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A set of indices to assess the real performance of daylight-linked control systems

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ABSTRACT

The installation of Building Automation Control Systems (BACs) in general is an effective action to achieve relevant energy savings. Commercial BACs, installed in residential or small offices, often include functions of lighting control, acting as Daylight-Linked Control Systems (DLCSs). Nevertheless, because system performance is strictly dependent on different parameters, BAC's hardware and software configuration and as well as an inaccurate commissioning do not always allow a perfect execution of the desired tasks; therefore, the system could not work as expected. Moreover, it is well known that energy saving potential is specifically related to the variability of the light environment. Although many methods to assess it are available, these are mainly based on average data, tabular factors, and climate/lighting time series embedded in weather files used in detailed simulations and, in general, they adopt as a benchmark the performance of ideal control systems. In this paper, actual performances of a daylight-linked control system have been evaluated by a set of indices which, in general, can be calculated, after measurement, during the commissioning stage or in periodic monitoring of the system. In particular, these indices take into account the excess and the deficiency of illuminance over time with respect to a target set point that a lighting system should provide and the related energy consumption. The indices have been tested using data measured in a laboratory set up where a commercial daylight-linked control system, working not close to an ideal one, is installed and has been evaluated for different end uses, operating schedules, control strategy (dimming and ON/OFF) and daylight conditions. Finally, useful relations between system performance and environmental conditions have been found.

1. Introduction

In the last years, an increasing attention has been focused by researchers, designers and technicians on the use of automated light control systems, which are today widespread components of smart buildings. This kind of system can play a key role in achieving a significant reduction in the electrical consumption for lighting and all of the well-acknowledged benefits received from daylight (e.g. occupant comfort, health, well-being and productivity). It is very common, during the design steps, to build reliable relationships between energy saving and available daylight. This is an important task for designers and architects [1]. Many studies have tried to gain understanding of how to assess the energy savings achievable by installing a lighting control system for lighting that works according to the daylight contribution. Most of these compared the energy consumption with and without a control system [2], others used simulation software [3–13], others used field tests and monitoring [14–19], others developed algorithms or combined more methods [20,21]. Furthermore, many indices have been defined to synthetize this information, taking into account climate and luminous contexts. Reinhart improved the Daylight Autonomy originally proposed by "Association Suisse des Electriciens" [22]. Two modifications of Daylight Autonomy are the "continuous daylight autonomy (DA_{con})" and the "daylight autonomy max (DA_{max})". DA_{con}, as proposed by Roger's [23] associates partial credit for daylight levels below a user-defined threshold in a linear fashion.

Abbreviations: ALD, artificial lighting demand; BAC, building automation control; DA, daylight autonomy; DF, daylight factor; DF_{ave}, average daylight factor; ELEC, electrical consumption; E_{art}, illuminance due to the artificial lighting; E_{in}, indoor illuminance; E_{nat}, illuminance due to the natural lighting; E_{out}, outdoor illuminance; E_{set}, illuminance target value on task area; E_{tot}, illuminance due to the natural and artificial lighting; ERI, energy ratio of illuminance; OAR, over illuminance avoidance ratio; UAR, under illuminance avoidance ratio; UDI, useful daylight illuminance.

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The Useful Daylight Illuminance (UDI) is another index that considers three ranges/bins of annual illuminance distribution [24]. Tregenza proposed simple calculation procedures for determining the daylight illuminance in rooms facing sunlit streets [25]. Another index used to evaluate the annual Daylighting Performance is called Annual Sun Exposure (ASE). In the forthcoming IES LM-83 [26], it is defined as the percentage of area that has direct sunlight for more than 250 h a year and is, therefore, used to evaluate how much space receives too much direct sunlight, which can cause visual discomfort (glare) or increase cooling loads. Spatial Daylight Autonomy (sDA) describes how much of a space receives sufficient daylight. Specifically, it describes the percentage of floor area that receives at least 300 lx for at least 50% of the annual occupied hours.

The European Standard EN 15193 [27] contains a method to estimate the electrical energy consumption for lighting through the Lighting Energy Numeric Indicator (LENI), which indicates the annual energy consumption per m^2 for artificial lighting in a building. This index takes into account several parameters such as the total power installed for lighting, the yearly operating time, the Daylight Autonomy of the zone under consideration, the type of daylight responsive control system and the installed shading system.

The new standard prEN15193-1:2015 introduced a new method for the calculation of energy requirements for lighting. The expression of energy performance of a given lighting system can be indicated by the expenditure factor, wherein the higher the expenditure factor is, the less efficient the lighting system is. This can be derived by correlation of the previously derived values. Applying this methodology allows a quick analysis of the energy flows in an electric lighting system. The expenditure factor for lighting systems is defined as the ratio between the energy used for lighting (either calculated or measured) and the reference energy needed for lighting. This is a conventional figure that can be calculated combining a series of factors related to the delivery of electric light to the task area, the luminaire efficiency, as well as the light source efficiency.

Actual performances of Building Automation Control (BAC) and Daylight-Linked Control systems (DLCs) are often far from those achievable in their ideal operation; therefore, an evaluation of their "efficiency" is required but almost never done [28]. Control systems for electric lighting are frequently found to be poorly implemented, calibrated or commissioned, or perhaps too complex, resulting in reduced energy savings, annoyance of users or even in complete deactivation of the control system. This highlights the need for better guidance on the installation, commissioning and operation of lighting control systems [29]. For this reason, many recent studies have been carried out about the optimization of lighting control systems [30]. Valíþek et al. [31] drew attention to possible problems connected with the principle of regulation to constant illuminance in a smart home (SH) using the Konnex (KNX) technology. First of all, since average illuminance standard values in the places of visual tasks may not be observed, it is important to pay attention to the placement of the photosensors during the design step and to set a constant for the conversion of these measures to real illuminance values on the places of visual tasks. E.g. Bellia et al. [32] mentioned the factors that can influence the performance of the energy savings achievable with the lighting control systems for each category of controls and Doulas et al. [33] explained that the performance of the photosensor depends on a lot of variables, such as the distribution of the lighting and the adjustment settings of the commissioning control. The same author in another paper [34] reminded us that, since there is no standard rule among manufacturers, a trial-and-error method is often used by the contractors in order to obtain descent dimming response. Moreover, commercial BACs, installed in residential or small offices to manage several functions of home services, often include functions of lighting control, acting as DLCSs. Its hardware and software configuration, as well as an inaccurate commissioning, could not always allow it to perfectly reach the desired tasks; therefore, the system could not work as expected.

This paper proposes a method based on a set of indices which make possible the evaluation of the efficiency of an installed automation system for lighting control either in terms of energy consumption or the ability to maintain visual comfort targets. This assessment can be made through a set of scheduled measurements. It allows estimating the actual system operation which very often is far from the results derived from simulations or assessed by frequency indices which generally assume that the system is running in ideal ways. For this reason, the method can be utilised in the commissioning stage or in periodic or ex post monitoring of system performances. The efficacy and reliability of these indices have been tested by using data collected during an experimental campaign in a monitored space equipped with commercial DLCs.

2. The experimental set up

The measurement campaign has been carried out at the Solarlab laboratory [35]. It is located on the third floor of the building hosting the DEIM of the University of Palermo, Italy. The area is 106 m^2 and the height is 4.40 m including the false ceiling, and 3.40 m excluding the false ceiling. Across the long side, four windows (2.40 × 2.90 m) are present. They are equipped with double-glazing with aluminium frames without any blind system and are located on the southeast side. In front of them, there is a green roof (albedo average value = 0.25). Medium height plants on the green roof cover two windows. Furthermore, the facade is partially shaded by a shelter (2.70 × 19 m). In the laboratory, the following lighting luminaires are installed: four suspended luminaires equipped by LED (each one with a power of 54W) and four mono optic indoor LED spotlights (15 W). The first luminaries are characterized by a power supply unit with DALI interface and are equipped with micro-lens optics in a polycarbonate cover. The initial luminous flux declared by the manufacturer is 3600 lm and the initial LED luminaire efficacy 92 lm/W. Regarding the mono optic LED, the initial luminous flux was 700 lm and the luminaire efficacy was 50 lm/W. Both luminaires have a colour temperature of 3000 K and a colour rendering index of ≥80. The lighting power density is 1.86 W/m^2 for the whole area and 2.9 W/m^2 for the area of the zone considered in this work (where the three dimmable suspended luminaires are installed).

The luminaires have been selected in order to achieve for each zone the illuminance values, suggested by the Italian UNI 10380 standard [36], for the residential case, and by the EN 12464 [37] standard, for the office case. Preliminary calculations have been performed using the lighting simulation software DIALUX (Fig. 1) in order to design the lighting system.

The DLCSs is composed of photosensor, a scenarios programmer, a DALI controller unit, two dimmer actuators and four manual actuators.

The system is a commercial product manufactured by BTICINO and is settable using the proprietary software MyHome Suite which can manage several BAC functions, including lighting control.

Fig. 2 shows the plan and the section of the Solarlab with the identification of the zone where the lighting task has been analysed, and the distribution of the luminaires and of the control system devices. In particular, according to the CEI Guide 205-18 [38], the lighting control functions classified as F48A (presence detection Auto-ON/Reduction/OFF) have been implemented. The photosensor used to control the three luminaires is installed on the ceiling about m 1.60 away from the window, (close to one of the two photosensors Delta Ohm installed on the ceiling utilised for the measurements) and is characterized by an angle view of 180° longitudinally and 360° horizontally. As in most lighting control