Addis Ababa University
College of Technology & Built environment
Center for Renewable Energy Technology

Study of Lighting Energy Reduction using Intelligent Lighting Control Systems: The case of the Commercial Bank of Ethiopia Head Quarter Building

By

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Declaration

I, Yonas Woubshet, declare and certify that this thesis titled, "Study of Lighting Energy Reduction using Intelligent Lighting Control Systems: The case of the Commercial Bank of Ethiopia Head Quarter Building" is my original work, and that all sources and materials used in this thesis have been duly acknowledged. This thesis is submitted in partial fulfillment of the requirement for the Master of Science degree in Renewable Energy Technology at Addis Ababa University, College of Technology and Built environment, Center for Renewable Energy Technology, and to be made available at the university's library. I confidently declare that this thesis has not been submitted to any institutions anywhere for the award of any academic degree, diploma, or certificate.

Author	Signature	Date

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Acknowledgment

First of all, I want to praise God and his mother St. Mary for the wisdom, perseverance, strength, and patience they gave me to get through this work. I would like to express my heartfelt appreciation to my advisor Dr. Fitsum Salehu, for his insightful conversations and comments which improved my understanding of the topic, and also, I would like to thank my co-advisor Mr. Nebyu Yonas for his expertise guidance that encourages me to learn more about this research. I also like to express my deepest gratitude to the staff members of college of Technology and built environment, Center for Renewable Energy Technology for their deep concern, valuable comments and suggestions as well as timely progress follow-up during the course of this thesis work. Further, my sincere thanks go to my family, colleagues and friends, for their unlimited support and encouragement.

Dedication

To my beloved family and friends.

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List of Acronyms

A.A.	Addis Ababa
A.A.U.	Addis Ababa University
BMS	Building Management System
CBE	Commercial Bank of Ethiopia
CMS	Centralized Management System
CSCEC	China State Construction Engineering Corporation
DALI	Digital Addressable Lighting Interface
DBB	Design-Bid-Build
DHS	Daylight Harvesting System
DMX	Digital Multiplex
DoE	Department of Energy
EC	Ethiopian Calendar
ETB	Ethiopian Birr
EU	European Union
FIDIC	Fédération Internationale Des Ingénieurs-Conseils
GHGs	Greenhouse Gases
HQ	Head Quarter
HVAC	Heating, Ventilation and Air Conditioning
IBMS	Integrated Building Management System
ID	Identification
ILS	Intelligent Lighting System
IoT	Internet of Things
IR	Infrared Radiation
KWh	Kilo-Watt hour
LA	Los Angeles

LED	Light Emitting Diode
LEED	Leadership in Energy and Environmental Design
LVDC	Low Voltage Direct Current
Mtoe	Millions of tons of oil equivalent
MW	Mega Watt
OLED	Organic Light-Emitting Diode
PIR	Passive Infrared Radiation
PMS	Power Management Systems
SDB	Sub-Distribution Board
SSL	Solid State Lighting
UPS	Uninterrupted Power Supply
USA	United States of America
USD	Unites States Dollar
WSN	Wireless Sensor Networks
WWR	Window-to-Wall Ratios
ZEB	Zero-Energy Buildings
ZNE	Zero Net Energy

Abstract

Artificial lighting powered from non-renewable energy sources is a major contributor to energy consumption, greenhouse gas emissions, and environmental pollutions. In buildings, lighting systems account for a significant share of total energy use. The demand for energy is rising daily due to population growth, lifestyle changes, and technological advancements. This surge in demand has triggered an energy crisis, particularly alarming for developing countries like Ethiopia. This crisis has profoundly affected daily life, business operations, and building construction. Therefore, it is crucial to optimize the use of available electric energy sources by adopting new, highly efficient lighting control systems to bridge the gap between gross power production and the nation's energy demand. This research study work examines the use and functionality of presence-based intelligent lighting control and daylight harvesting systems installed in the tallest structure in East Africa, the Commercial Bank of Ethiopia Headquarters (CBE-HQ). To evaluate system effectiveness, actual lighting energy consumption measurements and comparisons with other traditional lighting control approaches were carried out. According to the results, the CBE-HQ daylight harvesting system saved 79.88% more energy than fluorescent lighting systems and 59.76% more than conventional Light Emitting Diode (LED) systems. Similarly, compared to conventional LED and fluorescent systems, the presence-based lighting management system reduced energy consumption by 44% and 72%, respectively. Beyond substantial energy savings, the study reveals that the intelligent lighting control systems also considerably decreased the building's potential carbon footprint, reducing annual CO_2 *emissions by about 50 tons when compared to ordinary LED systems and 138 tons when compared to fluorescent-based lighting systems. The study recommends design reconsiderations, policy interventions, public awareness and education, regulatory measures, research and development support, and international collaborations to advance the adoption of state-of-the-art lighting technologies and enhance national energy efficiency efforts.*

Key Words: Lighting, Intelligent Lighting Control Systems, Daylight Harvesting System, Presence-Based Lighting System, SSL, LED.

Chapter One

1. Introduction and Background

1.1. General Overview

As global warming, environmental pollution, and resource depletion become major concerns, inefficient energy production and consumption are significant contributors worldwide [1,3]. Energy saving and environmental protection are now critical, including in artificial lighting, which accounts for 20–45% of total building energy use[4,5] the energy consumed in buildings for lighting purpose is in the range of 20-45% of the total energy consumption in the building.

Globally, lighting represents nearly one fifth of overall energy consumption, contributing about 6% of greenhouse gas emissions [6, 13]. Consequently, maximizing energy efficiency, monitoring, and control in building lighting systems has been a major research focus over the past decades, emphasizing both energy savings and user comfort of living [2,14,15].

Buildings consume roughly 30% of global energy and about 60% of electricity, with lighting constituting a significant portion [1,7]. Studies have shown that intelligent lighting systems, including daylight harvesting and occupancy-based controls, can significantly reduce energy consumption by optimizing artificial lighting and leveraging natural daylight [7,8,16]. Figure **1-1** illustrates energy consumption across sectors, highlighting the substantial share of buildings in developed regions. For example, more than 35% of energy in the European Union and around 30% in the USA is consumed in buildings.

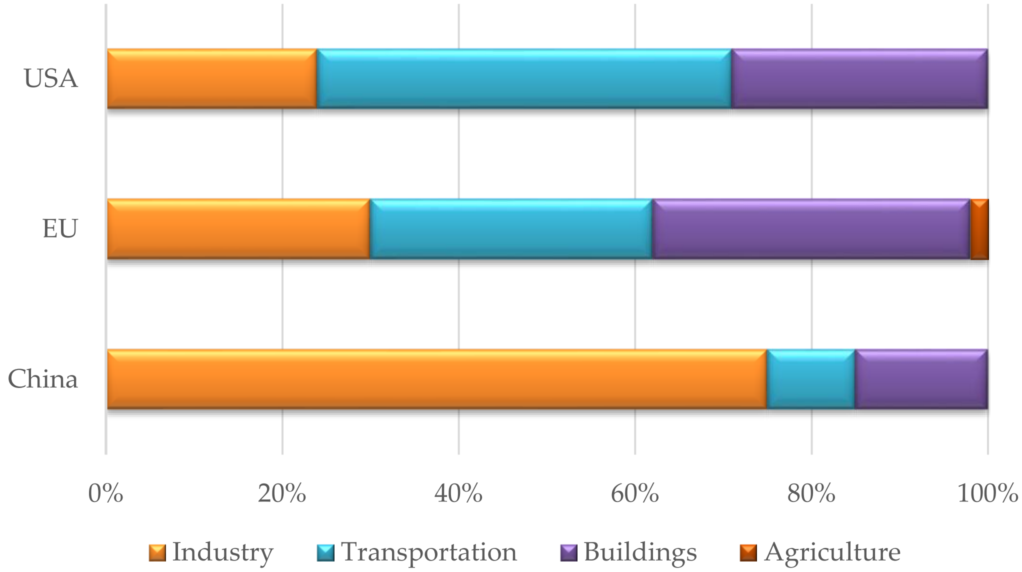


Figure 1-1: Energy consumption of different sectors in the world [1]

Intelligent lighting control systems, often integrated with Building Management Systems (BMS), can achieve 50–60% energy savings, improved durability, lower maintenance costs, and environmental benefits [6, 15]. These systems automatically adjust illumination and color temperature to user needs, enhancing comfort while reducing energy use. The continuous evolution of electronics, sensors, and solid-state lighting technologies has further improved monitoring, control, energy efficiency, and system longevity [3, 17, and 18].

Despite advances globally, Ethiopia currently lacks active lighting industry guidelines, policies, and officially reported research on intelligent and energy-efficient lighting systems. The country faces a shortage of skilled professionals in lighting engineering and has yet to develop national policies or roadmaps for smart lighting adoption. Given Ethiopia's ambitious electrification projects and regional power interconnections, prioritizing intelligent, energy-efficient lighting systems is essential. Such systems can enable effective energy management, simplify metering and planning, and optimize infrastructure usage while improving user comfort and overall quality of life.

1.2. Background of the CBE-HQ Building

The Commercial Bank of Ethiopia (CBE) Headquarters, located in Addis Ababa, is a landmark skyscraper symbolizing modern architectural and technological progress in Ethiopia. Inaugurated in February 2022, it stands 209 meters tall with 53 floors, making it the tallest building in East Africa. The 150,000 m² facility accommodates offices, conference halls, and commercial spaces, featuring advanced engineering and smart building technologies. Among its notable systems is the intelligent lighting control system, designed to optimize energy use, enhance comfort, and reduce operational costs. This makes the CBE HQ an exemplary case for studying energy-efficient lighting in modern high-rise buildings. Insights from this study can support sustainable design practices and future policy development in Ethiopia. Figure 1.2 below shows the new CBE Headquarters building.

Figure 1-2: CBE new headquarter building

1.2.1. CBE-HQ Interior Lighting Control Systems

The interior lighting system of the CBE-HQ building combines traditional lighting control with intelligent lighting control systems featuring daylight harvesting and presence sensing to maintain predefined luminance levels. These intelligent systems are flexible, convenient, and significantly enhance both user experience and energy efficiency, representing a transition from conventional lighting control to smart, dimmable solutions. Their benefits include improved visual comfort, productivity, mood, health, and substantial energy savings over the building's lifespan.

The CBE-HQ high-rise is equipped with multiple intelligent lighting systems, including façade lighting, daylight harvesting in tower pool offices, and occupancy-based lighting in all washrooms. By integrating sensors, controllers, and software, these systems dynamically adjust lighting output based on occupancy, daylight availability, schedules, and user preferences, optimizing energy use while enhancing occupant comfort and productivity.

Moreover, the intelligent lighting control systems support sustainability by reducing overall energy consumption and minimizing environmental impact, demonstrating CBE's commitment to innovative, efficient, and occupant-focused building solutions. To achieve maximum efficiency and comfort, LED luminaires are deployed and controlled according to natural light levels, occupancy, schedules, and user settings.

In the tower's pool office areas, the building is divided into eight zones—Zone A, B, C, D normal areas and Zone A, B, C, D Window Zones—aligned with the architectural layout. The daylight harvesting system is specifically implemented in the window zones around the façade. Figure 1-3 illustrates the typical floor zoning of the daylight harvesting lighting control system.

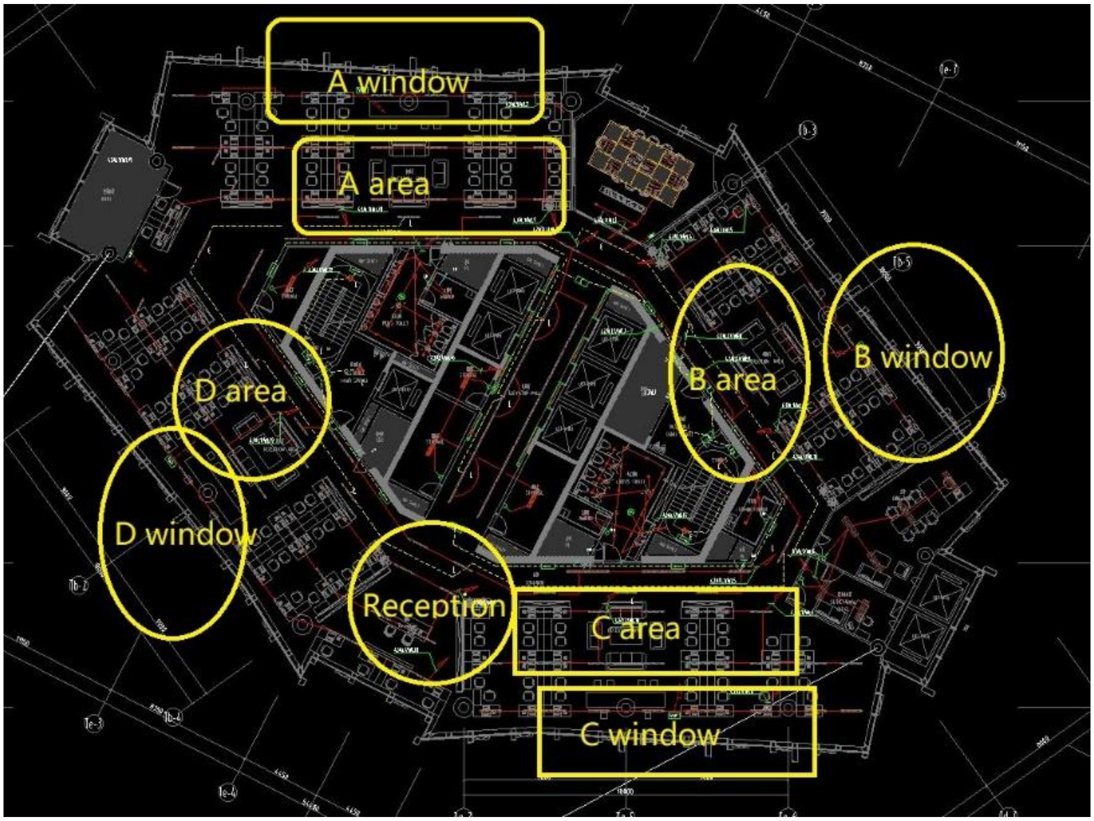


Figure 1-3: Daylight harvesting system typical zones

The CBE HQ building implements daylight harvesting techniques in its main tower building pool offices, leveraging ample daylight available year-round due to its location near the equator. The daylight harvesting system maintains a minimum suggested light level of 300 lux at a height of 75cm from the ground in the pool offices, ensuring optimal illumination while reducing energy consumption. Figure 7-1(Appendix B) shows daylight harvesting control sensor with the dimmable lighting system installed in the windows perimeter of the tower building.

Further, all toilet areas situated in the building are equipped with presence-based sensors and lighting system control system. These sensors and systems regulate the energy usage for intelligent lighting luminaires based on the occupancy behavior of the users.

1.3. Problem Statement

The quality of life is intrinsically linked to the built environment and its lighting systems. Rapid urbanization and advancements in construction have led to significant increases in the number and size of buildings, resulting in soaring electricity consumption. At the same time, there is growing demand for comfortable indoor environments and intelligent lighting solutions, coupled with rising energy costs and global energy demands. By 2050, urban areas are projected to house two-thirds of the global population, accounting for 70% of greenhouse gas emissions and energy consumption. Developing countries like Ethiopia face unique challenges, including resource depletion, environmental pollution, and outdated lighting systems. Buildings account for 40% of global energy consumption, with lighting systems contributing significantly, underscoring the need for optimization to ensure sustainability and energy efficiency.

Despite the global emphasis on energy-efficient and smart lighting systems, Ethiopia lacks comprehensive studies on the energy efficiency of lighting system designs and their consumption patterns. This research aims to fill that gap by selecting the Commercial Bank of Ethiopia (CBE) Headquarters building as a case study. The CBE HQ is unique in Ethiopia as it deploys a smart lighting control system, making it an ideal candidate to analyze energy-saving potential and intelligent lighting management practices. Investigating this system will provide valuable insights into energy efficiency, highlight opportunities for optimization, and serve as a benchmark for future projects in Ethiopia. Furthermore, the findings will help formulate a national roadmap for sustainable lighting solutions, aligning the country with global efforts to reduce energy consumption and environmental impacts.

1.4. Objectives

1.4.1. General Objective

The general objective of this thesis work is to study and analyze the lighting energy reduction realized using intelligent lighting control systems in the case of CBE-HQ building.

1.4.2. Specific Objective

The specific objectives are:

- To Quantify & Analyze the energy consumption reductions via day light harvesting and presence-based control mechanisms.
- To compare the ILS energy consumption reduction with the lighting sections of the normal lighting control mechanisms.
- To compare the lighting energy consumption reduction techniques with global benchmarking.

1.5. Scope and limitations

The case study in this research work is CBE-HQ, the new tallest building in east Africa, which will be used to illustrate typical findings and recommendations for an energy consumption reduction realization in artificial lighting systems which cover intelligent lighting control systems. As such, the study will be limited to cover only the lighting system energy consumption analysis within the building (daylight harvesting and presence-based lighting control systems), and the identified energy-saving measures may not be applicable to other Electro-mechanical systems of the buildings.

1.6. Thesis Document Organization

This final thesis document of the research work is divided into the following five main chapters. The current chapter, Chapter One, presented general overview, background of the CBE-HQ project (CBE-HQ interior lighting control systems), problem statement, objectives (general objective and specific objective), scope and limitation, and thesis document organization.

Chapter Two, gives details on general introduction, importance of energy saving in the lighting sector, intelligent lighting system and control (intelligent lighting systems, and intelligent lighting control systems), global benchmark practices (European Union, and USA: a retrofit project in Los Angeles and California), review of past related works in ILS, summary of literature review, and research gap.

Chapter Three of this thesis document discusses in details on the methodology followed in the research study work via detailing on general introduction, data collection and analysis (data collection, and analysis), software used in the research study work (DIALux EVO, Microsoft Excel, and MATLAB), quantitative study of energy consumption for CBE-HQ (daylight harvesting system, and occupancy-based lighting control system), and summary.

In Chapter Four, section one: daylight harvesting lighting control system (yearly average calendar working days, CBE daylight harvesting system daily lighting power consumption, and daylight harvesting system average power consumption comparison), section two: presence-based lighting control system, section three: overall lighting energy consumption reduction cuts realized, and section four: simulation analysis results and comparison with past related works and reports is presented.

Chapter Five summarizes the fundamental findings and aspects of the research work delivering details on conclusion, and recommendation.

Chapter Two

2. Literature Review

2.1. General Introduction

In our day to day live, lighting system has a significant impact on both functionality as well as aesthetics [19]. However, these systems are responsible for a large portion of energy consumptions in both commercial and residential settings. Around one-fifth of the world's energy consumption is attributed to lighting systems, which is also responsible for 6% of greenhouse gas emissions and environmental pollutions [20, 21]. Commercial and office buildings, which are one of the vital locations where lighting system has a big impact on user comfort, productivity, and energy usage, are the main focal players here. Hence, as these buildings are vital to our everyday existence, it's critical to optimize their lighting system energy use among the many other systems. The following sub-sections of this thesis document Chapter gives details on past related literature review works reported.

2.2. Importance of Energy Saving in the Lighting Sector

Lighting fulfills illumination demands of users both in indoor and outdoor usages in residential and or industrial breadths. However, due to inefficient control system and ineffective light source luminaires, large amount of energy is misused [14, 22]. Therefore, reducing the energy consumption in the lighting sector is one of the main challenges of the current world [23]. Therefore, as lighting system is responsible for large energy consumptions worldwide, lighting designs should aim for both illumination demand fulfillment and energy consumption reduction desires/objectives [24].

Moreover, artificial lighting is one of the major electrical systems responsible for significant electric energy consumption in commercial buildings [10, 22]. Particularly in office buildings it is responsible for an energy consumption of almost a quarter. In order to reduce energy consumption in artificial lighting systems, different lighting control systems has been designed, studied and implemented with promising outcomes [25]. Especially dimmable luminaries based on daylight harvesting, task, user activities and occupancies has been and are major research topics today [26]. Currently, lighting designs are easier and more flexible than ever before thanks to the development of contemporary lighting control systems and their introduction [27].

Lighting sector in a building environment typically incorporates artificial lighting luminaire types and control systems designed and installed in the building [28]. In areas where no natural light is adequately available, due to perimeter covers or weather conditions, lighting system is even more critical [29]. Lighting system control is an integral part of any building lighting system which is used to control the luminaires in direct relation to the illumination demand in the environment and weather conditions [25]. There is no doubt that, through controlling of the luminaires efficiently, lighting energy consumption will be better managed [30].

Environmental awareness creation and energy savings is one of the hot research topic areas of the current ever-changing world [14]. The fact that carbon dioxide emission is closely related with energy production, consumptions and Green House Gas (GHG) emissions in power plants, there is a huge focus of attention towards minimizing it. One good indicator of the awareness created is that, just few years ago lighting was accountable for more than 25% of the total global energy production [31]. However, after the introduction of different energy efficient lighting technologies and advanced management and control systems, it has been reduced to a scale of 20% [8, 32].

Further, since lighting systems are accountable for the major share of electrical power consumption in the world and responsible for about 35% carbon dioxide emission in the world, there is an apparent interest in optimizing these systems all over the world [14].

Hence, reducing energy consumption in lighting system is one of the main principal objectives of the present scientific world [33].

Several past related studies conducted on intelligent and advanced lighting systems showed that there is a great potential to achieve considerable energy savings and hence environmental friendliness for better quality of livings and sustainability [11, 14]. Hence, it is apparent that significant amount of energy consumption cut can be accomplished via deploying intelligent lighting control systems with advanced luminaire types and sources like Solid-State Light (SSL) devices [21, 34, and 35].

One way of lighting energy consumption cut is accomplished via adjusting the light intensity level of a light source (dimming) according to light intensity of a surrounding the real working environment (task area) [9]. Light dimming is achieved by an electronic control circuit which adjusts the energy reaching the light source according to light intensity demands on ground [36]. In early days this operation was realized using very large adjustable transformers and power resistors. However, their size, power demand, price, very poor efficiency and difficulty to operate them remotely were their main limitations and reason for their substitution with thyristor based light control systems recently [37, 38].

Intelligent lighting control systems are the future of the lighting industry and can be applied in a wide range of specialized lighting systems including industrial, commercial and residential applications [37]. Two main approaches of intelligent lighting systems installations that are contemplated in different literatures are, wired and wireless lighting control systems [14]. Since wired systems are difficult to install in already existing buildings, the wireless option becomes more appropriate. This guarantees a reduced cost of installation and ease of deployment and control and monitoring. Wireless Sensor Networks (WSN) evolution played a major role in realization of such wireless lighting control systems [39]. Such systems are easy to deploy and flexible to amend. Further, fast switching capability of the lighting system make them preferred in present day data communication [40].

2.3. Intelligent Lighting System and Control

Energy-efficient designs and solutions are becoming increasingly necessary and popular in all universal systems due to concerns about environment and global energy consumptions [41, 42]. Lighting solely contributes significantly to global energy use among other systems and viable solutions for maximizing energy efficiency and improving functionality is proposed through the use of different smart/intelligent lighting systems [21]. These smart lighting systems offer a promising avenue for optimizing energy consumption and enhancing functionality [43].

By combining various sensors, actuators, electronics, and communication systems with a closed-loop control strategy, intelligent lighting control systems are able to provide automatic lighting control [11]. These systems can be made to improve user comfort and pleasure while also drastically lowering lighting energy usage [47]. Depending on the users' activity and eye health, they offer varying appropriate illumination levels and color temperatures [15, 48]. The components of an intelligent lighting control system consist of [35, 49];

- Sensors:
    - Occupancy Sensors: Detect the presence of individuals and adjust lighting accordingly to ensure lights are only on when needed.
    - Daylight Sensors: Measure the amount of natural light and adjust artificial lighting to maintain a consistent light level.
    - Environmental Sensors: Monitor temperature, humidity, and air quality, providing data to optimize the lighting environment.

- Control Systems:
    - Centralized Control Systems: Manage lighting across multiple zones from a single point, often integrated with building management systems.
    - Distributed Control Systems: Utilize local controllers in each zone, providing flexibility and reducing the impact of a single point of failure.
- Communication Protocols:
    - Wired Protocols: Include DALI (Digital Addressable Lighting Interface) and DMX (Digital Multiplex), providing reliable communication in large installations.
    - Wireless Protocols: Such as Zigbee, Z-Wave, and Bluetooth, offer easier installation and scalability but may face challenges with interference and range.

A typical block diagram of an intelligent lighting control system based on LED luminaire system is given in Figure 2-1 given below.

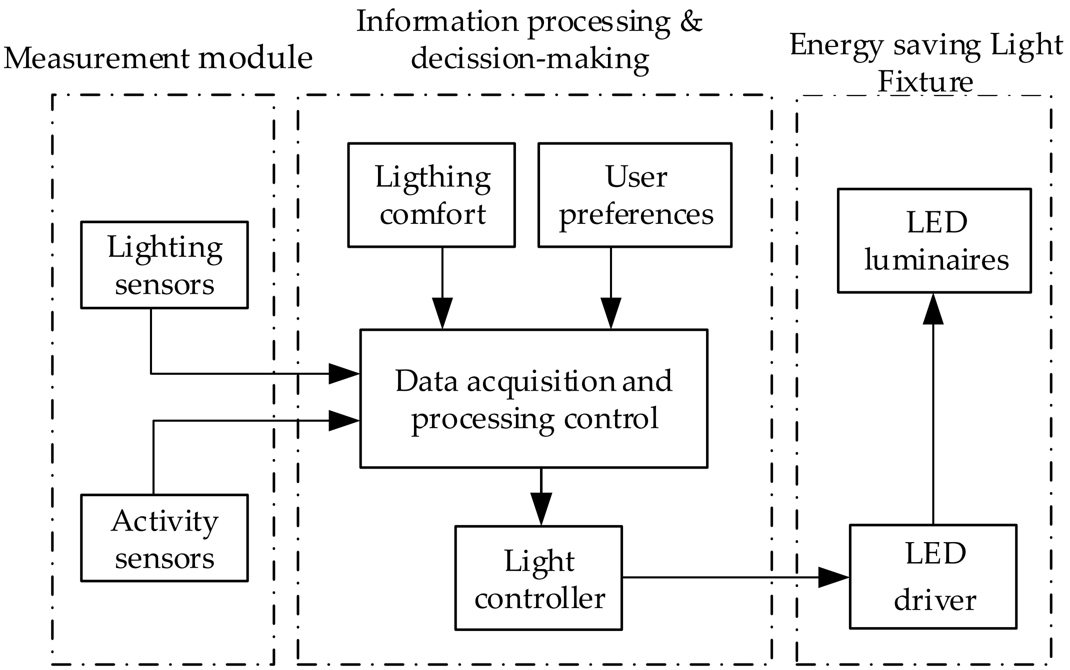


Figure 2-1: Typical Intelligent Lighting system [7]

Measurement module is the front-end part of an intelligent luminaire system which is responsible for monitoring real-time situations according to design specification including illumination level and activity to deliver vital information for decision making [50]. The information processing and decision-making part is the main part of any intelligent luminaire system and is responsible for information processing and decision making on the luminance level of luminaires. The information processing is done according to user preferences and lighting comfort levels defined before. Then once the analysis is done the decision-making part luminaire controller sends signal to the luminaire driver part of the system.

2.4. Global Benchmark Practices

Over the last few decades, a number of countries have taken the lead in developing frameworks and policies for their lighting industries. These include the European Union (EU), as well as several states in the USA, Australia, and Asia. Pilot projects have also been implemented in this process of transformation, with encouraging results toward intelligent lighting systems that control the energy consumption of various systems, including luminaire types [50]. This lighting revolution is expected to pick up steam in the near future if governments and multinational corporations take advantage of the opportunity [25]. Hence, understanding the advantages that intelligent lighting control and management systems provide will depend on how quickly global stakeholders, including governments, embrace, publicize, and implement them [50].

Many countries and organizations have actively supported global political and economic initiatives in recent years to change building management systems and use intelligent lighting control for greater energy efficiency [51]. Consequently, a number of countries across the globe have created laws to initiate and facilitate sophisticated smart lighting control and building management system initiatives. Examples of the worldwide practices come from the United States, EU members, Canada, Australia, China, and Japan.

Countries that are able and willing to organize the necessary laws and regulations, unite their markets, and rationalize private investment in luminaire production capacity are expected to lead the lighting revolution, control the majority of the lighting industry, and snatch up the jobs that it will create [50]. Based on several reports and pieces of data, it is anticipated that nations such as China, with their well-balanced standards, aggressive market policies, and subsidies for smart technologies like intelligent lighting controls, will control the majority of the worldwide markets for lighting systems [21, 50,51]. Subsections that follow offer further details on a few chosen global benchmark practices.

2.4.1. European Union

The European Union (EU) has recognized the need to improve energy efficiency in order to promote sustainable growth throughout the union and raise the standard of living for its citizens [52]. It has therefore made the most efforts in the world to advocate for and push for energy-efficient lighting solutions. As a result, the European task force was established, and its responsibility is to enhance Union cities' sustainability and energy efficiency. It has begun developing a long-term strategy to establish a low-carbon economy and make better use of its finite energy resources.

The task force concluded that in order to achieve decarburization, the current EU energy system needed to undergo considerable adjustments. As a result, it established an ambitious target to cut the energy consumption of the lighting sector by at least 20% in the near future. This objective can be readily attained with the global implementation of building management and lighting control systems.

The present European legislation and standards provide customized intelligent lighting control and integrated building management systems for lighting system installations. Since 70% of the nation's population lives in cities, switching to state-of-the-art smart lighting control and building management systems will significantly reduce energy usage and greenhouse gas emissions. Furthermore, considering that over 90 million traditional lamps exist in Europe, with over 75% of those installations being older than 25 years, the transition to intelligent lighting control and building management systems is expected to dramatically increase energy consumption savings. Thus, there is a great deal of room for energy savings in EU cities if intelligent lighting control, integrated building management systems, and Solid-State Lighting (SSL) technology are widely implemented [53]. In many European municipalities, smart lighting has already proven to be more advantageous than traditional lighting systems. They have reported notable cost and maintenance savings, enhanced lighting performance, and energy savings of up to 50% to 60%.

The EU established the two guidelines below for its lighting sector;

1. EN 12 464-1 Light and Lighting - Lighting of Workplaces - Part 1: Indoor Workplaces: European Indoor Lighting Standard. Specifies the lighting needs for inside work spaces.
2. EN 12 464-2 Light & Lighting: Lighting of Work Places, Part 2: Outdoor Work Places: European Outdoor Lighting Standard. Specifies the lighting needs for outdoor work zones.

2.4.2. USA: A Retrofit Project in Los Angeles and California

One of the largest LED street light conversion projects in the world was completed by the city of Los Angeles in 2013. In order to complete the project, more than 140,000 LED luminaires—the second-highest number of street lights in the USA—had to be replaced. The project, dubbed "the green street light program," was owned by the Los Angeles Bureau of Street Lighting. Following the project's completion, the city's energy consumption and street lighting quality greatly improved [50, 53].

In this project, smart, automated management system-based luminaires were installed in place of the antiquated, conventional street lights in Los Angeles. This resulted in a large reduction in energy consumption, decreased maintenance expenses, longer street lighting lifespans, and a decrease in CO_2 emissions and pollution to the environment. The city's street lights initially produced 110,000 metric tons of greenhouse gas emissions yearly and consumed 68 gigawatts of energy, costing the city more than $15 million. After the project was finished, the city was able to reduce its CO_2 emissions by 40,500 metric tons and its energy use for street lighting by 63.1%. The city may also save more than $7 million a year on electricity bills by reducing its energy use by 63.1% and saving $2.5 million a year on maintenance costs [50, 53].

The project was funded by a mixture of energy rebates and loans totaling $40 million. It took five years to finish and cost approximately $57 million. The energy savings should allow for the debt to be fully repaid in seven years. By the eighth year, the city will have saved over $10 million annually, considerably exceeding Los Angeles's goal of 63 percent energy efficiency. Currently, LA boasts the second-largest smart street lighting network in the United States, just behind New York. There are 250,000 housing units in New York, 42,000 in Las Vegas, and 21,000 in Seattle, among other American cities [23]. The U.S. Department of Energy (DOE) projects that 86% of all lighting installations in the country by 2035 will be smart lighting systems.

As part of its building energy efficiency regulations, California and many other states are enacting more stringent restrictions linked to daylighting in order to take advantage of the potential for energy efficiency and reduction of peak electricity demand through daylight harvesting. California announced in 2008 that new commercial buildings must have Zero Net Energy (ZNE) by 2030 [54]. In order to fulfill 100% of their annual energy consumption, new construction projects must integrate distributed renewable energy generation with extremely efficient building technologies. Exceeding code requirements for new buildings is necessary to achieve this ambitious objective, but meeting building and appliance energy efficiency standards is a good place to start.

Mandatory and prescriptive requirements for major retrofits of existing buildings and new construction are outlined in the California Building Energy Efficiency Standards, also known as the Energy Standards. The Appliance Regulations (California) set forth performance standards for systems and building components that are marketed through commercial channels.

2.5. Review of Past Related Works on ILS

Based on the study in [26], reducing artificial lighting is crucial, especially in zero energy buildings, as it greatly affects overall energy consumption. The study highlights that while daylight harvesting has significant potential for energy savings in buildings, improper control can disrupt the preferred visual environment of occupants. It also notes that advancements in sensing and communication technologies have led to the development of various energy-efficient lighting solutions for office buildings. The study has investigated and compared different lighting systems energy consumption in experimental setting including, fluorescent light at full brightness, LED light at full brightness, LED light with user comfort and daylight harvesting in cloudy condition, occupancy-based LED light with users' comfort and daylight harvesting in cloudy conditions, LED light with users' comfort and daylight harvesting in clear sky, and occupancy-based LED light with user comfort and daylight harvesting in clear sky. Under clear sky conditions, the LED light with user comfort and daylight harvesting in clear sky technique achieves energy savings of 61–69%, and on foggy days, it conserves 42–55% of energy. Overall, the study reports lighting energy consumption savings ranging from 42–69%.

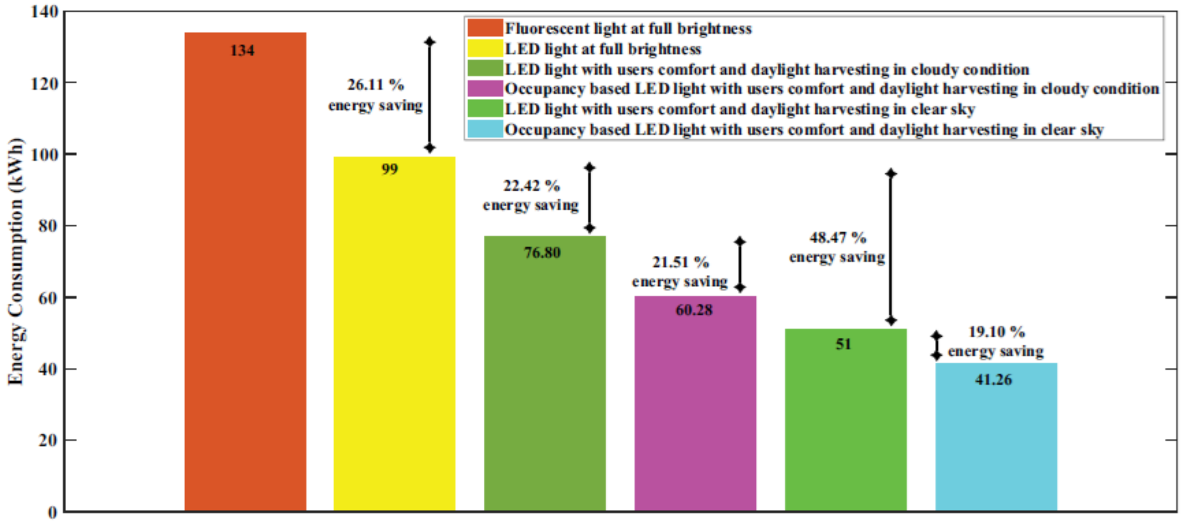


Figure 2-2: Lighting energy saving analysis result under different conditions [26]

According to the study in [55], buildings account for nearly 40% of global energy consumption, including up to 65% of electrical energy. The study suggests that while buildings have significant potential to reduce energy usage, more efforts are needed to achieve this. It highlights the importance of assessing energy savings before implementing lighting control algorithms in specific facilities. Consequently, experimental testing was conducted in a university building equipped with KNX building automation systems in its laboratories and other rooms. The research focused on a dimmable control scheme dependent on daylight illumination. Findings indicate that non-residential buildings can reduce lighting energy consumption by 28% in offices and 24% in educational buildings in Poland, although these reductions depend on certain construction features.

The study referenced in [56], evaluates the effectiveness of various lighting control systems employed by the shading industry in commercial buildings through integrated daylight and whole-building energy modeling. It analyzed three different vintages of medium-sized buildings across six US locations. The findings indicate that these control strategies can achieve up to 40% energy savings in cooling through external shading and up to 25% energy savings in lighting.

The study in [31], claims that LED (Light-Emitting Diodes) based street lighting offers energy savings of 50–70% compared to older technologies. The study also highlighted the following major findings:

- New York, USA: The New York Street lighting refurbishment project, which started in 2009, was completed in 2012. As part of the pilot program, over 500 luminaires from 27 different LED product types underwent independent performance evaluations. The most notable findings from the study indicate that LED lighting, when combined with intelligent control systems, can achieve energy savings of up to 80% and reduce energy costs by as much as 50%.
- Manchester, United Kingdom: As part of Manchester's "smart city" initiative, an extensive plan to replace street lighting with LED bulbs was completed in three years, resulting in the replacement of 56,000 luminaires. The new LED system is expected to be 60% more efficient than conventional lighting, saving the city approximately €2.3 million annually in energy costs and reducing its annual carbon footprint by 7,500 tones.
- Cardiff, Wales: As part of Cardiff's LED upgrade scheme, 14,000 LED street lighting luminaires were installed, leading to an estimated 60% energy savings. The projected annual financial savings are around €855,000. All 14,000 bulbs will be wirelessly connected to a Centralized Management System (CMS), allowing city administrators to remotely monitor and control lighting assets and further optimize savings through advanced operational analysis.
- Los Angeles, USA: Los Angeles was one of the pioneering cities in the extensive use of LEDs. Starting in 2009, the city began replacing street lamps with LED lighting. To date, 180,000 lamps have been fitted with LED luminaires, resulting in a 65% energy savings, which translates to an annual cost reduction of €8.17 million and a reduction of 65,000 tons of CO_2 equivalent. By the end of 2020, the city had saved approximately €8.17 million annually on electricity bills, with an additional

€2.45 million saved on maintenance. Businesses are leveraging connected LED lighting to save 50–70% on energy consumption, and when combined with sensors, smart controls, and Internet of Things (IoT) technology, savings can reach 80–90%.

- Copenhagen, Denmark: As part of the "Smart City" project, 20,000 networked LEDs were installed for street lighting, achieving 65% energy savings. Intelligent modules in the LED streetlights enhance bicycle safety by brightening the lights when a cyclist approaches a junction. When the area is empty, the lights dim, reducing light pollution.
- Jakarta, Indonesia: The city has installed nearly 90,000 LED street lights, achieving 70% energy savings, making it one of the largest systems globally. The lighting system is integrated with other smart city systems, allowing the city to remotely control the lights and adjust their intensity to meet the specific needs of different districts.
- Buenos Aires, Argentina: The city plans to upgrade over 70% of its street lighting to LED diodes. With 126,000 city luminaires, LEDs have already replaced 55% of them. The new technology allows for monitoring light levels, and adjustments will result in a reduction of luminous flux.

The study reported in [59], reaffirmed that buildings are significant energy consumers, and improper lighting control can lead to unnecessary energy waste. By implementing a smart lighting system that integrates sensor technologies, a distributed Wireless Sensor Network (WSN) using the ZigBee protocol, and illumination control algorithms, the study aimed to reduce energy consumption. The sensing module included an ambient light sensor, lighting control rules, and occupancy sensors such as microwave Doppler and Passive Infrared Radiation (PIR) sensors. Each luminaire's dimming level was managed by rules that consider daylight harvesting and occupancy. The proposed system's effectiveness was evaluated in two settings: an office space and a metro station, achieving average energy savings of 36% and 45%, respectively.

In the past related work stated in [60], various lighting conditions were simulated to explore the application of the proposed systems, along with different control technologies and strategies, in a real academic classroom case study. The results showed up to 69.6% energy savings and a 30.5% reduction in CO_2 emissions compared to traditional scenarios. Economically, the proposed control system has a shorter payback period, reducing from nine to five years compared to commercial solutions. The energy outcomes for each scenario were also reviewed. The installation of daylight control (61.4%) and occupancy control (60.5%) resulted in similar energy savings. The combination of occupancy and daylight adaptation achieved the highest energy savings at 69.5%.

According to the study in [44], excellent performance in terms of energy efficiency and occupant satisfaction can be achieved by utilizing LED modules in conjunction with state-of-the-art control systems. The essay explains the process of designing lighting and highlights the important role controls play in energy performance. A thorough case study of the restoration of a library room's lighting system was given. The library was divided into numerous areas. In every zone, the optimal control was applied. Utilizing the recommended techniques enhanced performance and reduced energy consumption, according to energy data. The energy performance measured before and after the restoration was 72 kWh/m^2 per year and 8.5 kWh/m^2 per year, respectively, with savings of over 70%. Finally, the study in [44], asserted that savings from occupancy-based control varied significantly, from 7% to 55%. Further, daylighting harvesting may save artificial lighting energy use by 50–80%, according to a study published in [64].

2.6. Summary of Literature Review

Past studies on Intelligent Lighting Systems (ILS) emphasize their potential to significantly reduce energy consumption through advanced technologies and control strategies. In buildings, ILS can achieve energy savings of 28–69% by combining daylight harvesting, dimming controls, and occupancy-based management. However, these savings vary based on environmental conditions, occupant preferences, and building features. Studies also highlight the economic benefits of smart controls, which, despite higher initial costs, offer rapid payback periods through reduced energy consumption and operational costs.

In urban applications, adaptive smart lighting systems integrating motion sensors, cameras, and control algorithms have demonstrated energy savings of up to 82.99%, particularly in street lighting. Case studies from cities like Los Angeles, Copenhagen, and Jakarta show energy reductions of 60–70% through LED upgrades combined with intelligent control systems. These projects also significantly lower carbon emissions and maintenance costs, demonstrating the environmental and economic advantages of ILS.

Additional research underscores the role of advanced lighting technologies, such as OLEDs and LEDs, in achieving up to 70% energy savings compared to traditional lighting. Innovations in daylight and occupancy sensing technologies, coupled with integrated building automation systems, enable savings of 13–73% across various building types. Smart lighting systems not only optimize energy use but also enhance occupant comfort and safety, underscoring their transformative potential in both residential and urban contexts.

2.7. Research Gap

Despite significant advancements in Intelligent Lighting Systems (ILS) globally, no prior studies have investigated their application in Ethiopia. Existing research primarily focuses on energy savings from daylight harvesting, dimming controls, and occupancy-based management in specific environments, such as office buildings or urban street lighting, but lacks analysis tailored to Ethiopia’s unique climatic, economic, and infrastructural contexts. Additionally, the integration of advanced ILS technologies with real-time environmental data and cost-effective strategies for resource-constrained settings remains underexplored.

Given the growing need for energy-efficient solutions and Ethiopia’s reliance on traditional lighting systems, studying and analyzing the potential of ILS in the country is crucial. This research seeks to fill this gap by evaluating ILS performance, energy-saving potential, and feasibility in Ethiopia, paving the way for sustainable and energy-efficient lighting solutions.

Chapter Three

3. Methodology

3.1. General Introduction

This research aims to investigate, analyze, and quantify interior lighting energy consumption reduction techniques employed in the CBE-HQ building. As the tallest building in East Africa, the CBE-HQ serves as a notable case study due to its advanced technologies for monitoring and controlling electrical and electro-mechanical systems, including intelligent lighting systems. The building's integration of daylight harvesting and occupancy-based (presence sensor) lighting control systems presents a valuable opportunity to explore the effectiveness of these techniques in reducing energy consumption.

The decision to focus on the CBE-HQ building is also supported by the researcher's direct involvement in the design review process and material selection, alongside prominent professionals and researchers, including Addis Ababa University engineers. This involvement provided the researcher with a deep understanding of the building's infrastructure and facilitated access to critical data, including daily energy consumption and actual illuminance levels. Moreover, the availability of energy meters for each floor's lighting system circuit line allows for precise measurement and analysis of lighting groups equipped with sensors in controlled setups.

The methodology followed in this study is outlined in Figure 3-1. It begins with an extensive literature review of global practices and policies in lighting energy management, establishing a foundation for the study. The research then identifies and analyzes lighting energy reduction techniques implemented in the CBE-HQ building, with a particular focus on daylight harvesting and occupancy-based lighting controls. The study evaluates the actual reductions in lighting energy consumption achieved through these intelligent systems and compares them to theoretical consumption of conventional LED and fluorescent based lighting systems without such controls.

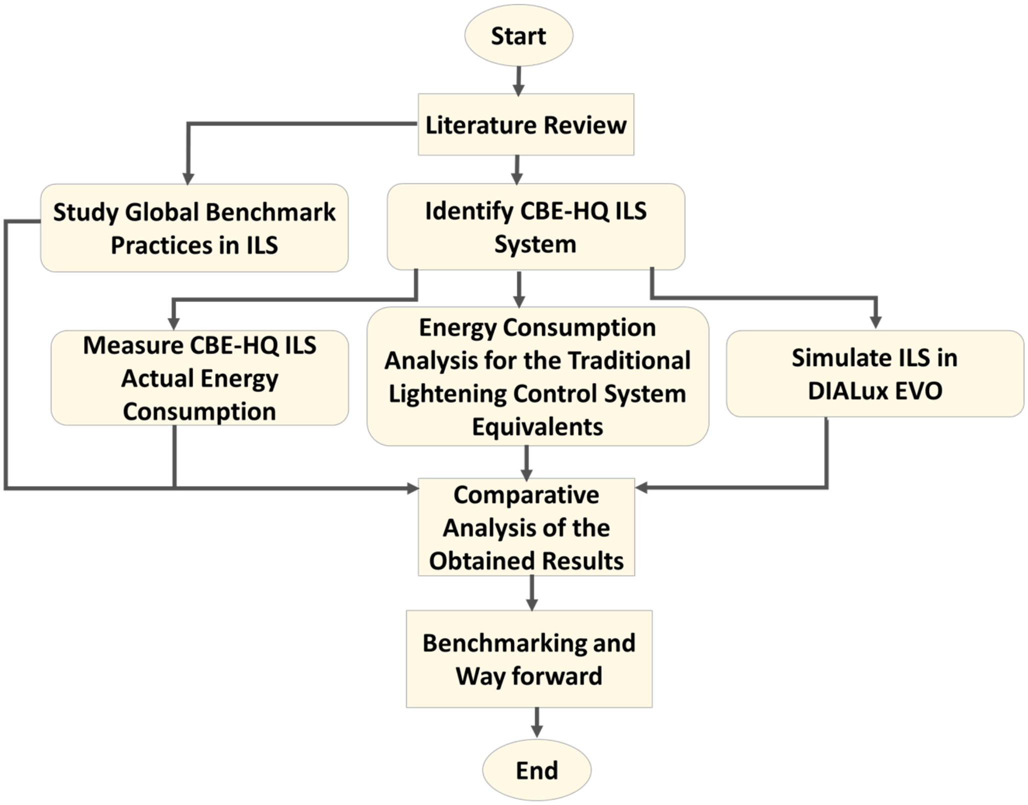


Figure 3-1: General methodology adopted and followed

Additionally, the research examines the actual illuminance levels achieved in spaces where these energy-saving techniques are applied. Insights gained from this analysis are used to formulate recommendations for future projects in Ethiopia, positioning the CBE-HQ building as a benchmark for energy-efficient lighting design and implementation. The findings of this study are expected to contribute significantly to the understanding and adoption of intelligent lighting systems in similar projects across Ethiopia.

3.2. Data Collection and Analysis

This research employed a systematic approach to collect and analyze real-time data on lighting energy consumption within the CBE-HQ building. The primary focus was to evaluate the performance of intelligent lighting control systems and quantify energy savings achieved.

3.2.1. Data Collection

The data collection for this research focused on real-time energy consumption and lighting performance in the CBE-HQ building, specifically evaluating the daylight harvesting and occupancy-based lighting control systems. Over 31 days, primary data were collected using the dedicated building's sub-distribution boards (SDBs) power meters, located at each floor of the tower building, to measure power consumption. These meters, located on each floor, enabled accurate tracking of energy use. Furthermore, portable power meters shown in Figure 3-3(a) were also used to cross check the reliability of the SDB power meters, which were found to be accurate. Figure 3-2 given below and & Figure 7-2 (Appendix B) show typical floor SDBs in the CBE-HQ tower building different floors.

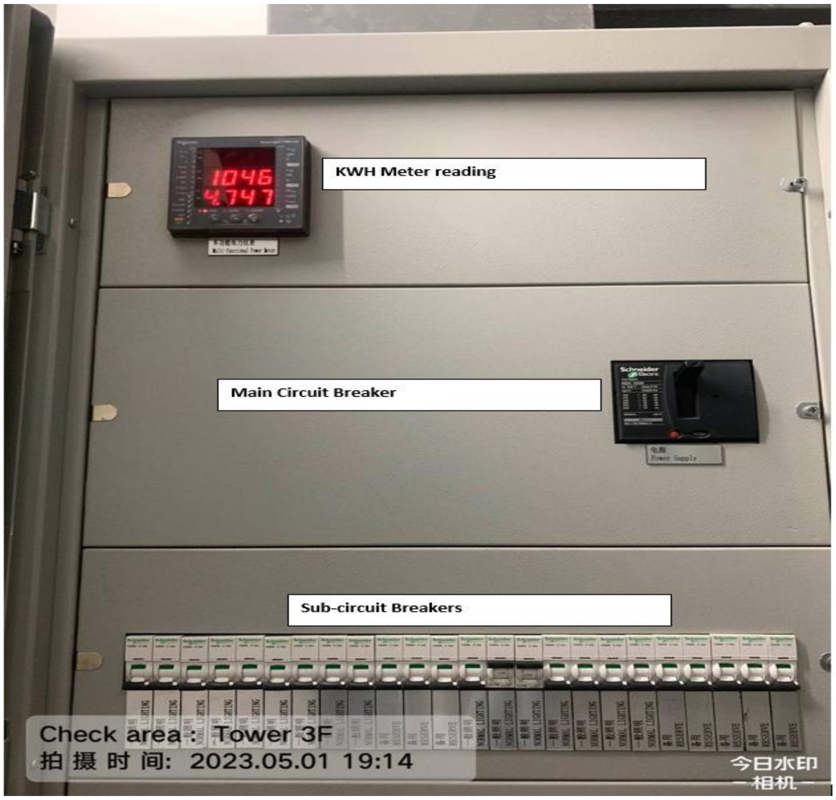


Figure 3-2: Typical tower building SDB

Additionally, portable illuminance meters shown in Figure 3-3(b) measured real-time lighting levels (lux) to assess lighting efficiency and energy savings. The study also tracked the operating hours of luminaires, providing insights into energy consumption patterns. Data were collected on both sunny and rainy days to account for daylight variation, ensuring realistic conditions.

(a) (b)

Figure 3-3: (a) Portable Energy Meter, (b) Smart Sensor Digital Lux Meter used for data collection

3.2.2. Analysis

To assess the effectiveness and energy savings of the intelligent lighting management systems in comparison to traditional lighting techniques, the gathered data methodically cleaned up, examined, and interpreted. The primary goal of the analysis was to measure the installed lighting systems' real energy consumption and compare the results with those of conventional LED and fluorescent lighting systems operating in comparable environments.

All recorded data from the Smart Distribution Board's (SDB) integrated energy meters compared to readings from portable energy meters to guarantee precision and dependability. Before moving on to computational analysis, this procedure guaranteed data consistency and removed any possible measurement errors.

Microsoft Excel used to organize and process the actual measured data, including data cleaning, tabulation, and first trend visualization. Values for energy use transformed into daily, monthly, and annual equivalents to enable thorough comparisons between various kinds of lighting systems. Advanced computational analysis, such as curve fitting, data validation, and graphical depiction of performance differences between the various lighting control systems, then conducted using MATLAB.

Two benchmark systems, the conventional LED-based and fluorescent-based lighting configurations, the daylight harvesting system, and the presence-based control system all compared. Determining the percentage decrease in energy consumption attained by intelligent systems in comparison to conventional systems was the goal of the analysis. The entire energy savings, possible cost savings, and associated carbon emission reductions were then calculated using the data.

Via ensuring that the study's conclusions were based on real measured data and substantiated by quantitative comparisons, this multi-stage analytical approach produced a solid assessment of how well intelligent lighting control systems reduced energy consumption in the CBE-HQ building.

3.3. Software Used in the Research Study Work

In this research, a variety of software tools were employed to simulate, analyze, and process the collected data related to energy consumption and lighting performance in the CBE-HQ building. These tools played a crucial role in assessing the effectiveness of the lighting control systems and optimizing energy efficiency under various conditions. The following software applications were utilized:

3.3.1. DIALux EVO™

DIALux EVO™, developed by DIAL GmbH, is an advanced lighting simulation software widely used for designing and analysing both indoor and outdoor lighting systems. In this study, it was employed to model and evaluate the lighting performance of the CBE-HQ building. The software enabled the creation of a detailed 3D model that incorporated actual lighting fixture types, configurations, and control mechanisms such as daylight harvesting. It also simulated light distribution by considering factors like building geometry, surface reflectance, and the interaction of natural and artificial light sources. One of its key features is the automatic computation of daylight values based on geographic location, allowing accurate simulation of daylight availability throughout the year by factoring in seasonal variations in sunlight angles.

The simulation used actual architectural and lighting design data, including luminaire specifications and control system parameters, while environmental conditions such as sunny and cloudy days were automatically integrated through the software’s built-in features. After configuring the system and control mechanisms, multiple simulations were conducted under different environmental scenarios to assess energy-saving performance. The outputs, including illuminance maps and energy consumption reports, were analysed and compared with real site data. This comprehensive approach provided reliable insights into the efficiency and performance of the intelligent lighting control systems, demonstrating their contribution to energy savings and sustainable building operation.

3.3.2. Microsoft Excel™

Microsoft Excel played a key role in this research by organizing, recording, and analysing energy consumption and lighting data collected from the CBE Headquarters building. Real-time data, including power usage, illuminance levels, and luminaire operating hours, were systematically entered and processed using Excel’s analytical functions. This ensured accurate tracking and simplified comparison of energy performance across different floors and time periods.

In addition to data management, Excel was used to estimate potential energy consumption if conventional lighting systems, such as standard LED or fluorescent fixtures, had been used instead of intelligent lighting controls. Using information from the building’s lighting design documents, the software enabled a comparative analysis between actual and simulated energy performance. The results clearly demonstrated the efficiency and energy-saving benefits of the intelligent lighting systems implemented in the building.

3.3.3. MATLAB™

MATLAB™ was used to process the data recorded and computed in Microsoft Excel™ and generate visual diagrams for enhanced data interpretation. The data, which included energy consumption, illuminance levels, and other relevant parameters collected on-site, were imported into MATLAB™ for further analysis. By reading the processed data from Excel, MATLAB™ was able to create various plots. These visualizations helped in better understanding the relationships between different variables, such as lighting energy consumption and illuminance levels across the building.

MATLAB™ facilitated the generation of these diagrams, enabling the research to illustrate the performance and efficiency of the lighting systems in a clear and accessible manner. The software's powerful plotting functions allowed for the comparison of intelligent lighting control systems' effectiveness versus traditional lighting systems. This visual approach supported the identification of patterns and trends in the data, providing meaningful insights for the evaluation of energy-saving strategies and lighting performance throughout the building.

Together, these software tools enabled the effective simulation, analysis, and interpretation of lighting energy consumption data, providing valuable insights into the energy efficiency and performance of the CBE-HQ building's intelligent lighting systems.

3.4. Quantitative Study of Energy Consumption for CBE-HQ

The past few decades have witnessed remarkable advancements in building technologies designed to enhance energy efficiency and minimize power consumption. However, in Ethiopia, there is still a scarcity of measurable data and evidence supporting the performance of green buildings. This research addresses that gap by examining the role and effectiveness of intelligent lighting control systems, specifically daylight harvesting and occupancy-based lighting, in the Commercial Bank of Ethiopia (CBE) Headquarters building. The study employed a combination of qualitative and quantitative methods, including interviews, observations, and detailed analysis of electrical circuit line diagrams for each floor to ensure precision and relevance. The daylight harvesting system, which integrates photo sensor-based luminaires, was a key focus area. This system minimizes the use of artificial lighting by dynamically adjusting brightness according to the amount of available natural light. Circuits connected to the photo sensors were isolated to monitor their individual energy performance, providing an accurate measure of energy savings. Similarly, the occupancy-based lighting systems, installed primarily in washrooms, automatically adjusted illumination based on movement detection, ensuring lights operated only when needed.

To evaluate lighting quality and occupant comfort, a Digital Lux Meter with smart sensors was utilized to measure and maintain appropriate light levels that support user productivity and visual well-being. The building’s dimmable luminaires, placed strategically along the façade and interior zones, adjusted brightness in real time according to environmental light variations such as cloudy or bright daylight conditions.

Energy consumption data were collected twice daily from sub-distribution board meters during the building’s 12-hour operational schedule (7:00 AM to 7:00 PM), focusing on both daylight harvesting and occupancy-based systems. The resulting data offered valuable insights into the performance of these intelligent lighting systems, demonstrating significant improvements in energy efficiency, visual comfort, and operational sustainability. Overall, the research highlights how integrating smart lighting technologies into large commercial buildings can play a transformative role in reducing energy consumption and advancing Ethiopia’s green building initiatives.

3.5. CBE-HQ Building Typical Intelligent Lighting Control Systems Design

This research focuses on analyzing two key intelligent lighting control systems implemented in the CBE-HQ building: the daylight harvesting system and the occupancy-based lighting control system. These systems are integral to the building’s energy efficiency strategy and provide valuable insights into modern lighting practices in high-rise buildings.

3.5.1. Daylight Harvesting System

The daylight harvesting system is employed in the tower building’s pool offices, specifically along the façade of the building where ample natural light is available. This system is designed to optimize the use of natural daylight, minimizing reliance on artificial lighting during the day. Photo sensors strategically placed in these areas monitor the incoming daylight and adjust the luminaires' brightness levels accordingly. This dimming functionality ensures that lighting levels meet user comfort and productivity needs while significantly reducing energy consumption.

The design of the daylight harvesting system includes specific circuit elements, such as photo sensors, dimmable luminaires, and control modules, which were carefully analyzed in this research. The number and type of luminaires installed on each floor were extracted from the building's lighting design plans to facilitate detailed comparisons with traditional lighting systems. Figure 3-4 illustrates the typical design of the daylight harvesting system implemented in the CBE-HQ building.

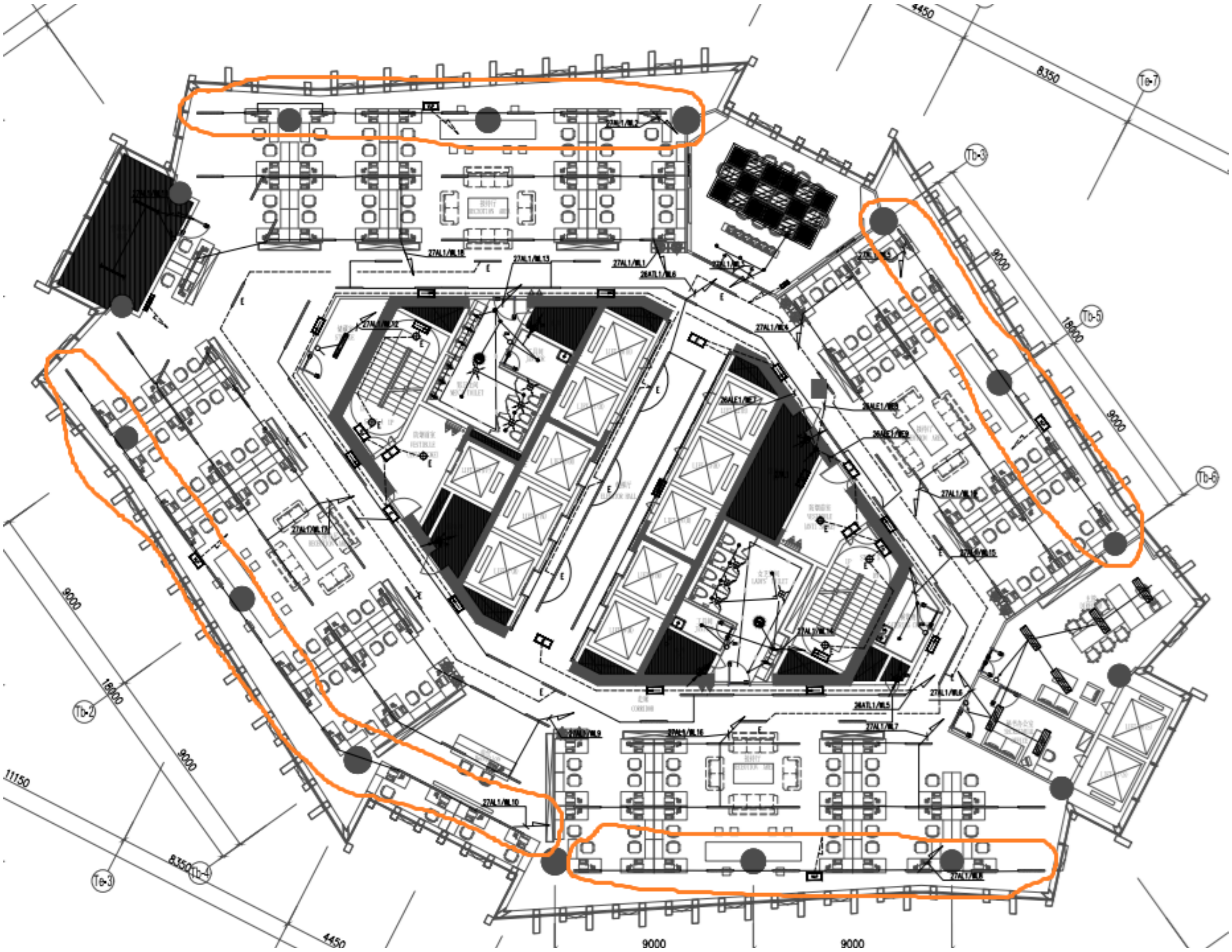


Figure 3-4: CBE-HQ typical daylight harvesting control system design

The CBE-HQ daylight harvesting lighting control system is deployed in the main tower building pool offices, on lighting system luminaires located near the curtain wall on a single loop. This intelligent lighting control system is deployed on 41 of the main tower building floors and includes the following main components;

- Hanging Dimmable LED Luminaires: The daylight harvesting system encompasses a total of 1059 pieces of 50W dimmable LED luminaires [PAK-

460137, 4000K, 50W, Beam Angle 120°, Dimmable]. This device is used for the artificial illumination purpose and is capable of dimming its brightness level according to triggering signals provided. Furthermore, it is equipped with Dimmable constant current LED Driver from BOKE [BK- BTL010]. Figure 7-6 and Figure 7-7(Appendix B), given below shows image of the dimmable luminaire used from Pak and the dimmable LED driver from BOKE.

- KNX ARGUS Presence with light control and IR receiver: The daylight harvesting system encompasses a total of 106 pieces of KNX ARGUS Presence with light control and IR receiver [MTN630919, Schneider Electric]. This gadget provides sophisticated functionality for controlling lighting and other systems within a building by combining presence detection, light control, and infrared reception capabilities. The presence detection feature uses sensors to determine if individuals are present or not in a given location. Various actions, including turning on or off lights, modifying heating or cooling systems, or turning on security measures, can be triggered by this information. Furthermore, the light management feature enables intelligent lighting settings to be automatically adjusted in response to ambient light levels. The device may optimize artificial lighting to save energy and improve occupant comfort by keeping track of the amount of natural light in a space. Figure 3-5, given below shows image of the presence sensor with light control and IR receiver from Schneider Electric.

Figure 3-5: MTN630919 KNX ARGUS Presence with light control and IR receiver

3.5.2. Occupancy-Based Lighting Control System

The occupancy-based lighting control system at CBE Headquarters is mainly installed in washrooms, where lights automatically turn on when motion is detected and turn off after a pre-set delay when the area becomes vacant. It uses Legrand ceiling-mounted PIR sensors (model 048941) and dimmable LED luminaires from PAK, including strip, spot, and decorative lights, all connected within a single circuit.

This setup removes the need for manual switches, ensuring efficient and automatic lighting control. Since the washrooms lack natural light, the system maintains proper illumination only when occupied, reducing unnecessary energy use. Design data, such as luminaire number and wattage, were analysed to evaluate its energy-saving potential compared to conventional systems. Overall, this motion-based lighting design improves both energy efficiency and operational performance in the building.

Figure 7-8 (Appendix B), provides a schematic representation of the typical design of the occupancy-based lighting control system in the building. The systems motion sensor detector is shown in the Figure 3-6 given below.

Figure 3-6: 048941 PIR 360° motion sensor

3.5.3. Design Analysis

For both systems, the typical design circuit elements, including the type and total quantity of luminaires, were carefully analyzed to assess their performance and energy efficiency. The extracted data formed the basis for the comparative analysis conducted in this study, highlighting the significant energy savings achieved through the deployment of these intelligent lighting control systems. These designs demonstrate the building's commitment to sustainability and serve as a reference model for similar projects in Ethiopia.

Chapter Four

4. Result and Discussion

In this chapter, an in-depth details and analysis of data collection findings, analysis, interpretation, discussions and presentations on the study of lighting energy reduction using intelligent lighting control systems in the CBE-HQ is presented. The intelligent lighting control systems exhibits significant lighting energy consumptions cut. The findings in this research thesis work are found to be a role model and a recommendable way forward for future similar projects in Ethiopia. The following subsections deliver the major findings and results recorded systematically.

4.1. Section One: Daylight Harvesting Lighting Control System

In order to investigate the daylight harvesting system energy consumption reduction yields in the CBE-HQ building, a systematic energy consumption data collection setup was established in the tower building and each floors energy consumption data was collected and recorded. For the actual on-site lighting energy consumption data collection, energy meter readings found in each floor's Sub Distribution Boards (SDB) and portable wat meters were used for the study. The following figure, Figure 7-9 (Appendix B), shows the lighting energy consumption data recording procedures/techniques followed.

Actual real-time lighting energy consumption data was obtained and recorded for a month duration of time from the Sub Distribution Boards power meters and portable wat meters used in the research work. Moreover, in order to systematically extrapolate and arrive at the average annual energy consumption reductions, average calendar working days in one calendar year was computed based on the past six years' data. The following sub-sections give details on the major findings of the research study work.

4.1.1. Operation Hours /Active working days/ considerations in CBE-HQ

Table 4-1: Average total working days in one calendar year

Year in G.C.	Total days in the Calendar year	Total Holiday on Calendar Working Days	Net Total Working Days in the Calendar Year
2018	365	9	299
2019	366	11	299
2020	365	10	300
2021	365	11	297
2022	365	10	298
2023	366	10	299
Total 6 Years Average		**10.17**	**298.67**

Hence, based on Table 4-1 data, a single calendar year is expected to have an average of 298.67 working days in a single calendar year. Hence, a total of 298.67 working days is presumed for the total power consumption reductions computations cut analysis for the intelligent lighting control systems in the building. Furthermore, please note that the average operating working hours in a single day was taken to be 12 hours, starting from 7:00AM – 7:00 PM. This duration is the time at which the CBE-HQ building is occupied via different CBE employees and customers.

4.1.2. CBE Daylight Harvesting System Daily Lighting Power Consumption

CBE's HQ daylight harvesting based lighting control system of the main tower building lighting energy consumption profile was continuously monitored and recorded in each floor for 31 consecutive calendar days, starting from 25th of April 2023, up to 25th of May 2023. The following table, Table 4-2, gives summary of the tower building daylight harvesting based lighting system 12 hours daily total electric energy consumptions observed and recorded.

Table 4-2: CBE daylight harvesting system 12-hour daily power consumptions

No.	Measurement Date	Total Daily 12 Hours Energy Consumption in KWh
1	25-Apr-2023	259.39
2	26-Apr-2023	248.57
3	27-Apr-2023	264.77
4	28-Apr-2023	261.37
5	29-Apr-2023	263.51
6	30-Apr-2023	259.07
7	1-May-2023	262.08
8	2-May-2023	262.40
9	3-May-2023	247.16
10	4-May-2023	246.31
11	5-May-2023	251.15
12	6-May-2023	257.30
13	7-May-2023	252.43
14	8-May-2023	257.55
15	9-May-2023	262.69
16	10-May-2023	248.42
17	11-May-2023	248.64
18	12-May-2023	256.36
19	13-May-2023	254.57
20	14-May-2023	246.13
21	15-May-2023	250.45
22	16-May-2023	262.33
23	17-May-2023	256.55
24	18-May-2023	246.49
25	19-May-2023	263.46
26	20-May-2023	245.24
27	21-May-2023	251.42
28	22-May-2023	260.52
29	23-May-2023	267.41
30	24-May-2023	261.17
31	25-May-2023	250.92
Average Daily 12 Hours Power Consumption in KWh		**255.67 KWh**

Based on the results displayed in Table 4-2 above, the average daily energy consumption of the CBE HQ main tower daylight harvesting system exhibited an average of daily 12-hour energy consumptions of **255.67 KWh**. Figure 4-1, given below shows the MATLAB plot of the real time recorded data.

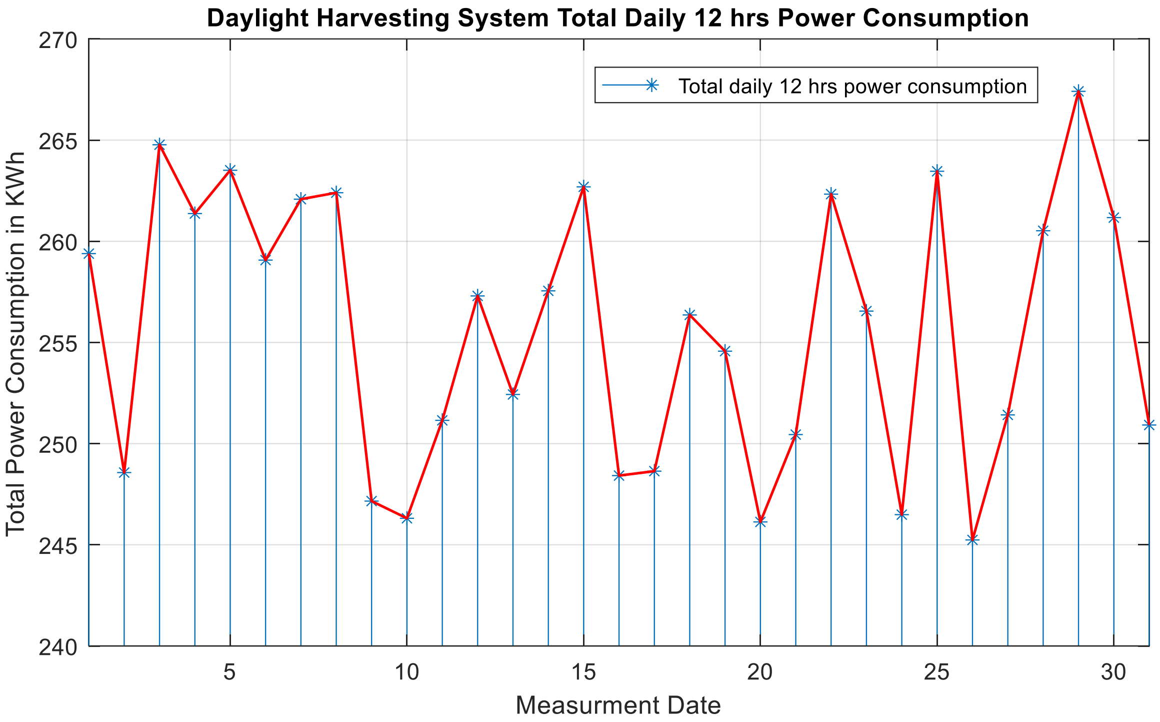


Figure 4-1: CBE daylight system total daily 12 hour's power consumption

4.1.3. Daylight Harvesting System Average Power Consumption Comparison

Next the CBE-HQ building daylight harvesting lighting control system's average 12-hours power consumption profile was compared and related with lighting systems power consumptions if normal LED based lighting system and lighting system based on fluorescent luminaires were used in place, for the 31 days under investigation. The following table, Table 4-3, shows the total daily 12-hour average power consumptions profiles of the three different lighting systems under consideration for the analysis, that are daylight harvesting, normal LED based and fluorescent based lighting control systems.

Table 4-3 : Average daily 12-hour energy consumption of 3 different lighting systems

Lighting System Under Study	**Average Daily Power Consumption in KWh**
Daylight Harvesting System	255.67
Normal LED Based System	635.40
Fluorescent based System	1,270.80

The normal LED based lighting and fluorescent based lighting systems average 12-hours daily power consumptions were computed based on the luminaires wattage power consumptions under use. Please note that for the normal LED system the non-dimmable equivalent the LED luminaires are taken for the analysis and for the average number of luminaires required going to have the same lighting scenes if the LED luminaires were replaced with fluorescent based luminaires on site was taken to be two times that of the LED luminaire quantity on site.

Based on the results shown in Table 4-3 given above; the total average electric power consumption would have looked the following if the following different lighting systems were deployed on the building;

- Daylight harvesting lighting control system: 255.67 KWh (actual system on site).
- Normal LED with no daylight harvesting system: 635.40 KWh.
- Fluorescent Based lighting system: 1,270.80 KWh.

The average lighting electric energy power consumption comparisons/relations between the three different lighting control systems for an average daily 12-hours of operation and a total of 31 days under investigation.

Hence, based on the above data, one-year annual average total electric energy power consumptions for the three different lighting systems under investigations will be the average 12-hours daily power consumption multiplied via the average **298.67** average working days a single calendar year. The following table, Table 4-4, displays the annual average power consumptions of the three different lighting systems under investigation.

Table 4-4 : Average annual power consumptions comparison

Lighting System Under Study	Total Annual Power Consumption in KWh
Daylight Harvesting System	76,361.52
Normal LED Based System	189,774.92
Fluorescent based System	379,549.84

4.2. Section Two: Presence-Based Lighting Control System

Next, CBE's HQ presence-based lighting control system deployed in the main tower building washrooms were carefully monitored, recorded and analyzed in order to arrive at the total average power consumption cuts realized through its intelligent lighting control system. For the presence-based lighting control systems analysis, a total of 9 different lighting scenarios, one with no intelligent lighting control system as reference and 8 different level activity levels, were articulated and analyzed. The following sub-sections of this thesis document gives details on the findings.

4.2.1. CBE-HQ Presence-Based Lighting System Analysis

Once again, the average calendar working days in one year based on last six years calendar analysis and on the fact that CBE HQ employees work 6 days a week was adopted, equating to 298.67 days. The following legends are used for the data analysis visualizations;

- TYN: Total yearly power consumption if normal lighting system was used.
- TY20: If the presence-based lighting system is active only 20% of the time.
- TY30: If the presence-based lighting system is active only 30% of the time.
- TY40: If the presence-based lighting system is active only 40% of the time.
- TY50: If the presence-based lighting system is active only 50% of the time.
- TY60: If the presence-based lighting system is active only 60% of the time.
- TY70: If the presence-based lighting system is active only 70% of the time.
- TY80: If the presence-based lighting system is active only 80% of the time.

- TY90: If the presence-based lighting system is active only 90% of the time.

Hence, based on the total number of luminaires in the presence-based lighting system located in the tower building washrooms of the CBE HQ, it can be forecasted that the average lighting energy power consumption would have been the following figures, if the presence-based lighting control system was not deployed on site and normal LED based luminaire system was used instead.

- Total 1-hour electric energy consumption = 13.65 KWh.
- Total 1-day electric energy consumption = 163.8 KWh.
- Total annual electric energy consumption = 48,922.146 KWh.

The following table, Table 4-5, gives average yearly total power consumptions of the presence-based lighting system under the different operation modes stated above.

Table 4-5 : Annual power consumption profile of the different presence-based system

No.	Working Mode	Abbreviation	Annual Actual total Power Consumption in KWh
1	Normal	**TYN**	48,922.146
2	20%	TY20	9,784.4292
3	30%	TY30	14,676.6438
4	40%	TY40	19,568.8584
5	50%	TY50	24,461.073
6	60%	TY60	29,353.2876
7	70%	TY70	34,245.5022
8	80%	TY80	39,137.7168
9	90%	TY90	44,029.9314

The following figure, Figure 4-2, shows total annual power consumption of the presence-based lighting system plots under different operation modes investigated;

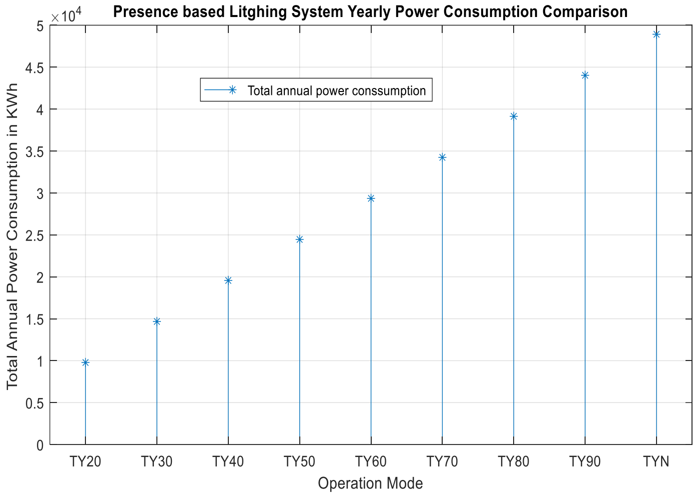


Figure 4-2: Presence-based lighting system plots under different operation modes

Furthermore, the following table, Table 4-6, gives monthly total power consumption of the presence-based lighting system in the different operation modes under investigation.

Table 4-6 : Monthly power consumption profile presence-based lighting systems

No.	Working Mode	Abbreviation	Monthly Total Power Consumption in KWh
1	Normal	TYN	4,076.8455
2	20%	TY20	815.3691
3	30%	TY30	1,223.05365
4	40%	TY40	1,630.7382
5	50%	TY50	2,038.42275
6	60%	TY60	2,446.1073
7	70%	TY70	2,853.79185
8	80%	TY80	3,261.4764
9	90%	TY90	3,669.1609

The following figure, Figure 4-3, shows total monthly power consumption of the presence-based lighting system plots in the different operation modes under investigations;

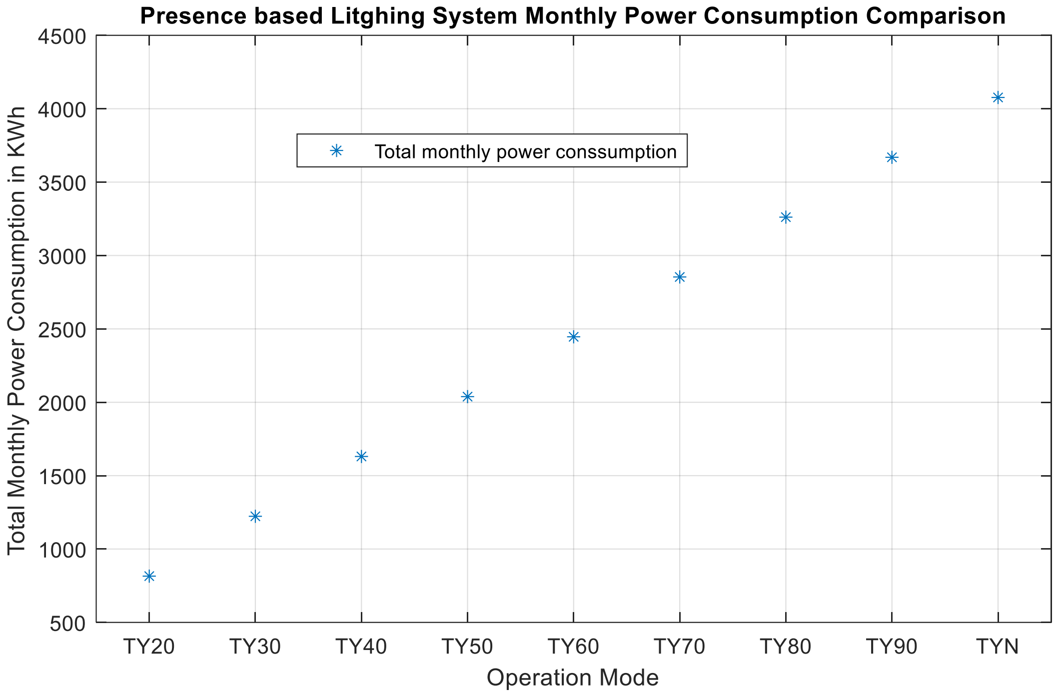


Figure 4-3: Presence-based lighting system monthly average power consumption

The figure below, Figure 4-4, shows expected annual average total power consumptions of the different presence-based lighting system operation modes under investigations;

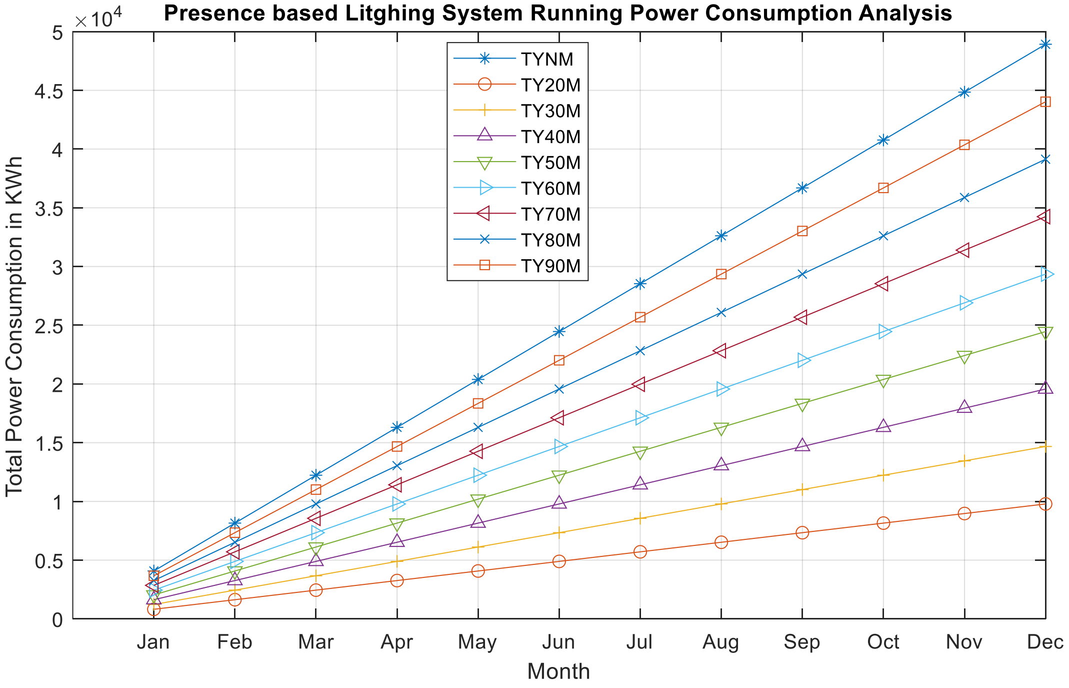


Figure 4-4: Presence-based lighting system annual power consumption

Based on the actual data collected on 10 sample washrooms in the CBE HQ taken in to consideration and occupied during this research study work period, the average occupancy of the washrooms in each floor under investigations were found to be active for 56% of the time and idle for the remaining 44% of the normal 12-hours average daily working hours. Hence, it is extrapolated and concluded that the presence-based lighting system activation for all washrooms located in the tower building is 56% of the 12-hours daily active time duration.

4.2.2. Presence-Based Lighting System Power Consumption Comparison

In order to visualize the actual lighting energy power consumption reduction cuts realized in the presence-based lighting control system, three different lighting control scenarios of, the real presence-based light control, normal LED based system and fluorescent based lighting system control was considered for comparison and analysis. The following table, Table **4-7**, displays the annual average power consumptions of the three different lighting systems under investigation.

Table 4-7 : Total annual power consumption comparison in the presence-based system

CBE HQ Lighting System	Total Annual Power Consumption in KWh
Presence-based Lighting System	27,396.40
Normal LED based System	48,922.15
Fluorescent based System	97,844.30

Moreover, the following figure, Figure 4-5, shows incremental average annual power consumption comparison between the Presence-based, Normal LED and Fluorescent based lighting systems under investigations.

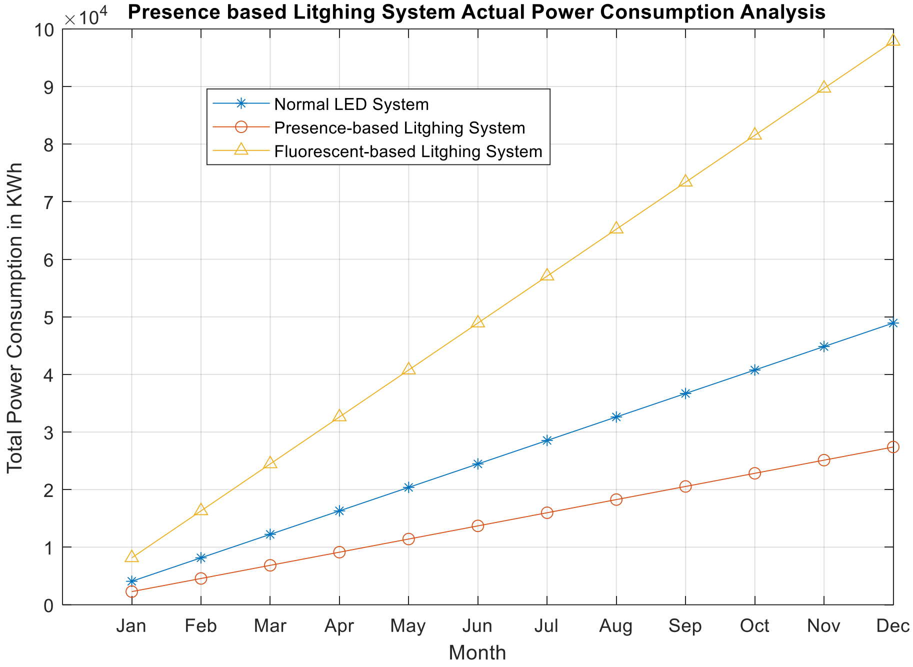


Figure 4-5: Comparison of the presence-based lighting system

4.3. Section Three: Overall Lighting Energy Consumption Reduction Cuts

The following sub-sections of this final thesis document gives details on the overall lighting energy consumption reductions cuts realized in the CBE-HQ building.

4.3.1. Total Energy Consumption Reduction Cut Realized

From the daylight harvesting lighting control system and the presence-based lighting control system, the newly inaugurated CBE-HQ building, realizes the following average annual lighting electric energy power consumptions reductions shown below. Hence, via taking in to consideration annual lighting energy consumption profile given in, Table 4-4 and comparing the total annual lighting energy electric power comparison comparisons taking in to consideration if a fluorescent based lighting system as reference, CBE-HQ building realizes the following power consumption reductions profiles;

- From the Daylight Harvesting Control System (379,549.84 - 76,361.52) = 303,188.32 KWh reduction, and

- From the Presence-based Lighting Control System (97,844.30-27,396.40) = 70,447.90 KWh reduction,
- Hence, the total annual lighting energy electric power consumption reduction realized will be (303,188.32 + 70,447.9) = 373,636.22 KWh yearly power consumption reductions.

Furthermore, comparing the total annual lighting energy power comparisons taking in to consideration a normal LED based lighting system as reference, CBE HQ building realizes the following power consumption reductions profile;

- From the Daylight Harvesting Lighting Control System (189,774.92 - 76,361.52) = 113,413.40 KWh reduction, and
- From the Presence-based Lighting Control System (48,922.15 - 27,396.40) = 21,525.75 KWh reduction,
- Hence, the total annual lighting energy electric power consumption reduction realized will be (113,413.40 + 21,525.75) = 134,939.15 KWh yearly power consumption reductions.

Hence, the overall annual lighting energy power consumption reductions of the two intelligent lighting control systems under study and investigation in percentages, taking in to consideration the following two lighting control system considerations will be;

- If reference lighting control system is fluorescent based lighting control system;
    - The daylight harvesting control system realizes a total of 303,188.32 KWh lighting energy power consumption reduction.
    - The presence-based lighting control system realizes a total of 70,447.90 KWh lighting energy power consumption reduction.
- If reference lighting control system is normal LED based lighting control system;
    - The daylight harvesting control system realizes a total of 113,413.40 KWh lighting energy power consumption reduction.

  - The presence-based lighting control system realizes a total of 21,525.75 KWh lighting energy power consumption reduction

Hence, the overall lighting energy power consumption reduction can be summarized as;

- Normal LED based lighting system control realizes 50% lighting energy consumption cut compared to fluorescent based lighting control systems.
- The daylight harvesting lighting control system offers an additional 40.24% lighting energy consumption cut compared to normal LED based lighting control systems, resulting in a total of 59.76% energy consumption cut.
- The daylight harvesting lighting control system offers 79.88% total energy consumption cut compared to fluorescent based lighting system. It is apparent that devices and components of the daylight harvesting system control system are responsible for the 20.12% energy consumption.
- The presence-based lighting control system deployed in washrooms realizes 72.00% total energy consumption cut compared to fluorescent based lighting system and 44.00% compared to normal LED based lighting system.

4.3.2. Section Four: DIALux Evo Simulation Analysis Results

The actual results recorded and analyzed on site were next validated and cross-checked with the DAILux Evo lighting simulator simulations. CBE' HQ building 36th floor was used as a typical floor for the lighting scenes simulation. The details of the simulation result are in reference to a normal LED based lighting system and it would have required a total annual lighting power energy of 416 KWh if normal LED lighting control system was deployed on site and it requires 254 KWh annual power if daylight harvesting is deployed on site. Please note that this result is well in line with the actual lighting energy consumption recorded of 40.24% and 59.76% lighting energy consumption cut compared to normal LED based lighting control systems.

The current daylight harvesting lighting control system deployed on site is only in a single line located immediately next to the façade/curtain wall of the building. Hence, it is fair to conclude that if additional two lines were made to be intelligent controlled lighting system, further lighting energy consumption can be realized. The following figure, Figure 4-6, shows the actual daylight harvesting system deployed on the floor.

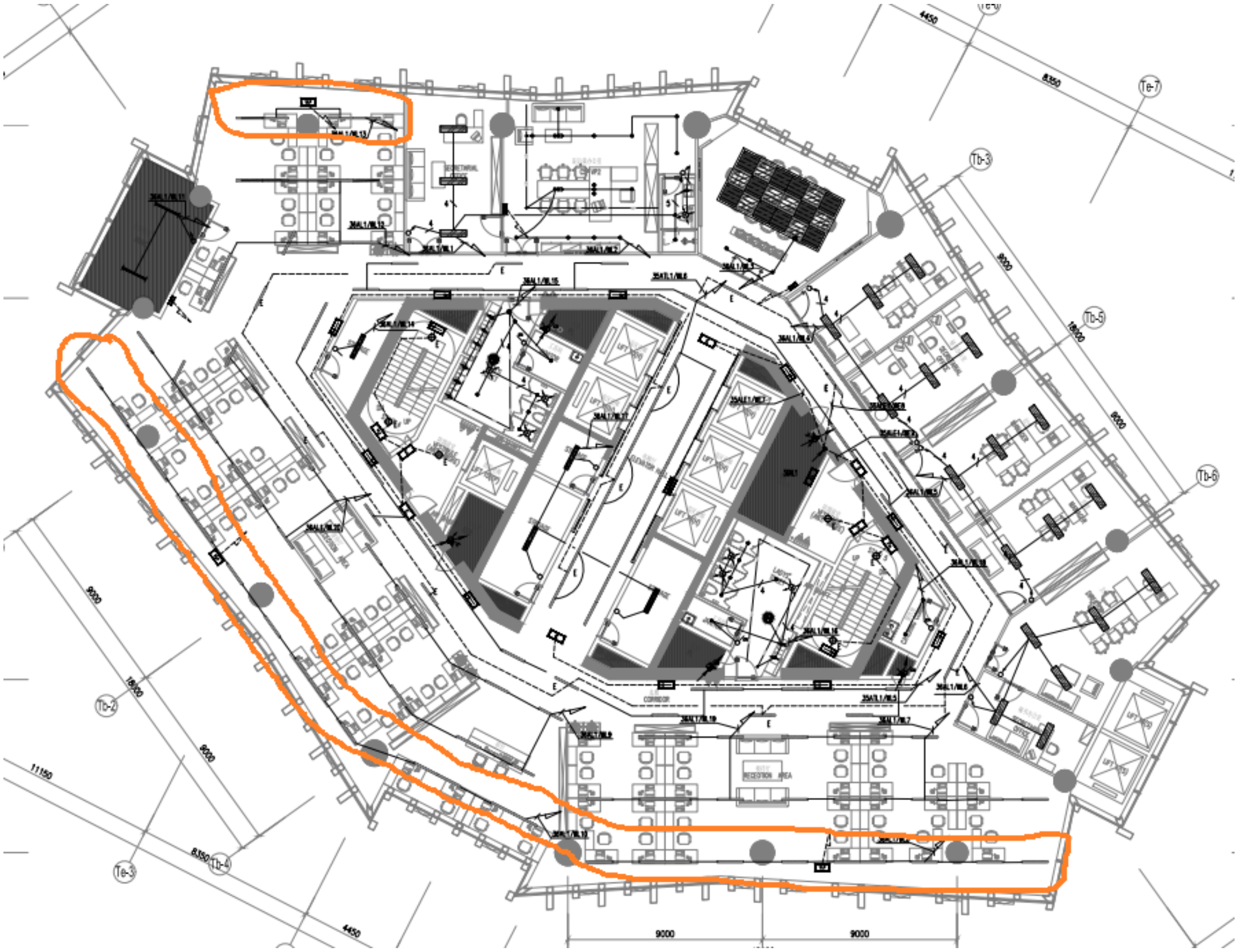
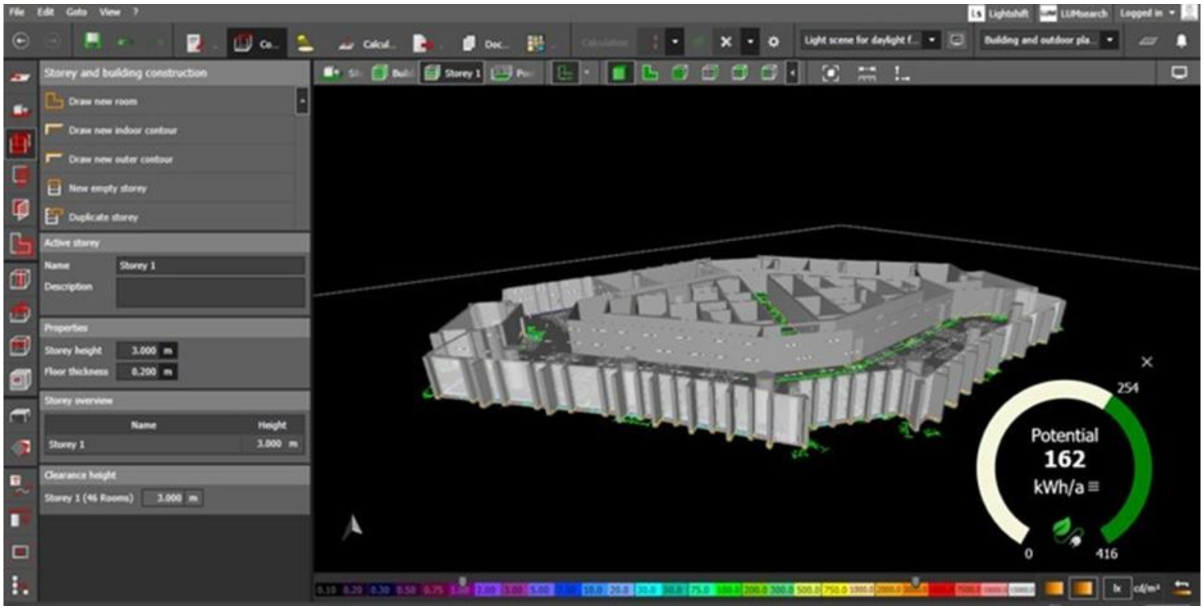


Figure 4-6: 36th floor daylight harvesting system



Name: Storey 1
Description:
Storey height: 3.000 m
Floor thickness: 0.200 m

Name	Height
Storey 1	3.000 m

Storey 1 (46 Rooms): 3.000 m

Figure 4-7: CBE HQ 36th floor DIALux Evo simulation result

In summary, based on the results shown in section 3 of this thesis document and results obtained from DIALux Evo simulations, CBE HQ realizes the following lighting energy power consumptions, CO_2 footprint, and lighting energy bill reductions on the actual single row daylight harvesting system and presence-based lighting control system investigated;

- In reference to Fluorescent based lighting control system; **[As per the simulation outputs]**
    - 373,636.22 KWh yearly power consumption reduction,
    - 0.371 x 373,636.22 = **138,619.0376** Kgs of yearly CO_2 footprint reduction, and
    - 2.124 x 373,636.22 = **793,603.33** ETB yearly money reduction.
- In reference to Normal LED based lighting control System; **[As per the simulation outputs]**
    - 134,939.15 KWh yearly power consumption reduction,
    - 0.371 x 134,939.15 = **50,062.42465** Kgs of yearly CO_2 footprint reduction, and
    - 2.124 x 134,939.15 = **286,610.75** ETB yearly money reduction.

Please note that CBE HQ building could have reduced its electricity bill, power consumption and carbon dioxide foot print if more than one line of daylighting harvesting system were deployed instead of the single line currently installed on site.

4.4. Comparison with Past Related Works and Reports

Table 4-8, given below shows comparison of the CBE-HQ intelligent lighting control system energy consumption cut with reported past works. Energy savings from alternative control strategies, including occupancy-based control schemes, dimmable systems, and daylight harvesting, implemented in varied building contexts, are the main emphasis of the comparison.

The CBE-HQ building's daylight harvesting systems reduced lighting energy consumption by 79.88% when compared to fluorescent lighting systems and by 59.76% when compared to typical LED systems. These outcomes are in good agreement with earlier research that found that, depending on the building type, control strategy, and geographic location, energy savings varied from 28% to 93%. In an office context, for example, reference [45] showed a reduction of 45%, whereas [62] reached a maximum of 93% under ideal daylight conditions. The efficiency of the daylight harvesting system in place is demonstrated by the CBE-HQ performance, which falls within this range. Variations in the type of glazing, internal shading management, lighting pattern design, and the calibration level of daylight sensors are some of the reasons for the somewhat lower percentage when compared to the highest reports.

Furthermore, the geographical advantage of the CBE-HQ building—its closeness to the equator and year-round sun availability—improves the daylight harvesting system's performance. The great performance of the CBE-HQ system in comparison to other published studies carried out in areas with varying daylight availability is justified by the high solar exposure, which guarantees constant natural illumination levels.

Overall, the CBE-HQ reduced energy usage for the presence-based (occupancy) lighting control system by 72% when compared to fluorescent-based systems and 44% when compared to regular LED systems. These findings are also in line with earlier research, which found that occupancy-based controls can save energy by anywhere from 55% to

86%, depending on the occupancy type, room function, and behavioral characteristics of the subjects. For example, the study in [63] found that restrooms used 86% less energy, and [49] found that office applications used 55% less energy. User behavior patterns that impact sensor response times and overall system performance, such as irregular occupancy durations and partial detection zones in restrooms, can be used to rationalize the somewhat lower savings seen at CBE-HQ.

Overall, the study's results are highly consistent with previously published research, demonstrating that the intelligent lighting control systems installed at CBE-HQ are operating within the anticipated worldwide range. The outcomes provide more evidence of these technologies' usefulness in large, tall office buildings during tropical daytime hours. The potential for using comparable intelligent lighting solutions in other commercial and institutional buildings throughout Ethiopia and similar climatic regions to achieve significant energy efficiency increases is further highlighted by the consistency between this study and earlier research.

Table 4-8 : Comparison with past reported works

ILS Control Scheme	Application Area	Maximum energy cut reported due to the implementation of ILS	Reference
Daylight Harvesting	Office	69%	[26],
Daylight Harvesting	Non-residential	28%	[55],
Dimmable	Commercial	25%	[56],
Dimmable	Office	79.36%	[57],
Smart Dimmable	Street lighting	80%	[58],
Dimmable	Street lighting	80%	[31],
Daylight Harvesting	Office	45%	[45],
Daylight + occupancy	Office	69.5%	[60],
Daylight Dimming	Office	80%	[46],
Daylight + Occupancy	Office	73.2%	[61],
Daylight Harvesting	Office	93%	[62],
Occupancy	Washrooms	86%	[63],
Several different	Library	70%	[44],
Occupancy	Office	55%	[49],
Daylight Harvesting	Office	80%	[35],

Table 4 9 : Findings from this research work

ILS Control Scheme	Application Area	Maximum energy cut reported due to the implementation of ILS
Daylight Harvesting ILS compared to LED	Office	59.76%,
Daylight Harvesting ILS Compared to Fluorescent	Office	79.88%
Occupancy sensor-based ILS compared to LED	Washrooms	44%,
Occupancy sensor-based ILS compared to Fluorescent	Washrooms	72%

Chapter Five

5. Conclusion and Recommendation

5.1. Conclusion

In recent years, the urgency to enhance energy efficiency and reduce environmental impact has intensified due to global concerns over climate change and resource depletion. Within this context, exploring intelligent lighting control systems has emerged as a crucial strategy for achieving significant energy savings in buildings. This research examines the application of these advanced technologies in the CBE-HQ building, the tallest in East Africa, as a case study to evaluate their effectiveness in reducing energy consumption and mitigating environmental impact. By assessing the implementation of daylight harvesting and presence-based lighting control systems, this study aims to highlight the transformative potential of intelligent lighting systems in promoting sustainable building practices.

The study revealed that the lighting system based on solid state lighting (SSL), specifically LED based systems, achieved a 50% reduction in lighting energy consumption compared to fluorescent lighting control systems. Additionally, the daylight harvesting system provided a further 40.24% reduction in energy consumption compared to standard LED lighting systems, culminating in a total energy savings of 59.76%. Overall, the daylight harvesting lighting control system resulted in a 79.88% reduction in energy consumption compared to fluorescent lighting systems. Furthermore, the presence-based lighting control system at CBE-HQ achieved an overall energy consumption reduction of 44% compared to standard LED systems and 72% compared to fluorescent systems. The findings not only demonstrate substantial energy savings but also advocate for the broader adoption and integration of these technologies into global energy efficiency frameworks.

These findings underscore the significant energy savings that intelligent lighting control systems offer compared to traditional systems. They highlight the importance of integrating such technologies into energy efficiency frameworks and policies. The results demonstrate that smart lighting systems and management practices can substantially reduce energy consumption from lighting. This thesis emphasizes the need to optimize lighting systems to conserve energy, ensuring a sustainable future for the built environment.

5.2. Recommendation

The research study work on intelligent lighting control systems at the CBE-HQ building in East Africa has demonstrated significant reductions in lighting energy consumptions. These findings provide a model and a recommendable approach for future similar projects in Ethiopia. Globally, governments and large corporations should prioritize integrating intelligent lighting systems into their energy efficiency policies and frameworks to enhance market penetration and achieve better economic and environmental outcomes.

Key recommendations based on the findings from this research;

- Design considerations: there should be a clear standard in the EBCS that shows the importance of the intelligent lighting energy reduction mechanism to be designed and implemented in all constructions sectors of the country.
- Policy Intervention Recommendations:
  - Governmental Purchasing Policies: As it is clearly observed from the analysis done in this research work there is a huge energy reduction by replacing the fluorescent lamps with intelligent controlled LED luminaires since the findings demonstrate substantial energy savings.
  - Subsequently, the government of Ethiopia should be a role model by regulating the purchase of electrical materials and installation of the LED

lighting and intelligent control systems in all public buildings and infrastructure projects. Further, bulk purchasing agreements to reduce costs and encourage widespread adoption should be escalated as well.

- Financial Incentives: The Ethiopian government should be at the forefront of developing and implementing grants and subsidies, tax Incentives, and low-interest loans for manufacturers, suppliers, and contractors of materials for intelligent light control systems. This is because the results of this research clearly indicated that the implementation of these systems significantly reduces energy consumption.
- Specific recommendations from the study include extending daylight coverage indoors, implementing presence-based lighting systems in offices, revising building codes to include LED and smart controls, enhancing governmental oversight on imported materials, promoting LED luminaires among contractors, and benchmarking future projects against the CBE-HQ building.

- **Recommendations for Future works:**
    - The system analysis clearly indicates that we have only measured the daily energy readings from 10 floors of the case study site power distribution cabinets for this research work, with regard to the data collection from the case study building for the presence-based intelligent lighting control systems. The data collection technique will be more prosperous and provide more insight into energy consumption reduction if additional floors can be taken for future works.
    - Regarding the data collection obtained from the case study project for the daylight harvest systems area covered by the photometric sensors, the current daylight harvesting lighting control system deployed on the selected site is only in a single line located immediately next to the façade/curtain wall of the building. Hence, it is more recommended as of the findings from the analysis and simulation that is done for this study if additional two lines were made to be intelligent controlled lighting system, further lighting energy consumption can be realized.

By implementing these recommendations of policy interventions, governmental bodies and organizations in Ethiopia can accelerate the adoption of LED lighting and intelligent control systems, leading to significant energy savings and environmental benefits.

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Appendix

Appendix A: Tables

Table 7-1: Dimmable LED Control System Total KWh per Day

Date	Floor	Total No. of Luminaires	Dimmable LED Control System Total KWh per Day	Normal LED Based System Power Consumption KWh	Fluorescent Based System Power Consumption KWh
25-Apr	G - 15	312	97.26	187.2	374.4
	16 -32	432	111.15	259.2	518.4
	33 -48	315	50.98	189	378
26-Apr	G - 15	312	93.87	187.2	374.4
	16 -32	432	103.28	259.2	518.4
	33 -48	315	51.42	189	378
27-Apr	G - 15	312	95.81	187.2	374.4
	16 -32	432	104.41	259.2	518.4
	33 -48	315	64.55	189	378
28-Apr	G - 15	312	95.48	187.2	374.4
	16 -32	432	111.15	259.2	518.4
	33 -48	315	54.74	189	378
29-Apr	G - 15	312	96.09	187.2	374.4
	16 -32	432	104.41	259.2	518.4
	33 -48	315	63.01	189	378
30-Apr	G - 15	312	94.99	187.2	374.4
	16 -32	432	107.5	259.2	518.4
	33 -48	315	56.58	189	378
1-May	G - 15	312	101.25	187.2	374.4
	16 -32	432	111.15	259.2	518.4
	33 -48	315	49.68	189	378
2-May	G - 15	312	98.83	187.2	374.4
	16 -32	432	115.85	259.2	518.4
	33 -48	315	47.72	189	378
3-May	G - 15	312	96.45	187.2	374.4
	16 -32	432	105.41	259.2	518.4
	33 -48	315	45.3	189	378
4-May	G - 15	312	97.92	187.2	374.4
	16 -32	432	104.41	259.2	518.4
	33 -48	315	43.98	189	378

5-May	G - 15	312	95.84	187.2	374.4
	16 -32	432	111.15	259.2	518.4
	33 -48	315	44.16	189	378
6-May	G - 15	312	99.07	187.2	374.4
	16 -32	432	115.85	259.2	518.4
	33 -48	315	42.38	189	378
7-May	G - 15	312	102.75	187.2	374.4
	16 -32	432	107.5	259.2	518.4
	33 -48	315	42.18	189	378
8-May	G - 15	312	100.17	187.2	374.4
	16 -32	432	112.54	259.2	518.4
	33 -48	315	44.84	189	378
9-May	G - 15	312	100.13	187.2	374.4
	16 -32	432	113.69	259.2	518.4
	33 -48	315	48.87	189	378
10-May	G - 15	312	97.51	187.2	374.4
	16 -32	432	105.57	259.2	518.4
	33 -48	315	45.34	189	378
11-May	G - 15	312	95.08	187.2	374.4
	16 -32	432	107.62	259.2	518.4
	33 -48	315	45.94	189	378
12-May	G - 15	312	98.78	187.2	374.4
	16 -32	432	109.14	259.2	518.4
	33 -48	315	48.44	189	378
13-May	G - 15	312	95.5	187.2	374.4
	16 -32	432	107.63	259.2	518.4
	33 -48	315	51.44	189	378
14-May	G - 15	312	96.42	187.2	374.4
	16 -32	432	105.17	259.2	518.4
	33 -48	315	44.54	189	378
15-May	G - 15	312	93.31	187.2	374.4
	16 -32	432	105.73	259.2	518.4
	33 -48	315	51.408	189	378
16-May	G - 15	312	96.11	187.2	374.4
	16 -32	432	111.15	259.2	518.4
	33 -48	315	55.07	189	378
17-May	G - 15	312	94.26	187.2	374.4
	16 -32	432	106.95	259.2	518.4
	33 -48	315	55.34	189	378
18-May	G - 15	312	93.64	187.2	374.4
	16 -32	432	107.94	259.2	518.4

	33 -48	315	44.91	189	378
19-May	G - 15	312	98.32	187.2	374.4
	16 -32	432	114.65	259.2	518.4
	33 -48	315	50.49	189	378
20-May	G - 15	312	96.85	187.2	374.4
	16 -32	432	102.9	259.2	518.4
	33 -48	315	45.49	189	378
21-May	G - 15	312	99.39	187.2	374.4
	16 -32	432	105.51	259.2	518.4
	33 -48	315	46.52	189	378
22-May	G - 15	312	101.29	187.2	374.4
	16 -32	432	116.49	259.2	518.4
	33 -48	315	42.74	189	378
23-May	G - 15	312	104.08	187.2	374.4
	16 -32	432	113.91	259.2	518.4
	33 -48	315	49.42	189	378
24-May	G - 15	312	99.23	187.2	374.4
	16 -32	432	114.79	259.2	518.4
	33 -48	315	47.15	189	378
25-May	G - 15	312	99.36	187.2	374.4
	16 -32	432	107.81	259.2	518.4
	33 -48	315	43.75	189	378

Table 7-2: Comparisons, Difference (in Raw KWh Consumptions)

Comparisons, Difference (in Raw KWh Consumptions)			**Percentage Comparisons (in %)**		
Dimmable VS Normal LED (The difference in KWh)	**Dimmable VS Fluorescent (The difference in KWh)**	**LED VS Fluorescent (The difference in KWh)**	**Dimmable VS Normal LED (in %)**	**Dimmable VS Fluorescent (in %)**	**Normal LED VS Fluorescent (in %)**
89.94	277.14	187	48.0449	74.022	50
148.05	407.25	259	57.1181	78.559	
138.02	327.02	189	73.0265	86.513	
93.33	280.53	187	49.8558	74.928	
155.92	415.12	259	60.1543	80.077	
137.58	326.58	189	72.7937	86.397	
91.39	278.59	187	48.8194	74.41	
154.79	413.99	259	59.7184	79.859	
124.45	313.45	189	65.8466	82.923	

91.72	278.92	187	48.9957	74.498	
148.05	407.25	259	57.1181	78.559	
134.26	323.26	189	71.037	85.519	
91.11	278.31	187	48.6699	74.335	
154.79	413.99	259	59.7184	79.859	
125.99	314.99	189	66.6614	83.331	
92.21	279.41	187	49.2575	74.629	
151.7	410.9	259	58.5262	79.263	
132.42	321.42	189	70.0635	85.032	
85.95	273.15	187	45.9135	72.957	
148.05	407.25	259	57.1181	78.559	
139.32	328.32	189	73.7143	86.857	
88.37	275.57	187	47.2062	73.603	
143.35	402.55	259	55.3048	77.652	
141.28	330.28	189	74.7513	87.376	
90.75	277.95	187	48.4776	74.239	
153.79	412.99	259	59.3326	79.666	
143.7	332.7	189	76.0317	88.016	
89.28	276.48	187	47.6923	73.846	
154.79	413.99	259	59.7184	79.859	
145.02	334.02	189	76.7302	88.365	
91.36	278.56	187	48.8034	74.402	
148.05	407.25	259	57.1181	78.559	
144.84	333.84	189	76.6349	88.317	
88.13	275.33	187	47.078	73.539	
143.35	402.55	259	55.3048	77.652	
146.62	335.62	189	77.5767	88.788	
84.45	271.65	187	45.1122	72.556	
151.7	410.9	259	58.5262	79.263	
146.82	335.82	189	77.6825	88.841	
87.03	274.23	187	46.4904	73.245	
146.66	405.86	259	56.5818	78.291	
144.16	333.16	189	76.2751	88.138	
87.07	274.27	187	46.5118	73.256	
145.51	404.71	259	56.1381	78.069	
140.13	329.13	189	74.1429	87.071	
89.69	276.89	187	47.9113	73.956	
153.63	412.83	259	59.2708	79.635	
143.66	332.66	189	76.0106	88.005	
92.12	279.32	187	49.2094	74.605	

151.58	410.78	259	58.4799	79.24	
143.06	332.06	189	75.6931	87.847	
88.42	275.62	187	47.2329	73.616	
150.06	409.26	259	57.8935	78.947	
140.56	329.56	189	74.3704	87.185	
91.7	278.9	187	48.985	74.493	
151.57	410.77	259	58.4761	79.238	
137.56	326.56	189	72.7831	86.392	
90.78	277.98	187	48.4936	74.247	
154.03	413.23	259	59.4252	79.713	
144.46	333.46	189	76.4339	88.217	
93.89	281.09	187	50.1549	75.077	
153.47	412.67	259	59.2091	79.605	
137.592	326.592	189	72.8	86.4	
91.09	278.29	187	48.6592	74.33	
148.05	407.25	259	57.1181	78.559	
133.93	322.93	189	70.8624	85.431	
92.94	280.14	187	49.6474	74.824	
152.25	411.45	259	58.7384	79.369	
133.66	322.66	189	70.7196	85.36	
93.56	280.76	187	49.9786	74.989	
151.26	410.46	259	58.3565	79.178	
144.09	333.09	189	76.2381	88.119	
88.88	276.08	187	47.4786	73.739	
144.55	403.75	259	55.7677	77.884	
138.51	327.51	189	73.2857	86.643	
90.35	277.55	187	48.2639	74.132	
156.3	415.5	259	60.3009	80.15	
143.51	332.51	189	75.9312	87.966	
87.81	275.01	187	46.9071	73.454	
153.69	412.89	259	59.294	79.647	
142.48	331.48	189	75.3862	87.693	
85.91	273.11	187	45.8921	72.946	
142.71	401.91	259	55.0579	77.529	
146.26	335.26	189	77.3862	88.693	
83.12	270.32	187	44.4017	72.201	
145.29	404.49	259	56.0532	78.027	
139.58	328.58	189	73.8519	86.926	
87.97	275.17	187	46.9925	73.496	
144.41	403.61	259	55.7137	77.857	

141.85	330.85	189	75.0529	87.526	
87.84	275.04	187	46.9231	73.462	
151.39	410.59	259	58.4066	79.203	
145.25	334.25	189	76.8519	88.426	

Table 7-3: Energy Consumption Data Reading in KWh for 12 hours from 7:00AM till 7:00 PM

No.	**Date**	**Energy Consumption Data Reading in KWh for 12 hours from 7:00AM till 7:00 PM**		
		Dimmable LED Based System	**Normal LED Based System**	**Fluorescent Based Luminaire System**
1	25-Apr-23	259.39	635.40	1270.80
2	26-Apr-23	248.57	635.40	1270.80
3	27-Apr-23	264.77	635.40	1270.80
4	28-Apr-23	261.37	635.40	1270.80
5	29-Apr-23	263.51	635.40	1270.80
6	30-Apr-23	259.07	635.40	1270.80
7	1-May-23	262.08	635.40	1270.80
8	2-May-23	262.40	635.40	1270.80
9	3-May-23	247.16	635.40	1270.80
10	4-May-23	246.31	635.40	1270.80
11	5-May-23	251.15	635.40	1270.80
12	6-May-23	257.30	635.40	1270.80
13	7-May-23	252.43	635.40	1270.80
14	8-May-23	257.55	635.40	1270.80
15	9-May-23	262.69	635.40	1270.80
16	10-May-23	248.42	635.40	1270.80
17	11-May-23	248.64	635.40	1270.80

18	12-May-23	256.36	635.40	1270.80
19	13-May-23	254.57	635.40	1270.80
20	14-May-23	246.13	635.40	1270.80
21	15-May-23	250.45	635.40	1270.80
22	16-May-23	262.33	635.40	1270.80
23	17-May-23	256.55	635.40	1270.80
24	18-May-23	246.49	635.40	1270.80
25	19-May-23	263.46	635.40	1270.80
26	20-May-23	245.24	635.40	1270.80
27	21-May-23	251.42	635.40	1270.80
28	22-May-23	260.52	635.40	1270.80
29	23-May-23	267.41	635.40	1270.80
30	24-May-23	261.17	635.40	1270.80
31	25-May-23	250.92	635.40	1270.80
Mean		255.67	635.40	1270.80

Dimmable Vs Normal LED (in %)	**59.76205997**
Dimmable Vs Fluorescent (in %)	**79.88102998**
Normal LED Vs Fluorescent (in %)	**50**

Actual Annual energy consumption in KWh	
Fluorescent	406656
LED	203328
Dimmable	81814.99871

Annual Energy Consumption Cut Realized in KWh	
Fluorescent	0
LED	203328
Dimmable	324841.0013
Dimmable VS N. LED	121513.0013

Table 7-4: Presence Based Lighting system collected Data for each floor

Floor	Total Number of Presence Based Luminaires per floor	Spot types Presence Luminaires (10watt each)	Linear types Presence Luminaires (50watt each)	Total power consumption of Lamps per floor in watt
GF	N/A	N/A	N/A	N/A
1	19	16	3	310
2	19	16	3	310
3	19	16	3	310
4	19	16	3	310
5	18	15	3	300
6	18	15	3	300
7	19	16	3	310
8	19	16	3	310
9	20	17	3	320
10	22	19	3	340
11	18	18	0	180
12	22	19	3	340
13	22	19	3	340
14	22	19	3	340
15	22	19	3	340
16	22	19	3	340
17	18	16	2	260
18	18	16	2	260
19	18	16	2	260
20	18	16	2	260
21	20	18	2	280
22	20	18	2	280
23	17	15	2	250
24	18	18	0	180
25	20	18	2	280
26	17	15	2	250
27	20	18	2	280
28	20	17	3	320
29	23	20	3	350

30	19	17	2	270
31	19	17	2	270
32	18	16	2	260
33	20	18	2	280
34	20	18	2	280
35	17	15	2	250
36	20	18	2	280
37	20	18	2	180
38	19	17	2	270
39	20	18	2	280
40	20	18	2	280
41	20	18	2	280
42	20	18	2	280
43	20	18	2	280
44	20	18	2	280
45	20	18	2	280
46	20	18	2	280
47	20	18	2	280
48	20	18	2	280
Total				13650

Table 7-5: Energy reading of the presence based lighting systems in different scenarios-1

If average time spent in Toilet is considered to be 40% of the working hour (4.8 hr./12hr) per floor Actual Lighting Energy consumption will be	If average time spent in Toilet is considered to be 60% of the working hour (7.2 hr./12hr) per floor Actual Lighting Energy consumption will be	If average time spent in Toilet is considered to be 80% of the working hour (9.6 hr./12hr) per floor Actual Lighting Energy consumption will be
N/A	N/A	N/A
1,488	2,232	2,976
1,488	2,232	2,976
1,488	2,232	2,976
1,488	2,232	2,976
1,440	2,160	2,880
1,440	2,160	2,880
1,488	2,232	2,976

1,488	2,232	2,976
1,536	2,304	3,072
1,632	2,448	3,264
864	1,296	1,728
1,632	2,448	3,264
1,632	2,448	3,264
1,632	2,448	3,264
1,632	2,448	3,264
1,632	2,448	3,264
1,248	1,872	2,496
1,248	1,872	2,496
1,248	1,872	2,496
1,248	1,872	2,496
1,344	2,016	2,688
1,344	2,016	2,688
1,200	1,800	2,400
864	1,296	1,728
1,344	2,016	2,688
1,200	1,800	2,400
1,344	2,016	2,688
1,536	2,304	3,072
1,680	2,520	3,360
1,296	1,944	2,592
1,296	1,944	2,592
1,248	1,872	2,496
1,344	2,016	2,688
1,344	2,016	2,688
1,200	1,800	2,400
1,344	2,016	2,688
864	1,296	1,728
1,296	1,944	2,592
1,344	2,016	2,688
1,344	2,016	2,688
1,344	2,016	2,688
1,344	2,016	2,688
1,344	2,016	2,688
1,344	2,016	2,688

1,344	2,016	2,688
1,344	2,016	2,688
1,344	2,016	2,688
1,344	2,016	2,688
65,520	98280	131040

Table 7-6 : Energy reading of the presence based lighting systems in different scenarios-2

If not smart, the total power consumption (considering 12hr as a base reference) in KWh	**Energy consumption Cut baseline 12hr Vs 40% working time**	**The difference for energy consumption in 12hr Vs 60% working time**	**Energy consumption Cut baseline 12hr Vs 80% working time**
N/A	N/A	N/A	N/A
3,720	2,232	1,488	744
3,720	2,232	1,488	744
3,720	2,232	1,488	744
3,720	2,232	1,488	744
3,600	2,160	1,440	720
3,600	2,160	1,440	720
3,720	2,232	1,488	744
3,720	2,232	1,488	744
3,840	2,304	1,536	768
4,080	2,448	1,632	816
2,160	1,296	864	432
4,080	2,448	1,632	816
4,080	2,448	1,632	816
4,080	2,448	1,632	816
4,080	2,448	1,632	816
4,080	2,448	1,632	816
3,120	1,872	1,248	624
3,120	1,872	1,248	624
3,120	1,872	1,248	624
3,120	1,872	1,248	624
3,360	2,016	1,344	672

3,360	2,016	1,344	672
3,000	1,800	1,200	600
2,160	1,296	864	432
3,360	2,016	1,344	672
3,000	1,800	1,200	600
3,360	2,016	1,344	672
3,840	2,304	1,536	768
4,200	2,520	1,680	840
3,240	1,944	1,296	648
3,240	1,944	1,296	648
3,120	1,872	1,248	624
3,360	2,016	1,344	672
3,360	2,016	1,344	672
3,000	1,800	1,200	600
3,360	2,016	1,344	672
2,160	1,296	864	432
3,240	1,944	1,296	648
3,360	2,016	1,344	672
3,360	2,016	1,344	672
3,360	2,016	1,344	672
3,360	2,016	1,344	672
3,360	2,016	1,344	672
3,360	2,016	1,344	672
3,360	2,016	1,344	672
3,360	2,016	1,344	672
3,360	2,016	1,344	672
3,360	2,016	1,344	672
163800	98280	65520	32760

Table 7-7: Energy reading of the presence based lighting systems in different scenarios-3

If average time spent in Toilet is considered to be 20% of the working hour (2.4 hr./12hr) per floor Actual Lighting Energy consumption will be	**Energy consumption Cut baseline 12hr Vs 20% working time**
N/A	N/A
744	2,976
744	2,976
744	2,976
744	2,976
720	2,880
720	2,880
744	2,976
744	2,976
768	3,072
816	3,264
432	1,728
816	3,264
816	3,264
816	3,264
816	3,264
816	3,264
624	2,496
624	2,496
624	2,496
624	2,496
672	2,688
672	2,688
600	2,400
432	1,728
672	2,688
600	2,400
672	2,688
768	3,072
840	3,360
648	2,592

648	2,592
624	2,496
672	2,688
672	2,688
600	2,400
672	2,688
432	1,728
648	2,592
672	2,688
672	2,688
672	2,688
672	2,688
672	2,688
672	2,688
672	2,688
672	2,688
672	2,688
672	2,688
32760	131040

Appendix B: Figures

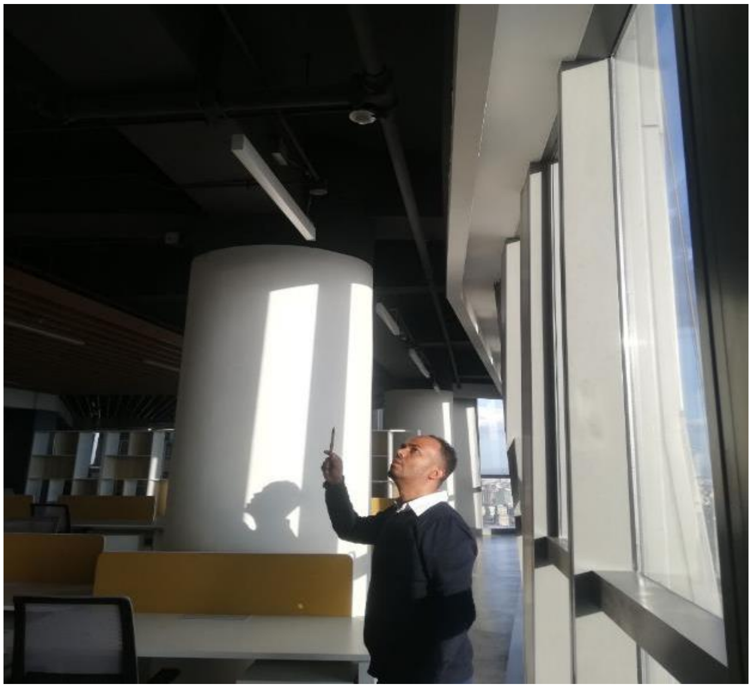

Figure 7-1: Daylight harvest sensors installed with the windows perimeter

Figure 7-2: SDB based energy meters taken from different floors in CBE-HQ building

Figure 7-3: Identification and setting up of selected circuit breakers

Figure 7-4: Real-time lighting control system energy consumption recording process

Figure 7-5: Smart Sensor Digital Lux Meter

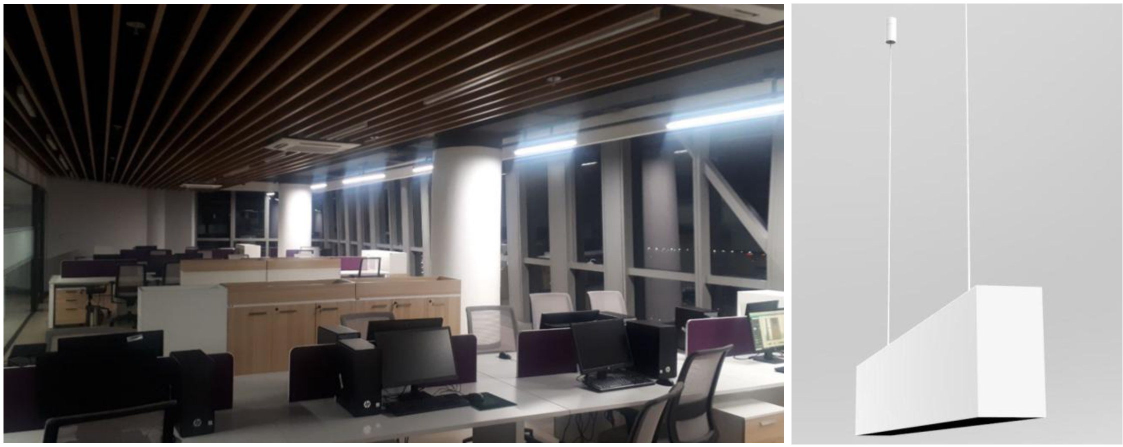

Figure 7-6: PAK-460137 LED dimmable luminaire

Figure 7-7: BK- BTL010 Dimmable constant current LED Driver

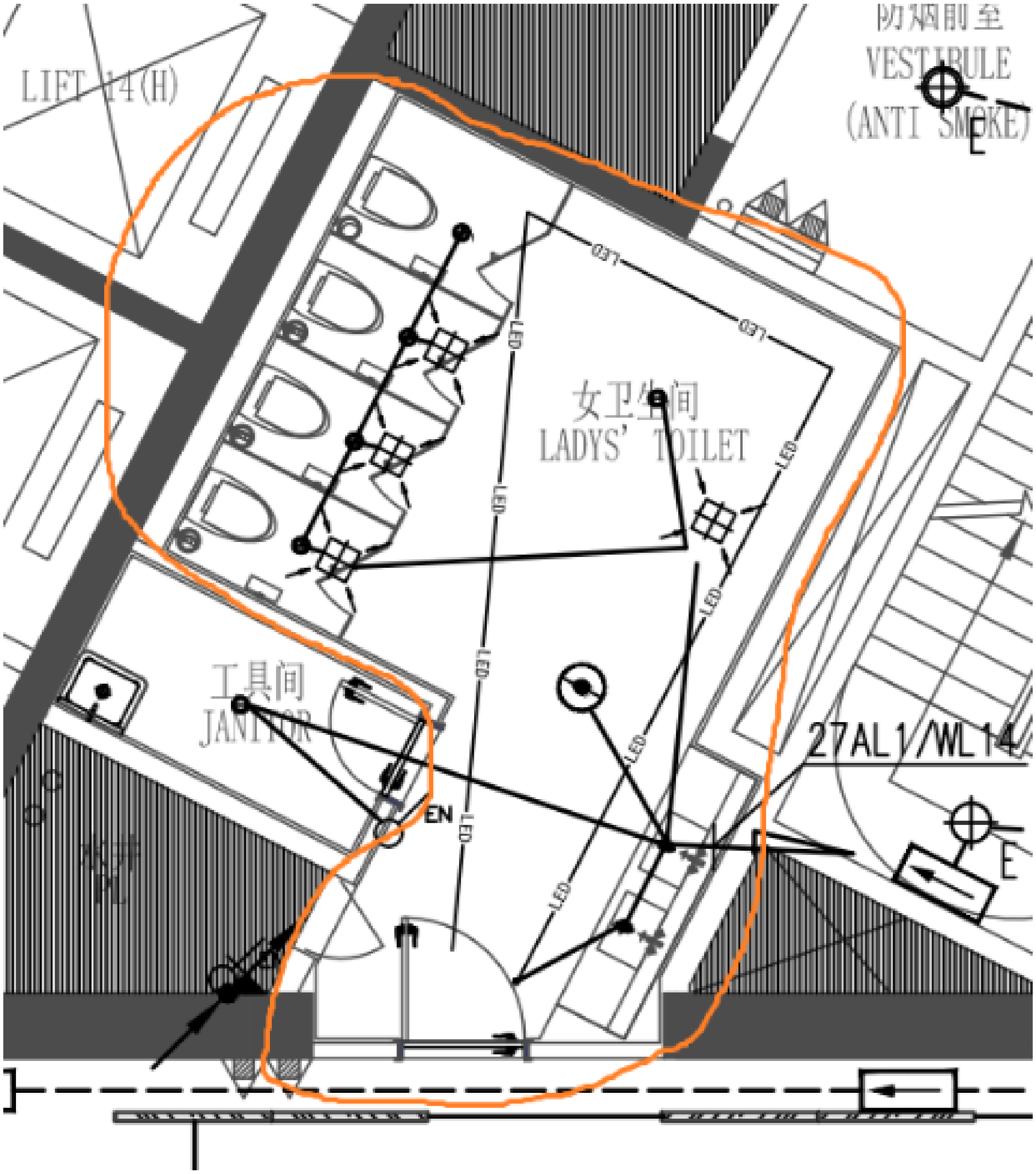

Figure 7-8: CBE-HQ typical occupancy-based lighting control system design

Figure 7-9: Lighting energy consumption reading recording procedure