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A first approach to universal daylight and occupancy control system for any lamps: Simulated case in an academic classroom

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ABSTRACT

This paper presents a lighting control system based on natural light monitoring and on occupancy control, characterized by installation easiness, even for existing plants, and cheapness.

The system is based on a smart control unit and lighting control devices that can be directly mounted on the lamps in series connection. The installation is noninvasive and does not require any changes in the wiring system, since the communication between each lamp and the control system is realized by means of a 2.4 GHz wireless protocol. The system functionality is ensured with any lamps, also with non-dimmable ones. Tests and functionality verifications on the system were performed in laboratory, proving the applicability to real cases and performances that are comparable to the ones achievable with dimmable LED lamps, but with a significant cost saving.

Hypothesizing the application of the proposed system and of different control technologies and strategies to a real academic classroom case study, different lighting scenarios have been simulated. Obtained results allow quantifying the effects in terms of energy consumption and CO_2 emissions relative to such scenarios, achieving up to 69.6% of energy saving and 30.5% of CO_2 emissions avoided. From an economic point of view, the comparison between the proposed control system and commercial systems shows a shorter PayBack Period, from 9 to 5 years.

1. Introduction

Energy consumption for lighting is, nowadays, responsible of about 20% of the overall energy consumption [1]. This datum justifies the recent attempts for searching efficient technologies, able to contribute to energy consumption reduction.

The high performances of LED (light emitting diodes) lamps pushed their rapid spread [2], leading to a direct energy saving.

According to a study of Ozenc et al. [3], LED lamps, besides having a higher lighting efficiency compared to fluorescent lamp, allow high savings in case of dimming. Hypothesizing a 50% dimming ratio, fluorescent lamps lose 24% of lighting efficiency, whilst LED lamps 1.3%. Therefore, in terms of energy efficiency, LEDs are more suitable for dimming than fluorescent lamps.

Differently, according to Doulos et al. [4], control systems are still not sufficiently examined. Lighting control techniques and strategies represent a complex matter, due to their planning process, to the proper matching of the dimming system for the used luminaires [4], to the installation features [5] and to the difficulties on the evaluation of investment payback time [5,6]. For all these reasons, spread of lighting control systems is slower than lamps and luminaires. Nevertheless, research on lighting control systems proceeds along different directions. In some cases, scientific developments aim to an upgrade of light control technologies [7,8]. In other cases, the scope is searching for a reliable evaluation system of real energy savings [9].

An interesting review on lighting control technologies is presented by Haq et al. [10]. Yu and Su [11] presented a literature review in which they state that, amongst all lighting control systems, the ones more commonly employed are the high frequency dimming control and the on-off control; the choice of the control system deeply influences the energy saving potential. Salata et al. [12] discussed a case study of a classroom of an academic building. Results obtainable by considering the interplay between natural and artificial light are highlighted. A new lighting system is proposed, able to manage the automatic partialization of motorized indoor roller blinds and the presence of occupants in the room.

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Energy saving is well discussed in literature. The energy saving amount can vary on monthly and seasonal basis, as assessed in [13]. In the paper, monthly savings vary from 20% in December to 47% in June and July. Energy saving of 21% in winter season increases to 45% in summer. On seasonal basis, savings differ according to weather conditions. The overall annual energy saving achievable by adopting a daylight responsive control system is up to 31% for climate conditions similar to the ones of Istanbul. In the paper by Martirano [14], the consumption relative to two adjacent classrooms has been evaluated. In particular, the light control system foreseen for the two rooms is conceived to meet the needs required by scheduling, luminance control, occupancy, daylighting and zoning. The evaluations are carried out using the LENI (lighting energy numeric indicator) methodology. According to the author, the energy saving achievable by adopting action in power reduction (like, for instance, more efficient lamp) is almost the 20%, while the savings obtainable by using lighting control systems (like occupancy sensors) depend on the control mode (dimming or switching) and swing between 35% and 42%. By implementing control systems and efficient equipment, the energy saving accounts for 54%. The work of Bardhan and Debnath [15] deals with the analysis of the energy saving potential of a residential building when, as daylight performance parameter, the Useful Daylight Illuminance (UDI) is considered. It turns out that energy saving potential depends on the orientation and on the window-to-wall (WWR) ratio. The maximum energy saving for the analyzed building, equal to 26%, is achieved with a south-east orientation of the functional space and WWR of 20%. In the work of Choi et al. [16], two methodologies of predicting the lighting power savings are compared. One (Method A) refers to the relationship between lighting energy and illuminance. These two parameters, which can be considered as input and output of the system respectively, are also evaluated according to the dimming ratio of the luminaire. The second approach (Method B) consists in taking into account the indirect illuminance in the evaluations carried out through Method A. Results obtained via method A and B are then compared to the lighting energy saving experimentally measured. In reference [17], the energy and power consumption of three identical classrooms equipped with different dimming systems have been compared. An open-loop system was installed in a classroom, whilst in the other two there were two different closed-loop systems (with individual daylight sensor per luminaire or centrally positioned sensor). Results gathered during 12 months, during which the rooms were occupied for teaching purposes, showed that the daylight control system with open-loop system lead to a 46% lighting energy saving. This value is higher than the saving due to closed-loop system, which yielded to 34% and 18% energy saving, the latter being recorded for the room with central positioned sensor.

Detailed studies on lighting control for daylighting and occupancy adaptation show the different approaches adoptable. A work proposed by Peruffo et al. [18] discussed a wireless mesh networked lighting system with multiple sensors equipped with a central controller, evaluated through a simulation performed with DIALux. In this study, it is underlined that wireless connections are simpler than wired ones, and they are useful for lighting controls retrofitting. Aghemo et al. [6] presented an experimental analysis given by the installation of custom-designed building automation and control systems for lighting and air conditioning on 11 offices in Turin (Italy). Lighting control is realized with digital dimming ballast (DALI protocol), while system nodes communicate with LonWorks protocol. Results show an energy saving variable from 17% to 32%, considering both the annual electric consumption and the parasitic energy consumption, due to sensors and controllers. A study conducted by Xu et al. [19] presented an energy performance evaluation for lighting systems with 8 different control strategies. The employed technology is based on commercial sensors (OSRAM LS/PD MULTI 3) and the data gathering core is a PLC (programmable logic controller). Results show that the employment of a generic lighting control system allows energy savings of the order of 50%. The combination of task lighting and dimming allows achieving energy saving up to 59%, still guaranteeing comfort for occupants. Doulos et al. [5] presented a study in which they quantify energy savings among 18 different EDBs (electronic dimming ballasts), identifying the relationship between light output ratio and control voltage, consumed power and control voltage, power factor and control voltage and between consumed power and light output ratio. Simulation results of an office building reveal significant differences in energy saving due to tested ballasts. Rossi et al. [20] discussed a comparison between two lighting control scenarios in an open office lighting model: the first scenario considered a daylight and occupancy adaptation based on pre-specified illumination targets, whereas the second scenario evaluated via simulations the performance of a lighting control based additionally on user control requests. In the work of Caicedo et al. [21], a lighting system with light sensors co-located at light source was considered, in order to assess by means of simulations how a central controller can minimize power consumption maintaining a minimum average illuminance level on the workspace plane. Prior-information for sensor calibration step were also provided.

In this work, different types of control systems, the development of the related technologies, the savings obtainable from their application and factors affecting their performance are debated. Moreover, trend of developments on lighting control and possible future advancements are discussed. The next part of the paper is organized as follows. In Section 2 the objectives of the work are presented. Section 3 reports the novel lighting control system and the simulated case study. Section 4 deals with obtained results. Finally, in Section 5 conclusions are given.

2. Objectives

Lighting control systems, although allowing relevant reduction of energy consumption, are often affected by design and installation complexity, high costs, difficulties in evaluating real energy benefits and technical management problems [5,6,22]. These reasons determine their smaller spread compared to the possible expectations. As stated in Ref. [23], the spread of lighting control system is wider in new buildings than in old ones. This point of view negatively influences results on overall energy savings obtainable by the lighting sector. In fact, according to Pellegrino et al. [24], based on the small amount of new buildings realized in developed Countries, the energy saving potential can be realized only with the retrofitting of the existing building stock.

For these reasons, the main objective of the present work is the proposal of a novel automatic daylight control system and occupancy sensing, employable with different lamp typologies; it is conceived especially for application on existing buildings, thanks to its extreme ease of installation, wireless communication capability and to low investment cost. The idea of creating a new control system usable with any lamps aims at minimizing the negative aspects that usually characterize the installation of a lighting control system in existing buildings, i.e. high investment costs and possible modifications of lighting fixture, with the attempt of maximizing the diffusion of such systems. The proposed system differs from available literary solutions [25–28] and available commercial products because it allows to define a lighting control systems making use of any type of lamps, regardless of their dimmable and non-dimmable characteristic, also including the conventional light bulbs such as halogen and fluorescent lamps, beyond of LED ones. Up to now, all literary contributions that have been presented try to manipulate the driver circuit inside the LED lamp in order to make