Development of a Smart and Energy-Saving Lighting System for Classroom

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ABSTRACT*: The paper presents the results in development of a smart and energy-saving lighting system for classroom. The lighting system is consisted of Smart LEDs, each of which includes a LED driver integrated with a communication and control module, LED lamps and a light sensor; and the central control panel. Mathematical and simulation models of an automatic lighting control system according to natural light have been built. The controller is designed, fabricated and programmed basedon thecontrol algorithm in the mathematical model. The control panel is responsible for controlling and configuring the system. The system has been tested at Vietnam Academy of Science and Technology and piloted in 05 primary schools, 2 classes each in Quang Nam province.*
KEYWORDS-*LED drive, automatic lighting control, class room lighting, smart lighting, IoT*

I. INTRODUCTION

The lighting system consumes a large amount of electricity in the total energy use of buildings. According to statistics, the electricity used for lighting worldwide accounts for about 19-20% of the total global electricity consumption [1,2]. Therefore, using energy economically and efficiently in lighting are researched in many countries.

In recent years, LEDs are growing very rapidly. In 2019, LED sales has exceed fluorescent lamps and it is expected that LEDs will make up to over 90% of sales by 2030 [3]. LEDs save 50-70% more energy than traditional lamps and the price is decreasing. LEDs are also easier for dimming than traditional lamps [4]. LED lights open up new possibilities in smart lighting.

Smart lighting can bring comfort, save energy by automatically turning on or off according to occupancy and regulating the illuminance according to the natural light.

In Vietnam, the survey results on the current status of 20 primary schools in Quang Nam province (2016) by the Institute of Energy Science showed that the classrooms were not provided enough illuminance (average below 300lx), and the brightness was not even. During the sunny time, the natural light intensity during the day, especially from 9am to 4pm, the desks near the windows are overexposed, while the inside is dim. Changing light intensity not only affects children's eyesight but also has a negative impact on students' teaching and learning.

This paper will present the results of development of a smart, energy-saving lighting system for classroom. The system has been installed experimentally at Vietnam Academy of Science and Technology and piloted at 05 primary schools in Quang Nam province.

II. SYSTEM DESCRIPTIONS

A. System overview

The smart and energy-saving lighting system for classroom includes the lamps and the control panel (**Figure 1**).The system has the following components:
-    Smart LED includes the following subcomponents:
     o   A LED driver, which is integrated with control and communication
     o   A LED panel
     o   An Illuminance sensor is a light dependent resistor
-    Control panel, which allows:
     o   end users to turn on/off the system, switch mode, ...

- o technical personnel to set configure the system through a web based graphic interface from a mobile phone or a laptop through wifi
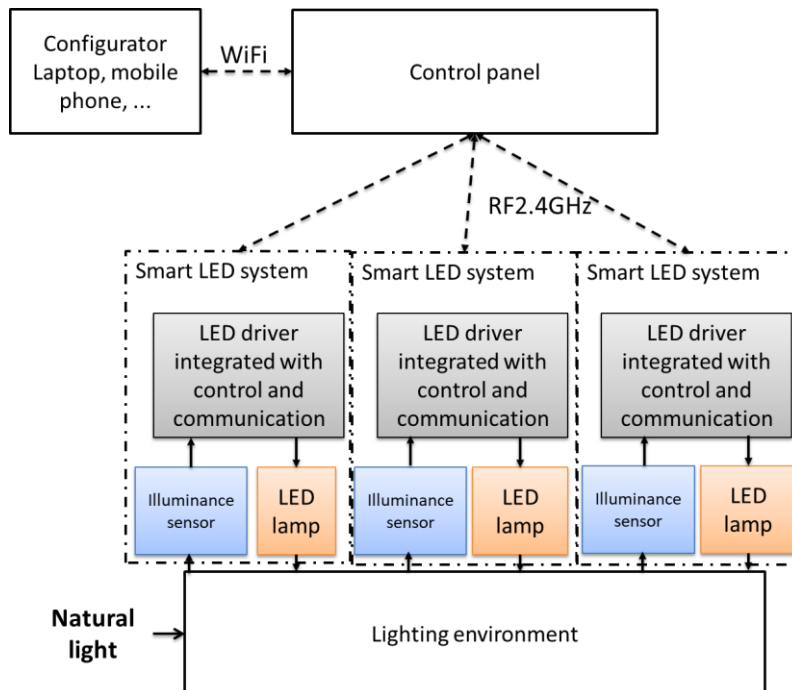- o the control panel itself to control each Smart LED individually

Figure 1. Diagram of the smart and energy-saving lighting system for classroom

B. LED driver integrated with control and communication

The LED driveris integrated with:
- a control module, which measures iluuminance using a light dependent resistor and automatically regulates the power supplied to the LEDs so that the illuminance on the working plane track to the a set point
- a communication module, which wirelessly communicates with control panel and allows control panel to manage LEDs in the system, to configure the set point, the control parameters of each control module.
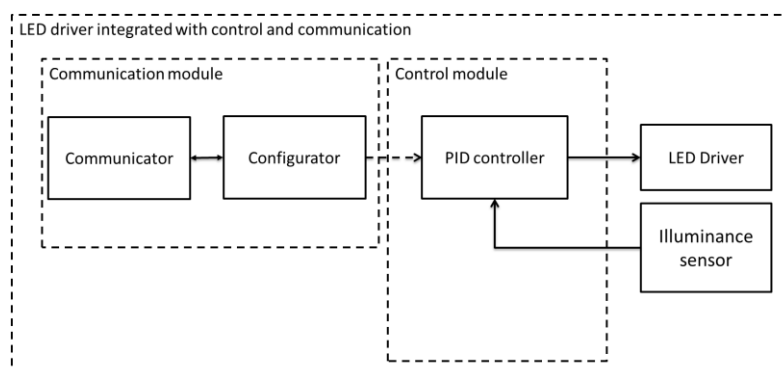-

Figure 2.. Block diagram of LED driver integrated with control and communication modules

The control module implemented the automatic control algorithm which was presented by the authors in [5]. A typical lighting automatic control system is shown in Figure 3. The lighting environment considered in this system is consisted of a LED lamp, a working plane and natural light. A LED lamp is supplied from a LED driver, which is controlled by a microcontroller through PWM. The light from LED is mixed with natural light at a given point on the working plane. From automatic control point of view, natural light is load disturbance. Illuminance measured by an illuminance sensor (In this system, it is a light dependant resistor) is an analog value, which is converted to digital value by an analog-digital converter (ADC). PID controller compares this feedback value with the set point and regulates the LED lamp power through PWM and LED driver.
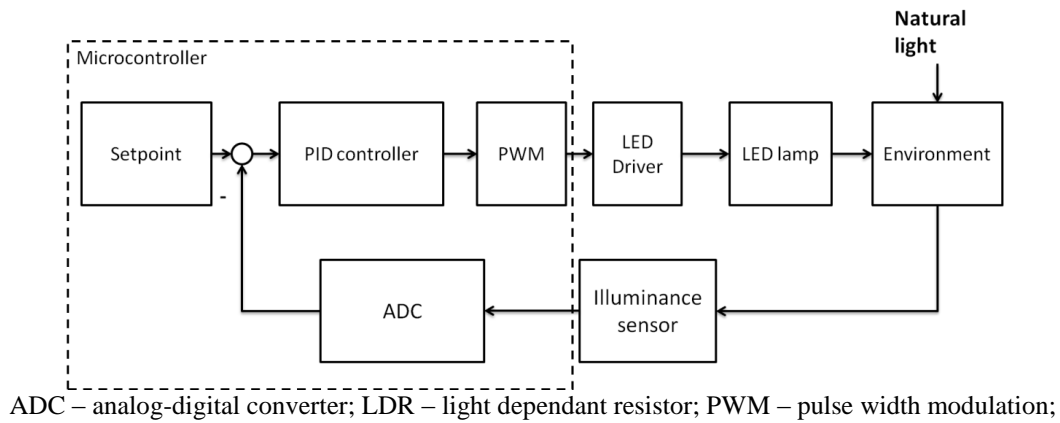
ADC – analog-digital converter; LDR – light dependant resistor; PWM – pulse width modulation;
Figure 3. Lighting automatic control schematic in according to natural light [5]

The mathematical model of each component in the system has been carefully described by the authors in [5], in which:
- Actuator (Power supply, LED) is modeled as a K1 scale
- Light sensor (photoelectric) and analog-digital transformation stage (ADC) are modeled in a nonlinear function based on the photoelectric properties; It is then linearized to a first order inertia stage $\dfrac{K_2}{T_2 s + 1}$

Based on the model of the system, the PID controller is synthesized in the form of a PI controller with an integral anti-windup component.Integral term in the controller helps to eliminate the static error of closed loop, but also brings integral windup when output saturation is used. The integral term accumulates a significant error, thus overshooting. When output saturation is used, overshoot can be smaller but the transient time is longer.Therefore, it is necessary to have an integral anti-windup component in the PI controller. This component calculates the difference between the output before and after saturation block, multiply with a coefficient K_C and add the result to the integral term output in the controller. The diagram of PI controller with saturation block and integral anti-windup component is presented on Figure 4.
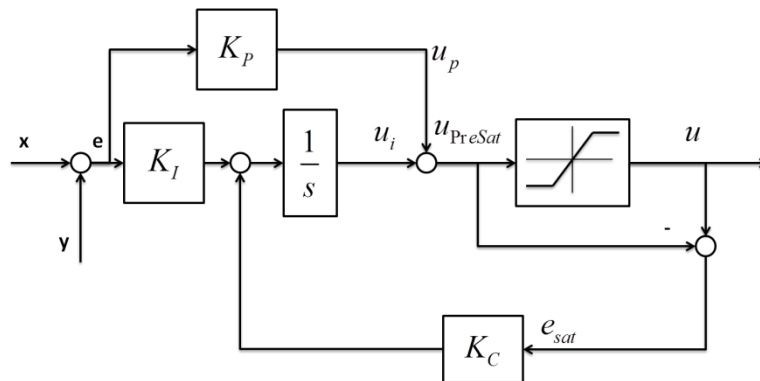
u_p - proportional term; u_i – integral term; u_{PreSat} – output signal before saturation block; u – output signal after saturation block; e_{sat} – error between signal before and after the saturation block; K_c – coefficient of integral anti-windup.
Figure 4. Diagram of PI controller with saturation block and integral anti-windup component

The Smart LED uses NRF24L01 as the communication module. NRF24L01 is a single chip 2.4GHz transceiver with an embedded baseband protocol engine, suitable for ultra low power wireless applications. Through the communication module, the control panel can send commands to for each Smart LED: power up and down; change the setting parameters for the control module such as the upper and lower threshold values, parameters of PI controller, and the communication module itself.
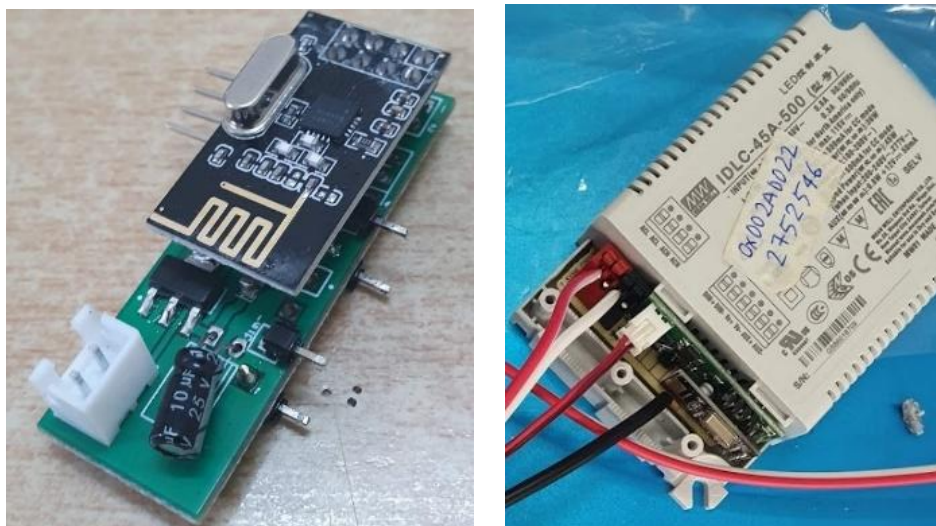
Figure 5. Control and communication modules (left) and LED driver integrated with control and communication module (right)

C. Central control panel

Central control panel is for remote control and system configuration. The configuration includes the following specific functions:

- Add, remove and modify Smart LEDs (LED driver integrated with control and communication) in the system

- Configuration settings for each Smart LED: set point for automatic regulation, static value for constant lighting, maximum and minimum value of automatic control; automatic calibration based on the conditions of the classroom

- Setting the parameters of the communication module

Figure 6. Control panel circuit board inside and buttons outside

The control panel allows mobile devices (mobile phone, laptop) to connect via WiFi to set up the system configuration. In Figure 7 is the interface to configure the lighting system from the phone.
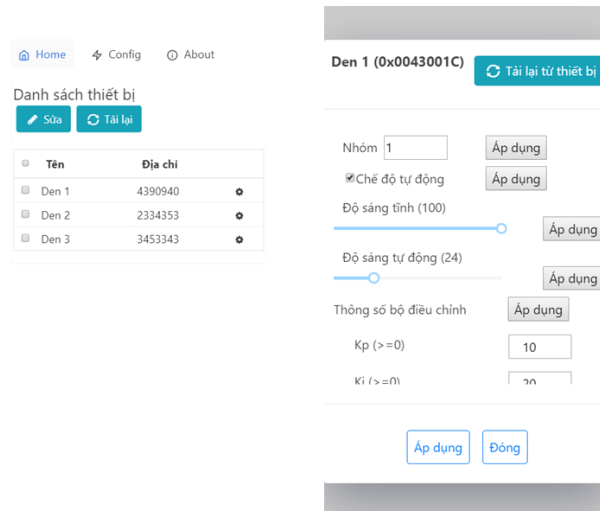
Figure 7. Web-based configuration interface of the system

III. TEST AND PILOT IMPLEMENTATION

A. System testing

The lighting system was tested to verify the following items:
- Correlation between Smart LED's light sensor and the actual illuminance on the desk surface.
- Operation of the control module
- Communication distance between the Smart LEDs and the central control panel

Since the system uses light dependent resistor (LDR) as the light sensor and the LDR is mounted facing down on the LED panel instead of mounting on the desks (Figure 8), it is necessary to verify the correlation between the LDR and the actual illuminance sensor on the desk. The results on Figure 9 shows that the correlation R^2=0.9712.

Operation of the control module were tested with the set up in Figure 8. The results on Figure 10 shows the response of the control module to the change in illuminance of natural light. When the natural light decreases (dimmer), the power output to LED panel increases to compensate the lack of natural light. When the natural light increases (brighter), the power output to LED panel decreases. In both cases, the illuminance on the desk is maintained fairly constant.

The communication distance between the Smart LEDs and the central control panel were tested and shows that central control panel can connect, control, set parameters of the Smart LED from the distance up to 65m, which is more than enough for application in a classroom.
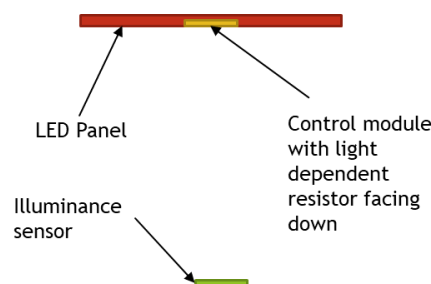

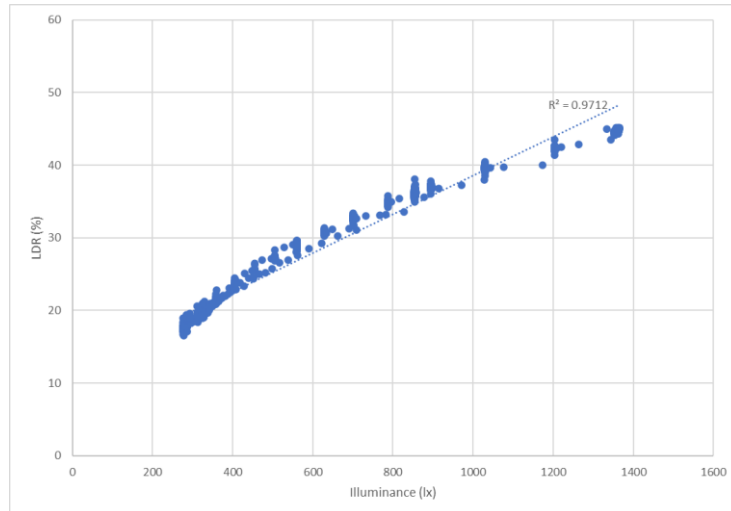**Figure 8**. LDR location and correlation between LDR and illuminance sensor verification experiment

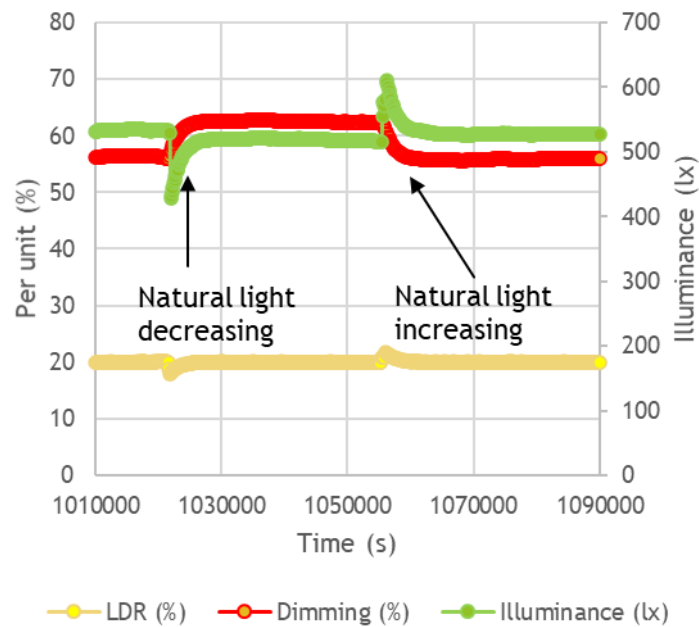**Figure 9**. Correlation between LDR and illuminance sensor

Figure 10. Control module reacts to the change in illuminance

B. Pilotedly deployment

     The smart and energy-saving lighting system for classroom has been pilotedly installed at 05 primary schools in Quang Nam province, with 2 classes each. Initially the system worked well and gave positive results.Some pictures of the classroom with the smart and energy-saving lighting system are shown in figures 10 (before and after installation).

Figure 11. Classroom 1/1 of Son Phong Primary School, Hoi An (before and after installation)

A telemetry device was installed in room P12, Tran Quoc Toan Primary School. Data is collected and transmitted via WiFi to an MQTT Server on the internet. A PC at our institute also connects to this MQTT Server to get the data. The data is used as a basis for analyzing the system's operation.

Figure 12 shows the power consumption for lighting in a typical day. The power consumption ranges from 150W to 250W. The class starts in 6:30 AM, natural light is low, the power consumption is the highest (250W). As the time goes, natural light is brighter, the power consumption decreases more and more and reachs a value as low as 150W.

Figure 13shows the distribution of power consumption for lighting. Accordingly, the system has a nominal power of 250W but most of the time it is regulated automatically and operates at different power: 150W (11.58%), 210W (30.64% of the time), 220W (9.39%), 230W (9.46%), 250W (18.67%).
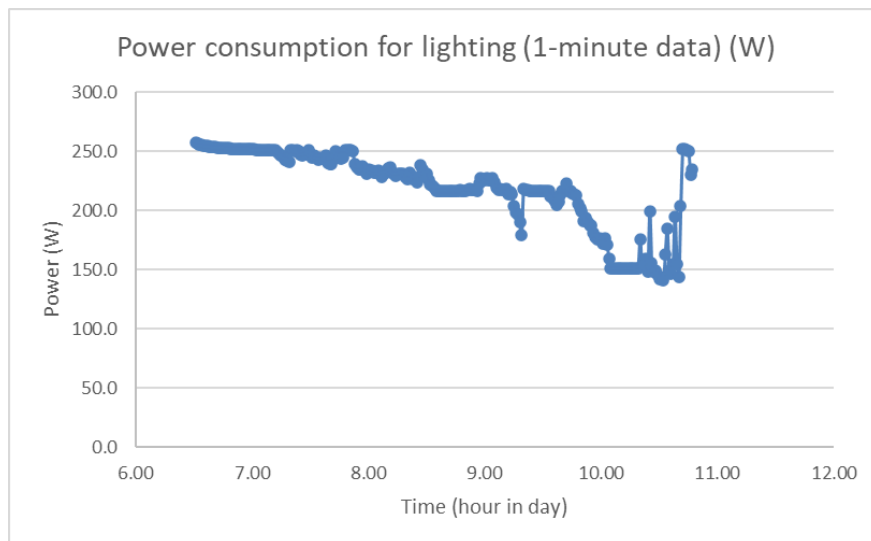

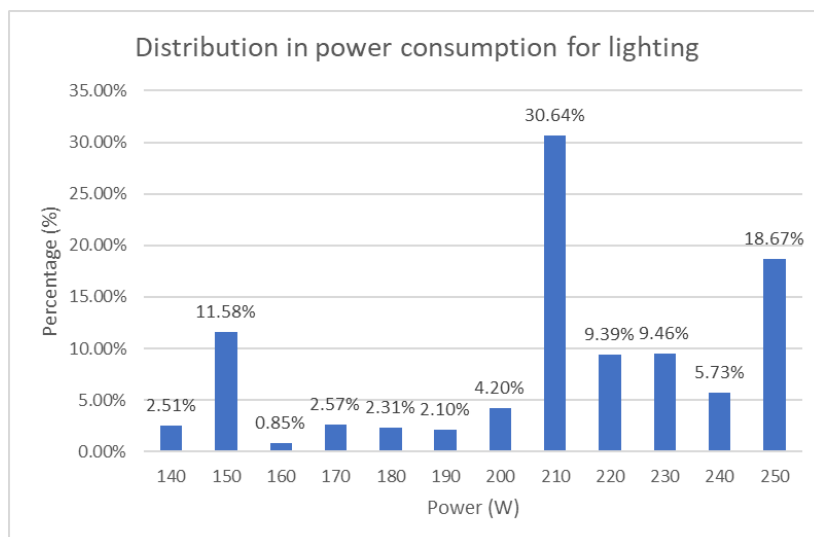**Figure 12.** Power consumption for lighting in a typical day

Figure 13. The distribution in power consumption for lighting in classroom P12, Tran Quoc Toan school.

Table 1 shows the illuminance measured on the desks before and after installation. Table 2 shows power consumption before and after installation.

Table 1: Average illuminance on the desks before and after installation in all classes

School	Class	Before		After		
		Power (W)	Average illuminance (lux)	Power (W)	Lowest illuminance (lux)	Average illuminance (lux)
Son Phong Primary School, City. Hoi An	Class 1/1	320	143	240	415	568
	Class 3/1	480	196	240	424	581
Tran Quoc Toan Primary School, City. Tam Ky	P12	320	282	240	426	583
	P9	320	245	240	426	583
Vo Thi Sau Primary School, City. Tam Ky	P1	480	227	240	326	447
	P2	480	222	240	301	413
Le Hoan Primary School, Phu Ninh District	Library room for teachers	320	202	240	445	610
	Library room for pupils	320	201	240	426	584
Nguyen Van Troi Primary School, Nui Thanh District	P2	320	246	240	442	605
	P1	320	239	240	418	572

Table 2: Calculation of energy savings per year for installed classes

School	Class	Power before (W)	Nominal power after (W)	Average power consumption (W)	Annual energy saving (kWh)	Saving percentage (%)
Son Phong Primary School, City. Hoi An	Class 1/1	320	240	210	176	34%
	Class 3/1	480	240	210	432	56%
Tran Quoc Toan Primary School, City. Tam Ky	P12	320	240	210	176	34%
	P9	320	240	210	176	34%
Vo Thi Sau Primary School, City. Tam Ky	P1	480	240	210	432	56%
	P2	480	240	210	432	56%
Le Hoan Primary School, Phu Ninh District	Library room for teachers	320	240	210	176	34%
	Library room for pupils	320	240	210	176	34%
Nguyen Van Troi Primary School, Nui Thanh District	P2	320	240	210	176	34%
	P1	320	240	210	176	34%

IV. CONCLUSION

The paper presented the results in the development of smart and energy-saving lighting system for classrooms:

- Development of a Smart LED, in which LED driver is integrated with control and communication modules
- Development of Mathematical, simulation models and control algorithm to control LED lamps according to natural light
- Development of a communication system that allows the central control panel to configure each and every Smart LEDs by web interface through wifi connection
- Pilot installation at 05 primary schools in Quang Nam province.

The installed smart and energy-saving lighting systems at primary schools in Quang Nam province operates stably according to the designed parameters and brings many benefits:

- It provides better lighting environment for the teachers and the pupils.On the desk surfaces, average illuminance is from 400lx or higher, minimum illuminance is about 300lx. In comparison, old lighting system only provides illuminance from 143lx to 282lx.
- It saves electric energy is up to 56% compared to the old lighting system.

ACKNOWLEDGEMENTS

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