# DESIGN OF A SMART LIGHTING SYSTEM FOR AN EDUCATIONAL FACILITY-A CASE STUDY

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SUBMITTED BY

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RECOMMENDATION CERTIFICATE

This is to certify that the thesis entitled "DESIGN OF A SMART LIGHTING SYSTEM FOR AN EDUCATIONAL FACILITY-A CASE STUDY" submitted by SUMIT PAUL,(Examination Roll No. M4ILN22025, Registration No. 154048 of 2020-2021) of this University in partial fulfilment of requirements for the award of degree of Master Of Engineering in Illumination Engineering, Department of Electrical Engineering, is a bonafide record of the work carried out by him under my guidance and supervision.

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This foregoing thesis is hereby approved as a creditable study in the area of Illumination Engineering, carried out and presented by SUMIT PAUL, in a manner of satisfactory warrant its acceptance as a pre-requisite to the degree for which it has been submitted. It is notified to be understood that by this approval, the undersigned do not necessarily endorse or approved the thesis only for the purpose for which it has been submitted.

FINAL EXAMINATION FOR EVALUATION OF THESIS

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DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of my Master of Engineering in Illumination Engineering studies.

All information in this document have been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by thesis rules and conduct, I have fully cited and referenced all material and results which are not original to this work.

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| NAME | : SUMIT PAUL |
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# Contents

## Chapter 1

# 1 Introduction

In recent years, increased usage of appliances such as airconditioning and heating systems, lighting systems and entertainment systems has led to dramatic growth of electricity consumptions in residential and commercial buildings. Most of the electricity is generated by using fossil fuels which contribute to global warning. Energy consumption in the household has been growing in aggregate over time and there is a need to reduce electricity consumption to preserve natural resources. With increasing effect on global warming, energy conversation is one of the main objective of this generation to reduce the further negative impact on the environment. Today, cities are under immense pressure to remain livable due to the fast urbanization of the world's population. Smart city concept and its development are gaining popularity as it has the capability to use diverse technologies in different aspects of urban life. As a result, it can improve the sustainability and the quality of life of its inhabitants.With increasing demand and reduced budget, smart and intelligent solutions are needed to manage a smart city.The Indian government has plans to build at least 100 smart cities by the year 2050. Visual comfort without compromising the energy efficiency and set standards is a major concern in an official building.Indoor lighting accounts for 15-20 percentage of the total energy consumption amongst electrical loads in residential buildings.

Even though the importance of light in classroom is generally recognized, knowledge about the most suitable settings of illumination for a diversified educational situation and practice is still insufficient and sometimes controversial.

## 1.1 Literature Review

Indoor environment, like classroom and office, is an integrated and complex system, which involves physical layout, interior design, infrastructure, furniture, and equipment, as well as indoor environmental factors including light, temperature, humidity, air quality and acoustics. The impact of indoor environmental quality (IEQ) on occupants' comfort and wellbeing is critical but very complicated (*Al horr et al., 2016*). As to students, existing studies have proved that IEQ of classroom can significantly impact on their well-being and performance (*Blackmore et al., 2011; Earthman, 2004; Gabrielle Wall, 2016; Gilavand and Jamshidnezhad, 2016; Higgins et al., 2005; Yang et al., 2013; Y. Zhang et al., 2016*). More particularly, lighting environment is believed to be one of the most important factors among all environmental aspects in classroom. For instance, the result of data study regarding 153 classrooms in 27 schools in England showed that light explained 21 percent to the increase in student progress and contributed the biggest share among seven environmental factors, including light, sound, temperature, air quality, links to nature, ownership and flexibility (*Barrett et al., 2015*).

Daylight comes from the natural and was once the primary light source before artificial light became widely available. Initially, people intended to tell the preference of users and different effects between daylight and artificial lighting. Eventually, many researchers have reached consensus that daylight is not only preferable by teachers and students (*Earthman, 2004; Heschong, 2003*), but also reduces the risk of myopia (*Ballina, 2016; Torii et al., 2017; Y. Wang et al., 2015*). However, daylight featured by its variability in amount, spectrum and distribution due to the time, weather and site (*Peter Robert Boyce, 2014*) can not solely support activities in classroom. In most cases, artificial light dominates indoor illuminance, while daylight acts as a supplementary light source.

Since the advent of Edison light bulb, the lighting industry has developed for more than one century. Though there are several thousand different types of electric lamps, those can be put into three categories: 1) incandescent lamps, e.g. the filament light bulbs and halogen lamps; 2) discharge lamps, e.g. fluorescent lamps; and 3) solid-state lamps, e.g. light-emitting diodes (LED) (*Peter Robert Boyce, 2014*). Although fluorescent lamps still hold a considerable market share, LED replacement of traditional lamps is accelerating at about 13 percent CAGR (Compound Annual Growth Rate) globally (*Zion Market Research, 2017*). Compared to incandescent and fluorescent lamps, the advantages of adopting LED in schools include not only higher brightness, longer life span, lower maintenance cost, and more savings on energy, but also the capability of being precisely controlled in terms of the brightness level and CCT. As a critical aspect of a LED light source, illuminance uniformity represents the homogeneity of light distributed onto the work plane (*Moreno and Tzonchev, 2004*). It is cogent that LED will predominate in learning spaces in near future. This may be one of the reasons that most relevant research in recent years were all under LED environment, as is this study.

Glare is the "sensation produced by luminance within the visual filed that is sufficiently greater that the luminance to which the eyes are adapted to cause annoyance, discomfort, or loss of visual performance and visibility" (*Zion Market Research, 2017*). Glare can be induced by a couple of reasons, including excessive luminous intensity, direct light (sunlight or lamps), and non-uniform spatial distribution of luminance. Classroom should avoid all kinds of glare by applying blinds or curtains and using glare-free LED lamps with rational layout. In practice, the Unified Glare Rating (UGR) (*Commission Internationale de l'Eclairage, 1983*) is widely recognized as a glare metric for indoor lighting. The degree of UGR ranges from 7 (insensitive) to 31 (unbearable). In classroom, the value of UGR is usually restricted below 19 according to the standards of many countries.

Although blue ray is one of ubiquitous components of daylight and almost all artificial light sources, exposure to excessive blue light is risky to human's photobiological safety. The consequences of blue light hazard include eyestrain, visual fatigue, circadian disruption and photo retinitis (*Leccese et al., 2015*).

Flicker is defined as "a rapid and repeated change over time in the brightness of light" (*Wilkins et al., 2010*). It should be noticed that almost all types of light sources could produce flicker. As shown in figure 1, flicker whose frequency ranges from 3 Hz to 70 Hz is called visible flicker, which means it can be consciously perceived by human. Visible flicker can cause immediate health impact, such as malaise, headache, and epileptic seizures. On other hand, invisible flicker can be divided into two categories. Flicker with frequency above 3125 Hz is considered safe to human, because human's optic nerves can not sense that high frequency. So lighting sources with 3125 Hz or higher frequency are exempt from flicker testing by international standards including IEEE and IEC (*IEC TR 61547-1, 2017; IEEE Power Electronics Society, 2015*). However, invisible flicker with lower frequency may lead to discomfort and chronic health problems, like eyestrain, headache, reduced visual performance, etc. In practice, low frequency invisible flicker requires much vigilance, because it is not perceptible, and people can get hurt without knowing it.

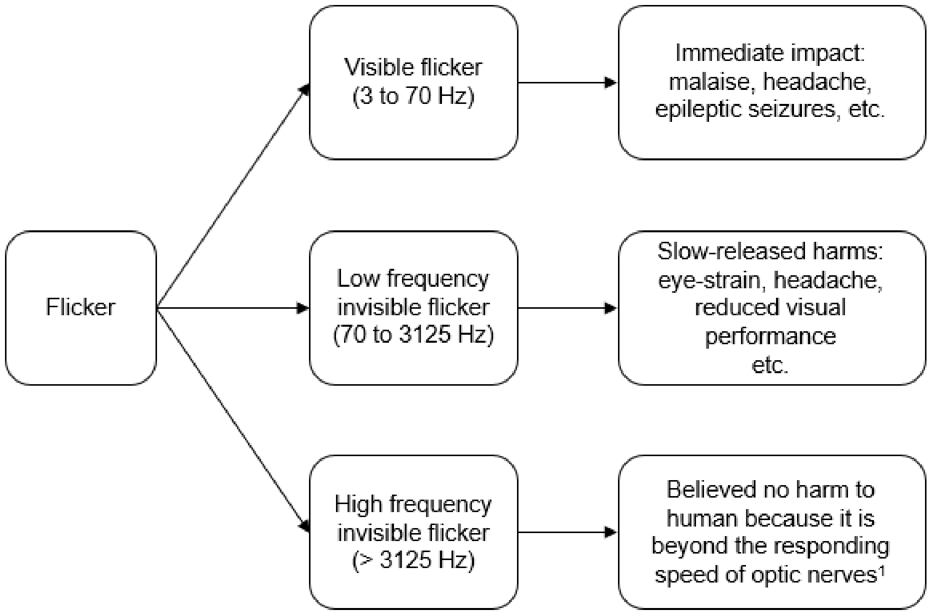



Figure 1: Types of Flicker(*IEEE Std 1789-2015*)

Despite few conflicting evidence and disputation regarding the optimum configuration of CCT in classroom, forceful opinions on the effects of CCT have been established. Studies demonstrated that different illumination configurations, including brightness and CCT (*Borbély et al., 2001*), had different impacts on students' behaviour and cognition, but the impact differed depending on learning context and age group (*Ballina, 2016; Fabio et al., 2015; Keis et al., 2014; Singh and Arora, 2014; Sleegers et al., 2013; Smolders and de Kort, 2014; Wessolowski et al., 2014*). Furthermore, CCT settings may also have influence on energy-efficiency, which attribute to the occupant's thermal perception under different CCT condition. Some recent studies argued that occupants sensed warmer under lower CCT (warm light) environment (*Golasi et al., 2019; Toftum et al., 2018*) and this could lead to around 8 percent of the annual energy savings (*Toftum et al., 2018*).

The combination of colour temperature and illumination has a more complex effect on occupants. In general, it can be roughly evaluated by Kruithof's Curve (*Davis and Ginthner, 1990*). As demonstrated in the below figure, the horizontal and vertical coordinates of the figure are CCT and illuminance, respectively [Figure2].

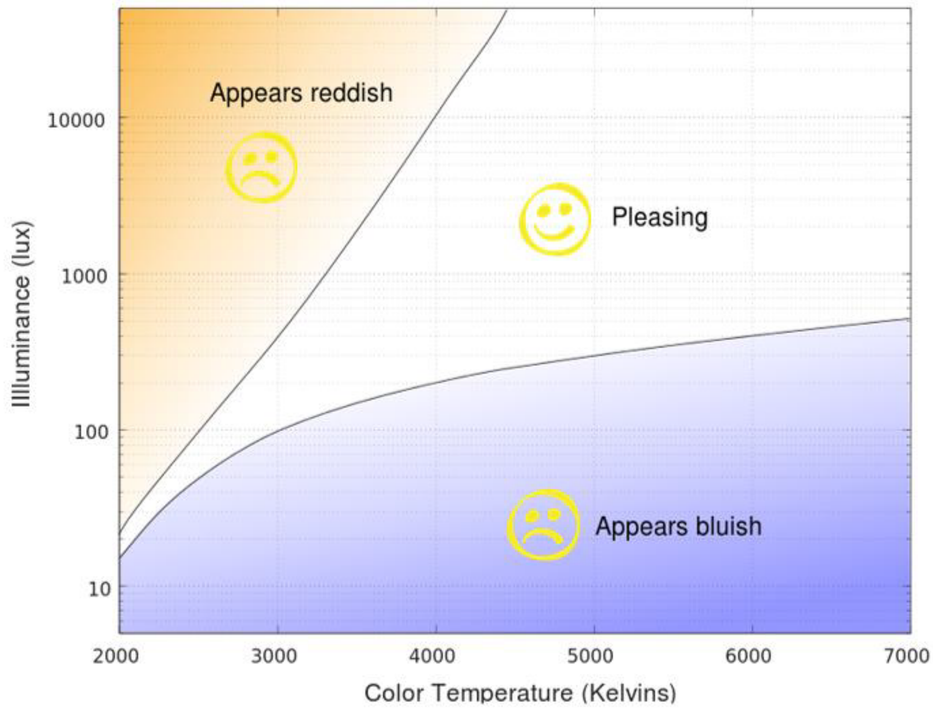



Figure 2: Kruithof's Curve (*Davis and Ginthner, 1990*)

The middle part is the pleasing zone with preferred combination of colour temperature and illumination, while other zones are considered uncomfortable. The upper left zone appears reddish (low CCT and high illumination), and the lower right zone appears bluish (high CCT and low illumination). Therefore, when determining the classroom lighting settings, we should keep in mind to constraint the pair of parameters within the pleasing zone.

Indoor lighting is a complex system, involving many aspects, such as the characteristics of the light source, the application and context, the preference and difference of occupants and so on. With the development of lighting technology as well as the ever-changing of application environment, research focus on classroom lighting environment has kept shifting throughout decades.

Before 2005, research mainly focused on the difference between daylight and artificial lighting, and their impact on occupants. Hathaway (*Hathaway, 1983*) found that teachers and pupils preferred natural light, and subsequent studies (*Earthman, 2004; Heschong, 2003; Rittner-Heir, 2002*) have shown that daylight has a more positive impact on students. However, replying only on daylight is not realistic (*Higgins et al., 2005*), either too much daylight or insufficient illuminance will be complained by students (Singh and Arora, 2014). Therefore, controlled daylight combined with appropriate artificial lighting is very important for learning environment and students' performance (*McCreery and Hill, 2005*). Considering that the control of daylight mainly depends on windows, blinds, or curtains after a building is finished, the adjustment scale is very limited. Therefore, studies of indoor lighting had gradually turned to artificial lighting.

After, study focus turned to artificial lighting around 2005, researchers primarily paid rapt attention to the quality of artificial lighting sources that relates to people's wellbeing. Quality issues, including glare, flicker, low color-rending index (CRI), and blackening phenomenon of fluorescent lamps, can cause considerable health problems. Many complaints were reported in this regard, such as headaches, eyestrain, fatigue, distraction, and myopia (*Higgins et al., 2005; Youn-Ki et al., 2008*). With the improvement of schools' environmental quality standards, because of its high efficiency, compact in size, savings on energy and environmental friendliness, as well as real-time tunability of spectrum (*Artūras Žukauskas et al., 2010; Kevin A.G. Smet et al., 2011*), LEDs have become the most popular lighting sources and been used to replace fluorescent lamps, which used to dominate classrooms. When the quality of artificial lighting was no longer a concern, light settings such as brightness and CCT, became the primary research topic of the area.

More and more studies regarding the optimum brightness in learning environment can be found from around 2010. Some studies claimed that high lighting levels (1000 lux) can benefit learners by improving their concentration (*Singh and Arora, 2014; Sleegers et al., 2013*), suppressing sleepiness, enhancing brain activity, and increasing arousal and alertness (*Fabio et al., 2015; Smolders and de Kort, 2014*). However, other researchers (*Kim and Koga, 2005; Osterhaus, 2005; Winterbottom and Wilkins, 2009*) argued that excessive illuminance could cause discomfort and disability glare. Therefore, they suggested to constrain the brightness less than 1000 lux, which can be achieved by using blinds and dimmable lamps. In addition, evidence (*Leichtfried et al., 2015*) showed there was no significant difference on the change of serum melatonin levels under difference brightness levels. But high brightness (5000 lux) had negatively impact on cognitive performance. Moreover, a survey in the UK (*Y. Zhang et al., 2016*) pointed out that computer interactive smart boards have been widely used in primary school classrooms and a high brightness level may not be desirable most of the time. According to the survey, teachers preferred a balanced illuminance solution with low enough and bright enough brightness as using smart board and studying on desktop, respectively. In particular, brightness distribution needs to be adjusted in some specific learning contexts.

Shortly later, the correlation between CCT and students' performance became a popular research topic. Sleegers (*Sleegers et al., 2013*) concluded that high CCT (6500K) helps students gain more concentration. As to student's cognitive performance, Ferlazzo (*Ferlazzo et al., 2014*) found that cooler light (4000K) exposure improves the cognitive system's capacity to deal with multiple task representations and 3-D visuo-spatial ability, whereas researchers from Ulm university (*Keis et al., 2014*) argued that blue-enriched white light can lead to faster cognitive processing speed and better concentration, but has no effects on short-term encoding and retrieval of memories. As mentioned before, CCT settings are also related to energy-savings (*Golasi et al., 2019; Toftum et al., 2018*). When putting all these considerations into account, it will be very interesting and challenging to determine the proper illuminance configuration for a learning space.

Furthermore, several state-of-the-art studies began to engage in the diverse requirements of light schema for different learning contexts. Ayash (*AL-Ayash et al., 2016*) said that the hue had a significant impact on students' emotions, and vivid color conditions significantly improved their reading scores. Weesolowski (*Wessolowski et al., 2014*) discovered that variable light could reduce pupils' restlessness and improve their social behaviors.

Two researchers of South Korea (*Choi and Suk, 2016*) suggested to shift colour temperature among 3500K, 5000K and 6500K in accordance with easy, standard and intensive learning activities respectively. In the same year, another Korean team (*Lee et al., 2016*) proposed and tested an adaptable lighting control system with five illuminance settings for five different educational contexts, such as language/memorizing, mathematics, P.E., arts, and rest.

There is no lighting control solution that can satisfy all situations due to the variety of educational institution's physical attributes, learning context, as well as the diversity of students' and faculties' characteristics and preferences. Lang (*Lang, 2002*) pointed out that lighting preferences are not fixed but vary depending on many factors, such as classroom size, teaching activity, and individual needs of teachers and students. Therefore, it is strongly advised that classroom lighting systems should provide users with the flexibility of lighting control. By reviewing existing studied about lighting control system, we found the majority of them focused on energy saving, and they achieved considerable outcomes (*Chew et al., 2017*). As summarized in a review on lighting control technologies (*Haq et al., 2014*), the saving on energy ranged from 35 percent to 68 percent in classroom and office environment. An abstracted lighting control system model for energy saving is created, which is developed based on the control strategies suggested by Martirano (*Martirano, 2011*). Fundamentally, adopting high energy-efficiency LED and turning off or dimming the lights whenever possible are major methods to save energy. A study about the trend of lighting industry indicated that the benefits of promoting LED include not only energy saving and environment conservation, but also increasing automation (*Z. Li et al., 2018*). Therefore, almost all pertinent studies used LED as the light source and applied on-off control. Most of them implemented brightness control at the same time, whereas a few of studies implemented CCT control.

Some studies also considered to improve user experience (*Byun et al., 2013; May and Mohd Yaseen, 2013; Parise et al., 2014*). Some researchers advocated the integrated lighting control with occupancy sensors, photocells, and central control module for users' convenience and better experience (*Middleton-White et al., 2013*). A few researchers developed mobile applications for better user experience in terms of operability and mobility

(*Choi and Suk, 2016b; de Rubeis et al., 2017; Moon et al., 2016; Suresh S. et al., 2016*). Evidence indicated that a well-designed mobile application can not only improve user experience, but also guarantee the compliance of illumination regulations and reduce energy consumption (*Castillo-Martinez et al., 2018*). In other studies, both illuminance and CCT were considered for improving users' visual comfort and wellbeing by adapting lighting environment to users' activity (*Kwon et al., 2014; Lee et al., 2016*). Recently, more and more learning-context based lighting control systems have been proposed (*Choi and Suk, 2016*). In recent years studies increasingly focused on the improvement of control algorithms. Statistics, data modelling, and machine learning methods have been used for energy saving purpose, but yet rarely for other objectives. For example, a neural network controller was designed and tested. It could control the lighting level of lamps in a classroom with regard to the ambient illuminance and the number of people (*Chen and Sun, 2013*). In another study (*L. Wang et al., 2015*), in order to optimize the output of the lighting system by calculating daylight contribution, a data model based on statistics records was developed to determine the layout of lux sensors in large industrial buildings. Up to 80 percent energy savings on cloudy days was reported. Similarly, a statistical method was employed to optimize lighting control parameters, including sampling rate, converging speed, and error range of brightness, which achieved 55 percent or more energy savings (*Chew et al., 2016*). In a later study (*Borile et al., 2017*), an advanced daylight harvesting model was proposed, which could map the daylight contribution from ceiling to workplaces. It was reported to have better energy efficiency comparing to a reference method. Recently, more and more learning-context based lighting control systems have been proposed (*Choi and Suk, 2016b*). These proposed systems generally applied lower brightness and CCT for subjects like arts and language, and higher brightness and CCT for subjects like science and mathematics (*Lee et al., 2016; Moon et al., 2016; Zhong et al., 2016*).

It is easy to understand that sufficient brightness in classroom is essential to wellbeing of students. Although almost all related standards stipulated the minimum level of brightness in classroom. According a national-wide random survey in China in 2019, nearly 60 percent classrooms are below the national standards (*GB 7793-2010*) in terms of illuminance level. with the development and diversification of learning contexts and teaching methods, the requirements for lighting in classroom are refining and upgrading. Thanks to the development of technology, including LED, smart devices, and Internet of Things (IoT), large-scale deployment of dynamic lighting control systems has become viable. However, the knowledge of optimized lighting schemas is still limited. Especially, there is neither solid evidence about how flexible lighting solutions affect students' real academic performance, nor feasible methodology for adjusting better light settings corresponding to a variety of real learning contexts.

## 1.2 Objectives

The objectives of this thesis are:

(1) To simulate lighting designs for an educational institution using conventional light sources

(2) To do a case study on upgrading it to a smart lighting system.

## 1.3 Steps of Execution

(1) Stusy literatures related to this topic.

(2) Creation of the floor plans of certain areas of an educational institution with the help of AutoCAD.

(3) Proposition of lighting design with the help of DIALux Softwares for those areas using conventional light sources.

(4) A case study on how to develop a smart lighting system for that institution.

## 1.4 Overall Organization of the Thesis

This thesis consists of several chapters. In each chapter we have discussed about certain topics which led to the completion of this thesis. The overview of each chapter is given below,

**Chapter 1 :** This gives the Introduction to the project. It also consists of objectives, the execution process and the methodology of the project.

**Chapter 2 :** This whole chapter comprises of the theoretical background of the project. Here, the technical terms and their importance on this project has been discussed.

**Chapter 3:** It consists a brief idea about the design procedure and the result from the design. This is a case study where we have shown how to achieve a lighting design for educational institution using conventional light sources.

**Chapter 4 :** It deals with a case study about how to upgrade an educational institution from conventional lighting design to smart lighting design.

**Chapter 5 :** It consists of a brief discussion of the entire project we have done. It also draws the conclusion to the project.

**Chapter 2**

# 2 Theoretical Background

## 2.1 Why Lighting Design is done for an Educational Institution?

The natural daylight is the ideal light for humans. The interplay between sun and blue sky and changes in brightness and light colour during the day has an extensive and enormously positive effect on hormone balance. But unfortunately, people nowadays hardly get any daylight. A biologically active smart lighting provides a daylight-like light, whose dynamic course indoors has the same positive effects. For instance, during the day a bright, cold white light improves vitality and well being and thus people can concentrate better and make fewer mistakes. On the other hand, during evening darker, warm white light provides relaxation and makes you calm. The smart lighting can stabilize the circadian rhythm of humans and provides a better night's sleep. Clever lighting design offers many advantages for learners and teachers. This begins with the use of natural daylight, which is perceived as more pleasant and promotes concentration. It extends to significant energy savings through automatic switching off luminaires in empty rooms. Flexible lighting management allows the selection of different lighting programmes to suit the specific teaching methods and to best support pupils in their learning. The advantage of modern sensors is the possibility of evaluating data. This allows information about room and energy use to be collated and educational institutions to be optimised accordingly. Some of the benefits of implementing smart lighting system in educational institution are given below,

**(1) Budget Friendly :** When considered from a pure energy savings perspective, smart lighting helps an institution save money on utilities by turning off and/or dimming lights in spaces that are vacant.

**(2) Enhanced Control and Flexibility :** From a controllability standpoint, smart lighting can provide dimming and more granular zones in a space to help teachers or faculties highlight a teaching wall or provide extra light over desks while lowering light levels on a video or whiteboard presentation wall.

**(3) Integration With Natural Light :** Daylighting controls help lighting systems maintain a constant light level while utilizing natural light from windows, clerestory glazing, and/or skylights.

**(4) Tunable White Light Technology :** Tunable Lighting provides adjustable colour as well as intensity. Tunable Lighting can help boost concentration and attention span by using light to manage student mood and energy levels. Faculties can select different color and intensity settings to instantly adjust classroom lighting to keep students focused and comfortable as the day progresses. They can also align lighting with different classroom activities to improve student engagement of such as quiet reading or group activities.

**(5) Meets Standards for Educational Accommodations :** Many educational institutions have adopted standards for tunable lighting in classrooms, including soft-uplight distribution, minimal contrast ratios, low light levels, natural daylight, low glare, no flicker, and no sound.

So, we can say uniform brightness is a room's most pleasant lighting atmosphere. Daylight is optimal for well-being and attention, which is supplemented by artificial light in places farther away from the window. Brightness sensors in the luminaires measure the naturally incidental light and homogenise the lighting in the room. This creates a positive atmosphere while saving energy. Luminaires often remain lit even when classrooms are unoccupied, for example during free periods or breaks. Presence sensors activate the light when people enter the room and switch the light off when they leave. The same principle can be used to reduce energy consumption for corridor. Instead of switching off the corridor lighting completely, it can be dimmed to a minimum level during lessons.

Now take an example of Classroom for simplicity. Modern teaching methods are diverse and varied, making flexible lighting all the more important. This is where a lighting management system is particularly useful. Lighting scenes can be stored as programmes and teachers or faculties can call up and change them simply by pressing a button or using a control display, whether for a teacher-centred lecture, evening class, or media presentation. The board light should be manually controllable, independently of the room light, because an optimal, reflection-free view from any place is crucial. Pre-settings are already stored for certain formats. An 'Eco' scene saves time and energy by simply increasing the lighting intensity from 300 lux – standard-compliant for daytime lessons – to 500 lux for evening classes. If there is a need to take notes or work in groups during a lesson, the light can be dimmed for a 'multimedia' scene in the board area and intensified on the table surface. This allows teachers to provide ideal learning and working conditions at the touch of a button to best meet the class's needs.

## 2.2 DIALux Software for Lighting Design

DIALux is a 3D graphics software for indoor and outdoor lighting design developed and distributed by DIAL GmbH company. Numerous manufacturers of lamps and lights offer plug-ins(A plug-in or software extension is an optional software component that extends or changes an existing software. Plug-ins are usually installed by the user and then integrated by the corresponding main application during runtime) for their products that make the radiation characteristics available in DIALux. 3D models created with DIALux can be rendered using the ray tracer POV-Ray.DIALux also supports the lighting planning of sports facilities and the planning of emergency lighting. Energy assessments can also be carried out in this software. The software is available free of charge from the manufacturer's website.

## 2.3 Smart Lighting System

Light provides us with the ability to see. Either in a building or outside, light is a crucial ingredient of any task one may want to carry out. Furthermore, for any given task and place human being feel comfortable with certain levels of light intensity. For example a low light intensity level is preferable for watching a movie at home, while bright light is required for video conferencing on a PC since a typical web-cam is usually not able to capture good quality picture in low light conditions. Due to these reason, there is a growing demand towards lighting systems to meet user requirements for different use cases and in different places. Smart lighting can create various types of atmosphere such as romantic, relaxed, enjoyable, and comfortable feelings. Smart lighting is an important component of smart living.

The target of a smart lighting system is to control light sources in an environment (e.g. home, office) adaptively according to user contexts and preferences. Nowadays, smart lighting systems are gaining popularity and are successful due to their ease of use through automatic control, visual comfort, low carbon footprints and low energy consumption. In the first look, these lighting systems seem to be fairly simple to develop as they employ modern communication technologies and smart sensors. But they are not easy to develop as the integration of sensors, calibration and development of sensor nodes are always challenging.

With the emergence of energy efficient light bulbs such as compact florescent lamps (CFLs) and light emitting diode (LED) lamps, traditional lamps such as incandescent light bulbs have slowly being phased out and being replaced by improved energy efficient LEDs. Traditional way of lighting control for a household, works by switching ON and OFF the lights manually for a desired location. Nowadays, energy efficient lights are installed at certain areas in the buildings with the help of sensors such as occupancy sensors (PIR) to turn them ON automatically when human movements are detected and turn OFF automatically if there is no activity. They are also very useful for outdoor security and utility lighting but limited use for interior lighting as user preference vary in households. Dimmer switches are also available for indoor usage. Though, it is inconvenient for the user to manually adjust the tuning of the dimmer switches. Smart lighting control is an efficient way to reduce energy consumption, to prevent energy waste, to increase visual comfort, and it can be effectively used in conjunction with LED systems. Light can radiate, sparkle or simply shine- light is a fascinating phenomenon with many different facets. But it is only with a demand-driven, sensor-based light management that the best lighting for people can be realized. With a sensor technology that automatically provides an optimal light atmosphere and also turns off the light automatically, when no one else is present. With a sensor technology that creates quality of light and energy efficiency we can get intelligent lighting solutions that always create the right light in every room. The principle of demand-driven automation is to use energy only when it is really needed. It is based on typical human behaviour. Only by using a simple presence detector we can make a significant improvement in energy efficiency. Each presence can be equipped with a light sensor that checks the brightness during operation. If the light falling from the windows is already sufficient the presence detector switches off the artificial lighting.

This is the best possible way to use daylight and also is a very convenient solution. Human centric lighting is also a huge part of smart lighting system. A biologically active light simulates key properties and the dynamic course of natural daylight and greatly improves the quality of life.

### 2.3.1 Segments of Smart Lighting System

The smart lighting system is the modern way to light up homes, streets, or any institutions. The smart light bulbs are all connected to a single app on smartphone. We can control all of them just by the tap of our fingers. This reduces the hassle of multiple remotes or traditional wall-switches. Earlier the light bulbs were controlled via on-off switches. They are not that flexible in their functions. Whereas the smart lights provide us with full control over the lights installed all around the space. All the intelligent lights are connected wirelessly, and all of those relate to an app present on our tablets or computers or smartphone. A sound lighting system will also save us from spending excess energy and also helps in saving money by reducing the electric bill. Smart lighting system gives us control to monitor the number of lights you have switched on or off, thereby saving energy. Some components that are needed for setting up a smart light system are briefly mentioned below,

**(1) Lighting Fixtures :** First and foremost, a light system does not include just the on-off switches and bulbs. For a good lighting system, we need to include LED bulbs rather than the ordinary ones as they have better lifespans and also help in saving energy. They can also be controlled very easily. We can dim the light any time by setting timers or by a touchscreen panel or using the app on our smartphones. We can also use CFL bulbs which will help in reducing electric bills. Though due to the increasing popularity of LEDs recent recent samrt lighting solutions are using LEDs.

**(2) Occupancy Sensors :** An occupancy sensor is an indoor motion detecting device used to detect the presence of a person to automatically control lights or temperature or ventilation systems. The sensors use infrared, ultrasonic, microwave, or other technology. Occupancy sensors are devices which are placed in the corners of the room. When someone enters a room, the lights automatically switch on. SO, we don't have to worry about if we have switched off the lights when we are not in that area because Occupancy sensors are equipped to turn off the lights after a few minutes when they sense no movement in that room. The field of view of the sensor must be carefully selected/adjusted so that it responds only to motion in the space served by the controlled lighting. For example, an occupancy sensor controlling lights in an classroom should not detect motion in the corridor outside the classroom. Some types of occupancy sensors which are used for lighting control are mentioned below,

**PIR Sensor :** A passive infrared sensor (PIR sensor) is an electronic sensor which works on heat difference detection, measuring infrared radiation. Inside the device is a pyroelectric sensor which can detect the sudden presence of objects (such as humans) who radiate a temperature different from the temperature of the background, such as the room temperature of a wall.

**Ultrasonic Sensor :** Ultrasonic sensors are devices that generate or sense ultrasound energy. They work on the doppler shift principle. An ultrasonic sensor will send high frequency sound waves in area and will check for their reflected patterns. If the reflected pattern is changing continuously then it assumes that there is occupancy and the lighting load connected is turned on. If the reflected pattern is the same for a preset time then the sensor assumes there is no occupancy and the light is switched off.

**Microwave Sensor :** It also works on the doppler shift principle. A microwave sensor will send high frequency microwaves in an area and will check for their reflected patterns. If the reflected pattern is changing continuously then it assumes that there is occupancy and the lighting load connected is turned on. If the reflected pattern is the same for a preset time then the sensor assumes there is no occupancy and the load is switched off. A microwave sensor has high sensitivity as well as detection range compared to other types of sensors.

**(3) Motion Detectors :** A motion detector is an electrical device that utilizes a sensor to detect nearby motion. The motion sensor and occupancy sensor are same because they work via same principle. These are mainly used for outdoor lighting. n case of motion sensors, the lights switch-on as soon as they detect any movement and only turn off after a few minutes of no activity. These sensors help in cutting the lighting costs and also help in saving energy. Apart from the above mentioned detectors, some Motion Detectors are discussed below,

**Tomographic Motion Detector :** These systems sense disturbances to radio waves as they pass from node to node of a mesh network. They have the ability to detect over large areas completely because they can sense through walls and other obstructions. RF tomographic motion detection systems may use dedicated hardware, other wireless-capable devices or a combination of the two.

**Dual-Technology Motion Detectors :** Many modern motion detectors use combinations of different technologies. While combining multiple sensing technologies into one detector can help reduce false triggering, it does so at the expense of reduced detection probabilities and increased vulnerability. For example, many dual-tech sensors combine both a PIR sensor and a microwave sensor into one unit. For motion to be detected, both sensors must trip together. This lowers the probability of a false alarm since heat and light changes may trip the PIR but not the microwave. Often, PIR technology is paired with another model to maximize accuracy and reduce energy use. PIR draws less energy than emissive microwave detection, and so many sensors are calibrated so that when the PIR sensor is tripped, it activates a microwave sensor.

**(4) Lighting Controls :** A lighting control system is an intelligent network based lighting control solution that incorporates communication between various 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 commercial, industrial, and residential spaces. 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 may include a lighting technology designed for energy efficiency, convenience and security. This may include high efficiency fixtures and automated controls that make adjustments based on conditions such as occupancy or daylight availability. So, by suitable integrated control and automation we can access all the lights of a certain area only by the touch of our fingers on our smartphones. We can also customise the light settings according to our preferences. We can tap on the app on our smartphone or we can set timers so that the lights of a room switch on automatically at a preset time. Smart lighting systems brings a lot of comfort and satisfaction to our lifestyle.

**Networked Lighting Control Systems :** Building Automation System (BAS) is a networked system which is the most advanced system for controlling the smart lighting system. Using the networked lighting control systems, the we can handle all the settings of the lights just by our computers or tablets or smartphones that have the particular lighting network software. Users can turn the light on/off and also set timers for when to turn on the lights. Nowadays, the lighting system apps also store data regarding energy consumption and can make charts for close monitoring.

**(5) Light Sensors :** Light Sensors, also called photosensors, are sensors of light or other electromagnetic radiation. Semiconductor-based photodetectors typically have a p–n junction that converts light photons into current. They feed this light level to the controller and thus controller decides whether to dim to light level or increase the light level in that area. Light sensors have a very important role in daylight harvesting. Electric lighting energy use can be adjusted by automatically dimming and/or switching electric lights in response to the level of available daylight. Reducing the amount of electric lighting used when daylight is available is known as daylight harvesting. In response to daylighting technology, daylight-linked automated response systems have been developed to further reduce energy consumption. These technologies are helpful, but they do have their downfalls. Many times, rapid and frequent switching of the lights on and off can occur, particularly during unstable weather conditions or when daylight levels are changing around the switching illuminance. Not only does this disturb occupants, it can also reduce lamp life.

**(6) Dimmers :** A dimmer is a device connected to a light fixture and used to lower the brightness of the light. By changing the voltage waveform applied to the lamp, it is possible to lower the intensity of the light output. Although variable-voltage devices are used for various purposes, the term dimmer is generally reserved for those intended to control light output from resistive incandescent, halogen, and (more recently) compact fluorescent lamps (CFLs) and light-emitting diodes (LEDs). More specialized equipment is needed to dim fluorescent, mercury-vapor, solid-state, and other arc lighting. Modern professional dimmers are generally controlled by a digital control system like DMX or DALI. In newer systems, these protocols are often used in conjunction with Ethernet. In 1959, Joel S. Spira, who would found the Lutron Electronics Company in 1961, invented a dimmer based on a diode and a tapped autotransformer, saving energy and allowing the dimmer to be installed in a standard electrical wallbox. In 1966, Eugene Alessio patented a light bulb socket adapter for adjusting a light level on a single light bulb using a triac. When solid-state dimmers came into use, analog remote control systems (such as 0-10 V lighting control systems) became feasible. The wire for the control systems was much smaller (with low current and lower danger) than the heavy power cables of previous lighting systems. Each dimmer had its own control wires, resulting in many wires leaving the lighting control location. More recent digital control protocols such as DMX512, DALI, or one of the many Ethernet-based protocols like Art-Net, ETCnet, sACN, Pathport, ShowNet or KiNET[5] enable the control of a large number of dimmers (and other stage equipment) through a single cable. Dimmer switches allow us to change the level of lighting as we desire. This feature of smart lighting system saves a lot of energy.

### 2.3.2 Types of Smart Lighting Systems

There are many types of smart lighting systems that we can use. The choice of these system is based on preference. Following types of smart lighting systems are available in the market according to their applications and how they are controlled,

**Smart Light Bulbs :** An individual smart light bulb can be connected to an existing socket and subsequently paired with local Wi-Fi system at the most basic level. This feature allows us to control these individual bulbs from a dedicated smart-phone app. These are a low cost smart lighting solutions. According to requirements, users can install multiple smart light bulbs. We can choose how many individual smart light bulbs to install and which room they could be most helpful. Different smart light bulb products offer several features, including adjustable brightness, programmable scheduling, mood-based lighting schemes, remotely controllable, IFTTT compatible and controlling from Alexa or Google assistant.(*www.smlease.com*)


Figure 3: Smart Light Bulb

**Smart Lights Connected With HUB :** Hub-controller smart lights are generally larger in scope and can act as a whole-house smart lighting system. We need to carefully source this type of smart lighting system to ensure it is compatible with the smart hub that we use. For areas with several different smart gadgets, incorporating hub-controlled smart lights can allow for several IFTTT (if this, then that) applications. So, existing smart systems can be expanded by installing smart lights working on the same communication technology. As, shown in the below image, these smart lights connect with the internet through HUB. Their disadvantage is that they can't be used without a HUB.(*www.smlease.com*)

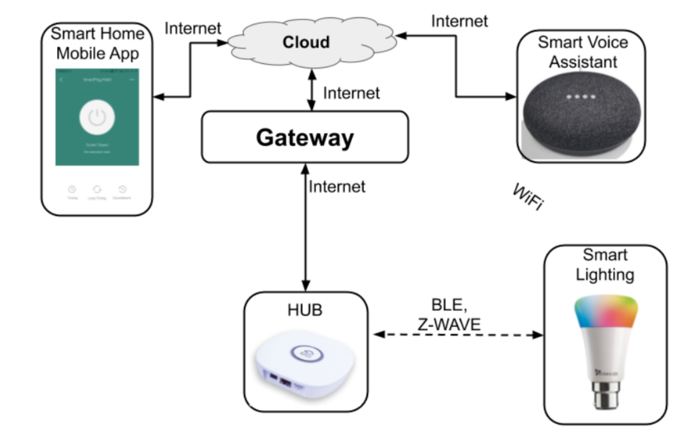



Figure 4: Smart Light Connected with HUB

**Motion Sensing Light, Smart Switches and Dimmers :** Generally, PIR sensors are used in motion detection smart lights to detect motion and turn on lights. Smart switches and dimmers are other smart lighting technology types that give us more control over the lighting fixtures. These smart switches and dimmers can generally exist with existing light bulbs and tend to be less expensive.

Figure 5: Motion Sensing Light

### 2.3.3 Communication Technologies For Smart Lighting System

In this context first we have to understand the standards and protocols for lighting controls. In the 1980s there was a strong requirement to make commercial lighting more controllable so that it could become more energy efficient. Initially this was done with analog control, allowing fluorescent ballasts and dimmers to be controlled from a central source. Tridonic was an early company to go digital with their broadcast protocols, DSI, in 1991. DSI was a basic protocol as it transmitted one control value to change the brightness of all the fixtures attached to the line. The simple wiring of it made this protocol more attractive. There are two types of lighting control systems : (1) Analog lighting control, (2) Digital lighting control. In production lighting 0-10V system was replaced by analog multiplexed systems such as D54 and AMX192, which themselves have been almost completely replaced by DMX512. For dimmable fluorescent lamps (where it operates instead at 1-10 V, where 1 V is minimum and 0 V is off) the system is being replaced by DSI, which itself is in the process of being replaced by DALI.

Examples for analog lighting control systems are -

**0-10V based system :** 0–10 V is one of the first and simplest electronic lighting control signaling systems, used as an early fluorescent dimming system. Here, the control signal is a DC voltage that varies between zero and ten volts. The simplicity of the lighting system makes it straightforward to understand, implement and diagnose, and its low current (typically 1 mA) means it can be run along relatively thin cables with little voltage drop. However, since it requires one wire per control channel (plus a common return wire), a sophisticated system could have hundreds of wires, requiring expensive multicore cables and connectors. Over a long cable, the voltage drop requires every channel of the receiving device to be calibrated to compensate for the voltage losses.

**AMX192 based systems(USA Standard) :** AMX192 (often referred to simply as AMX) is an analog lighting communications protocol used to control stage lighting. It was developed by Strand Century in the late 1970s. Originally, AMX192 was only capable of controlling 192 discrete channels of lighting. AMX192 has mostly been replaced in favour of DMX. The name AMX192 is derived from an acronym of Analog MultipleXing and the maximum number of controllable lighting channels (192). In the late 1970s, the AMX192 serial analogue multiplexing standard was developed in the US, permitting one cable to control several dimmers.

**D54 based systems (European standard) :** D54 was developed in the United Kingdom at approximately the same time as AMX192 was developed in the United States. D54 is an analogue lighting communications protocol used to control stage lighting. It was developed by Strand Lighting in the late 1970s and was originally designed to handle 384 channels. Generally a protocol converter is now used to convert DMX (lighting) down to the native D54.

Examples for digital lighting control systems are -

**DSI based system :** Digital Serial Interface (DSI) is a protocol for the controlling of lighting in buildings. It was created in 1991 by Austrian company Tridonic and is based on Manchester-coded 8-bit protocol, data rate of 1200 baud, 1 start bit, 8 data bits (dimming value), 4 stop bits, and is the basis of the more sophisticated protocol Digital Addressable Lighting Interface (DALI). The technology uses a single byte to communicate the lighting level (0-255 or 0x00-0xFF). DSI was the first use of digital communication in lighting control, and was the precursor to DALI. Its simple nature makes it straightforward to understand, implement, and diagnose, while its low voltage means it typically runs along relatively thin cables. It requires one wire per control channel so a sophisticated system could have hundreds of wires, thereby making diagnoses of problems difficult.

**DALI based system :** Digital Addressable Lighting Interface (DALI) is a trademark for network-based products that control lighting. DALI is specified by a series of technical standards in IEC 62386. A DALI network consists of at least one application controller and bus power supply (which may be built into any of the products) as well as input devices (e.g. sensors and push-buttons), control gear (e.g., electrical ballasts, LED drivers and dimmers) with DALI interfaces. Application controllers can control, configure or query each device by means of a bi-directional data exchange. Each device is assigned a unique short address between 0 and 63, making up to 64 control gear devices and 64 control devices possible in a basic system. Address assignment is performed over the bus using a "commissioning" protocol, usually after all hardware is installed. Data is transferred between devices by means of an asynchronous, half-duplex, serial protocol over a two-wire bus with a fixed data transfer rate of 1200 bit/s. DALI offers complete control of the equipment, on/off as weel as dimming.

It is the most common technology that operates on a 4 wire systems. All LED lighting luminaires and sensors are connected to a DALI controller via 4 cables, of which two are for power and other two are for controls. All the commands from the user are sent to the controller and to the respective devices, ensuring reliable and fast communication. This system is suited for new or old constructions alike, where simplicity is prefered over the sophistication. DALI is very popular because of its bi-directional nature. On the other hand, DMX is unidirectional. For this reason, though DMX can connect upto 512 devices whereas DALI can connect only 64 devices, DALI is prefered. A block diagram depicting a smart lighting system using DALI is shown below [Figure 6].

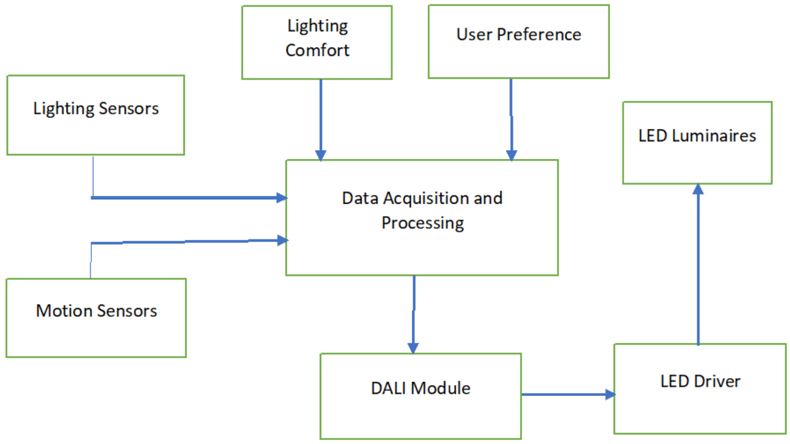



Figure 6: Smart Lighting Block Diagram Using DALI

**DMX based system :** DMX512 is a standard for digital communication networks that are commonly used to control lighting and effects. It was originally intended as a standardized method for controlling stage lighting dimmers. A DMX512 network employs a multi-drop bus topology with nodes strung together in what is commonly called a daisy chain. A network consists of a single DMX512 controller – which is the master of the network — and one or more slave devices. This is a unidirectional protocol. At the datalink layer, a DMX512 controller transmits asynchronous serial data at 250 kbit/s.

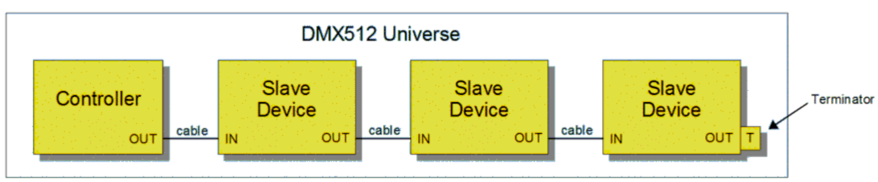



Figure 7: DMX Working

**KNX based system :** KNX is an open standard for commercial and domestic building automation. KNX devices can manage lighting, blinds and shutters, HVAC, security systems, energy management, audio video, white goods, displays, remote control, etc.

Following communication technologies are usually used to connect smart lighting system with the internet or smartphone and control remotely,

**Wi-Fi Connected Smart Lighting Systems :** Wi-Fi based smart lights are connected to the internet using Wi-Fi routers and can be controlled remotely. But they can not be controlled if an internet connection is not available.

**Bluetooth Connected Smart Lights :** Bluetooth based smart lights can create a mesh network and can be controlled using BLE-enabled smartphones. To control bluetooth based smart lights remotely, a bluetooth HUB is required. This HUB is used to connect bluetooth connected devices to the internet. So, it is the most convenient method of enabling controls, as there are no control cables involved. It allows for the easiest method of commissioning and operating the lighting system. The existing AC cables can be used to power the wireless modules which sit inconspicuously on the fixtures and connect to an authorized mobile device to provide fast and instant operation, as well as the most intuitive method of automating the On/Off/dimming of the luminaires. This technology is best suited for existing offices that are undergoing a renovation or spaces where installing new wiring is extremely difficult or impossible, or for new spaces where the highest priority is to have the easiest method of operating the lighting systems.

**ZigBee/Z-wave Connected System :** Similar to bluettoth-based lights, ZigBee and Z-wave based smart lights also create a mesh network. But they can't be controlled without a HUB.

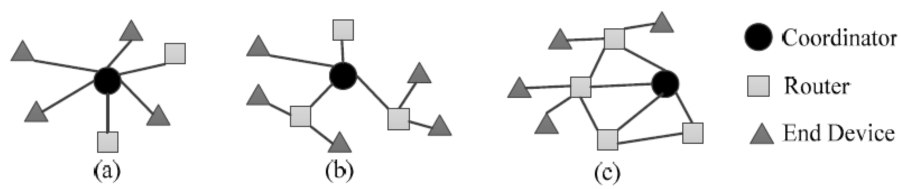



Figure 8: ZigBee Network Topologies : (a)Star, (b)Tree and (c)Mesh

**PoE System :** PoE lighting uses Power over Ethernet technology to connect, monitor, and control LED light fixtures used in smart building solutions. Smart PoE lighting reduces installation and operating costs by more than half and helps building owners meet wellness and sustainability goals. PoE refers to the ability to provide low-voltage (less than 100W), direct current (DC) electrical power to network devices via the same twisted-pair copper Ethernet cables that are used to transmit data. This eliminates the need for a separate AC power source and allows for more flexible placement options, without concern for proximity to a power outlet. PoE is a low-cost, reliable, and flexible approach to powering smart devices in a network. So, we can see these systems drastically improve the control of the lighting while lowering cost and exponentially increasing the length of the life of the light fixtures. PoE technology can be controlled through smart phone apps. It enables a true IoT where things can really talk to each other without human interference. All LED lighting luminaires and sensors are connected to a PoE switch, which is the only AC powered device in the entire system. The switch sends the power as well as the control signals through the DC powered CAT6 cables and makes installation and maintenance easier and faster. This system is best suited for new construction (or deep retrofits) where the entire cabling is being done freshly.

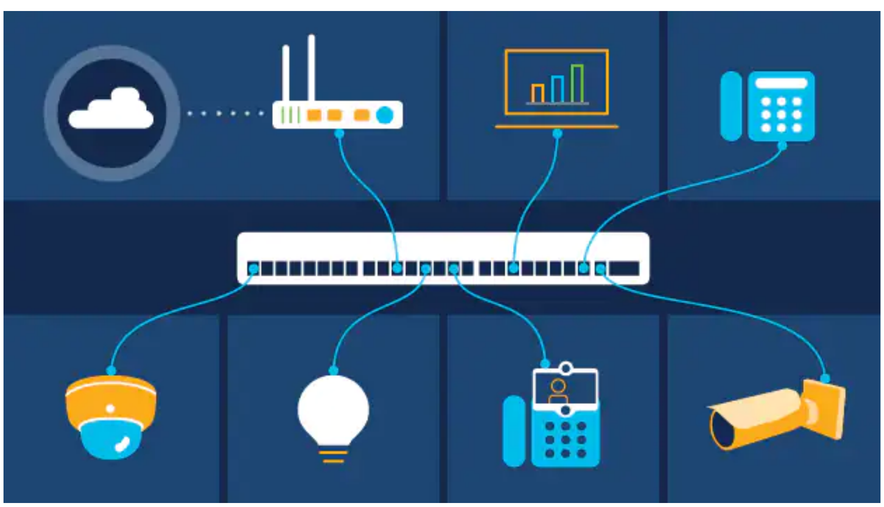


Figure 9: PoE System

This technology is becoming more and more popular because,

(1) Savings is more and it increases LED efficiency
(2) It converges electrical and communication network into a single infrastructure. It uses low voltage DC power so, it is easy and safe to handle
(3) Luminaire level control for dimming, scheduling, occupancy and daylight control helps in individual level metering and spacing optimization.
(4) Smart and connected lighting systems can be seamlessly integrated with building management system and have a customized GUI for ease in operation and control using touch panels.
(5) Personalized lighting for enhanced comfort with individual luminaire level controls for intensity and colour.

### 2.3.4 How it Works?

Most smart systems will operate around a central 'bridge', a device that connects to local Wi-Fi network and allows us to control smart lights through smartphone. Some newer smart light bulbs do not require a bridge to function. On the other hand, Some smart systems use an industry-standard wireless protocol called ZigBee to communicate with each other. It is similar to Wi-Fi signal, but one big difference is that where products connected to a Wi-Fi network can only communicate with one central router, Zigbee products can communicate with each other. This means that each light bulb in a smart lighting system can relay the signals from the bridge to each other. So, even if the bridge/HUB is on the other side of the building, the 'boost' in the signal provided by each product extends the range considerably. According to user requirements, a smart lighting system can be controlled in the following different ways(*www.smlease.com*),

**Mobile Apps and Voice Assistant :** As shown in the below figure[Figure 10], according to the type of technology used in the lighting system, smart lights are controlled using smart phone apps or smart voice assistants (Google Assistant, Alexa, Siri etc.) by connecting them to the internet or bluetooth via a smart HUB, gateway or directly.

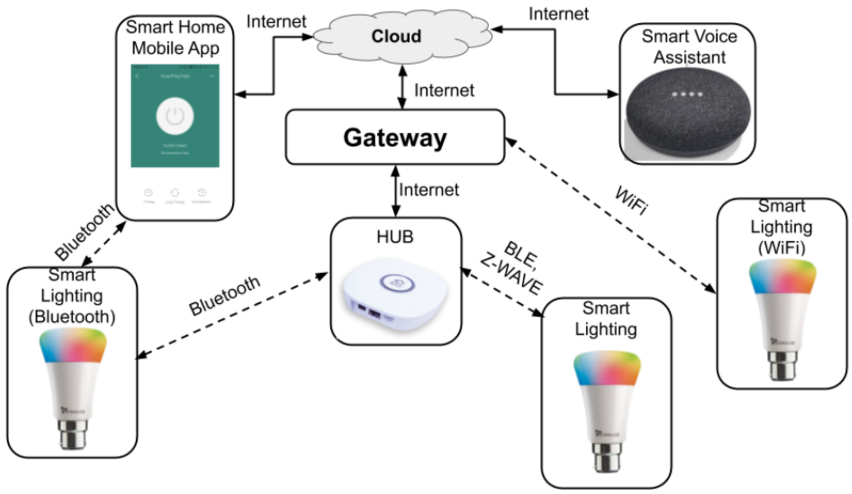



Figure 10: Working of Smart Light using Mobile Apps or Voice Assistant

**Motion Detection :** As shown in the below figure[Figure 11], the smart lights are connected with motion sensors or wireless connection. When the Motion Sensor detects motion, it sends a signal to the HUB or directly to the smart bulb to turn on.

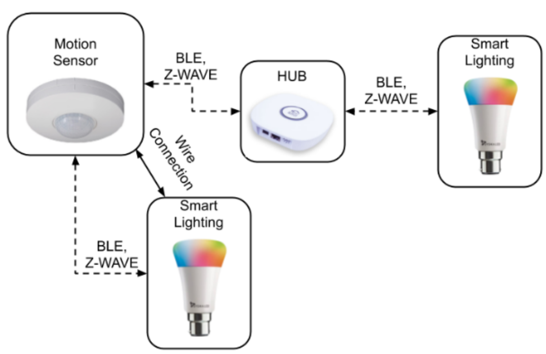



Figure 11: Working of Motion Sensing Smart Lights

**IFTTT - If This Then That :** Smart lights can be controlled using IFTTT which is a condition based technology. To achieve this we must have an IFTTT enabled smart lighting system. In the below figure [Figure 12] working of the IFTTT controlled smart lights has been shown,

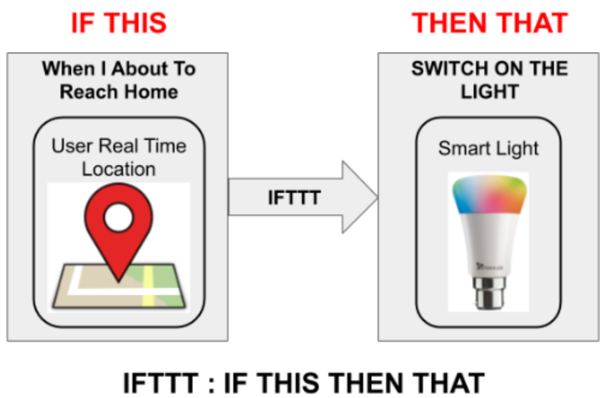



Figure 12: Working of IFTTT Controlled Smart Light

### 2.3.5 Benefits of Using Smart Lighting System

Lighting plays an important role in our well-being and use of smart lighting system adds elegance, ambience, convenience and energy efficiency to any place. Warm, dimmed light creates a calming atmosphere which encourages socializing and relaxation. These smart lights can make decisions, follow schedules, or can be controlled remotely using a mobile app, voice activated personal assistants, or condition based IFTTT technology. Some smart lights can be even controlled depending on occupancy as well. The major advantage of a lighting control system over stand-alone lighting controls or conventional manual switching is the ability to control individual lights or groups of lights from a single user interface device. This ability to control multiple light sources from a user device allows complex lighting scenes to be created. A room may have multiple scenes pre-set, each one created for different activities in the room. A major benefit of lighting control systems is reduced energy consumption. Longer lamp life is also gained when dimming and switching off lights when not in use. Wireless lighting control systems provide additional benefits including reduced installation costs and increased flexibility over where switches and sensors may be placed. There are many advantages of using Smart Lighting. Some of these are mentioned below,

**(a)Ease of Use :** Traditional bulbs require a switch to control the lights. If we want to be able to dim the lights, we need to wire a dimmer switch into wall. Smart LED lights, however, can be controlled -including dimming- via the app or other smart accessories.

**(b)Saves Electricity :** Smart LED bulbs last much longer and generate less heat than the conventional light bulbs, thus using less energy.

**(c)Ease of Control :** Since, the smart lights are controlled via an app, we can see their status from anywhere. In simpler words, it means that if we forget to switch off our lights when we are going out, we won't have to worry as we can turn the lights off using our mobile app.

**(d)Mood Selection :** Most smart lights available in the market have features to change intensity and colour. Preset and customized light scenes create ambiance for any occasion, whether we are using warm-to-cool white light or colour LED lights and all we have to do is tap a button.

**(e)User Convenience :** Motion based smart lights can detect motion and turn on/off automatically. It improves the user experience.

## 2.4 Fluorescent Lamp

A fluorescent lamp, or fluorescent tube, is a low-pressure mercury-vapor gas-discharge lamp that uses fluorescence to produce visible light. An electric current in the gas excites mercury vapor, which produces short-wave ultraviolet light that then causes a phosphor coating on the inside of the lamp to glow. A fluorescent lamp converts electrical energy into useful light much more efficiently than an incandescent lamp. The typical luminous efficacy of fluorescent lighting systems is 50–100 lumens per watt, several times the efficacy of incandescent bulbs with comparable light output. They require a ballast to regulate current through the lamp. Because they contain mercury, many fluorescent lamps are classified as hazardous waste. The United States Environmental Protection Agency recommends that fluorescent lamps be segregated from general waste for recycling or safe disposal, and some jurisdictions require recycling of them.

### 2.4.1 History

By the middle of the 19th century, experimenters had observed a radiant glow emanating from partially evacuated glass vessels through which an electric current passed. One of the first to explain it was the Irish scientist Sir George Stokes from the University of Cambridge in 1852, who named the phenomenon ”fluorescence”. Thomas Edison briefly pursued fluorescent lighting for its commercial potential. He invented a fluorescent lamp in 1896 that used a coating of calcium tungstate as the fluorescing substance, excited by X-rays, but although it received a patent in 1907, it was not put into production. All the major features of fluorescent lighting were in place at the end of the 1920s. In 1934, Arthur Compton, a renowned physicist and GE consultant, reported to the GE lamp department on successful experiments with fluorescent lighting at General Electric Co., Ltd. in Great Britain (unrelated to General Electric in the United States). Stimulated by this report, and with all of the key elements available, a team led by George E. Inman built a prototype fluorescent lamp in 1934 at General Electric's Nela Park (Ohio) engineering laboratory. By 1951 more light was produced in the United States by fluorescent lamps than by incandescent lamps.

### 2.4.2 Principle of Operation

The fundamental mechanism for the conversion of electrical energy to light is the emission of a photon when an electron in a mercury atom falls from an excited state into a lower energy level. Electrons flowing in the arc collide with the mercury atoms. If the incident electron has enough kinetic energy, it transfers energy to the atom's outer electron, causing that electron to temporarily jump up to a higher energy level that is not stable. The atom will emit an ultraviolet photon as the atom's electron reverts to a lower, more stable, energy level. Most of the photons that are released from the mercury atoms have wavelengths in the ultraviolet (UV) region of the spectrum, predominantly at wavelengths of 253.7 and 185 nanometers (nm). These are not visible to the human eye, so ultraviolet energy is converted to visible light by the fluorescence of the inner phosphor coating.Here the circuit of a fluorescent lamp or the circuit of a tube light is shown,

We connect one ballast, and one switch and the supply is series as shown. Then we connect the fluorescent tube and a starter across it.
(1) When we switch ON the supply, full voltage comes across the lamp and

as well as across the starter through the ballast. But at that instant, no discharge happens, i.e., no lumen output from the lamp.
(2) At that full voltage first the glow discharge is established in the starter. This is because the electrodes gap in the neon bulb of starter is much lesser than that of the fluorescent lamp.
(3) Then gas inside the starter gets ionized due to this full voltage and heats the bimetallic strip. That causes to bend the bimetallic strip to connect to the fixed contact. Now, current starts flowing through the starter. Although the ionization potential of the neon is more than that of the argon but still due to small electrode gap, a high voltage gradient appears in the neon bulb and hence glow discharge gets started first in the starter.
(4) As soon as the current starts flowing through the touched contacts of the neon bulb of the starter, the voltage across the neon bulb gets reduced since the current, causes a voltage drop across the inductor(ballast). At reduced or no voltage across the neon bulb of the starter, there will be no more gas discharge taking place and hence the bimetallic strip gets cool and breaks away from the fixed contact. At the time of breaking of the contacts in the neon bulb of the starter, the current gets interrupted, and hence at that moment, a large voltage surge comes across the inductor(ballast).

$$V = L\frac{di}{dt}$$

where, L= Inductance of inductor
$\frac{di}{dt}$= Rate of change of current.

(5) This high valued surge voltage comes across the fluorescent lamp (tube light) electrodes and strikes penning mixture (mixture argon gas and mercury vapor).
(6) Gas discharge process gets started and continues and hence current again gets a path to flow through the fluorescent lamp tube (tube light) itself. During discharging of penning gas mixture the resistance offered by the gas is lower than the resistance of starter.
(7) The discharge of mercury atoms produces ultraviolet radiation which in turn excites the phosphor powder coating to radiate visible light.
(8) Starter gets inactive during glowing of fluorescent lamp (tube light) because no current passes through the starter in that condition.

### 2.4.3 Construction

A fluorescent lamp tube is filled with a mix of argon, xenon, neon, or krypton, and mercury vapor. The pressure inside the lamp is around 0.3 percent of atmospheric pressure. The partial pressure of the mercury vapor alone is about 0.8 Pa (8 millionths of atmospheric pressure), in a T12 40-watt lamp. The inner surface of the lamp is coated with a fluorescent coating made of varying blends of metallic and rare-earth phosphor salts. The lamp's electrodes are typically made of coiled tungsten and are coated with a mixture of barium, strontium and calcium oxides to improve thermionic emission. Fluorescent lamp tubes are often straight and range in length from about 100 millimeters (3.9 in) for miniature lamps, to 2.43 meters (8.0 ft) for high-output lamps. Some lamps have the tube bent into a circle, used for table lamps or other places where a more compact light source is desired. Larger U-shaped lamps are used to provide the same amount of light in a more compact area, and are used for special architectural purposes. Light-emitting phosphors are applied as a paint-like coating to the inside of the tube. The organic solvents are allowed to evaporate, then the tube is heated to nearly the melting point of glass to drive off remaining organic compounds and fuse the coating to the lamp tube. The coating must be thick enough to capture all the ultraviolet light produced by the mercury arc, but not so thick that the phosphor coating absorbs too much visible light.

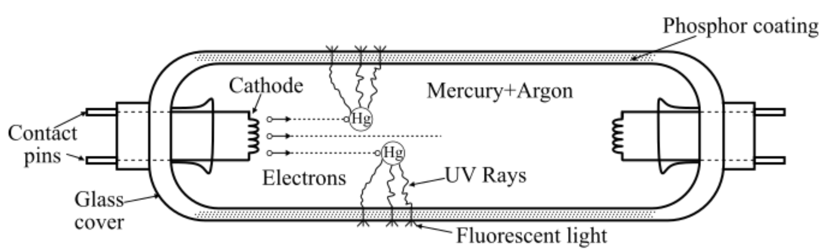



Figure 13: Construction of Fluorescent Lamp

### 2.4.4 Ballasts

Fluorescent lamps are negative differential resistance devices, so as more current flows through them, the electrical resistance of the fluorescent lamp drops, allowing for even more current to flow. Connected directly to a constant-voltage power supply, a fluorescent lamp would rapidly self-destruct because of the uncontrolled current flow. To prevent this, fluorescent lamps must use a ballast to regulate the current flow through the lamp. The simplest ballast for alternating current (AC) use is an inductor placed in series, consisting of a winding on a laminated magnetic core. The inductance of this winding limits the flow of AC current. Ballasts are rated for the size of lamp and power frequency. Fluorescent lamps can run directly from a direct current (DC) supply of sufficient voltage to strike an arc. The ballast must be resistive, and would consume about as much power as the lamp. When operated from DC, the starting switch is often arranged to reverse the polarity of the supply to the lamp each time it is started; otherwise, the mercury accumulates at one end of the tube. Fluorescent lamps are (almost) never operated directly from DC for those reasons. Instead, an inverter converts the DC into AC and provides the current-limiting function as described below for electronic ballasts.

Electronic ballasts employ transistors to change the supply frequency into high-frequency AC while regulating the current flow in the lamp. These ballasts take advantage of the higher efficacy of lamps, which rises by almost 10 percent at 10 kHz, compared to efficacy at normal power frequency. Electronic ballasts convert supply frequency AC power to variable frequency AC. Many electronic ballasts are controlled by a microcontroller, and these are sometimes called digital ballasts. Digital ballasts can apply quite complex logic to lamp starting and operation. This enables functions such as testing for broken electrodes and missing tubes before attempting to start, detection of tube replacement, and detection of tube type, such that a single ballast can be used with several different tubes. Features such as dimming can be included in the embedded micro-controller software, and can be found in various manufacturers' products.

### 2.4.5 Starting and Preheating

The gas used in the fluorescent tube must be ionized before the arc can "strike" . For small lamps, it does not take much voltage to strike the arc and starting the lamp presents no problem, but larger tubes require a substantial voltage (in the range of a thousand volts). So, many different starting circuits are used. The working of starter has been discussed in subsequent section. The choice of starter circuit is based on cost, AC voltage, tube length, instant versus non-instant starting, temperature ranges and parts availability.

Preheating, also called switch-start, uses a combination filament–cathode at each end of the lamp in conjunction with a mechanical or automatic (bi-metallic) switch (see circuit diagram to the right) that initially connect the filaments in series with the ballast to preheat them; after a short preheating time the starting switch opens. If timed correctly relatively to the mains supply, this causes the ballast to induce a voltage over the tube high enough to initiate the starting arc. With glow switch starters a failing tube will cycle repeatedly. Some starter systems used a thermal over-current trip to detect repeated starting attempts and disable the circuit until manually reset. A power factor correction (PFC) capacitor draws leading current from the mains to compensate for the lagging current drawn by the lamp circuit.

### 2.4.6 Advantages

(1) Fluorescent lamps have higher luminous efficacy than Incandescent Lamps.
(2) They have long life span.
(3) There running cost is low.
(4) The heat output is also low for a fluorescent lamp.
(5) Compared with an incandescent lamp, a fluorescent tube is a more diffuse and physically larger light source. So, light can be more evenly distributed without point source of glare such as seen from an un-diffused incandescent filament.
(6) Real-life fluorescent tubes achieve CRIs of anywhere from 50 to 98.

### 2.4.7 Disadvantages

(1) Fluorescent lamps suffer from stroboscopic effect.
(2) The choke used in fluorescent lamps produces magnetic hum causing disturbance.
(3) Fluorescent lamps with magnetic ballasts flicker at a normally unnoticeable frequency of 100 or 120 Hz and this flickering can cause problems for some individuals with light sensitivity.
(4) Fluorescent lamps operate best around room temperature. At lower or higher temperatures, efficacy decreases.
(5) Frequent switching (more than every 3 hours) will shorten the life of lamps.
(6) If a fluorescent lamp is broken, a very small amount of mercury can contaminate the surrounding environment. Due to the mercury content, dis-

carded fluorescent lamps must be treated as hazardous waste.

### 2.4.8 Applications

(1) Fluorescent lamps can provide light output in large area, thus these lamps are suitable for lighting in industrial applications.
(2) Fluorescent lamps are used for lighting in offices as they provide uniform light level.
(3) In residential applications, the fluorescent lamps provide effective lighting for kitchens, valences, and fascia, etc.
(4) Fluorescent lamps are also used in classroom lighting and retail lighting, etc.

## 2.5 CFL

A Compact Fluorescent Lamp (CFL) is also called energy-saving light and compact fluorescent tube. It is a fluorescent lamp designed to replace an incandescent light bulb; some types fit into light fixtures designed for incandescent bulbs. The lamps use a tube that is curved or folded to fit into the space of an incandescent bulb, and a compact electronic ballast in the base of the lamp. Compared to general-service incandescent lamps giving the same amount of visible light, CFLs use one-fifth to one-third the electric power, and last eight to fifteen times longer. Like all fluorescent lamps, CFLs contain toxic mercury which complicates their disposal.

Figure 14: CFL

The principle of operation remains the same as in other fluorescent lighting: electrons that are bound to mercury atoms are excited to states where they will radiate ultraviolet light as they return to a lower energy level; this emitted ultraviolet light is converted into visible light as it strikes the fluorescent coating, and into heat when absorbed by other materials such as glass. CFLs radiate a spectral power distribution that is different from that of incandescent lamps. Improved phosphor formulations have improved the perceived color of the light emitted by CFLs, such that some sources rate the best "soft white" CFLs as subjectively similar in color to standard incandescent lamps. White LED lamps compete with CFLs for high-efficiency lighting.

**Fluorescence and Incandescence :** Incandescence is the conversion of heat to light, which requires the filament inside an incandescent lamp to burn at a high temperature (350° F or 176° C). This conversion is very simple but the disadvantages are that only 5 percent of the total energy consumed by the lamp is used to generate light (95 percent is wasted as heat!) and the lifetime is limited to about 2,000 hours.

Fluorescence is the conversion of ultraviolet (UV) light to visible light. Electrons flow through the fluorescent lamp and collide with mercury atoms, causing photons of UV light to be released. The UV light is then converted into visible light as it passes through the phosphor coating on the inside of the glass tube.This two-stage conversion process is much more efficient than incandescent lamp process, resulting in 25 percent of the total energy consumed used to generate light, lower lamp temperatures (40° C) and longer lifetime (10,000 hours).

### 2.5.1 History

The parent to the modern fluorescent lamp was invented in the late 1890s by Peter Cooper Hewitt. The spiral CFL was invented in 1976 by Edward E. Hammer, an engineer with General Electric. Although the design met its goals, the invention was shelved. In 1980, Philips introduced its model SL*18, which was a screw-in or bayonet mount lamp with integral magnetic ballast. The lamp used a folded T4 tube, stable tri-colour phosphors, and a mercury amalgam. In 1985, Osram started selling its model Dulux EL, which was the first CFL to include an electronic ballast. In 1995, helical

CFLs, manufactured in China by Shanghai Xiangshan, became commercially available. These were first proposed by General Electric. The rise of LED lighting, however, significantly affected CFL sales and production. As a result of decreasing cost and better features, customers increasingly migrated toward LEDs.

### 2.5.2 Components

There are two types of CFLs - integrated and non-integrated lamps, where CFL-i denotes an integrated ballast and CFL-ni denotes a non-integrated ballast. Integrated lamps combine the tube and ballast in a single unit. These lamps allow consumers to replace incandescent lamps easily with CFLs. Integrated CFLs work well in many standard incandescent light fixtures, reducing the cost of converting to fluorescent. Non-integrated CFLs have the ballast permanently installed in the luminaire, and usually only the fluorescent tube is changed at its end of life. Since the ballasts are placed in the light fixture, they are larger and last longer compared to the integrated ones, and they don't need to be replaced when the tube reaches its end-of-life.

CFLs have two main components: a magnetic or electronic ballast and a gas-filled tube (also called bulb or burner). Replacement of magnetic ballasts with electronic ballasts has removed most of the flickering and slow starting traditionally associated with fluorescent lighting, and has allowed the development of smaller lamps directly interchangeable with more sizes of incandescent light bulb. Electronic ballasts contain a small circuit board with a bridge rectifier, a filter capacitor and usually two switching transistors, which are often insulated-gate bipolar transistors. The incoming AC current is first rectified to DC, then converted to high frequency AC by the transistors, connected as a resonant series DC to AC inverter. The resulting high frequency is applied to the lamp tube. Since the resonant converter tends to stabilize lamp current (and light emitted) over a range of input voltages, standard CFLs respond poorly in dimming applications and will experience a shorter lifespan and sometimes catastrophic failure. Special electronic ballasts (integrated or separate) are required for dimming service. The components and assembly of a CFL is shown below,

### 2.5.3 Characteristics

CFLs emit light from a mix of phosphors, each emitting one band of color with some bands still in the ultraviolet range as can be seen on the light spectrum. Modern phosphor designs balance the emitted light color, energy efficiency, and cost. Every extra phosphor added to the coating mix improves color rendering but decreases efficiency and increases cost. Good quality consumer CFLs use three or four phosphors to achieve a "white" light with a color rendering index (CRI) of about 80. CFLs typically have a rated service life of 6000–15,000 hours, whereas standard incandescent lamps have a service life of 750 or 1000 hours. The life of a CFL is significantly shorter if it is turned on and off frequently. he luminous efficacy of a typical CFL is 50–70 lumens per watt (lm/W) and that of a typical incandescent lamp is 10–17 lm/W. Electronic devices operated by infrared remote control can interpret the infrared light emitted by CFLs as a signal; this may limit the use of CFLs near televisions, radios, remote controls, or mobile phones. Incandescent lamps reach full brightness a fraction of a second after being switched on.

### 2.5.4 Dimming

Only some CFLs are labeled for dimming control. Using a dimmer with a standard CFL is ineffective and can shorten bulb life and void the warranty. Dimmable CFLs are available. The dimmer switch used in conjunction with a dimmable CFL must be matched to its power consumption range. The dimming range of CFLs is usually between 20 percent and 90 percent, but many modern CFLs have a dimmable range of 2 percent to 100 percent. Cold-cathode CFLs can be dimmed to low levels, making them popular replacements for incandescent bulbs on dimmer circuits. When a CFL is dimmed, its color temperature (warmth) stays the same. This is counter to incandescent light sources, where color gets redder as the light source gets dimmer. To use a CFL bulb on a dimmer switch, we must have a CFL bulb that's specifically made to work with dimmers and dimmer switches. For dimming, all we need to do is reduce the lamp current within the lamp after the discharge arc within the lamp has struck.

### 2.5.5 Advantages

(1) CFLs are up to four times more efficient than incandescent bulbs. We can replace a 100-watt incandescent bulb with a 22-watt CFL and get the same

amount of light. CFLs use 50- to 80-percent less energy than incandescent lights.
(2) They have good lumen maintenance means their light output does not depreciate very much over their life time. Even after a couple of years of usage a CFL will be almost as bright as day one. This is not the case for HID metal halide or high pressure sodium bulbs which can depreciate by as much as 50 percent.
(3) Their average life is about 10,000 hours compared to only an average of 2000 hours for incandescent lamp.
(4) With the versatility of CFLs, we can use them in any setting that you would with incandescent bulbs. Also, they come in various sizes and shapes that they can be used for table lamps, recessed fixtures, ceiling lighting and track lighting. There are even 3-way CFLs that offer more versatility.
(5) CFL lamps do not require the starting gear. CFL lamps start immediately.

### 2.5.6 Disadvantages

(1) While CFLs are supposed to last about 10,000 hours, turning them on and off too frequently can reduce that lifetime substantially. They are unsuitable for places where we generally turn on the light only briefly. These bulbs should be used only where they will be left on for a while without being turned on and off.
(2) CFLs are not suitable for focused or spotlights or where narrow beams of light are required. They are meant only for ambient light.
(3) Not all CFLs can be used with Dimmers. If we use regular CFLs with dimmers then the CFLs can burn out quickly.
(4) CFLs are not environment friendly as they have mercury content.

### 2.5.7 Applications

(1) Compact fluorescents are being used in residential applications replacing incandescent and halogen lights. They provide relatively shadow-free lighting in residential applications and because of their small size can fit nicely into sconces, ceiling lights and table lamps.
(2) In commercial applications compact fluorescents are extremely popular for hallway sconces in hotels and condominium associations as well as recessed lights in offices.

(3) These are well-suited for detailed task work as well as ambient lighting.

## 2.6 LED

A light-emitting diode (LED) is a semiconductor light source that emits light when current flows through it. Electrons in the semiconductor recombine with electron holes, releasing energy in the form of photons (Energy packets). The color of the light (corresponding to the energy of the photons) is determined by the energy required for electrons to cross the band gap of the semiconductor. White light is obtained by using multiple semiconductors or a layer of light-emitting phosphor on the semiconductor device. An LED lamp or LED light bulb is an electric light that produces light using light-emitting diodes (LEDs). LED lamps are significantly more energy-efficient than equivalent incandescent lamps and can be significantly more efficient than most fluorescent lamps. The most efficient commercially available LED lamps have luminous efficacy of 200 lumen per watt (lm/W). Commercial LED lamps have a lifespan many times longer than incandescent lamps. LED lamps require an electronic LED driver circuit to operate from mains power lines, and losses from this circuit means that the efficiency of the lamp is lower than the efficiency of the LED chips it uses. The driver circuit may require special features to be compatible with lamp dimmers intended for use on incandescent lamps. Generally the current waveform contains some amount of distortion, depending on the luminaires' technology. LEDs come to full brightness immediately with no warm-up delay. Frequent switching on and off does not reduce life expectancy as with fluorescent lighting. Mixing red, green, and blue sources to produce white light needs electronic circuits to control the blending of the colors. Since LEDs have slightly different emission patterns, the color balance may change depending on the angle of view, even if the RGB sources are in a single package, so RGB diodes are seldom used to produce white lighting. Nonetheless, this method has many applications because of the flexibility of mixing different colors, and in principle, this mechanism also has higher quantum efficiency in producing white light.

### 2.6.1 History

Electro-luminescence (The p–n junction in any direct band gap material emits light when electric current flows through it. This is electrolumines-

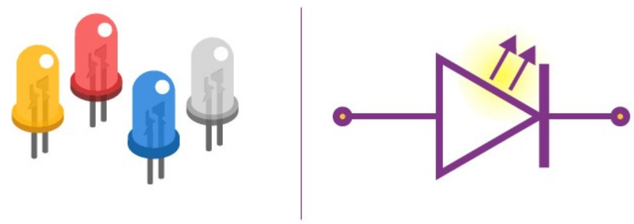


Figure 15: Appearance and Symbol of LEDs

cence. Electrons cross from the n-region and recombine with the holes existing in the p-region. Free electrons are in the conduction band of energy levels, while holes are in the valence energy band. Thus the energy level of the holes is lower than the energy levels of the electrons. Some portion of the energy must be dissipated to recombine the electrons and the holes. This energy is emitted in the form of heat and light. As indirect band gap materials the electrons dissipate energy in the form of heat within the crystalline silicon and germanium diodes, but in gallium arsenide phosphide (GaAsP) and gallium phosphide (GaP) semiconductors, the electrons dissipate energy by emitting photons. If the semiconductor is translucent, the junction becomes the source of light, thus becoming a light-emitting diode) as a phenomenon was discovered in 1907 by the English experimenter H. J. Round of Marconi Labs, using a crystal of silicon carbide and a cat's-whisker detector. Russian inventor Oleg Losev reported creation of the first LED in 1927. His research was distributed in Soviet, German and British scientific journals, but no practical use was made of the discovery for several decades. In September 1961, while working at Texas Instruments in Dallas, Texas, James R. Biard and Gary Pittman discovered near-infrared (900 nm) light emission from a tunnel diode they had constructed on a GaAs substrate. By October 1961, they had demonstrated efficient light emission and signal coupling between a GaAs p-n junction light emitter and an electrically isolated semiconductor photodetector. The first blue-violet LED using magnesium-doped gallium nitride was made at Stanford University in 1972 by Herb Maruska and Wally Rhines, doctoral students in materials science and engineering. Even though white light can be created using individual red, green and blue LEDs, this results in poor color rendering, since only three narrow bands of wavelengths of light are being emitted. The attainment of high efficiency blue LEDs was quickly followed by the development of the first white LED.

### 2.6.2 Working Principle

LEDs work on the principle of Electroluminescence. On passing a current through the diode, minority charge carriers and majority charge carriers recombine at the junction. On recombination, energy is released in the form of photons. As the forward voltage increases, the intensity of the light increases and reaches a maximum. Like an ordinary diode, the LED diode works when it is forward biased. In this case, the n-type semiconductor is heavily doped than the p-type forming the p-n junction. When it is forward biased, the potential barrier gets reduced and the electrons and holes combine at the depletion layer (or active layer), light or photons are emitted or radiated in all directions. A typical figure below shows the light emission due to electron-hole pair combining on forward biasing[Figure16],

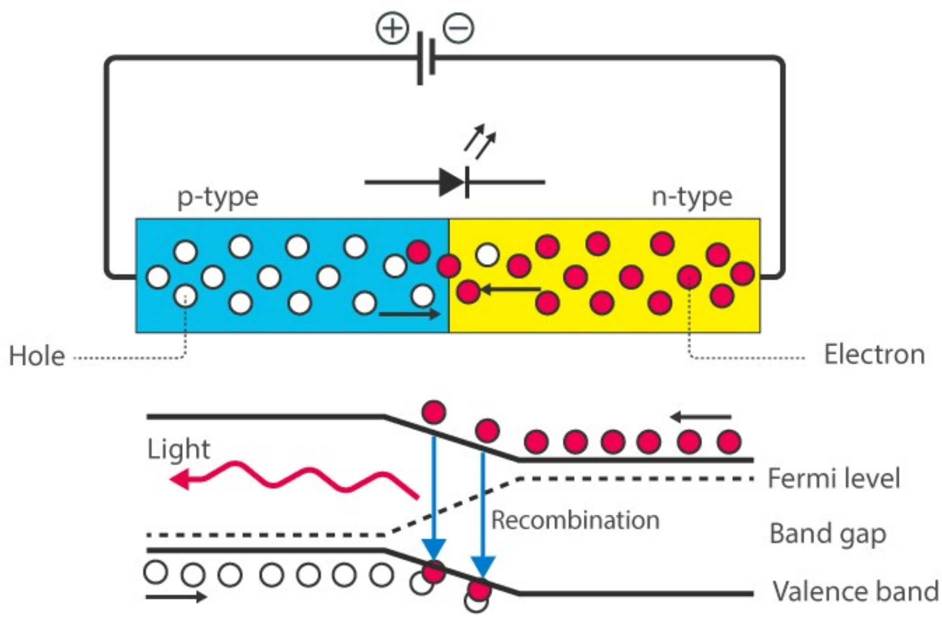



Figure 16: Working of a LED

LED lamps, bulbs, street lighting are becoming very popular these days because of the very high efficiency of LEDs in terms of light output per unit input power, as compared to the incandescent bulbs and Fluorescent lamps. So for general purpose lightings, white light is preferred. To produce white light with the help of LEDs, two methods are used :

(1) Mixing of three primary colors RGB to produce white light. This method has high quantum efficiency.
(2) The other method is coating an LED of one color with phosphor of a different color in order to produce white light. This method is commercially popular to manufacture LED bulbs and lightings.

Mixing white LEDs with different color temperature will produce a bouquet of white light, and luminous flux of this mixed white light is the sum of white LEDs with different color temperatures. Spectral distribution curve of the mixed white light is the sum of spectral power distribution curve of different color temperature white LED, which determines the color temperature of mixed white light. By changing LED drive current, we can change their luminous, which also changes spectral power distribution curves of different LEDs. The new spectral power distribution generated by different color temperature LED results in dynamic tunable white light.

### 2.6.3 Advantages

(1) Long Lifetime, Energy efficient, No warm-up period
(2) Doesn't get affected by cold temperatures
(3) Colour Rendering is excellent
(4) Environmentally friendly
(5) Very high luminous Efficacy
(6) Easily controllable.

### 2.6.4 Disadvantages

(1) The light emitted by LEDs is directional, i.e., LEDs emit light in a particular direction, whereas other light sources such as incandescent bulbs or fluorescent lamps emit light in every direction rather than in a particular direction. Hence, specially designed LED bulbs are needed to spread the light in all directions.
(2) The quality of light emitted by the LED is highly dependent upon the operating temperature. High temperature may result in changes in the various parameters of the LED.
(3) LEDs must be supplied with a voltage above their threshold voltage and a current below their rating. Current and lifetime change greatly with a small change in applied voltage. They thus require a current-regulated supply

(4) Because white LEDs emit more short wavelength light than sources such as high-pressure sodium vapor lamps, the increased blue and green sensitivity of scotopic vision means that white LEDs used in outdoor lighting cause substantially more sky glow

### 2.6.5 Applications

They are used in traffic lights and automotive brake lights due to their long shelf life, clear visibility even in the bright daylight, and fast switching time. The use of LEDs in brake lights is a great advantage as they have a fast rise time (nearly o.1 seconds), hence improves safety. In recent years LEDs are being used in every lighting solutions due to their many advantages over other lighting sources. Form indoor to outdoor in different applications the designer are choosing LEDs.

## 2.7 Dimming and Lighting Control

Dimming means reducing the output of a lamp on lighting fixture. As a lamp or fixture is dimmed its lumen output decreases.All conventional light sources can not be dimmed but all LED can be dimmed though it is not always simple.The dimming of a LED lamp or a lighting fixture depends on the driver that is been used to control it.The main function of a driver is to run the LEDs at the correct voltage and current,converting the mains AC supply(in India 240 volt,50 Hz)to usually 12-24 volt DC.This is necessary because LEDs don't operate on mains.LEDs work at low voltages on DC.

The driver can be separated from the LED or integrated with the LEDs.

**Dimming driver-** It acts as a driver as well as a dimmer.As a driver it converts mains AC supply to low voltage DC and as a dimmer it raises and lowers the amount of electrical energy flowing out to the LEDs.Now a days mainly Pulse Width Modulation(PWM) or Amplitude Modulation(AM)are being used to carry out this function.

**Sealed in Drivers-** With most LED lamps the driver is sealed inside.So,there is no means of delivering any dimming control signal to the driver.Therefore,if dimming is required,it must be done by fitting an external dimmer.

There are several ways to control a driver or instruct it what to do.The most common methods of controlling a driver are Digital Addressable Lighting Interface(DALI),Digital Multiplex(DMX),1-10 V analog control etc.DALI is the most wide spread communications protocol for commercial lighting control.A DALI signal is delivered to the LED driver via two wires that are in addition to the wires delivering the mains supply.On the other hand 1-10 V analog control is an analog communication protocol.Like DALI,it is delivered to the driver on two wires that are in addition to the main wires.DMX512 is a standard for digital communication networks that are commonly used to control lighting and effects.It is widely used for colour changing applications such as facade lighting.In recent years there are several wireless technologies available for communicating with LED drivers including Zigbee and bluetooth.

### 2.7.1 Methods of Dimming Control:

Drivers may use either of two techniques to reduce the amount of energy flowing to the LEDs-

**i. PWM-** An LED driver that dims by using PWM is switching the power to the LED s on and off.The longer the on pulses the brighter the LEDs will appear to be and vice-versa,provided this takes place at a frequency greater than about 200 Hz any flickering will not be visible to the human eye and the brain will average the perceived level of brightness.

**ii. AM-** Here the driver simply increase or decreases the output currents to the LEDs.The risk of flicker is eliminated,but some LEDs change colours slightly if their current is altered,especially at low level.
Some LED driver manufacturer use a combination of PWM and AM to achieve an optimal performance.

### 2.7.2 Types of LED dimmer:

The most common LED dimmers are phase-cutting dimmers.The two types of this is given below-

**(1) Leading Edge phase cutting dimmer/Triac dimmer :** These work by switching the current off at the zero crossing point and on again later in the same main cycle.The amount of energy flowing to the LEDs depends on the duration of the off period.The longer the off period the dimmer the LEDs will appear to be.

**(2) Trailing Edge Phase cutting Dimmer :** These work by switching the current at the zero crossing point and off later in the mains cycle.Usually this is done using Isolated Gate Bipolar Transistor(IGBT).The amount of energy flowing to the LEDs depends on the duration of the off period.The longer the off period the dimmer the LEDs will appear to be.

## 2.8 Indoor Spaces of an Educational Building

Lighting is a crucial element of creating an environment conducive to learning. This means classrooms and other educational facilities need to be well-lit whenever students and faculty are present. Smart Lighting systems not only offer more control over which lights are used and when, but they also deliver a greater degree of customization. Whether illumination needs to be bright to help students focus during classes or softer for after-hours library study sessions, smart lighting allows users to find the perfect setting. Various researches have asserted that environmental conditions in educational institutions lay a significant influence on the health and behaviour of the students. Acoustic levels, ventilation, heating, air quality, etc. are some of the notable aspects that determine the appropriateness of an institute's environment. However, favourable lighting conditions and suitable illumination plays a much superior role in the respective sense. The top LED lighting manufacturers believe that a proper lighting system aids in the creation of an optimal visual setting that is conducive to learning. Be it schools, colleges or research institutes, right lighting conditions encourage a comfortable and vibrant environment that surges the student's concentration and motivation levels. It helps in improving the productivity of the students that eventually reflects in their academic performance.

The primary and main activity for a student is reading and writing. These may range from easy tasks of reading clear and bold printed matter to more difficult tasks like pencil writing, maps or graph sheet work. There may also be fine and detailed work such as art work, needle work, dissection activity in biology laboratory, etc. The difficult tasks would need higher levels of illumination.

Some points regarding the importance of right lighting in educational institutions are,

**Appropriate Illuminance :** Right lighting setup ensures appropriate illuminance. Illuminance is an important lighting aspect that can greatly affect the performance of the students. For instance, low illuminance is often linked to slow reading and reduced concentration levels, whereas excessively high illuminance can allegedly result in reduced visual performance and hyperactivity.

**Glare Reduction :** Glare is commonly referred to as the vision impairment that typically occurs in the presence of bright and shiny lights. In educational institutes, glares can obstruct the vision of the students, making them vulnerable to physical discomforts like headaches and eye strains. It can also reduce their concentration and eventually their productivity levels.

**Ensuring Safety :** Educational institutes experience high occupancy throughout the day. They comprise of various areas like corridors, stairs, hallways, etc. that are vulnerable to accidents and mishaps. Thus, authorities are required to install proper lighting systems in order to ensure the safety of the students and the staff.

Various researches have also asserted that the integration of natural light in educational institutions is one of the best ways to boost the overall efficiency of the students. Experts claim that humans are biologically designed to feel more alert and awake when exposed to natural light. This refers to human centric lighting solution that works in harmony with the earth's natural cycle and can be programmed to emulate natural daylight. This further aids in improving the concentration and energy levels of the students that can eventually increase their motivation to learn.

Now, getting back to the topic at hand, we can use the above mentioned concept in many parts or areas of an educational institution, some of which are briefly discussed below,

**(1) Classrooms :** If we install smart lighting in these areas then we can achieve flexible use of the classroom due to wide ranging configuration options. Due to the integration of daylight, artificial light and presence/motion detectors it would provide comfortable lighting for students and faculties. It will also enables different kind of light scenes as per requirement. A comfortable general system which is flexible enough to provide a moderately high level for general use and a subdued level for use during projection or special demonstrations should be provided for a typical class room.

**(2) Canteens :** Implementing smart lighting system in canteens would provide energy efficiency. It will also ensure well-being through relaxing, biologically effective light at midday and in the evening.

**(3) Break Rooms :** Break room with smart lighting system along with HCL technology would ensure a relaxing environment. This biologically effective light will help the students to feel rejuvenated. It can also provide demand driven automation based on the activities. The staff room is a place where teachers assemble for discussions, study or rest during recess periods. These rooms should have general illumination for performing visual tasks like reading and writing (correcting papers and notebooks).

**(4) Office Rooms :** Installing smart lighting systems in these sections of an educational institution will provide glare free direct and indirect lights. So, the employees would feel comfortable and concentrated. They would not feel stressed when they return home after a long day at the office. Through constant light control we can achieve energy efficiency also.

**(5) Corridors :** Corridors are not frequently used areas in an educational institution. But it still holds the chance of accident. That's why the lighting should be well in this kind of area. But if we keep the lights on all the time it will affect energy efficiency. Through integrated presence detectors we can achieve the aesthetic appearance of these areas and the energy efficiency through daylight dependent light control. Thus through careful design we can also get cost effectiveness.

**(6) Staircases :** As the corridor areas, staircases are also very injury prone area. By using smart lighting system we can achieve high light quality, cost effectiveness and safety.

**(7) Sanitary Facilities :** Pleasant atmosphere in sanitary facilities can be achieved through homogeneous light emission. Through demand driven light control and using presence detectors smart lighting system enables energy efficiency.

**(8) Entrances :** Smart lighting system in entrance areas enables prestigious lighting for a friendly, inviting appearance. We can also achieve energy efficiency. etc.

**(9) Libraries :** The library is an important section in an educational complex, which requires detailed consideration. General reading, both casual and sustained of a wide variety of printing types, fonts and styles, examination of drawings and maps, writing, etc. are among the more common visual tasks that are encountered in a library. So, the lighting should be of very high quality as printed illustrative matter involves veiling reflections from overhead lighting; special care should be taken to use lighting equipment that will minimize the concentration of the light directly downward which in turn causes reduction of contrast.

**(10) Laboratories :** These involve laboratory tables or benches at which very detailed work is done in dissection, inspection of reactions, instrumentation and measurement. So, good diffusion with some directional component and appropriate colour quality is required. In some cases, localised lighting may be needed. In chemical laboratories where the presence of corrosive fumes and vapour is expected, it is recommended to use luminaires which are able to withstand the ill effects ofthe chemical fumes present in the atmosphere.

Chapter 3

# 3 Design of Coventional Lighting System-A Case Study

In this chapter, the Lighting Design of the Educational facility has been done using DIALux 4.13 and DIALux evo softwares. As discussed earlier, DIALux software is used for complex 3D interior lighting design. The light sources which are generally used for the indoor lighting design purpose has been mentioned in the earlier chapter. At first the lighting Design has been done using the conventional light sources and in the later chapter we will see how the LED luminaires can be used in place of the conventional light sources and why LEDs are prefered nowadays.

The conventional light sources for indoor lighting designs are compact fluorescent lamps or fluorescent tubes. In the present time also we can see that CFLs or Fluorescent Tubes are still in use in many educational facilities. So, this lighting design has been done using the CFLs as the conventional lighting sources. For simplicity,we have divided the whole educational facility in some sections or rooms depending on types of tasks as mentioned earlier and have done the lighting design seperately for each room.

## 3.1 Design without considering Daylight :

Here, only the lighting design of a classroom is described briefly. This procedure of designing is applicable for every room in an edcational facility. The step by step procedures for lighting design in the classroom is given below,
After opening DIALux 4.13 or DIALux evo software at first we have to select 'New interior project' or 'import a plan or IFC'. The later is used when AutoCAD plan is available otherwise we use the first option and then begin the design of the room. After this step a new window appears where we have to set the dimension(length,width and height) of the room. In this step we create our desired room and we can also change the maintenance factor(MF) or light loss factor(LLF) according to room condition. After this we set the co-efficient of reflection for the room surfaces(ceiling, floor and walls) depending on the color and textures of those surfaces. It is a very important input parameter as the result of the lighting design is dependent

on the inter-reflection of light. The identification of four walls is also very important as it helps us to easily put windows and doors which in turn will help us when daylighting calculation will be integrated in the design. DIALux automatically take 0.8 m as the height of the workplane though it can be changed. After this, we have to insert windows, doors or rooflights and different objects in the room as per our requirement.Furthermore, we have to put calculation surfaces or points and calculation grid in the required position where we want to measure the output.e.g. in the classroom we have a table in front of the teacher,a writing board behind this table and many benches where students keep their books and notebooks.so these surfaces are very important as these decide whether a student can view the board or his own books properly, comfortably and without any glare.so in this example we have to put calculation grids on the surfaces of the above mentioned objects as we want to know the illuminance and uniformity on these particular surfaces.we have to pur UGR calculation Point or surfaces at eye-view height when the students are seated on the chair(generally 1.2 m). Then we have to select the luminaire which we intend to use for our design purpose and get the ies file for that particular luminaire so that we can use it as plug-in in DIALux. Now we have every details of the room(area, maintenance factor) and luminaire(lumen package of a single luminaire, co-efficient of utilization). We can also get the value of desirable illuminance from the dedicated Indian Standards for indoor lighting design. so now we can easily calculate the number of luminaires that are required to successfully complete the lighting design by using the Lumen Method Formula. Which is Given by,

$$E_(avg) = \frac{N*\phi*COU*MF}{A}$$

Where, E=Average Illuminance,
N= Number of Luminaires required,
$\phi$ = Luminous Flux of each luminaire,
MF=Maintenance Factor,
LLF= Light Loss Factor,
COU=Co-efficient of Utilization and
A= Area of the room surface or Workplane.
DIALux considers MF=LLF.

After this we have to figure out which type of luminaire arrangement (Individual Luminaire ,Field, Line or Circular Arrangement)we will use so that all lighting design parameters(Average Illuminance, Overall Uniformity,Unified

Glare Ratio, Lighting Power Density etc.) are achieved. The last step is to calculate the entire project and get result based on the design we have done. Sometimes it can happen that the results obtained after calculating are not satisfying the required values given in the Lighting Design Standards. In this case we need to use trial and error method. Thus the Lighting design for an Indoor facility is done.

A Flowchart depicting the whole process of lighting design is given below[Figure17]

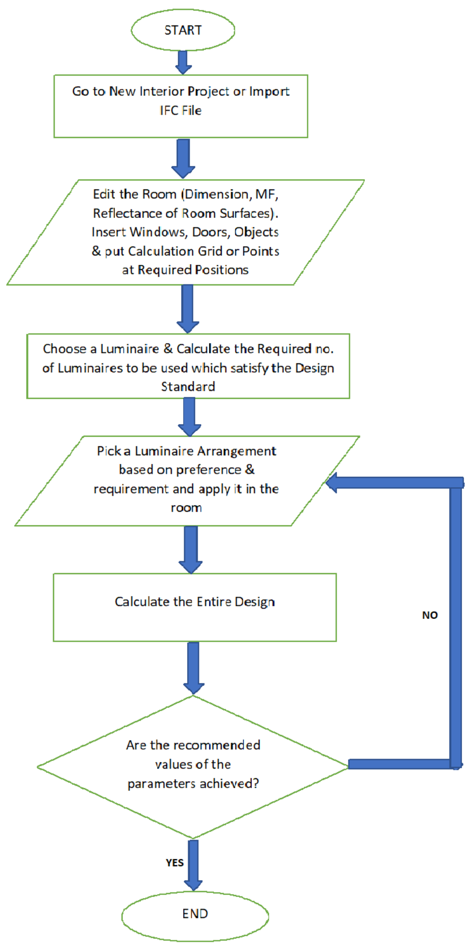



Figure 17: Flowchart of Lighting Design Without Daylighting

## 3.2 Design considering Daylighting :

Special attention should be paid to the location of windows and openings in educational institutions which allow in a generous amount of daylight, while designing a lighting system for any areas. For night time use illumination should be planned depending on various factors such as evening classes, topography of the institution, climatic conditions of the place where the institution is located. Many conventional Indoor Lighting Luminaires are available with dimmer circuit. In DIALux this is done by implementing Light Scene. Though previously we used windows and doors,it will not incorporate the effect of daylighting as we didn't use the concept of light scene. In the next part, we will discuss step by step approach to integrate daylighting calculation with artificial lighting in DIALux.

The first and most important thing in daylighting design is to specify when and where this calculation is being carried out.so,we have to specify the Date and Place. The previously mentioned steps are also executed in this case. After we put the luminaire arrangement in the design, we have to Split the Whole arrangement. It enables us to control each luminaire seperately. That's how Light Scene is done in DIALux. Next, we have to create Control groups. Through these control groups we can dim or increase the lux level of a luminaire of our choice which is a member of any control groups. We can even keep a certain luminaire off if the need arises. Daylight is a variable quantity i.e.the level of daylight doesn't stay constant throughout the day. For example, in a cloudy weather the daylight level is less and thus we have to keep artificial light sources on which will give high light output so that the task in that room is not hampered. But on a sunny day, we may not have to switch on the luminaires or we may keep the luminaires at lower light level, but still we will get the required illuminance. This will help in saving energy and will help the students remain comfortable and concentrated.

There are many standards depicting the required illumination level and unified glare rating for different parts of an educational institution. Here, in our design we have followed the Indian Standard. The Indian Standard for Interior Lighting is IS 3646 (Part 1 and Part 2).
The levels of il1uminance and glare index recommended (National Lighting Code 2010-SP 72 : 2010) for some areas in an educational institutions are given below,

Table 1: Recommended Values

| Serial No. | Areas | Illuminance(lux) | UGR |
|---|---|---|---|
| i) | Classrooms | 300 | 19 |
| ii) | Seminar Rooms | 300 | 19 |
| iii) | Libraries | 300 | 19 |
| iv) | Laboratories | 300 | 19 |
| v) | Reading Rooms | 150-300 | 21 |
| vi) | Canteens | 100 | - |
| vii) | Corridors | 70 | - |
| viii) | Offices | 150 | - |
| ix) | Auditorium hall | 70 | - |

Another important electrical parameter which must be considered during lighting design is Light Power Density(LPD). It is the maximum lighting power per unit area of a space as per its function or building as per its classification. The installed interior lighting power for a building or a separately metered or permitted portion of a building shall not exceed the interior lighting power allowance provided by The Energy Conservation Building Code(ECBC, 2017). Some examples of LPD for Educational Building is shown below,

Table 2: ECBC Buildings

| Areas | LPD(W/$m^2$) | Areas | LPD(W/$m^2$) |
|---|---|---|---|
| Classrooms | 13.8 | Seminar Rooms | 13.7 |
| Laboratories | 15.1 | Libraries | 10.0 |

Table 3: Super ECBC Buildings

| Areas | LPD(W/$m^2$) | Areas | LPD(W/$m^2$) |
|---|---|---|---|
| Classrooms | 6.90 | Seminar Rooms | 6.80 |
| Laboratories | 7.50 | Libraries | 5.70 |
| Breakrooms | 3.80 | Corridors | 2.30 |
| Staircases | 2.70 | Offices | 5.70 |

A flowchart showing the integration of daylighting with artificial lighting is shown below[Figure 18],

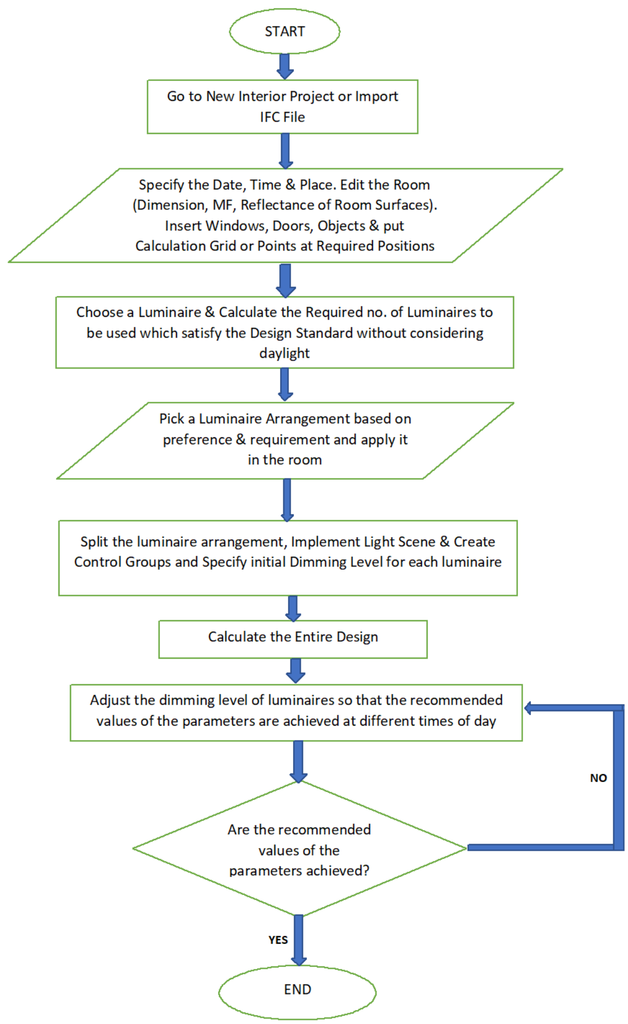
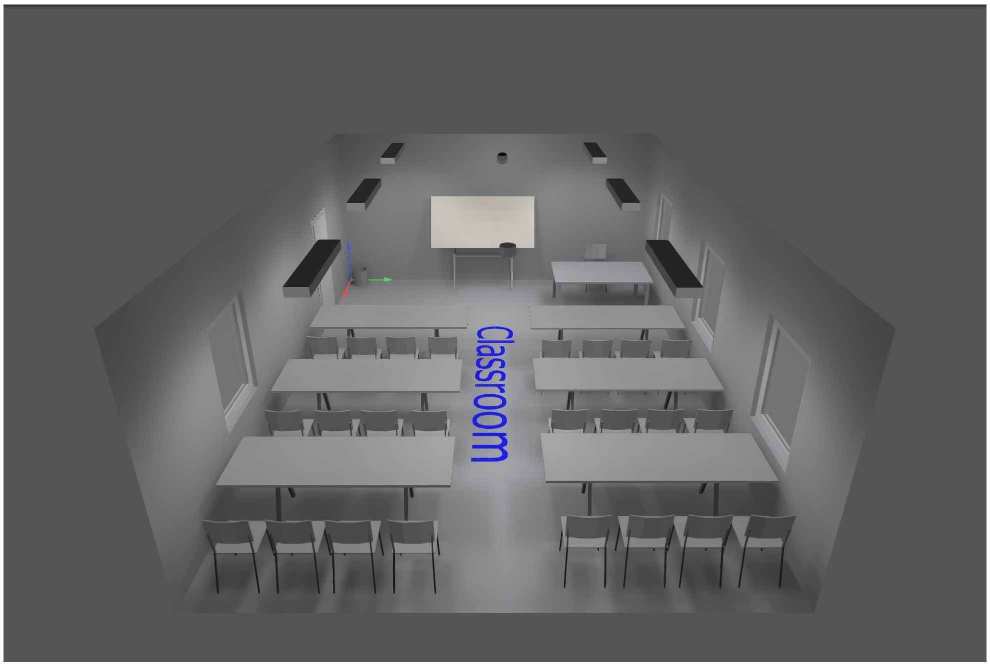



Figure 18: Flowchart of Lighting Design Considering Daylighting

## 3.3 DIALux Design

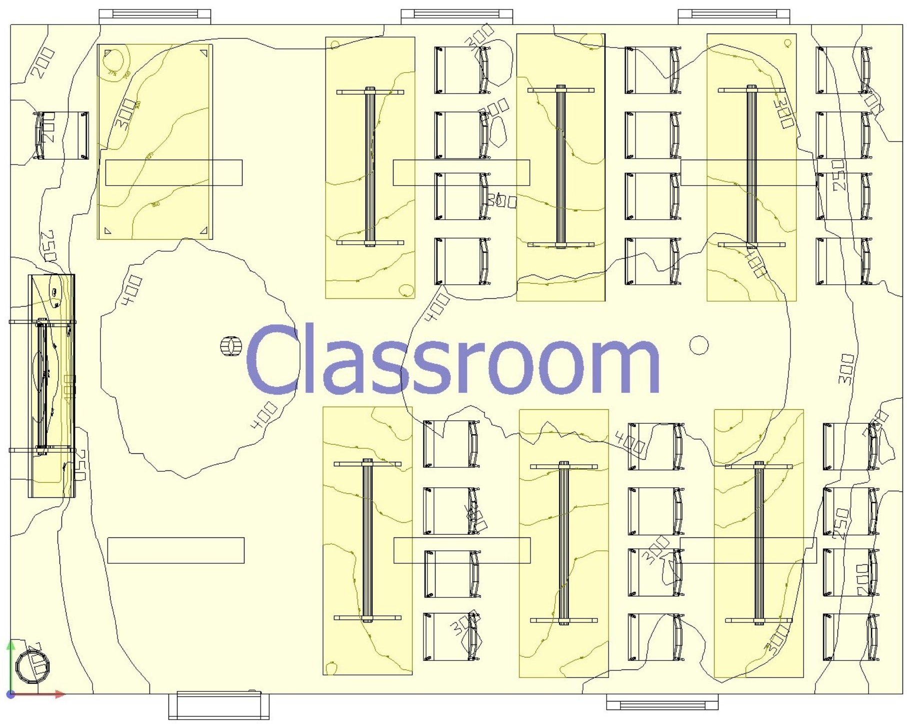
The lighting Design of a Classroom is shown here. The design of other rooms(Auditorium, Sanitary Facility etc.) will be shown in later part. Here, we have considered a classroom of dimension 8 m* 6 m* 3 m and have used both CFLs and LEDs for the design purpose. The construction of the classroom is shown below,




We have taken the calculation surfaces on the benches and on the white board. And the work-plane is considered at a height of 0.8 m from the floor. Here, daylight hasn't been considered. The lighting standard for the classroom has been specified as,

$$E_(avg) >=300 \text{ lx}$$
$$U_0 >=0.7$$
$$\text{UGR}<=19$$
$$\text{LPD}<=11\ W/m^2$$

Maintenance Factor or Light loss Factor has been considered as 0.8 and the coefficient of utilization is 0.4. From the lumen formula, the number of luminaires required for this design has been calculated. The luminaires details and the results from the design is shown below,




| Article name | P | $\Phi_{Luminaire}$ |
|---|---|---|
| TBS285/236;MIRROR-M5,HF | 72.4 W | 3201 lm |
| Recess mounted LED Downlighter | 14.6 W | 1427 lm |

The lighting power density is calculated as 9.66 $W/m^2$, which is less than 11 $W/m^2$. We have achieved 322 lx as $E_(avg)$ and we can see that on all the calculation surfaces the calculated illuminace is greater than 300 lx. The overall uniformity on the taken calculation surfaces is shown in Table 4 and we can observe that $U_0$ is greater than 0.7 for every cases.

So, we can see that this design satisfies the given standard for classroom design. The detailed report will be shown in annexures.

Table 4: Results on Calculation Surfaces

| Surface | $E_(avg)$ (lux) | $U_0$ |
|---|---|---|
| Workplane | 322 | - |
| Calculation Surface 1 | 322 | 0.85 |
| Calculation Surface 2 | 337 | 0.89 |
| Calculation Surface 4 | 345 | 0.86 |
| Calculation Surface 6 | 344 | 0.80 |
| Calculation Surface 7 | 345 | 0.90 |
| Calculation Surface 8 | 348 | 0.87 |
| Calculation Surface 9 | 339 | 0.81 |
| Calculation Surface on Board | 301 | 0.85 |

Results

| | Symbol | Calculated | Target | Check |
|---|---|---|---|---|
| Working plane | $\bar{E}_{perpendicular}$ | 332 lx | ≥ 300 lx | ✓ |
| | $g_1$ | 0.15 | - | - |
| Consumption values | Consumption | [560 - 890] kWh/a | max. 1700 kWh/a | ✓ |
| Room | Lighting power density | 9.66 W/m² | - | - |
| | | 2.91 W/m²/100 lx | - | - |

Chapter 4

# 4 Upgradation to a Smart Lighting System-A Case Study

Conventional light bulbs work by flipping a switch on and off. Sometimes they are hardwired into a dimmer switch, allowing us to dim or brighten the lights. Smart lighting, on the other hand, gives us far more control over the lights. Each smart bulb and LED-integrated fixture allows us to control it wirelessly with our phone, tablet, or smart assistant, such as Google Assistant or Amazon Alexa. Integrating daylighting with Artificial lighting is indispensable in the case of smart lighting design. After the invention of LEDs, the concept of smart lighting spread rapidly. As, the control of lEDs is very easy so by using it we can easily implement a smart lighting system as per our requirement.

In the previous section we discussed about how to incorporate Daylighting Calculation in DIALux. In this section we will focus on how to implement a smart lighting system in an educational facility. As this is a case study, we will describe how the administration can create a smart educational facility with the help of recommended products and what benefits they will get after implementing it.

Here, we have taken help from ESYLUX Company. ESYLUX develops, manufactures and distributes intelligent automation and lighting solutions that ensure better quality of life and energy efficiency in office buildings, educational institutions and health facilities. They are using electronics and automation for development of LED-based systems for energy efficient and biologically effective light. Their works mainly involve Intelligent Lighting, Demand-Driven Automation, Human Centric Lighting etc. With SymbiLogic, ESYLUX has developed a technology that also applies Human Centric Lighting in an extra energy-efficient way with the help of an intelligent sensor technology.

An overall block diagram for smart lighting design is shown in the next page [Figure 19],

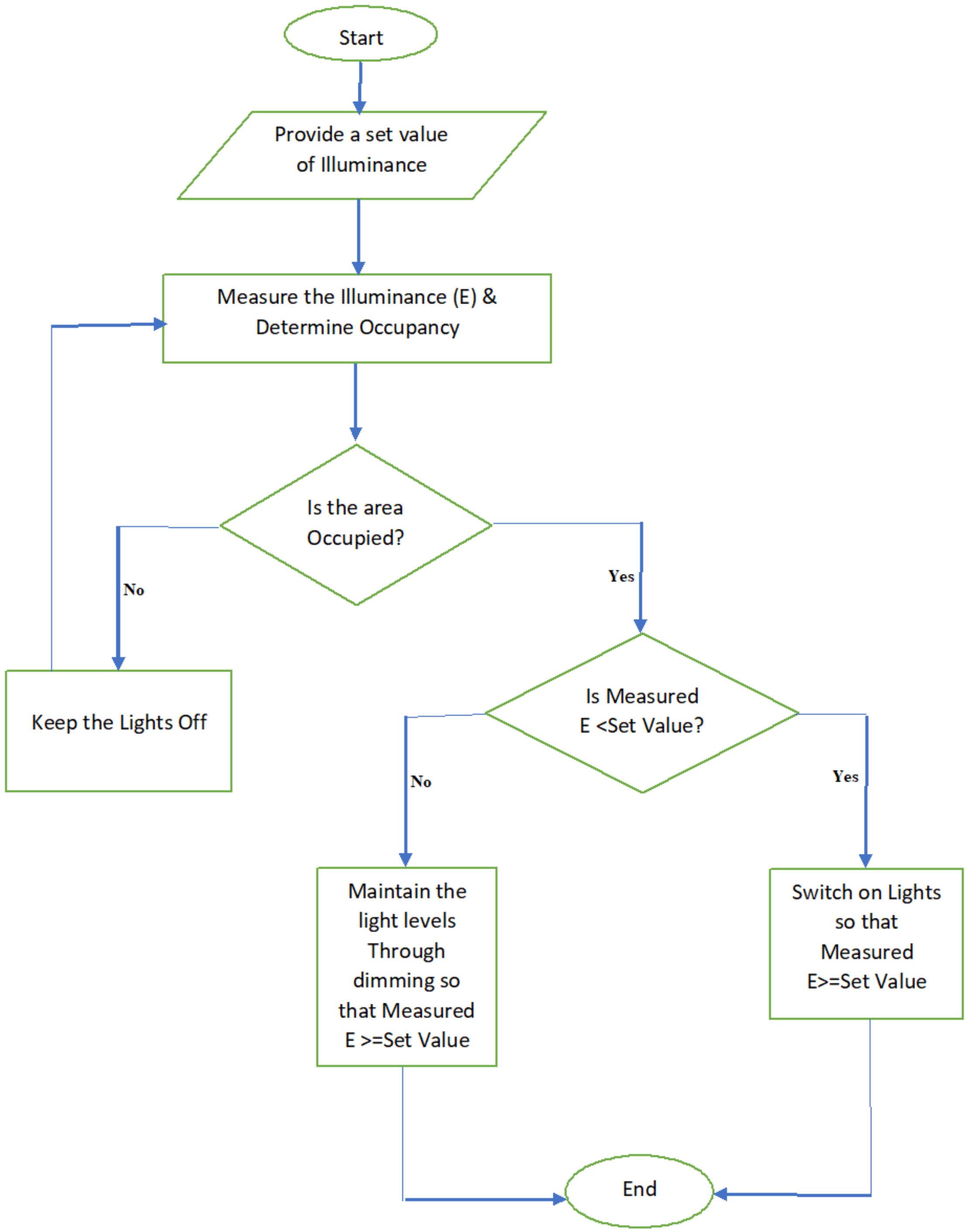



Figure 19: Block Diagram for Smart Lighting Design

First of all we need to understand in which areas or sections we need to implement smart lighting system so that we can be greatly benefited from it. Previously, we have discussed about the Indoor spaces of an Educational Building in detail. The main areas where we can implement this are as follows:
(1) Classroom
(2) Canteen
(3) Break-room
(4) Office Room
(4) Staircase
(5) Sanitary Facility
(6) Library
(7) Auditorium and many more. A Block Diagram for designing smart lighting is shown.

ESYLUX has mentioned many solutions for smart lighting designing. They have also mentioned many equipments which we can potentially use for a certain area. Obviously this depends on the type of work that will be done in that area and on preferences. For the implementation purpose we require many equipment, which are mentioned below,

**(1) Lighting Fixtures :** There are many smart lighting fixtures available in the market. But this fixtures should be chosen based on the environment in which they will be used. The Number of lighting fixtures which is required has to be calculated for a certain section. This is calculated by,

$$N = \frac{E_(avg) * A}{\phi * COU * MF}$$

Where, E=Average Illuminance,
N= Number of Luminaires required,
$\phi$ = Luminous Flux of each luminaire,
MF=Maintenance Factor,
LLF= Light Loss Factor,
COU=Co-efficient of Utilization and
A= Area of the room surface or Workplane.
DIALux considers MF=LLF.

**(2) Smart Drivers :** These are the main controlling force of whole smart lighting system network. All the sensors and smart fixtures are connected to these. These receives data from sensors and after analyzing those data, send control signal to the lighting fixtures. And that's how we get the smart lighting experience.

**(3) Push Buttons :** Though we are implementing a smart system, we can't ignore the role of Push Buttons. By using the push buttons we can change the ambience of a room or during a projector session we can simply push a button and all the lights will turn off. Using this we can also implement Human Centric Lighting (SymbiLogic technology) as per our requirement.

**(4) Presence and Motion Detectors :** Presence and motion detectors are an indispensable part of smart lighting design. As the name suggests they detect the presence in a certain area. In simple words, we can say, suppose we have installed smart lights in a classroom. At a certain time a student enters there but how will the smart lights operate? The answer is , the motion detectors will detect the motion and send the signal to smart-driver and thus the lights will turn on automatically. Similarly, if the detectors don't sense any motion in that particular area the lights will remain off.

**(5) Light Sensors :** These are used to constantly monitor the amount of light that is falling on a particular surface. These a photoelectric devices that convert light energy detected to electrical energy. This acts as the bridge between Daylight and artificial lights. These sense the light level in a particular area and constantly send these data to smart-drivers. If the light level is higher/lower than the level that is recommended or required in that area, then the smart drivers will control the dimming levels of the lights accordingly by sending control signals to the smart fixtures.

**(6) Actuators :** An actuator is a device that uses a form of power to convert a control signal into mechanical motion. It converts the lighting control signal into switch actions.

**(8) Escape Sign Lights :** An exit sign is a pictogram or short text in a public facility denoting the location of the closest emergency exit to be used in case of fire or other emergency that requires rapid evacuation. Exit signs are designed to be absolutely unmistakable and understandable to anyone. These must operate on different power sources. Standalone batteries or cells are mainly used for this purpose. As in case of an emergency if the main power source is deactivated , then these power sources will keep the escape lights on.

**(9) ESY-Pen and ESY-App :** ESYLUX uses the principle of intelligent synergy for the ESY-Pen and ESY-App. These allow easy configuration, remote control, mobile project management and documentation for all ESYLUX remote-controlled products and solutions. The ESY-App allows users to easily parameterise all remotely controlled ESYLUX presence detectors, motion detectors and lighting systems via their smartphone or tablet. The ESY-Pen uses infrared technology to simply transmit the Bluetooth commands from the mobile end device.

ESYLUX has manufactured many equipments for providing lighting solutions for different sections of different public facilities. In the next part we will focus on the equipments that we will require for the implementation of a smart lighting system in a educational facility. Here, we have recommended different equipments based on their uses for different areas of a educational institution. The brief details of different equipments are also mentioned below,

## 4.1 Classrooms

Whether learning subject content, engaging in discussions or accessing knowledge together - for many years, the classroom has been one of the most important places where people meet and pave the way for a successful future. Intelligent lighting always provides the right light at the right time. The optimal light provides the perfect environment for visual tasks, Well-being and concentration. Here a lighting solution is provided,

**(a) CELINE-2 PNL 600 DDP TR 4200 8TW IP20 ELC :** The LED recessed lights in the CELINE-2 series provide the highest-quality lighting in workplaces such as offices, educational institutions and medical facilities. These lights are suitable for use as system lights with ESYLUX Light Control

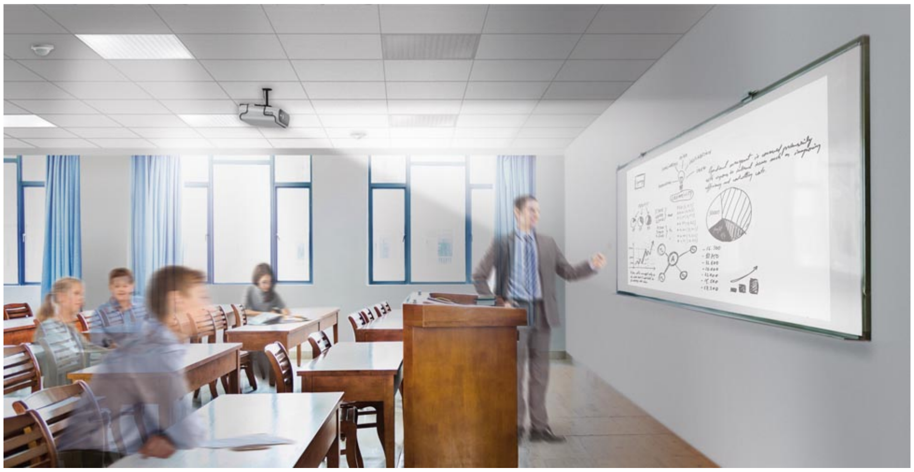


Figure 20: Classroom

(ELC) via their plug-and-play connection and can also be used in DALI lighting systems via driver sets that are available as an optional accessory. These lights also comes with Tunable White enable energy-efficient human centric lighting with SymbiLogic technology using ELC system lights or DALI-2 presence detectors from ESYLUX. The Technical Specifications are given below,

Device Category: Recessed Light
Warranty: 5 Years
Installation Position: Ceiling
Connector:RJ45
Protection Type: IP20
Impact Resistance: IK02
Installation Dimension: 600mm*600mm*140mm
Control System: ELC(ESYLUX Light Control)
Protection Class: III
Nominal Voltage: 42 V dc
Power Consumption: 33 W
Diffuser: Transparent
Light Emission: Direct
Beam Angle: 94°
$UGR < 19$
Rated Output: 33 W

Luminous Flux: 4400 lm
Luminous Efficacy: 133 lm/W
Color Temperature: 2700-6500 K(Tunable White)
$CRI > 80$
Color Tolerance: 2 SDCM
Lifetime at 25° C: 70000 h

(a) CELINE-2 PNL 600 DDP TR 4200 8TW IP20 ELC

(b) SMARTDRIVER TW ELC

**(b) SMARTDRIVER TW ELC :** The SMARTDRIVER is the control unit for ESYLUX lighting systems with simple plug-and-play installation and no programming required. The combination of control unit, ceiling lights and sensors delivers intelligent, presence-based and daylight-dependent controlled lighting — and at the highest configuration level it enables the biologically effective light with the SymbiLogic Technology. The Technical Specifications are mentioned below,

Device Category: Control
Warranty: 5 Years
Installation Type: Recessed Mounting
Installation Position: Ceiling
Protection Type: IP20
Type of Connection: Push Terminal

Power Consumption: 260 W
Control System: ELC, DALI
Protection Class: I
Nominal Voltage: 230 V ac/50 Hz
Stand-by Consumption: 7.5 W
Number of Light Channels: 2
Number of Control Units per Group: 5
Number of light Groups: 10
Number of Scenes : 4
Number of Output luminaires ELC: 8
Number of Output Luminaires DALI: 4

**(c) CABLE RJ45 5m BL, CABLE RJ45 5m RD :** RJ stands for Registered Jack. The number 45 only refers to the number of the interface standard. RJ45 is a kind of connector usually employed for Ethernet networking. It looks very similar to a phone jack but is slightly bigger. RJ 45 connector is made up of 8 pins where 8 copper cords are connected. an RJ45 is frequently utilized for CAT5 and CAT6 wires.

Figure 22: RJ45 Cable

Device Category: Cable
Length: 5 m

**(d) PUSH BUTTON CLASSROOM ELC :** Buttons are the key controls for adjusting the lighting equipment to suit users' individual needs. Different variants of the ELC push buttons provide appropriate push button assignments for different applications. Below the key data are mentioned,

Device category: Push Button

Installation Type: Recessed Mounting
Installation position: Wall
Installation Dimension: 55.5 mm*55.5 mm*8 mm
Type of Connection: push Terminal
Protection Type: IP20
Control System: DALI
Protection Class: III
Bus Voltage: 9.5 V-24 V dc

**(e) PD-C 360i/24 ELC :** These are the Presence and Motion Detectors. Simple parameterisation, remote control and documentation with ESY-Pen and ESY-App. The Technical Details are given below,

Device Category: Ceiling Mounted Presence Detector
Installation Type: Flush Mounting
Installation Position: Ceiling
Installation Depth: 24 mm
Type of Connection: Push Terminal
Protection Type: Recessed Mounted IP20
Control System: ELC
Protection Class: III
Nominal Voltage: 9-22 V dc
Power Consumption: 0.3 W
Detection Angle: 360°
Detection Range Diagonally: $\phi$24 m
Detection Range Head on: $\phi$11 m
Detection Range Presence: $\phi$8 m
Field of Detection: up to 453 $m^2$
Recommended Installation Height: 3 m
Level of Brightness: 5-2000 lx
Number of Light Channels: 4
Mode: Semi-automatic, Fully Automatic
Switch off Delay time: 60 s- 240 min

**(f)PD-C 360i/8 ELC :** The Technical Details are same as PD-C 360i/24 ELC apart from two cases. These are mentioned below,

Detection Range Diagonally: $\phi$8 m

Detection Range Head on: $\phi 6$ m
Detection Range Presence: $\phi 4$ m
Field of Detection: Up to 50 $m^2$


(a) PUSH BUTTON CLASSROOM ELC

(b) PD-C 360i/24 ELC

(c) ACTUATOR FULL AUTO C3 DALI

**(g) ACTUATOR FULL AUTO C3 DALI :** The COMPACT series actuators (DALI switch) convert the digital commands from ESYLUX DALI presence detectors and other ESYLUX light controls such as lighting systems into switch actions. This enables the lighting to be controlled conveniently. The Technical Specifications are mentioned below,

Device Category: Electrical Accessories
Installation Type: Recessed Mounting
Protection Type: IP20
Control System: DALI
Protection Class: II
Nominal Voltage: 13-22.4 V
Power Consumption: 0.2 W
Bus Voltage: 9.5-22.5 V dc
Rated Current: 10 A
DC Switching Capacity(Resistive Load): 10 A/12 V dc
Switching Capacity Incandescent lamp: 2300 W

## 4.2 Canteens

Cafeterias are communication hubs. They bring people in educational institutions together and offer a spatial and mental time-out. Pupils, students, and teachers often only have short breaks between lessons. An atmospheric lighting concept is thus all the more critical. Increased natural light in a canteen boosts the quality of stay. Dynamic lighting management systems balance available daylight with artificial light to create a bright, friendly atmosphere with optimised energy consumption. The most pleasant lighting is a combination of indirect lighting and accent lighting. Canteens are not only for eating purposes. It also provides refreshment and comfort after a period of hard work. So, students and employees should enjoy their time here as much as possible. ESYLUX provides solutions that are effective, elegant and efficient. To achieve the proper lighting effect, we will need different layers of light. Ambient light sets the general level of lighting, while accent lighting can draw attention to the architecture of the room. We also need direct lighting in areas where workers will need more light, such as cash registers, the kitchen etc. We also want to make sure the cafeteria lighting design shows the true colour of the food and drinks being served. If the lighting changes the colour of the food, it could create a poor visual impression of the food and negatively impact the customer experience.

Figure 24: Canteen

**CELINE PNL 1200 LDP TR 4100 8TW IP20 ELC :** Linear luminaires in the CELINE series with adjustable Tunable White light colour create a pleasant atmosphere. The system provides light management functions using integrated sensors and control units. They are designed for suspended system ceilings, but are also suitable for other installation types with suitable accessories — and are also impressive as special designs in intelligent lighting systems due to their high light quality. The Technical Details are given below,

Figure 25: CELINE PNL 1200 LDP TR 4100 8TW IP20 ELC

Device Category: Recessed Light
Installation Position: Ceiling
Connector: RJ45
Dimension: 1195 mm*296 mm*91 mm
Protection Type: IP20
Control System: ELC
Protection Class: III
Nominal Voltage 42 V dc
Diffuser: Transparent
Light Emission: Direct
Beam Angle: 90°
$UGR <= 19$
Rated Output: 27 W
Luminous Flux: 4000 lm
Luminous Efficacy: 148 lm/W

Color Temperature: 2700-6500 K(Tunable White)
$CRI > 80$
Color Tolerance: 5 SDCM
Life time at 25° C: 60000 h

Apart from this SMARTDRIVER TW ELC, CABLE-SET RJ45 5m TW, PD-C 360i/24 ELC, PUSH BUTTON TW ELC, ACTUATOR FULL AUTO C3 DALI are to be used. These are explained in the previous pages.

## 4.3 Break Rooms

Break rooms require a friendly room environment so that people feel well, relax and re-energized. Rapid recuperation is only possible in bright rooms flooded with light where there is a climate conducive to communication. Canteens are often located toward the building exterior where daylight enters, which can be supplemented with artificial light if necessary. Break rooms are not constantly occupied throughout the day. For convenience, or simply due to carelessness, the light is often left switched on in empty rooms. This wastes energy. Here a smart lighting solution is provided,

Figure 26: Break Room

**CELINE-2 PNL 600 DDP OP 3800 8TW IP20 ELC :** The Technical details are as follows,

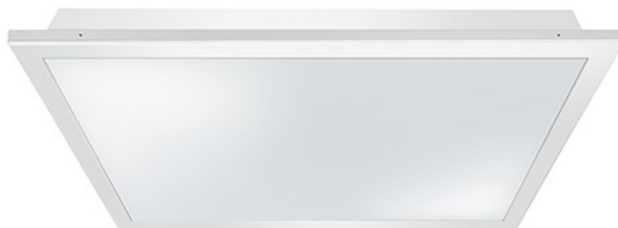


Figure 27: CELINE-2 PNL 600 DDP OP 3800 8TW IP20 ELC

Device Category: Recessed Light
Warranty: 5 Years
Installation Position: Ceiling
Connector: RJ45
Dimension: 596 mm*596 mm*65 mm
Protection Type: IP20
Impact Resistance: IK02
Control System: ELC
Protection Class: III
Nominal Voltage: 42 V dc
Power Consumption: 33 W
Diffuser: Opal
Light Emission: Direct
Beam Angle: 94°
$UGR < 19$
Rated Output: 33 W
Luminous Flux: 4000 lm
Luminous Efficacy: 121 lm/W
Color Temperature: 2700-6500 K(Tunable White)
$CRI > 80$
Color Tolerance: 2 SDCM
Lifetime at 25° C: 70000 h

Again here also we will require the Smart-driver, Cables and Presence Detectors all of which are discussed previously.

## 4.4 Office Rooms

The offices are the nerve centres of an Educational Institution. All important paper works are carried out here. That's why everything has to run smoothly. Good lighting creates a pleasant atmosphere and promotes concentration and well-being. A Smart Lighting Approach for these rooms is given below,

Figure 28: Office Room

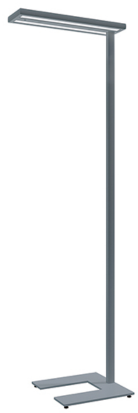
**(a) ISABELLE FSL U-BASE DDP TR 6300 840 PD IR WH :** The ISABELLE free-standing light is an intelligent and particularly flexible lighting solution for individual workplaces that is easy to relocate and transport due to its high degree of portability. The light is characterised by the sleek design of the aluminium housing; the presence detector integrated in the lamp head enables demand-driven control of the direct and indirect light. The Technical Specifications are given below,

Device Category: Office Floor Light
Warranty: 5 Years
Installation Type: Free Standing

Installation Position: Floor
Dimension: 600 mm*400 mm*1950 mm
Protection Type: IP20
Control System: On/Off
Protection Class: I
Nominal Voltage: 230 V ac/ 50 Hz
Stand by Consumption <0.1 W
Diffuser: Transparent Light
Emission: Direct/Indirect
Beam Angle: 90°
$UGR <= 19$
Flicker Factor <3 Percent
Rated Output: 47 W
Luminous Flux: 6300 lm
Luminous Efficacy: 134 lm/W
Color Temperature: 4000 K
Color Rendering Index>80
Color Tolerance: 3 SDCM
Lifetime at 25 degree C: 70000 h
Sensor Detection Angle: 360°
Field of Detection: 13 $m^2$
Level of Brightness: 5-2000 lx
Switch off Delay Time: 300 s-30 min

**(b) ISABELLE PDL 1200 DDP TR 8800 840 PD IR DALI WH :**
The Technical Details are as follows,

Device Category: Pendant Light
Warranty: 5 Years
Installation Type: Pendant
Installation Position: Ceiling
Dimension: 1206 mm*166 mm*30 mm
Protection Type: IP20
Control System: DALI
Protection Class: I
Nominal Voltage: 220-240 V ac/ 50 Hz
Stand by Consumption: 1 W



(a) ISABELLE FSL U-BASE DDP TR 6300 840 PD IR BK

(b) ISABELLE PDL 1200 DDP TR 8800 840 PD IR DALI WH

Diffuser: Transparent
Light Emission: Direct/Indirect
Beam Angle: 80°
Luminous Flux: 8830 lm
Luminous Efficacy: 110 lm/W
Color Temperature: 4000 K
Color Rendering Index >80
Color Tolerance: 4 SDCM
Lifetime at 25° C: 50000 h
Integrated Presence Detector with DALI Bus Voltage Supply
Sensor Detection Angle: 360°
Field of Detection: 7 $m^2$

**(c) ISABELLE PDL 1200 DDP TR 8800 840 DALI WH :** The ISABELLE pendant light is an elegant lighting solution for conference rooms, entrance areas and many other locations where an effective combination of style and light quality is important. The optional presence detector integrated in the luminaire head ensures control of glare-free direct and indirect light as required. The Technical Points are given below,

Device Category: Pendant Light
Warranty: 5 Years

Installation Type: Pendant
Installation Position: Ceiling
Dimensions: 1206 mm*166 mm*30 mm
Protection Type: IP20
Control System: DALI
Protection Class: I
Nominal Voltage: 220-240 V ac/ 50 Hz
Stand-by Consumption $< 1$ W
Diffuser: Transparent
Light Emission: Direct/ Indirect
Beam Angle: 80°
UGR $<= 19$
Flicker Factor $< 3$ percent
Rated Output: 80 W
Luminous Flux: 8830 lm
Luminous Efficacy: 110 lm/W
Colour Temperature: 4000 K
CRI $> 80$
Colour Tolerance: 4 SDCM
Lifetime at 25° C: 50000 h

## 4.5 Corridors

To keep the work process efficient, each movement in the corridors should be a step in the right direction. Even in less frequently visited areas, no-one should be left in the dark. Efficient Smart Lights respond to movement and also take the existing daylight into consideration when using light. This enables us to get to the destination in an energy efficient way at all times with perfect light quality.

**(a) ELSA-2 DL 225 OP 110° 1800 840 PD IR PS DALI WH :** The Technical Details are mentioned below,

Device Category: Down light
Warranty: 5 Years
Installation Type: Recessed Mounting
Installation Position: Ceiling
Type of Connection: Push Terminal

Figure 30: Corridor

Protection Type: IP20
Control System: DALI
Protection Class: I
Nominal Voltage: 220-240 V ac/ 50 Hz
Stand By Consumption< 0.5 W
Diffuser: Opal
Beam Angle: 110°
UGR<= 25
Flicker Factor: 0 percent
Rated Output: 19.5 W
Luminous Flux: 1850 lm
Luminous Efficacy: 94 lm/W
Color Temperature: 4000 K
Color Rendering Index> 80
Lifetime at 25° C: 40000 h
Integrated Presence Detector With DALI Bus Voltage Supply
Detection Angle: 360°
Field of Detection: 28 $m^2$
Recommended Installation Height: 2.5 m
Level of Brightness: 100-1000 lx
Switch off Delay Time: 60 sec-240 min

**(b) ELSA-2 DL 225 OP 110° 1800 840 PD IR DALI WH :** Technical Specifications are,

(a) ELSA-2 DL 225 OP 110° 1800 840 PD IR PS DALI WH

(b) ELSA-2 DL 225 OP 110° 1800 840 PD IR DALI WH

Device Category: Down light
Warranty: 5 Years
Installation Type: Recessed Mounting
Installation Position: Ceiling
Type of Connection: Push Terminal
Protection Type: IP20
Control System: DALI
Protection Class: I
Nominal Voltage: 220-240 V ac/ 50 Hz
Stand By Consumption< 0.5 W
Diffuser: Opal
Light Emission: Direct
Beam Angle: 110°
UGR <= 25
Flicker Factor: 0 percent
Rated Output: 19 W
Luminous Flux: 1850 lm
Luminous Efficacy: 97 lm/W
Colour Temperature: 4000 K

CRI > 80
Colour Tolerance: 2 SDCM
Lifetime at 25° C: 40000 h
Sensor's Detection Angle: 360°
Field of Detection: 28 $m^2$
Recommended Installation Height: 2.5 m
Level of Brightness: 100-1000 lx
Number of light channels: 1
Function: Switch-Dimming
Switch-off delay time : 60 s - 240 min (adjustable in steps)

**(c) ELSA-2 DL 225 OP 110° 1800 840 DALI WH :** The Technical Details are as follows,

Device Category: Down Light
Installation Type: Recessed Mounting
Installation Position: Ceiling
Type Of Connection: Open-end
Length of Cable: 0.18 m
Protection Type: IP20 / IP44 below the ceiling (built-in)
Control System: DALI
Protection Class: II
Nominal Voltage: 220-240 V ac/50 Hz
Diffuser: Opal
Beam Angle: 110°
UGR<= 25
Rated Output: 19 W
Luminous Flux: 1800 lm
Luminous Efficacy: 94 lm/W
Colour Temperature: 4000 K
CRI > 80
Color Tolerance: 1 SDCM
Lifetime at 25° C: 40000 h
Switch-Dim function

**(d) ELH EL LED 3h SC RM CORRIDOR :** The ELH series provides escape route lighting for single-battery operation with a lens construction that is specially designed for extensive areas — either for oval illumination of floors or circular illumination of large rooms. Its larger-than-average range reduces the number of lights required. The integrated DALI interface ensures high levels of control flexibility during operation and convenient maintenance. The Technical Details are given below,

Device Category: Safety Light
Installation Type: Recessed Mounting
Installation Position: Ceiling
Type of Connection: Push Terminal
Protection Type: IP20
Control System: DALI
Protection Class: II
Nominal Voltage: 230 V ac/50 Hz
Light Emission: Direct
Rated Output: 4 W
Luminous Flux: 155 lm
Luminous Efficacy: 38 lm/W
Color Temperature: 4500 K
CRI> 75
Light Duration: 3 h
Switching Type: Continuous Mode/Standby Mode
Power Supply System: Decentralized(Single Battery)
Status Display: By LED

**(e) ELH FM BATTERY 2000mAh :** This is used as the power supply of safety lights.

Device Category: Battery
Nominal Voltage: 4.8 V

## 4.6 Staircases

Staircases highlight the need for optimal lighting at a very high level: Since only the best possible and dependable light reduces the risk of accidents when going up and down them. Because staircases are only used the most at peak times, constant, bright lighting is not required. Here, a smart lighting approach is given. This solution involves light and automation concepts that fulfil the most demanding requirements for safety standards and reliability while providing efficient control.

(a) ELH EL LED 3h SC RM CORRIDOR

(b) ELH FM BATTERY 2000mAh

Figure 33: Staircase

**(a) ELLEN WCL 300 OP 1600 840 IP20 MD :** Round lights from the ELLEN series with a curved diffuser provide a classic design on the wall, while intelligent sensors remain hidden: An HF motion detector integrated into the luminaire allows energy-efficient operation. The luminaires can be intelligently connected to each other. The Technical Specifications are as follows,

Device Category: Wall and ceiling light
Installation Type: Surface mounting
Installation Position: Ceiling/Wall
Type Of Connection: Push Terminal
Protection Type: IP20

Impact Resistance: IK07
Control System: On/Off
Protection Class: I
Nominal Voltage: 220-240 V ac/50 Hz
Stand By Consumption< 0.5 W
Diffuser: Opal
Beam Angle: 120°
UGR<= 22
Rated Output: 11.5 W
Luminous Flux: 1550 lm
Luminous Efficacy: 134 lm/W
Colour Temperature: 4000 K
CRI> 80
Color Tolerance: 1 SDCM
Lifetime at 25° C: 60000 h
Integrated HF Motion Detector
Zero-Cross Switching
Detection Angle: 360°
Field of Detection: 315 $m^2$
Level of Brightness: 2-50 lx
Switch off Delay Time: 5 sec- 30 min

Figure 34: ELLEN WCL 300 OP 1600 840 IP20 MD

**(b) ELLEN WCL 300 OP 1600 840 IP20 :** The LED lights in the ELLEN series feature a beautiful, timeless design, making them ideal for ceiling or wall mounting in hallways, staircases and function rooms. The optional concealed motion and light sensor technology and high level of luminous efficacy ensure energy-efficient operation on demand. The Technical Details are as follows,

Device Category: Wall and Ceiling Lights
Warranty: 3 Years
Installation Type: Surface Mounting
Installation Position: Ceiling/Wall
Type of Connection: Push Terminal
Protection Type: IP20
Impact Resistance: IK07
Control System: On/Off
Protection Class: I
Nominal Voltage: 220-240 V ac/50 Hz
Stand by Consumption: 0 W
Diffuser: Opal
Light Emission: Direct
Beam Angle: 120°
UGR <= 22
Flicker Factor < 3 percent
Rated Output: 11 W
Luminou Flux: 1550 lm
Luminous Efficacy: 140 lm/W
Colour Temperature: 4000 K
CRI > 80
Colour Tolerance: 1 SDCM
Lifetime at 25° C: 60000 h

## 4.7 Sanitary Facilities

In Sanitary Facilities discretion is equally important as hygiene and cleanliness. Excellent ventilation is an extremely important issue, too. Designing these areas with appropriate and practical light is more than worth mentioning. Round ELSA downlights with soft, homogeneous light emission illuminate the room, while the COMPACT presence detectors switch on the ventilation system as required and control the downlights in an energy efficient manner. By implementing these we can get perfect air combined with optimal lighting. The ELX escape sign luminaire shows the way in case of emergency. Here a solution is provided which is also energy efficient,

Figure 35: Sanitary Facility

**(a) ELSA-2 DL 225 OP 110° 1800 830 WH :** With their minimalist design, ELSA-2 downlights are ideally suited as supplement to main lighting or as a stand-alone solution in conference rooms, hallways, staircases, entrance areas and sanitary facilities. Installation requires no additional accessories and the light ensures a harmonious appearance. The Technical Details are as follows,

Device Category: Down Light
Installation Type: Recessed Mounting
Installation Position: Ceiling
Type of Connection: Open-end
Length of Cable: 0.18 m
Protection Type: IP20/ IP44 below the ceiling (built-in)

Control System: On/Off
Protection Class: II
Nominal Voltage: 220-240 V ac/50 Hz
Diffuser: Opal
Beam Angle: 110°
UGR<= 25
Rated Output: 18 W
Luminous Flux: 1700 lm
Luminous Efficacy: 94 lm/W
Light Emission: Direct
Colour Temperature: 3000 K
Colour Rendering Index> 80
Colour Tolerance: 2 SDCM
Lifetime at 25° C: 40000 h

(a) ELSA-2 DL 225 OP 110° 1800 830 WH

(b) PD-C 360i/8plus

**(b) PD-C 360i/8plus :** The Technical Details are given below,

Device Category: Ceiling-Mounted Presence Detector
Installation Type: Flush Mounting
Installation Position: Ceiling
Type of Connection: Push Terminal

Protection Type: IP20
Control System: On/Off
Protection Class: II
Nominal Voltage: 230 V ac/ 50 Hz
Power Consumption: 0.3 W
Sensor Detection Angle: 360°
Detection range diagonally: $\phi$8 m
Detection range head-on: $\phi$6 m
Detection range presence: $\phi$4 m
Field of Detection: up to 50 $m^2$
Recommended Installation height: 3 m
Level of brightness: 5-2000 lx
Number of light Channels: 1
Maximum Number of Slave Detectors: 10
Mode: Semi automatic/Fully Automatic
Switching Delay From Dark to Light: 300 sec
Switching Delay from Light to Dark: 30 sec

**(c) PD-C 360/8 Slave :** The ceiling or wall detector, whether 230 V, KNX, DALI or DALI-2, whether switching, dimming or HVAC, they ensure a perfect combination of convenience and energy efficiency at all times and offer an innovative solution with touch-sensitive lens surfaces due to the touch detectors. The Technical Specifications are given below,

Device Category: Ceiling Mounted Presence Detector
Installation Type: Flush Mounting
Installation Position: Ceiling
Type of Connection: Push Terminal
Protection Type: IP20
Control System: On/Off
Protection Class: II
Nominal Voltage: 230 V ac/ 50 Hz
Power Consumption: 0.3 W
Sensor Detection Angle: 360°
Detection range diagonally: $\phi$8 m
Detection range head-on: $\phi$6 m
Detection range presence: $\phi$4 m
Field of Detection: up to 50 $m^2$

Recommended Installation Height: 3 m
Switching Delay From Dark to Light: 300 sec
Switching Delay From Light to Dark: 30 sec

(a) PD-C 360/8 Slave

(b) SLX EL LED FLAT COVER 3h 14m IR WM

**(d) SLX EL LED FLAT COVER 3h 14m IR WM :** The SLX series emergency lights provide variable LED solutions for indicating escape routes. In addition to the single-battery variants, versions for systems with central battery operation are also available.The Technical Details are given below,

Device Category: Escape Sign Lights
Warranaty: 5 Years
Installation Type: Surface Mounting
Installation Position: Wall
Type of Connection: Push Terminal
Protection Type: IP54
Control System: On/Off
Protection Class: II
Nominal Voltage: 230 V ac/50 Hz
Light Emission: Direct
Rated Output: 3 W

Viewing Distance: 14 m
Light Duration: 3 h
Switching Type: Continuous Mode/Standby Mode
Power Supply System: Decentralised (single-battery)
Battery: NiCd 3,6 V / 0,8 Ah
Status Display: By LED

## 4.8 Entrances

With the right design, the entrance area of a building alone can convey a warm feeling and perfectly speak the language of the institution. For this type of area, a harmonious lighting mood is just as important as the lighting design. A harmonious concept that also cleverly takes efficiency into account is the key to this. Here a lighting solution is provided. The lighting with ISABELLE pendulum lights, together with ELSA-2 downlights and the intelligent DALI-2 control unit with COMPACT APC presence detector is implemented perfectly to workplace requirements. It provides optimum energy efficiency and creates a prestigious appearance. The lighting is controlled by presence and daylight.

**(a) ISABELLE PDL 1200 DDP TR 8800 840 DALI WH :** The ISABELLE pendant light is an elegant lighting solution for conference rooms, entrance areas and many other locations where an effective combination of style and light quality is important. In case of this type of Pendant Light optional Presence Detector Integrated in the Luminaire Head Ensures Control of Glare-free Direct and Indirect Light as required.The details are given below,

Device Category: Pendant Light
Installation Type: Pendant
Installation position: Ceiling
Protection Type: IP20
Control System: DALI
Protection Class: I
Nominal Voltage: 220-240 V ac/50 Hz
Stand By Consumption: ¡1 W
Diffuser: Transparent
Light Emission: Direct/Indirect

Beam Angle: 80°
UGR<= 19
Flicker Factor < 3 percent
Rated Output: 78 W
Luminous Flux: 8830 lm
Luminous Efficacy: 113 lm/W
Colour Temperature: 4000 K
CRI > 80
Colour Tolerance: 4 SDCM
Life Time at 25° C: 50000 h

**(b) ELSA-2 DL 68 OP 100° 500 840 DALI WH :** The Technical Details are as follows,

Device Category: Down light
Installation Type: Recessed Mounting
Installation Position: Ceiling
Protection Type: IP20/ IP44 Below The Ceiling
Control System: DALI
Protection Class: II
Nominal Voltage: 220-240 V ac/ 50 Hz
Diffuser: Opal
Light Emission: Direct
Beam Angle: 100°
UGR<=30
Flicker Factor: 0 percent
Rated Output: 6.5 W
Luminous Flux: 500 lm
Luminous Efficacy: 76 lm/W
Colour Temperature: 4000 K
CRI > 80
Colour Tolerance: 2 SDCM
Lifetime at 25° C: 40000 h

**(c) PD-C 360/8 BMS DALI-2 :** The Technical Details are as follows,

Device Category: Ceiling-Mounted Presence Detector
Installation Type: Flush Mounting

Installation Position: Ceiling
Type of Connection: Push Terminal
Protection Type: IP20
Control System: DALI-2
Protection Class: II
Nominal Voltage: 9.5 -22.5 V dc
Stand by Consumption< 0.1 W
Detection Angle: 360°
Detection range diagonally: $\phi 8$ m
Detection range head-on: $\phi 6$ m
Detection range presence: $\phi 4$ m
Field of Detection: up to 50 $m^2$
Recommended Installation height: 3 m
Level of Brightness: 5-2000 lx
Push Button Input Lighting: 2

(a) PD-C 360/8 BMS DALI-2

(b) PD-C 360bt/8 APC10 PS plus DALI-2

**(d) PD-C 360bt/8 APC10 PS plus DALI-2 :** This detectors offer individual control of up to 16 groups and 16 scenes and help to implement presence and daylight dependent constant light control. The Details are given below,

Device Category: Ceiling Mounted Presence Detector
Installation Type: Recessed Mounting
Installation Position: Ceiling
Type of Connection: Push Terminal
Protection Type: IP20
Control System: DALI-2
Nominal Voltage: 230 V ac/ 50 Hz
Output Voltage: 16 V dc
Power Consumption: 5 W
Stand by Consumption$<$ 0.4 W
Detection Angle: 360°
Detection range diagonally: $\phi$8 m
Detection range head-on: $\phi$6 m
Detection range presence: $\phi$4 m
Field of Detection: up to 50 $m^2$
Recommended Installation Height: 3 m
Level of Brightness: 5-2000 lx
Number of Light Groups: 16
Push Button Input Lighting: 4
Mode: Semi-automatic, Fully automatic
Fuctions: Regulate, Control, Dimming, Switching

## 4.9 Seminar Rooms

Seminar room is an important part of an educational institution. Large and important presentations are presented here. So, use of projectors is important for this room. That's why the control of lighting has to be very smooth in this type of room. Here we are suggesting a solution,

**CELINE PNL 600 DDP TR 4200 8TW IP20 ELC :** The LED recessed lights in the CELINE series provide energy-efficient lighting in offices, conference rooms and other areas. They are designed for suspended system ceilings, but are also suitable for other installation types with suitable accessories and are also impressive as special designs in intelligent lighting systems due to their high light quality. The Technical Specifications are given below,

Device Category: Recessed Light
Installation Type: Insert

Figure 39: Seminar Room

Installation position: Ceiling
Connector: RJ45
Protection Type: IP20
Control System: ELC
Protection Class: III
Nominal Voltage: 42 V dc
Diffuser: Transparent
Light Emission: Direct
Beam Angle: 90°
UGR<= 19
Rated Output: 32 W
Luminous Flux: 4160 lm
Luminous Efficacy: 130 lm/W
Colour Temperature: 2700-6500 K(Tunable White)
CRI> 80
Colour Tolerance: 6 SDCM
Lifetime at 25° C: 70000 h

Apart from this we can also use the fixture ELSA-2 SERIES DL 68 OP 100° 500 840 DALI WH as a different option. We have to use PD-C 360i/8 ELC, SMARTDRIVER ELC, Push Button TW ELC, Actuator Full Auto C3 DALI, all of which are discussed previously.

## 4.10 Laboratories

Different types of scientific experiments are performed in the laboratories. We can also categorize laboratories depending on which type of experiments are performed there. And after this we can do our lighting designs based on different categories. The lighting design should be top notch in this area because if concentration is faltered even for a small period many large accidents can occur. Here, a energy efficient lighting system is described,

Figure 40: Laboratory

**CELINE-2 PLN 600 DDP OP 3800 8TW IP20 ELC :** It is Suitable For Lighting Systems With ELC and via optional Lead Sets, also for Use in DALI Lighting Systems. Versions with Tunable White allow the use of Energy-Efficient Human Centric Lighting with SymbiLogic Technology with ELC lighting systems or ESYLUX DALI-2 presence detectors. The Technical Specifications are given below,

Device category: Ceiling Recessed Luminaire
Connection Type: Connector
Connector: RJ45
Degree of Protection: IP20
Impact Resistance: IK02

Control System: ELC
Protection Class: III
Rated Voltage: 42 V dc
Power Consumption: 33 W
Diffuser: Opal
Light Distribution: Direct
Beam Angle: 94°
UGR$<$ 19
Luminous Flux: 4000 lm
Luminous Efficacy: 121 lm/W
Color Temperature: 2700-6500 K (Tunable White)
CRI$>$ 80
Color Tolerance: 2 SDCM
Lifetime at 25° C: 70000 h

Also, Smart Driver TW ELC, Cable-Set RJ45 5m TW, PD-C 360i/8 ELC, Push-Button TW ELC are to be used to make the lighting system smart.

## 4.11 Auditorium

Big events such as Convocation, Annual Award ceremony, Cultural Programmes etc. take place in the Auditorium. Usually, it is a very large space with huge seating capacity. So, the lighting system need to be dynamic for different types of lighting requirement (Colours as well as lighting level) depending on the event happening on the stage. In auditorium lighting we need to focus on artificial lights more than natural light, because auditoriums usually require a certain level of low lighting.

A good rule of thumb is to have three zones of lighting for an auditorium. The first one would be the board lights that project towards a screen on the stage if needed. The second layer would be presenter lights which shed illumination on the event or presentation happening on the stage. And the third layer is the audience lighting. Each layer has its own considerations but the overall goal is to make everything more visible without straining the eyes of the audience. Here a smart solution is provided for a small auditorium ,

**(a) STELLA PNL 600 DDP OP 3800 840 IP20 DALI :** With their low profile design, LED recessed lights in the STELLA series are well-

Figure 41: Auditorium

suited to flexible applications in large offices, Auditorium and healthcare facilities. They fulfil all requirements of contemporary light installations in terms of their straightforward handling, light quality and energy efficiency. The Technical Details are as follows,

Device Category: Recessed Light
Installation Type: Insert
Installation Position: Ceiling
Type Of Connection: Push Terminal
Protection Type: IP20
Control System: DALI
Protection Class: II
Nominal Voltage: 110-240 V ac/ 50 Hz
Diffuser: Opal
Light Emission: Direct
Beam Angle: 116°
UGR<= 19
Flicker Factor< 3 percent

Rated Output: 37 W
Luminous Flux: 3800 lm
Luminous Efficacy: 102 lm/W
Colour Temperature: 4200 K
CRI> 80
Colour Tolerance: 5 SDCM
Life time at 25° C: 40000 h

Apart from this we can also choose ISABELLE SERIES FSL U-BASE DDP TR 6300 840 PD IR WH, ISABELLE PDL 1200 DDP TR 8800 840 PD IR DALI WH as different options or we csn use combination of the above mentioned lighting fixtures. Though Lighting Control is not that much important in this area, but we will still discuss the presence and motion detector.

**(b) PD-C 360bt/8 APC10 PS plus DALI-2 :** This allows individual control of up to 16 groups and 16 scenes.The details are given below,

Device Category: Ceiling Mounted Presence Detector
Installation Type: Recessed Mounting
Installation Position: Ceiling
Type of Connection: Push Terminal
Protection Type: IP20
Control System: DALI-2
Nominal Voltage: 230 V ac/ 50 Hz
Output Voltage: 16 V dc
Power Consumption: 5 W
Stand-by Consumption $<$ 0.4 W
Detection Angle: 360°
Detection Range Diagonally: $\phi$8 m
Detection Range Head on: $\phi$6 m
Detection Range Presence: $\phi$4 m
Field of Detection: Up to 50 $m^2$
Recommended Installation Height: 3 m
Level Of brightness: 5 - 2000 lx
Number of Light Groups: 16
Push Button Input Lighting: 4
Mode: Semi-Automatic, Fully-Automatic
Function: Regulate, Control, Dimming, Switching

## 4.12 Interconnections Between the Equipments

From the above discussion we can get the overview of the components that we require for the implementation of the smart lighting system. Now, questions may arise that how can one implement it and if it will require a huge amount for installing smart system in a existing institution. These questions will be answered in this part of the discussion. Here, mainly we will focus on how to assemble the previously mentioned components so that we can get our desired outcomes. For simplicity, we are only discussing the connection procedures of the equipments for classroom and it will be applicable for all the areas where we intend to implement smart lighting. The components that are to connected are luminaires, smart drivers, presence detectors, actuators etc. And the connection should be done with the help of RJ45 cable.

For the ease of discussion we have divided the whole connection in two parts. These two parts are,

(1) Connection between Smart Driver, Luminaire and Presence Detector.

(2) Connection between Actuator and Presence Detector.

These are discussed below,

**Smart Driver, Luminaire and Presence Detector :** Recessed Surface Mounted Ceiling Light (CELINE, ISABELLE etc.) can simply be placed in the Ceiling System. The Sensors (PD-C360i/8 Duo DALI, PD-C360i/24 Duo DALI etc.) i.e. Presence Detectors are placed accordingly so that it can have clear view of the presence of people. Genrally this are placed in the corner or in the middle of the room at ceiling height. The recommended mounting height have also been mentioned in the previous part. These Presence Detectors will be connected to Sensor Interface.

If we want to combine multiple smart driver there are two possibilities,

(a)Connecting via DALI C0 Interface
(b) Connecting via ELC Bus.

In case of C0 interfacing, all connected lights form a lighting group i.e. light target value, switch off delay time, DALI button command and triggering of presence detector are applied to all lights. Therefore it is not ideal for some room configurations.

In case of ELC Bus interfacing different lighting groups can be connected through the ELC bus, so the illuminance of each group is controlled individually. When a lighting group detects the presence of a person and switches on the group's light, the other lighting group switch to the harmonious and energy efficient orientation light mode. Refering to the above

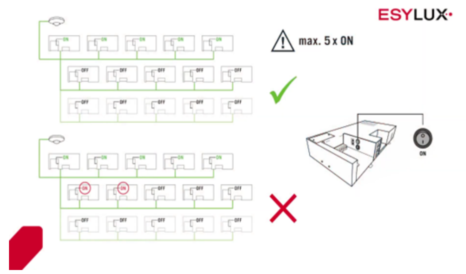
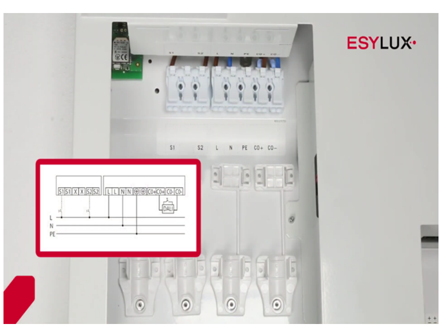



Figure 42: Smart Driver

figure, the Lower switch (i.e. Black on/off switch) must be set to on if only one ELC bus cable is inserted for proper operation.

If several smart drivers are connected to each other via C0 interface, only a maximum of 5 smart drivers may have an active DALI power supply. DALI devices including DALI switches can be connected via DALI interfaces C1 and C2. Up to 25 DALI devices can be connected per channel. The figures showing the smart driver is given below,



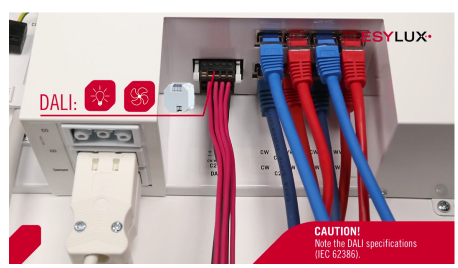



Figure 43: Connection of Smart-Driver

**Connection between Actuator and Presence Detector :** PD-C360i/8 Duo DALI has a detection Range of 8 m at recommended installation height of 2.5-3 m. and PD-C360i/24 Duo DALI has a detection range of 24 m. The detector has 2 channels(expandable to 4). These are,

(a) C1: Channel 1 of the detector is used for detection in the dark side of the room.

(b) C2: Channel 2 is responsible for detection in the bright side of the room/ window area. Settings for switch of delay time, operating mode, light level value(lux) can be configured through C1 and C2. DALI plus switches can be used to expand the circuit by 2 channels,

(a) C3 : SW DALI Full Automation.
(b) C4 : SW DALI Semi Automation.

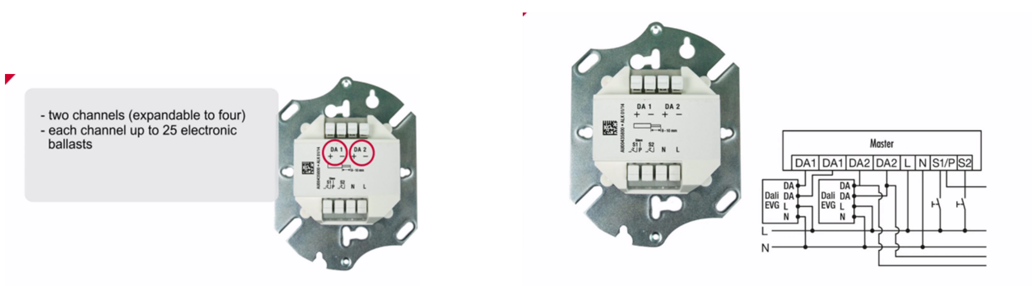



Figure 44: Presence Detector

Buttons for relevant terminals can be connected in 2 terminals i.e. S1 and S2. We can also connect Slave Devices to S1 to extend detection area. Maximum 10 slave devices can be connected to one Master device. Detector is equipped with its own DALI voltage supply (DA1 bus terminal of channel 1 and DA2 bus terminal of channel 2.

In Classroom we have to use Semi Automatic mode. Similarly we have to choose the mode according to the requirement of different areas. The figure depicting it is shown below,

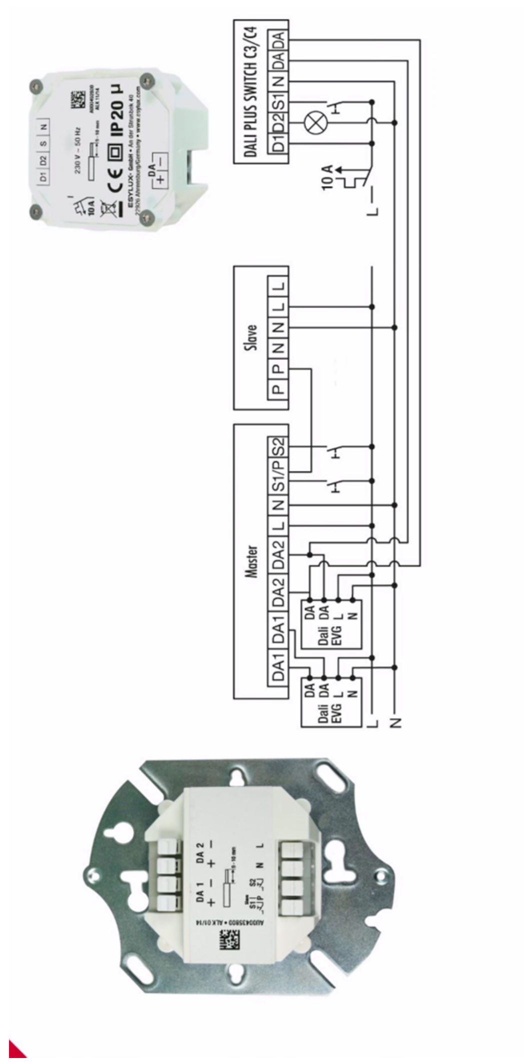


Figure 45: Connection Between Actuator and Presence Detector

**Chpater 5**

# 5 Overall Discussion and Conclusion

## 5.1 Discussion

Nowadays, smart lighting systems are gaining popularity and are successful due to their ease of use through automatic control, visual comfort, low carbon footprints and low energy consumption. LEDs, with their ability to produce tunable light spectrums, present a significant opportunity to improve on existing lighting systems. They can be applied to smart and specialized lighting, which can be highly beneficial in the residential, commercial and industrial sectors. The development of the Internet of things has promoted smart lighting coming into our lives. Solid-State Lighting (SSL) is one of the best choices for realizing smart lighting system due to its advantages such as low power consumption and long lifetime. Internet Of Things is known for Global network in the cloud which connects various things through sensors. The IoT is a system that connects various devices which are intelligently communicates with other objects, machines, infrastructures and also environments. The use of IoT for universities or any educational institutions can be highly beneficial due to its capability to be flexible and accessible anywhere. In this study a solution is provided for smart lighting system which is a significant step towards implementing Smart Campuses. Smart campus brings in new experiences like location based and context – aware services, smart parking, smart lighting, smart transits and smart building climate control. It also increases safety and security within the campus with connected surveillance cameras, smart locks, asset tracking and smart emergency services. It enables tracking of the facilities / resources and use them more efficiently. This helps in reducing the cost by the intelligent use of water, electricity and building controls. Innovative learning environment in a smart campus enhances the learning outcomes and the campus experience. It also improves the higher education facilities and operational efficiencies. Moreover, conserving electricity and reducing carbon footprint results in a greener smart campus. In this study we can notice that the lights can be controlled from a remote network by accessing mobile application. Automation with the use of a PIR sensor helped in preventing the lights from being left turned ON if a certain area had no occupants in the set schedule. The overall design is slick, compact, durable, and lightweight.

We know that, determination of spectral properties of smart light sources and their impact on the human body requires the measurement of their spectral characteristics, not the determination of only selected indicators like $T_a$ (Colour Temperature) and $R_a$ (Colour Rendering Index).

## 5.2 Conclusion

Previous studies have found the effects of environment lighting on human circadian rhythm, subject comfort, attention, and cognitive performance. The recent development on smart LED lighting systems provides new ways to control the brightness and color temperature of environment lighting in classrooms dynamically. However, there is no existing knowledge about how to optimize the lighting for different classroom activities, and it is still a question whether the new environment lighting system could improve student performance. This study proposed a case study on how the administration of an educational institution can make the lighting of their institution smart so that they can provide comfort, satisfaction and a great learning environment for their students and faculties. This study is also enriched with the knowledge regarding how to implement smart lighting system in educational institution. This study introduced in detail the system design, hardware as well as the implementation of the system in a project as the form of a case study.

# 6 Future Aspects of this Work

Based on this study, there are many topics that need further research in both engineering and human factors domains. These are mentioned below,

Some of the discussed equipments can control lighting as well as HVAC system. But to achieve full automation we need to be able to control the curtains, fans etc through the same system. This is not only to make the system more in line with the actual needs of the users, but also to provide technical support for comprehensive environmental factors research.

Although the different sensors are discussed, but their positioning (installation location) and sensor data calibration have not been discussed here.

We have just suggested the components for installation of smart lighting, but the results after implementing it in real life has not been done. So, the performance of the system in energy saving has not been evaluated in this study. Follow up needs to be supplemented.

Students' individual characteristics, such as age, gender, regional and cultural differences, may have different responses to the proposed lighting system. It is also worth to investigate into this.

In this study, we have seen that the smart drivers are already programmed, we just have to buy these and install it as mentioned in subsequent section. A software of a complete learning-context based lighting control system can be an improvement over these drivers.

Further improvements are still possible through the application of machine learning and AI concepts, less reliance on the sensor and more on the patterns generated from the day to day activity can be used for future improvements in automating the operation of the lights.

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# 8 Annexures

In this study, some designs have been done using DIALux and AutoCAD softwares.The result of classroom design has been given in Chapter 3. The detailed results from those designs (classroom, office room, toilet) are given in this section.

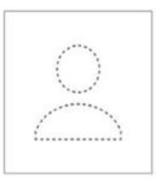
**Date** 25-05-2022

## Classroom

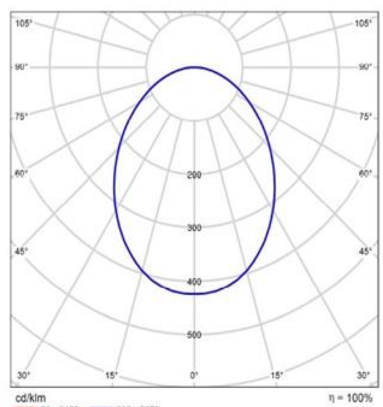
Classroom

# Product data sheet

Not yet a DIALux member - Recess mounted LED Downlighter



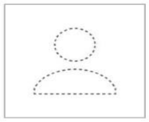
| | |
|---|---|
| Article No. | LD90-191-XXX-65-XX |
| P | 14.6 W |
| $\Phi_{Lamp}$ | 1427 lm |
| $\Phi_{Luminaire}$ | 1427 lm |
| η | 100.00 % |
| Luminous efficacy | 97.8 lm/W |
| CCT | 3000 K |
| CRI | 100 |



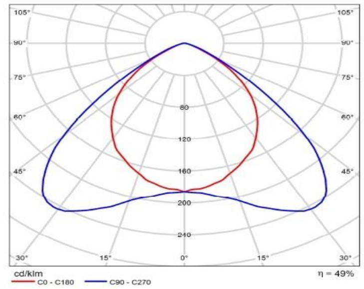

Polar LDC

## Product data sheet

Not yet a DIALux member - TBS285/236;MIRROR-M5,HF



| | |
|---|---|
| P | 72.4 W |
| $\Phi_{Lamp}$ | 6500 lm |
| $\Phi_{Luminaire}$ | 3201 lm |
| η | 49.25 % |
| Luminous efficacy | 44.2 lm/W |
| CCT | 3000 K |
| CRI | 100 |




Polar LDC

**Glare evaluation according to UGR**

| ρ Ceiling | | 70 | 70 | 50 | 50 | 30 | 70 | 70 | 50 | 50 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ρ Walls | | 50 | 30 | 50 | 30 | 30 | 50 | 30 | 50 | 30 | 30 |
| ρ Floor | | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Room size X | Y | Viewing direction at right angles to lamp axis | | | | | Viewing direction parallel to lamp axis | | | | |
| 2H | 2H | 15.7 | 16.9 | 16.0 | 17.1 | 17.4 | 16.9 | 18.1 | 17.2 | 18.3 | 18.6 |
| | 3H | 15.7 | 16.8 | 16.1 | 17.0 | 17.3 | 16.9 | 18.0 | 17.3 | 18.2 | 18.5 |
| | 4H | 15.7 | 16.7 | 16.0 | 17.0 | 17.2 | 16.9 | 17.9 | 17.2 | 18.1 | 18.4 |
| | 6H | 15.6 | 16.6 | 16.0 | 16.9 | 17.2 | 16.8 | 17.7 | 17.2 | 18.0 | 18.3 |
| | 8H | 15.6 | 16.5 | 16.0 | 16.8 | 17.1 | 16.8 | 17.7 | 17.2 | 18.0 | 18.3 |
| | 12H | 15.6 | 16.4 | 15.9 | 16.7 | 17.1 | 16.8 | 17.6 | 17.1 | 17.9 | 18.2 |
| 4H | 2H | 15.9 | 16.9 | 16.2 | 17.2 | 17.4 | 17.0 | 18.0 | 17.3 | 18.3 | 18.5 |
| | 3H | 16.0 | 16.8 | 16.3 | 17.1 | 17.4 | 17.0 | 17.9 | 17.4 | 18.2 | 18.5 |
| | 4H | 16.0 | 16.7 | 16.3 | 17.0 | 17.4 | 17.0 | 17.7 | 17.4 | 18.1 | 18.5 |
| | 6H | 15.9 | 16.5 | 16.3 | 16.9 | 17.3 | 17.0 | 17.6 | 17.4 | 18.0 | 18.4 |
| | 8H | 15.9 | 16.5 | 16.3 | 16.9 | 17.3 | 16.9 | 17.5 | 17.4 | 17.9 | 18.3 |
| | 12H | 15.9 | 16.4 | 16.3 | 16.8 | 17.2 | 16.9 | 17.4 | 17.3 | 17.9 | 18.3 |
| 8H | 4H | 15.9 | 16.5 | 16.3 | 16.9 | 17.3 | 16.9 | 17.5 | 17.4 | 17.9 | 18.3 |
| | 6H | 15.8 | 16.3 | 16.3 | 16.7 | 17.2 | 16.9 | 17.4 | 17.3 | 17.8 | 18.2 |
| | 8H | 15.8 | 16.3 | 16.3 | 16.7 | 17.2 | 16.9 | 17.3 | 17.3 | 17.7 | 18.2 |
| | 12H | 15.8 | 16.2 | 16.3 | 16.6 | 17.1 | 16.8 | 17.2 | 17.3 | 17.7 | 18.2 |
| 12H | 4H | 15.8 | 16.4 | 16.3 | 16.8 | 17.2 | 16.9 | 17.4 | 17.3 | 17.8 | 18.3 |
| | 6H | 15.8 | 16.2 | 16.3 | 16.7 | 17.2 | 16.8 | 17.3 | 17.3 | 17.7 | 18.2 |
| | 8H | 15.8 | 16.2 | 16.3 | 16.6 | 17.1 | 16.8 | 17.2 | 17.3 | 17.7 | 18.2 |
| Variation of the observer position for the luminaire distances S | | | | | | | | | | | |
| S = 1.0H | | +0.7 / -1.2 | | | | | +0.9 / -1.5 | | | | |
| S = 1.5H | | +2.1 / -4.4 | | | | | +2.2 / -4.7 | | | | |
| S = 2.0H | | +2.6 / -7.0 | | | | | +3.8 / -7.0 | | | | |
| Standard table | | BK01 | | | | | BK01 | | | | |
| Correction Summand | | -4.4 | | | | | -3.3 | | | | |
| Corrected glare indices referring to 6500lm Total luminous flux | | | | | | | | | | | |

UGR diagram (SHR: 0.25)



Building 1 · Story 1

## Luminaire list

| $\Phi_{total}$ | $P_{total}$ | Luminous efficacy |
|---|---|---|
| 22060 lm | 463.6 W | 47.6 lm/W |

| pcs. | Manufacturer | Article No. | Article name | P | Φ | Luminous efficacy |
|---|---|---|---|---|---|---|
| 6 | Not yet a DIALux member | | TBS285/236;MIRROR-M5,HF | 72.4 W | 3201 lm | 44.2 lm/W |
| 2 | Not yet a DIALux member | LD90-191-XXX-65-XX | Recess mounted LED Downlighter | 14.6 W | 1427 lm | 97.8 lm/W |

Building 1 · Story 1 (Light scene 1)

## Room List

### Classroom

| $P_{total}$ | $A_{Room}$ | Lighting power density | $\bar{E}_{perpendicular (Working plane)}$ |
|---|---|---|---|
| 463.6 W | 48.00 m² | 9.66 W/m² = 2.91 W/m²/100 lx (Room) | 332 lx |

| pcs. | Manufacturer | Article No. | Article name | P | $\Phi_{Luminaire}$ |
|---|---|---|---|---|---|
| 6 | Not yet a DIALux member | | TBS285/236;MIRROR-M5,HF | 72.4 W | 3201 lm |
| 2 | Not yet a DIALux member | LD90-191-XXX-65-XX | Recess mounted LED Downlighter | 14.6 W | 1427 lm |



Building 1 · Story 1 (Light scene 1)

## Calculation objects

### Working planes

| Properties | $\bar{E}$ (Target) | $E_{min}$ | $E_{max}$ | $g_1$ | $g_2$ | Index |
|---|---|---|---|---|---|---|
| Working plane (Classroom)<br>Perpendicular illuminance (adaptive)<br>Height: 0.800 m, Wall zone: 0.000 m | 332 lx<br>(≥ 300 lx)<br>✓ | 48.4 lx | 469 lx | 0.15 | 0.10 | WP1 |

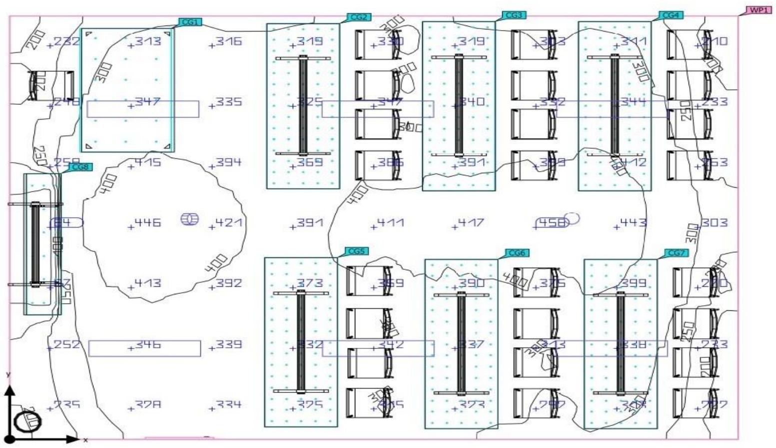
### Calculation surfaces

| Properties | $\bar{E}$ | $E_{min}$ | $E_{max}$ | $g_1$ | $g_2$ | Index |
|---|---|---|---|---|---|---|
| Calculation surface 1<br>Perpendicular illuminance<br>Height: 0.720 m | 322 lx | 273 lx | 375 lx | 0.85 | 0.73 | CG1 |
| Calculation surface 2<br>Perpendicular illuminance<br>Height: 0.750 m | 337 lx | 300 lx | 391 lx | 0.89 | 0.77 | CG2 |
| Calculation surface 4<br>Perpendicular illuminance<br>Height: 0.750 m | 345 lx | 298 lx | 412 lx | 0.86 | 0.72 | CG3 |
| Calculation surface 6<br>Perpendicular illuminance<br>Height: 0.750 m | 344 lx | 274 lx | 442 lx | 0.80 | 0.62 | CG4 |
| Calculation surface 7<br>Perpendicular illuminance<br>Height: 0.750 m | 345 lx | 310 lx | 397 lx | 0.90 | 0.78 | CG5 |
| Calculation surface 8<br>Perpendicular illuminance<br>Height: 0.750 m | 348 lx | 302 lx | 413 lx | 0.87 | 0.73 | CG6 |
| Calculation surface 9<br>Perpendicular illuminance<br>Height: 0.750 m | 339 lx | 276 lx | 434 lx | 0.81 | 0.64 | CG7 |
| Calculation surface 14<br>Perpendicular illuminance<br>Height: 1.376 m | 301 lx | 255 lx | 325 lx | 0.85 | 0.78 | CG8 |

DIALux

Building 1 · Story 1 · Classroom (Light scene 1)

**Summary**



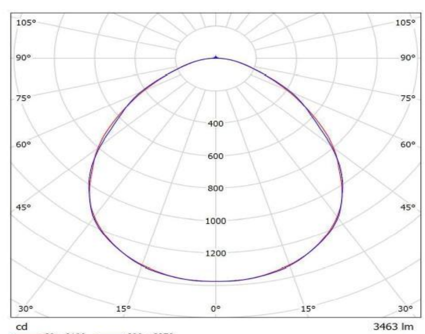


Operator
Telephone
Fax
e-Mail

## ESYLUX eq10110481 PNLCLA10030830WHP01-10LC / Luminaire Data Sheet

See our luminaire catalog for an image of the luminaire.

Luminous emittance 1:




Luminaire classification according to CIE: 99
CIE flux code: 54 85 97 99 100

Luminous emittance 1:

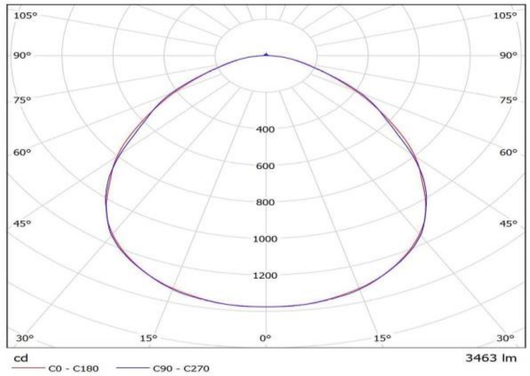
**Glare Evaluation According to UGR**

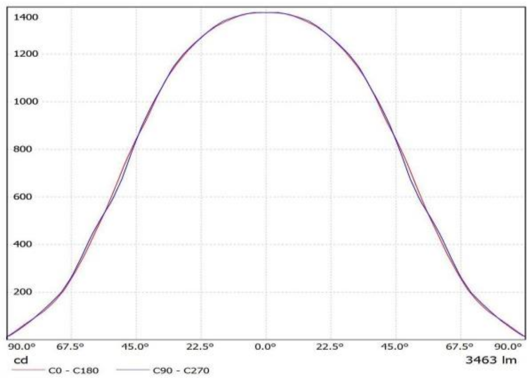
| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ρ Ceiling | | 70 | 70 | 50 | 50 | 30 | 70 | 70 | 50 | 50 | 30 |
| ρ Walls | | 50 | 30 | 50 | 30 | 30 | 50 | 30 | 50 | 30 | 30 |
| ρ Floor | | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Room Size X | Y | Viewing direction at right angles to lamp axis | | | | | Viewing direction parallel to lamp axis | | | | |
| 2H | 2H | 16.8 | 18.0 | 17.1 | 18.3 | 18.5 | 16.8 | 18.1 | 17.1 | 18.3 | 18.5 |
| | 3H | 17.7 | 18.8 | 18.0 | 19.1 | 19.4 | 17.8 | 18.9 | 18.1 | 19.2 | 19.4 |
| | 4H | 18.1 | 19.1 | 18.4 | 19.4 | 19.7 | 18.1 | 19.2 | 18.5 | 19.5 | 19.8 |
| | 6H | 18.4 | 19.3 | 18.7 | 19.6 | 20.0 | 18.5 | 19.4 | 18.8 | 19.7 | 20.1 |
| | 8H | 18.5 | 19.4 | 18.9 | 19.7 | 20.1 | 18.6 | 19.5 | 19.0 | 19.8 | 20.2 |
| | 12H | 18.6 | 19.5 | 19.0 | 19.8 | 20.2 | 18.7 | 19.5 | 19.1 | 19.9 | 20.2 |
| 4H | 2H | 17.3 | 18.3 | 17.6 | 18.6 | 18.9 | 17.3 | 18.3 | 17.6 | 18.6 | 18.9 |
| | 3H | 18.3 | 19.2 | 18.7 | 19.6 | 19.9 | 18.4 | 19.3 | 18.8 | 19.6 | 20.0 |
| | 4H | 18.8 | 19.6 | 19.2 | 19.9 | 20.3 | 18.9 | 19.7 | 19.3 | 20.0 | 20.4 |
| | 6H | 19.2 | 19.9 | 19.7 | 20.3 | 20.7 | 19.3 | 20.0 | 19.8 | 20.4 | 20.8 |
| | 8H | 19.4 | 20.0 | 19.9 | 20.5 | 20.9 | 19.5 | 20.1 | 20.0 | 20.5 | 21.0 |
| | 12H | 19.6 | 20.2 | 20.1 | 20.6 | 21.0 | 19.7 | 20.2 | 20.1 | 20.6 | 21.1 |
| 8H | 4H | 19.0 | 19.6 | 19.4 | 20.0 | 20.5 | 19.1 | 19.7 | 19.5 | 20.1 | 20.5 |
| | 6H | 19.6 | 20.1 | 20.0 | 20.5 | 21.0 | 19.7 | 20.2 | 20.1 | 20.6 | 21.1 |
| | 8H | 19.9 | 20.3 | 20.3 | 20.8 | 21.3 | 19.9 | 20.4 | 20.4 | 20.8 | 21.3 |
| | 12H | 20.1 | 20.5 | 20.6 | 21.0 | 21.5 | 20.2 | 20.5 | 20.7 | 21.0 | 21.5 |
| 12H | 4H | 19.0 | 19.6 | 19.5 | 20.0 | 20.4 | 19.1 | 19.6 | 19.6 | 20.1 | 20.5 |
| | 6H | 19.6 | 20.1 | 20.1 | 20.5 | 21.0 | 19.7 | 20.1 | 20.2 | 20.6 | 21.1 |
| | 8H | 19.9 | 20.3 | 20.5 | 20.8 | 21.3 | 20.0 | 20.4 | 20.5 | 20.9 | 21.4 |
| Variation of the observer position for the luminaire distances S | | | | | | | | | | | |
| S = 1.0H | | +0.2 / -0.2 | | | | | +0.2 / -0.2 | | | | |
| S = 1.5H | | +0.4 / -0.7 | | | | | +0.3 / -0.6 | | | | |
| S = 2.0H | | +0.8 / -1.2 | | | | | +0.7 / -1.2 | | | | |
| Standard table | | BK04 | | | | | BK04 | | | | |
| Correction Summand | | 2.2 | | | | | 2.2 | | | | |
| Corrected Glare Indices referring to 3463lm Total Luminous Flux | | | | | | | | | | | |

## ESYLUX eq10110481 PNLCLA10030830WHP01-10LC / LDC Data Sheet

Luminaire: ESYLUX eq10110481 PNLCLA10030830WHP01-10LC

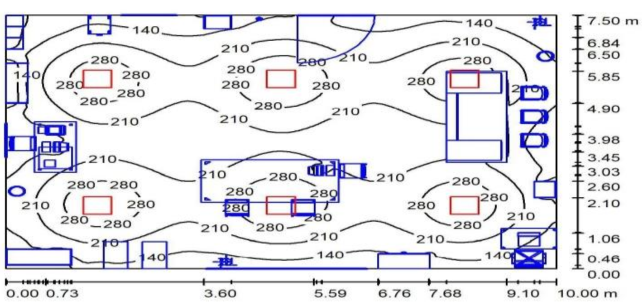
Lamps: 1 x LED3K 33W 3271lm






## Room 1 / Summary




Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80 — Values in Lux, Scale 1:97

| Surface | ρ [%] | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|---|---|
| Workplane | / | 205 | 13 | 343 | 0.061 |
| Floor | 20 | 143 | 7.83 | 223 | 0.055 |
| Ceiling | 80 | 40 | 26 | 50 | 0.661 |
| Walls (4) | 50 | 72 | 8.99 | 137 | / |

**Workplane:**
Height: 1.000 m
Grid: 128 x 128 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.351, Ceiling / Working Plane: 0.193.

**Luminaire Parts List**

| No. | Pieces | Designation (Correction Factor) | Φ (Luminaire) [lm] | Φ (Lamps) [lm] | P [W] |
|---|---|---|---|---|---|
| 1 | 6 | ESYLUX eq10110481 PNLCLA10030830WHP01-10LC (1.000) | 3463 | 3463 | 33.0 |
| | | | Total: 20781 | Total: 20781 | 198.0 |

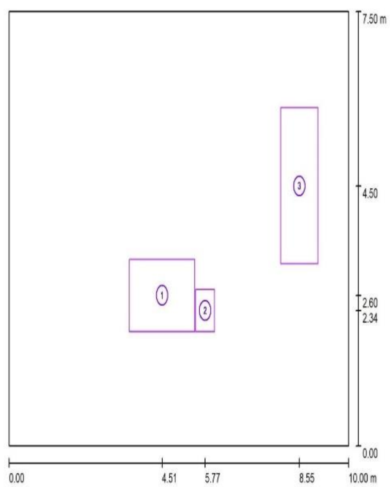
Specific connected load: 2.64 W/m² = 1.29 W/m²/100 lx (Ground area: 75.00 m²)

Project 1

DIALux
01.08.2022

Operator
Telephone
Fax
e-Mail

## Room 1 / Calculation Grid (Coordinates List)




Scale 1 : 72

### List of the Calculation Grids

| No. | Designation | Position [m] X | Y | Z | Size [m] L | W | Rotation [°] X | Y | Z |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Calculation Grid 2 | 4.512 | 2.600 | 0.719 | 1.925 | 1.250 | 0.0 | 0.0 | 0.0 |
| 2 | Calculation Grid 3 | 5.775 | 2.337 | 0.719 | 0.551 | 0.725 | 0.0 | 0.0 | 0.0 |
| 3 | Calculation Grid 4 | 8.550 | 4.500 | 1.000 | 1.100 | 2.700 | 0.0 | 0.0 | 0.0 |

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01.08.2022

Operator
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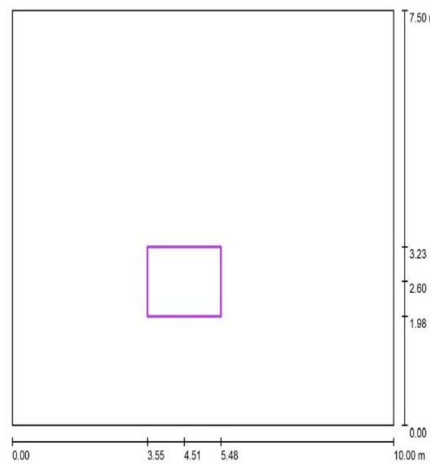
Fax
e-Mail

## Room 1 / Calculation Grid 2 / Summary




Scale 1 : 72

Position: (4.512 m, 2.600 m, 0.719 m)
Size: (1.925 m, 1.250 m)
Rotation: (0.0°, 0.0°, 0.0°)
Type: Normal, Grid: 7 x 5 Points

### Results overview

| No. | Type | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 | $E_{min}$ / $E_{max}$ | $E_{h\,m}/E_m$ | H [m] | Camera |
|---|---|---|---|---|---|---|---|---|---|
| 1 | perpendicular | 245 | 200 | 288 | 0.81 | 0.69 | / | 0.000 | / |

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

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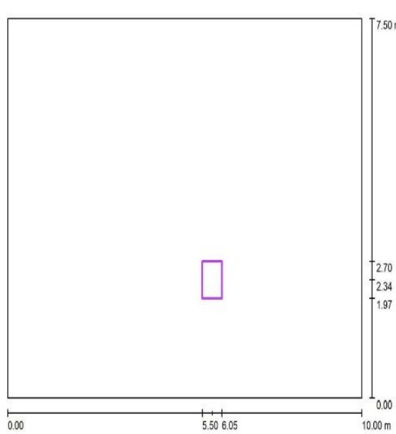
## Room 1 / Calculation Grid 3 / Summary




Scale 1 : 72

Position: (5.775 m, 2.337 m, 0.719 m)
Size: (0.551 m, 0.725 m)
Rotation: (0.0°, 0.0°, 0.0°)
Type: Normal, Grid: 3 x 5 Points

### Results overview

| No. | Type | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 | $E_{min}$ / $E_{max}$ | $E_{h\,m}/E_m$ | H [m] | Camera |
|---|---|---|---|---|---|---|---|---|---|
| 1 | perpendicular | 247 | 222 | 271 | 0.90 | 0.82 | / | 0.000 | / |

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

Project 1

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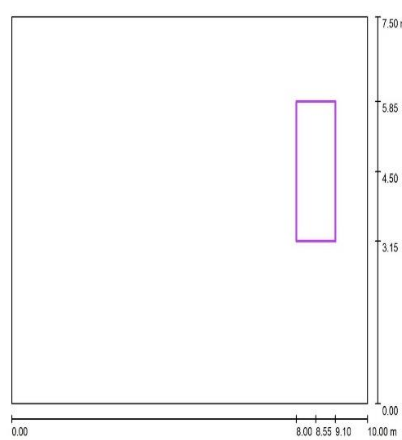
## Room 1 / Calculation Grid 4 / Summary



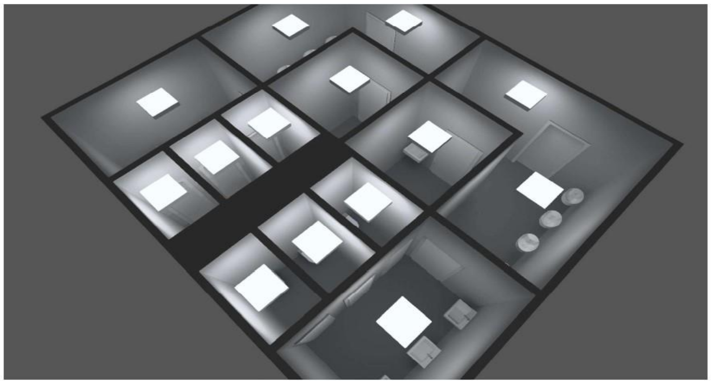

Scale 1 : 72

Position: (8.550 m, 4.500 m, 1.000 m)
Size: (1.100 m, 2.700 m)
Rotation: (0.0°, 0.0°, 0.0°)
Type: Normal, Grid: 3 x 7 Points

### Results overview

| No. | Type | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 | $E_{min}$ / $E_{max}$ | $E_{h\,m}/E_m$ | H [m] | Camera |
|---|---|---|---|---|---|---|---|---|---|
| 1 | perpendicular | 239 | 170 | 329 | 0.71 | 0.52 | / | 0.000 | / |

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height



## Toilet



## Luminaire list

| $\Phi_{total}$ | $P_{total}$ | Luminous efficacy |
|---|---|---|
| 45150 lm | 462.0 W | 97.7 lm/W |

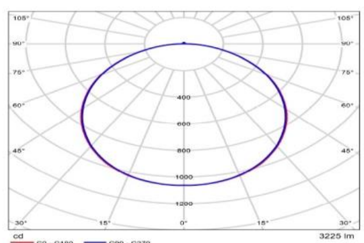
| pcs. | Manufacturer | Article No. | Article name | P | Φ | Luminous efficacy |
|---|---|---|---|---|---|---|
| 14 | ESYLUX | eq1011125 9 | PNLCLA10030840WHO0DALILC | 33.0 W | 3225 lm | 97.7 lm/W |



## Product data sheet

ESYLUX - PNLCLA10030840WHO0DALILC

| | |
|---|---|
| Article No. | eq10111259 |
| P | 33.0 W |
| $\Phi_{Luminaire}$ | 3225 lm |
| Luminous efficacy | 97.7 lm/W |
| CCT | 3000 K |
| CRI | 100 |




Polar LDC

**Glare evaluation according to UGR**

| | | 70 | 70 | 50 | 50 | 30 | 70 | 70 | 50 | 50 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ρ Ceiling | | 70 | 70 | 50 | 50 | 30 | 70 | 70 | 50 | 50 | 30 |
| ρ Walls | | 50 | 30 | 50 | 30 | 30 | 50 | 30 | 50 | 30 | 30 |
| ρ Floor | | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Room size X | Y | Viewing direction at right angles to lamp axis | | | | | Viewing direction parallel to lamp axis | | | | |
| 2H | 2H | 17.2 | 18.6 | 17.5 | 18.9 | 19.1 | 17.2 | 18.6 | 17.5 | 18.8 | 19.1 |
| | 3H | 18.9 | 20.1 | 19.2 | 20.4 | 20.7 | 18.8 | 20.1 | 19.2 | 20.4 | 20.7 |
| | 4H | 19.6 | 20.8 | 20.0 | 21.1 | 21.4 | 19.6 | 20.7 | 19.9 | 21.0 | 21.4 |
| | 6H | 20.2 | 21.3 | 20.5 | 21.6 | 21.9 | 20.1 | 21.2 | 20.5 | 21.5 | 21.9 |
| | 8H | 20.4 | 21.4 | 20.8 | 21.8 | 22.1 | 20.3 | 21.4 | 20.7 | 21.7 | 22.1 |
| | 12H | 20.5 | 21.6 | 20.9 | 21.9 | 22.3 | 20.5 | 21.5 | 20.9 | 21.8 | 22.2 |
| 4H | 2H | 17.9 | 19.1 | 18.5 | 19.4 | 19.7 | 17.9 | 19.1 | 18.5 | 19.4 | 19.7 |
| | 3H | 19.8 | 20.8 | 20.2 | 21.2 | 21.5 | 19.8 | 20.8 | 20.2 | 21.1 | 21.5 |
| | 4H | 20.6 | 21.6 | 21.1 | 21.9 | 22.3 | 20.6 | 21.5 | 21.0 | 21.9 | 22.3 |
| | 6H | 21.4 | 22.2 | 21.8 | 22.6 | 23.0 | 21.3 | 22.1 | 21.7 | 22.5 | 22.9 |
| | 8H | 21.6 | 22.4 | 22.1 | 22.8 | 23.2 | 21.6 | 22.3 | 22.0 | 22.7 | 23.2 |
| | 12H | 21.8 | 22.5 | 22.3 | 23.0 | 23.4 | 21.8 | 22.5 | 22.3 | 22.9 | 23.4 |
| 8H | 4H | 21.0 | 21.7 | 21.4 | 22.1 | 22.6 | 20.9 | 21.7 | 21.4 | 22.1 | 22.5 |
| | 6H | 21.9 | 22.5 | 22.3 | 22.9 | 23.4 | 21.8 | 22.4 | 22.3 | 22.9 | 23.4 |
| | 8H | 22.2 | 22.8 | 22.7 | 23.2 | 23.7 | 22.2 | 22.7 | 22.7 | 23.2 | 23.7 |
| | 12H | 22.5 | 23.0 | 23.1 | 23.5 | 24.0 | 22.5 | 23.0 | 23.0 | 23.5 | 24.0 |
| 12H | 4H | 21.0 | 21.7 | 21.5 | 22.1 | 22.6 | 21.0 | 21.7 | 21.4 | 22.1 | 22.6 |
| | 6H | 21.9 | 22.5 | 22.4 | 23.0 | 23.5 | 21.9 | 22.4 | 22.4 | 22.9 | 23.4 |
| | 8H | 22.4 | 22.8 | 22.9 | 23.3 | 23.9 | 22.3 | 22.8 | 22.8 | 23.3 | 23.8 |
| Variation of the observer position for the luminaire distances S | | | | | | | | | | | |
| S = 1.0H | | +0.1 / -0.1 | | | | | +0.1 / -0.1 | | | | |
| S = 1.5H | | +0.2 / -0.3 | | | | | +0.2 / -0.3 | | | | |
| S = 2.0H | | +0.3 / -0.6 | | | | | +0.3 / -0.6 | | | | |
| Standard table | | BK07 | | | | | BK07 | | | | |
| Correction Summand | | 5.4 | | | | | 5.4 | | | | |
| Corrected glare indices referring to 3225lm Total luminous flux | | | | | | | | | | | |

UGR diagram (SHR: 0.25)

Building 1 · Story 1 (Light scene 1)

## Room List

### Room 1

| $P_{total}$ | $A_{Room}$ | Lighting power density | $\bar{E}_{perpendicular}$ (Working plane) |
|---|---|---|---|
| 33.0 W | 5.41 m² | 6.10 W/m² = 2.68 W/m²/100 lx (Room) | 228 lx |

| pcs. | Manufacturer | Article No. | Article name | P | $\Phi_{Luminaire}$ |
|---|---|---|---|---|---|
| 1 | ESYLUX | eq10111259 | PNLCLA10030840WHOODALILC | 33.0 W | 3225 lm |

### Room 2

| $P_{total}$ | $A_{Room}$ | Lighting power density | $\bar{E}_{perpendicular}$ (Working plane) |
|---|---|---|---|
| 33.0 W | 5.41 m² | 6.10 W/m² = 2.69 W/m²/100 lx (Room) | 227 lx |

| pcs. | Manufacturer | Article No. | Article name | P | $\Phi_{Luminaire}$ |
|---|---|---|---|---|---|
| 1 | ESYLUX | eq10111259 | PNLCLA10030840WHOODALILC | 33.0 W | 3225 lm |

### Room 3

| $P_{total}$ | $A_{Room}$ | Lighting power density | $\bar{E}_{perpendicular}$ (Working plane) |
|---|---|---|---|
| 66.0 W | 9.72 m² | 6.79 W/m² = 2.62 W/m²/100 lx (Room) | 259 lx |

| pcs. | Manufacturer | Article No. | Article name | P | $\Phi_{Luminaire}$ |
|---|---|---|---|---|---|
| 2 | ESYLUX | eq10111259 | PNLCLA10030840WHOODALILC | 33.0 W | 3225 lm |



Building 1 · Story 1 (Light scene 1)

## Room List

### Room 4

| $P_{total}$ | $A_{Room}$ | Lighting power density | $\bar{E}_{perpendicular}$ (Working plane) |
|---|---|---|---|
| 66.0 W | 9.72 m² | 6.79 W/m² = 2.61 W/m²/100 lx (Room) | 260 lx |

| pcs. | Manufacturer | Article No. | Article name | P | $\Phi_{Luminaire}$ |
|---|---|---|---|---|---|
| 2 | ESYLUX | eq10111259 | PNLCLA10030840WHOODALILC | 33.0 W | 3225 lm |

### Room 5

| $P_{total}$ | $A_{Room}$ | Lighting power density | $\bar{E}_{perpendicular}$ (Working plane) |
|---|---|---|---|
| 33.0 W | 3.78 m² | 8.73 W/m² = 3.78 W/m²/100 lx (Room) | 231 lx |

| pcs. | Manufacturer | Article No. | Article name | P | $\Phi_{Luminaire}$ |
|---|---|---|---|---|---|
| 1 | ESYLUX | eq10111259 | PNLCLA10030840WHOODALILC | 33.0 W | 3225 lm |

### Room 6

| $P_{total}$ | $A_{Room}$ | Lighting power density | $\bar{E}_{perpendicular}$ (Working plane) |
|---|---|---|---|
| 33.0 W | 3.78 m² | 8.73 W/m² = 3.78 W/m²/100 lx (Room) | 231 lx |

| pcs. | Manufacturer | Article No. | Article name | P | $\Phi_{Luminaire}$ |
|---|---|---|---|---|---|
| 1 | ESYLUX | eq10111259 | PNLCLA10030840WHOODALILC | 33.0 W | 3225 lm |



Building 1 · Story 1 (Light scene 1)

## Room List

### Room 7

| $P_{total}$ | $A_{Room}$ | Lighting power density | $\bar{E}_{perpendicular}$ (Working plane) |
|---|---|---|---|
| 33.0 W | 1.35 m² | 24.44 W/m² = 8.41 W/m²/100 lx (Room) | 291 lx |

| pcs. | Manufacturer | Article No. | Article name | P | $\Phi_{Luminaire}$ |
|---|---|---|---|---|---|
| 1 | ESYLUX | eq10111259 | PNLCLA10030840WHOODALILC | 33.0 W | 3225 lm |

### Room 8

| $P_{total}$ | $A_{Room}$ | Lighting power density | $\bar{E}_{perpendicular}$ (Working plane) |
|---|---|---|---|
| 33.0 W | 1.35 m² | 24.44 W/m² = 8.47 W/m²/100 lx (Room) | 289 lx |

| pcs. | Manufacturer | Article No. | Article name | P | $\Phi_{Luminaire}$ |
|---|---|---|---|---|---|
| 1 | ESYLUX | eq10111259 | PNLCLA10030840WHOODALILC | 33.0 W | 3225 lm |

### Room 9

| $P_{total}$ | $A_{Room}$ | Lighting power density | $\bar{E}_{perpendicular}$ (Working plane) |
|---|---|---|---|
| 33.0 W | 1.35 m² | 24.44 W/m² = 8.45 W/m²/100 lx (Room) | 289 lx |

| pcs. | Manufacturer | Article No. | Article name | P | $\Phi_{Luminaire}$ |
|---|---|---|---|---|---|
| 1 | ESYLUX | eq10111259 | PNLCLA10030840WHOODALILC | 33.0 W | 3225 lm |



Building 1 · Story 1 (Light scene 1)

## Room List

### Room 10

| $P_{total}$ | $A_{Room}$ | Lighting power density | $\bar{E}_{perpendicular}$ (Working plane) |
|---|---|---|---|
| 33.0 W | 1.35 m² | 24.44 W/m² = 8.52 W/m²/100 lx (Room) | 287 lx |

| pcs. | Manufacturer | Article No. | Article name | P | $\Phi_{Luminaire}$ |
|---|---|---|---|---|---|
| 1 | ESYLUX | eq10111259 | PNLCLA10030840WHOODALILC | 33.0 W | 3225 lm |

### Room 11

| $P_{total}$ | $A_{Room}$ | Lighting power density | $\bar{E}_{perpendicular}$ (Working plane) |
|---|---|---|---|
| 33.0 W | 1.35 m² | 24.44 W/m² = 8.44 W/m²/100 lx (Room) | 290 lx |

| pcs. | Manufacturer | Article No. | Article name | P | $\Phi_{Luminaire}$ |
|---|---|---|---|---|---|
| 1 | ESYLUX | eq10111259 | PNLCLA10030840WHOODALILC | 33.0 W | 3225 lm |

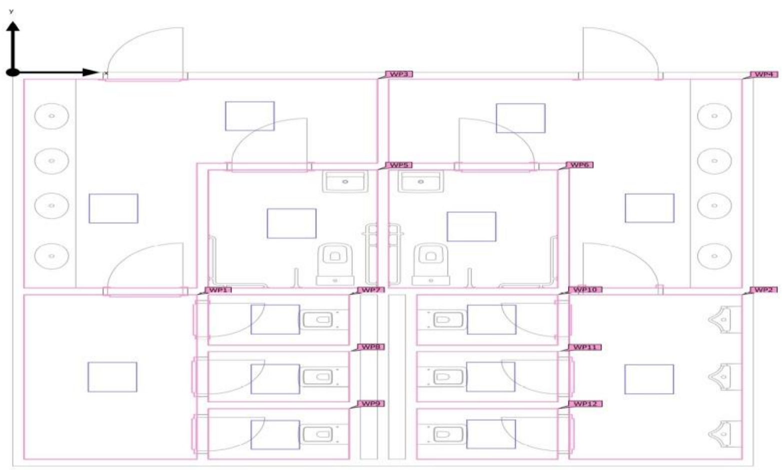
### Room 12

| $P_{total}$ | $A_{Room}$ | Lighting power density | $\bar{E}_{perpendicular}$ (Working plane) |
|---|---|---|---|
| 33.0 W | 1.35 m² | 24.44 W/m² = 8.44 W/m²/100 lx (Room) | 290 lx |

| pcs. | Manufacturer | Article No. | Article name | P | $\Phi_{Luminaire}$ |
|---|---|---|---|---|---|
| 1 | ESYLUX | eq10111259 | PNLCLA10030840WHOODALILC | 33.0 W | 3225 lm |

Building 1 · Story 1 (Light scene 1)

**Calculation objects**




Toilet

Building 1 · Story 1 (Light scene 1)

**Calculation objects**

Working planes

| Properties | Ē (Target) | $E_{min}$ | $E_{max}$ | $g_1$ | $g_2$ | Index |
|---|---|---|---|---|---|---|
| Working plane (Room 1)<br>Perpendicular illuminance (adaptive)<br>Height: 1.000 m, Wall zone: 0.000 m | 228 lx<br>(≥ 200 lx)<br>✓ | 142 lx | 304 lx | 0.62 | 0.47 | WP1 |
| Working plane (Room 2)<br>Perpendicular illuminance (adaptive)<br>Height: 1.000 m, Wall zone: 0.000 m | 227 lx<br>(≥ 200 lx)<br>✓ | 138 lx | 306 lx | 0.61 | 0.45 | WP2 |
| Working plane (Room 3)<br>Perpendicular illuminance (adaptive)<br>Height: 1.000 m, Wall zone: 0.000 m | 259 lx<br>(≥ 200 lx)<br>✓ | 113 lx | 360 lx | 0.44 | 0.31 | WP3 |
| Working plane (Room 4)<br>Perpendicular illuminance (adaptive)<br>Height: 1.000 m, Wall zone: 0.000 m | 260 lx<br>(≥ 200 lx)<br>✓ | 110 lx | 366 lx | 0.42 | 0.30 | WP4 |
| Working plane (Room 5)<br>Perpendicular illuminance (adaptive)<br>Height: 0.800 m, Wall zone: 0.000 m | 231 lx<br>(≥ 200 lx)<br>✓ | 128 lx | 277 lx | 0.55 | 0.46 | WP5 |
| Working plane (Room 6)<br>Perpendicular illuminance (adaptive)<br>Height: 0.800 m, Wall zone: 0.000 m | 231 lx<br>(≥ 200 lx)<br>✓ | 108 lx | 282 lx | 0.47 | 0.38 | WP6 |
| Working plane (Room 7)<br>Perpendicular illuminance (adaptive)<br>Height: 0.800 m, Wall zone: 0.000 m | 291 lx<br>(≥ 200 lx)<br>✓ | 263 lx | 315 lx | 0.90 | 0.83 | WP7 |
| Working plane (Room 8)<br>Perpendicular illuminance (adaptive)<br>Height: 0.800 m, Wall zone: 0.000 m | 289 lx<br>(≥ 200 lx)<br>✓ | 260 lx | 314 lx | 0.90 | 0.83 | WP8 |
| Working plane (Room 9)<br>Perpendicular illuminance (adaptive)<br>Height: 0.800 m, Wall zone: 0.000 m | 289 lx<br>(≥ 200 lx)<br>✓ | 264 lx | 311 lx | 0.91 | 0.85 | WP9 |
| Working plane (Room 10)<br>Perpendicular illuminance (adaptive)<br>Height: 0.800 m, Wall zone: 0.000 m | 287 lx<br>(≥ 200 lx)<br>✓ | 259 lx | 312 lx | 0.90 | 0.83 | WP10 |
| Working plane (Room 11)<br>Perpendicular illuminance (adaptive)<br>Height: 0.800 m, Wall zone: 0.000 m | 290 lx<br>(≥ 200 lx)<br>✓ | 263 lx | 315 lx | 0.91 | 0.83 | WP11 |
| Working plane (Room 12)<br>Perpendicular illuminance (adaptive)<br>Height: 0.800 m, Wall zone: 0.000 m | 290 lx<br>(≥ 200 lx)<br>✓ | 264 lx | 314 lx | 0.91 | 0.84 | WP12 |