Energy and Buildings 73 (2014) 184–191

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Experimental and simulation study on the performance of daylighting in an industrial building and its energy saving potential

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ARTICLE INFO

Article history:
Received 1 July 2013
Received in revised form 3 January 2014
Accepted 16 January 2014

Keywords:
Large space building
Daylighting performance
Energy saving potential
Field measurement
Ecotect simulation

ABSTRACT

Proper use of daylighting cannot only improve the visual comfort in indoor environment, but also reduce building energy consumption effectively. Studies on this topic have been mostly conducted for office buildings, but were limited for industrial buildings, where lighting is a major electricity consumer. This paper presents a study of daylighting performance in a large space industrial building (Tianjin, China) by both field measurements and numerical simulations. The daylighting illuminance distribution was measured with 6 m × 6 m grid size during four periods on a sunny spring day. The average daylighting illuminance during the four measurement periods (9:00–10:30, 11:00–12:30, 13:00–14:30, 15:00–16:30) were 373 lux, 397 lux, 360 lux and 254 lux, respectively. The daylighting illuminance simulations done by Ecotect and Desktop Radiance simulation program were applied for comparison with the field measurements. The simulated daylighting illuminance distributions matched well with the measurements. Furthermore, quantitative analysis of the energy saving potential of artificial lighting controls integrated with daylighting and the effect of reducing artificial lighting on the heating energy consumption were conducted with EnergyPlus simulation program. The electricity saving potential for the On/Off control and the dimming control integrated with daylighting were 36.1% and 41.5%, while the reducing of artificial lighting by the two strategies would lead to an increase of the heating energy consumption by 7.1% and 8.7%, respectively.

1. Introduction

Artificial lighting is one of the major electricity consumers in many non-residential buildings [1]. According to the United States Department of Energy, commercial buildings consumes 32% of the total electrical energy in the country, of which 33% go to artificial lighting [2]. For office buildings, artificial lighting consumes about 20–35% of the total building electricity consumption in Hong Kong [3]. For industrial buildings, the percentage varies widely depending on different manufacture process. A summary of seven factories showed that artificial lighting consumes about 1–34% of the total building electricity consumption in Dongguan, China [4]. To reduce the energy consumption therefore manufacture cost, increasing effort has been made to minimize the energy consumption of artificial lighting [5]. Proper use of daylighting cannot only reduce energy consumption effectively, but also improve the indoor visual comfort. People prefer natural lighting than artificial lighting as it gives the best color rendering and matches with human visual response [6]. It has been proved that good daylighting can provide a more pleasant and attractive indoor environment that can contributes to higher productivity and performance [7].

Recently, there has been an increasing interest in incorporating daylighting with architectural and building designs to save building energy consumption [8,9]. A variety of results have indicated that proper lighting controls integrated with daylighting have a strong potential for reducing energy consumption in office buildings. Field measurements and simulation studies have showed that the energy saving potential by utilization of daylighting is about 30–40% for constant lighting system [10] and 20–40% even up to 60% for dimming control system [11–13]. However, it is noted that the existing studies have mainly focused on office buildings, which are normally small room spaces. The study on the performance of daylighting for industrial buildings is limited, which are normally large spaces. Compared with office buildings, industrial buildings usually have more intensive energy use, and higher indoor illuminance requirement for some special manufacture process. For large space industrial buildings, there are more room spaces which can gain daylighting benefits due to the open floor planning. Therefore,

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0378-7788/$ – see front matter © 2014 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.enbuild.2014.01.030

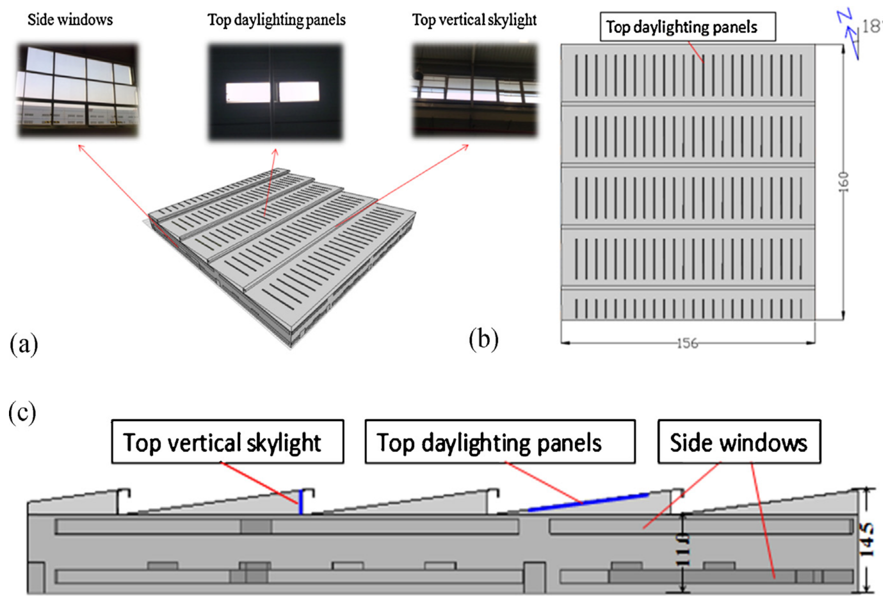

Fig. 1. Structure and fenestration of the building: (a) Schematic view, (b) Top view, and (c) Side view.

quantitative analysis of the daylighting performance and the daylighting design effectiveness in the large space industrial buildings are needed and will help to improve the building performance through guiding the future design.

The study of daylighting performance can be achieved by experimental measurements and computer modeling. The experimental measurements can be either field measurements or scaled model tests. As the experimental measurements are usually expensive and time-consuming, computer modeling becomes increasingly popular. With the recent advances in computer technology, the application of Radiance becomes more attractive in modeling building daylighting performance. Radiance [14] is a ray-tracing daylight and electrical lighting analysis software developed by Lawrence Berkeley National Laboratory (LBNL) and has been successfully applied to the building lighting design. Researchers have used Radiance to predict various aspects of daylighting performance, including the illuminance distribution based on information of the incoming light [15,16], the problem of glare [17], and sky luminance distribution [18]. Li and Tsang (2005) [19] measured and simulated the daylight illuminance in a daylit corridor and found that the indoor illuminance simulated by Radiance using daylight coefficient approach showed reasonably good agreement with measured data. However, Radiance can only predict the daylighting performance at a fixed weather condition and time point. It is not capable of predicting long term energy saving potential by lighting control integrated with daylighting. The building energy consumption simulation program EnergyPlus [20] has been validated for accuracy in predicting the performance of daylighting and lighting control systems in actual buildings [21,22]. Therefore, EnergyPlus can be coupled with Radiance to predict the energy performance of daylighting.

This study conducted both field measurement and numerical simulation of the daylighting performance in a large space industrial building in Tianjin. The objective of this study is to: (1) evaluate the daylighting environment quality of the industrial building; (2) validate the accuracy of experimental method and procedure which was used in the daylighting environment evaluation; (3) evaluate the effectiveness of the integrated daylighting and lighting control system; (4) estimate the electricity saving potential of artificial lighting controls integrated with daylighting and the effect of reducing artificial lighting on the heating energy consumption for the industrial building.

2. Method

2.1. Investigated industrial building

This study was conducted in a single floor elevator factory building in Tianjin, China, (39.08N, 117.07W). The floor area is 156 (long) × 162 (wide) m^2 and the ceiling height is from 14.5 m to 11.0 m. Fig. 1 shows the factory building model and its fenestration. The factory has a hackle-shape roof and five spans (the width is 18 m for one span, and 36 m for the rest four spans). Three kinds of daylighting fenestration were designed: the side windows on the walls, the top daylighting panels and top vertical skylights on the roof. The window to wall ratio (WWR) and skylight to roof ratio (SRR) are showed in Table 1.

The factory has an electricity monitoring system, which can record electricity for different usages: production, lighting, heating, ventilation and air-conditioning (HVAC, which is used for the office zone; there is no HVAC system in the factory zone) and reserved (The electricity consumption which is reserved for additional sockets). By analyzing the history data of the year 2009 (see Fig. 2), it was found that the artificial lighting contributed to about 30% of the total electricity consumption, which is the second biggest electricity consumer following the production process in the factory.

2.2. Field measurement

The illuminance was measured by illuminance meters. TES 1330A (0–20,000 lux, TES Electrical Electronic Corp) was used for the measurement of indoor daylighting illuminance and TES 1332A

Table 1
Window to wall ratio (WWR) and skylight to roof ratio (SRR).

Orientations	North	East	South	West	Roof
WWR/SRR	37.5	31.1	0	29.1	8.2