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ScienceDirect

Solar Energy 122 (2015) 834–846

SOLAR ENERGY

www.elsevier.com/locate/solener

Dynamic analysis of daylight metrics and energy saving for rooftop window integrated flat roof structure of building

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Received 16 April 2015; received in revised form 2 October 2015; accepted 5 October 2015
Available online 10 November 2015

Communicated by: Associate Editor J.-L. Scartezzini

Abstract

In the present paper, the earlier developed model for wall window has been modified for rooftop window. The model has been validated for dynamic behavior by considering the hourly measured both direct and diffuse components of the sunlight and skylight under clear sky conditions. It can be used to predict the Daylight Illuminance Ratio (DIR) and daylight at a given point in living space. The annual energy saving from rooftop window has been estimated for different climatic locations in India. It has been observed that highest DIR was always along the line normal to the rooftop window and decreases as we go away from the normal line in all directions. It was found that, for increasing aperture to floor area ratio, the energy saving potential increases. The minimum annual energy saving was found to be 65.74 kW h/m^2 for Srinagar whereas the maximum was 77.10 kW h/m^2 for Bengaluru. The monthly average value of model exponent (p) has been computed as 1.25. Hence, the present model can be used to design building for optimum daylighting at a given point inside living space.

Keywords: Daylight illuminance ratio; Daylight metrics; Energy saving; CO_2 mitigation; Carbon credit

1. Introduction

An artificial lighting system and air-conditioning in buildings are widely used to generate a visually comfortable and thermally built environment. It contributes to most of the energy consumption in the building (Li et al., 2006, 2008, 2009). In the worldwide background of continuous depletion and demand of fossil fuels, there is a strong need to reduce the energy consumption in building (Li et al., 2010a,b). As an alternative to artificial lighting, the proper daylight is used in the building (Li et al., 2010a,b; Darula et al., 2010). Use of daylight inside the building enhances the occupant's comfort (visual and thermal) and gives better physical health. It also improves the indoor environment, light quality and energy efficiency (Littlefair, 1992; Chow et al., 2013). Daylighting permits an additional flexible building facade design strategy for more energy-efficient building. The illuminance level received inside building depends upon the size, position and orientation of window/atria/skylight and the sky illuminance distributions (Li and Lam, 2003a,b; Ochoa et al., 2012). The daylight incident on a vertical surface is the sum of direct-beam, sky-diffuse and externally reflected components (CIE, 1994).

The major energy consumption for the fully air-conditioned office buildings is 20–30% of the total electricity whereas it is 10% for the residential buildings (Galasiu

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http://dx.doi.org/10.1016/j.solener.2015.10.012
0038-092X/

Nomenclature

A_f	floor area (m^2) of a room/light well
A_g	glazing area of the rooftop window/aperture (m^2)
A_t	total area of room/light well-surfaces (m^2)
B_F	ballast factor
DIR	Daylight Illuminance Ratio (%)
DF	daylight factor (%)
E_i	internal illuminance (Lux or lm/m^2)
E_o	outside illuminance (Lux or lm/m^2)
H	total height of a room/light well (m)
h	vertical height of the given point above the ground surface (m)
L_a	electrical lighting losses (%)
L_{td}	transmission and distribution losses (%)
LW	light well
M	maintenance correction factor
N	sunshine hours (h/day)
O_F	orientation factor for glazing
P (W)	lighting power (W)
R	average reflectance of all room-surfaces
SBC	SODHA BERS COMPLEX
Greek letters	
β	inclination of the window (°)
θ_w	angle between the given point and the perpendicular axis to the window (°)
θ_i	angle of incidence (°)
ε_e	luminous efficacy (lm/W)
ϕ	luminous flux (lumen or lm)
θ	vertical angle of visible sky from the center of the window (°)
τ	transmittance of glazing

and Veitch, 2006; Krarti et al., 2005; Chirarattananon et al., 2002). The grid based electricity is directly related to CO_2 emissions which creates problems in terms of greenhouse effects and climate change. To reduce the energy use and its impact on the climate, many strategies are necessary, including energy demand reduction and increased energy efficiency (Morrissey and Horne, 2011; Li et al., 2010a,b). Energy efficiency in a lighting system can be obtained mainly by the minimisation of two variables viz. the lighting power density and the lighting system use. First variable can be optimized by using energy-efficient lamp or by reducing the lighting power density. The second variable i.e. the lighting systems use; could be optimized through the lighting controls and proper daylighting schemes, such an approach could reduce the demand of energy resulting increase vision efficiency (Ghisi and Tinker, 2005; Li and Lam, 2003a,b). Peacock et al. (2005) have reported the Carbon Vision with help of TARBASE programme in which the carbon emissions of UK buildings was investigated, with the aim of identifying how technological interference might reduce emissions by 50% by the year 2030. In their study they have reported that the heating and cooling load of a building is strongly associated with the use of artificial source of light and hence the carbon emission. In the last few years, global awareness and environmental effects like depletion of ozone layer and climate change enforces reduction in emission in buildings (Carter, 2004; Sudan and Tiwari, 2014; CIBSE, 1999).

Chel et al. (2010) had developed a model for rooftop aperture for the skylight integrated dome shaped building by considering vertical height of working surface. Dua and Sharples (2011) had studied vertical daylight factor of adjoining spaces in atrium buildings under overcast sky conditions. Acosta et al. (2013, 2014) have studied skylight components and daylight factor in a courtyard under overcast sky conditions on floor. Further, Acosta et al. (2015) have done the analysis of daylight factor and energy saving allowed by the windows under overcast sky conditions. Indeed, the most common method, the "daylight factor", under overcast sky conditions does not even consider the contribution of the sunlight but only skylight. And also, prediction of DF is insensitive to building orientation with respect to sun, time of the day and the intended locale (Hopkinson, 1963; Mardaljevic et al., 2009). In recent literature (Carlucci et al., 2015) the DF has been defined where the direct component of sun light has also been excluded. Whereas, direct sunlight contributes over 85% of the light reaching the earth on a sunny day, which could not be neglected (Muhs, 2000). Further, Sudan et al. (2015) have studied the daylight illuminance for the clear sky conditions where both direct (i.e. that received directly from the sun) and diffuse (i.e. all skylight and diffuse-reflected sunlight) components have been considered for computation of the illuminance level at a given point inside a living space for wall window. In their study they have considered the effect of time, orientation, and location of the place.

In the present study, the climate-based model has been developed following Sudan et al. (2015) to determine DIR and daylight metric at a given point which is sensitive to building orientation with respect to sun, time of the day and the intended locale of the building for rooftop window. Effect of both direct and diffuse components of daylight has been taken into account for estimating the illuminance level and DIR which gives the more realistic results. The term 'DIR' in present paper is used to refer to the totality of daylight illumination provided by directly and indirectly from both the sun and the sky. The experimental validation of the given model has also been carried out for climatic condition of Varanasi at SODHA BERS COMPLEX (SBC) which can be further examined for the different