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Uncertainty and sensitivity analyses of energy and visual performances of office building with external venetian blind shading in hot-dry climate

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HIGHLIGHTS

- Various alternatives of glazing and venetian blind were simulated for office space.
- Daylighting and energy performances were assessed for each alternative.
- Large uncertainties were estimated in the energy consumptions and UDI values.
- Glazing design parameters were prioritised by performing sensitivity analysis.
- WWR, glazing type, blind orientation and slat angle were identified top in priority.

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ABSTRACT

Fenestration has become an integral part of the buildings and has a significant impact on the energy and indoor visual performances. Inappropriate design of the fenestration component may lead to low energy efficiency and visual discomfort as a result of high solar and thermal heat gains, excessive daylight and direct sunlight. External venetian blind has been identified as one of the effective shading devices for controlling the heat gains and daylight through fenestration. This study explores uncertainty and sensitivity analyses to identify and prioritize the most influencing parameters for designing glazed components that include external shading devices for office buildings. The study was performed for hot-dry climate of Jodhpur (Latitude 26° 180′N, longitude 73° 010′E) using EnergyPlus, a whole building energy simulation tool providing a large number of inputs for eight façade orientations. A total 150 and 845 data points (for each orientation) for input variables were generated using Hyper Cubic Sampling and extended FAST methods for uncertainty and sensitivity analyses respectively. Results indicated a large uncertainty in the lighting, HVAC, source energy consumptions and useful daylight illuminance (UDI). The estimated coefficients of variation were highest (up to 106%) for UDI, followed by lighting energy (up to 45%) and HVAC energy use (around 33%). The sensitivity analysis identified window to wall ratio, glazing type, blind type (orientation of slats) and slat angle as highly influencing factors for energy and visual performances regardless of façade orientation. The other influencing parameters are interior surface absorptance of wall and front surface solar reflectance of blind slat; however, the magnitude of influence varied with façade orientation.

1. Introduction

Buildings consume significant energy (approximately 35% of global final energy consumption) and have a considerable energy saving potential [1]. In India, buildings demand about 30% of total electricity usage in the country [2]. Energy consumption characteristics of different types of buildings in different climatic zones need to be understood thoroughly in order to minimise energy use and associated greenhouse gas (GHG) emissions in the sector. A number of design parameters define the energy performance of buildings and need to be selected rationally. In general, the formulation of the decision making problem is difficult to elaborate and solve due to high complexity in designs of modern buildings [3]. Inappropriate values of design parameters, particularly in highly glazed buildings may lead to high energy consumption and indoor visual and thermal discomfort [4,5]. Glazed component is a point of

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attraction in modern architecture and its selection is crucial from the energy as well as indoor visual comfort points of view. Shading devices either internal, external or in between the glass, are commonly used with glazed components, and control solar heat gain, excessive daylight and sunlight, and privacy [6]. Venetian blind is one of the shading devices used for many years in buildings fenestration components. In recent years, improving energy and indoor visual performances have become primary focus in designing glazed components. The blind shading devices seem to be an attractive choice for building physicists and engineers [7–13] due to their capability to control solar heat and glare effectively if installed at external of the glazing [14]. A recent review discussed the energy implications of blind use, blind occlusion and rate of change, specific quantitative measures influencing user blind control, and user acceptance of automated blind control [15]. The blinds can be used in fixed or controllable mode. Meerbeek et al. [16] studied the behaviour and experience of users in 40 offices, which use automatically controlled exterior venetian blinds. They demonstrated a significant correlation between weather parameters and blind adjustments. Lee et al. [11] also demonstrated a significant energy saving potential by an automated venetian blind over static blind with the same dimmable electric lighting system in office building in Oakland, California. Oleskowicz-Popiel and Sobczak [17] estimated about 45% heat loss saving by external roller blind shade in night and 44% heat loss saving with double-glazing window of low emissivity coatings ($\varepsilon = 0.20$). Kurian et al. [18] estimated 20–80% of annual energy savings through blind and artificial lighting control over the base case of manual blind systems without daylighting control.

Despite extensive research in this area, a detailed and comprehensive study to make a rational choice of design parameters for glazed component with external venetian blind shading in hot-dry climate has probably not been cited yet, and is probably worth investigating, considering the harsh climate and consequent high demand for air conditioning. Both, energy performance and indoor visual comfort are highly sensitive to the design parameters. Therefore, the design parameters for glazed component must be selected prudently. In the literature, several approaches were developed to support building designers in the decision making process [3]. Uncertainty and sensitivity techniques were used in many scientific disciplines including chemical engineering [19], environmental impacts [19,20], water quality [21,22], renewable energy production [23,24], combustion mechanism [25], nuclear reliability [26] and buildings [27,28] appropriately and effectively to prioritize the design parameters. The Monte Carlo (MC) simulation is the most common technique for the uncertainty analysis, but several other sensitivity analysis methods, such as sampling base methods [29], Factorial method [30], Morris method [31], sequential bifurcation [32] and ANOVA method [3] were also cited in the literature. Saltelli et al. [33] described different local and global sensitivity analysis techniques. Recently, Tian [34] compiled a review on both types of methods and provided practical guidance based on the advantages and disadvantaged of different sensitivity analysis methods in assessing building thermal performance. The study indicates that both local and global sensitivity analysis approaches have been employed extensively in the field of building energy analysis, though the global approach is regarded a more reliable method. The disadvantage of using global methods is a high computational demand compared to local sensitivity analysis. In global methods, the information is collected for a subset of input variables in a wider domain by varying all the parameters and global sensitivity methods explore the whole search space of input variables [35]. In many research, sensitivity analysis was performed to study the building energy performance with different parameters and determined most influencing parameters [34–41]. Heiselberg et al. [42] identified lighting control as one of the two most important parameters out of 21 parameters that affect the energy consumption significantly. Recently, Mechri et al. [3] performed uncertainty and sensitivity analyses using Monte Carlo method with Latin Hypercube Sampling (MC-LHS) and the Analysis Of Variance-Fourier Amplitude (ANOVA) respectively. They identified envelope transparent surface ratio one of the significant parameters based on the first order index.

This study aims to perform uncertainty and sensitivity analyses to prioritize the most influencing design parameters for glazed components with external venetian blind shading in office buildings. The simulations were performed for Jodhpur location, a representative city of hot-dry climate, in India. The study used two steps strategy for continuous alternative solutions to reach the design choices for glazed façade with the external blind shading. In first step, Monte Carlo simulation was performed to assess the global range of uncertainty of the main output of the model we used. Due to incapability of the first step in determining the source of the uncertainties among the inputs, we are motivated to perform sensitivity analysis as a second step. In the second step sensitivity analysis was performed using a variance-based extended FAST method and the design parameters were prioritized based on first and total order indices. The approach is purely statistical and being used for few years [34]. The energy and indoor visual performances were assessed, using whole building energy simulation tool EnergyPlus, for eight different façades orientations (i.e. South, South-west, West, West-north, North, North-east, East and East-south). The first and total order indices were estimated for lighting, HVAC, total source energy consumptions and useful daylight illuminance for energy and indoor visual performances of the office room.

2. Methodology

2.1. Uncertainty analysis

This study uses the Latin Hypercube Sampling (LHS), which is suitable for stratified sampling and to achieve a better coverage all portions of a factor distribution by input values [43]. The range of each input factor is divided into l (l > 2) intervals of equal marginal probability, and within each interval one observation is made randomly. It was recommended, the number of executions (n) should not be less than 1.5 times of the number of factors [44]. The uncertainty of the output is presented by coefficient of variation (υ), which is a good indicator to evaluate the dispersion of the outputs. The coefficient of variation is a ratio of the standard deviation (σ) to the mean value (μ). The mean value and standard deviation are estimated as follows:

$$\mu = \frac{1}{n}\sum_{i=1}^{n} y_i \tag{1}$$

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(y_i - \mu)^2} \tag{2}$$

2.2. Sensitivity analysis

The variance based method is preferred for analysing complex building physics problems owing to strong capabilities of method to cope with non-linear and non-monotonic models. It also appreciates the interaction effects among input factors. In this study, the extended FAST method [45], which is neither linear nor monotonic, has been used to analyse the sensitivities of design variables of glazed component in office building for its energy and daylighting performances. The method is one of the most efficient variance based methods and it was evolved from the classic FAST method