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Switching frequency and energy analysis for photoelectric controls

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ABSTRACT

In a well day-lit space when the daylight intensity is far more than the required value, photoelectric switching can result an excellent energy saving. However, a problem with the switching control type is the frequent and rapid switching of lights on and off, particularly during the unstable sky conditions when daylight levels are fluctuating around the switching lighting level. This can annoy occupants and lessen lamp life. This paper studies the simple and a few variants of photoelectric switching controls namely standard, differential, switching time delay, daylight time delay and solar reset types which can affect the number of switching operations and the corresponding lighting energy use. For a given time delay, daylight linked time delay performed better than switching linked time delay in terms of the number of switching operations. Several mathematical expressions were established to predict the lighting energy savings at various atrium floors. The findings provide important information and insight into the effects of different switching controls in terms of energy savings and real-time operations.

1. Introduction

Daylighting is an essential sustainable development to alleviating the problems in energy and pollution, and enriching the environment and visual comfort [1–4]. Daylight is the best source of light for good colour rendering and most closely matches human visual responses. The amount of natural daylight entering an interior space is mainly via window openings which give visual connection between internal and external environments, and brightens the internal spaces. For a good indoor space, as much glare free light as possible is essential [5]. The energy savings derived through the use of daylighting not only facilitate the sparing use of electric lighting and reduced peak electrical demand, but also reduce cooling loads and offer the potential for smaller air-conditioning plants to be built [6,7].

It is argued that photoelectric controls should be installed for lamp fittings installed in day-lit spaces. Energy reduction can be achieved when the brightness from daylight is more than the design value. It can be attained with proper daylight-linked lighting controls to shut off or dim down the electric lightings such that the indoor illuminance levels can still meet the required values [8]. Generally, photoelectric dimming controls are more effective than photoelectric switching control particularly at high design illuminance levels [9]. In a well daylit room or low setting illuminance levels when daylight intensities are far more than the required values, the energy savings from photoelectric switching controls can be larger than those from the photoelectric dimming controls [10]. However, a problem with the on–off control type is the frequent switching, annoying occupants and reducing the lamp life [11,12]. It is crucial to visual comfort, building energy and cost aspects. In circulation areas such as corridors, people expect the way ahead to be lit sufficiently. It has been reported that in daylit corridors photoelectric lighting controls can give excellent energy savings [13,14]. Daylighting design techniques are often best illustrated via field measurements to provide reliable operational data and establish design strategies [15–20]. It is essential to indicate the energy savings and the number of switching operations. This paper analyses the electric lighting energy savings and switching frequency for a number of daylight-linked lighting switching controls. Well day-lit corridors located in an atrium building were selected for the study. The findings are reported and design implications discussed.

2. Photoelectric lighting controls

The methods of controlling lighting energy consumption can be classified into two basic categories. The first type of control allows the level to be set between maximum and minimum levels by

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dimming (top-up), and the second type provides for either an on or off state. Automatic on–off and dimming lighting controls can be employed in daylighting schemes. Dimming controls vary the light output of lamps in accordance with the prevailing daylight level. When daylight is insufficient to achieve the required design illuminance, the indoor lighting level is topped up by artificial lighting. Recently, high frequency dimming controls have been increasingly used and the electronic circuitry employed is more energy efficient than conventional ballast [21]. A high frequency dimming control does not have the ideal characteristic of light output being perfectly proportional to power consumed. The light output can be roughly assumed proportional to power consumed but the lamps cannot be dimmed to total extinction [22]. In normal operation, their residual light output and power consumption occur throughout working hours even if the illuminance level far exceeds the design value [23,24]. However, such operations may be less noticeable and less disturbing to occupants.

An on–off daylight-linked lighting control is designed to switch electric lighting on and off automatically as the daylight level falls and rises through a predetermined level. However, the main drawback with this lighting control type is the rapid and frequent switching of lights on and off, particularly during unstable weather conditions when daylight levels are fluctuating around the switching illuminance. This can disturb occupants and shorten the lamp life. Good switching controls would be the lighting system always off or the number of switching is very low. There are a few variants of the simple on–off control to lower the number of switching [11,25]. The basic one is the 'differential switching or dead-band' photoelectric control that has two switching illuminance levels: one at which the lights are switch on (E_{on}), and another of higher illuminance, at which the lights are switched off (E_{off}). The main strength is that it can reduce rapid switching on and off when the illuminance swings around the desired level. Also, it makes switching off less obtrusive, as it is performed when daylight represents a higher proportion of the illuminance to which the eye is accommodated [11]. It is very important to set appropriately the two switching illuminance values which affect both the number of switching and the electric lighting energy consumption. There is no simple analytical expression for lighting use under a differential switching control. To a good approximation, the fraction of the working year that electric lighting would be off under an on–off control is simply given by the fraction of the working year that the daylight threshold illuminance level (E_{mean}) which is the average of the two switching illuminances E_{on} and E_{off} [11]. Another technique to decrease the number of switching is to introduce a time delay into the process. Two different types of time delay namely switching-linked and daylight-linked time delays are categorized. The switching-linked time delay only allows switching off until the pre-set delay had to elapse after the last switch on. For daylight-linked time delay, the lighting could only be switched off when the daylight illuminance had exceeded the target value for the pre-set time period. Delay in switching on is not considered as it could lead to illuminances falling well below desired levels. The third control mode is solar reset. In solar reset switching, the daylight illuminance is sampled at certain set times of day. When the daylight illuminance is more than the switching illuminance at any of the solar reset times, then the lighting is switched off. To ensure that the illuminance levels are not lower than the desired values, the electric light fittings will be automatically switched on whenever the daylight illuminance falls below the design values. There are several advantages for solar reset switching. Firstly, the switching frequency can be limited as the solar reset time can be set at certain periods. Moreover, the occupants can face with switching off at expected times, and the reset times can coincide with their schedule such as during lunchtime and afternoon breaks which may be appropriate to offices and schools. For a very short reset time interval, the performance would be close to the standard photoelectric control.

3. Background information

The analysis was based on the long-term measured daylight illuminance data in an institutional building. It is a 13-storey block located in Hong Kong within the subtropical region at latitude of 22.3 °N and longitude of 114.2 °E. The building was designed with a skylight and an enclosed stepped atrium to harvest daylight. The stepped atrium increases daylight and improves sky views by splaying the well walls away from the vertical, but the sky component and hence the daylight factor of the lower floors are significantly reduced [26]. The lower part of the atrium between 2/F and 9/F contains typical classrooms, with four open corridors surrounding the atrium. The upper part, from 10/F to 13/F, consists of largely mechanical rooms and offices. The atrium corridors are used for circulation among rooms at different rooms. There are 67 numbers of ceiling-mounted energy-efficient T5 fluorescent tubes, with rated power ranging from 14 W to 35 W for the corridors at every floor. Daylight-linked dimming controls were installed in the corridors at 9th floor. The system detected both the reflected electric light and the daylight values to give a 'closed loop' control. The recorded lighting levels were sent to the dimmable electronic ballasts which adjust the light outputs of the lamp fittings accordingly. Four photoelectric sensors were mounted on the ceiling of the four corridors to record the light intensity. The daylight performance and energy use due to the daylight-linked dimming controls in the 9/F corridors were examined and reported [23,24]. There are three additional ceiling mounted photoelectric light level sensors installed respectively along the same plummet line from 6/F to 8/F to record the daylight illuminance. The data were transmitted to a logging system for storage. The recorded illuminance readings only provided the daylight availability for the corridors and the sensor itself did not form any part of the lighting controls. The present study analyzes the various types of control algorithms, namely differential switching, time delay and solar reset based on the daylight illuminance data measured in the atrium corridors.

4. Data analysis and simulation

The daylight illuminance data were recorded at 2.5 min intervals from 9:00 am to 6:00 pm. each day between February 2012 and July 2013. Totally, there are 216 daylight illuminance readings collected for each photo-sensor every day without any missing record. The analysis was on daily basis. The whole day illuminance data would be rejected if some data were omitted. It is inevitable that there would be some short periods of missing data due to different reasons including instrumentation malfunction and power failure. Considerable efforts were made to obtain a continuous record of data and in all about 257,000 data were recorded for use. The illuminance levels at a particular time were assumed to have applied for the whole of the time interval of 2.5 min since the previous scan. As pointed out by Littlefair [11] that such an assumption in practice might cause to a slight underestimate of the switching numbers during periods of very substantial daylight illuminance variation (i.e. on a less than 2.5 min timescale). Under a standard switching control, the daylight illuminance recorded by every photocell at each time was checked and if this was less the target illuminance (E_t), the control was assumed to have kept the lights on since the last scan. If it was larger than the E_t, the lights were assumed to have been off. At the end of the working day, the percentage of time the lights off was computed. The number of