roller shade Material reflectance of roller shade	SR	[-]	[0.05-0.5]	Uniform

2.5 Performance assessment criteria

We calculated the energy consumptions for cooling, heating, lighting, fans, and equipments, as well as the total energy consumptions for all simulated cases, in this study. However, total energy and lighting energy consumptions were used in the analysis because these two factors are heavily weighted in the decision-making process for building design parameters. A useful daylight illuminance (UDI) and shading deployed time fraction (SDTF) were used to assess indoor visual performance in all simulated scenarios. A UDI of 100-2000lux was first proposed by Mardaljevic and coworkers[34]. The UDI was further classified into three bins[35]: i) 100-500 lux, ii) 500-1000 lux, and iii) 1000-2000 lux. Only the first bin's results are presented in this study because the variation in the values of these bins adequately explains the impact of daylight on lighting energy consumption. Moreover, illuminance values greater than 500 lux completely eliminate the use of artificial light. The results presented for glare exceeded time also help to understand the effect of excessive illuminance, which causes glare.

3. RESULTS

Table 3 and Fig 3, show the results for uncertainty analysis.

Table	3	Mean,	standard	deviation	and	coefficient
variation fo	or p	erforma	nce parame	eters		

	μ	σ	υ
HVAC energy			
consumption Indoor lighting	116.58	39.34	33.75
energy			
consumption	27.85	12.55	45.06
UDI			
(100-500)	37.2	21.67	58.25
Glare			
exceeded time			
fraction	22.36	19.66	87.92



Fig. 3. Probability distribution of energy and indoor visual performance of south oriented glazed façade office

Further, the sensitivity indices estimated in the analysts are shown in Fig., which clearly highlights the most influential design parameters. The effect of variation in values of most influential design parameters on the energy and indoor visual environment of south oriented glazed façade office are depicted in the Figs. 5 & 6.



Fig. 4. First-order and total-effect sensitivity indices for different performance parameters



Fig. 5. Variation of energy and indoor visual performance parameters with different glazing g types in south glazed façade office



Fig. 6. Effect of shade transmittance, aspect ratio of the room and WWR on the energy and indoor visual performance of south oriented glazed façade office

4. **DISCUSSION**

The statistics in the Table 3 and probability density curves for energy consumptions in HVAC and indoor lighting, UDI and Glare exceeded time indicate a significant dispersion in the performance results on changing the design parameters values. The high value of the variation coefficient and rightly skewed energy consumption curves and left skewed glare exceeded indicate high uncertainty time curve in the performances. However, the results in Table 3 and Fig. 3 unable to inform about the parameters that play a major role in the arose uncertainty. Therefore, sensitivity analysis has been performed for the same input parameters. The results of the sensitivity analysis are shown in Fig.4, which clearly highlights the major influencing parameters in terms of first-order and totaleffect sensitivity indices for energy and indoor visual performance indicators. Both indices show, that the WWR, Gt, ASR are major influencing parameters that regulate the HVAC energy consumption in the buildings. The total-effect index shows Ar, Aw, Af and SR put low influence but almost equal (3-5%) in the HVAC energy consumption. Further, WWR, ST, Aw, Gt and ASR are the artificial indoor lighting controlling parameters as highlighted by both sensitivity indices. The UDI is mainly regulated by the WWR, ASR, ST and Gt as indicated by first-order index. However, total -effect index analysis

shows that ST is more influential than ASR and Aw, Af also play a role in UDI access to indoor. Further, the first-order and total-effect indices demonstrate that glare is majorly regulated by ST, Gt, WWR and Aw. Therefore, values of these major influencing parameters need to select carefully in order to develop energy efficient and indoor visually comfortable office buildings. The random or inappropriate value of any of these parameter would lead to highly inefficient design.

Further, Figs. 5 and 6 show the variation in the performance parameters with significant design parameters. From fig.5, it is clear that the performance of the buildings significantly varies with the values of design parameters. The HVAC and lighting energy consumption distributed in narrow ranges for glazing type G and B respectively. However, for glazing A the values are distributed in broader range and skewed to right that indicate inefficiency in the design. Moreover, UDI values are highly skewed toward right and distributed in narrow range for glazing H, such distribution is highly desirable for UDI. The higher UDI indicates lower requirement of artificial lighting use. The exceeded glare time fraction is distributed in very narrow range for glazing type I indicating less requirement of shade deployment but may increase the artificial lighting. The glazing I and G may be more acceptable option over other as they offer lower HVAC energy requirement, high UDI values and comparatively less glare exceeded time. Further, Fig. 6 indicates that lower values of WWR are highly desirable from the HVAC energy consumption point of view also appropriate for indoor visual performance. Lower value of shade transmittance seems to be good for indoor visual performance but may increase the artificial lighting use. However, random distributions of performance parameters over a range of design parameters clearly indicate dependency of performance of building more than one value. Therefore, selection of the design parameters must be done prudently.

5. CONCLUSIONS

The variation coefficients for HVAC & indoor lighting consumptions, UDI and glare exceeded time fraction have been estimated 33.75, 45.06, 58.25 and 87.92 respectively, which indicate large dispersion in the performance parameters. Further, sensitivity analysis yielded WWR, Gt and ASR as most influencing design parameters, from the HAVC energy consumption viewpoint, for south glazed façade office buildings. For lighting energy performance, ST and Aw are additional significant design parameters. Moreover, UDI is identified to be regulated mainly by WWR, ASR, ST and Gt. For discomfort glare, ST, Gt, WWR and Aw are identified most influential design parameters. The variation of performance parameters with design parameters range demonstrates that prudential selection of the design parameters values is required.

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REFERENCES

[1] R. Singh and V.V.N. Kishore, Introduction to Energy-Efficient Building Development and Sustainability, in: Amritanshu Shukla and Atul Sharma (Ed.), Sustainability through Energy-Efficient Buildings, 1st ed., CRC Press, 2018: pp. 1–31.

[2] IPCC, Climate change 2014: Synthesis report, Contribution of working groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change, in Core Writing Team: R.K. Pachauri and L.A. Meyer (Ed.)., IPCC, Geneva, Switzerland, 2014.

[3] A. Tulsyan, S. Dhaka, J. Mathur, J.V. Yadav, Potential of energy savings through implementation of Energy Conservation Building Code in Jaipur city, India, Energy and Buildings. 58 (2013) 123–130. doi:10.1016/j.enbuild.2012.11.015.

[4] N. Patel, D. Buddhi, Analysis on Energy-Efficient HVAC System for Buildings BT - Recent Trends in Thermal Engineering, in: R. Kumar, A.K. Pandey, R.K. Sharma, G. Norkey (Eds.), Springer Singapore, Singapore, 2022: pp. 213–218.

[5] A. Kumar, S. Sharma, N. Goyal, A. Singh, X. Cheng, P. Singh, Secure and energy-efficient smart building architecture with emerging technology IoT, Computer Communications. 176 (2021) 207–217. doi:https://doi.org/10.1016/j.comcom.2021.06.003.

[6] R.R.J. Al Doury, T.K. Salem, I.T. Nazzal, R. Kumar, M. Sadeghzadeh, A novel developed method to study the energy/exergy flows of buildings compared to the traditional method, Journal of Thermal Analysis and Calorimetry. 145 (2021) 1151–1161. doi:10.1007/s10973-020-10203-1.

[7] A.H. Wolfgang Feist, Jürgen Schnieders , Viktor Dorer, Parametric study of the impact of window attachments on air conditioning energy consumption, Energy and Buildings. 37 (2005) 1186–1203.

[8] T. Ihara, S. Grynning, T. Gao, A. Gustavsen, B.P. Jelle, Impact of convection on thermal performance of aerogel granulate glazing systems, Energy and Buildings. 165-173.

88

(2015) doi:https://doi.org/10.1016/j.enbuild.2014.12.001.

[9] J. Xamán, Y. Olazo-Gómez, Y. Chávez, J.F. Hinojosa, I. Hernández-Pérez, ١. Hernández-López, et al., Computational fluid dynamics for thermal evaluation of a room with a double glazing window with a solar

control film, Renewable Energy. 94 (2016) 237-250.

doi:https://doi.org/10.1016/j.renene.2016.03.055.

[10] M. Arıcı, H. Karabay, M. Kan, Flow and heat transfer in double, triple and quadruple pane windows, Energy and Buildings. 86 (2015) 394-402. doi:https://doi.org/10.1016/j.enbuild.2014.10.043.

[11] J. Xamán, C. Pérez-Nucamendi, J. Arce, J. Hinojosa, G. Álvarez, I. Zavala-Guillén, Thermal analysis for a double pane window with a solar control film for using in cold and warm climates, Energy and Buildings. 76 (2014)429-439.

doi:https://doi.org/10.1016/j.enbuild.2014.03.015.

[12] I. Konstantzos, A. Tzempelikos, Y. Chan, Experimental and simulation analysis of daylight glare probability in of fi ces with dynamic window shades, Building and Environment. 87 (2015) 244–254. doi:10.1016/j.buildenv.2015.02.007.

[13] R. Singh, I.J. Lazarus, Energy and daylighting performances of highly glazed buildings, in: 14th International Conference of IBPSA - Building Simulation 2015, BS 2015, Conference Proceedings, 2015.

[14] Y.-C. Chan, A. Tzempelikos, I. Konstantzos, A systematic method for selecting roller shade properties for glare protection, Energy and Buildings. 92 (2015) 81-94. doi:10.1016/j.enbuild.2015.01.057.

[15] R. Singh, I.J. Lazarus, V.V.N. Kishore, Effect of internal woven roller shade and glazing on the energy and daylighting performances of an office building in the cold climate of Shillong, Applied Energy. 159 (2015) 317-333. doi:10.1016/j.apenergy.2015.09.009.

[16] H. Shen, A. Tzempelikos, Sensitivity analysis on daylighting and energy performance of perimeter offices with automated shading, Building and Environment. 59 (2013) 303-314. doi:10.1016/j.buildenv.2012.08.028.

[17] W. Tian, A review of sensitivity analysis methods in building energy analysis, Renewable and Sustainable Energy Reviews. 20 (2013) 411-419. doi:10.1016/j.rser.2012.12.014.

[18] F. Branger, L.-G. Giraudet, C. Guivarch, P. Quirion, Global sensitivity analysis of an energy-economy model of the residential building sector, Environmental Modelling & Software. 70 (2015) 45-54. doi:10.1016/j.envsoft.2015.03.021.

[19] F. Encinas, A. De Herde, Sensitivity analysis in building performance simulation for summer comfort assessment of apartments from the real estate market, Buildings. Energy and 65 (2013) 55-65. doi:10.1016/j.enbuild.2013.05.047.

[20] G. Han, J. Srebric, Comparison of survey and numerical sensitivity analysis results to assess the role of life cycle analyses from building designers' perspectives, Energy and Buildings. 108 (2015) 463-469. doi:10.1016/j.enbuild.2015.09.017.

[21] T.L. Hemsath, K. Alagheband Bandhosseini, Sensitivity analysis evaluating basic building geometry's effect on energy use, Renewable Energy. 76 (2015) 526-538. doi:10.1016/j.renene.2014.11.044.

[22] Y. Sun, Sensitivity analysis of macro-parameters in the system design of net zero energy building, Energy and Buildings. (2015) 464-477. 86 doi:10.1016/j.enbuild.2014.10.031.

[23] C.W. Mckay MD, Beckman RJ, A comparison of three methods of selecting values of input variables in the analysis of output from a computer code., Technometrics. 21 (1979) 239-245.

[24] R. Singh, I.J. Lazarus, V.V.N. Kishore, Uncertainty and sensitivity analyses of energy and visual performances of office building with external venetian blind shading in hot-dry climate, Applied Energy. 184 (2016) 155–170. doi:10.1016/j.apenergy.2016.10.007.

[25] JRC, European Commission Joint Research Center., 2008.

[26] http://www.ishrae.in/, (n.d.).

[27] EnergyPlus,

www.eere.energy.gov/buildings/energyplus, (2015).

[28] EnergyPlus, EnergyPlus Engineering Reference. The US Department of Energy, 2013.

[29] Y. Zhang, I. Korolija, Performing complex parametric simulations with jEPlus, SET2010-9th International Conference on Sustainable (2010).

[30] D.H.W. Li, K.L. Cheung, S.L. Wong, T.N.T. Lam, An analysis of energy-efficient light fittings and lighting controls, Applied Energy. 87 (2010) 558-567. doi:10.1016/j.apenergy.2009.07.002.

[31] Bureau of Energy Efficiency, Energy Conservation Building Code, 2017.

[32] R.G. Hopkinson, Glare from Daylighting in Buildings, Applied Ergonomics. 3 (1972) 206.

[33] A. Tzempelikos, H. Shen, Comparative control strategies for roller shades with respect to daylighting and energy performance, Building and Environment. 67 (2013) 179-192. doi:10.1016/j.buildenv.2013.05.016.

[34] J.M. A. Nabil, Useful daylight illuminances: a replacement for daylight factors, Energy and Buildings. 38 (2006) 905–913.

[35] H. Shen, A. Tzempelikos, Daylighting and energy analysis of private offices with automated interior roller shades, Solar Energy. 86 (2012) 681–704. doi:10.1016/j.solener.2011.11.016.