

Lighting systems to save energy in educational classrooms

Luigi Martirano IEEE member
University of Rome Sapienza
DIAEE – Electrical Engineering Area
Rome, Italy
luigi.martirano@uniroma1.it

Abstract

In educational buildings a significant component of the energy used is spent in illuminating the interior of the building. As the energy costs rise, increasing effort has gone into minimizing the energy consumption of lighting installations. This effort could follow three basic directions: new more efficient equipment (lamps, control gear, etc.), utilization of improved lighting design practices (localised task lighting systems), improvements in lighting control systems to avoid energy waste for unoccupied and daylight hours. By controlling the lighting in such a way that the lighting level is always accurately matched to the actual need allows to save on the energy costs and to improve the human comfort and efficiency. Establishing an integrated lighting control concept is a very important part of the lighting design process. The paper describes two different smart control systems designed according the same concept but with different components, for the lighting systems in two classrooms at the Engineering Faculty of the University of Rome Sapienza. The installations are realized according to a research project about the assessment of the impact of lighting control systems in electrical energy consumption and energy commitments. The results are useful to compare the two different control approaches (switching and dimming) and the two different kind of actions (with or without luminaries upgrade) in order to analyze costs, energy consumption and comfort.

The two different control technologies are compared with respect to a third classroom without smart control, used as reference for evaluations.

Keywords – *lighting systems; lighting controls; building automation; energy management*

I. INTRODUCTION

In educational buildings a significant component of the energy used is spent in illuminating the interior of the building. In recent years the European Union EU has actively promoted political campaigns toward energy efficiency [1]. An energetic management program could be follow three basic directions: new more efficient equipment (lamps, control gear, etc.), utilization of improved lighting design practices (localised task lighting systems), improvements in lighting control systems to avoid energy waste for unoccupied and daylight hours. Building Automation and Control systems (BACS) allow pursuit of intelligent energy management; they provide complex and integrated energy saving functions based on the actual use of a building, depending on the user's real needs to avoid unnecessary energy use. The key to design an integrated lighting system is the electric lighting control strategy. An appropriate light control system improves the operating efficiency of a

building by combining the electric lighting with daylighting and real presence of personnel.

Several lighting control strategies are available to manage lighting energy use in buildings: scheduling, occupancy, daylighting and luminance control are the most significant. An appropriate electric lighting control concept for a daylight-building consists of a group of components coherent and integrated in a certain sequence. The two main components are: the integrated lighting control zones and the control strategy for each zone. This paper concentrates on identifying the integrated lighting control strategy in educational classrooms, taking into consideration the available daylight and the actual occupancy of persons in each zone of the classroom.

The main strategies of the concepts are:

- 1) to subdivide the classroom in different zones with different uses (i.e corridor zone, teacher zone and scholars zone) and with different lux values (zoning strategy);
- 2) to schedule the general ON/OFF switch by a remote controller (scheduling strategy);
- 3) to integrate the electric lights with available daylighting in the room (daylighting strategy);
- 4) to switch OFF automatically the lights according the real occupancy of the different zones (occupancy strategy);
- 5) to organize fixed scenarios activate d by manual push buttons (i.e. teaching, projection, etc.)

The designer has to arrange the control groups in order to satisfy the strategies above mentioned. In particular the lights have to subdivided:

- a) in control groups GC according to the zones;
- b) in regulation groups GR constituted by rows parallel respect the windows.

The concept could be implemented in two different ways:

- by adopting normal ballasts and switching mode, useful in cheap restoration cases;
- by adopting electronic control gear and dimming mode, useful for new installations or deep restorations.

The author arranged the lighting control concept in two classrooms with same extension and same exposition but adopting the two different ways mentioned in order to analyze the installation costs and the energetic impact. A third classroom is used as benchmark value. The system is completed by electrical energy meters and supervisory system to monitor the hours of utilization of classrooms, the electricity consumed by the lights and the related energy savings achieved. The project could be offer helps to organize reference guides for future installations and actions in educational buildings in order to save energy.

II. CLASSROOMS

The two classrooms used for the installations are the number 7 and the number 8 of the first floor of the Engineering Faculty of the University of Rome.

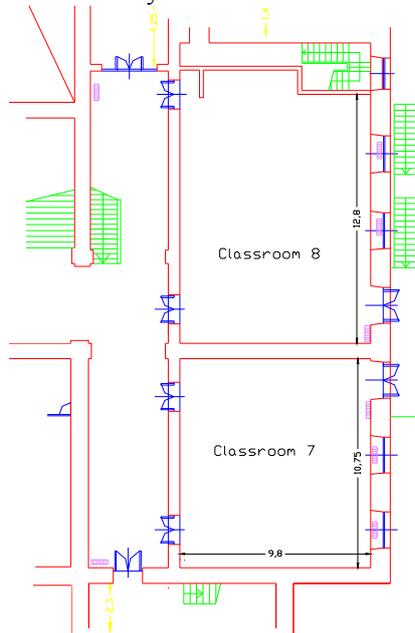


Figure 1. Classroom 7 and 8 dimensions.

Classroom number 7

The classroom 7 is a squared room of 9,80 x 10,80 m with two large windows and one external door.

For this room the 12 luminaries ceiling 4x18W are to be upgraded by the replacement of the electric auxiliaries with high efficiency and dimmable electronic ballasts with DALI protocol. Dimming control will be used to maintain the optimal luminance level. The BUS of the control system will be implemented with standard Konnex technology by using input equipment for sensors. Luminance and occupancy sensors will be used.

Classroom number 8

The classroom 8 is a rectangular room of 9,80 x 12,80 m with two large windows and one external door.

For this room the existing 15 luminaries ceiling 4x18W are not to be upgraded. Switching control will be used to maintain the optimal luminance level, by organizing the luminaries in several switch-groups. The installation will consist in the implementation of the control system with standard technology BUS Konnex. Luminance and occupancy sensors will be used.

Reference classroom number 4

To analyze the different energy consumption of the 7 and 8 classrooms in comparison with a reference normal classroom, it will be installed a meter system for a classroom with a similar extension, exposure and use (room number 4).

Tab I. Summary of actions to be taken

Actions	Classroom 4	Classroom 7	Classroom 8
Smart metering	X	X	X
Smart control		X	X
Luminarie upgrade		X	

III. LIGHTING CONTROL CONCEPT

Principle of operation of the control system of a single classroom: the strategies

The light control of a single classroom will be built to meet the following operating strategies: scheduling, daylighting, occupancy, luminance control, zoning.

Centralized switching scheduling

The classroom lighting system will be switched on off in a general way through a command available to the staff of the faculty. This command will be made with key-operated switch inside the classroom and the remote generally guard the entrance.

Automatic mode (daylighting, occupancy, luminance control, zoning)

When turned on the lights will be in automatic mode, the system will operate with input signals from sensors placed in the field of light and presence.

Lights will be:

- Turned on (occupancy strategy) according to the actual occupancy in the classroom. The room is divided in three different zones (zoning strategy) with three different design luminance level (figure 2). Zone 1 “student zone” is served by three control groups: GC1.1, GC1.2, GC1.3; zone 2 “teaching zone” by one control group GC2; zone 3 “corridor zone” by one control group GC3.

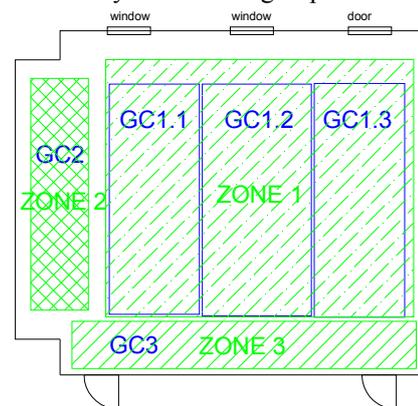


Fig. 2. Classroom 8: control Groups GC according to the occupancy of the single zones. GC1.1, GC1.2, GC1.3 are for zone 1; GC2 is for zone 2; GC3 is for zone 3.

- Adjusted in flux emitted according to the natural available lighting in the classroom (daylighting strategy). At this aim the luminaries will be divided in 8 regulation groups (GR1-GR8) organized for parallel rows respect the windows. The adjustments' will be made automatically in switching mode for the classroom number 8 and in dimming mode for the classroom number 7. The average maintained luminance values of reference for the adjustment will be independent for the 3 zones of the classroom: 300 lux for zone 1, 500 lux for zone 2 and 150 lux for Zone 3.
- Constantly adjusted only for the room number 7 (luminance control strategy) according to the average maintained luminance values above mentioned.

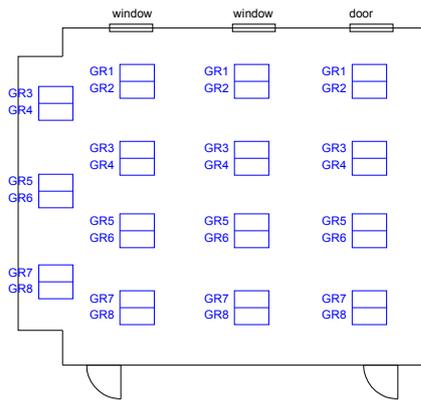


Fig. 3. Classroom 8: Regulation Groups GR by switching according to the daylight available

Scenario mode

The smart control will offer several scenarios activated by touch screen or manual pushbuttons, for example in case of slides projection. The scenarios could be programmed during the startup up process.

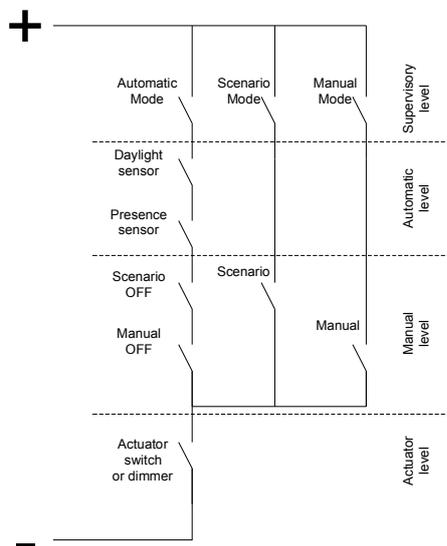
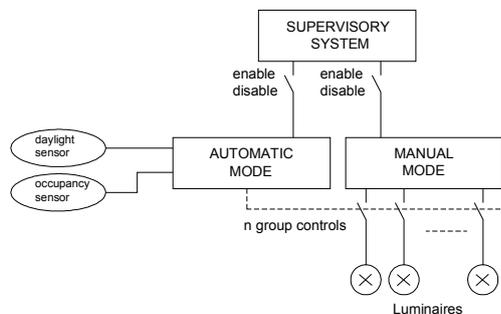


Fig.4 Schemes of the lighting control concept.

Manual mode (override)

The system is completed by pushbuttons to manage manually the lighting system. It is possible:

- To force on or off (override) the status of single lighting groups.
- To manage directly the system in manual mode excluding the automatic mode.

The automatic, manual and scenario modes could be enabled by the general supervisory system located in the security entrance box.

IV. LIGHTING CONTROL ARCHITECTURE

The control is organized according to the HBES standards (EN 50110) adopting a KNX system. HBES systems are with "distributed intelligence" as each device is properly programmed, it has an "address" unique in the whole system needed to be recognized as the recipient of the message, scheduled to make an accurate function, according to a expected mode, with another component of the system established by the program.

The system is programmable by a PC software system (ETS mode). The operation of the system is independent of the presence of a PC or a supervisory system and therefore it ensures high reliability. In fact, each component of the system has electronic elements in which contains all information relevant to the very functioning of the device. In this way it is not necessary to have a central (industrial PLC) to coordinate communication between devices and for managing the entire operation of the system. The lack of a central element is an undoubted advantage for the continuity of service; any failure on a device only creates the inefficiency of the device in question, while the rest of the plant continues to operate normally.

The system thus created is expected to support the system for manual control by local control (generic buttons) or remote controls (buttons or touch screen) and a manual or automatic programmed scenarios described above.

The system will consist of:

- power supply KNX system and other KNX devices;
- input devices as interfaces of sensors and KNX system and output device (actuators) to switch the luminaires;
- occupancy sensors and daylighting sensors interfaced with the KNX system using the input devices.

The line between KNX devices is provided by a simple twisted pair cable.

Classroom number 8 – SWITCHING MODE

In the classroom number 8 the total flux emitted by the system is regulated by switching the single ballasts (ECG1 and ECG2) of each luminaires (*switching mode*) in order to guarantee 3 different values of light: 0%, 50%, 100% (fig.4).

The control system consists in:

- 2 lux sensors
- 1 KNX input device for the lux sensors
- 5 presence sensors (double technology infrared and microwave with special detector area;
- 1 KNX input device for the presence sensors
- 4 KNX actuators with 8 channels for the lamps control

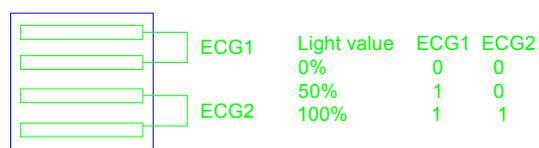


Fig. 5 Scheme of the switching mode for a 4 lamps- 2 ECGs luminaire

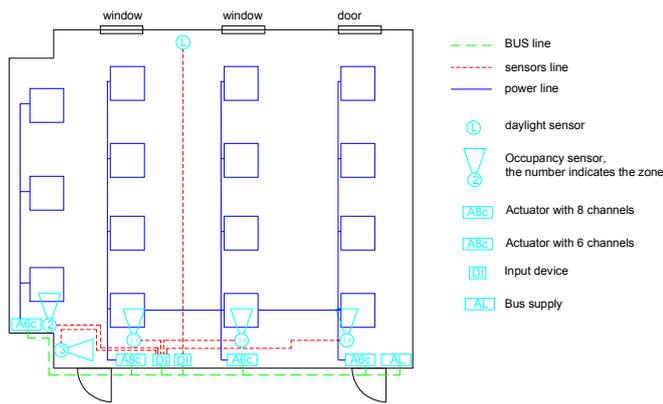


Fig. 6 Classroom 8: architecture of the control system

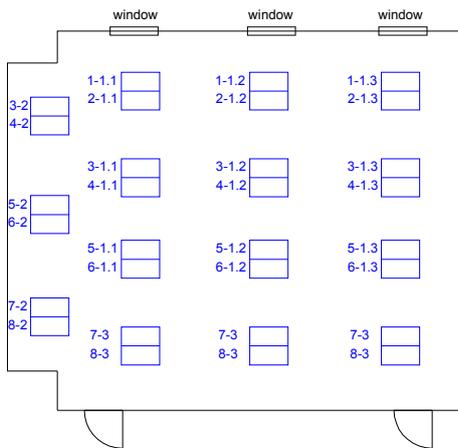


Fig. 7 The control systems of the classroom number 8. There are 15 individual channels used. Each channel is represented by the symbol X-Y(Z) where X is the regulation group RG according to the natural light; Y is the zone 1, 2 or 3 and Z is the subzone of zone 1.

Classroom number 7 – DIMMING MODE

In the classroom number 7 the flux regulation will be done by dimming mode of each couples of lamps of the luminaries. In this case it is necessary to substitute the magnetic ballasts with new electronic control gear adopting DALI protocol (digital addressable lighting interface). this kind of ballast offers a complete 0-100% regulation for each luminaire.

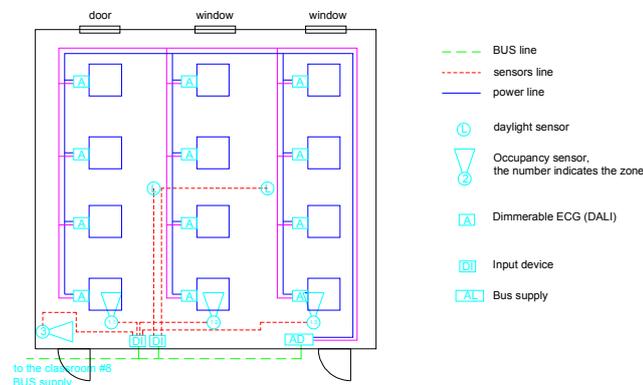


Fig. 8 Classroom 7: architecture of the control system

The control system of classroom 7 consists in:

- 2 lux sensors
- 1 KNX input device for the lux sensors

- 4 presence sensors (double technology infrared and microwave with special detector area);
- 1 KNX input device for the presence sensors
- 1 KNX actuator/DALI interface for the lamps control

Smart metering and supervisory system

The scheme is completed by a smart metering system for each classroom and a general supervisory system that uses Winswitch™ software.

All the metering, command, regulation, occupancy, luminance, daylight signals will be stored and managed by the supervisory system to realize a database useful for the energy management office of the university.

By the supervisory system it will be possible also control the switching and the regulations.

For each room it will be possible to show in real time:

- The real presence of activity;
- The real energy consumed by the lightings

The supervisory system data will be collected in a web page.

V. ENERGETIC IMPACT

To estimate the actual energy efficiency of lighting control systems is an important goal since an accurate evaluation could help and guide designers towards the most appropriate choice among a great number of available solutions. In particular the control strategies can be based on daylight availability, on room occupancy or on pre-defined scenes and the type of control can be automatic, manual or both using different management criteria.

The EN 15193-1 [3] provides the Lighting Energy Numeric Indicator LENI used for certification purposes and very useful in designing the light control system:

$$LENI = W/A \text{ [kWh/(m}^2 \times \text{year)]}$$

where

A is the considered useful area [m²]

W is the total annual energy used for lighting, equal to

$$W = W_L + W_P \text{ [kWh/year]}$$

as sum of the W_L estimated annual lighting energy and W_P parasitic energy (emergency and standby controls). The light control systems consume some energy also in the standby mode so that a night-time switching is recommended.

The author evaluated the energetic impact of the control system by adopting the LENI methodology.

Calculation of W_L depends on the installed lighting power corrected by 3 derating factors: - F_D "daylight dependency factor", - F_C "constant illuminance factor", - F_O "occupancy dependency factor".

An estimate of the lighting energy (W_L) required to fulfill the illumination function and purpose in the building shall be established using the following equation [kWh/year]

$$W_L = \sum \frac{P_n F_C (t_D F_O F_D + t_N F_O)}{1000}$$

where:

- P_n is the total installed lighting power in considered area A [W],
- t_D "daylight time usage" are the operating hours during the daylight time, [h]

- t_N "non-daylight time usage" are the operating hours during the non-daylight time, [h].

The standard EN 15193-1 [3] offers information, methods and reference values. A previous paper shows the methodology application [5].

The author suggest to introduce an *utilization factor* F to simplify the LENI approach equal to:

$$F = F_0 \cdot F_C \cdot [p \cdot (\tau \cdot F_D + 1 - \tau) + 1 - p]$$

where:

$$p = P_D / P_N \text{ [p.u.]}$$

P_D = is the installed lighting power in the daylight zone [W]

$$\tau = t_D / t \text{ [p.u.]}$$

$$t = t_D + t_N \text{ [hours]}$$

LENI is equal to:

$$\text{LENI} = (P_N \cdot t_0 \cdot F) / (1000 \cdot A) \text{ [kWh/ (m}^2 \text{ x year)]}$$

Table II shows the LENI evaluated for classrooms 7 and 8 according to the standard UNI15193, before and after the actions proposed.

Table II Energetic impact of actions in classroom 7 and 8

			Room 7	Room 8
Area		[m ²]	106	126
Before actions	Number of luminaries	[#]	12	15
	Power of each luminaire	[W]	90	90
	Power of the lighting system	[W]	1080	1350
	Annual operating time	[h]	2000	2000
	Utilization factor	[p.u.]	1	1
	LENI	[kWh/m ² /y]	20,4	21,4
After action on power	Power of each luminaire	[W]	72	90
	Power of the lighting system	[W]	864	1350
	LENI	[kWh/m ² /y]	16,3	21,4
	Savings total	[kWh/m ² /y]	4,1	0,0
		[%]	20%	0%
After action on control	Utilization factor	[p.u.]	0,6	0,65
	LENI	[kWh/m ² /y]	11,8	13,9
	Savings total	[kWh/m ² /y]	8,5	7,5
		[%]	42%	35%
After actions	LENI	[kWh/m ² /y]	9,5	13,9
	Savings total	[kWh/m ² /y]	10,9	7,5
		[%]	54%	35%

The parasitic energy consumption W_p could be stimulated by adding 1 kWh/m²/year for emergency lighting and about 2-5 kWh/m²/year for the automatic lighting controls.

VI. CONCLUSIONS

Intelligent management of energy efficiency, optimizing of costs and quality, requires imagination that can reveal opportunities, expose risks and support strategic decision making. In the energy management of buildings like educational ones, an effective program could be follow three basic directions: actions on efficient equipment, actions on lighting design practices, actions in lighting control systems. The paper considered possible actions in power reduction like new more efficient equipment (lamps, control gear, etc.) and

action in energy reduction like improvements in lighting control systems to avoid energy waste for unoccupied and daylight hours. In the case study, energy savings due to the action in power reduction could be assumed about the 20%, savings due to the action in controls about 35-42% according to the control mode if by switching or dimming, and total savings obtainable by adopting both actions together about 54% .

References:

- [1] European Council, Directive 2002/91/EC of the European parliament and of the council of 16 December 2002 on the energy performance of buildings, Official Journal of the European Communities. 2002.
- [2] CEN/BT WG 173 EPBD n° 36 Version V5 – Explanation of the general relationship between various CEN standards and the Energy Performance of Buildings Directive (EPBD) ("Umbrella document") December 2005.
- [3] EN15193_1 "Energy performance of buildings – Energy requirements for lighting - part 1: Lighting energy estimation", March 2005.
- [4] EN 12464-1 "Light and lighting - Lighting of work places - Part 1: Indoor work places" Standard 2002
- [5] L. Martirano, G. Parise, Ecodesign of lighting systems, Industry Applications Magazine, March-April 2011, pages 14-19.

Luigi Martirano (StM'98-M02) received the M.S. and Ph.D. degrees in electrical engineering from the University of Rome "La Sapienza", Italy, in 1998 and 2002, respectively. He discussed a PhD thesis on "Electric Power Systems Circuit Protection". In 2000, he joined the Department of Electrical Engineering of the University of Rome "La Sapienza" where he is currently an Assistant Professor. He is the author or coauthor of more than 40 technical published papers and a co inventor of one international patent. His research activities cover power systems design, planning, safety, home and building automation, protection and coordination, lighting systems. He is a member of the IEEE Industry Applications Society, of the AEIT (Italian Association of Electrical and Electronics Engineers) and of the CEI (Italian Electrical Commission) Technical Committees CT205 and SC311B. He has been Registered Professional Engineer.