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Effect of internal woven roller shade and glazing on the energy and daylighting performances of an office building in the cold climate of Shillong

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HIGHLIGHTS

- We simulated a number of glazing and interior roller shade alternatives.
- Office room has been simulated for three window-to-wall ratios in a cold climate.
- Daylighting and energy performances have been assessed for each alternative.
- Maximum energy savings have been estimated in the office with a 30% glazed area.
- Energy saving decreases for larger glazed area and fabric transmittance.

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ABSTRACT

The energy and visual performances of the façades are defined by many parameters including façade size, properties of glazings and shadings, and their arrangements as well as control strategies. In this study, a number of combinations of internal woven roller shades and four double glazings have been proposed and assessed in integrated manner in order to improve the energy efficiency and visual comfort in new or existing office buildings. Office rooms facing south, east, north and west have been simulated for cold climate, by varying glazed areas and proposed glazing and shading alternatives. Results have been calculated, compared and analyzed in terms of the energy consumptions, energy saving potentials, daylight autonomy, useful daylight illuminance and discomfort glare free time, for each of the combinations. Simulation results show that the choice of glazing and shading alternatives can have substantial impact on energy and visual performances of the office space. Regardless of façade orientation, the maximum energy saving is achieved for a window-to-wall ratio (WWR) of 30%. Saving potential decreases significantly for larger glazed area and for each façade orientation. For all façade orientations and glazed areas (except for 30% WWR in the north wall), a bare low-e coated double glazing ($U = 1.616$ W/m^2 K, SHGC = 0.209, $\tau_v = 0.301$) is found to be the most energy efficient choice. For 30% north glazing, the energy efficiency can be maximized with a different bare low-e coated double glazing ($U = 1.628$ W/m^2 K, SHGC = 0.370, $\tau_v = 0.581$). Moreover, glare affected time, daylight autonomy and useful daylight illuminance in the office spaces with these glazing choices are estimated $\geqslant$50%, between 46% and 99% and in the range of 53–88% respectively. Also, the visual comfort can further be improved just by deploying even a highly transparent fabric (50% transmittance, 20% reflectance, 45% average openness) as an interior roller shade with these glazing choices.

1. Introduction

Worldwide, buildings consume annually about 30–40% of primary energy in construction, operation and maintenance [1]. Particularly, Indian buildings demand about 30% of total electricity usage in the country [2]. New trend of extensive use of glazed façades, to project a 'hi-tech' sophisticated look, has been observed in the modern office buildings. The use of excessive glass in the façades often leads to high cooling and heating demands as well as discomfort glare [3–5]. However, larger glazed façade provides a broader view to outdoor and also higher access to daylight, which results in lower demand of artificial lighting [6–8]. Therefore,

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energy efficiency and indoor visual comfort have become increasingly important in façade designs. In cold climates where heating is mostly required, solar radiation is desirable into the building, however, excessive solar gain may lead to high cooling demand in the cold climates too [9]. Moreover, access to direct sun and excessive daylight, which are main sources of discomfort glare, need to be addressed suitably in all climatic conditions. The energy and visual performances of the façade are defined by many parameters: for example façade size, properties of glazings and shadings, and their arrangements as well as control strategies [10–13]. Thus, various glazing and shading options have been proposed in the recent literature to regulate thermal and visual environments in the buildings [14–18]. As combination of glazing and solar shading devices plays a vital role in providing overall comfort in the office space and hence needs to be assessed in an integrated manner [19]. 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 [16,20–22]. Automatic controlled dynamic shading with controllable electric lightings leads to substantial energy savings in cooling, heating and lighting, but a significant variation with climatic conditions and façade orientations was observed [23]. Moreover, the automatic dynamic shadings are generally preferred over fixed shadings because of their better energy and visual performance as well as easier operation for effective shading conditions [20,24]. A comprehensive global uncertainty and sensitivity analysis shows that shade transmittance and glazing type are two major factors that have substantial impact on the energy and daylighting performances in the office space [22].

1.1. Study objectives

Focusing on cold climate, internal woven roller shadings and four double glazings have been proposed and assessed in an integrated manner in order to improve both energy efficiency and the visual comfort in office buildings. Internal shading devices can be more appropriate and efficient options to reduce/eliminate discomfort glare by blocking direct sun and excessive daylight, while allowing solar heat inside, which is desirable in the cold climate or during winter [9]. A number of studies on the energy and visual performances, in the buildings, considering different types of internal shading devices have been pursued [14,17,21,22,25–29]. Some researchers have focused their studies on the interior woven roller type of shading. Recently, Jian Yao [30] investigated the driving factor of control behavior of manual solar shades in a typical office building with internal roller shades in hot summer and cold winter zones. His study showed that manually adjusted solar shades can perform more energy efficiently than clear-pane windows while only external shades perform better than regularly used LOW-E windows. Shen and Tzempelikos [17,22] have investigated the impact of internal roller shades, on the energy consumption and indoor visual comfort by varying window to wall ratios (WWRs) and glazing type. Moreover, four different shading control strategies for interior roller shades of different shading properties to maximize daylight utilization, minimize energy consumption and to reduce the risk of visual discomfort were also investigated [17]. The effect of glazing and interior roller shade properties on the balance between daylighting benefits and energy demands has also been assessed previously considering a radiation based shading control strategy and different window sizes [21]. It was seen that transmittance of roller shades considered in the literature is limited to a maximum value of 0.25. Moreover, a glare based shading control has also been neglected. It may be possible that the use of interior woven roller shade with a little higher transmittance can lead to even better indoor visual comfort and a higher energy saving in the cold climates, particularly when used in the north façade and also in other façades if a low transmittance glass is used and direct sun is mainly source of glare.

The purpose of this study is to investigate the effect of extended values of shade transmittance on energy and visual performances of the office building. The study has been conducted for Shillong (Latitude 25° 34′N, Longitude 91° 52′E), which can be considered as representative of cold climates in India. Simulations of a number of glazing and internal roller shade combinations have been performed for south, west, north and east facing offices with varying window size, properties of glazing and shading devices. The aim of the study is to optimize the properties of glazing and internal roller woven shade in order to improve overall energy performance and indoor visual comfort. Results have been calculated, compared and analyzed in terms of the energy consumptions, energy saving potentials over similar base case office (room with 30% glazed area and clear single glazing), daylight autonomy, useful daylight illuminance and discomfort glare free time, for each of the combinations.

2. Methodology

2.1. Simulation tool

EnergyPlus, a whole building energy simulation tool of the DOE, promoted by the Building and Technology Program of the Energy Efficiency and Renewable Energy Office [31] has been used in the present study. The tool has been accepted widely by the building energy analysis community to simulate different types of buildings [32]. Moreover, several essential features such as solar irradiance, illuminance under different sky conditions, advanced fenestration systems, blind controls, indoor illuminance maps, and artificial lighting controls and integration capability of effect of daylighting in the total energy demand made the tool suitable for this study [33,34]. The EnergyPlus uses the split flux method to calculate the daylight at the interior after reflection from the interior surfaces [35]. Despite some inaccuracies in the daylight results calculated by the split flux method compared to Radiance/Daysim programme [36], the method can still be used in this study as a great similarity was found between the internal illuminance obtained by the two programmes with a maximum difference of 20% [37]. Also, the external illuminance in both the EnergyPlus and the Daysim/Radiance programmes is estimated using the same sky model developed by Perez et al. [38]. Moreover, the EnergyPlus uses the integral approach for performing the daylighting and thermal simulations. Hence, despite some limitations of the EnergyPlus, it is still a good tool to use in order to perform simulations to evaluate the impact of the glazed façade on the energy and daylighting performances of the office room.

2.2. Climate

Shillong is the capital of Meghalaya, one of the smallest states in India. The city is located (latitude at 25° 34′N and longitude at 91° 52′E) at an average altitude of 1500 m above sea level. Climate of the city has been classified as cold climate by national building code of India [39]. Under Köppen's climate classification, the city features a subtropical highland climate (Cwb) [40]. It has a temperate climate with winter rains and a 7–8 month long dry season. January is the coldest month and August is the hottest one. Mean, maximal and minimal temperatures during January are 6.8 °C, 17.5 °C and 0.0 °C respectively. For August, mean, maximal and minimal temperatures are 19.3 °C, 27.0 °C and 14.1 °C respectively (see Fig. 1). The mean monthly global solar radiation, on a horizontal surface, for January is 117.67 Wh/m^2; and for August, this value