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Study of daylight data and lighting energy savings for atrium corridors with lighting dimming controls

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ABSTRACT

Daylighting has been recognized as an essential element in architecture for enhancing visual comfort, energy-efficiency and green building developments. An appropriate lighting control linked with daylight can save electric lighting energy consumption and reduce peak electrical demands. In well day-lit spaces such as atria, daylight-linked lighting controls can provide substantial energy reductions. This study presents the visual performance and electric lighting energy use for an atrium building using high frequency dimming controls. The general features and characteristics of the results including electric energy expenditures and daylight illuminance were reported. Simple prediction approaches were used to demonstrate the lighting savings. The findings revealed that the dimming controls could be applicable to places with similar architectural layouts and lighting schemes.

1. Introduction

In Hong Kong, electric lighting is one of the major electricity-consuming sectors representing about 20–30% of the total energy use in commercial buildings [1]. There are many adverse effects on the environment from the burning of fossil fuels for electricity generation. It would be an important energy-efficient building design in displacing the need for electricity used in indoor lighting. Daylighting is recognized as an effective and sustainable development strategy for enhancing visual comfort, energy-efficiency and green building schemes [2–5]. Many studies have revealed that proper lighting controls integrated with daylighting have a strong potential for reducing energy demand in commercial buildings [6–9]. The electric lighting levels are adjusted by dimmable electronic ballasts according to the daylight illuminance sensed by the photosensor [9] and such ballasts can be controlled with the designed fuzzy logic controller [10]. Currently, lighting control system using a digital camera as a luminance meter instead of photosensor was proposed [11]. For light fittings, various energy-efficient lighting systems such as dimmable light emitting diodes (LEDs) luminaires were adopted [12,13].

An atrium allows daylight to penetrate into the core of a building that contributes not only cultural and architectural contents but also the potential to resolve many environmental issues [14]. It is an essential step to have sufficient well-distributed daylight from the atrium to achieve visual comfort and remarkable electric lighting savings if appropriate controls are adopted [15,16]. Daylight may vary significantly with different floor levels. For deep atria, rooms on the top floors can be over-lit and may cause glare while daylight levels on the lower floors may be very small and electric lightings are always required [17]. It is argued that photoelectric controls should be adopted for lamp fittings installed in day-lit spaces. Energy reduction can be achieved when the brightness from light fittings together with the daylight is more than the target value. It can be attained with proper daylight-linked lighting controls to dim down the electric lighting such that the indoor illuminance levels can meet the required values with less amount of electricity consumed. The actual savings, environmental benefits and quite short payback periods [18] can convince building owners and occupants to accept photoelectric lighting controls as an appropriate building designs and energy saving strategies. In day-lit circulation areas such as corridors, photoelectric lighting controls can provide excellent energy savings [19]. In Hong Kong, building incorporating daylighting schemes are not popular particularly for atrium spaces. The main reason for such unenthusiastic response to daylighting designs is the insufficient local field measured data to provide the actual energy savings for daylighting designs and evaluations. Previously, we presented the 6-month general daylighting and energy performance of an atrium space using photoelectric dimming controls [20]. This paper extends the study to analyze the actual lighting energy consumption and daylight illuminance in the atrium corridors recorded between February 2012 and January

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Fig. 1. Photo of the skylight.

2013 (i.e. a whole year). Simple prediction models were used to illustrate the lighting energy reductions and design implications discussed.

2. Building description and lighting controls in the atrium

The institutional building is a 13-storey block located in Hong Kong which is situated along the southern coast of China 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 skylight as shown in Fig. 1 contains a building integrated photovoltaic (BIPV) system mounted on the roof aperture [21]. The atrium corridors with the dimensions of 2.65 m (width), 14.65 m (along the atrium) and 2.22 m (height) are used for circulation to different classrooms. 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 each floor. Daylight-linked dimming controls were installed in the corridors at 9th floor. 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 [22]. 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 [23]. In normal operation, their residual light output and power consumption occur throughout working hours even if the illuminance level far exceeds the design value. However, such operations may be less noticeable and less disturbing to occupants [24]. The system detected both the reflected electric light and the daylight levels to provide a 'closed loop' control. The recorded lighting level was sent to the dimmable electronic ballasts which adjust the light outputs of the fluorescent lamps accordingly. To provide the minimum pre-set lighting level and record the light intensity along the corridors, four adjustable photoelectric sensors were mounted on the ceiling of the four corridors. Each T5 fluorescent tube is regulated by one dimmable high frequency electronic regulating ballast which can dim the lamp output smoothly and uniformly. The daylighting performance and energy use due to the daylight-linked dimming controls in the 9/F corridors were examined. The lighting circuitry for every corridor was separated with each other. As the individual corridor is a narrow plan walkway, a single-zone control is considered sufficient [25]. The maximum lighting load is 2261 W plus accessories including electronic ballast loads for the corridors at 9/F. The lighting power density defined as the electrical power consumed by lighting installations per unit floor area in the corridor was found of 14.6 W/m^2. In addition, three other ceiling-mounted photoelectric light level sensors were installed respectively along the same plummet line from 6/F to 8/F to record the illuminance. The data were transmitted to an illuminance level logging system for recording. The collected illuminance data only provided the daylight availability for the corridor and the senor itself did not form any part of the lighting controls. The details regarding the equipment set-up can be found in our previous work [20].

3. Measured data analysis

Measurements of the illuminance level due to electric lighting were conducted at night when all of the lamp fittings were on without any occupants walking through the corridors. The mean illuminance level for the corridors was found to be about 200 lx. According to the Chartered Institution of Building Services Engineers (CIBSE) Code for Interior Lighting [26], circulation areas such as corridors should have a design illuminance level of 100 lx. It means that the existing interior illuminance level was 100 lx more than the recommended value. However, such a design approach may be a necessity for an energy-efficiency scheme. An energy-efficient light fitting of high luminous efficacy often means that a less amount of energy is required to provide the same illuminance for a given indoor space. The illuminance after the energy-efficient lightings replacement can be far more than the required value which may cause glare and excessive brightness problems [8]. With the unchanged luminary layout and relocation of other building services, for instances, sprinkler heads and air diffusers are not required such that the excess installation costs can be minimized. Also, lighting design approaches such as the Lumen Method include maintenance factors, accounting for the decrease in illuminance due to the aging of lamps and dirt accumulation on luminaire and room surfaces. For newly installed lighting systems, the illuminance level would be more than the required design value. Further lighting energy reduction can be attained with proper photoelectric dimming controls to dim down the illuminance to the recommended level. In addition, the design can be more flexible to allow a wider range of setting illuminance up to 200 lx. Field measurements including illuminance levels and electric lighting energy expenditures were conducted between February 2012 and January 2013. Data were recorded at 2.5-min intervals for illuminance and 5-min intervals for lighting energy consumption from 9:00 am to 6:00 pm each day. These 12 months of measured data formed the basis for further study and evaluation. Setting aside any missing data including instrumentation malfunction and power failure, totally around 420,000 data for illuminance (6–8/F and 4 corridors at 9/F) and 140,000 readings (4 corridors at 9/F) for lighting energy consumption were made.

3.1. Lighting energy consumption

Electricity consumption for the T5 fluorescent light fittings in the corridors located at 9th Floor under the automatic dimming controls were recorded and analyzed. Fig. 2 presents the monthly mean electricity use for the 12 months. The pattern can reflect the monthly variations in daylighting performance. Due to the longer day-length, electric lighting expenditures in summer months between June and September were less than those in other periods. The monthly mean lighting energy use for the 4 zones at 9th Floor varied between 72 kWh for Zone 2 in August and 182 kWh for Zone 1 in November. In general, Zone 1 consumed the largest lighting energy while Zone 2 the lowest. On average, the lighting energy