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Analysis of energy savings of three daylight control systems in a school building by means of monitoring

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ABSTRACT

Daylight control systems, which automatically adjust the artificial light levels depending on the daylight penetration, can result in substantial energy savings. However, their energy saving potential cannot be estimated accurately because it depends on several building and system parameters, climate conditions, occupant behaviour and type and commissioning of the daylight control system. The objective of this paper is to compare the energy saving potential and operation of different daylight control systems in school buildings. One year monitoring has been carried out simultaneously in 3 neighbouring classrooms, equipped with a different type of control system. The active power and the electric energy consumption of the artificial lighting were measured continuously on a minute-by-minute basis, as well as the occupancy of the classrooms and the global irradiance outside the building under an unobstructed horizon. Momentary visual comfort assessments were carried out in the classrooms.

Although all classrooms have comparable occupancy and identical building characteristics, differences between the annual energy savings of the different daylight control systems are found to be significant: the total annual energy savings varied from 18% to 46%. Under the given conditions, the open loop system with the outward facing daylight sensor was noticed to yield the largest while the closed loop system with centrally positioned sensor produced the smallest savings. However, it has to be made sure that the energy savings are not at the expense of the visual comfort. The performance of the systems regarding both energy savings and visual comfort is related to the operation and the initial commissioning. An in-depth analysis of the monitoring campaign is discussed to explain the differences in energy savings and visual comfort. The energy savings due to the implementation of a daylight control system are divided into on the one hand dimming due to daylight penetration and on the other hand initial dimming to compensate for the over dimensioning of the lighting system and to take into account constant illuminance control.

1. Introduction

Lighting is estimated to represent on average 40% of the total electrical consumption in office buildings [1] and can amount to 70% of the total electrical consumption in school buildings without mechanical ventilation [2]. Besides the replacement of the luminaires, lighting control systems can be installed to decrease the energy consumption while preserving the visual comfort. Although many different lighting control systems are available, it is rather difficult to quantify their energy saving potential. This is particularly the case for photosensor-controlled electric lighting systems (hereafter called “daylight control systems”), which automatically adjust (switch on-off or dim) the luminous flux out of the luminaires as a function of the available amount of daylight. The reason for this is that the energy saving potential is dependent on a wide range of parameters. Bodart and De Herde [3] examined the impact of the window position, the fenestration area, the glazing transmission factor and the internal wall reflection coefficients on the lighting consumption when using daylight control systems. Yang and Nam [4] studied the impact of glazing ratios on lighting consumption and on reduction of energy cost using daylight linked lighting control system. Also the location and orientation of the building [5] and possible external obstructions and the usage of blinds [6] affect the energy saving potential of daylight control systems. The artificial lighting and the lighting control systems themselves, including for instance the number of rows of dimmed luminaires parallel to the window side [7] and the commissioning of the daylight control system [8], have to be considered as well.

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As a result of the difference of these parameters from case to case, widely divergent results for the energy saving potential of daylight control systems have been reported. Atif and Galasiu [9] determined by extrapolation of field measurements in winter and summer that the annual savings in electrical light consumption would be 46% in the investigated case. Jennings et al. [10] speak about 21% of lighting energy savings over a seven-month monitoring period with automatic daylight dimming controls. Yun et al. [11] found from a monitoring campaign of 5 months in four offices in Korea that the application of automatic dimming control for lighting with a design illuminance of 500 lx can reduce lighting energy consumption by up to 43%. Aghemo et al. [12] measured potential energy savings from 17% to 32% in offices, taking into account both the monitored annual electric energy consumption (for operation) and the parasitic energy consumption due to the installed devices (luminaire ballasts, sensors and controllers). In 2 different research projects of Li about daylight control in office buildings, energy savings of 50% and 33% respectively are obtained [13,14]. Li et al. [15] also found that the monthly electric lighting energy saving for the atrium corridors in a case study ranged from 14% to 65% using the present high frequency dimming controls. Haq et al. [16] summarizes a savings potential of 20–31% in office buildings worldwide. Hackel and Schuetter [8] monitored an average energy savings potential of 63% in 20 office buildings in the USA after commissioning. Williams et al. [17] concluded from a meta-analysis an average savings range of daylight control of 39% in 73 office and school buildings as a result from both measurements and simulations. When only measurements are considered, an average savings potential of 28% is noticed (32 cases). Simulation results of Bodart and De Herde [3] showed savings from 50 to 80%, depending on the window configuration and the orientation.

However, each research studies a certain type of daylight control system. The impact of the type of daylight control system itself, including the commissioning of the system, on the energy saving potential of daylighting may be important as well. Daylight control systems are generally divided into open loop and closed loop systems [18]. In an open loop control system, the photosensor is positioned to only detect daylight and thus is insensitive to the artificial light that it controls (no feedback). A lighting control system is considered to be a closed loop system when the photosensor is able to detect both the available daylight and the artificial light that the system controls. Three main types of daylight sensors can be distinguished: outward facing daylight sensors (open loop), centrally positioned daylight sensors (closed loop) and built-in daylight sensors in luminaires (closed loop), controlling one or several luminaires. There are also control systems integrating both open loop and closed loop into a dual loop system, combining the advantages of both systems. However, these are rarely installed in Europe and therefore not studied in this paper.

The objective of this study is to compare the energy saving potential and operation of different daylight control systems in school buildings. Therefore, a full year monitoring has been carried out simultaneously in 3 neighbouring classrooms in the same building of a secondary school, all equipped with a different type of daylight control system. Only continuous dimming systems are studied. All rooms are equal in the matter of parameters such as location, orientation and geometry of the room and windows. The monitoring takes place in real circumstances, including real use of the classrooms but also possible sub-optimal commissioning and design of the lighting and control system.

Throughout this paper, at first, the cases (geometry, building, lighting and light control characteristics) which are monitored in this study are presented. Secondly, the monitoring system (energy consumption, active power, presence detection, global irradiance and illuminance) and the data processing is discussed. Afterwards, the results of the monitored energy savings of the different types of daylight control systems are discussed and compared, after which the effect of initial dimming and dimming due to daylight penetration is studied. Finally, these energy savings are related to the operation of the control systems and the obtained illuminance levels in the classrooms.

Fig. 1. Monitored classroom of Don Bosco Haacht.

Table 1
Classroom characteristics.

	ρ (%)	A (m^2)	LT
Walls	37	85.26	–
Ceiling	79	71.64	–
Floor	12	71.64	–
Window	–	11.18	0.78

2. Description of the monitored cases

2.1. Building and environment

The three classrooms are located at the first floor of a building of a secondary school in Haacht (Belgium). The prevailing climate in Belgium can be described as a temperate maritime climate. The building was delivered in 2008 and the windows of the side-lit classrooms are oriented north/north-west. The daylight penetration in the classrooms is not hampered by external obstructions, since there are no trees or bushes in the neighbourhood and the opposite building is a single-storey building at about 25 m distance. This leads to a very low obstruction angle and thus an obstruction factor of 1 according to Robinson and Selkwitz [19].

All 3 classrooms have the same geometry and interior finish. Fig. 1 shows one of the classrooms. A general floor plan of the classrooms with indication of the position of the luminaire rows is shown in Fig. 2. The window configuration in the exterior wall is shown in Fig. 3. Room and window characteristics are summarized in Table 1. The classrooms are used for regular teaching activities and are equipped with a computer, a whiteboard, a beamer and a smart board. The floor area is fully occupied by chairs and tables with a mean reflection coefficient of 40%. The reflection coefficients of the walls and floor are rather low compared to the recommended values of the European standard EN 12464-1 [20]. Obscuration of the classrooms as well as sun protection is carried out using curtains. The curtains have a beige colour and are opaque.

The windows are made up of double glazing with a light transmission factor of 0.78. The Window-To-Floor-Ratio (WFR) in the classroom is 16% corresponding to the guidelines of Reiter and De Herde [21]. The ratio of the classroom's total depth to the window-head-height measures 3 and is rather high compared to the rule of thumb of Reinhart [22].