Modern Lighting Sources and Controls for Energy Efficient Lighting and a Smart Control Algorithm Application

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Abstract: - Energy is an important measure of prosperity of a nation. Energy has been the life-blood for continual progress of human civilization. Since the beginning of industrial revolution around two centuries ago, the global energy consumption has increased by leaps and bounds to accelerate the human living standard, particularly in the industrialized nations of the world. In order to assess the energy efficiency of an indoor lighting installation, a criterion for the installed electrical power is proposed which is broadly applicable and easy to use. Introducing target values for lamps and gear and taking into account some basic lighting comfort requirements, the maximum electrical power to be installed can be predicted for any kind of application. Herewith, one or more task areas with appropriate target illuminance values may be defined. The key parameter of the criterion is the analytical expression for the target utilance as a function of common lighting design parameters. Improved system is provided automatically controlling a light level of an interior space. The system includes a light sensor, motion sensors, electronic control cards, and a PC for fuzzy controller. Fuzzy Controller is determined turning on or turning off lamp groups according to information of light level and motion sensors.

Key-Words: Modern Lighting, Energy Efficiency, Energy Saving, Smart Controls, Fuzzy Logic, Sensors

1 Introduction

The developed nations have much higher per capita energy consumption than the developing world. The available resources of energy are limited. There is a need to locate and harness new sources of energy or to use the available ones judiciously so as to make them last longer. Energy conservation is a step in this direction. Broadly stated energy conservation means is the practice of decreasing the quantity of energy used. It may be achieved through efficient energy use, in which case energy use is decreased while achieving a similar outcome, or by reduced consumption of energy services.

Energy conservation may result in increase of financial capital, environmental value, national security, personal security, and human comfort. Individuals and organizations that are direct consumers of energy want to conserve energy in order to reduce energy costs and promote economic security. Industrial and commercial users desire to increase efficiency and thus maximize profit. Infact industrial sector is the area in which there is highest consumption of energy and therefore there exists a huge scope for adopting energy conservation measures in industry. Today, energy efficiency assumes even greater importance because it is the most cost effective and reliable means of mitigating global climate change[1].

Modern buildings have to be design for low energy consumption. Energy savings in buildings can be achieved by reduction of energy consumption for heating, ventilation and artificial lighting. The design of buildings with respect of solar radiation and daylighting gives possibility for energy efficient buildings. Modern technologies have brought possibility to solve these problems [2].

Electricity is the most versatile form of energy we have. It is what allows citizens of the developed countries to have nearly universal lighting on demand, refrigeration, hygiene, interior climate control in their homes, businesses and schools, and widespread access to various electronic and electromagnetic media [3]. Energy flows through the building envelope are present all the time. The properties of the building envelope have significant influence on the interaction between the inner and the outer energy conditions in the sense of thermal and lighting flows. Optical and thermal responses of the building correspond mostly to the solar radiation and the outside temperature. The development of the technology increases the positive aspect of thermal and illuminance energy flow through the building envelope with its automatically active response [4],[5].

The Problem of energy saving and the achievement of visual comfort conditions in the interior environment of a building is multidimensional. Scientists from a variety of fields have been working on it for quite few decades, but it still remains an open problem. People spend about %80 of their lives inside buildings. So, achieving lighting comfort conditions in a building is very important and has direct implication to the energy efficiency of the building [6].

The achievement of the lighting controller depends on its efficiency and properness in light level controlled illumination systems. In parameters of the controllers, which will lead to minimum time response are tuned manually by running extensive simulations using computer software. Here in this work, the controller is optimized by an optimization process, which will lead to minimum response time for different initial conditions [7].

The use of daylight in buildings is an important and useful strategy in replacing the need for high level of conventional energy for inside illumination. It also increases the psychological benefit that is impossible to achieve with electrical lighting. Daylight can be used to reduce the lighting energy consumption and the heat gains associated with the electrical lighting. Daylight in spaces has been shown to increase occupant satisfaction and improve worker productivity [8], [9].

In this study, system is designed considering energy saving and lighting comfort together. Lighting armatures and ballasts are chosen from new generation products for energy saving purpose. System is controlled by fuzzy logic algorithms controller. Fuzzy inputs are determined by day light level, human motion information in. Light level is kept at standard light level by the fuzzy logic controller using this input values at the work environment [10],[11].

2 Modern Lighting Sources

The light sources are those that give out visible light by using electricity. The luminaries are the accouterments that in conjunction with light sources provide visible light. The luminaries are the devices that make it possible to harness energy efficiently. They give the direction to light. Various light sources are available such as

- Incandescent Lamps
- Fluorescent Lamps
- Compact Fluorescent Lamps
- High Intensity Discharge Lamps
- Low Pressure Sodium Lamps
- Solid-State Lighting

<u>Color Rendering Index (CRI)</u> a measurement of a light source's accuracy in rendering different colors when compared to a reference light source with the same correlated color temperature. The highest attainable CRI is 100. Lamps with CRIs above 70 are typically used in office and living environments.

<u>Correlated Color Temperature (CCT)</u> a measurement on the Kelvin (K) scale that indicates the warmth or coolness of a lamp's color appearance. The higher the color temperature, the cooler the color appearance. Typically, a CCT rating below 3200 K is considered warm, while a rating above 4000 K is considered cool.

<u>Efficiency</u> the ratio of the light output to the power, measured in lumens per watt (lm/w). The higher the efficacy, the more efficient the lamp [12],[13],[14].

2.1 Incandescent Lamps

A standard incandescent lamp consists of a fairly large, thin, frosted glass envelope. Inside the glass is an inert gas such as argon and/or nitrogen. At the center of the lamp is a tungsten filament. Electricity heats the filament. The heated tungsten emits visible light in a process called incandescence (Fig. 1. (a))

Most standard light bulbs are incandescent lamps. They have a CRI of 100 and CCTs between 2600-3000, making them attractive lighting sources for many applications. However, these bulbs are typically inefficient (10-15 lm/w), converting only about 10 percent of the energy into light while transforming the rest into heat.

Another type of incandescent lamp is the halogen lamp. Halogen lamps also have a CRI of 100. But they are slightly more energy efficient, and they maintain their light output over time [12], [14], [15]. **2.2** Fluorescent Lamps

A fluorescent lamp (70-100 lm/w) consists of a sealed glass tube. The tube contains a small amount of mercury and an inert gas, like argon, kept under very low pressure. In these electric-discharge lamps, a fluorescing coating on the glass—called phosphor powder—transforms some of the ultraviolet energy generated into light. Fluorescent lamps also require a ballast to start and maintain their operation (Fig. 1. (b))

Early fluorescent lamps were sometimes criticized as not producing enough warm colors, making them appear as too white or uncomplimentary to skin tones, and a cool white fluorescent lamp had a CRI of 62. But today, there are lamps available with CRIs of 80 and above that simulate natural daylighting and incandescent light. They also are available in a variety of CCTs: 2900 to 7000.

Cold cathode fluorescent lamps are one of the latest technological advances in fluorescent technology. The "cold" in cold cathode means there is no heating filament in the lamp to heat up the gas. This makes them more efficient. Also, since there is no filament to break, they are ideal for use in rough service environments where a regular lamp may fail. They are often used as backlights in LCD monitors. They are also used in exit signs [12], [14], [15].



Fig. 1 Incandescent (a), Fluorescent (b) and Compact fluorescent (c) lamps stuctures

2.3 Compact Fluorescent Lamps

Compact fluorescent lamps (CFLs) are smalldiameter fluorescent lamps folded for compactness, with an efficacy of 50-75 lm/w for 27-40 watts. There are several styles of CFLs: two-, four-, and six-tube lamps, as well as circular lamps. Some CFLs have the tubes and ballast permanently connected. Others have separate tubes and ballasts (Fig. 1. (c)).

Some CFLs feature a round adaptor, allowing them to screw into common electrical sockets and making them ideal replacements for incandescent lamps. They last up to 10 times longer than incandescent lamps, and they use about one-fourth the energy, producing 90 percent less heat [12], [14], [15].

2.4 High Intensity Discharge Lamps

Compared to fluorescent and incandescent lamps, high-intensity discharge (HID) lamps produce a large quantity of light in a small package.

HID lamps produce light by striking an electrical arc across tungsten electrodes housed inside a specially designed inner glass tube. This tube is filled with both gas and metals. The gas aids in the starting of the lamps. Then, the metals produce the light once they are heated to a point of evaporation. Like fluorescent lamps, HID lamps require a ballast to start and maintain their operation (Fig. 2. (a)).

Types of HID lamps include mercury vapor (CRI range 15-55), metal halide (CRI range 65-80), and high-pressure sodium (CRI range 22-75). Mercury vapor lamps (25-45 lm/w), which originally produced a bluish-green light, were the first commercially-available HID lamps. Today, they are also available in a color corrected, whiter light. But they are still often being replaced by the newer, more efficient high-pressure sodium and metal halide lamps. Standard high-pressure sodium lamps have the highest efficacy of all HID lamps, but they produce a yellowish light. High-pressure sodium lamps that produce a whiter light are now available, but efficiency is somewhat sacrificed. Metal halide lamps are less efficient but produce an even whiter, more natural light. Colored metal halide lamps are also available [12], [14], [15].

2.5 Low Pressure Sodium Lamps

Low-pressure sodium lamps—producing up to 180 lumens/watt—have the highest efficacy of all commercially available lighting sources (Fig. 2. (b)).

Even though they emit a yellow light, a lowpressure sodium lamp should not be confused with a standard high-pressure sodium lamp—a highintensity discharge lamp. Low-pressure sodium lamps operate much like a fluorescent lamp and require a ballast. The lamps are also physically large (about 120 cm long for the 180-watt size) so light distribution from fixtures is less controllable. There is a brief warm-up period for the lamp to reach full

brightness [12], [14], [15].



Fig. 2 High intensity discharge (a), Low pressure sodium (b), Solid-State lamps stuctures

2.6 Solid-State Lighting

Compared to incandescent and fluorescent lamps, solid-state lighting creates light with less directed heat. A semi-conducting material converts electricity directly into light, which makes the light very energy efficient. Solid-state lighting includes a variety of light producing semiconductor devices including light-emitting diodes (LEDs) and organic light-emitting diodes (OLEDs). Warm white LEDs have an efficacy of 50 lm/w, while cool white LEDs can achieve efficacies up to 100 lm/w.

Until recently, LEDs—basically tiny light bulbs that fit easily into an electrical circuit—were used as simple indicator lamps in electronics and toys. But recent research has achieved efficiencies equal to fluorescent lamps. And the cost of semiconductor material, which used to be quite expensive, has lowered, making LEDs a more costeffective lighting option (Fig. 2. (c)).

Research shows that LEDs have great potential as energy-efficient lighting for residential and commercial building use. New uses for LEDs include small area lighting, such as task and undershelf fixtures, decorative lighting, and pathway and step marking. As white LEDs become more powerful and effective, LEDs will be used in more general illumination applications, perhaps with entire walls and ceilings becoming the lighting system. They are already being used successfully in many general illumination applications including traffic signals and exit signs.

OLEDs currently are used in very thin, flat display screens, such as those in portable televisions, some vehicle dashboard readouts, and in postage-stamp-sized data screens built into pilots' helmet visors. Because OLEDs emit their own light and can be incorporated into arrays on very thin, flexible materials, they also could be used to fashion large, extremely thin panels for light sources in buildings [12], [14], [15].

3 Lighting Controls

Lighting controls help conserve energy and make a lighting system more flexible. The most common light control is the on/off switch. Other types of lighting control technologies include:

- Manual dimming
- Photosensors
- Occupancy sensors
- Clock switches or timers
- Centralized controls

3.1 Manual dimming

Manual dimming controls allow occupants of a space to adjust the light output or illuminance. This can result in energy savings through reductions in input power, as well as reductions in peak power demand, and enhanced lighting flexibility.

Slider switches allow the occupant to change the lighting over the complete output range. They are the simplest of the manual controls. Preset scene controls change the dimming settings for various lights all at once with the press of a button. It is possible to have different settings for the morning, afternoon, and evening. Remote control dimming is also available. This type of technology is well suited for retrofit projects, where it is useful to minimize rewiring [14],[16].

3.1.1 Photosensors

Photosensors automatically adjust the light output of a lighting system based on detected illuminance. The technology behind photosensors is the photocell. A photocell is a light-responding silicon chip that converts incident radiant energy into electrical current.

While some photosensors just turn lights off and on, others can also dim lights. Automatic dimming can help with lumen maintenance. Lumen maintenance involves dimming luminaires when they are new, which minimizes the wasteful effects of over-design. The power supplied to them is gradually increased to compensate for light loss over the life of the lamp [14],[16].

3.1.2 Occupancy sensors

Occupancy sensors turn lights on and off based on their detection of motion within a space. Some sensors can be also be used in conjunction with dimming controls to keep the lights from turning completely off when a space is unoccupied. This control scheme may be appropriate when occupancy sensors control separate zones in a large space, such as in a laboratory or in an open office area. In these situations, the lights can be dimmed to a predetermined level when the space is unoccupied. Sensors can also be used to enhance the efficiency of centralized controls by switching off lights in unoccupied areas during normal working hours as well as after hours

There are three basic types of occupancy sensors:

- Passive infrared
- Ultrasonic
- Dual-technology (hybrid)

Passive infrared (PIR) sensors react to the movement of a heat-emitting body through their field of view. Wall box-type PIR occupancy sensors are best suited for small, enclosed spaces such as private offices, where the sensor replaces the light switch on the wall and no extra wiring is required. They should not be used where walls, partitions, or other objects might block the sensors' ability to detect motion.

Ultrasonic sensors emit an inaudible sound pattern and re-read the reflection. They react to changes in the reflected sound pattern. These sensors detect very minor motion better than most infrared sensors. Therefore, they are good to use in spaces such as restrooms with stalls, which can block the field of view, since the hard surfaces will reflect the sound pattern.

Dual-technology occupancy sensors use both passive infrared and ultrasonic technologies to minimize the risk of false triggering (lights coming on when the space is unoccupied). They also tend to be more expensive [14],[17].

3.1.3 Clock switches or timers

Clock switches or timers control lighting for a preset period of time. They come equipped with an internal mechanical or digital clock, which will automatically adjust for the time of year. The user determines when the lights should be turned on and when they should be turned off. Clock switches can be used in conjunction with photosensors [14].

3.1.4 Centralized controls

Centralized building controls or building automation systems can be used to automatically turn on, turn off, or dim electric lights around a building. In the morning, the centralized control system can be used to turn on the lights before employees arrive. During the day, a central control system can be used to dim the lights during periods of high power demand. And, at the end of the day, the lights can be turned off automatically. A centralized lighting control system can significantly reduce energy use in buildings where lights are left on when not needed [13].

3.2 Daylighting Controls

A building designed for daylighting but without an integrated electric lighting system will be a net energy loser because of the increased thermal loads. Only when the electric lighting load is reduced will there be more than offsetting savings in electrical and cooling loads. The benefits from daylighting are maximized when both occupancy and lighting sensors are used to control the electric lighting system.

Occupancy sensors detect when a space is occupied by using passive infrared, ultrasonic, or a combination of the two technologies. Once the heat or movement of the occupant is no longer detected, and after a preset delay time, the sensor will emit a signal to extinguish the lights. Occupancy sensors used alone are good for low or intermittent use areas such as storage rooms, restrooms, and even corridors.

Light level sensors have a photoelectric "eye" that measures the illumination in a room. Threshold on and off values can be set to respond to specific lighting conditions. These sensors can operate on/off switching of various luminaires or lamps within luminaires and they can also operate a continuous dimming system. Continuous dimming system will obviously cost more than switching systems but they have greater user satisfaction because the change in light levels is not as noticeable. Fluorescent lighting systems are the most common daylight control lamp source because of the availability of step switching and dimming systems. HID sources are typically not a good choice for daylight switching because of the extended strike and re-strike times. There are now two-step HID sources available that may be useful in some step switching applications where the "off" mode is not desired during a typical day. A daylighting design will use both occupancy and light sensors. With these two control strategies the lights will come on only when the room is occupied and only if there is insufficient daylight. In most designs a manual override is provided for user convenience [14], [16], [17].

3.3 Intelligent Control Systems

Artificial intelligence (AI) is a by-product of the information technology (IT) revolution, and is attempt to replace human intelligence with machine intelligence. An intelligent control system combines the techniques from the fields of control engineering to design autonomous systems that can sense, reason, plan, learn, and act in an intelligent manner. Such a system should be able to achieve sustained desired behavior under conditions of uncertainty, which include;

- uncertainty in plant models
- unpredictable environmental changes
- incomplete, inconsistent or unreliable sensor information
- actuator malfunction.

An intelligent control system comprises of a number of subsystems as shown in Fig. 3 [18], [19].



Fig. 3 Intelligent control system structure

3.3.1 The perception subsystem

These collect information from the plant and the environment and process it into a form suitable for the cognition subsystem. The essential elements are:

- *sensor array* which provides raw data about the plant and the environment

- *signal processing* which transforms information into a suitable form
- *data fusion* which uses multidimensional data spaces to build representations of the plant and its environment. A key technology here is pattern recognition [18].

3.3.2 The cognition subsystem

Cognition in an intelligent control system is concerned with the decision making process under conditions of uncertainty. Key activities include:

- Reasoning, using
- (a) knowledge-based systems
- (b) fuzzy logic
- Strategic planning, using
- (a) optimum policy evaluation
- (b) adaptive search and genetic algorithms
- (c) path planning
- Learning, using
- (a) supervised learning in neural networks
- (b) unsupervised learning in neural networks
- (c) adaptive learning [18], [20].

3.3.3 The actuation subsystem

The actuators operate using signals from the cognition subsystem in order to drive the plant to desired states. In the event of actuator (or sensor) failure, an intelligent control system should be capable of being able to re-configure its control strategy.

3.4 Fuzzy Logic Control Systems

Fuzzy logic was first proposed by Zadeh (1965) and is based on the concept of fuzzy sets. Fuzzy set provides a means for representing theory uncertainty. In general, probability theory is the primary tool for analyzing uncertainty and assumes that the uncertainty is a random process. However, not all uncertainty is random and fuzzy set theory is used to model the kind of uncertainty associated with imprecision, vagueness and lack of information [18], [19].

Conventional set theory distinguishes between those elements that are members of a set and those that are not, there being very clear or crisp boundaries.

The central concept of fuzzy set theory is that the membership function, μ , like probability theory, can have a value of between 0 and 1. In Fig. 4 Crisp set "medium temperature" can be seen.



Fig. 4 Crisp set "medium temperature"

Fuzzy sets represented by symmetrical triangles are commonly used because they give good results and computation is simple. Other arrangements include non-symmetrical triangles, trapezoids, Gaussian and bell shaped curves.



Fig. 5 Fuzzy set "medium temperature"

For "medium temperature" sample membership function can be seen in Fig. 5 [19], [20].

3.4.1 The Fuzzification process

The Basic structure of a fuzzy logic controller (FLC) shown in Fig. 6.



Fig. 6 Fuzzy logic control system

Fuzzification is the process of mapping inputs to the FLC into fuzzy set membership values in the various input universes of discourse. Decision need to be made regarding

- (a) number of inputs
- (b) size of universes of discourse
- (c) number and shape of fuzzy sets.

A FLC that emulates a PD controller will be required to minimize the error e(t) and the rate of change error de/dt or ce.

The size of universes of discourse will depend upon the expected range (usually up to the saturation level) of the input variables. Asume for system about to be considered that *e* has a range of ± 6 and *ce* a range of ± 1 .

The number and shape of fuzzy sets in a particular universe of discourse is a trade-off between precision of control action and real-time computational complexity [19], [21].

3.4.2 The fuzzy rulebase

The fuzzy rulebase consists of a set of antecedent-consequent linguistic rules of the form

IF *e* is PS AND *ce* is NS then *u* is PS

This style of fuzzy conditional statement is often called a "Mamdani" type rule, after Mamdani (1976) who first used it in a fuzzy rulebase to control steam plant.

The rulebase is constructed usin a priori knowledge from either one or all of the following sources:

- (a) physical laws that govern the plant dynamics
- (b) data from existing controllers
- (c) imprecise heuristic knowledge obtained from experienced experts [19], [20], [21].

3.4.3 The defuzzification process

Defuzzification is the procedure for mapping from a set of inferred fuzzy control signals obtained within a fuzzy output window to a non-fuzzy (crisp) control signal.

The centre of area method is the most well known defuzzification technique, which in linguistic terms can be expressed as

Crisp control signal= $\frac{\text{Sum of first moments of areas}}{\text{Sum of areas}}$ For a continuous system, equation becomes;

$$u(kT) = \frac{\int u\mu(u)du}{\int \mu(u)du}$$

or alternatively, for a discrete system, equation can be expressed as [18], [19].

$$u(kT) = \frac{\sum_{i=1}^{n} u_i \mu(u_i)}{\sum_{i=1}^{n} \mu(u_i)}$$

4 System Description

In this study, Illuminated indoor environment is the laboratory where approximately 50 m². System has sensors, ISA data acquisition card, PC, twelve high efficiency fluorescent lamps and designed electronic cards.

4.1 Designed Electronic Cards

These cards are designed for controlling lamp groups, measuring light level and providing isolation between PC and System.

Relay control card is designed with five single pole double throw (SPDT) relays which can be drived digitally. Electric energy controlled by first two relays and other three relays are used for controlling lamp groups. Optic isolation card provides electrical isolation between PC and system, using optocoupler.

Luxmeter circuit is designed for measuring outside light level. Si photo diodes are used as light sensor. Sensor is isolated optically in order not to be affected from interior lighting. Depending to the light level, the circuit is producing 0-5 volt analogue output signal against 0-300 lux light levels. Calibration of circuit is made by using two digital luxmeter. Luxmeter circuit is sensing outside light level. The sensors at the working plane produce faulty outputs because of the people movements in indoor area. During the lesson hours students are always made movements for doing their experiments. For that reason, light level at the working plane could not be measured properly. According to the results of the experiments, interior light level is measured depending on the outside illumination level and light sensing circuit is calibrated accordingly.

4.2 Designed Fuzzy Controller

Optimization of fuzzy logic system is of interest to researchers in past and will remain in future as

Rule No	Motion	Illumination Information	Lamp Group 1	Lamp Group 2	Lamp Group 3
1	No	Dark	Off	Off	Off
2	No	Fair Bright	Off	Off	Off
3	No	Medium Bright	Off	Off	Off
4	No	Bright	Off	Off	Off
5	Yes	Dark	On	On	On
6	Yes	Fair Bright	On	On	Off
7	Yes	Medium Bright	On	Off	Off
8	Yes	Bright	Off	Off	Off

Table 1 Fuzzy logic rules

new applications are emerging. The important factor in optimization of fuzzy logic controller is to determine which parameter is to be tuned.

Due to the results of this experiment, to stabilizing light level at 300 lux on the working plane depending on the natural light level, lamp group on-off period is determined at the diagram shown in Fig. 7 for one day (24 hours).



Fuzzy logic based controller is designed for the system. It is aimed that to stabilize light level at the 300 lux in the lighting controlling environment. Experiments were performed for designing fuzzy logic controller to recognize system working conditions. Fuzzy logic rules are shown in Table 1. Fuzzy control system first checks if there is a movement in area. So if there is a movement system turn on the lamp groups according the illumination level which is measured by electronic luxmeter circuit.

5 Experimental Results

System whole day tests were performed after determining fuzzy logic controller rules. In these tests, system behaviors are examined for different atmospheric conditions. (Clear Sky, Partly Cloudy, Foggy, Mostly cloudy) One of the results, which are found by using designed fuzzy logic controller, is shown in Fig. 8 as an example.



Fig. 8 Luxmeter, luxmeter circuit and lamp groups comparison graphics.

Natural light level was decreased under the limit value, determined for working plane around the time 14:10, so, LG1 was turned on as shown in Fig. 8. LG2 was turned on at 15:45 when the light level has decreased again. The last group, LG3 was turned on at 19:21 and maximum light level has been reached with three lamp group. These results show that fuzzy logic controller could control system as aimed.

6 Conclusions

As the cost of energy has continued to rise, increasing effort has gone into minimizing the energy consumption of lighting installation. This effort has evolved along three major directions:

1. The development of new energy efficient lighting equipment

2. The utilization of improved lighting design practice

3. The improvement in lighting control systems

The technologies and systems used to control lighting are of a great importance in the process of design and construction in accordance with the energy saving criteria. The selection and/or the practicability of the control system can permit optimum use of the design decisions. In addition good control systems can also provide appreciable economic benefits in existing buildings not designed properly.

After installation of the system, measurements were done in 3 months period, which cover spring term. During the one week usage period in normal conditions at the experiment laboratory, after calculations and measurements it was determined that designed system used ¹/₄ of conventional lighting system energy.

As a result; lighting control could be performed by using fuzzy logic controller at the laboratory during the lesson hours with providing required light level in the lighting system controlled by fuzzy logic study. Lamp groups are turned on using motion sensors when motion is detected at the laboratory. Thus, energy consumption was prevented by turning off the lamp groups when laboratory was not in use.

It is provided that, lighting system was operated with stabilizing total lighting of 300 lux value at working plane, depending on the natural light level. Lamp groups turned on and off in three steps, so over-lighting was prevented. Lamp groups were turned off gradually when light level exceeds 300 lux; in this way maximum benefit from natural light level is gained.

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