

Addis Ababa University
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School of Electrical & Computer Engineering



**Power Consumption Reduction and User Satisfaction Using
Office Task Tailored Automatic Lighting System with
Manual Controllability**

**A Thesis submitted to the School of Graduate Studies of Addis
Ababa Institute of Technology in partial fulfillment of the Degree of
Master of Science in Microelectronics Engineering**

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JULY 7, 2023

Declaration

I, Sosina Abiyot, declare that this thesis entitled “Power Consumption Reduction and User Satisfaction Using Office Task Tailored Automatic Lighting System with Manual Controllability” submitted in partial fulfillment of the requirements for the degree of Microelectronics Engineering at Addis Ababa Institute of Technology represents my own work, except where due acknowledgement is made.

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Abstract

Lighting that is artificial represents a substantial portion of international electrical power consumption. This high power consumption affects the cost of the power. In work places and offices there is fixed light intensity, mainly in Ethiopia. This fixed light intensity affects the health and comfort of workers in addition to high power consumption. To minimize these problems dimmable or variable light intensity is required. Light dimming can be attained by adjusting the voltage or current which gets to the LED lamp. In this research paper light intensity controller automatically using MAX44009 sensor and manually using android devices to control light intensity via Bluetooth was designed, to satisfy users and the amount of the reduced power is calculated and analyzed but not measured due to lack of proposed materials. The light intensity can be controlled automatically using the MAX44009 sensor when this sensor senses the surrounding light intensity and sends a digital I2C signal into the microcontroller. This microcontroller board, in this research, is Arduino Uno, processes the input data from the sensor and decides to adjust the LED lamp brightness. This system is automatic and users cannot interact with it if they want to adjust the brightness. To overcome this problem there is an additional method to control light intensity manually. Controlling light intensity can be done via Bluetooth. To achieve this system android application that can interact with the Bluetooth module and microcontroller was developed. After developing these two methods independently, they are integrated as one system so that the user can adjust the brightness when he wants to create comfortable environment, or else it can be adjusted automatically to reduce power consumption.

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List of Abbreviations

CFL	Compact Fluorescent Lamp
DGP	Daylight Glare Probability
DTMF	Dual Tone Multi-Frequency
HDR	High Dynamic Range
HID	High Intensity Discharge
HVAC	Heating, Ventilation, and Air Conditioning
I2C	Inter-Integrated Circuit
LDR	Light Dependent Resistor
LED	Light Emitting Diode
MCU	Microcontroller unit
OTP ROM	One-Time Programmable Read-Only Memory
PIR	Passive Infrared Sensor
PWM	Pulse Width Modulation
RAM	Random Access Memory
VLSI MOS	Very Large Scale Integration Metal Oxide Semiconductor

Chapter 1. Introduction

Lighting accounts for 20% of global power consumption in offices and in public places it can soar up to 50% [1]. Most of the power expended on lighting is wasted because of ineffective management of occupancy and daylight situations. In order to decrease power consumption, control of artificial lighting has been an active topic of research lately [2]. Dimmable luminaires are essential to perform such lighting control systems. The introduction of light emitting diode based luminaires has made this feasible since they can be dimmed easily and flexibly, aside from the use of these devices that emit light using a semiconductor material (LED) [3], numerous lighting control approaches have been designed and applied in office buildings. Examples of these techniques include occupancy-based lighting management, dimming management, and daylight-linked automated lighting management [4]. But these control methods are only automatic methods, they have not yet extended a fully developed stage, and also there is still ample room for improvement. However, if the user wants more bright light or more dim light than the automatically adjusted light intensity these methods are not flexible.

Light dimming is based on adjusting the voltage/current which gets to the lamp [5]. Light dimming has been achievable for many years by using variable power resistors and variable transformers. Those systems have been used in stages, movie theatres, and other public places. The issue with those light-controlling techniques has been that they have been massive, costly, inefficient, and difficult to manipulate from a distance.

There has recently been a significant interest in remotely controlling various applications and systems without physically touching or operating the device being controlled [6]. Among these systems, controlling light intensity in offices is becoming very essential. The brightness of the light can be adjusted automatically using light sensors and remotely as the user demands using mobile phones or computers [5]. The major reasons behind light intensity control are to create a comfortable working environment, boost productivity, efficiency, safety, and quality of life for the user, and save power consumption. Saving power is the main important criterion in the present world.

Controlling light intensity was achieved automatically by designing the circuitry using the MAX44009 light sensor. So that the light sensor senses the environment light intensity and sends an I2C digital output to the microcontroller and the microcontroller will adjust the light intensity.

Controlling light intensity automatically is not enough for some users who want extremely bright or dim light intensity. In case the user desires to adjust the light intensity instead of the automatic adjustment, remote controlling light intensity is essential without physically touching the switch or without any difficulty. Controlling light intensity using devices like mobile phones, tablets or computers is achievable using their Bluetooth system. The main purpose of this research was after designing an office task-tailored automatic lighting system with manual controllability, to study the designed system based on user satisfaction and power efficiency compared to the current existing lighting system. In this paper, the designed system will be presented and the analyzed power reduction percentage is discussed.

1.1. Lighting System

Lighting or illumination is the deliberate use of light to achieve practical or aesthetic properties. Illumination involves utilizing both man-made light sources such as lamps and light fixtures, as well as natural light by harnessing sunlight. From time to time, buildings may employ the practice of daylighting, which involves utilizing openings, windows, or light shelves to bring natural light into the interior spaces [7] as their primary cause of light throughout the day. By avoiding the use of artificial lighting, which is responsible for the bulk of power consumption in office blocks, this approach can help save power. Proper lighting can improve chore performance, advance the presence of a region, or have affirmative psychological possessions on users. The focus of this research paper is on the artificial lighting control system.

1.1.1. Types of Lighting

There are three types of lighting: task lighting, accent lighting, and general lighting.

- 1. Task Lighting:** is essentially practical and is frequently the most intense, for tasks like studying or inspection of materials. Task lighting settings of until 1500 lux (150-foot candles), for instance, may be necessary to read low-quality items) [7]; some inspection jobs or surgical operations need more intense lighting.
- 2. Accent Lighting:** is essentially decorative, proposed to draw attention to specific images, plants, or other gardening or interior design components [7]. A focus point is formed by accent lighting. It adds depth to the room's basic lighting and can be utilized to draw attention to a specific item, such as a piece of art or a plant, or to emphasize a standout

design element, such as a wall surface or ornamental coving. Accent lighting should shine more than three times as much light on the focal point as it does on the rest of the room in order to heighten the drama and draw attention [8]. Accent lighting should draw your attention to the object or feature being highlighted rather than the lighting itself. Track lighting, recessed lighting, or wall-mounted fixtures like picture lights and sconces, which can be tilted and directed to generate a spotlight, are most commonly ways to achieve this.

- 3. Ambient or Common Lighting:** is suggested for an area's general illumination. Within the house, there would be a straightforward table lamp or other light. A parking lot's ambient lighting can be as dim as around 10-20 lux (1 or 2-foot candles) outside [7] because drivers and pedestrians familiar with the dark won't need much illumination to cross the space.

1.1.2. Forms of Lighting

There are two forms of lighting systems called Indoor lighting and Outdoor lighting.

- **Indoor lighting:** these forms of lighting are used inside the house, workplace, halls, stadiums, and other places. This is regularly done with rope light or fluorescent lighting [7], as well as with LED strip lighting. It functions as backlighting.
- When utilized to highlight texture (such stucco or plaster) on a wall, soffit or close-to-wall lighting can be popular or ornamental, though this has drawbacks as well. Fixtures for dipping lighting are frequently mounted to the ceiling framework so that they seem flush with it. These lightings can use either wider-angle floodlights or spotlights with a narrower beam—both of which are light sources with built-in reflectors. There are also down-lights with inner reflectors planned to receive light bulbs or 'A' lamps that are regularly less expensive than reflector lamps. Some kinds of down-lights are fluorescent, incandescent, HID (high-intensity discharge), and LEDs.

Track lighting, introduced by Lightolier, [9] was common at a point in time since it was less complicated to set up than dipped lamps and because separate fixtures may be simply pointed at a wall and are ornamental. It is now regaining some favor in low-voltage paths, which frequently differ greatly from their forebears because of the lack of safety concerns that line-voltage circuits have, making them smaller and visually appealing. As an alternative of each light source having a separate line-to-low voltage transformer, a master

transformer supplies up to 24 volts to all of the fittings on the pathway or rod. Cable lighting is an enhanced version of conventional spots, floods, and other tiny hanging fixtures in which lights can be suspended from or fastened to exposed metal cables in strain.

A chandelier is a wall-mounted light fixture that primarily illuminates upward and occasionally downward [10]. An up-light designed for general lighting is called a torchère. Although it is often a floor lamp, a sconce-style wall mount is an option. Suspended lights, chandeliers, flush or close-to-ceiling lights, and many kinds of lamps are extra interior lighting systems.

The most prevalent fixture is the table or transportable lamp, which is present in many households and businesses [7]. Ambient lighting refers to the typical table lamp with shade, whereas task lighting refers to the desk lamp. Task lighting also includes magnifying lamps.

- **Outdoor lighting:** These lightings are implemented to light up sidewalks and highways during the night. To deliver an energy-efficient replacement for conventional street light fixtures, some manufacturers are constructing LED and photovoltaic luminaires[11][12]. During the hours of darkness, searchlights can be applied to light up work zones [13] or outdoor sports fields. The most common kinds of searchlights are metal halides and high-pressure sodium lights.

Occasionally along roadways in cities, or in the backyards of homes or commercial areas, safety lightings can be used. Extremely bright lights like these are used to prevent crime. Floodlights are one type of security light that may be used. PIR (passive infrared sensor) switches that sense moving heat bases in the dark are used to turn on security lights.

Entrance lightings can be implanted outside to signal and illuminate the property's entrance [14]. Also utilized for fountains, koi ponds, swimming pools, and similar structures is submerged accent lighting. Instead of illuminating, neon signs are typically utilized to increase attraction to themselves.

1.1.3. Measurement

The measurement of light, also known as photometry, is frequently concerned with the quantity of light that illuminates from a light bulb or other light sources, the quantity of light that falls on a external surface, and the colors that this light can produce. The luminosity function should be considered when evaluating the amount of useable light since different persons eye reacts in a

different way to light from various wavelengths of the visible range. The rest of the photometric units originated from candela (cd), which is the fundamental SI (System of Units) unit of quantity and denotes luminous intensity [7]. For instance, luminosity is a measurement of the intensity of light density in a specific direction. It describes how much light enters or leaves a specific space and falls inside a specified solid angle. Candela per square meter (cd/m²) is the brightness SI unit. Lumens are units used to describe the quantity of useful light that a source emits, also recognized as luminous flux.

The radiant power per area, or luminous emittance, is measured with SI unit of Lux. It serves as a gauge for the quantity of light which strikes or penetrates a surface as observed by the persons eye in photometry [15]. It is equivalent to the radiometric measure watts per square meter but weights the power for each wavelength based on the luminosity function, a reliable representation of how people perceive brightness in visual displays. The word "lux" can be used both plural and singular in English.

1.1.4. Power Consumption

There are several ways to reduce how much power is implemented to light up a building [7]:

- A description of the lighting needs for each specific usage area
- Lighting quality inspection to ensure that unfavorable lighting elements—like glare or an inaccurate color spectrum—do not influence the design
- Combining interior architecture, space planning, and lighting design
- Design of time-of-day use that can save unnecessary power
- Choosing fixtures and lights that represent the finest accessible technology for power saving
- Training of building residents to use lighting tools in the most efficient manner
- Keeping lighting systems maintained to prevent power waste
- Using natural light
- Load detaching can assist in lowering the amount of power that people require from the main power source. Load detachment can be carried out at the individual, building, or even regional levels.

The fundamental idea behind evaluating how much brightness is necessary for a particular work is the description of illumination demands. The quantity of light needed to light up a hallway is obviously far lower than that needed to illuminate a workstation for word processing. In general, the power utilized is inversely correlated with the design illumination intensity. For instance, a light intensity of 400 lux could be nominated for a workspace with conference rooms and meeting rooms, while a light intensity of 80 lux might be selected for a building's halls[16][17][18]. In this paper light intensity controlling system is designed to reduce power consumption inside offices. It will take far more effort than necessary to merely match the conference room requirements to the hallway norm.

1.1.5. Health Effects

Delivering the appropriate light spectrum and intensity for each work or setting is valued. Otherwise, not only could power be squandered, but excessive illumination can have negative psychological and physiological repercussions [7].

In addition to taking power efficiency into account, it is crucial to avoid over-designing illumination in order to avoid the greater lighting levels from having negative health impacts including increased headache frequency, tension, and blood pressure. Additionally, glare or too much light might impair worker productivity [19].

While spectral content is taken into account if artificial lighting is needed, the study of lighting quality emphasizes the usage of natural lighting in particular. Increased use of sun light will improve people's health and performance as well as reduce power use. According to recent studies, pupils' performance is impacted by the amount and timing of daylight during their typical routines. The performance and wellbeing of students may improve if school buildings are designed to provide the proper kinds of light at precise times of day for precise quantity of time. Similarly, creating lighting systems for the elderly that optimize the optimum quantity of lighting at precise time of day may lessen the signs of Alzheimer's disease [20][21]. The 24-hour light-dark configuration of the human circadian rhythm mimics the natural light-dark cycle of the earth. The ordinary circadian cycle is disrupted when certain arrangements are changed. Circadian interruption may lead to several health problems including seasonal affective disorder, breast cancer, late sleep phase syndrome, and other ailments.

In two studies by Robert Ulrich, one in 1972 and the other in 1981, 23 surgery patients allocated in places with views of the outdoors were surveyed [22]. According to the study's findings, patients allocated in places with windows that let in a lot of natural light experienced smaller postoperative hospital times, gets less critical notes from nurses, and required less intoxicating painkillers than 23 patients with similar condition in rooms with windows that faced a brick wall [23]. According to this study, patients who were exposed to natural surroundings and daylight were undoubtedly healthier than those who were exposed to too little light from a brick wall. The right use of openings and daylighting passes the borders between untainted aesthetics and general health in addition to improving work effectiveness.

Researchers Alison Jing Xu and the Northwestern University of Aparna Labroo and assistant professors of management at the University of Toronto Scarborough examined the relationship between lighting and emotional responses in a number of studies. Under various lighting conditions, the researchers requested members to judge several items, including the violence of a character from fictional books, the spiciness of chicken wing sauce, their sentiments about particular words, how handsome someone was, and the flavor of two liquids [24]. They find in their research that strong light intensifies both happy and sad human sensations. As the expression of professor Xu, they found that on a sunny day depression-prone people really become more depressed and they also discover that low light intensity affects people to make more balanced judgments and resolve negotiations easier [25]. Emotions are slightly muted in the dark. However, the bright light heightens feelings.

1.1.6. Lighting Control System

A lighting control system is an intelligent network-based lighting control solution that integrates communication between various system inputs and outputs associated with lighting control with the use of one or more central computing devices [26]. Systems for controlling lighting are frequently used in the interior and exterior lighting of business center, residential, and industrial settings. Systems for controlling lighting help to provide the appropriate level of light at the required time and place it is needed. Lighting control methods are used to maximize power reduction from the lighting method, meet building code requirements, or adhere to power-saving and green building initiatives. Smart Lighting is a word that is frequently used to describe lighting control systems.

By assisting in the delivery of light just at the required time and place it is required, lighting control systems save power consumption and costs. Lighting control systems often include timers, occupancy sensors, and photocell controls (also known as daylight harvesting) [27]. In order to benefit from utility incentive, some systems additionally offer occupant preference reply and will voluntarily dim or switch off lights. Grander building automation schemes occasionally incorporate lighting control systems.

The use of wireless network exposed standards in recent control systems, such as ZigBee [28], has several advantages, including quicker installation, and compatibility with additional standard based building control systems (such as security).

Systems for sun harvesting have improved in reply of daylighting technology to further reduce power use. These technologies have their limitations, despite the fact that they are useful [29]. Lighting can be turned on and off quickly and frequently, especially in erratic weather or when the quantity of daylight varies around the time of the switching illuminance [30]. This not only irritates the residents, but it also might shorten light life. Differential switching, also known as dead-band photoelectric control, is a kind of this technology that shifts between several illuminations with a minimum amount of noise to the occupants.

Lighting can be controlled by occupancy sensors, which can take action each time someone enters the region being detected. The lights go out when no longer detectable motion is present. Infrared passive sensors react to variations in temperature, with the shape produced by a moving object. The building area that is being scanned must be visible to the control clearly [31] Motion detection will be blocked by objects like doors, walls, stairways, etc., which will reduce its effectiveness. Open areas with a pure sight of the region being scanned are the best places to use inactive infrared occupancy sensors. Ultrasonic sensors conduct sound beyond the audible range and keep track of how long it takes sound waves to get back. Any movement in the vicinity causes a disruption in the pattern, which activates the control [32]. For places with cupboards and shelving, toilets, and open spaces requiring 360-degree coverage, ultrasonic sensors work best since they can see around barriers. Some occupancy sensors, which are often more expensive, combine ultrasonic technology and inactive infrared. One light bulb, one fixture, or a number of fixtures can all be controlled by them.

The term lighting control system is usually used to specify stand-alone control of the lighting inside a space [33]. This may include occupancy sensors, time clocks, and photocells that are hard-wired to control fixed groups of lights individually. Modification occurs manually at the position of each device.

A smart networked system of lighting control-related devices is known as a lighting control system. Relays, occupancy sensors, microcontrollers, photocells, light control switches or touchscreens, and signals from other building systems (including HVAC or fire alarms) [27] are a few examples of these gadgets. Software applications or other interface devices are used to modify the system at both the device locations and the central computer locations.

The modern method of lighting system control employs a direct Bluetooth connection to the lighting system. Recently, Philips HUE and Signify, the company's new moniker after being formerly known as Philips Lighting, were unveiled [7]. A smartphone or tablet with the ability to install the specific Philips Hue Bluetooth app is required for this setup. A Philips Hue bridge is not required for the Bluetooth lamps to work. When using such a system, a Wi-Fi or data connection is not required in order to change the lights.

1.2. Purpose of Research Work

Even if no research data exists, most offices in Ethiopia use 100% on and 100% off fluorescent lights with simple switches. This lighting system is not only uncomfortable for users it also wastes a high amount of power. To solve this problem variable light intensity based on the environment and the user's demand is required. Variable or controllable light intensity also adds value in cost reduction in addition to increasing productivity and accuracy. The light intensity can be controlled automatically without the intervention of humans by using light sensors. And when the user desires to adjust the brightness of the lamp based on his comfort, the user can control light intensity manually by means of the combination use of an android application from his phone or tablet and Bluetooth communication with microcontroller. This paper presents the integrated system of light intensity controlling automatically without the intervention of humans and manually by means of the combination use of android application and Bluetooth. For the purpose of creating a comfortable work environment for the user and power consumption reduction. This system gives priority to the user's comfort than power consumption reduction.

1.3. Objective

1.3.1. General Objective

The main objective of this thesis is to design manual light intensity controller to give user a power to adjust light intensity in addition to analyzing power consumption reduction due to automatic light intensity controller.

1.3.2. Specific objectives

- Programming the microcontroller, which is the Arduino Uno microcontroller,
- Interfacing the Arduino Uno with MAX44009 light sensor,
- Measuring the light intensity during different times on different days,
- Calculate the required light intensity for the measured data,
- Developing the required android application,
- Interfacing the Arduino Uno with Bluetooth module and LED lamp,
- Study user's comfort and
- Analyzing power consumption reduction due to the new lighting system.

1.4. Scope of Study

In this paper, improving user satisfaction and power reduction of lighting system in offices using automatic lighting system with manual controllability was studied. At the beginning automatic lighting system with manual controllability was designed and implemented. After the implementation of this system, manual light intensity controller was designed for the user and power consumption reduction was also analyzed. This system contains a microcontroller board (Arduino Uno), MAX44009 light sensor, transistors, different value resistors, power supply, LEDs, Bluetooth module, and android application. The Arduino Uno was programmed to accept data either from the light sensor or from the android application via Bluetooth. Improving user satisfaction is the first priority in this research, so when the user sends data from an android application, the microcontroller decides to adjust the light intensity of the LED based on the data received from the user's mobile phone or tablet. If the user does not want to adjust the light intensity, this system enters into automatic light intensity adjusting mode based on the data received from the light sensor. During this mode the system will give priority to reduction of power consumption based on the daylight occupancy of the office.

1.5. Organization of the Thesis

As presented earlier chapter 1 expresses about lighting system, purpose of the research work, the general and specific objectives of the thesis, and the scope of the study. The next chapter presents the reviewed literatures related with the thesis idea. In literature review there are four subtopics; the first one introduces about the whole chapter, then the literatures related with basic light intensity controlling systems are reviewed, thirdly literatures related with smart lighting system are reviewed, the final part concludes the whole chapter. In the third chapter methods used for the research paper are presented. In this chapter there are three subtopics; the first one expresses the method used for power reduction using automatic light intensity controller, the second subtopic presents the method used for improving user satisfaction using manual light intensity controller, and finally the third subtopic talks about the integration of both methods to get improvement of user satisfaction and power reduction in one system. The research result is presented in the fourth chapter. In this chapter both the level of improvement of user satisfaction and the percentage of power consumption reduction are presented. Finally in chapter five the conclusion of the research work and the future work of the research are presented.

Chapter 2. Literature Review

2.1. Introduction

According to a recent in-depth investigation into the relationship between office worker productivity and lighting quality, reasonable adjustments to lighting intensity can demonstrably boost workers' comfort, motivation, tenacity, and alertness. These variations in light intensity can also save power wastage and they can reduce the cost of the power. The following review of the literature shows that there are a lot of research done at different times to solve controlling light intensity problems as the users want using phone devices and based on the signal from sensors to reduce power wastage and improve users' comfort.

2.2. Basic Light Intensity Controlling Systems

In 2004, Jones and Gordon present an exciting value proposition for commercial office buildings. Two significant market opportunities have been identified by research that the power efficiency sector should seriously consider pursuing [34]. Variable lighting is planned to have affirmative effects on performance and well-being. In a field experiment, de Kort and Smolders (2010) tested whether these effects are detectable and stable over time when employed in actual work settings. The study contains two cases, the first was based on a monthly alternating experimental design, and the second case was a yearly alternating one [35]. Survey results show no appreciable variations in subjective performance, mental health, need for recovery, vitality, alertness, headache, eyestrain, or quality of sleep, while employees did report feeling more pleased with the variable lighting.

For light dimming and brightening purposes, LEDs are preferable. Light Emitting Diodes (LEDs), with their capability to yield tunable light spectrums, give an important opportunity to advance on existing lighting systems. They can be implemented in smart and specified lighting, which can be extremely helpful in the residential, commercial, and industrial sectors. Padmaja and Venkateshwarulu (2015) [5] aimed to develop an power-saving smart light-emitting diode lighting system for industrial and domestic use which can be integrated with agent-based Micro-Grid systems. The proposed LED control modules have the properties of low power consumption and low cost which can be integrated with agent-based Micro-Grid systems. The hardware of the

proposed control modules is an Arm-based controller, light intensity measuring sensor, and (Light Dependent Resistor) LDR.

They designed wireless data communication to function in agreement with the ZigBee standard, and signal processing on detected data is made through a self-adaptive weighted data fusion algorithm.

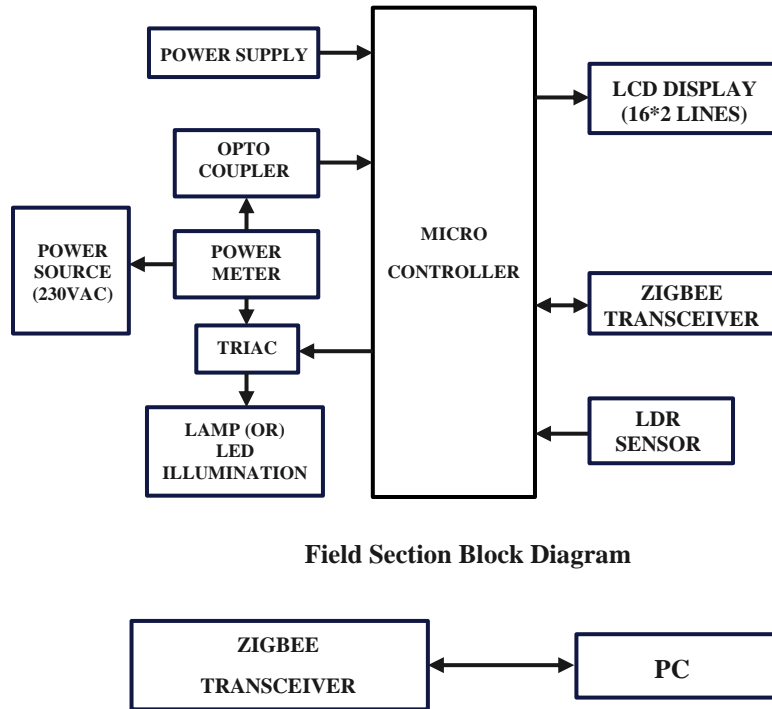


Figure 1. Power-Saving Intelligent LED Lighting filed and monitoring block diagram [5]

Additionally, Chew, Kalavally, Win Oo and Parkkinen (2016) present an power-saving controller that is capable of shaping the light output of an LED lighting system autonomously based on data received from sensors. To handle the sensor feedback, they develop an improved smart algorithm on a controller, and they use pulse width modulation dimming to change the luminaire's brightness. To provide the controller with accurate sensor feedback, a wireless sensor module was created. To evaluate the implementation of the control system, a specifically designed and built smart luminaire equipped with an LED driver was created. They test the developed controller's ability to save power in several real-world scenarios. They demonstrated through experimentation that the controller saved power under their test conditions by 55% in a continuous usage pattern environment and 62% in a discrete usage pattern environment. With the promise of further power savings due to the employment of additional power-saving techniques, a cost study revealed that

the suggested power-saving technique is 32% cheaper than a nearly identical commercial system [36].

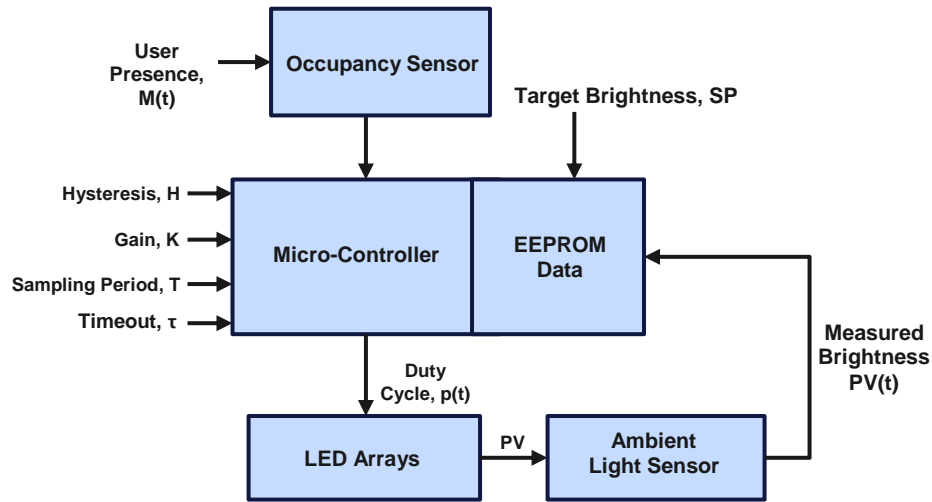


Figure 2. The block diagram of the power saving control system [43]

As expressed earlier, adjusting lighting is considered one of the most important issues in reducing the power consumption of a building. Over the last three decades, there has been a growing concern about decreasing power intake associated with artificial lighting. In 2017 Shishegar N, and Boubekri M studied quantifying electrical power savings in offices by installing daylight responsive control systems in hot climates. Day-lighting could be considered a cost-effective substitute for artificial lighting which not only reduces the demands for electrical power, but also provides occupants with a pleasant, attractive, and healthy indoor environment [37]. By installing sensors and controllers, daylighting is able to diminish and even eliminate the use of artificial lighting desired to deliver sufficient illuminance levels in an office. Their study was simulation-based research that examines the impacts of various types of day-lighting controllers on improving total and lighting electrical power consumption of office buildings located in hot climates. In this study, they evaluated the impacts of On/Off, Stepped, and Dimming (5%, 10%, and 20% light) control systems. The power simulation program, E-Quest, is used to examine and contrast electrical and lighting power consumption. Miami, Houston, and Phoenix, which are located in ASHRAE 90.1 climate zones 1A, 2A, and 2B, respectively, have been chosen as the three locations for the test site building in order to assess the impact of daylight control techniques in wet and arid hot climates. The prototype structure was an east-west oriented, four-story open office building

with dimensions of 18 m wide by 36 m long by 15 m high. In all directions, the window-to-wall ratios of 20, 40, 60, and 90% are measured. Windows with blinds in the East and West and horizontal shading on all fronts. The findings of this study demonstrate that putting daylighting controllers in office buildings considerably lowers the building's electrical power consumption, particularly its lighting usage, in all analyzed cities.

2.3. Smart Lighting System

A smart lighting system provides automatic control of lighting illumination and color temperature for a high quality of life as well as power savings in smart cities. A real-time activity tracking method with precise human location estimation under dynamic illumination is essential for smart lighting control since comfortable lighting situations vary according to human activities. Human position estimation based on inverse-perspective mapping of depth map images is presented by Chun, Lee, and Jang in 2015 [45]. Activity estimation using location, walking direction, and height valuation of the moving person from multiple-depth cameras is also presented [45]. Both methods are used in real-time smart lighting control systems. Lighting management based on predicted proximity to the targeted activity area, distance to the specified lighting zone, and the person's walking orientation provides a self-sustaining activity-dependent lighting environment and power savings. They applied the recommended lighting management system to the living room, controlling the lighting with electronics, well-known furniture, and several Kinect depth cameras. They included a number of activity modes, including study mode, conversation mode, and TV-watching mode. Their approach, which was based on localized proximity-based lighting management, can be integrated with approaches for international lighting control to offer a lighting control that is more thorough. By offering more comfortable lighting settings than the standard approach, their suggested strategy conserves electricity.

But there was the problem of daylight estimation in this smart lighting system. Borile, Pandharipande, Caicedo, and Luca Schenato (2016) considered this problem. The smart lighting method contains numerous luminaires with collocated occupancy and light sensors. Using sensor information, their objective was to achieve light levels at the workplaces that are higher than the indicated values [3]. They take into account a training phase in which light sensors are utilized at workplaces to gather initial data. To estimate the mapping across the sensors, information from the light sensors at the workplaces and ceiling is used. In the operational phase, they approximated

the illuminance value at the workplaces using the estimated mapping at the lighting controller. The controller increases the luminaires' dimming levels to reduce power consumption when the estimated illuminance exceeds a predetermined target value. By taking into account various daylight circumstances, they assess the performance of the suggested strategy in a model of open-office lighting. Their conclusion was comparisons with alternative approaches and standard practices show the major benefit of the proposed approach both in terms of reduced under-illumination and power-saving.

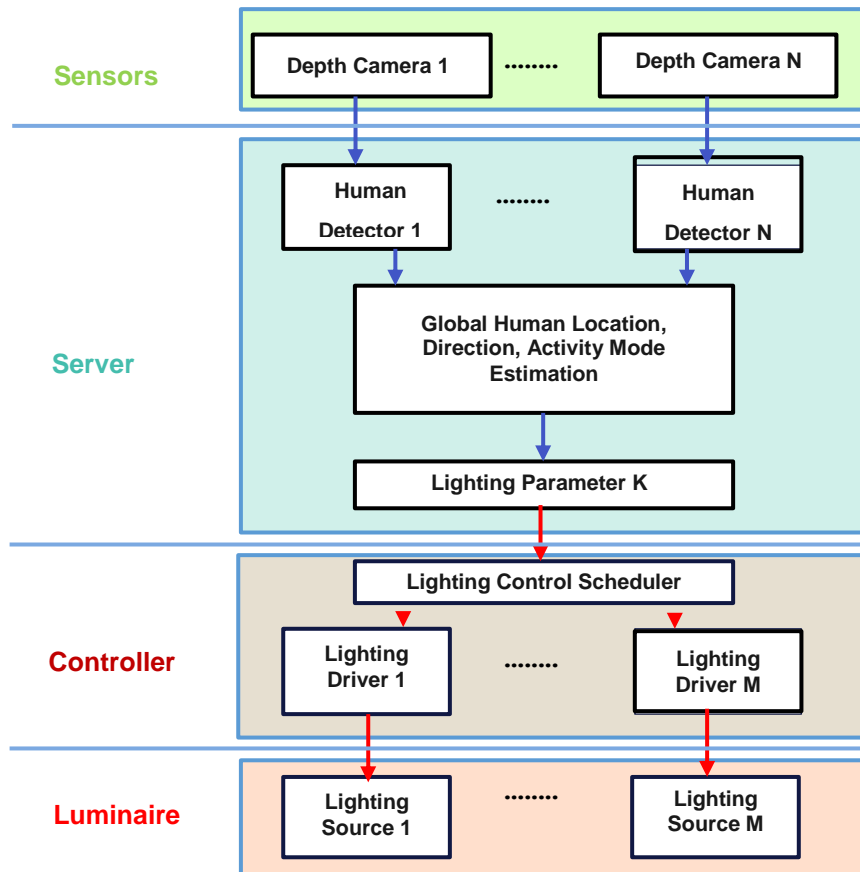


Figure 3. System configuration of Real-time Smart Lighting [45]

The light output spectrum can converge towards a target spectrum thanks to a novel closed-loop control technique presented by Chew, Kalavally, Tan, and Parkkinen (2016) [38]. A considerable amount of the visible light spectrum is covered by a wireless smart lighting system that uses eight programmable LED channels with various prominent wavelengths (450-650 nm). They validated the control system experimentally. The results of the experiments demonstrate a nearly flawless duplication of the target spectra, with an accuracy of 5% for the corresponding color temperatures.

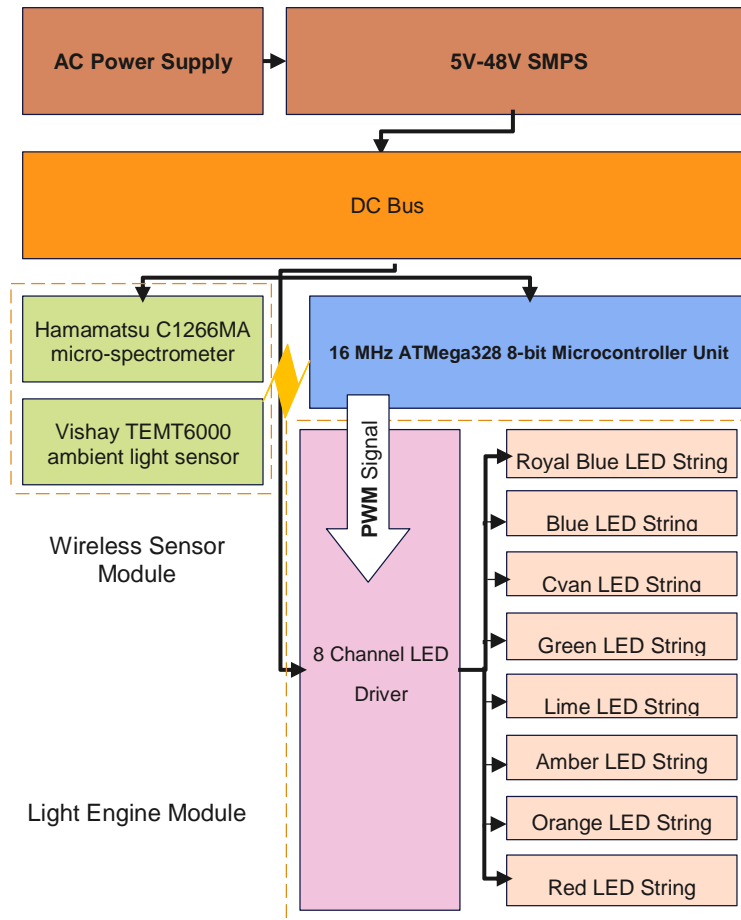


Figure 4. A Spectrally-Tunable Smart LED Lighting System [46]

Smart indoor lighting methods use occupancy and light sensor information to adjust artificial lighting based on the changing occupancy and daylight conditions. This system can be designed to minimize lighting power consumption considerably. These technologies, however, are unable to take into account specific user interests at work in real-time. Recently, there has been a lot of interest in managing various systems and applications from a distance without the necessity of touching objects. And also controlling light intensity based on the demand of the user is becoming essential. Beza and Hussain (2015) did their research on the project and simulation of an electronic system for remote controlling the brightness of light intensity of an electrical lighting system used for some chosen applications [2]. They recommend remote control utilizing any Dual Tone Multi-Frequency (DTMF)-based phone handset's keypad.

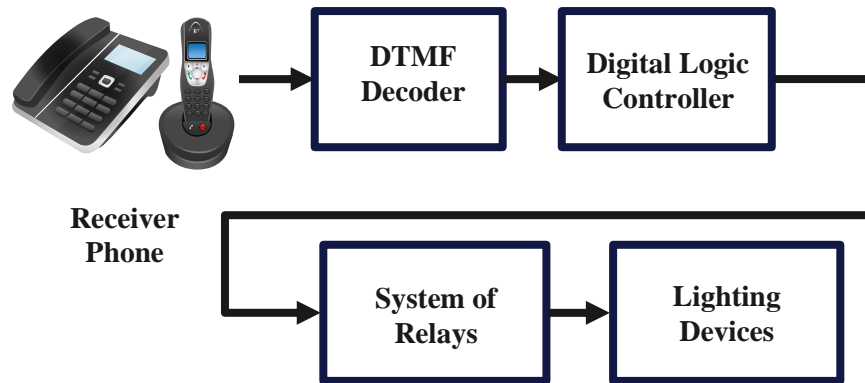


Figure 5. System block diagram for DTMF based lighting system controller [2]

They use a DTMF tone data sent from a transferring fixed or mobile phone terminal to trigger a system of relays that control the necessary level of light intensity [2]. Additionally, they create the proper active bandpass filters for decoding the transmitted digit's DTMF tones. Using MULTISM, they tested and simulated bandpass filters as well as the further electronic system stages that followed.

The same year, 2017 saw the completion of a study by Caicedo D, Li S, and Pandharipande A titled "Smart Lighting Control with Workspace and Ceiling Sensors" [39]. They take into account power-efficient indoor lighting control to adjust for variations in user behavior and daylight. In addition to user presence data from occupancy sensors at roof luminaires, light sensors at tables and roof luminaires are employed to send illumination data response to an illumination controller. Compared to the sensors on the ceiling, the office's light sensors update information less often. They presented a technique to adjust the luminaires' dimming levels such that desirable light levels are obtained at the workstation level using this sensing data. In a testbed for office lighting, the proposed system's effectiveness is assessed.

Similarly, a study by Gao Y, Cheng Y, Zhang H, et al. (2019) presents the dynamic lighting measurement and control used for smart lighting with LED. The indoor power control of lighting is essential for the construction of a smart city; a lighting system that dims electric lights based on the daylight level helps in power conservation [40]. The measurement of the mix of daylight and electric light and limiting the electric light's attenuation level are two of the most popular ways of attaining this daylight control. They outline a low-cost, partially-feedback closed-loop control technique for LEDs based on the PWM dimming concept that only counts and feeds back daylight's contribution, not that of the other light stage, in order to calculate the output of the electric light.

They show off a prototype to verify the partial feedback technique using the TEMT6000 picture sensor. Their research demonstrates that the partial-feedback controller can successfully stabilize lights.

In another research conducted in Switzerland, Motamed A, Deschamps L, and Scartezzini J studied on-site monitoring and subjective comfort assessment of sun shadings and electric lighting controllers based on novel high dynamic range vision sensors in 2017 [41]. Electric lighting is accountable for about 20% of the electricity demand of buildings in Switzerland. Then, with user comfort and performance maintained, coordinated control of sun shades and artificial illumination can lower electricity consumption. However, the disadvantage of the current smart building technologies is that they do not take visual comfort efficiently into consideration, one of the necessary features of indoor human comfort. In order to enhance the location of the sunshades and the condition of the electric lighting, these researchers integrate an 'on-the-fly' assessment of a visual comfort metric, Daylight Glare Probability (DGP), by a unique High Dynamic Range (HDR) vision sensor into the building management system. Two identical office rooms (reference and advance) of the LESO solar experimental building were occupied by 30 employees for 15 afternoons and were used to experimentally compare the performance and users' approval of the fuzzy logic-based control system contrary to the greatest practice reference system. A thorough evaluation of the amount of electricity used for illumination as well as personal self-reported visual comfort assessments was also conducted. According to the findings, the upgraded system's electricity consumption is 32% less than that of the standard system. It also demonstrates that while the workers' visual performance in the two office spaces is equivalent, the sophisticated control system is effective in reducing uncomfortable glare sensations.

As smartphones become progressively powerful and abundant, integrating them into smart lighting systems can increase both accessibility and power efficiency. Tanga, Kalavally, Yew, and Parkkinen (2016) demonstrate a smart house model with increased security capabilities for the lighting technology [42]. An innovative closed-loop feedback technique was used in the developed Android mobile application to implement daylight collecting. Therefore, they created a new closed-loop feedback system using the light sensor on the smartphone enabling users to perform daylight harvesting while maintaining their desired lighting color.

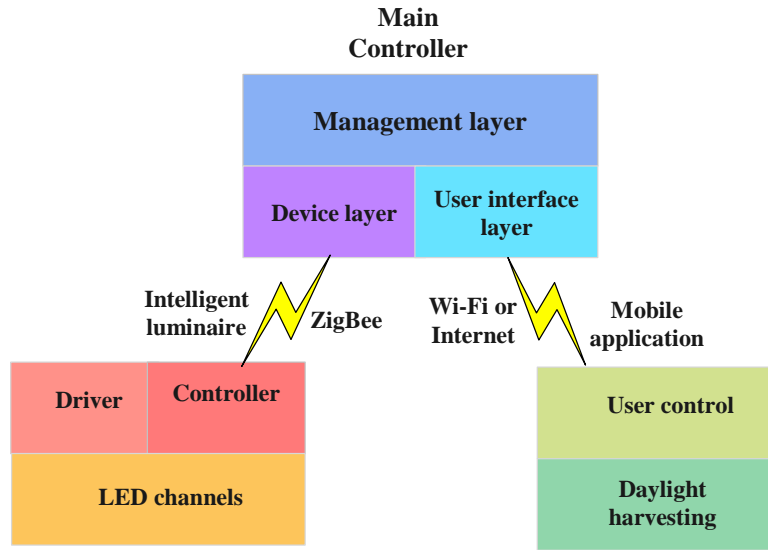


Figure 6. Architecture of the proposed smart home lighting control system [50]

Similarly, a study by Tan, Caicedo, Pandharipande and Zuniga (2017) proposes an occupancy and light sensor-driven, human-in-the-loop lighting framework that also takes user feedback into account [43]. Luminaires transmit distinctive visible light communication identifying signals in this system. A user can obtain two pieces of information by processing an image acquired with a smartphone camera: the average picture pixel value and the visible light communication identities of nearby luminaires. They created a control algorithm that takes into account these user inputs as well as inputs from occupancy and light sensors to decide how much to lower the luminaires to provide levels of illumination that users will find acceptable. In an office test bed, they contrast the performance of the suggested lighting management system with a sensor-driven lighting control system and they concluded as a proof-of-concept human-in-the-loop component was introduced in a sensor-driven lighting control system.

Basically, lighting is a vital component of contemporary living that helps consumers feel more comfortable. But in addition to vision issues, poor illumination can lead to health issues like headaches and eye tiredness. For that reason, Castillo-Martinez, Amelio, Merodio, Maria, Gutierrez-Martinez, Delgado, de-Pablos-Heredero, and Otón (2018) propose the creation of a smartphone-based app to aid in lighting assessment in order to ensure compliance with lighting rules and to help improve lighting efficiency, hence reducing its power consumption [44]. They employed a smartphone to evaluate the lighting for this evaluation, and an intelligent agent that could make decisions based on those measures was used to assess those measurements. Therefore,

this technology makes it possible to assess the actual working environment to determine lighting needs, assisting in the prevention of health issues brought on by poor illumination while also increasing lighting efficiency.

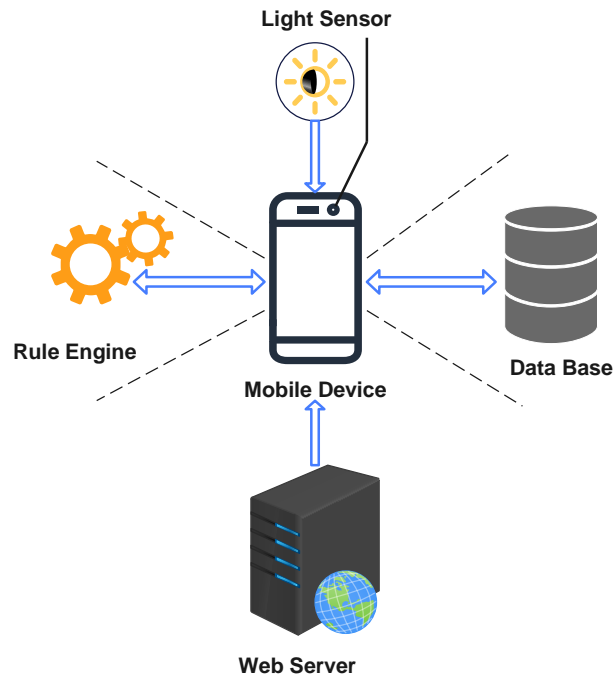


Figure 7. Evaluation and Improvement of Lighting Efficiency system structure [52]

2.4. Conclusion

Some researchers study the importance of light intensity control based on power reduction and some of their works on how to create a comfortable and healthy work environment by adjusting the light intensity of the workplace. And finally, some researchers work on smart lighting systems which can address user comfort-ability and power reduction. These researchers' conclusion was light intensity control is useful to avoid unnecessary electrical power wastage and it can create a healthy and comfortable work environment for the users. Even if these researchers solve the problem of power wastage and comfort of users, further work needs to be done on user interface aspects and also these researchers consider their own environment and they did research in their surroundings. So the research about controlling light intensity automatically and with the interaction of the user in our environment (Ethiopia) based on the daylight conditions and the preference of users is the final goal of this research.

Chapter 3. Methodology

The primary task is to identify the type of office and its light requirement according to European standards, since Ethiopia uses European AC lighting standard [45]. As expressed earlier most offices in Ethiopia uses fluorescent light, but compared to fluorescent light LED lamps save high amount of power consumption [46]. Then the available light intensity from daylight or any other artificial light source was measured to fill the remaining light on top of the existing illumination amount by driving the LED-based luminaire. To drive the LED-based luminaire controlling light intensity is essential. Controlling light intensity automatically is necessary but the system should have flexibility for the user. Controlling light intensity manually gives the user an opportunity to adjust the light intensity based on his comfort. In this paper light intensity controlling automatically and manually was designed, tested, and presented. And finally, user comfort and power consumption reduction are analyzed and studied.

Automatic light intensity controlling was designed using MAX44009 light sensor, microcontroller, AC light dimmer, DC power supply, and LEDs. Manual light intensity controlling system was designed using an android application on an android device, a microcontroller (Arduino Uno), a Bluetooth module, AC light dimmer, and LEDs. And finally, these two separate systems were integrated as one, tested, and analyzed.

3.1. Automatic Light Intensity Controller

Controlling light intensity was achieved automatically using MAX44009 ambient light sensor. This was done when the sensor senses the surrounding light intensity and sends I2C digital output to the microcontroller (Arduino Uno), then the microcontroller processes the received digital data and adjusts LEDs' light intensity through the AC light dimmer based on the received data from the light sensor. In this method programming the microcontroller device and interfacing it with the light sensor, AC light dimmer, DC power supply, and LEDs were the key tasks.

In this research the first task to do was measuring daylight occupancy of the room. The measured value from light sensor is compared with 300 lux (European standard office light illumination) [47]. If the measured data is smaller than 300 lux, then the LED lamp is set to provide the remaining illumination to maintain constant 300 lux light intensity in the room. But if the measured light intensity value is greater or equal to 300 lux, the LED lamp will be turned off.

The microcontroller was programmed to accept I2C data from the light sensor and to process it. After processing the data the microcontroller decides to adjust the input voltage for the gate of AC light dimmer. The output voltage from the microcontroller is the input voltage for the AC light dimmer. This voltage varies from 0V – 5V. The light dimmer adjusts the voltage input for LEDs based on the input voltage from the microcontroller. The different value of voltage creates a different level of LED brightness. The block diagram of automatic light intensity controller system is shown below in figure 8.

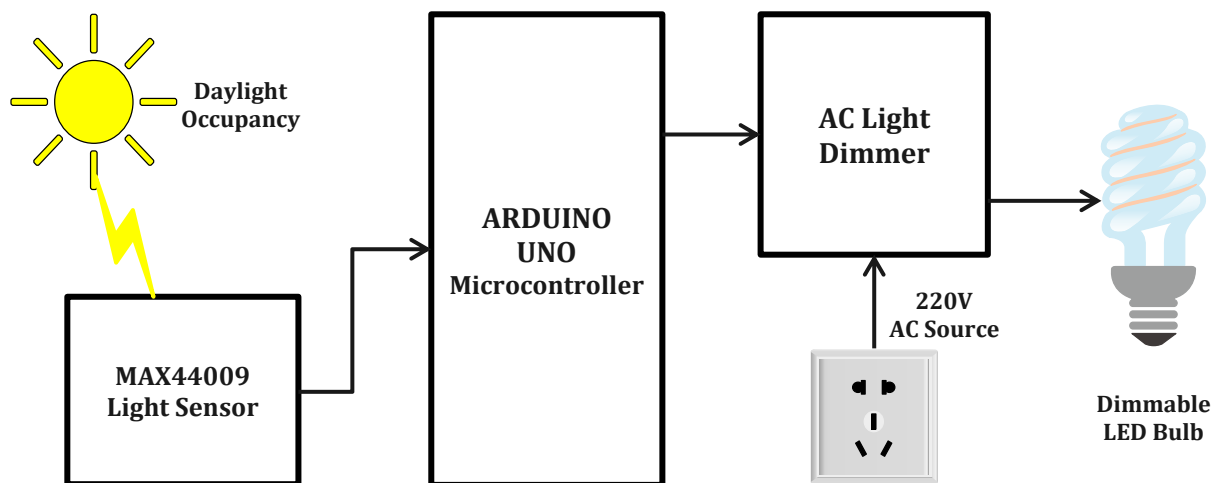


Figure 8. Automatic Light Intensity Controller System

3.1.1. Light Sensor

The light sensor is an inactive device that transforms the light power into an electrical signal output. Because they convert light power (photons) into electronic signals (electrons), light sensors are occasionally stated as photosensors or photoelectric devices.

Some of the most popular kinds of light intensity sensors include photoresistors, photodiodes, and phototransistors.

To detect the presence or absence of an object, photoelectric or photosensors use a beam of light. It emits a visible or infrared light beam from its light-emitting component [48]. Instead, a phototransistor determines how much current can flow through the circuit based on how much light it can detect. Thus, the sensor only allows a limited amount of electricity to pass in a dark space. It allows more current to flow when it detects a bright light.

For this thesis, the MAX44009 light sensor, which is among the photodiode types of sensors, was chosen as a light sensor for automatic light intensity controlling system.

3.1.1.1. MAX44009 Light sensor

For a variety of portable application devices, including smartphones, notebooks, and industrial sensors, the MAX44009 light sensor provides an I2C digital output that is ideal. It is the smallest power light sensor available and has the widest 22-bit dynamic range, ranging since 0.045 lux to 188,000 lux, making it the smallest power light sensor in the market. Simple functionality in dark-glass applications is made possible by low-light operation [49]. The on-chip photodiode's spectral response has been enhanced to more closely resemble how the human eye perceives ambient light and now has IR and UV blocking capability.

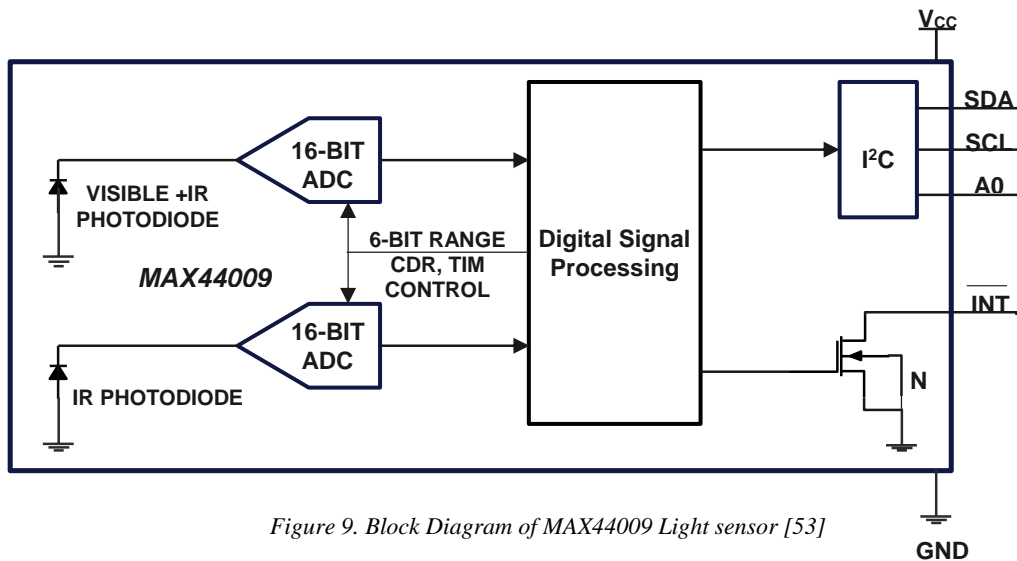


Figure 9. Block Diagram of MAX44009 Light sensor [53]

3.1.1.2. Why MAX44009 Light Sensor?

Light sensors are a class of photodetectors or photo sensors that measure light intensity, as previously explained. To convert light power into electricity, measure illuminance, or react to fluctuations in the quantity of light received, various kinds of light sensors can be utilized. A light source's brightness or intensity is detected using light sensors. Light sensors come in a variety of forms, including photoelectric, photodiode, phototransistor, and photoresistor. The MAX44009 light sensor, a sensor that includes a photodiode light sensor, was selected for this thesis out of all of the various versions of light sensors presented.

MAX44009 light sensor is better than other sensors for this thesis because of the following reasons.

- It can measure the light intensity directly in lux and give I2C data to the microcontroller.

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- It has the highest range of light intensity measurement. Which is 0.045 to 188,000 lux.
 - Since it does not contain a resistor inside it, its power consumption is the lowest compared to other light sensors like a light-dependent resistor (LDR).

3.1.2. Microcontroller

A microcontroller (MCU) is a miniature computer that is housed on a single VLSI MOS integrated circuit (IC) chip. A microcontroller contains one or more CPUs with programmable memory and input/output peripherals. On-chip programmable memory usually includes a small bit of RAM in addition to ferroelectric RAM, NOR flash, or OTP ROM[50]. The purpose of microcontrollers is for embedded applications.

Arduino Uno is one of the microcontroller boards. It was used in this thesis to control the whole lighting system.

3.1.2.1. Arduino Uno Microcontroller

The Arduino Uno is a microcontroller board material established on the ATmega328. There are 14 digital input/output pins in it. From these input/output pins 6 of them are analog inputs, a power jack, a 16 MHz ceramic resonator, a USB port, 6 pulse width modulation (PWM) outputs, and a reset button. It comes with the whole thing required to support the microcontroller [51]; and simply needs to be linked to a computer via a USB cable. It can also be powered by a battery or an AC-to-DC adapter. The Uno varies from all earlier Arduino versions in that it does not apply the future technology devices international (FTDI) USB-to-serial driver chip. As an alternative, it structures the Atmega16U2 programmed as a USB-to-serial converter.

3.1.2.2. Why Arduino Uno as a Microcontroller?

There are different types of microcontrollers that are compatible with this thesis's system, such as ARM microcontroller, Raspberry Pi, and Arduino. But for this thesis, Arduino was chosen to use as a microcontroller for the whole system. There are plenty of reasons to choose Arduino as a microcontroller for this thesis from the rest of the other microcontrollers. Some major reasons are listed below.

- **Less expensive to get started:** The low-priced Arduino board is the Arduino Nano that costs as small as 11.90 US dollar. Additional Arduino products usually vary in price from 18 to 70 US dollar.

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- **Easier to build programs:** Writing code to achieve the required program on an Arduino is considerably easier than it is on a Raspberry Pi or an ARM microcontroller.
 - **Consumes less power:** Arduino may be programmed to consume very little power [52]. This is the best choice for cases where the Arduino must run on a battery and the power source is erratic.
 - **Hardware is accessible to code easily:** Developing an Arduino draft which interacts with input and output pins and additional hardware components is simpler on Arduino compared to on Raspberry Pi or ARM. Naturally, Arduino boards lack a fully functional operating system. This eliminates the need to interact by means of the operating system during gain access to hardware, greatly simplifying the procedure.
 - **Code can access memory more readily:** Additional advantage of not containing a full operating system is, an Arduino sketch can access more of the Arduino's memory [52].

3.1.3. AC Light Dimmer

A contemporary dimmer is an electronic tool created to control the quantity of light created by incandescent and halogen bulbs, as well as fluorescent lamps in fixtures that have specialized dimming ballasts. Additionally, certain modern LED lamps can also be dimmed using these devices.

Modern resistors use a different approach to dimming lights instead of consuming power by diverting it into a resistor. They quickly turn the light circuit on and off to adjust the whole quantity of power passing inside the circuit. This means that the light bulb circuit is repeatedly switched off and on multiple times per second.

A contemporary dimmer switch breaks up the sine wave by interrupting the light bulb circuit whenever the current changes direction, resulting in zero voltage going inside the circuit. This occurs twice each cycle, or approximately 100 times a second. The switch then turns the circuit back on once the voltage reaches a specific level.

The "turn-on value" of the circuit depends on the place of the knob or slider on the dimmer switch. If the dimmer switch is set to a brighter lighting level, it will switch on almost immediately after turning off. This means the circuit will be turned on for a more significant portion of the cycle, providing more power to the light bulb. On the other hand, if the dimmer switch is adjusted to a lower lighting level, it will delay turning back on up until far ahead in the cycle.

Dimmer modules that are commonly used provide cost-effective digital forward phase angle dimming for traditional loads such as incandescent, low voltage, quartz, neon, cold-cathode, and fluorescent ballasts with 2/4 wires.

3.1.3.1. Working Principle

The AC light dimmer of today includes a zero crossing detector, Triac, and Optocoupler. Its operation involves removing segments from the AC voltage waveform, which permits only certain portions to reach the lamp. The amount of power transferred to the lamp dictates its brightness, meaning that the more segments are removed from the waveform, the greater the dimming effect.

Zero Crossing Detection

In order to regulate the AC voltage, the initial step is to identify the instances where the AC signal crosses zero voltage. Zero-crossing detectors are designed to detect these points and relay this information to the controller or control circuit. The MCT2E optocoupler is employed as a zero-crossing detector component within the AC light dimmer module. This component serves to reduce the rate of current change with respect to time (di/dt), leading to lower levels of heating and start-up current in the load, hence extending the lifespan of the load, such as a lamp.

TRIAC

A dimmer switch is used to regulate the amount of power supplied to a light circuit by rapidly switching the circuit on and off. The key component in this switching system is a triode alternating current switch, also known as a triac. An electronic circuit determines the precise moment when the triac should turn ON (conduct), and the triac remains in the ON state until the next zero-crossing point is reached, at which point it turns itself OFF. After a brief delay, which corresponds to the desired level of dimness, the control device is turned back on by the electronic circuit. The load's slight capacitance filters the chopped waveform, resulting in a smooth and consistent light output.

In this particular scenario, the AC signal has a frequency of 50 Hz, resulting in a time period of $1/f$, which is 20 ms. As a result, for a half cycle, the duration would be 10 ms or 10,000 microseconds. Therefore, in order to regulate the power of the AC lamp, the "t1" duration can be adjusted within the range of 0-10,000 microseconds. The BT136 TRIAC is utilized in this AC light dimmer module for the purpose of dimming AC lamps.

Optocoupler

An optocoupler, also known as an optoisolator, is employed to maintain isolation between two distinct electrical circuits, such as DC and AC signals. This component consists of an LED that emits infrared light and a photosensor that detects it. In this particular scenario, a MOC3021 optocoupler is utilized to regulate AC lamps via microcontroller signals, which are DC signals.

3.1.4. Light Emitting Diode Lamp

A light emitting diode is a semiconductor light basis that releases light during current runs inside it. Electrons inside semiconductors connect with holes, discharging power in the way of photons of light. The color of light, equivalent to the power of photons, is decided by the power needed for electrons to pass the band gap of semiconductors. White light is attained by using numerous semiconductors or a layer of light-emitting phosphor on the semiconductor device [53].

Lighting

Effective lighting is desired for consistent architecture. As of 2011, some LED bulbs deliver up to 150 lm/W and even cheap low-end models normally surpass 50 lm/W, so a 6-watt LED could attain the same brightness as a standard 40-watt incandescent bulb. The smaller heat output of LEDs also minimizes requests for air conditioning systems. International, LEDs are quickly accepted to relocate less efficient sources such as incandescent lamps and CFLs and decrease electrical power dissipation and its related radiations. Solar-driven LEDs are used as street lights and in architectural lighting.

3.1.4.1. Why LEDs?

LEDs have lots of importance over incandescent light sources, counting longer lifetime, lower power dissipation, smaller in size, improved physical strength, and quicker switching. In exchange for these mostly positive qualities, drawbacks of LEDs contain electrical restrictions to low voltage and totally to DC (not AC) power supply, failure to deliver constant illumination from a vibrating DC or an AC electrical supply source, and smaller maximum functioning temperature and storage temperature. Compared to LEDs, incandescent lamps can be made to fundamentally run at virtually any supply voltage, can use either AC or DC current interchangeably, and will deliver constant brightness when driven by AC or vibrating DC even at a frequency as low as 50 Hz. LEDs regularly need electronic support apparatuses to operate, while an incandescent bulb can and commonly does function directly from an unregulated DC or AC power source. [54] Despite these

disadvantages, LEDs are more suitable for this thesis based on their longer lifetime, lower power dissipation, smaller size, improved physical strength, quicker switching, and dimmable properties.

3.2. Manual Light Intensity Controlling

Controlling light intensity manually is another light intensity controlling method. This method was implemented by interfacing an android phone or tablet, a microcontroller which is Arduino Uno, MOSFET, Bluetooth module, and LEDs together. In this method, the user can control light intensity via Bluetooth by means of application on an android phone or tablet. Programming the microcontroller device and interfacing it with the Bluetooth module, Android phone application, and LED were the key tasks to design manual light intensity controlling system. Since microcontroller, AC light dimmer, and LEDs are described earlier it is not necessary to repeat it. To achieve this system android application development, Bluetooth module HC-05, programming of microcontroller to control the current/voltage driver which can limit the current/voltage input into LED lamp, and interfacing these all devices were essential processes. The following block diagram shows how these all devices are connected to design manual light intensity controlling system.

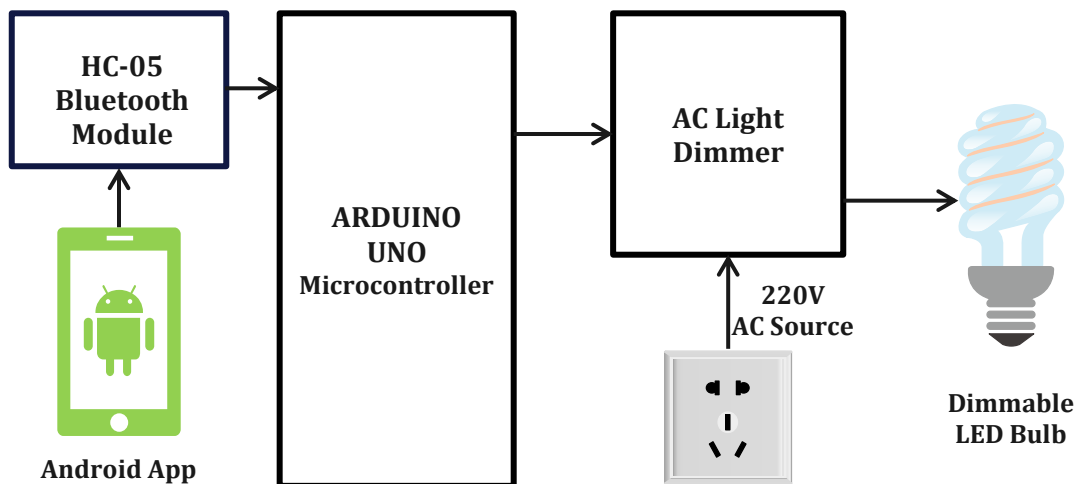


Figure 10. Controlling Light Intensity manually using Android Device

3.2.1. Android Application

The application was built using the online application development tool called MIT App Inventor online application. The main purpose of this application is to empower the user to adjust light intensity manually. In this application there is list picker that is used to connect with the Bluetooth module. After successfully connected with the required Bluetooth device, the user can send data

by moving the slide. The slide bar can send data from 1 to 255 to the microcontroller. Based on the received data the microcontroller maps 1 to 0% and 255 to 100% intensity level. This intensity level will be implemented on the LED lamp.

3.2.1.1. Why MIT App Inventor?

MIT App Inventor is a web application combined development environment formerly delivered by Google and now continued by the Massachusetts Institute of Technology (MIT). It uses a block-based programming language constructed on Google Blockly and stimulated by languages such as StarLogo TNG and Scratch, enabling anyone to build a mobile phone app to meet a requirement.

In this thesis, MIT App Inventor is used to develop an android application for the manual light intensity controlling system. There are different reasons that make MIT App Inventor a better android application development environment than using the actual android studio for the thesis. Some of the reasons to choose the MIT app inventor for building an android app are listed below.

- The developed application was simple light intensity controlling app so
 - No need to install a bulky android studio on a personal computer.
- Every working file can be saved and retrieved easily from the website.
- Building an app is done in a drag and drop manner.
- Easy to test your application.
- Power of natural apps with a simple User Interface.
- MIT App Inventor offers the user some initial lessons which support designing the app and that help in an accurate understanding of how the MIT app inventor platform works for the user [55].

3.2.2. Communication Device System

A communication device is a hardware device that has the ability to transfer and/or accept an analog or digital signal through the telephone, wirelessly or other communication wire. For this thesis, there are two major communication device options to use [56]; ZigBee and Bluetooth. ZigBee is a wireless communications protocol method, somewhat like Bluetooth, applied for machine-to-machine (M2M) interconnection and control. In this thesis, Bluetooth was chosen as a communication device.

3.2.2.1. The Bluetooth Module

In this experiment a Bluetooth module, HC-05 was used. This device is a simple-to-use Bluetooth Serial Port Protocol (SPP) unit, intended for an apparent wireless serial communication arrangement. Its communication is through serial communication which creates an easy way to interface with a microcontroller or PC. The function of this module is to transfer the data from the Android application into the microcontroller (Arduino Uno) and vice versa. After receiving the data, the microcontroller decides to adjust the light intensity of the LED-based on its program and received data from the application.

3.2.2.2. Why Bluetooth Module?

Bluetooth module was the best communication device for this thesis. There are different reasons to conclude this. Some reasons are presented in the following table. The table shows the major differences between Bluetooth and ZigBee to give more clarification on why Bluetooth is better than ZigBee for this specific thesis. [56]

Item	Bluetooth	ZigBee
Network speed	1 Mbit/s	250 Kbit/s
Protocol stack size	120 kbyte	28 kbyte
Network range	1 or 100 m, depending upon radio class	70 m
Usual network join time	3 seconds	30 milliseconds
Modulation technique	Frequency Hopping Spread Spectrum (FHSS)	Direct Sequence Spread Spectrum (DSSS)
Battery lifetime	Proposed for frequent charging	Not rechargeable – depends on long battery life (up to 10 years)

Table 1. Comparison between Bluetooth module and ZigBee [101]

As shown above from the specifications the Bluetooth module has a faster network speed, and a large protocol stack size, the network range can reach up to 100m and it is more compatible and easy to communicate with an android application without being online [56]. So for this thesis Bluetooth module was chosen for the manual light intensity controlling system.

3.3. Integrated Automatic and Manual Light Intensity Controller

After working on the individual light intensity controlling system (automatic and manual light intensity controlling systems), the final step was integrating them into one system. So that the user can use the system automatically or manually. When these systems are integrated, the manual light intensity controlling system takes the priority. This means if the user desires to adjust the light intensity at any time, the system mode can be changed from an automatic controlling system to a manual controlling system. Otherwise automatic controlling mode is the default mode of the integrated system. The system was integrated as shown in the block diagram below.

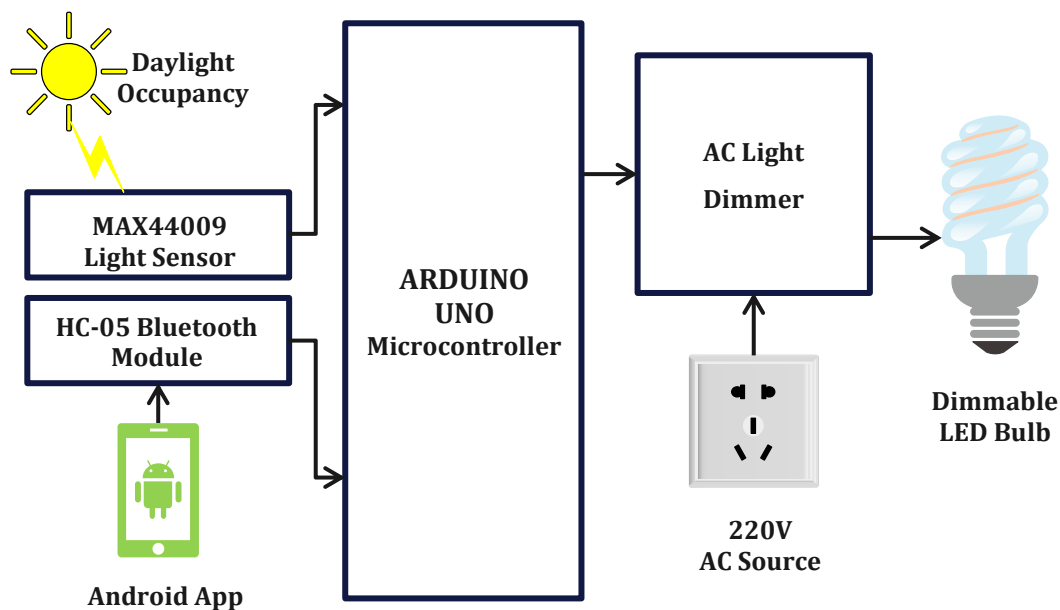


Figure 11. Integrated Light Intensity Controlling System

Chapter 4. Result

4.1. Automatic Light Intensity Controller

In the automatic light intensity control system the MAX44009 light sensor sends I2C signal into the Arduino Uno, then the Arduino interprets this data into lux units based on the given algorithm below [49]. Register 0x03 and 0x04 is register address of MAX44009 light sensor for lux reading. These registers contain 8 bits each.

Register Address	BIT 0	BIT 1	BIT 2	BIT 3	BIT 4	BIT 5	BIT 6	BIT 7
0x03	M4	M5	M6	M7	E0	E1	E2	E3

Table 2. Lux High-Byte Register 0x03 [49]

$$\text{Exponent} = 8 \cdot E3 + 4 \cdot E2 + 2 \cdot E1 + E0$$

$$\text{Mantissa} = 8 \cdot M7 + 4 \cdot M6 + 2 \cdot M5 + M4$$

$$\text{Lux} = 2^{(\text{Exponent})} \cdot \text{Mantissa} \cdot 0.45$$

This data shows the light intensity entered into the workplace from daylight. Based on this data the program inside the Arduino (microcontroller) decides to adjust the brightness of the LED lamp to maintain fixed 300 lux brightness inside the office (300 lux is standard office light brightness for the offices which works on paper and computer work in Europe). If the data from the light sensor shows light intensity less than 300 lux, then the brightness of the lamp will be automatically adjusted to maintain 300 lux. But if the data from the daylight is greater than or equal to 300 lux then the lamp will be off. This case is very rare because most offices have curtains to prevent sunshine.

To achieve this system, the intensity of daylight occupancy in offices was measured for 10 different days inside AAiT compound at Samsung building N115B office with absolute location of 9.03988479312119 latitude, and 38.75286860645225 longitude. This office contains two windows with curtains. The sample was taken in every 30 seconds during working hours (9:00 AM – 5:00 PM). Which is totally around 960 data for 8 working hours of each day. In these 10 days 7 days was cloudy and rainy, so one average data was formed from them. And the rest 3 days was sunny,

so one additional average data was taken for sunny days. Minimum and maximum data value for 7 cloudy and 3 sunny days are presented in the table below.

Day	1	2	3	4	5	6	7
Minimum Intensity (Lux)	8.07	8.53	7.65	6.42	5.98	9.34	7.65
Maximum Intensity (Lux)	130.25	124.6	138.57	124.62	128.96	130.25	134.64
Average Intensity (Lux)	60.4125	48.5674	58.8946	56.6543	50.256	52.3467	54.5256

Table 3. Data for intensity of daylight occupancy in cloudy or rainy days

The data presented in table 3 are collected in mostly cloudy and rainy days. In these days the daylight occupancy of offices are very low, so power consumption reduction might not be as high as power consumption reduction in sunny days.

Day	1	2	3
Minimum Intensity (Lux)	97.45	95.31	91.29
Maximum Intensity (Lux)	232.38	229.41	235.39
Average Intensity (Lux)	178.181	175.23	180.67

Table 4. Data for intensity of daylight occupancy in sunny days

The data presented in table 3 can be expressed as a chart below. In the chart the blue line shows the exact measured light intensity from the sun in the office. The green line shows the approximate equation line which is designed to fit the scattered data from the sun throughout the day. In the following graphs time is expressed in decimal points. It starts from 3 and ends at 11 to represent 9AM to 5PM East African Time in ascending order.

$$\text{Time (t)} = \frac{(((\text{Hour} \times 60) + \text{Minute}) \times 60) + \text{Seconds}}{3600}$$

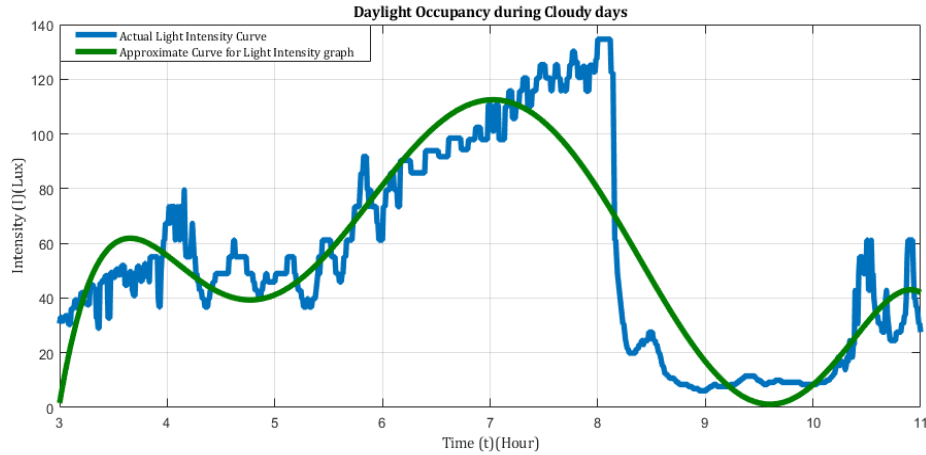


Figure 12. Modelling actual data of daylight occupancy intensity in cloudy or rainy days

The data from light sensor which measures the daylight occupancy of the room during cloudy days at one of working tables is approximated with the following equation. This equation is a polynomial equation with degree 6 and with 7 coefficients, which was found from fitting a data into equation using MATLAB. It does not fit the scattered data perfectly but it is the most efficient approximation model. The equation is presented below: I_{s1} stands for light intensity from sun in lux and t stands for time in decimal points.

$$I_{s1} = -24.42*x^6 + 12.129*x^5 + 127.55*x^4 - 33.851*x^3 - 193.37*x^2 + 4.4128*x + 112.47$$

Where $x = (t - 7.0001)/2.3129$

The data presented in table 3 can be expressed as a chart below. In the chart the blue line shows the exact measured light intensity from the sun in the office. The green line shows the approximate equation line which is designed to fit the scattered data from the sun throughout the day.

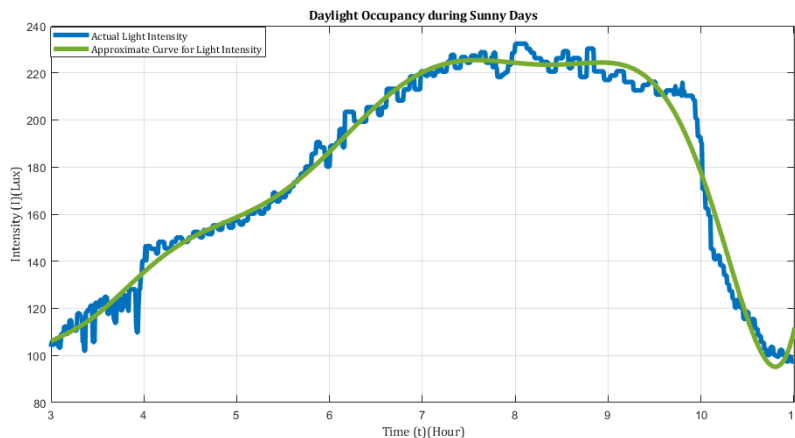


Figure 13. Modelling actual data of daylight occupancy intensity in sunny days

The data from light sensor which measures the daylight occupancy of the room during sunny days at one of working tables is approximated with the following equation. This equation is a polynomial equation with degree 10 and with 11 coefficients. It does not fit the scattered data perfectly but it is the most efficient approximation model. The equation is presented below: I_{S2} stands for light intensity from sun in lux and t stands for time in decimal points.

$$I_{S2} = -2.673*x^{10} + 3.202*x^9 + 32.15*x^8 - 13.01*x^7 - 118.7*x^6 + 8.915*x^5 + 161.5*x^4 - 10.74*x^3 - 105.4*x^2 + 45.4*x + 220.2$$

$$\text{Where } x = (t - 7)/2.313$$

After measuring and modelling the daylight occupancy in the office, now is the time to calculate the light intensity required from the lamp to maintain 300 lux in the office working table. Which can be calculated by subtracting the daylight occupancy from 300 lux. This data is presented below for 7 cloudy or rainy and 3 sunny days, respectively.

Day	1	2	3	4	5	6	7
Maximum Intensity (Lux)	291.93	291.47	292.35	293.58	294.02	290.66	292.35
Minimum Intensity (Lux)	169.75	175.4	161.43	175.38	171.04	169.75	165.36
Average Intensity (Lux)	239.5875	251.4326	241.1054	243.3457	249.744	247.653	245.474

Table 5. Intensity needed from LED lamp for cloudy and rainy day

Day	1	2	3
Maximum Intensity (Lux)	202.55	204.69	208.71
Minimum Intensity (Lux)	67.62	74.59	64.61
Average Intensity (Lux)	121.819	124.77	119.33

Table 6. Intensity needed from LED lamp for sunny days

Since the occupancy of daylight is modelled above, the modelling of data from lamp can be calculated easily as follows:

$$I_{L1} = 300 - I_{S1}$$

$$I_{L1} = 24.42*x^6 - 12.13*x^5 - 127.6*x^4 + 33.85*x^3 + 193.4*x^2 - 4.413*x + 172.5$$

Where $x = (t - 7)/2.313$

$$I_{L2} = 300 - I_{S2}$$

$$I_{L2} = 2.673*x^{10} - 3.202*x^9 - 32.15*x^8 + 13.01*x^7 + 118.7*x^6 - 8.915*x^5 - 161.5*x^4 + 10.74*x^3 + 105.4*x^2 - 45.4*x + 79.8$$

Where $x = (t - 7)/2.313$

In this equation I_{L1} and I_{L2} stands for required light intensity from lamp at time t during cloudy and sunny days, respectively.

The MAX44009 sensor senses the light intensity in the room and sends the signal to the microcontroller. The microcontroller compares the data with 300. If the data from the sensor is greater than 300, then the light intensity of the lamp will be reduced to maintain 300. But if the data from sensor is less than 300, then the light intensity of the lamp will be increased by the microcontroller to maintain 300 lux in the room. This light sensor acts as feedback device to adjust the stability of light intensity in the office.

The average data was calculated from the collected 960 data of cloudy and sunny days. Both intensity of daylight occupancy and required light intensity from lamp for cloudy or rainy and for sunny days are presented in figures below.

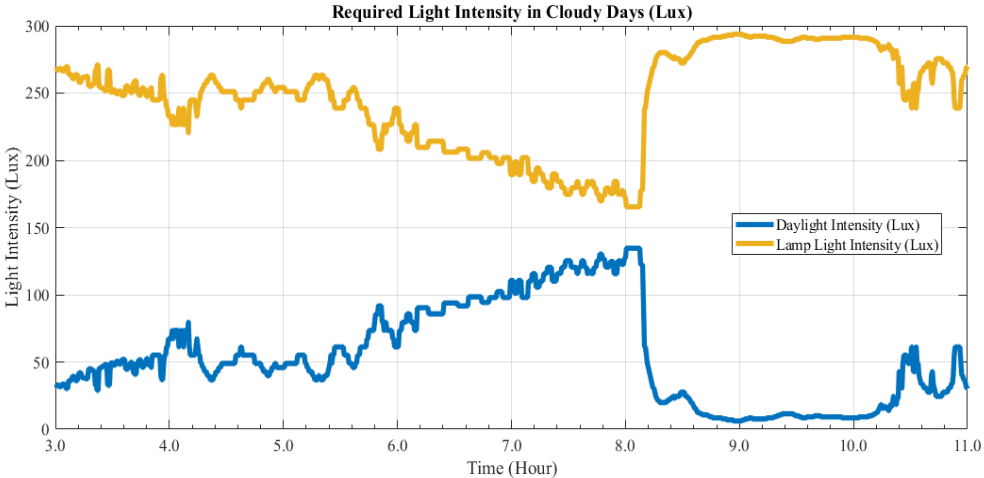


Figure 14. Required light intensity during cloudy or rainy days

The light sensor measures maximum of 134.64 lux around 2 PM and a minimum of 7.65 lux around 3 PM. These data shows that the daylight occupancy can contribute about 2.55 % up to 44.88% of the light intensity of the room in cloudy days. When the average light intensity from sun is calculated, it is 54.5256 (18.2%) during cloudy or rainy days. This means that the average required light intensity from the lamp can be reduced up to 18.2% during cloudy and rainy season. But the designed system to control light intensity can waste up to 750mW (400mW due to AC dimmer module [57][58], 250mW due to Arduino Uno Board [59], 2.145 μ W due to MAX44009 [49] and 100mW due to Bluetooth module [60]).Which in return contributes to the reduction of power consumption due to lighting but there is 750mW constant power wastage due to the new system.

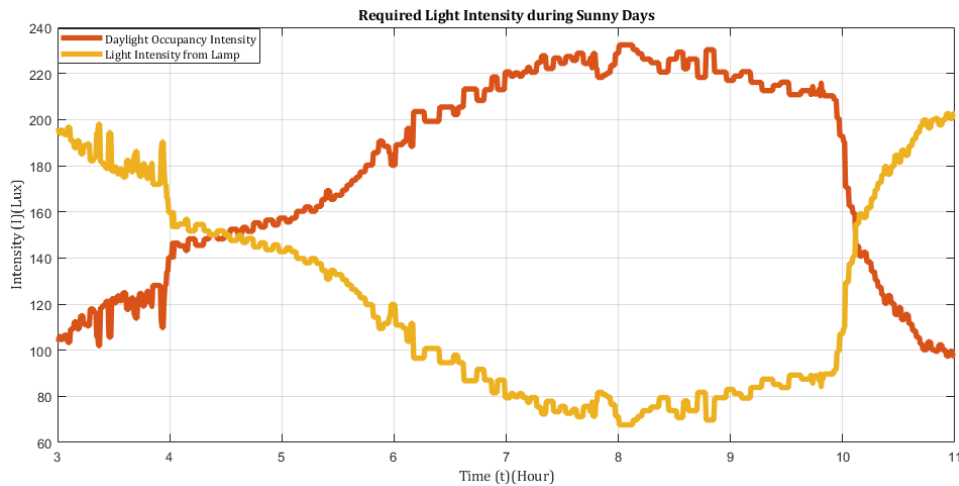


Figure 15. Required light intensity during sunny days

For sunny days the light sensor measures maximum of 232.38 lux around 2 PM and a minimum of 91.29 lux around 5 PM. These data shows that the daylight occupancy can contribute about 30.43 % up to 77.46 % of the light intensity of the room in cloudy days. When the average light intensity from sun is calculated, it is 178.18 (59.4 %) during sunny days. This means that the average required light intensity from the lamp can be reduced up to 59.4% during sunny season. Which in return contributes to the reduction of power consumption due to lighting but with constant power consumption of 750mW due to the system. This constant power consumption can be ignored for the large system. But if this system is used for one LED lamp with 5W power consumption rating then the system power consumption will be significant.

Based on this principle the data from light sensor and the lamp are analyzed to measure the power consumption reduction of the designed system.

The relationship of the lamp brightness (lumen) and power consumption is called efficacy. Nowadays efficacy of LED lamps is reached around 300 lm/W [61]. Meaning 300 lumen of brightness can be generated with 1 watt power.

Offices have around 2.5 meter standard height and office tables have average standard height of 0.8 meter. 300 lux of light intensity is required at this table inside every office. If this office have 5 meter length and 4 meter width, its area will be 20 m².

$$\text{Intensity (lux)} = \text{Lumen} / \text{Area}$$

So the required lumen can be calculated as:

$$\text{Lumen} = \text{Intensity} \times \text{Area}$$

$$\text{Lumen} = 300 \text{ lux} \times 20 \text{ m}^2 = 6000 \text{ lumen}$$

$$\text{Power} = \text{Lumen} / \text{Efficacy}$$

$$P = 6000 \text{ lumen} / 300 \text{ lumen watt}^{-1} = 20 \text{ watt}$$

To provide 6000 lumen in 20 m², 20 watt power will be needed. But using the designed system the lamps has not to provide 300 lux always. So the system can reduce up to 44.88% to 77.46% of illumination from lamps. So the power consumption of LED lamps will be reduced by 30.43% to 77.46% for sunny days and by 2.55% to 44.88% during rainy or cloudy days.

In this research power consumption reduction is only calculated not measured because the proposed dimmable LED lamp is not available in Ethiopia, so the system is designed using Incandescent lamp. Fortunately incandescent lamp is dimmable to show if the designed system is working or not. Since incandescent lamp provides heating purpose in addition to lighting, measuring power consumption reduction of the system using this lamp cannot show the amount of power consumption reduction for dimmable LED lamp.

4.2. Manual Light Intensity Controller

Nowadays people wants controlling things through remote controllers without physically touching the device. Also in light intensity controlling system, the user wishes to adjust light intensity as needed using remote controllers like android phones or tablets. In manual light intensity controlling mode the system contains android device, an application, Bluetooth module,

microcontroller board (Arduino Uno), voltage/current driver and LED lamp. In this system when the user needs to adjust the LED lamp light intensity, he simply sends the data from the Light Intensity Controller android application on his android phone. The graphical user interface of the android application is shown in figure 16. This data reaches to the microcontroller via Bluetooth, and this microcontrollers decides the level of the light intensity and applies it on the lamp through AC light dimmer module. So the user is free to adjust light intensity inside the office up to a maximum of 300 lux. The general designed system in this research gives priority to the users demand and wellbeing.

This additional feature makes the whole system flexible. If the user have health problem due to high light intensity, and also if the user prefers small brightness in the room, this additional feature makes the whole system preferable than automatic only system. Also this feature might reduce power consumption of lighting. But since it is personal preference the amount of reduced power consumption is not determined.

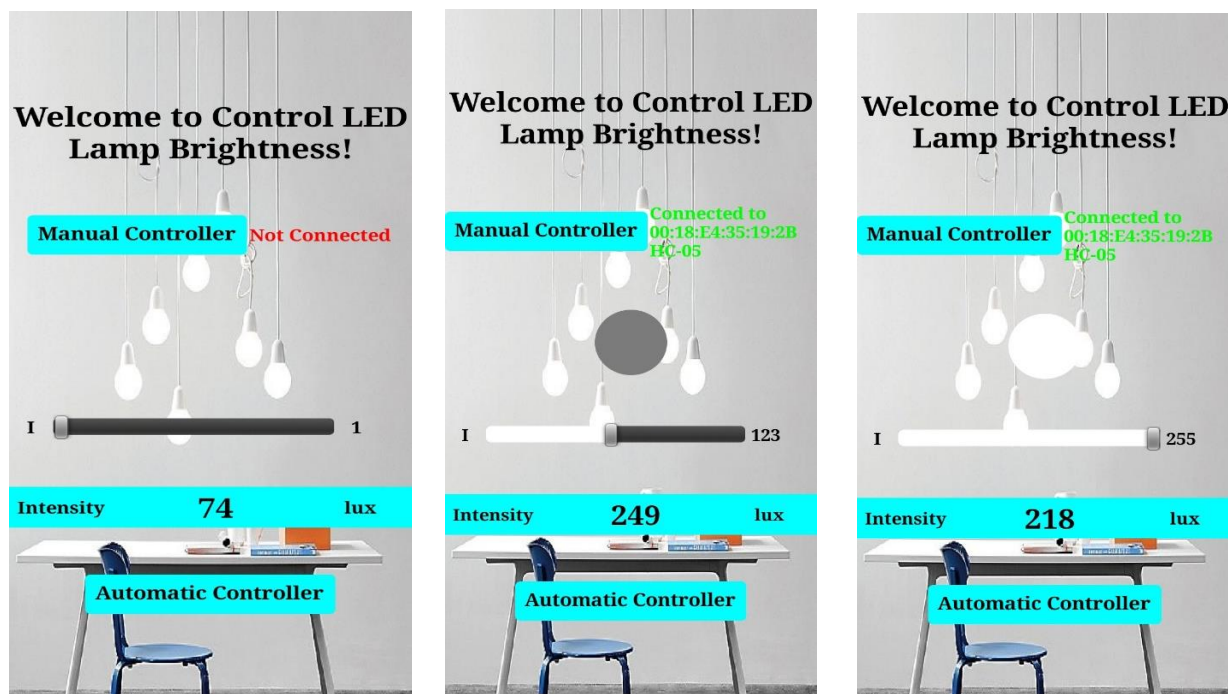


Figure 16. Graphical user interface of designed android application in different connection states.

The above figure shows graphical user interface of designed android application to controlling light intensity manually. First the user should click on Manual Controller button to connect the application with Bluetooth module. After successfully connecting with Bluetooth module, the user

can adjust the brightness of the lamp by moving the slide on the slide bar. If the user wants to enter automatic light intensity controller mode, clicking the Automatic Controller button will simply change the system into automatic light intensity controller mode. The whole integrated light intensity controlling system is shown in pictures below.

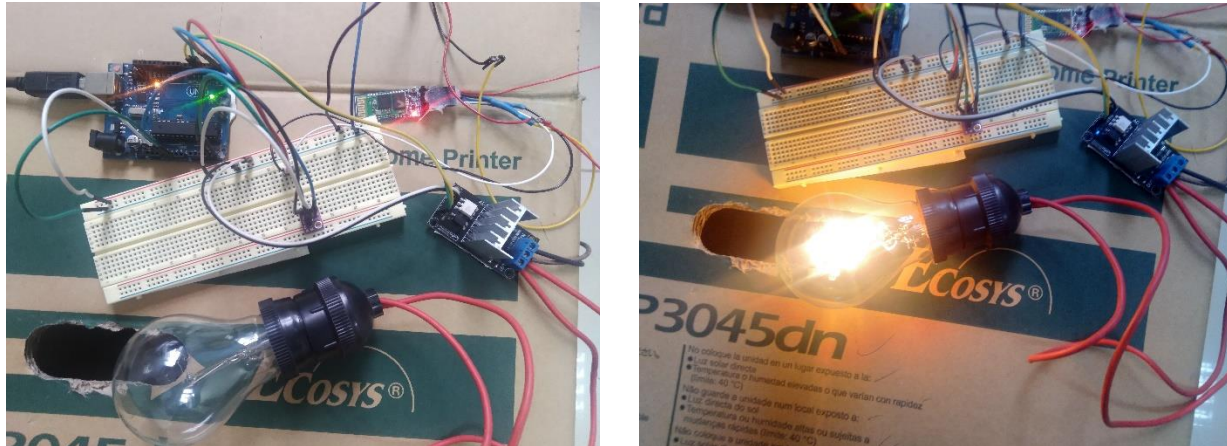


Figure 17. Light intensity controlling system with Incandescent lamp.

The first picture shows the integrated light intensity controlling system. This system contains Bluetooth module in the right corner, AC dimmer module in the right side, Incandescent lamp at the bottom, breadboard and MAX44009 light sensor in the middle and Arduino Uno microcontroller board at the left corner. The second picture from left to right shows when the incandescent lamp is varying its intensity.

Chapter 5. Conclusion and Future Work

5.1. Conclusion

Lighting accounts 20% of global power consumption in offices and in public places it can soar up to 50% [1]. A majority of power spent on lighting is wasted because of inefficient management of occupancy of daylight conditions. In this paper automatic light intensity controlling system using light sensor was designed and developed. In this system the LED lamp provides the required light intensity in addition of daylight occupancy to maintain 300 lux in the office. Based on the measured data from light sensor, the daylight can provide light intensity of a minimum 7.64 lux and maximum 134.65 lux during cloudy or rainy days. This means the required light intensity from lamp can be reduced up to 44.88%. This light intensity reduction will lead to power consumption and cost reduction of lighting up to 44.88%. But during sunny days power consumption reduction might reach up to 77.46%. Which leads to the average of 18.2% to 59.4% power consumption reduction.

In most parts of Ethiopia 3 months are known to be cloudy and rainy but the rest 9 months are sunny. So, the overall power consumption reduction can be calculated as follows:

$$\text{Power consumption reduction (\%)} = \frac{(9 \times 59.4\%) + (3 \times 18.2\%)}{12} = 49.1\%$$

So the overall power consumption can be reduced with 49.1%, in the office room where the daylight occupancy was measured.

In addition to automatic lighting controller, this system contains controlling light intensity manually using android applications. The purpose of adding this system is to create comfortable and healthy lighting situation in the workplace. If the user have health problem due to high light intensity, and also if the user prefers small brightness in the room, this additional feature makes the whole system preferable than automatic only system. This system shows how the light intensity of the LEDs can be adjusted with the use of android device application and Bluetooth device based on the user light intensity level preference. In this system the user sends data from his mobile application into Arduino Uno via Bluetooth module, then this microcontroller adjusts the light intensity of the lamp based on the received signal and its programming. If the user prefers low

light intensity level, then based on the received data the microcontroller adjusts the light intensity as needed. And also if the user wants high light intensity, the microcontroller decides to increase the LED light intensity. Or else if the user wants to turn off the light he can simply do it from his phone by sending a data into the microcontroller. Even if it is not determined this system might have the chance to reduce power consumption and cost reduction due to lighting.

5.2. Future Work

As mentioned previously, it is important to provide the appropriate level of light intensity and color spectrum for different tasks or surroundings. Failure to do so not only results in power wastage, but can also have negative impacts on health and psychological well-being due to over-illumination [7]. The main purpose of this research is to minimize power consumption and to create more comfortable and healthy work environment for workers. Based on the measured data from light sensor, the maximum light intensity from sun is 134.64 lux during cloudy days and 232.38 lux in sunny days. So power consumption reduction can be reach up to 49.1%. But since Ethiopia is known as “13 months of sunshine”, the daylight intensity of offices can be maximized by using transparent, anti-glare and also radiation minimizer materials. This can be achieved by using glass windows with required characteristics. If this can be done the power consumption of power due to lighting can be reduced up to 90% or more. And also, this can be achieved by re-arranging the tables in the office room by facing them towards the window.

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