A Smart LED Light Control System
for Environmentally Friendly Buildings

Michele Magno, Tommaso Polonelli and Luca Benini

Abstract This paper proposes a low cost, wireless, easy to install, adaptable smart LED lighting system to automatically adjust the light intensity of LED panels to save energy and to maintain user satisfaction. The wireless control system is based on ZigBee communication and combines a light sensor with a motion sensor to perform an energy saving algorithm. Measurements of total energy consumption over a continuous six-month period were acquired to verify the performance and evaluate the benefits in terms of power savings of the proposed solution. In the monitored application scenario, the total energy consumption has been reduced by over 60 % during a six-month period and up to 70 % in spring months.

1 Introduction

Current statistics show that even to this day, energy used for lighting continues to be a significant share of the entire energy consumption. For example, around 25 % of electricity in commercial buildings in the United States is used for lighting [1]. Although there has been a considerable research effort in recent years, there is still much that can be experimented to reduce energy waste. It is evident that artificial lighting uses a considerable amount of energy, and even a 1 % saving on that part alone will significantly increase the energy efficiency. For this reason, new intelligent lighting systems have been created in the past years and many continue to be developed. The goal has always been the pursuit of an optimized system from the energy efficiency point of view, paying less attention to the user's comfort. This can have an enormous effect on the productivity of employees, creating less than optimal working conditions, especially for focus intensive, problem-solving activities. Lighting does not just illuminate the office, it can affect the mood, energy and efficiency of workers and even increase their sense of comfort [1].

M. Magno (✉) · T. Polonelli · L. Benini
DEI, University of Bologna, Bologna, Italy
e-mail: michele.magno@unibo.it

Wireless sensor networks are today a mature technology used in many applications for energy conservation applications such as light control [1–4] or other applications [4–10]. In [3], the authors present a light controlling system that achieves both energy saving and user's satisfaction. The proposed approach on the decision of the controlled light is based on the user's location and his luminosity preference. Due to the centralized algorithms controls the light dimming and minimizes the consumed power. In [11] light sensors are added to the control system to take into account the change of daylight during the day. Due to the light sensors, it is possible to achieve better performance in terms of power saving of the controlled LED panels, as the control system can evaluate the optimal dimming level. The work described in [12] targets to minimize the overall cost of the energy spent in media production system. To achieve this goal, their control algorithm uses both cost functions and user's preferences. The authors' approach is interesting and show the benefit to use controlling system also in different application scenarios. The authors in [13], present a similar approach deploying a sensors network with wireless communication to minimize the energy consumed by lights in buildings. Unfortunately, the paper does not give enough detail on the proposed approach, especially it is not clear if the proposed control algorithm is centralized or distributed. However, the authors show an interesting approach similar to our work, where both motion sensors and lights sensors are used to adjust the light intensity with the aim to minimize the energy consumption. In this work we present long-term (over several months) and evaluation in a real office of the energy saved during three different seasons and weather conditions.

The contribution of this work is the in-field evaluation of real-time monitoring and control lighting system designed to improve the energy efficiency of building, optimizing the dimming of the LED lights. A flexible wireless sensor network has been deployed in-field in a real office to evaluate the energy saving performance in a long period. The developed system has been designed and developed in a previous work [2] and reduces the installation cost and guarantees smart and energy efficient building and office with a high return on investment in terms of energy saved. The presented system is composed of a ZigBee wireless sensor network that controls the lights according of user preferences and light/occupation condition and a distributed control module on a base station that will be able to control the lights of that system. For this reason, this prototype will provide a graphical user interface to allow the user to work on it. This system has been developed and deployed in collaboration with a Verde LED, Ireland.

2 Smart Lighting System Architecture

Figure 1 shows the architecture of the developed control system, and more information can be found in [2]. There are several wireless nodes connected through ZigBee [14] radios in a mesh network. The whole system includes one coordinator, many routers and several End Devices (EDs). In the proposed network, each
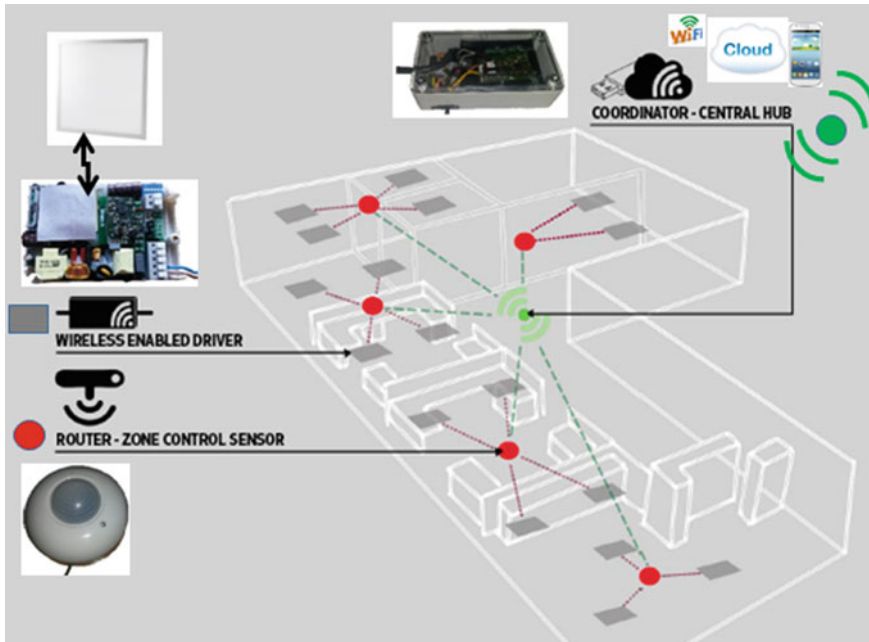
Fig. 1 Depolyment of the proposed wireless system with the types of nodes designed: (i) The network coordinator connected with a PC to the user interface and other wireless protocol (WiFi/Bluetooth); (ii) Sensor node programmed as a network router to monitor the controlled area with motion and light sensors, (iii) Wireless driver device inserted directly in the LED panel driver to dim the light intensity according with the user's preferences and the sensor data to minimize the energy consumption and reach the optima brightness in the rooms

ZigBee ED is directly connected to a LED panel driver that can directly set the dimming level of the panel through a pulse-width modulation (PWM) signal. The routers host one light sensor and one pyroelectric infrared (PIR) sensor to decide the optimal value of the brightness intensity of the associated LED panels according to sensors and users' preferences. The control algorithm evaluates the optimal value to minimize the energy used from the panels. The scalability of the network is permitted by the mesh configuration of the standard Zigbee allowing a modular system which is easily extendable. Moreover, each LED panel group is completely independent and comprises several units to monitor/control several different area sizes. In fact, the number of controllable associated LED panels and ED devices by every router/sensors device it is variable and can be dynamically adapted according to deployment requirements. Finally, the coordinator is responsible for the management of the whole wireless network ensuring that all the other devices are connecting in the proper way. The second important role of this device is to work as the main gateway with an ultra low power embedded device with Wireless Lan/Bluetooth interface to enable the simple user interface with phone or PC. Due to the user interface the manager of the network (or the user self) can set the light preferences

allowing the control system to match them to adapt the dimming of the LED panels. The designed system includes also a graphical user interface on pc or phone to allow the user to monitor run-time the value of the energy saved during all the activity period. The user can also group the LED panels with a specific sensor node in order to optimize the control system. The graphic interface allows the user also to be aware of the energy saved according to the light preferences. In fact, the energy consumed depends on different variables but the dominant is the user's preference. Another crucial factor that affects the energy saving is the position of the controlled lights, for instance in a room with a huge window and in direction of the sun it is possible to save much more energy than in a room without windows. Other factors are of course the weather conditions, season, geographical location, etc.

The wireless devices of the network have been designed using the CC2530 system on chip (SoC) from Texas Instruments. The main reason of the choice is the low power consumption, the integration of the 802.15.4 radio with the ZigBee Pro stack and the possibility to have a cheap and fast deployment in the field. All the designed devices have a dual core architecture including two chips: the MSP430 microcontroller has been used to implement the control algorithm and the firmware developed, while the CC2530 is the responsible of the wireless communication trough ZigBee PRO stack. As we used the ZigBee Stack there are three possible types of devices: 1 Coordinator, Routers, and end devices. In our implementation the coordinator is connected via an USB port the PC where the user interface has been developed. On the other hand, the routers are equipped with the light and motion sensors to monitor the buildings, finally the end devices are connected inside the LED driver to control the dimming level with a standard PWM or 0–10 V control port.

2.1 Wireless Driver Device

As we mentioned before, the intelligence is provided by a MSP430 microcontroller that is embedded in all the devices. The MSP430 is also managing the CC2530 SoC to exploit the ZigBee stack implemented on it. The architecture of the wireless driver device is presented Fig. 2. The wireless device includes the electronic circuits to control the industrial driver and the dc-dc converter to be supplied with an external power supply with a voltage rage of 3–24 V. This range allows the wireless driver to be adaptable for several LED panels to increase the flexibility of the solution (Fig. 2). The most important subsystem of the wireless driver is the PWM-Driver block shown in Fig. 2. In fact, this block converts the 3.3 V PWM signal provided by from the MSP430 in a 0–10 V signal adopted by most of the commercial LED drivers to control the diming of the LED panels. This control interface makes the developed wireless driver adaptable to a wide range of drivers on the market. The only requirements for the driver is to provide a standard 0–10 V port. In this work we present a wireless driver that has been directly incorporated directly into a commercial driver by Meanwell as shown in figure.
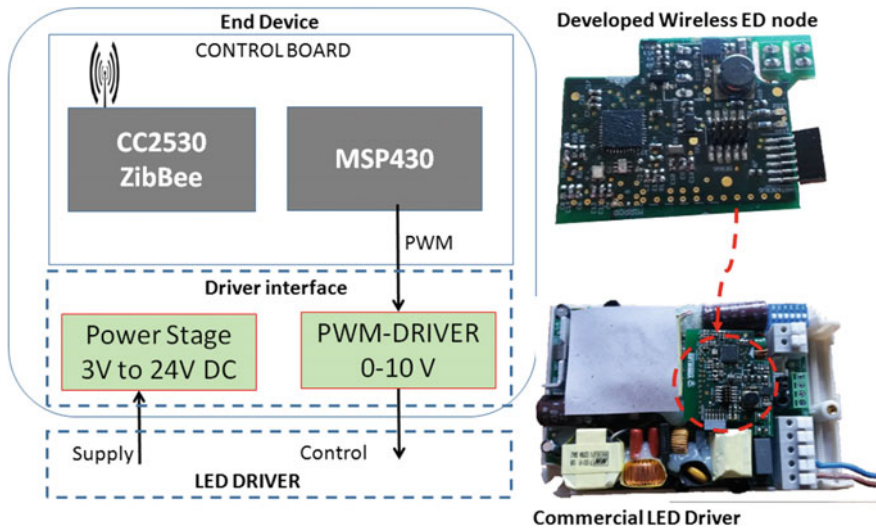
Fig. 2 Wireless driver device architecture designed to be inserted directly into commercial drivers. The wireless node can dim the panel trough the 0–10 V port and take supply voltage from it

2.2 Router for Monitoring and Decision Making

The router hardware architecture is presented in Fig. 3. The architecture is very similar to the wireless driver, with the only difference that the PWM driver block is replaced by the light and PIR sensors block. The PIR block includes also the coupling circuit that generates an interrupt when an everything is moving in its filed of view. The PIR selected is the Panasonic EW—AMN34111J due to its fast and accurate trigger in the range of 10 m of field of view. The PIR out trigger is directly connected to a General Purpose Input Output (GPIO) pin of the microcontroller that in this way is aware of every motion in the field of view. The designed sensor node includes also a low power light sensor to continuously monitor the intensity of light on the room or monitored area of interest. The light value is the most important information need by the controlling algorithm to decide the dimming level of the LED panels. The selected light sensor has been the Osram SFH 5711 that provides a analog output proportional to the light intensity. The analog output of the sensor is connected with th internal Analog digital converter of the microcontroller that can run the controlling algorithm to according with the user's preferences and the implemented power policy. As for the wireless driver, the wireless communication protocol is managed using the CC2530 that includes the ZigbeePRO stack. The routers are in charge of the most important duties for the wireless systems with the following main duties: (i) manage the routing protocol of the Zigbee stack, monitoring the environmental parameters throughout the sensors, (ii) take the decision
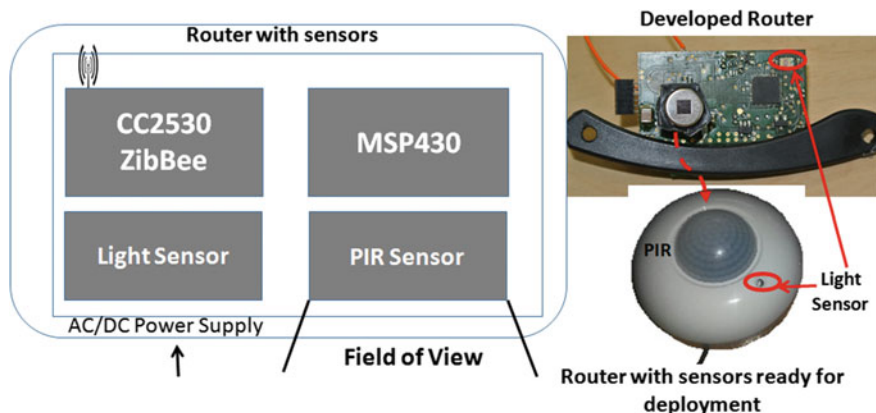
Fig. 3 Architecture of the sensor node designed. The node works also as a router of the Zigbee network [2]

on the light intensity, and (iii) send the control configuration to the panels that are assigned under its control during the network configuration.

2.3 Base Control Station

The base control station is the hub of the proposed system as it allows the visualization of the lighting system and the setting of important parameters such as the users' preferences. The role of the coordinator is only to manage the network and allow the user interface through a remote host (Fig. 4). Thanks to the interface and the remote host, it is possible to set the users' preferences, and monitor the whole network and store all the data to evaluate the power saving.

3 Experimental Results

The system was designed, implemented and deployed in a real office testbed to evaluate the benefits in terms of energy saving. Separate groups of LED panels were deployed in separated areas controlled by the sensors device. Although the entire area can be set with different users' preference, we set a default value to 600 lx, which is a standard value for office light. The wireless system has been run continuously for 12 months and the all the data of dimming value and power consumed by panel were stored in a database. Figure 5 shows the average power saving and consumption of 6 months for all the monitored LED panels in the office deployment. The data were compared with an office scenario without the smart control and the energy saving was from 60 % in October up to 70 % on May.
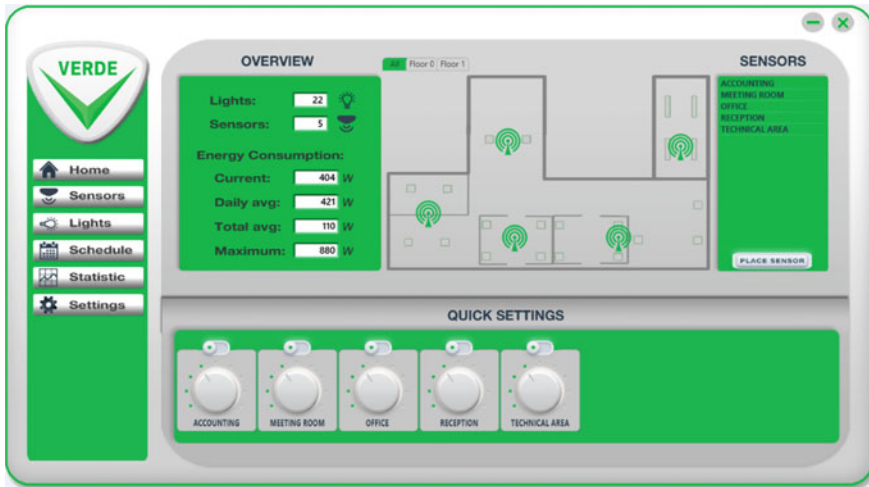
Fig. 4 User interface to manage the whole system network and the preferences. The user interface has been developed in collaboration with Verde LED

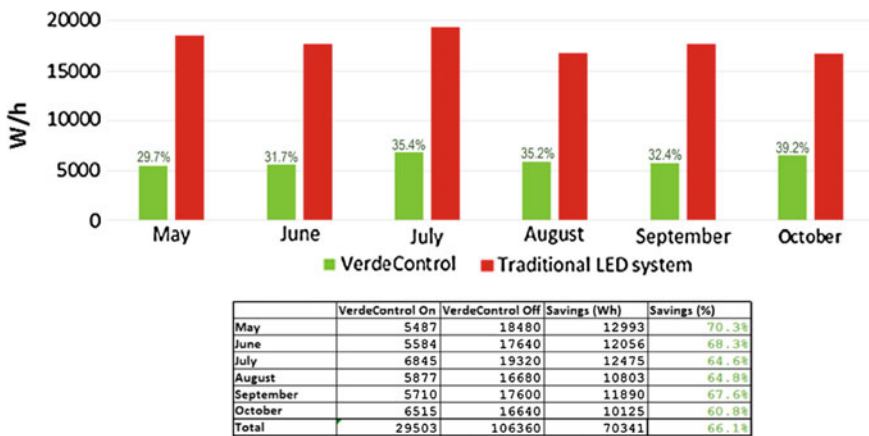|	VerdeControl On	VerdeControl Off	Savings (Wh)	Savings (%)
May	5487	18480	12993	70.3%
June	5584	17640	12056	68.3%
July	6845	19320	12475	64.6%
August	5877	16680	10803	64.8%
September	5710	17600	11890	67.6%
October	6515	16640	10125	60.8%
Total	29503	106360	70341	66.1%

Fig. 5 Energy saving and comparison with a system without smart control during 6 months

4 Conclusions

In this paper we presented the long term in-field evaluation of a novel smart lighting control system which has been designed and developed using a ZigBee network. The system has as main goal to be unobtrusive, low power, low cost, easy to be installed and scalable. Experimental results in a real office during several months show the developed systems is able to introduce up to 70 % power savings over the

same system without control. Due to the ZigBee communication protocol would be possible to cover huge deployment and future work will be focus on the scalability of the system deploying it in bigger buildings with more than 1000 devices.

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