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Daylighting and solar shading performances of an innovative automated reflective louvre system

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ABSTRACT

Traditional windows, as the major source of daylight, have a common problem which is uneven distribution of daylight in the room. Several innovative daylighting systems such as light shelves, fixed and movable reflective louvres, reflective sills, prismatic glazing, light pipes, etc., have been developed to address this problem. This paper reports on a research programme that investigates retrofitted solutions to uneven distribution of daylight in deep-plan office buildings. The work presented here follows initial investigations into the design and applicability of an automated retrofitted panel thermal shutters which can also act as a sunshade and daylighting system. The system has a patented function which allows each shutter/louvre to be controlled and placed separately from other louvres. This study evaluates the effectiveness of the system when acting as a sunshade, light shelf, reflective louvre, and reflective sill under clear, overcast, and sunny sky conditions. According to the results, the system significantly improved daylight distribution and reduced the need for artificial lighting by 60%.

Nomenclature

Average daylight factor (ADF): is the “ratio of total daylight flux incident on a reference area to total area of reference area, expressed as a percentage of outdoor illuminance on a horizontal plane due to an unobstructed hemisphere of sky of assumed or known luminance distribution” [1]. ADF can be calculated using the following equation [2]:

$$ADF = \frac{TAw\theta M}{A(1-R^2)}$$

T: the glass transmittance; Aw: the effective window area (excluding the frames); θ: the visible sky angle; R: the average reflectance of the room, M: the maintenance factor; A: the total surface area of the room in m^2 (floor + ceiling + walls including the windows).

Limiting depth of the room (*L*): the maximum room depth which is sufficiently daylit in a room with windows on one wall only. L is calculated from the following equation [2]:

$$\frac{L}{W} + \frac{L}{Hw} < \frac{2}{1-Rb}$$

W: room width; H: window head height above floor level; Rb: the average reflectance of surfaces in the back of the room.

1. Introduction

The UK’s government has long-term objectives to reduce carbon emissions by 80% by 2050 [3,4]. The construction industry is one of the major sectors which should contribute towards achieving these objectives. The construction industry is accounted for 47% of the CO_2 emission of the UK, 80% of which is generated from the “In-Use” buildings [5]. The government has announced its ambition to make new homes and non-domestic buildings carbon neutral in order by 2016 and 2019 [6,7].

Although important, such policies do not sufficiently address the existing commercial buildings. With an annual replacement rate of 1–1.5%, it is estimated that, by 2050, around 70% of the existing buildings will still be in use, 40% of which have been built before 1985 [4]. Therefore, to achieve such challenging targets, it is vital to improve the energy performance of the existing commercial buildings.

One of the major areas of improvement is the effective use of natural lighting. Lighting accounts for around 5% of the total energy consumption in the UK and 10–30% of the energy consumption in buildings such as offices [2]. Between 20 and 60% saving in lighting is achievable by improved use of daylight [8,9]. Appropriate lighting controls are however required to achieve such savings [2,10].

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There are no legal requirements for daylight levels in the UK [2]; however, according the Workplace (Health, Safety and Welfare) Regulations, “Every workplace shall have suitable and sufficient lighting” and the lighting “shall, so far as is reasonably practicable, be by natural light.” Moreover, “Dazzling lights and annoying glare should be avoided” [11]. Building regulations also do not specify the minimum requirements for daylighting; however, according to Part L of the Building Regulations, glazing area should not be much less than 20% of the total floor area as this may result in poor natural lighting and increased use of artificial lighting [12].

Meanwhile, increasing pressure on building designers and owners to improve the thermal performance of their buildings has resulted in the reduction of the total window areas and replacement of single glazed windows with double and triple glazed Low-E units. Although such systems improve the thermal performance of the building, they considerably reduce the transmitted visible light from the exterior to the interior. Typically “Low E” systems transmit 50% of the light compared to 70% transmission through double glazed units and 90% transmission through single glazing [10].

Daylight quality and distribution depends not only on the glazing type and area, but also on several other factors including sky conditions, time, building locations, window proportions and orientations. Daylight is not therefore a reliable source of lighting as its colour and intensity changes constantly [13,14]. For this reason, a combination of daylight and electric lighting is required in the buildings.

Average daylight factor (ADF) is a concept which is commonly used in early stages of design to estimate the required window area in order to achieve adequate daylight in a building [15,16]. In simple terms, ADF = $\bar{E}i/Eo \times 100\%$, where $\bar{E}i$ is the average internal and Eo is the external illuminance [17,18]. According to BS 6262-2:2005 and BS 8206-2:2008 if ADF is at least 5% and daylight distribution is satisfactory, artificial lighting is not normally required; and, if ADF is between 2 and 5% supplementary artificial lighting is usually required. If ADF drops below 2% electric lighting is almost always required [2,16,19,20].

The use of electric lighting not only depends on the ADF but also on the even distribution of daylight. Increasing ADF will not be effective on its own if daylight distribution in the building is poor [10]. In this respect, an area with a 2% daylight factor and a uniformity of 40% will look more attractive than a space with a daylight factor of 5% and a uniformity level of 10% [21]. A uniformity level of 30–50% [21] is recommended to maximise benefiting from natural lighting.

Traditional windows, as the major source of daylight, have a common problem which is uneven distribution of daylight in the room [13]. For this reason, if a room is daylit by windows in only one wall, the depth of the room should be limited to the “limiting depth of the room” to receive sufficient daylight. However, this is not always possible and therefore several innovative daylighting systems such as light shelves, fixed and movable reflective louvres, reflective sills, prismatic glazing, light pipes, etc. have been developed to address this problem. These systems have been explained and tested in several documents [8,10,13,22–33].

Daylighting systems improve natural light distribution and reduce the excessive contrast and use of electric lighting in buildings [10,13,22]. Many of these systems work optimally under sunny conditions [13,31] and may cover one or some of the following functions [23]:

- solar shading;
- glare protection; and
- daylight balancing.

Each of these systems, however, has its own problems and limitations. For instance, light shelves do not in general increase the light in deeper areas in the room [34] and they may require additional devices, such as blinds, to control sunlight and glare [10]. Fixed louvres may considerably reduce the interior light [10,20,22,23]; and, automated systems may cause distraction [10,34].

It is in this context that the author reports on a research programme that investigates retrofitted solutions to this problem. The work presented below follows initial investigations into the design and applicability of an automated retrofitted panel thermal shutters as a collaborative work between University College London and SE Controls. The system has a patented pick and place function [35] which allows each shutter/louvre to be controlled and placed separately from other louvres. This function makes the system extremely flexible resolving some of the abovementioned problems of daylighting systems. This study intends to evaluate the effectiveness of the system when acting as a sunshade and light reflector (in three different modes of reflective louvre, light shelf, and reflective sill) under clear and overcast sky conditions. The thermal performances of the system have been investigated and discussed in another paper [36].

2. Methodology and equipment

The methodology of this study is to directly compare the results of computer simulations, physical tests carried out on a one to one scaled model, and parallel measurements taken in an office located in the case study building. The focus of this study is mainly on the relative and not absolute daylight measurements.

All physical tests were carried out for a minimum of three days under similar sky conditions and averages were taken to minimise inaccuracies [23]. Also considering dynamic nature of the sky conditions, measurements were taken every minute to increase the accuracy of the results.

HOBO U12/12 data loggers were used for internal and HOBO Pendant for external daylight measurements. According to the manufacturer’s technical datasheets, the sensors are appropriate for relative daylight measurements. A handheld metre (Precision Gold NO9AQ) was also used for the absolute daylight measurements. The instrument is fully cosine corrected for the angular incidence of light. Pilot studies revealed considerable deviations in the readings by the HOBO data loggers. All sensors were therefore calibrated prior to starting the tests. Yet, 5 and 10% reading tolerances should be considered for the internal and external sensors respectively.

3. Case study building and surrounding environment

The physical tests took place at SE Controls located in Fradley Park, Lichfield, UK. The building is situated on a business park and is oriented 68° east of due south with some external natural obstructions. The test rooms were situated on the ground floor and the office was located on the first floor of the building. Fig. 1 shows the building orientation, the position of the test windows and the sun path on the 22nd of June, March and December.

As shown in the panoramic view (Fig. 2), apart from some distant rows of trees, the space in front of the tested building was almost free from obstructions; however, some leafless trees and bushes (around 1800 mm tall and 6 m away from the windows) were blocking some of the sky.

3.1. Test rooms and measurement processes

The test and reference rooms were created by dividing a four metre window into two equal parts. Blackout off-white curtains were used to stop the light from getting inside or outside the rooms.