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ORIGINAL ARTICLE

Performance of skylight illuminance inside a dome shaped adobe house under composite climate at New Delhi (India): A typical zero energy passive house

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Abstract This paper presents annual experimental performance of pyramid shaped skylight for daylighting of a dome shaped adobe house located at solar energy park in New Delhi (India). This approach of single story dome shaped building with skylight is more useful for rural and semi-urban sectors for both office and residential buildings reducing artificial lighting energy consumption. The hourly measured data of inside and outside illuminance for three different working surface levels inside the existing rooms are presented for each month of the year. The embodied energy payback time of the skylight is also determined on the basis of lighting energy saving potential.

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1. Introduction

Daylight is a gift of nature reported in the year 1966 by Hopkinson et al. [1]. Daylight is a natural, free and non-depleted resource coming from the sun. There are two components of daylight: sunlight (the direct beam), and skylight (the diffuse light scattered by the earth's atmosphere) reported by Joshi et al. [2] and Muneer [3]. The use of daylight has been a vital element in architecture throughout the history because it could create a pleasant visual environment. Generally speaking, the skylight serves as a primary source for interior daylighting design. Whereas the direct sunlight is usually avoided due to its magnitude and directional nature which brings visual discomfort (or glare) to indoor occupants with additional solar heat gain [1]. Daylighting allows a more flexible building facade design strategy and enhances a more energy efficient and greener building development with lighting energy savings reported by Li and Lam [4]. The amount of indoor daylight illuminance depends upon the size and position of a window/atria/skylight and the sky luminance distributions. Integrating daylight with

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Nomenclature

A_f	floor area (m^2)
A_g	total area of glazing (m^2)
A_s	working surface area (m^2)
A_t	total area of room surfaces (m^2)
B_F	ballast factor or efficiency, $0 \leqslant B_F \leqslant 1$
C	correction factor for glazing due to dust, poor maintenance, etc., $0.5 \leqslant C \leqslant 0.9$
DF	percentage daylight factor (%)
E	total lighting energy consumption (kW h)
H	total heat gain from artificial lighting (W/m^2)
h	vertical distance of skylight from the surface to be illuminated (m)
I_d	diffuse solar radiation (W/m^2)
I_g	global solar radiation (W/m^2)
L_i	illuminance level inside the room on horizontal working surface (Lux or lm/m^2)
L_o	outside diffuse illuminance on horizontal surface (Lux or lm/m^2)
M_F	maintenance factor, $0 \leqslant M_F \leqslant 1$
N	number of hours of operation per day (h/day)
O_F	orientation factor for glazing, $0.97 \leqslant O_F \leqslant 1.55$
P	total lighting power (W)
R	average reflectance of all room-surfaces, $0 \leqslant R \leqslant 1$
T_r	room air temperature (°C)
U_F	utilization factor, $0 \leqslant U_F \leqslant 1$

Symbols

ε	light source luminous efficacy (lm/W)
$\varnothing$	total luminous flux (lumen or lm)
τ	transmittance of glazing $0 \leqslant \tau \leqslant 1$
θ	vertical angle of visible sky from horizon (degrees)

architectural design is of great interest to those who are with the issues of energy and environment and visual comfort and health.

Physically, daylight is part of the electromagnetic radiation in the visible spectrum (0.39–0.78 μm). It was the prevalent lighting source in the buildings prior to the development of the electric lamp. With a boom in the economy, people stressed on the quality of a stable and comfortable indoor environment regardless of any external conditions. Thus, the use of active daylight declined and was replaced by electric lamps which not only consume electricity for lighting but also generates heat. This causes increase in the cooling load in summer especially in subtropical region. This phenomenon accelerates the rate of energy consumption in buildings for lighting as well as cooling.

Daylighting is one of the solutions to reduce the environmental impact on the climate as reported by Smith [5]. The global climate is changing and will continue to change because of the increased concentration of greenhouse gases in the atmosphere. The greenhouse gases mainly emitted are carbon dioxide produced during energy consumption activities from coal thermal power plants. In general, lighting and air-conditioning in office buildings account for about 80% of the total building electricity consumption as reported by Li and Lam [4].

Good daylighting design can reduce both the lighting energy consumption and the cooling load due to heat dissipation from electric lighting as reported by Hunt [6]. There are number of studies which had pointed out that effective daylighting can reduce energy demand in non-domestic buildings. It has been reported that, in daylight corridors, photoelectric lighting controls can give remarkable energy savings [4].

Physiologically, daylight is an effective stimulant to the human visual system and the human circadian system. The response of eyes to the light spectrum is determined by the spectral sensitivity of the photoreceptors (380–780 nm). The peak sensitivity of the human eye is about 555 nm. The quality of daylight is the light source that most closely matches with human visual response. Daylight is characterized by high illuminance which can provide an excellence of its spectrum for color discrimination and color rendering. These two properties give daylight a potential to produce good vision. Architectural designs are often enhanced using daylight by building designers and architects.

Daylighting is an important issue in modern architecture affecting the functional arrangement of spaces, occupant comfort (visual and thermal), structure and energy use in building. Daylight is considered as the best source of light for good color rendering and its quality is the one light source that most closely matches human visual response. It gives a sense of cheeriness and brightness that can have a significant positive impact on the people as reported by Muneer [3]. The term outside luminance ($lumen/m^2$) refer to the instantaneous incident energy contained within the visible part of the solar radiation spectrum (0.39–0.78 μm) [3]. The amount of daylight penetrating a building is mainly through window openings which provide the dual function not only of admitting light for indoor environment with a more attractive and pleasing atmosphere, but also allowing people to maintain visual contact with the outside world. People desire good natural lighting in their living environments [3].

The energy consumption of lighting in buildings is a major contributor to carbon emissions, often estimated as 20–40% of the total building energy consumption as reported by BRE energy consumption guide [7] and Guide [8]. Reducing lighting energy consumption using controls for the optimized configuration of daylight supplemented electrical lights was well-documented by Greenup et al. [9], Reinhart [10] and Li and Lam [4], with particular interest on the effect of thermal loads reported by Franzetti et al. [11]. However, the more advanced and material-based solutions were reported by Smith [5] and Tong et al. [12] for optimizing daylight. They provide innovative solutions for reducing lighting-energy consumptions. An approach for estimating the carbon emissions associated with office lighting with a daylight contribution was reported by Jenkins and Newborough [13].

The daylighting is one of the basic components of passive solar building design and has been the center of much attention in recent years for lighting energy conservation in buildings. The energy crisis in the world has provided the motive for making best use of daylight in buildings for artificial light-

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