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Natural light controls and guides in buildings. Energy saving for electrical lighting, reduction of cooling load

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ABSTRACT

The residential sector is responsible for approximately a quarter of energy consumption in Europe. This consumption, together with that of other buildings, mainly from the tertiary sector, makes up 40% of total energy consumption and 36% of CO_2 emissions. Artificial lighting makes up 14% of electrical consumption in the European Union and 19% worldwide. Through the use of well-designed natural lighting, controlled by technologies or systems which guarantee accessibility from all areas inside buildings, energy consumption for lighting and air conditioning can be kept to a minimum. The authors of this article carried out a state of the art on the technologies or control systems of natural light in buildings, concentrating on those control methods which not only protect the occupants from direct solar glare but also maximize natural light penetration in buildings based on the occupants' preferences, whilst allowing for a reduction in electrical consumption for lighting and cooling. All of the control and/or natural light guidance systems and/or strategies guarantee the penetration of daylight into the building, thus reducing the electrical energy consumption for lighting and cooling. At the same time they improve the thermal and visual comfort of the users of the buildings. However various studies have also brought to light certain disadvantages to these systems.

Contents

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1. Introduction

The residential and tertiary sector, makes up 40% of total energy consumption [1–8] and 36% of CO_2 emissions [9]. According to the International Energy Agency (IEA) [10], artificial lighting makes up 14% of electrical consumption in the European Union and 19% worldwide.

By acting on energy efficiency in buildings, it is possible to reduce energy consumption and therefore CO_2 emissions into the atmosphere [11,12]. Lancashir et al. [13] reported that each kWh of energy saved prevents the emission of 680.39 g of carbon dioxide, 5.67 g of sulfur dioxide, and 2.27 g of nitrogen oxide.

Many studies have been able to demonstrate the importance of natural light in buildings. Natural light significantly influences both the balance of energy use in buildings and actual human activity [14–17], offering the occupants comfort and health benefits, given that it plays an important biological role in the control of the physiological and psychological rhythms of living beings [18–20].

However, due its changing nature, it is necessary to control and guide natural light in order to supplement or replace artificial lighting. If it is not controlled, natural light can have a negative impact on the environment as excessive solar gains lead to an increase in energy consumption for cooling. On the other hand, most natural light control systems concentrate on minimizing the negative impact of natural light, whilst ignoring its positive impact. Through aiming to reduce the external heat load caused by solar radiation in a building, the amount of natural light often becomes insufficient and results in an increase in energy used for electrical lighting [21]. Thus, for example, windows allow daylight to enter into and illuminate the interior of a building, yet the effects of the natural light decrease as one moves away from the windows, making the use of artificial illumination a necessary complement [22].

Therefore, through a well-designed, controlled use of natural light, employing technologies or systems which ensure the penetration of light throughout the whole building, energy consumption designated to lighting and air conditioning can be kept at a minimum [23–35].

The authors of this article carried out a state of the art on the technologies or control systems of natural light in buildings. The efficiency of each of these systems in the reduction of energy consumption was evaluated. Specifically, the research concentrates on those control methods which not only protect the occupants from direct solar glare but also maximize daylight penetration into buildings based on the occupants' preferences, whilst allowing for a reduction in electrical consumption given over to lighting and cooling.

2. Impact of control systems of natural light

Electric lighting energy consumption [kWh] in conventional office buildings is as much as 35% of the total electric load – demands that are generated primarily during the day when daylight is abundant. Since the energy drawn for electric lighting is ultimately converted into heat, there is additionally a load on the cooling system. Proportional to the total energy used, electric lighting can add as much as 16% to the cooling energy bill, such that the combined electricity costs for lighting and cooling are almost 50% of total electric demand. While total energy consumption is made up of both electricity and fossil fuel energy uses, daylighting alone can reduce total energy use by as much as 25–30%, one of the most cost-effective investments for energy and carbon savings world-wide [21].

The economic impact of ignoring daylight is even more problematic because it is an electric load in buildings – for which source or primary energy costs are significant. 1 kW of power on site uses approximately 3–4 kW of primary energy, with the rest lost as heat up the chimney at the power plant. In conventional coal or oil fired power plants, only 35–40% of the primary energy is converted into power with a further 6% of the energy produced at the power plant lost in transmission. In developed economies such as the USA, Japan, Germany, power plants are to blame for approximately 50% of all CO_2 emissions. Over 40% of each nation's total energy consumption in developed economies is used for heating, cooling, air conditioning, lighting and other power requirements in buildings [21].

In addition, the benefits of a daylight building extend beyond simple energy savings [36,37]. Numerous studies also indicate that daylighting can help increase worker productivity and decrease absenteeism in daylight commercial office buildings, boost test scores in daylight classrooms [38], and accelerate recovery and shorten stays in daylight hospital patient rooms. Hourani and Hammad [39] reported impacts of daylight on students' health, emotions, attendance and performance. A 2 year study in U.S. elementary schools cleared more attendance by 3.6% for students in daylight classes than students in other classes depend mainly on electrical lighting and minimum day-lighting. Another study in U.S. schools investigated the impact of daylight on students' performance through scores' analysis for over (21,000) students. Whereas students in the most daylight classrooms showed progress 20% faster on math tests and 26% on reading tests within 1 year than students in classes depending on electrical lighting with minimum daylight [39].

3. Daylighting legislation

There are many types of building regulations, codes, standards or ordinances which are specifically related to ensure daylight in buildings. The requirements and regulations regarding daylight are very diverse. The existing daylighting standards in many European countries (comprehensive codes are for example in Germany [40] and Great Britain [41]) are more or less informative and are not intended to be applied in a prescriptive manner. The European Committee for Standardization will prepare the first European Code for daylighting in buildings and to define metrics for daylight and sunlight in all regularly occupied indoor spaces [42].

A good review of daylighting requirements of many sustainable rating systems was done in Ref. [43].

4. Selection of research studies

This paper systematically reviews recent research on the technologies or control systems of natural light in buildings. The main objective of such technologies or control systems is not only