Building and Environment 72 (2014) 368–376

Contents lists available at ScienceDirect

Building and Environment

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

New static lightshelf system design of clerestory windows for Hong Kong

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A R T I C L E I N F O

Article history:
Received 17 July 2013
Received in revised form
15 November 2013
Accepted 18 November 2013

Keywords:
Meniscus glazing panel
TracePro
Static lightshelf
Illuminance
Uniformity distribution

A B S T R A C T

This paper investigates the influence of clerestory window structures on the performance of daylighting lightshelves in terms of the interior illuminance level and uniformity distribution using the software TracePro7.0. Simulations were carried out for a window facing south at noon on both summer day and winter day. It is found that a meniscus glazing panel whose curved section is in a meniscus shape can change the light direction and affect daylighting performance. Further results show the best clerestory window structure for Hong Kong is the one whose meniscus section is wide at the top and narrow at the bottom with a curvature angle ranging from 44.3° to 90°. This improves the illuminance and uniformity of the interior space in the winter months (solar altitudes up to 60°) and has a relatively steady effectiveness of around 1.03 in comparison to a vertical clerestory glazing panel. For higher solar altitudes in summer, this structure improves uniformity for the middle and rear room areas by reducing the illuminance in the front, while the effectiveness drops to around 0.91. This is a good improvement which can promote confidence in the application. The proposed structure can be revised and applied in subtropical regions enabling lightshelves to be designed based on their specific requirements.

1. Introduction

Daylight is a gift which brings people close to nature. Accordingly, in recent years there has been considerable research interest in the design of green building features [1]. Careful utilization of daylight may reduce the consumption of the nonrenewable energy used in artificial lighting [2] and the radiant heat gain Ref. [3]. Some people use atrium [4], light tube [5], optical unit [6], and remote source lighting systems [7] to bring daylight into rooms more intentionally and efficiently and to improve the indoor illuminance level. Others use shading devices such as sunshades [8] and balconies [9] to reduce it, particularly in tropical areas. To combine the advantages of these approaches, a lightshelf can be used not only to reduce the sunlight near a window as a shading device, but also to redirect the light to the rear of the room as a daylighting system. Normally a lightshelf is a horizontal or inclined baffle which divides the glazing into two parts: a view window below the shelf, and a clerestory window above it.

1.1. Lightshelf

In an important prior study, Littlefair et al. [10] suggested that a lightshelf with a diffuse surface could result in an increase in interior daylight uniformity. Littlefair [11] later investigated the performance of this feature using both experiments and computer simulation and found that the illuminance level was reduced throughout the space. However, Soler and Oteiza [12] used a specular surface to test performance with scale models. The main result showed that a lightshelf could increase light levels at the back of a room, and obtain a higher efficacy of illuminance at a certain angle range of solar altitudes and on certain days of the year. Claros and Soler [13] tested four different painting materials for a lightshelf and three kinds of painting types for walls and floors over a three-year period in Madrid. Beltran et al. [14] concentrated on the structure of a lightshelf with different layers and tested the horizontal case plus single-, bi-, and multilevel lightshelves. They showed that these could provide adequate ambient daylight for office tasks in the deep zone. Ochoa and Capeluto [15] also evaluated the performance of three different structures for daylighting systems. Their influential study showed that the anidolic concentrator redirects more daylight in quantitative terms than the horizontal lightshelf. Unlike these studies, Freewan et al. [16] optimized the performance of a lightshelf by investigating ceiling geometries through physical model

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0360-1323/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.buildenv.2013.11.017

experiments and radiance simulations, showing that the best ceiling shape for subtropical climate regions is the one that is curved at the front and rear of the room. With this curved ceiling, Freewan [17] went on to show that the best lightshelf shapes are curved and chamfered to bounce more daylight deep into the space, thus improving both the illuminance and uniformity. Recently, Lim et al. [18] demonstrated a modification of a window system in an existing building using both a lightshelf and a blind, which significantly improved the indoor daylight quantity and quality.

1.2. Glazing

Walze et al. [19] developed the microstructuring of a surface, which combines its static light-guiding abilities with the possibility of actively controlling the properties of a glazing by using switchable coatings. Except for the work done in materials technology, the improvement of daylighting has focused more on the shape of the glass. Prismatic glass has been used for over 50 years as an efficient daylighting unit, mainly to redirect sky light to the interior. Nevertheless, strong sunlight from high angle is inevitable at some times of the year, potentially resulting in glare [20]. Moreover, in a Building Research Establishment (BRE) experiment, prismatic glazing fixed in a vertical position needed to be seasonally adjusted to maintain performance improvements [21]. Prisms also obscure the view out of a building and can cause color dispersion, so Andersen et al. [22] evaluated the daylight distribution by studying their bidirectional transmission distribution function.

1.3. Demands of different seasons

The above articles discuss the improved daylight performance of an interior by using static lightshelf systems and compare with standard window design. The significances of the results are limited by the fact that the changes in efficiency among different seasons are not fully described. It is expected that a lightshelf system will perform differently for different sun positions. Apart from solar altitude, another factor which affects the system performance significantly is the globe illuminance. In a subtropical area such as Israel [15], one simulation showed that an anidolic lightshelf failed to convey 300 lux to a depth beyond 7 m in winter. The illuminance level in summer was even lower than winter for the back of the room. Jordan [16] showed that all five lightshelves performed better in spring than in summer but still could not reach 300 lux at 7 m. Similarly, in Hong Kong, the daylight availability and intensity in winter may not be large enough to illuminate the whole room above the standard [23]. In conclusion, the general problem of a lightshelf system could be the case that a lightshelf fails to redirect the abundant daylight to the rear area of the room in summer, while winter daylight could penetrate into deeper part of the room but the lighting level is inadequate in general.

This paper focuses on how the structure of a clerestory window affects the performance of a lightshelf in deep rooms. Based on the principles of optics, specifically refraction and reflection, it assesses the interior illuminance level and uniformity distribution of a space equipped with different lightshelf systems using the software TracePro. A static meniscus glazing panel whose curved section is in a meniscus shape is proposed to meet different needs. This arrangement redirects more light to the room, especially the rear area, in winter and improves the uniformity of the light distribution in summer. This study is confined to a southerly direction simulation, where direct sunlight is considered in order to evaluate how the lightshelf performance changes with different structures of the meniscus glazing panel.

2. Method

2.1. Principles of optics

A vertical clerestory window does not normally change the direction of sunlight, while a meniscus glazing panel does. As shown in Fig. 1, the meniscus glazing panel has two spherical surfaces, with a shorter radius of curvature on the concave side, and a longer one on the convex side. They are commonly used in beam-expanding applications.

As seen in Fig. 1, a ray passing through the inner center (the thicker one) does not change direction, while other rays deviate outward from the original track. If this panel is rotated by 45°, a lightshelf system with probable sunlight rays from high and low solar altitudes is depicted in Fig. 2.

At summer noon or a high solar altitude, the meniscus glazing panel will redirect more rays which aim at the part of its concave side above a critical point to a lower elevation angle (or larger angle of incidence at the lightshelf reflective surface). The critical point is the point at which the rays are perpendicular to the lens surface and it is dependent on the solar altitude. Besides, a smaller portion of the rays aiming at the part of the concave side below the critical point will obtain a higher elevation angle (or smaller angle of incidence at the lightshelf reflective surface), as shown in Fig. 2(a). In contrast, in winter or at a low solar altitude, most rays will aim at the part of the concave side below the critical point and so will be redirected with a higher elevation angle. The rest of them will be redirected with a lower elevation angle, as shown in Fig. 2(b). This optic feature of a meniscus glazing panel offers the possibility to alleviate the general problem of a lightshelf system.

2.2. Simulation setup

In addition to light direction, the absorption coefficient, refractive index, transmittance, and window thickness should also be taken into consideration when studying daylight. In this case, a computer simulation is necessary to predict the system performance. Radiance has been used as a simulation tool for daylighting performance, but may suffer from limitations in refraction simulation. As the rays propagate along different paths throughout the solid model, TracePro7.0 can keep track of the optical flux associated with each and fully account for the absorption, specular reflection, refraction, diffraction, and light scattering [24]. In this paper, TracePro is used to quantitatively analyze the raytrace of direct sunlight, and two major performance indicators, the illuminance and uniformity distribution ratio, are simulated. Uniformity is generally used as an index to represent the illuminance difference between the minimal and the average, which can be defined as the following equation:

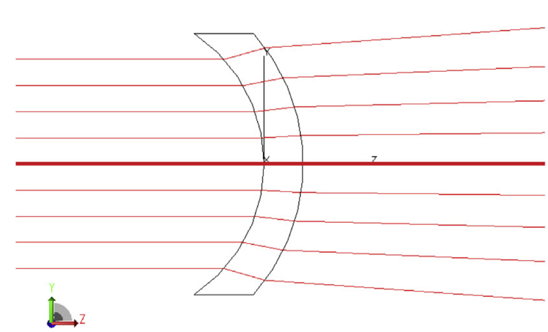

Fig. 1. Raytrace of the meniscus glazing panel.