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Classroom Lighting Control Systems and Level of Energy Consumption, Tehran, Iran

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ABSTRACT: Buildings play an important role in the energy demand sector. Due to the increase of environmental concerns and renewable energy sources restriction, lighting control systems will play an important role in the reduction of energy consumption of the lighting without impeding comfort goals. Lighting control systems can control lighting consumption according to the type of building, adequate luminance, occupation time, scheduled time etc. Better lighting not only can reduce the energy consumption of a room, it can improve the quality of work from its occupants. The main aim of the project is to determine the energy saved by using different artificial lighting control systems and find the best one. Honeybee plug-in for grasshopper in a space as a classroom simulated six different systems in this article and electricity, cooling and heating energy consumption for these systems were compared. Results show that "Auto dimming with switch off occupancy sensor" has the best annual operation and it saves eight times more electricity energy than the worst system which is the traditional "Always on during active occupancy sensor". Considering thermal energy consumption also proves the priority of occupancy and daylight dimming system. Selecting a suitable lighting control system in initial steps of design or after construction is very affordable and increases environment quality.

Keywords: *Lighting Control System, Energy Saving, Sensor, Dimmer, Honeybee*

INTRODUCTION

The demand for energy is increasing very fast, while the energy supply is going short (Zarei & Khademi Zare, 2012). Power conservation is no longer just a fashionable expression, it has now become a necessity (Nippun Kumaar et al., 2010).And the inappropriate indoor environment quality of a building causes different problems such as headache and breathing difficulties which are called the syndrome of building sickness (Ansarimanesh & Nasrollahi, 2014). So paying attention to energy and indoor quality are two basic matters in designing buildings. Quality lighting is an important aspect of our daily life that is often taken for granted. Light control is the ability to regulate the level and quality of light in a given space for specific tasks or situations (Ray & Verma, 2012). According to IEA study (IEA,2006), global grid based electricity consumption for lighting was about 2650 kwh in 2005, which was an equivalent of 19% of total global electricity consumption, and the share of electricity of lighting is around 10-15% in schools (Ticleanu,2014). The benefits of a carefully planned day lighting concept range from an enhanced visual comfort for the inhabitants to a reduced artificial lighting consumption (Reinhart & Walkenhorst, 2001). Getting information about lighting control systems and the ability to choose the best one for each building is a necessary proficiency for architect. The main aim of the article is to find out how much energy can be saved by using different light systems tested here and compare them to select the best one.

Lighting Control Systems

Lighting control system is a computerized or otherwise automated system, which controls the lights throughout a building, which is an intelligent network, based lighting control solution that incorporates communication between various

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system inputs and outputs related to lighting control with the use of one or more central computing devices. Lighting control systems are widely used on both indoor and outdoor lighting of educational, industrial, residential spaces, etc. Lighting control systems minimize waste by turning them off by providing the right amount of light where and when it is needed. Lighting control systems are employed to maximize the energy savings from the lighting system, satisfy building codes, or comply with green building and energy conservation programs. Lighting control systems are often referred to under the term Smart Lighting. There are different lighting control-systems for different needs, having information about these systems will help designer to select the best lighting control system for each space based on their occupation, users, geometry etc., which can save great amount of energy in buildings. Some of them are explained in the following.

Occupancy/Vacancy Systems

This is the most common control method employed today. Sensors automatically turn lights off in a space when it's unoccupied and turn them on when occupied. A number of smart lighting systems have been designed to adjust the lighting condition according to the occupancy in the space. They may use video systems, infrared, ultrasonic, microwave technology and electric eyes to assess energy efficiency in lighting a staff room (Wang et al., 2014). Occupancy Control Strategies are best used in applications where occupancy does not follow a set schedule and is not predictable, such as private offices, corridors, stairwells, conference rooms, library stack areas, storage rooms and warehouses (Maniccia et al., 2000).

Occupant Needs

The occupants need to control the system, because the needs and priorities of occupants vary from one occupant to another and with time for the same occupant. For example, energy savings may concern some occupants, and some prefer better algorithmic lighting scenes even if it requires more energy and generates higher costs. Therefore, it is recommended that the occupants should have possibility to change the system's behavior according to his will. Many new buildings are now equipped with personal Environment Modules (PEMs) (Bauman et al., 1997). The goal of providing PEMs is to enable occupants to control their own environment. Bakker et al. (2014) found that less frequent but discrete transitions in facade configuration are significantly better appreciated than smooth transitions at a higher frequency.

Daylight Harvesting

In addition to attention to natural light as a renewable, costless and environment-friendly source of energy in the late 20th century, numerous studies have been conducted into the effect of natural light on human being's soul and body and all such studies reiterate the undeniable role of natural lighting on people's behavior, attitudes, and efficiency (Makani et al., 2012). A research in Turkey showed that 30% approximate energy saving could be achieved by using daylight responsive lighting control system (Onaygil & Guler, 2003). The ability to control the level of light within a room of a building by use of wall mounted dimmer switch has given rise to the opportunity of automatically controlling the level of light within the room. Such systems attempt to control the output of the artificial lighting sources within the room as the light within the room changes. The amount of light within the room will change as the sunlight entering the room changes. Daylight harvesting strategy significantly reduces energy usage (Singhvi et al., 2005). Day lighting can be considered as a very important strategy to substitute electric energy for the artificial lighting. It can reduce not only the lighting, and cooling as well, consumption but it can be very efficient in reducing peak electrical loads (Doulos et al., 2008). All daylight-harvesting systems use a light level sensor, a photo sensor, to detect the prevailing light level, luminance or brightness. Fig. 1 shows how daylight-harvesting systems cause more uniformity and better visual comfort. By using shades or other daylight control systems, in conjunction with dimmers, light systems can create the perfect balance between the two sources of light to save

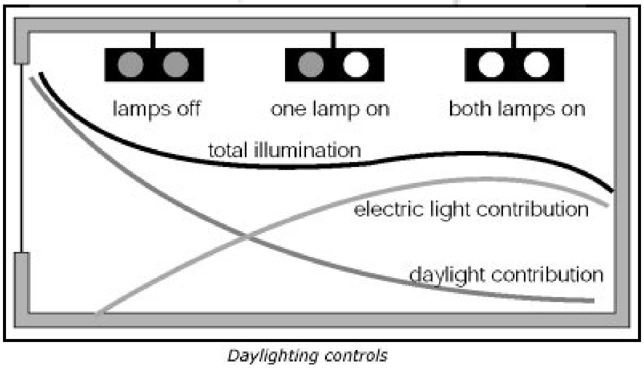

Fig.1: Daylight harvesting system

energy and create an inviting environment.

Dimming or Switching Systems

In an average building, most light controls are a simple on/off switch, rather than a dimmer. This means that a whether it is the middle of the day or it is midnight, sunny or cloudy, fixtures are putting out the exact same amount of light. In fact, light switches are one of the few appliances that only have two settings- on and off. Through dimming, users can control the quantity of light their fixtures provide to fit specific tasks, moods or situations. Quite simply, the more you dim, the more you save. This not only improves the experience, but also saves wasted energy in the process. Embrechts and Van Bellegem (1997) measured that an individual lighting dimming system can offer 20-40% of lighting consumption savings. If a dimming system is well calibrated, the occupants of the space will not notice changes in electric lighting. Replacing a standard light switch with a single dimmer is a simple do-it-yourself project.

Other Lighting Control Systems

There are other lighting systems, such as integrating lighting and HVAC. Shared sensors can detect room occupancy and automatically adjust the lighting and temperature levels to match the situation. Astronomical time clock scheduling is another system that is programmed to a geographic location to provide automatic control of lights and/or shades relative to sunrise and sunset for every day of the year. They are often used for day lighting control in exterior appliances (Williams et al, 2011). Chronological time schedules incorporate specific times of the day, week, month or year. This strategy is used most widely in applications where building occupancy patterns are predictable and follow daily and weekly schedules.

It is perfect to use Lighting Management System (LMS), which can be a part of Building Management System (BMS) in buildings. LMS governs all the devices connected to the Light lighting control panels. Using this intuitive, web-based software application, facility managers are able to analyze the building's lighting system usage easily and quickly update the system to improve the energy consumption. The high cost of retrofitting buildings with advanced lighting control systems is a barrier to adoption of this energy-saving technology. Wireless technology, however, offers a solution to mounting installation costs since it requires no additional wiring to implement (Park et al., 2009).

MATERIALS AND METHODS

In recent years, the design professions have begun experimenting with parametric design tools such as Grasshopper which was developed by David Rutten at Robert Mcneel Associates in 2007 as a parametric modeling plug-in (Elghazi et al., 2014). There have been various plug-ins for Grasshopper that connects the Rhino geometry to simulation software, such as Honeybee which is developed by Mostapha Sadeghipour Roudsari. Honeybee connects Grasshopper 3D to Energy Plus, Radiance, Daysim and Open Studio for building energy and day lighting simulation. The Honeybee project intends to make many of the features of these simulation tools available in a parametric way. Honeybee has the ability to simulate daylight, thermal and electricity energy in the space simultaneously, so a comprehensive analysis will be made using this software.

Six types of artificial lighting control systems (Table 3) are compared to each other and their energy consumption are listed. The first system is "always on during active occupancy sensor (Traditional systems)" which is used in most of the built schools. They are always on, without any changes in their luminous flux and do not respond to any environmental variables. The second system is like the first one, except for the affordance, which is taken to user to switch on/off lights to reach a preferred illuminance amount. They cannot change the light emitted by each lamp using dimmers, just can manage the total light produced in the space by switching on or off. The third system has the occupancy sensor, which is automatic, so the sensor acts based on the people presence in the space automatically. In the fourth system, users can switch on/off lights manually and the sensors act based on daylight entering the space, so some lights, usually front lights near the window, might be turned off or dimmed, when adequate illuminance on work plane surface is provided. In the fifth system, occupancy and daylight harvesting sensors are working simultaneously and dimmers for daylight and switchers for occupancy are used. The sixth system does not pay attention to vacancy, it has always on lights, but sensors will dim lights, usually front lights near the window, when daylight entering the roomies totally or somehow adequate.

The method applied in this study is simulation by using Honeybee 0.0.57which is a plugin for grasshopper 0.9.0076 on Rhinoceros 5 software. Tehran, where the model is originally developed, is the capital of Iran, with the latitude of 35.41° and longitude 51.19° and hot and dry climate, Tehran is counted in climate zone 4B (ASHRAE,2007). The climate-based sky for Tehran-Mehrabad is considered for this research. A sample room was used as a classroom with dimension of 8m in width, 6m in depth and 3.5m in height, located in the first floor of a hypothetical primary school building. The window area is 30% of the south elevation (Fig. 2).The light sensors are located at 9 pints near the ceiling, they are provided for measuring and controlling the level of light at work plane surface (Fig. 3).

Energy consumption in all lighting systems listed in this article are tested to supply the work plane light level to 500 lux, which is a proper illuminance range for educational buildings (Williams,1999; Kreider, 2011; Krarti,2011). The standard occupant air temperature of 24˚c during cooling and 19˚c during heating for Energy Plus zone thresholds are considered. The analysis period is from 23rd September at 8 o'clock, to 21st June at 14 o'clock. Default information for the lighting control recipe are considered as: Target illuminance for the space: 500 lux, lighting power: 250watts,

Table1. Energy Plus zone loads

Equipment load per area	10.97924
Infiltration rate per area	0.000227
Lighting density per area	15.06
Number of people per area	0.24
Ventilation per area	0.00061
Ventilation per person	0.004719

Table2. Selected materials for this research

Building elements	Energy plus material
Infiltration rate per area	Ashrae 90.1-2010 ExtWall steel frame climate zone 4
Base-wall	U value: 0.55
Number of people per area	Interior Wall, U v
Adjacent walls	value: 2.58
Ventilation per person	Ashrae 90.1-2010 ExtRoof IEAD climate zone 2-8
Ceiling	U value: 0.28
	Ashrae 90.1-2010 ExtFloor Climatezone 2-7
Floor	U value: 0.15
	Ashrae 90.1-2010 ExtWindow Nonmetal climate zone 4
Window	U value: 2.27

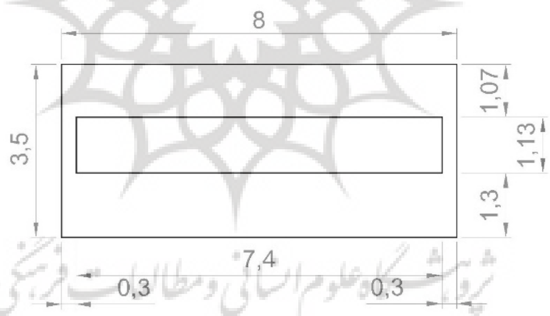

Fig. 2: Window position in south elevation

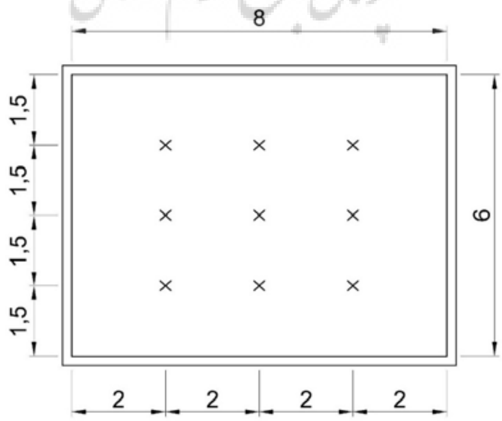

Fig. 3: light sensor positions in plan

standby power: 3watts, ballast loss factor: 20%, and switch off delay time: 5 minutes.

RESULTS AND DISCUSSION

Using occupancy systems decrease energy consumption because it turns off light when people are out of the space. Considering occupancy needs is good, because people can manage the amount of illuminance they need or prefer for the task they are doing, so individual differences might need different illuminance range. Daylight harvesting systems also turn off lights when the room is much shined. Adequate illuminance is provided by daylight entering from the window, lights, which are located at the front of the room, near the window, might be dimmed and produce less electricity and heating energy, on the other hand, uniformity ratio, which is one of the factors supplying visual comfort will get higher. Students and teachers will have higher efficiency in such a space. In this article, it is tried to find the best system and analyze energy consumption for each of these systems. Six lighting control systems are compared according to electricity consumption, and cooling and heating energy loads. Simulation results are organized in the table 3. Electricity consumption in the 5th system (Auto dimming with switch off occupancy sensor) is the most energy-efficient, because its function relates to occupancy needs and vacancy and dimmers which act based on daylight entering the room. The first system (Always on during active occupancy sensor) is the worst one in using energy. This system which is used in most of the buildings, does not have any attention to daylight and many lights might be on, producing electricity and heating, when it is

Table 3. Energy consumption in artificial lighting control systems

number	Type of sensor	Lighting electricity consumption	Cooling energy consumption	Heating energy consumption	Cooling and heating energy consumption	All energy consumption
1	Always on during active occupancy sensor (Traditional systems)	912.21	1922.20	1871.99	3794.19	4706.4
2	Manual on/off switch (Occupancy Preference)	295.31	1744.16	2003.26	3747.42	4042.73
3	Automate switch off occupancy sensor	182.84	1724	2018.61	3742.61	3925.45
4	Manual on/off switch with auto dimming(Daylight harvesting)	161.97	1725.80	2023.22	3749.02	3910.99
5	Auto dimming (Daylight harvesting) with switch off occupancy sensor	112.86	1703.45	2032.39	3735.84	3848.7
6	Always on during active occupancy hours with auto dimming(Daylight harvesting)	526.81	1829.27	1926.26	3755.53	4282.34

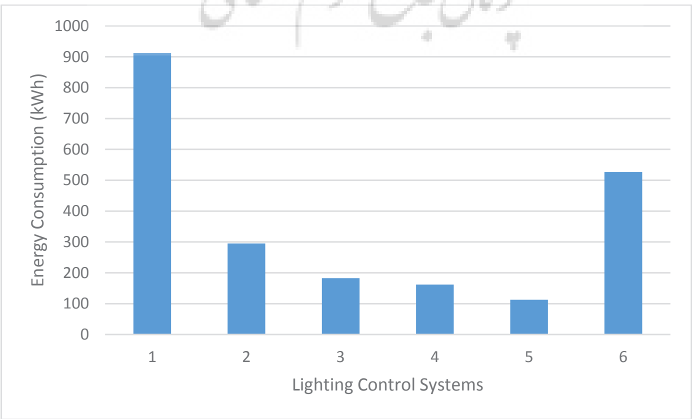

Fig.4: Electricity energy consumption of systems

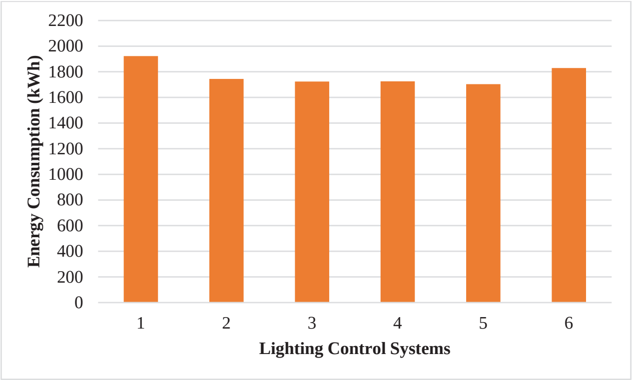

Fig. 5: Cooling energy consumption of systems

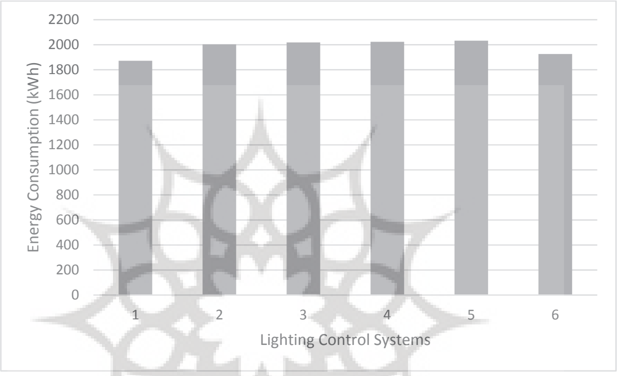

Fig. 6: Heating energy consumption of systems

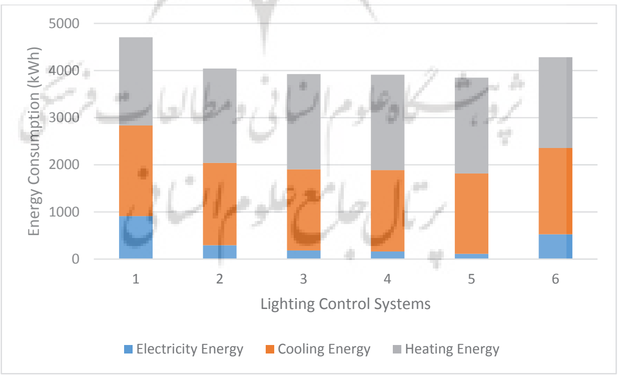

Fig. 7: Whole energy consumption of lighting control systems

unnecessary, on the other hand, when people leave the space, lights will be still on. The system which acts better in using electricity, also acts better in cooling energy usage (Fig. 4&5), because it does not produce unnecessary heat. Heating energy consumption has contradiction procedure with electricity and cooling energy (Fig. 6), because the specified system is turned-off or emitted low light when less illuminance is needed, then creates less heating. In general, considering the whole energy consumption, the Auto dimming with switch off occupancy system is in the first place (Fig. 7). It saves about 800 kWh(16.6 kWh/m2)electricity energy- uses about eight times less energy than the first traditional system-and

45kwh(0.93 kWh/m2) thermal energy.Accordingly, it saves 795.4 kWh (16.57 kWh/m2) per year. The second suitable system is Manual on/off switch (occupancy preference system) with auto dimming (Daylight harvesting) system that saves 780.95kWh (16.26 kWh/m2) per year. Schools have almost a typical scheduled program- here from 8 o'clock to 14 o'clock every day, expect for Tuesdays and Fridays-, it can be concluded that students and teachers occupy the classroom all the time when the school is open. So considering scheduled system instead of occupancy system does not have much more energy consumption, and the 4th system (Manual on/off switch with auto dimming-daylight harvesting) is almost the same as the 5th system (Auto dimming -Daylight harvesting- with switch off occupancy sensor) in classroom with specified occupancy program. It shows that for educational spaces, daylight harvesting system has more effect on reducing energy consumption and it can save more energy than other systems, such as occupancy system. Because sensors measure the illuminance on the work plane surface, which is differing from time to time by sun movement in the sky and decide which lights turn off or emit lower luminous flux in a zone that gets efficient daylight. It can be said that system 5 is a result of assembling of system 3 and system 4 and performs better that these two systems. Comparing system 4 and system 6, shows that integrating dimming systems and switching systems for different purposes cause energy reduction. In addition, the large amount of energy consumption by system 2, which emphasizes on occupancy preferences, proves that users cannot always understand what the best illuminance is, or sometimes they might forget or ignore to change the light specification during the occupancy time.

CONCLUSION

Due to the increase of environmental concerns and renewable energy sources restriction, lighting control systems will play an important role in the reduction of energy consumption of the lighting without impeding comfort goals. There are many lighting control systems for different purposes, such as occupancy sensors, occupancy needs, daylight harvesting, scheduled systems, etc. Comparing some of systems in a usual classroom, using Honeybee plug-in for Grasshopper simulation software, indicate that daylight harvesting systems and occupancy sensors with user preferences can have great effect on decreasing energy consumption. Integrating these systems with auto dimming sensors instead of switching ones increases the efficiency. The result shows that "auto dimming with switch off occupancy sensor" saves about eight times more energy per year. Therefore, the best lighting control system for classroom, as an educational space with a simple 30% window to wall ratio in Tehran, is an occupancy and daylight harvesting dimming system. Considering thermal energy consumption also proves the priority of using occupancy and daylight dimming system. Results also proved that for spaces like classroom, which have specified occupancy program daily and annually, using daylight harvesting system can save more energy and one of two systems of scheduled or occupancy systems can be selected. This research is done in a small classroom. If architects have information about these systems and their advantages, and use these systems in large projects such as an educational building with lots of classrooms, great amount of energy will be saved just by using these systems. This striking amount of energy saved by lighting control systems returns the primary investment in short period. Lighting control systems are one of the most cost-effective ways to reduce urban emissions and energy costs significantly that should be used to cause sustainable architecture. To have zero lighting buildings, it is perfect to use Lighting Management System (LMS) which can be a part of Building Management System (BMS) in buildings. In this way, all lighting consumption will be managed and consumed when and where it is necessary.

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