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Energy efficient control of lighting in an intelligent building

Marek Horyński

Lublin University of Technology, 38 D Nadbystrzycka Str., 20-618 Lublin, Poland

Summary. The present paper refers to the issues associated with energy efficient management in the scope of electric energy. The analysis of the energy balance indicates that the energy consumption for lighting purposes plays an important part in this balance. The introduction of the new energy efficient elements into the lighting control solutions refers not only to fully automatic so called intelligent buildings but is extremely important for the users of the systems based on conventional electrical installations.

Key words: lighting, control, energy efficient, designing, installation.

INTRODUCTION

The amendments in Energy *Performance* Buildings Directive (EPBD) have been adopted by the European Parliament on 18th May 2010. In accordance with these amendments, new buildings since the year 2021 in the territory of European Union will be erected exclusively as the objects with ultra low energy demand and with power supply, at least partially, from renewable energy sources. Thanks to new regulations, it will be easier to overcome the economic, energy and climatic crisis as well as to improve energy safety and security in Europe.

In accordance with adopted amendments, all new buildings built from 2021 onwards in the territory of European Union there will have to be nearly zero-energy buildings. This requirement must be met from 2019 onwards in case of new public buildings. The scope of amendments in Energy *Performance* Buildings Directive (EPBD) encompasses also the old, poorly insulated buildings causing the highest energy losses. The Community decided that, in case of modernization of such objects, each element to be overhauled shall meet the requirements in the scope of energy efficiency at least at minimum level.

It has been observed that electricity consumption by households increased by about 40% over the last decade as a result of growing affluence of the society. Therefore it is possible to use the household appliances which were at first considered luxuries or their potential users became aware of such possibility. The introduction of energy saving procedures into building systems is also imposed by EU and Polish legislation. Due to the fact that 14% of electric energy consumption in European Union and about 19% of electric energy consumption worldwide is used for lighting, the introduction of energy efficient solutions in this area is particularly important. As much as 75% technical solutions in the scope of systems in Europe is obsolete and non – energy – efficient. The bulbs commonly used in Poland as the light sources are characterized by the lowest efficiency and convert less than 5% of the electric energy into light and the rest into heat.

Apart from HVAC system in the building, the lighting system is an area which may be really and appreciably affected by the user via advanced control systems. [1, 4, 7, 9, 14]

The lighting control is needed owing to necessity to save electric energy and owing to the fact that high energy consumption is generated by lighting. The creation of comfortable work and rest environment is also important.

The use of high class lighting fittings (effective reflector, energy efficient light source, electronic stabilizer etc.) is the step required to reduce the energy consumption by the system.

The next decision should concern the application of lighting control systems. It is possible to use KNX or DALI based systems offering, except of remote turn ON and OFF functionality, the comfort improved through integrated control for lighting scenes with blinds or screens in conference rooms or office rooms [1].

Today a modern building is mainly an energy – efficient building i.e. an object with energy consumption lower than in the buildings erected in conventional technologies, environment friendly and built using state – of – the - art technologies.

Accordingly, the steps should be taken in order to optimize the energy performance in the buildings.

The design of the objects should be the first step in the descriptions of the solutions increasing the energy effectiveness in the buildings. A correctly designed object, selection of proper materials, thermal insulation or selection of windows with satisfactory thermal characteristics and method of their assembling are the basic steps to be completed in order to build an object classified in energy – efficient buildings category.

Another important aspect represents the selection of technological solutions i.e. heat and cool sources or power supply and lighting method. Furthermore the analysis should be carried out in order to check if it is possible to use state – of – the – art solutions i.e. heat pumps or wind or solar energy sources. The importance attached to the use of highly efficient equipment in the scope of refrigeration and heating engineering, ventilation, lighting or electric system is essential.

The essence of changes in an electric system consists in the energy consumption in justified cases only, in adaptation of energy amounts to factual requirements and in use of the equipment in highest possible energy efficiency class.

THE REQUIREMENTS FOR ELECTRICAL INSTALLATIONS.

The electrical installations shall meet three basic requirements:

– To ensure continuous supply of electric energy with the parameters corresponding to user's needs
– To protect the users and the system against electric shock, explosion, fire, switching overvoltages and lightning surges;
– To protect the environment and humans against the emission of magnetic field, noise, vibration with parameters exceeding permissible levels and against contamination [5].

In order to meet these requirements, the installations shall be designed and completed in a manner using determined technical solutions, among others the following:

– Neutral N conductors and protective PE conductors shall be applied as separate conductors,
– Copper wires shall contain the conductors with cross – section up to10 mm^2,
– Receiving circuits shall be protected by means of circuit – breakers and differential current switches;
– Equipotential bondings shall be completed;
– Conductors shall be laid along straight lines parallel to edges of the walls and ceilings [5, 6, 8].

Separate circuits shall be applied in the apartments for:

– Ceiling (main) lighting,
– General purpose plug – in sockets,
– Permanently installed appliances plug – in sockets (washing machine, dish washer etc.) [6].

INTERIOR LIGHTING DESIGN

In order to select the lighting in a correct manner, the choice shall correspond to individual needs. The lighting design is an important element of the building systems because it is crucial for future installation and operation costs.

INTERIOR LIGHTING PRINCIPLES

The designer of interior lighting shall consider several aspects in order to meet the complex human needs associated with lighting. The task to be performed by correctly designed and completed lighting is to meet the following human needs:

– Visual performance,
– Visual comfort,
– Safety [14].

It is necessary to meet the basic lighting requirements included in the lighting standards in order to satisfy these needs. Therefore the work performed by the occupants in a room will be carried out in an accurate manner in comfort conditions in proper time and without excessive tiredness with maintained safety. The essential requirement is to create a correct lighting environment consisting of the following components:

– Illumination
– Glare,
– Luminance distribution,
– Colour rendering,
– Colour temperature,
– Light ripple (pulsation),
– Directionality of light,
– Day light.

The illumination and its distribution in the work field and in its direct vicinity are the principal factors decisive for the execution of visual work and affecting the general evaluation of an interior. Glare occurs when there are excessively glaring objects occurring in the field of view of an occupant and may lead to the feeling of discomfort and may deteriorate the visual comfort. The luminance distribution i.e. the impression received by human eye from a luminous surface is also important. The luminance distribution affects the retinal adaptation status and is crucial for efficient performance of visual work and its impact on human behaviour and perceptions. In order to create a correct lighting environment, it is necessary to ensure a proper colour temperature and light direction. The parameters specified herein will be referred to the rooms in the office and presented below in a detailed manner [14].

In order to ensure the correct choice of lighting, a methodology should be followed. This methodology recommends to firstly determine the role of lighting i.e. if it will perform the role of general or local lighting. After the lighting role is determined precisely, it will be possible to obtain the information about required illumination and the number of lighting fittings resulting therefrom.

The following parameters shall be also determined:
- Anticipated annual operation time of the lighting.
- Required height of lighting fittings suspension (not always the lighting fittings shall be installed on significant height; the height of lighting fittings suspension can be reduced in the shop floors without travelling cranes. Therefore reduced number of lamps will be sufficient to achieve required illumination level).
- Work areas – this solution makes it possible to turn off unnecessary part of lighting.
- The areas with sufficient lighting by means of day light.

ENERGY-EFFICIENT LIGHTING IN THE BUILDING

The replacement of conventional bulbs by integrated compact fluorescent lamps, halogen lamps or LEDs is the basic and most simple method to achieve an energy-efficient lighting.

The integrated compact fluorescent lamps ("energy-efficient bulbs") introduced more than ten years ago generate much more light from lower power in relation to conventional bulbs. 20% up to 25% of electric energy supplied to the compact fluorescent lamp is converted into the light. Approximated power values for the equivalents of conventional bulbs to energy-efficient bulbs are presented in the table below.

Table 1. Approximated power values for the equivalents of conventional bulbs to energy-efficient bulbs

Power of a conventional bulb; [W]	Approximated power of an equivalent in the form of a compact fluorescent lamp [W]
100	20-23
75	15-16
60	11-12
40	8-9
25	5-6

The replacement of a conventional bulb by an integrated compact fluorescent lamp makes it possible to achieve the electric energy savings of 80%. This saving is very high. However, the use of these light sources is not possible everywhere. Owing to their design solution, the fluorescent lamps are characterized by large luminous surface. Their use is not recommended in the crystal chandeliers with bulbs generating „sparkling" light and various light reflections, because this effect would be eliminated in case of fluorescent lamps. The halogen bulbs can be applied in such situation. They make it possible to achieve the electric energy savings of 50%. This value is lower than in case of fluorescent lamps but an attractive lighting is ensured. The halogen bulbs can be used in the circuits with dimmers or motion sensors.

The significant electric energy savings are possible thanks to the application of LED technology. LED sources can be used to replace E27, E14 conventional lower power bulbs and 12 and 230 V halogen bulbs. The scope of their applications will be and already is significantly wider that in case of the compact fluorescent lamps, because the energy saving of several dozen percent is possible in this case. However further development of this technology is continued and better results may be expected in the years to come. In case of LED sources, particular attention should be paid to their parameters, for instance the colour temperature of generated light and *Colour* Rendering Index. They may significantly differ from each other, depending on the type of applied diodes and their manufacturer.

In case of the description of energy – efficient lighting in the building, mainly the replacement of conventional bulbs by more efficient equivalents is discussed. It should be emphasized that the whole scope of actions intended to achieve the energy – efficient lighting is not limited to the replacement of bulbs.

ENERGY-EFFICIENT LIGHTING CONTROL

The lighting control is performed:
- In manual mode, directly by the users by means of devices constituting the components of an electric installation, pushbuttons, dimmers or IR pilots.

Table 2. Parameters of the light sources which are most popular actually

Parameter	Conventional bulb	Halogen bulb	Integrated compact fluorescent lamp	LED
Durability	1000 h	2000-5000 h	6000-15000 h	30000-50000 h
Colour temperature	2856 K	3000-4000 K	2800-4000 K	Various temperatures and colours of light
Colour Rendering Index	100	100	>80	Various values, even more than 80
Available Power values	From less than ten up to several hundred W	From less than ten up to several hundred W	From less than ten up to several dozen W	
Savings in comparison with conventional bulb	-	For most modern solutions up to 50 %	About 80 %	About 80 %

- In automatic mode, via the system of sensors changing the lighting functions depending on changes of parameters settings.
- In semi-automatic mode, constituting a combination of manual and automatic mode.
- By means of clocks used for the setting of lighting installation operation schedules.

Energy-efficient lighting control in the building is based on the parameters of the applied lighting management system.

The purpose of another important functionality, except of turning ON/ OFF, is to make it possible to change the lighting level by the users for various light sources, from the conventional bulbs being slowly phased out, throughout fluorescent lamps, halogen lamps, HIDs or LEDs. More and more important is the setting of so called lighting scenes consisting in the controlling of various types of light sources in order to create the designed lighting system.

Its essential feature is to apply the proper level of day light in an flexible manner in order to ensure the environmental comfort for the inhabitants / users occupying a room e.g. in course of presentation by means of the projector in course of conference or lecture. The occupants should be also protected against negative effects of the impact of day light i.e. glare / dazzling, reflexes.

The lighting management system in the building should be parametrized in order to define the maximum/ minimum lighting levels for specified areas and lighting scenes to ensure the optimum lighting level as well as the use of lighting energy in an effective and productive manner.

Considering the comfort of users, the designer shall make it possible to individualize the lighting level i.e. the adaptation of the lighting levels in each zone or scene to their individual needs. The adjustment shall be possible in the scope of maximum and minimum lighting levels parametrized vs. existing standards for the user, norms and characteristics of the tasks being completed.

The management of lighting scenes and zones shall enable the programming (predefining) of lighting arrangement in individual zones.

The lighting management system should be also provided with lighting management possibility in central and local mode. Thanks to central management, the users are capable to quickly implement and change the lighting policy and its principles in order to ensure the possibility to change the lighting in individual zones in local mode by means of dimmers, wall – mounted switches, IR pilots.

Zone occupancy and presence control is another important element of the lighting management systems. The lighting management in this case is based on the use of motion, heat and IR sensors.

Further important element of the lighting management systems is an intelligent compensation i.e. the possibility to ensure required lighting level using the compensation of artificial light sources and adaptability i.e. quick adaptation of lighting levels to changes in the rooms' reconfiguration.

A correctly designed lighting management system shall also make it possible to forecast the load of lighting installation as well as to plan the actions intended to reduce the system load in peak pricing hours.

The comprehensive metering system is an extremely important aspect of the energy – efficient building. The metering systems shall be provided for all supplied utilities. Therefore it is possible to gain the knowledge on the amount of energy consumption and its type. Without an advanced monitoring system, the users and administrators of the objects are not able to indicate the locations with the highest energy consumption and the purpose of such consumption as well are not able to detect abnormal conditions. The lack of such systems prevents the improvement of energy balance in the building. A positive symptom consists in increasingly often extension of BMS systems functionalities in the form of electric energy monitoring.

ENERGY SAVING ACTIVITIES

Low saturation of intelligent lighting market creates a very high potential in the scope of energy efficiency – comparable to the replacement of magnetic stabilizers by electronic stabilizers. Owing to introduction of EPBD directive the following energy saving activities should be performed:

- To replace the conventional light sources (incandescent bulbs, fluorescent lamps) by energy efficient ones (compact fluorescent lamps, sodium lamps).
- To choose the appropriate light sources to be applied.
- To install the appropriate lighting fittings.
- To maintain the cleanness of lighting fittings.
- To install the illumination adjustment equipment.
- To install the equipment for lighting turn ON/ OFF in automatic mode.
- To replace the general lighting by general localised lighting
- To use day light properly.

DESIGN OF RESEARCH LABORATORY FOR ENERGY EFFICIENT INSTALLATIONS IN THE BUILDING

The adaptation design has been elaborated for the rooms in the Department of Computer and Electrical Engineering in Lublin University of Technology in line with the intelligent building standards in order to enable the testing of energy efficient lighting installations.

A particularly important aspect of this project concerns the fact that these rooms are situated in an object protected by the conservator of historical monuments. The control tasks in the laboratory have been designed in KNX system enabling the integration of building systems and the realization of established assumptions (Fig. 1).

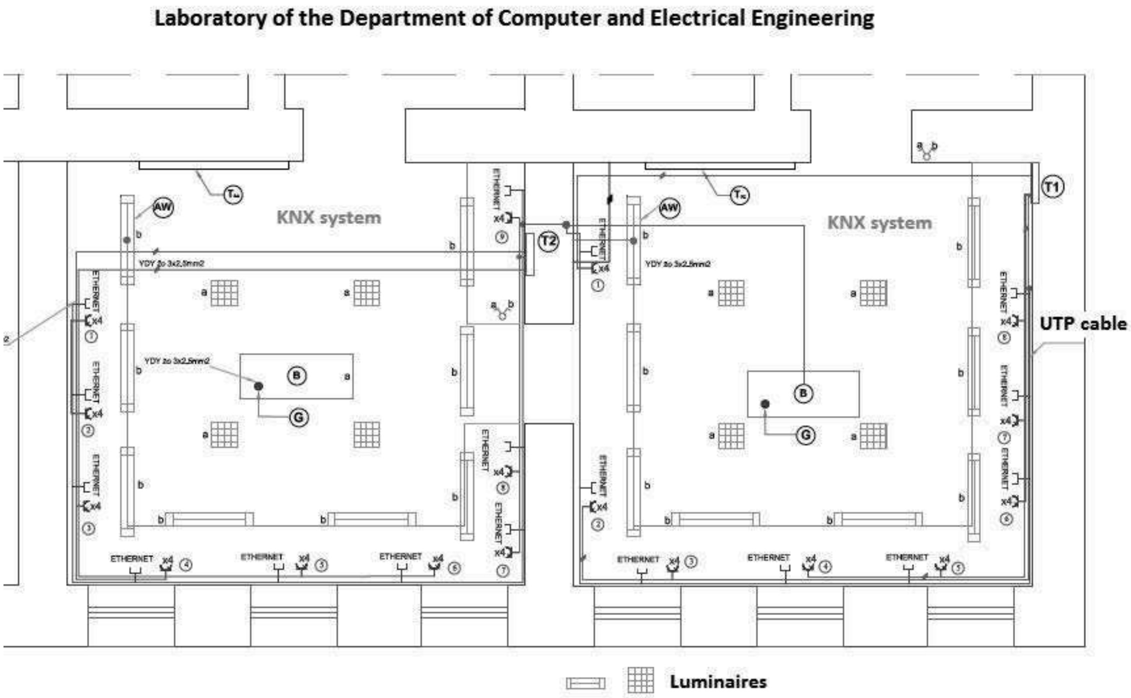

Fig. 1. Electric installations in the research laboratory

In order to achieve the established goal, the following assumptions have been made for KNX installation:

– Lighting control depending on illumination in individual rooms;
– Possibility to turn the lighting ON and OFF.

Fig. 2. Equipment and appearance of a sample room generated in DiaLux program

In order to fulfil the assumptions presented above, KNX devices have been selected and the installation point has been established. The devices will be installed in:

– Switchboard:
  ◦ Power supply unit with coil to provide KNX bus supply,
  ◦ USB communication interface to send created application,
  ◦ Dual channel binary input,
  ◦ Dual channel switching actuator turning ON the lighting in corridor,
  ◦ DALI KNX gate turning ON and controlling the lighting fittings; with DALI interface.
– Assistant Lecturers' room:
  ◦ Single channel switch used to turn ON the lighting via DALI gate,
  ◦ Illumination and motion sensor fastened on the ceiling.
– Laboratory I:
  ◦ Single channel switch used to turn ON the lighting via DALI gate,
  ◦ Illumination and motion sensor fastened on the ceiling.
– Laboratory II:
  ◦ Single channel switch used to turn ON the lighting via DALI gate,
  ◦ Illumination and motion sensor fastened on the ceiling.
– Laboratory III:
  ◦ Single channel switch used to turn ON the lighting via DALI gate,
  ◦ Illumination and motion sensor fastened on the ceiling.
– Corridor:
  ◦ Single channel switch used to turn ON the lighting in corridor.

DALI Light Controller DLR/S 8.16.1M gate is the principal device responsible for the installation control. The gate is able to support up to 64 individually addressed stabilizers operating in 16 independent lighting groups. The stabilizers of the lighting fittings are connected by means of NYM conductor 2x1,5- 2,5 mm^2. Among other things, DALI device makes it possible to determine the rate of illumination change for the sources, to set the values of illumination and to set the emergency lighting turning ON. LF/U 2.1 illumination sensors continuously monitoring the lighting in the rooms, send corresponding signals to DALI gate operating as an actuator control-

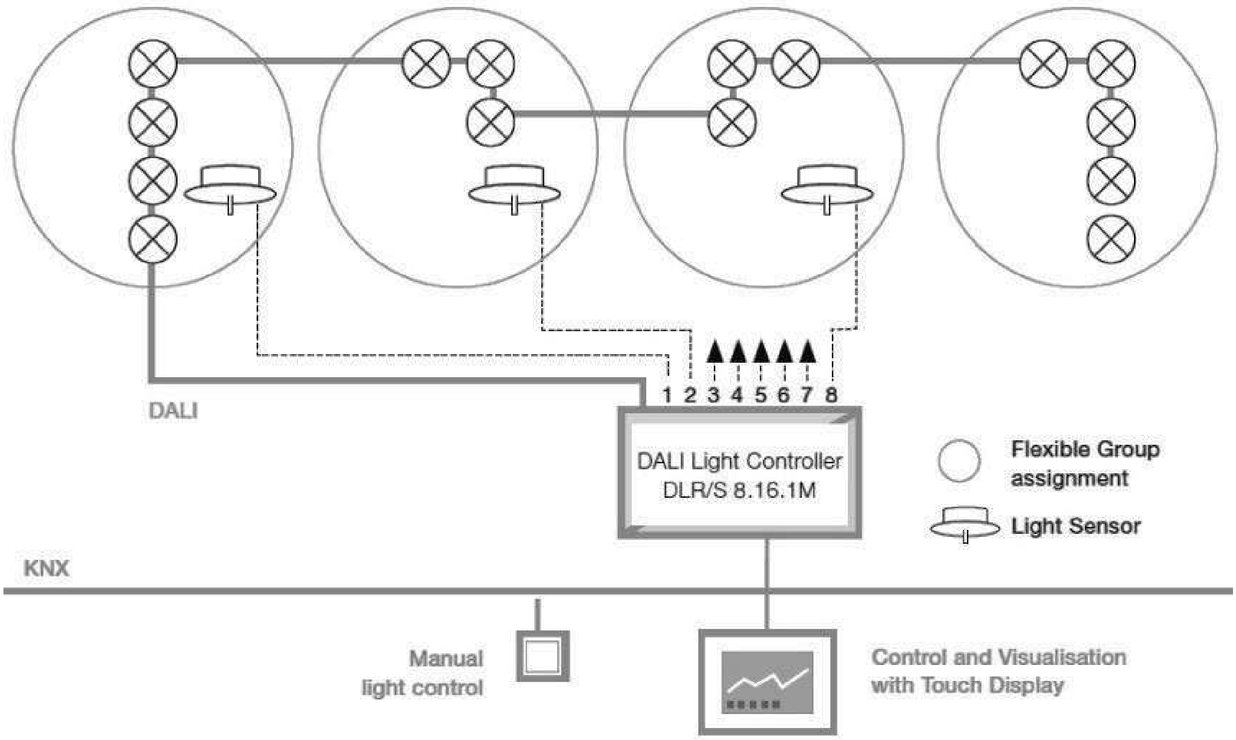

Fig. 3. Pictorial diagram of the connection and operating principles of DALI gate – DALI Light Controller DLR/S 8.16.1M [1,2]

ling the light sources i.e. brightening them or dimming to expected level

CONCLUSIONS

The electric energy consumption for lighting purposes constitutes one of the largest parts of global energy consumption among all types of energy receivers.

There are many technical solutions and types of lighting but still the majority of light sources being installed is characterized by low efficiency level.

The global energy consumption can be significantly reduced as result of the introduction of energy efficient tungsten bulbs, compact fluorescent lamps and LEDs in the market.

The issues associated with electric energy saving by means of energy efficient light sources and their effective use has been the subject of the research for many years. These issues are increasingly wider and often discussed in recent years. The energy saving is facilitated by more and more common control systems: motion detectors (automatically turning OFF the lighting in empty rooms), twilight sensors, turning ON and OFF the lighting and lighting adjustment by means of a pilot. However the effects of saving activities depend on the individuals engaged in the scope of designing, construction and the use of lighting installations. In the near future, we can expect further development of LED lighting technology and facilitated application of control systems. These trends may contribute to further savings in electricity consumption.

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ENERGOOSZCZĘDNE STEROWANIE OŚWIETLENIEM W INTELIGENTNYM BUDYNKU

S t r e s z c z e n i e . Niniejszy artykuł odnosi się do zagadnień związanych z energią efektywnego zarządzania w zakresie energii elektrycznej. Analiza bilansu energetycznego wskazuje, że zużycie energii do celów oświetlenia odgrywa ważną rolę w tej równowadze.Wprowadzenie nowych energii elementów skutecznych rozwiązań oświetleniowych do kontroli odnosi się nie tylko w pełni automatyczny tzw inteligentnych budynków, ale jest niezwykle ważne dla użytkowników systemów opartych na konwencjonalnych instalacji elektrycznych.

S ł o w a k l u c z o w e : oświetlenie, sterowanie, energooszczędne, projektowanie, instalacja.