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Effect of fenestration geometrical factors on building energy consumption and performance evaluation of a new external solar shading device in warm and humid climatic condition

Amrita Ghosh*, Subhasis Neogi

School of Energy Studies, Jadavpur University, Kolkata 700032, India

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ABSTRACT

Glazed facades are being increasingly used in modern buildings in order to improve the daylight availability in the interiors, offer better external views and also add to the architectural beauty of the building. However this increased usage of glazed facades is leading to higher solar gain inside the building which is becoming a major issue in hot climatic regions. External shadings are thus used to protect the buildings from direct solar radiation which cause high solar gain as well as discomfort due to glare. The present study summarizes the effect of geometrical factors like window to wall ratio (WWR) and window positioning on the heating, cooling and lighting energy consumption of a South facing building cell in warm and humid climate. The performances of different commonly used external solar shading devices have been compared. The study also proposes the design of an external shading device which, when compared with the existing shading designs, leads to reduction in annual energy consumption of the building. The simulations were carried out using building energy simulation program EnergyPlus for the warm and humid climate of Kolkata, India. In order to validate the applicability of the new shading in other locations experiencing similar climate, the performance of the proposed shading was also evaluated for two other locations- Naples in USA and Hanoi in Vietnam. In both of these cases the new shading offered better performance than the other existing shading designs.

1. Introduction

As per statistics, buildings around the world represent 32% of the total final energy consumption (Abanda and Byers, 2016). In India, buildings account for 35% of the total final energy consumption (www.pnnl.gov). Modern buildings are often characterised by large windows of glazing materials. With the increased usage of glazed areas the heat gain in the buildings also increase leading to larger cooling load. This becomes a matter of concern in summer season especially in cooling dominant regions. Thus shadings are essential as integral parts of fenestration systems in order to reduce the cooling load of the building as well as discomfort due to glare. Shadings may be installed internally or externally, may be fixed or movable, which again may be manual or automated. Several research studies evaluate the performances of shading devices. External shadings intercept the solar radiation before reaching the building interior. Whereas, if shadings are installed internally the solar radiation incident on the glazing system get absorbed and is then re-radiated inwards causing the cooling load to increase.

The performances of indoor and outdoor shading devices have been compared by Atzeri et al. (2014) in terms of thermal and visual comfort and overall energy use. Simulations using EnergyPlus showed that use of shades improved thermal comfort, however, internal shades could cause an increase in energy demand with particular orientations and glazing types. A number of shading strategies for north and south facing office cubicles with varying floor area, window sizes and parameters were simulated by Grynning et al. (2014). The simulations were carried out using COMFEN, which is a graphical user interface tool of EnergyPlus. The study found that automatically controlled shading devices were able to reduce energy demands with proper shading strategy. It also pointed that four-pane glazing will always be beneficial compared to two and three-pane glazing systems. The impact of shading device type, properties and control on building cooling and lighting energy demand was analysed using an exterior roller shade (Tzempelikos and Athienitis, 2007). The results showed that an integrated approach for automatic control of motorized shading along with controllable electric lighting systems can bring substantial reduction in energy demand for cooling and lighting depending on the climatic conditions and orientations. The effect of vertical and horizontal louver shading devices applied to different building facades for

* Corresponding author.
E-mail address: amritaghosh1986@gmail.com (A. Ghosh).

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different locations were evaluated using TRNSYS software (Palmero-Marrero and Oliveira, 2010). When compared to building without shading devices, the louver shadings resulted in significant energy saving and comfortable indoor thermal conditions. Ebrahimpour and Maerefat (2011) evaluated the effect of advanced glazing and overhangs on the transmitted solar radiation for residential buildings in Tehran. The annual energy use was predicted using simulation program EnergyPlus. From the results the best combination of overhangs, side fins and glazings for each window direction was determined. The effect of a series of shading devices applied to a highly glazed office building in Southern Italy was evaluated using EnergyPlus (Evola et al., 2017). Twenty-nine different types of shading devices including louvers, blinds, curtains, etc. were considered to identify the most suitable solution. The effects of solar shading strategies on thermal comfort were also evaluated for low income tropical housing in Uganda using EnergyPlus (Hashemi and Khatami, 2017). Results revealed that the shading strategies like curtains and overhangs were most effective during the hottest period of the year.

Li et al. (2016) evaluated the performance of building integrated solar thermal shading system on building energy consumption and daylight levels through simulations. The louvers were installed horizontally on the south facade and vertically on the east and west facades. The shading system reduced building energy consumption and improved interior useful daylight level. Hong et al. (2017) conducted the non linearity analysis of the shading effect on the technical-economic performance of building-integrated photovoltaic blind (BIPB). The findings can be used to define the design specifications of the BIPB before its implementation. The performance of electrochromic glazing and that of fixed external shading devices to prevent heat gains were compared by Aldawoud (2013). A typical office building was modelled using DesignBuilder software, a graphical interface for EnergyPlus, and the results showed that the electrochromic glazing provided the best performance in reducing solar heat gain. An experimental configuration of external shading device was designed and evaluated by Kim et al. (2012). Simulations carried out in energy analysis program IES_VE showed that the experimental shadings offered more efficient performance than other shading devices. Impact of louver shading properties like material, length of slats, distance between slats, etc on energy consumption, thermal comfort and daylighting were analysed by Stazi et al. (2014). Dynamic thermal simulations were carried out using EnergyPlus. An overview of the effects of shading devices on building thermal and lighting performances were analysed by Bellia et al. (2014). The performance of internal woven roller shades was also assessed in terms of energy efficiency and visual comfort using EnergyPlus by Singh et al. (2015).

Movable shading devices are more advantageous than fixed shading devices since they can be controlled effectively to block the direct solar radiation in summer and allow them in winter. However, manually operated movable shading devices depend largely on the occupants' behaviour for efficient functioning (O'Brien et al., 2013). In addition to thermal and visual preferences, manual adjustment of solar shades depends on the occupants' privacy, personal values, and even emotional conditions (Yao, 2014). This can be avoided by using automated shading devices. Firlag et al. (2015) analysed the effect of control algorithms for dynamic windows. Results showed that the use of automated shadings reduced the site energy consumption in the range of 11.6–13.0%. Additional energy consumption due to motor, sensors, etc was not much. However, the system leads to higher price, higher probability of failure and use of additional electrical energy. User acceptance is another problem in case of automatic control of shading.

Thermal and daylighting performances of several popular energy efficient window designs were simulated by Huang et al. (2014). Different types of shading devices, their properties, operations, performances and energy saving potential in different climatic regions were also evaluated in several studies (Kirimtat et al., 2016; Bellia et al., 2013; Cho et al., 2014; Nielsen et al., 2011; Al-Tamimi and Fadzil, 2011). However, proposition of new designs of shading that can effectively reduce the overall energy consumption is very rare.

The present study focuses on the effect of geometrical factors like window to wall ratio (WWR) and window positioning on the heating, cooling and lighting energy consumption of the building. In addition to that, a new external fixed shading design has been proposed and its performance has been compared with the existing commonly used external shading devices in warm and humid climate condition.

2. Methodology

2.1. Simulation tool

Study by Kirimtat et al. (2016) showed that simulation tools are significant in identifying the most suitable shading configuration for a particular building. Shading performance can be evaluated by a number of building energy simulation programs like EnergyPlus, DOE-2, IES_VE, TRNSYS, ESP-r, etc. However, the review study of simulation modelling for shading devices revealed that amongst the different tools EnergyPlus is the most widely used and the oldest one. Moreover, the tool is capable of simulating complex models accurately and in details. Thus, the present simulations have been carried out in EnergyPlus simulation software. EnergyPlus is a whole building energy simulation program which combines the best features of BLAST and DOE-2 programs (Crawley et al., 2001). It includes essential features like advanced fenestration models including controllable window blinds, heat balance-based solution of radiant and convective effects that produce surface temperatures, thermal comfort and condensation calculations, illuminance and glare calculations for reporting visual comfort and driving lighting controls, etc (EnergyPlus Engineering Reference, 2014). These features made the program suitable for the present study.

2.2. Location and climate

The present study was simulated using the weather data of Kolkata in India located at a latitude of 22.57°N and a longitude of 88.37°E (The Indian Astronomical Ephemeris, 1999). Kolkata, the capital city of the state of West Bengal, is situated in the Gangetic delta and nearer to the east coast of India.

Kolkata experiences a warm and humid climate (Energy Conservation Building Code User Guide, 2009). The long-term average of global irradiance at Kolkata is 191.4 $W\,m^{-2}$. The diffuse component accounts for 50% of the global irradiance (www.indiaenvironmentportal.org.in, 2010). Kolkata experiences an annual mean temperature of about 27 °C. The summer is hot and humid with mean temperatures about 30 °C but during dry spells the maximum temperatures often exceeds 40 °C during the months of April and May. Effective winter tends to last for only about two and a half months, with seasonal lows dipping to 12 °C between December and January (www.imdkolkata.gov.in, 2017).

Weather data of Kolkata provided by Indian Society of Heating, Refrigerating and Air-Conditioning Engineers (ISHRAE) was used to perform the simulations in the present work.

2.3. Building simulation

2.3.1. Building model description

An air conditioned building cell of dimension 5 m × 5 m × 3 m had been chosen for the present study. The South facing wall of the building had a glazed window. The detailed description of the building materials are provided in Table 1. The thermal properties of the materials were derived from ASHRAE Handbooks (1993, 2009). The thermal and optical properties of glass were derived from Pilkington Optifloat brochure (www.pilkington.com, 2017).