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**GRADUATE SCHOOL OF SCIENCE AND ENGINEERING**

**INFORMATION AND COMPUTER SCIENCE DEPARTMENT**

**INTELLIGENT SYSTEMS DESIGN LABORATORY**

# Advanced Intelligent Lighting System for Boosting Personal Comfort and Energy Saving of Workspaces

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# Abstract

Smart systems and intelligent models still cause a big concern in introducing to the office work environment. Despite hiring the creative system design to play a vital role in the daily life of a human, the intelligent system design has been considered by each worker to enhance intellectual productivity in the office environment.

Intelligent system design is a big concept that applies in different aspects of the houses, firms, and users. This research is going to study the appropriate perspectives of using the intelligent lighting system as an application of the smart design in the office workspace. The research aims to argue the concept of the innovative model and hiring the system in the office. Besides, the study concentrates on how the conventional and intelligent lighting system utilizes the concepts for boosting the innovation personal ergonomic ecosystem for each worker in the office.

In the office design, comfort spaces are applied to the work efficiency to enhance the performance of each user. Therefore, the personal comfort spaces play a vital part of the office design to boost the intelligent lighting system for each worker in the office. Further, the significance of the research study is in involving the user behavior to interact with the system performance. The relationship between the system and each user helps in the office design for covering saving energy and being healthy for the workers.

The smart lighting system offers a solution to reduce energy consumption in the office. Besides, utilizing the lighting properties and combining with the lighting systems may

has a positive influence on the performance, personal well-being, and intellectual productivity of workers. For instance, integrating the lighting color appearance changes the state attitude or the behavior of the user in the office, which affects the health being of the user.

The intelligent lighting system preserves an expected visual perception of workers, including the impact on the emotional, psychical, and biological perspectives of humans. Furthermore, the lighting system affects the aspects of smart technology on the lighting, ergonomic system, and save energy in the office. The revolutionized lighting systems design contributes to sustainable development science for humans, workers, and office design spaces.

The research is organized as follows. The next chapter argues the concepts of intelligent system design, besides the road map and theoretical part. Chapter Three is about the literature review. Chapter Four is about architecture. Chapter Five is related to system automation and evolutionary computation techniques in optimization.

Chapter Six connotates the combination of the innovation systems on the system response in the working office. Chapter Seven refers to utilize the technology of control like wireless technology to develop the lighting system. Chapter Eight analyze the user data and evaluation. The final chapter is the discussion and conclusions of the performed experiments conducted in verifying the results.

***Keywords –*** Intelligent system design, Automotive engineering, Innovation, Personal comfort, Energy saving, Office design, Workspaces.

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# List of Acronyms & Abbreviations

Here in this section, all acronyms which have been used in the research are indicated in A – Z as below:

- ANA / RC : Adaptive Neighborhood Algorithm using Regression Coefficient
- BLE : Bluetooth Low Energy
- CCT : Correlated Color Temperature
- CCTc : Current Color Temperature
- CCTt : Target Color Temperature
- cd : Candela
- E : Illuminance
- Ec : Current Illuminance
- Et : Target Illuminance
- HC: : Hill Climbing
- ISD : Intelligent System Design
- ILS : Intelligent Lighting System
- K : Kelvin
- L : Luminance
- lx : Lux
- P : Power or Eneryg Consumption
- RC : Regression Coefficient

- R : Influence Coefficient
- RSSI Received Signal Strength Indicator
- SOD : Smart Office Design
- t : Time or Iteration

# CHAPTER ONE

## Introduction

Intelligent system design is the main topic of the ergonomic system for organizations, firms, and houses [1]–[3]. The Intelligent systems design, and the smart models have emerged as a robust design of the ergonomic system and the innovation system solutions [2], [3]. Further, many innovative technologies are involved in smart models of office workspaces to boost the ergonomic system and office workspaces [1], [4], [5].

In the office spaces, intellectual productivity is considered the smart systems based on the ergonomic area and personal comfort for each worker before introducing the intelligent model in the workspaces [6], [7]. Furthermore, system performance and productivity have a level of significance for each user in the workplace environments [7], [8].

The office designs rapidly change to engage the primary elements of smart systems development [9]. The smart system aims to hire personal comfort concepts and apply the ergonomic system in the office [2], [10], [11].

The ergonomics design field allows the workers to interact with the systems used in the office inducting and engaging in some innovative technology [6], [12]. It is a part of is a part of the daily life of the office that focuses on the work efficiency to enhance the performance and productivity of the office [1], [6], [12].

The relationship between the system and worker is a philosophy that help in different aspects of the office covering technology resources, saving energy, and being healthy of the workers [6], [13], [14]. The term has a big extensive concept [6]. However, the most significant issue of the intelligent system design, which affects worker behavior in the office, is the intelligent lighting system [10], [15].

The intelligent lighting system is an automated lighting control system applied widely in different applications by each workspace [11], [16]. Computerized or automated lighting systems become more prominent and in various aspects of the office environment [5]. The lighting interests elaborate on the controllers of the office design [5], [17], [18].

The office work design has a standard level of the lighting control system, and the standard depends on the structure used to implement the lighting system in the office [19], [20]. However, the office design can install a new model of the lighting control system [17]. The policy of the office design has required the philosophy of hiring the concept of the intelligent lighting system to boost the ergonomic system for each user in the office [17], [21], [22].

The philosophy of the intelligent lighting system as a representative of the automated lighting control and the intelligent design system will argue the concept of the system design [22], [23]. The system concept design will discuss utilizing the new model of the intelligent lighting system in the working office environment [23]. Moreover, how the system performs as comfort system design can boost the innovation individual ergonomic environment of each user in the office [24].

## 1.1 Insights View

The insightful view of the lighting control system depends on how much the office design has ergonomic conformity for each user in the workplace [23]. Besides, integrating the lighting control system with the innovative technology to introduce an intelligent lighting system in the office [25].

The new technology and innovations systems have played a key role in transforming the traditional design or the conventional model of the lighting control system to become more efficient, dynamic for office design [26]. Further, the lighting control system made the way to transform from the traditional model to another new system that meets the dynamic changing needs of the work environment [5], [11], [26], [27].

The lighting system continues to be the first source of energy in the workplace [28]. In spite, the lighting system is a service offered to provide a comfortable place for each worker in the office, the best lighting control system contributes to saving energy of the office [8], [15]. Modern lighting control designs need continuously for improvement and development to engage with the new models of the intelligent system designs of the office space [29], [30]. The automated lighting control with innovative technology, such as the intelligent system and the sensing device technologies, has changed the control system of the office to become smarter and more dynamic than using the traditional model [31]. The conventional lighting system is not able to specify or control the office environment more than the intelligent lighting model [28]. For instance, the lighting control system has a standard level of energy consumption for the level amount of luminance in the office. However, the new model of lighting system employs the designated amount of energy based on the specified luminance for each user [29], [31]. Also, the automated lighting control has fixed other significant issues of the lighting control system [17].

Creating a new model of the intelligent lighting control system, besides proposing convenient algorithms to control the properties of the lights and luminance intensity, is verified by each workplace [31]. The work office, including biological information of each worker, evaluates utilizing the performance of the system performs on office for the energy and the behavior of each worker [6], [13].

The comfortable personal space and the insight view of the new concept have led to building the system possibility, besides changing the work office environment to be friendly for each worker [3], [28], [32]. Also, the intelligent system has reduced the amount level of energy in the office [17]. Thereby reducing the power consumption of lighting or the office brightness and bringing about significant energy savings [29], [33].

Each work office has the potential and key factors of utilizing innovative technology inside the office beside the intellectual productivity and wellbeing of each worker [29], [34], [35]. One of the most issues that affect energy consumption in the office is the lighting control system [3], [36]. However, many work office environments have used the next level of the lighting control system, which becomes with some technology or as named with the smart lighting system [36]. The model of the smart lighting system has mechanical control that allows the worker to change the direction of lights using remote controls or sensing devices [36], [37].

In the workplace, the smart lighting control systems are not a modern concept, and the working office has utilized the new technology with the lighting control system and combined to improve the energy waste inside the office [24], [37]. The office environments have transformed from using the traditional lighting system to the smart lighting system due to the past transformation action that has failed to achieve the goal of saving energy and providing the best workspace for each user in the office [16].

The intelligent lighting system is a new concept that refers to connecting the lighting control system or the smart lighting with a network and other devices to match the user needs [38], [39]. The intelligent lighting system employs various lighting fixtures to provide a comfortable place for each user [26]. Many modern offices have started to make a way of introducing the intelligent lighting system in different parts of the workplace [16], [37], [40]. Furthermore, the intelligent lighting system has been developed by each office to integrating with another technology, which is in attempting to make the system more reliable and dynamic in matching the needs of the workers and users.

The intelligent lighting system contributes to making the office more ergonomic for each worker [9], [13]. Besides, the intelligent lighting system adds value to the ecosystem office by reducing the energy and utilizing the technology with the biological data of the worker inside the office [1], [41]. The concept of the system is how the technology performs using the feedback data [39]. The worker engagement will take place in the performance of the system [13], [42]. For instance, the required lighting for each worker affects the energy of the office, but considerable to endeavor the comfort space for each worker. The concept has a big challenge to apply in the office, and it has other complicated factors that should be considered by each office individually [6], [12].

## 1.2 Problem Statement & Motivations

The introduction of the intelligent system design to the work office environment still causes concern for the workers and stakeholders in general, and the intelligent lighting system in specific due to some prominent factors [26], [39], [41]. The insight of the intelligent system design or the process requirements of the office design in the implementation of the intelligent lighting system has some concepts that should be considered by each work office [29], [41].

The problem statement of the research is the inefficiency of utilizing the traditional lighting control or the conventional system design to make a comfortable office for each worker and improve the intellectual productivity of the workplace. The problem has come from how the lighting system performs and effects on worker wellbeing, the energy consumption of the office, and modern working office design.

The research is motivated by implementing an intelligent lighting system design to boosting an innovation personal ergonomic comfort system of the working office environment. There are several factors to enhance the working office for each worker, and the lighting control system affects many substantial issues of the office, which affects the environment and each worker in the workplace [35], [39]. The research impulses lead in more specific to enhance energy consumption, intellectual productivity, and the wellbeing of the worker in the office. The improper use of the lighting systems consumes a big part of the energy of the office, and many office designs and workplaces operate to reduce the power consumption of the office by utilizing the proper use of the lighting energy during the work [17], [29].

The research investigation intends to find an answer to the next following issues. The first intention or issue of the work is on how to introduce the intelligent lighting system in the working office environment. Besides, the second issue of the problem intends to argue the concepts of applying the intelligent lighting system design in specific for boosting the innovation and enhance the intellectual productivity of the office. The argument leads to transforming the working office environment and become one of the ecosystems of the working office [17].

## 1.3 Research Perspective & Objectives

The intelligent lighting system has different states based on user data. The research intends to find the best state of the intelligent lighting system in providing a favorable work environment for each worker in the office. The scenario map of the system design came from the new perspective of the models used on the intelligent system design.

The research is going to study the effect of the intelligent lighting system on energy consumption, intellectual productivity, and the wellbeing of the worker in the office. The main objectives of the research as follow.

- Introducing the intelligent lighting system for the working office environment within a new perspective of the intelligent system design.
- Studying the concepts of applying the intelligent lighting system on the influencing factors for boosting the ergonomic personal lighting system of the office environment.

The first objective of the research has required knowing the difference between the various models of the lighting system while utilizing the lighting system in the office. Therefore, the sub-objectives of the previous concept aim as follows:

- First: analyzing the problem of using the traditional lighting system in the office.

- Second: developing a proposed model of the intelligent system design in the working office.
- Third: using an appropriate optimization method to control the personal lighting and other properties of the light in the office.

Beyond the second objective of the research, boosting and improving the personal comfort space for each worker has multi different influencing factors for the office environment. Therefore, the sub-objectives of the previous concept aim as follows.

- First: analyzing the impact of the design and the architecture on the lighting system configuration.
- Second: studying the effect of the intelligent methods on intelligent lighting system automation.
- Third: verifying the implication of the sensing device and wireless technology on the lighting system context.
- Forth: demonstrate the connotation of the innovation on the solutions of the intelligent lighting system.
- Fifth: evaluate the data analysis on the ergonomic system and the impact of distributed systems in controlling the big data of users to having an efficient lighting system in the office.

## 1.4 Significance of the Research

The lighting control has a crucial function in the intelligent lighting system [12], [17], [29]. The most significant role of the lighting control system is how to utilize the properties of the intelligent lighting system properly and significantly without affecting other resources of the office. For instance, the best use of the intelligent lighting system that enhancing the performance of the office and saving energy consumption.

The significance of the research lies in improving the performance of the office and the workers by applying the intelligent system design and building an innovation personal ergonomic ecosystem of the workplace. Therefore, the importance of office ergonomics is indoors the intelligent system design of the office design for healthy working conditions and comfortable performance for the best productivity and efficiency.

The lighting control system is one of the most significant issues in the workspaces besides the good desk posture of the user in the office. The office environment and the desirable lighting control system play a principal role in the health being system physically and emotionally for the workers [1], [6].

The significant impact of work is becoming in using the adequate processing of lighting information in the workplace environments. The data manipulation has the importance of controlling the lighting system to the office in optimizing the functions, automating the system, and reducing the loosing of the energy resources.

The influencing factors of the intelligent lighting system in the office depend on the ergonomic office design principles that have a positive influence on the performance, personal wellbeing, and the intellectual productivity of workers [1], [12], [35]. The intelligent lighting system does not only preserve the visual perception of workers but also the lighting system has an impact on the emotional and psychic biological of humans [9], [35]. A desirable lighting control system has abled each worker to set up the desired lighting level based on the user information, which has a convincing sense of motivation and performance [24].

## 1.5 Design of the Research

Regardless of the substantial amount of the works available on the lighting system development for the modern office designs, some limitations and conditions are still available for each working office on the installation of the intelligent lighting system inside the office.

The dominant point of research is on applying the concepts of using the intelligent lighting system for boosting the personal comfort lighting system for working office design. Therefore, the study focuses on the aspect of the intelligent system design of lighting control using the innovative technology that may affect the human being in the working office environment. The research has three aspects of the study as follows:

- First, using the automation approaches to enhance the lighting control system and make the optimization of realizing the target in the office.
- Second, applying intelligent methods to develop the system and transform to be flexible and dynamic for each user.
- Third, utilizing the sensing devices technology which allow the accessibility of the system based on the user data.

Moreover, some influencing factors of the lighting control system in the office exist, and this research concentrates on three factors that the ergonomic personal system of the working office has been affected. The influencing factors of the ergonomic system are intellectual productivity, wellbeing, and energy consumption.

Whatever some parts are measured and analyzed like energy consumption, and other factors have biased to additional aspects related to the office design issues. Besides, these factors will be considered based on user satisfaction and achieving the user target to comprehend the impact of subject factors on realizing the objective of the intelligent lighting system.

## 1.6 Organization of Dissertation

A lot of innovative lighting solutions have developed some models of the smart lighting system. Therefore, this research has used the combination of intelligent methods, automation, and sensing devices technology to offer a new model of the lighting control system. The performed work is under laboratory settings using the available equipment. Besides, a program is developed by simulating and demonstrating the system in the applied office.

The rest of this dissertation is organized as follows. Chapter Two is about the concepts of intelligent system design. The chapter argues the ideas and theoretical part of the research, and how concepts can apply to the intelligent system design in the office. Therefore, Chapter Two discusses the road map of the system context and the new perspective of the intelligent models to apply in the working office. Moreover,

Chapter Three is the following about relevant solutions of using the technology with the intelligent system design. This chapter is about the literature review of the intelligent lighting system and related works to some innovative solutions to apply the system in the working office.

In Chapter Four, the research discusses the impact of the office design and the system architecture on the intelligent lighting system configuration. Chapter Four argues how the structure of the system affects to lighting control, and the shape of the system. This chapter is related to the components and the modules of the intelligent lighting system needed in the working office. Besides, Chapter Four explains how the design of the office influences the system configurations.

Chapter Five is related to the control and automation of the intelligent lighting system. Chapter Five sheds light on working the evolutionary computation techniques in the optimization of the intelligent lighting system. Besides, this chapter includes the control system to corporate with communication with different parties related to the lighting control system.

Chapter Six connotates the effect of the system properties on system automation. The chapter discussed the directly affected elements of the intelligent lighting system, the calibration method of the lighting properties, and utilizing the proposed approach on the intelligent lighting system.

Chapter Seven studies the effect of the intelligent lighting system on energy consumption. This chapter performs a solution for using wireless technology to enhance the lighting control system.

Chapter Eight analyze the lighting data of using the intelligent lighting system and evaluates the system data in offering the best model of the ergonomic space for each worker in the office. This chapter explains the data manipulation, processing, and discovering or extracting the information used on the lighting system.

Finally, Chapter Nine is the discussion and conclusions of the performed experiments conducted. This chapter presents a summary of the research following some future works of the study. Besides additional stages may be added in this research.

# CHAPTER TWO

## Background of Lighting Environment in Office

Every innovation system has some concepts to use the design on the houses, firms, workplaces, and office environments [3], [37]. Therefore, the intelligent system design is an applied concept that has some concepts to employ before the installation in the office [37].

The intelligent lighting system has an applied philosophy that matches the office needs [29], [39]. Many workplaces embrace office spaces to support and apply ergonomic office principles [34]. The ergonomic office principles are different from the office to another working area, but it has some requirements to apply these principles in office environments [17], [35]. The concept of the intelligent lighting system hires the ergonomic principles to boost the ecosystem of the working office and improve performance or the intellectual productivity of the office environment [43]. The role of the intelligent lighting system design is to save energy and provide a health design space for each worker in the office [44].

In this section, the concept of the intelligent lighting system considered handling three perspectives. The first perspective comes from the view of the system parts or modules. The second perspective presents the system context, and what are the problems of the current lighting models in the office. The third perspective employs user data analysis to enhance the system.

Besides, this section is going to explain the respective of the previous system models, the computerized systems of the intelligent lighting system design in the office, and how the system performs to provide the service for each user. Therefore, a new perspective of the lighting model design is discussed and proposed by applying in this research.

## 2.1 System Philosophy

The philosophy and the system concepts come from how the system performs its functions in the context of the working office environment [22]. Also, it arises from the interaction with the components and entities of the working office [24], [27]. The office components involve the current state or reality of the space, the existence of the tools and technology, and the information transmission and sharing the knowledge [23].

The system philosophy comes from how the system performs together with these entities [45]. Handling the lighting data and processing the information includes the involvement of environment reality and the existence of technology to realize the target of the working place [39], [45]. The Figure 2-1 argues the three key elements of the intelligent lighting system design, and how the elements and components integration play a pivotal role in developing a lighting control model and improves the lighting functions to make a positive impact on the office.

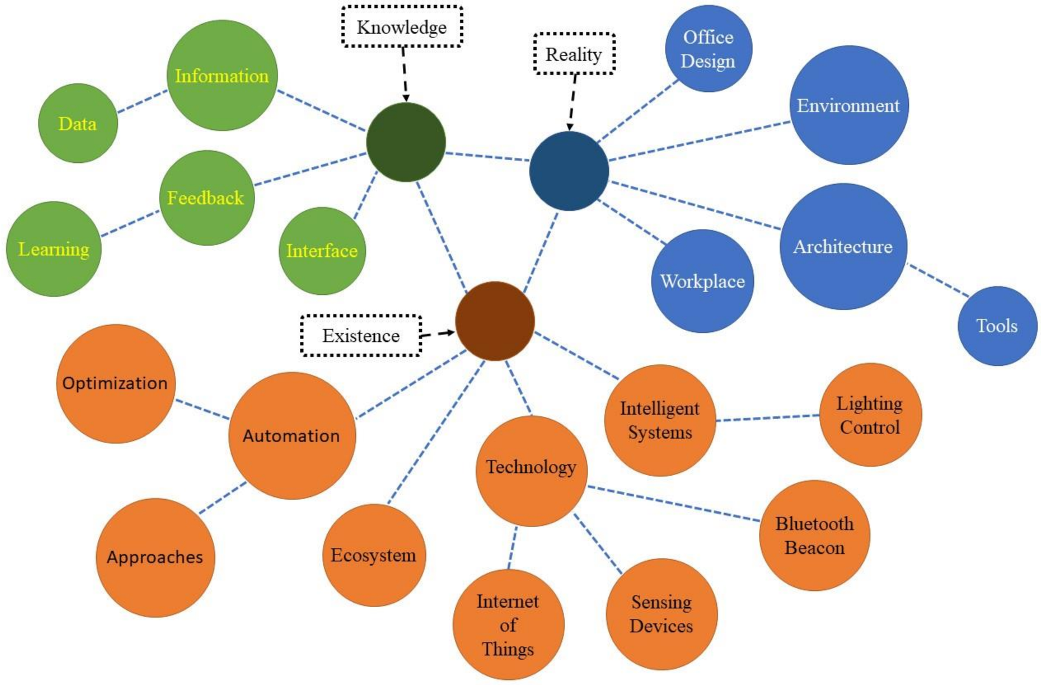



*Figure 2-1: The key elements of the philosophy to utilize the intelligent system design in the office. It consists of three parts, and each part has the category to classify the role of the functions of the intelligent lighting system.*

In the intelligent lighting system, office design is the first issue of using the lighting system, and this is the reality element of the workplace environment [3]. For instance, the ceiling lighting fixture is available, which provides the proper lighting for each user with different levels of luminance. The existence element is the available tools used to enhance the lighting system [39]. For instance, the lighting system makes its way to the improvement, and the integration of the lighting system with another technology. The knowledge element is part of the user data and information analysis, which used to involve the user on the system. For instance, each worker in the office has individual lighting and provided the data for utilizing the lighting control system as desire [44].

## 2.2 System Scope

There are three aspects that the intelligent lighting system design works in the office [6], [20]. The next Figure 2-2 shows how the lighting system takes part in the office. The first aspect is the technology used in the office, and the innovative tools or equipment, which is the intelligent lighting control, and the sensing devices [33], [46]. The second aspect is the ergonomic system offered by the intelligent lighting system for each worker [3], [24]. One desk has individual lighting while other working spaces have no lightings [26]. The third aspect is the ecosystem, and the intelligent lighting system turned on all the lights used for the occupied desk, which the system turned off other unused lights to save the energy [47].

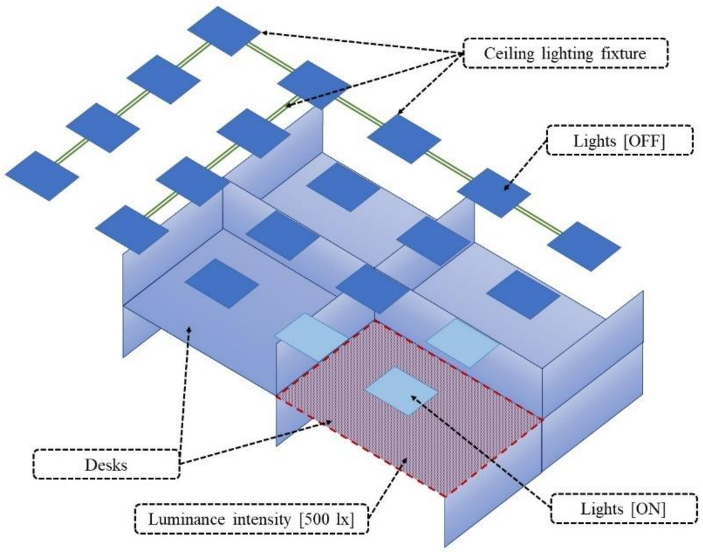



*Figure 2-2: A part of the office design to show the aspects of the intelligent lighting system for each worker. It shows that one desk has brightness while other desks have no lightings.*

Each worker has a desire luminance, and the lighting system provides the level of the luminance intensity for all the workers in the office [42]. Therefore, the lighting system accommodates all the changes that come from the worker inside the office to provide a comfortable space using innovative technologies [6]. The proper office ergonomics is not only a good desk posture, but how the intelligent lighting system performs to provide the individual lighting system as requested with each worker [48]. Each worker has a different level of lighting, and the lighting control system fits the adequate level of luminance for each worker, which does not affect other desks [49].

Offering an adequate level of luminance for each worker in the office helps the lighting control system to use the proper energy to provide the individual luminance for each desk [28], [50]. In the old way of the lighting system, each desk has the same level of luminance, and the lighting control system uses the highest level of energy consumption to provide the amount of all workers [33]. However, the intelligent lighting system utilizes the minimum requirement of energy to offer the requested luminance for each worker, which saves the power of the office [50].

## 2.3 System Features & Quality

The features of the intelligent lighting system depend on the user needs in the office [7], [23]. Whatever the features of the system offer for each user, but the lighting control system has several factors to realize the system quality of each worker in the office [37]. However, each worker expects to feel comfortable when using the lighting system [48]. Also, the uncomfortable lighting affects the performance and the intellectual productivity of each worker in the office [16]. Undesirable lighting affects the wellbeing of the worker [3]. Therefore, some limiting factors exist that are considered in the office to introduce the intelligent lighting system for each worker [35].

Providing the appropriate lightings for each worker is the first function of the system, but other factors exist and affect the level or the quantity of the lighting [45]. The lighting quality has the same significance besides the lighting quantity [9], [21], [39]. For instance, the lighting control system provides the luminance level on the desk, but the lighting system makes lighting distributions to reduce the energy inside the office. Lighting quality is prominent and influential more than just providing an appropriate quantity of lighting [9], [45].

The intelligent lighting system has some features to enhance the lighting, besides, to provide the appropriate lightings for each user [28]. The Figure 2-3 illustrates the functional and non-functional features of the intelligent lighting system.

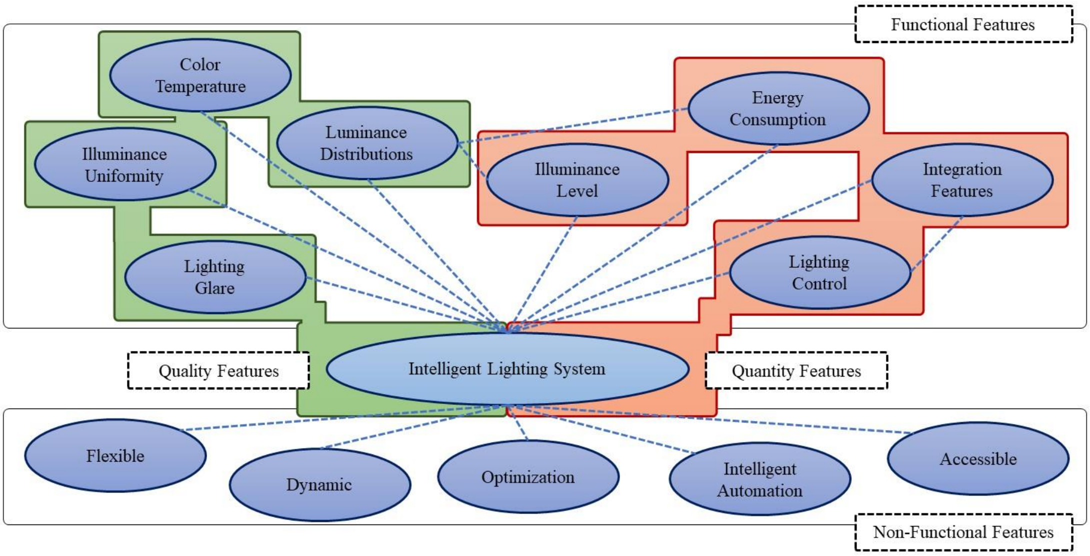



*Figure 2-3: The functional and non-functional features of the intelligent lighting system to figure out the requirements which are essential to ensure the usability and effectiveness of the system performance.*

The quantity features and the quality features play the essential roles of the practical characteristics of the intelligent lighting systems [9], [21]. However, the non-functional features of the system are the extra functions that the intelligent lighting system supports the functional features in offering the service [51]. Also, the non-functional features are the principal part of the intelligent lighting system that the system plays a pivotal role in the office [28]. Furthermore, these non-functional features distinguish the traditional lighting system from the smart modern lighting control or intelligent lighting system [49].

The quantity features of the system define the essential and practical attributes of the system performs [28], [39]. For instance, the intelligent lighting system has the dimming process to provide the illuminance level for each user. Another feature of the lighting system is to control the energy in the office. The system reduces the power of the lightings while providing the desire lighting level for each worker in the office. Table 2-1 illustrates the quantity attributes of the functional features of the intelligent lighting system.

*Table 2-1: The list illustrates the quantity attributes of the functional features in the intelligent lighting system and how the system performs with the features.*

| Attributes | System Performance |
|---|---|
| Illuminance Level | The first function of the intelligent lighting system is to provide the illuminance level or the desired lighting for each user so that the user satisfies the required lighting in the desk. |
| Energy Consumption | The intelligent lighting system considers energy consumption while achieving adequate lighting service. Energy is related to the overload of the lighting in the office, and the system must utilize the best use of the lighting resources to reduce the power consumption of the lightings. |
| Lighting Control | The most significant attribute of the intelligent lighting system is the lighting control and the dimming process of luminance. Controlling the lights has other issues related to the automation functions and how much time of the system to offer the lighting service for each user. |
| Integration Features | Creating a compatible platform or an integration solution for the intelligent lighting system is a complicated task due to the principle of the system structure. The integration |

| | |
|---|---|
| | feature of the intelligent lighting system involves the understanding of the design and the construction of other models to configure and perform as one part. It should be matched with the lighting control to be within the same an integrated system. |

The quality features are the potential attributes of the intelligent lighting system to enhance the lighting system in the environment because it has affected to physiological and wellbeing of the user [23]. Limited potential factors of lighting quality exist to boost the intelligent lighting system in the office [6]. The factors include the luminance distributions of the lighting, correlated color temperature in the office, illuminance uniformity in the desk, and lighting glare [24], [37]. Table 2-2 illustrates the quality attributes of the functional features of the intelligent lighting system and how the system performs with the elements or other solutions integration.

*Table 2-2: The list illustrates the quality attributes of the functional features in the intelligent lighting system and how the system performs with the features.*

| **Attributes** | **System Performance** |
|---|---|
| Luminance Distributions | The first purpose of the intelligent lighting system to achieve the quality of the system is the luminance distributions in all the lighting. Luminance distributions reflect on the visual lighting and comfort for each user besides the energy consumption of the office. |
| Correlated Color Temperature | The lighting appearance in the desk is defined by the correlated color temperature of the lighting, which is one |

| | |
|---|---|
| | of the lighting characteristics in the office. The correlated color temperature is a feature that indicates whether the light has a warm, midrange, or cool color appearance. |
| Illuminance Uniformity | Illuminance uniformity plays a crucial role in the health lighting and wellbeing of the user. Also, lighting uniformity is a feature that affects the efficiency of lighting and converges on the working space on the desk. |
| Lighting Glare | The lighting glare attacks the health lighting and visual comfort of the user due to the excessive luminance in the office. |

The quantity and quality features are interrelated elements that complement and are affected by each other [28]. For instance, the first feature of the quantity illuminance level has related to the luminance distributions, which affects energy consumption. On the other side, restricted factors and non-functional features affect the lighting system [9]. Therefore, extraordinary features are limited and prominent for the lighting control in the office, including the factor of dynamic, accessible, flexible, intelligent automation and optimization systems [9]. Table 2-3 captures the intended behavior of the intelligent lighting system with the non-functional features of the system.

*Table 2-3: The list illustrates the quality attributes of the non-functional features in the intelligent lighting system and how the system performs with the features.*

| **Features** | **System Performance** |
|---|---|
| Dynamic | The intelligent lighting system accepts the change of the lighting properties dynamically. The system behavior is |

| | |
|---|---|
| | not a fixed or a dedicated automation system, but each user can change the lighting properties as needed. The dynamic attribute of the system is the first key that the system works in different office designs. |
| Accessible | The intelligent lighting system has access to all the parts of the working office environment. Each worker feels free to use the system and adjust the lighting values needed. The system does not set the lighting values in a specific area, but the lighting system covers all the parts of the office and has control over all the lighting features. For instance, if the worker leaves the desk, the system controls the lighting based on worker behavior inside the office. |
| Flexible | This attribute refers to system architecture that can adapt to all internal and external changes of the model design. The intelligent lighting system integrates with some innovative solutions, for example, the technology of the wireless and sensing devices. The system is flexible in the devices connected or algorithms integration. |
| Intelligent Automation | The concept refers to the combination of the lighting process automation and intelligent approaches technologies to empower rapid lighting process automation and work together to accelerate the digital transformation of offering the lighting service for each worker in the |

| | |
|---|---|
| | office. The intelligent automation enables the user data and the feedback to involve in the lighting control process. |
| Optimization | The term refers to the performance of an intelligent lighting system to provide the most efficient solution for resource use examining several factors in the office. The factors depend on the functional features of the intelligent lighting system needed in the office. The optimization methods work in the action of the intelligent lighting system to making the best effective solution of utilizing the lighting properties or principles required in the office. The optimization of lighting is an objective function of finding the best lighting status from all feasible solutions to realize the lighting target of each worker. |

A part of the functional features reflects in the non-functional features of the lighting system in the working office [51]. For instance, the dynamic of the intelligent lighting system is how the lighting control utilizes the color property of the light to enhance the lighting service for each worker. The accessible characteristic is that the intelligent lighting system has some integration models or devices that enable the lighting control to provide the lighting service based on the worker movement inside the office and occupied the desk [44].

Moreover, the flexible attribute of the lighting control system is how the system adapts to offer the lighting service for each worker even there is a change of the working space inside the office [52]. Besides, the optimization function of the lighting system is how to distribute the lighting and luminance, which saves the energy of the office [26].

## 2.4 System Design Context

Whether the entire office design is available for the ideal workplace, three sources of lighting systems are available to install in the office [39]. Each type of lighting system has a particular purpose that affects the needs of the workers in the office, and the basic lighting source types are ambient lighting, task lighting, and accent lighting [28], [51].

Figure 2-4 illustrates a sample of the lighting shapes of fixtures used in various office designs. For instance, the ambient lighting is the first layer of the lighting to provide the overall lighting in the office environment. The ambient indoor lighting and the ambient outdoor lighting exist in the fixtures inside or outside the workplace. The task lighting source carries out in the desk of the worker or in each space that has troublesome harsh lighting or other issues of the lighting.

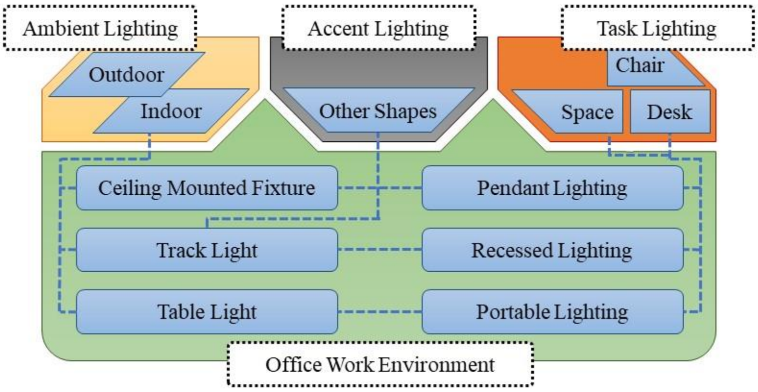



*Figure 2-4: The lighting source shapes exist in the office, and an example of each source type correlated with another source and applied in the office environment.*

The design context of applying the intelligent lighting system in the office revolves around the ambient indoor lighting fixtures. Besides, portable lighting is available in the working space of the desk for the lighting uniformity. The structure of the lights is part of the ceiling lighting fixture and makes the characteristics of the office design [51]. The lighting characteristics are much different than the standard lighting in the office environment [6]. However, the lighting system makes its way of development lighting development platforms in the office to form a discipline of the lighting system in the office [1], [24], [37], [39]. Four stages of lighting system development exist, as shown in Figure 2-5.

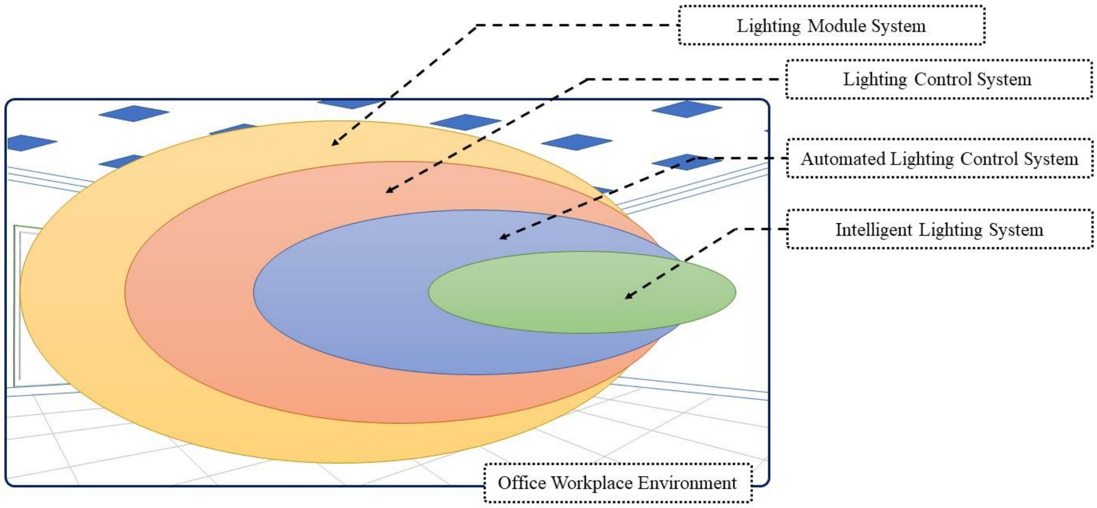



*Figure 2-5: The stages and the development models of the lighting control systems exist applied in the office work environment.*

The first standard lighting used in the ordinary office work environment is the lighting module system or the traditional lighting system [53]. Besides, the system provides a uniform level of brightness for each user in the office. Each worker in the office has the same level of luminance in the desk, and the worker cannot change the luminance level as desire [28]. The lighting system is not flexible, and each worker cannot have personal luminance in the office [54].

The second stage of the lighting system is the lighting control system, which allows the user to control the lighting level and change the luminance much simpler through a controller in the office [29], [55]. Therefore, the lighting control system can change the brightness level as needed, in addition to other properties like the color appearance of the luminance [24]. The worker adjusts the dimmer controller of lights as desire so that the lighting control system replaced the traditional way of switching or turning the lights to the controller module that provides a controlling of the lights functionalities

[46]. Occasionally, the worker turns the high level of luminance using the control, while another worker prefers to change the color appearance of the lights [34].

The automated lighting system is the third stage of the lighting systems development, and the system is an advanced lighting control system [37], [56]. The automated lighting system is a part of the adaptive lighting system that utilizes some computerized programs of the dimming process and controlling the luminance in the office [50], [57]. The automation processes offer considerable advantages, and the lighting and luminance level become flexible and dynamic more over the traditional lighting control system [5]. The techniques of the automated lighting system are to use optimization approaches of the dimming process of the luminance to become smarter and more efficient, so that the automation and optimization process affects and drives down the waste of energy usage in the office [50], [53].

The intelligent lighting system is a high-level model of the automated lighting control system with an aggregate of some emerging features and technologies [53], [54]. The integration of the advanced model and the combination of emerging features in the automated lighting system turns the workplace environment over convenient and flexible for each worker in the office [51]. The luminance control becomes more dynamic and efficient for each worker in the office [14].

The intelligent lighting system is not only a control solution applied in the office work environment, but the intelligent lighting system is a concept to address the individual lighting and the issues related to the ergonomic system principles of each worker in the office [33]. Therefore, introducing the intelligent lighting system in the whole office required a transformation in the structure of the network and the lighting operations [48].

The scalability of applying the intelligent lighting system has a full appropriation of the concept in the entire office [44]. The system context of intelligent lighting model design revolves in the indoor whole office work environment scope [58].

## 2.5 Conventional Control Model

There are various shapes for using intelligent lighting systems in office work environments [5], [33], [59]. The conventional approach of the intelligent lighting system has used the illuminance sensing device for each worker in the office [49], [60]. However, the traditional way of the system causes concern in the quality, automation, and energy consumption in the office [50], [61].

Therefore, other functions of the intelligent lighting system are implemented in advanced lighting models using different methods to develop the lighting automation process [58], [62]. The office work environments integrate innovation models with the intelligent lighting model to enhance the workplace and increase the lighting quality for each worker [12], [50], [63].

Figure 2-6 illustrates an example of the intelligent lighting system application in the office space. The intelligent lighting system has the elements of the lighting system, lighting control and dimming process, and the sensing devices which the interface between each worker and the lighting control system.

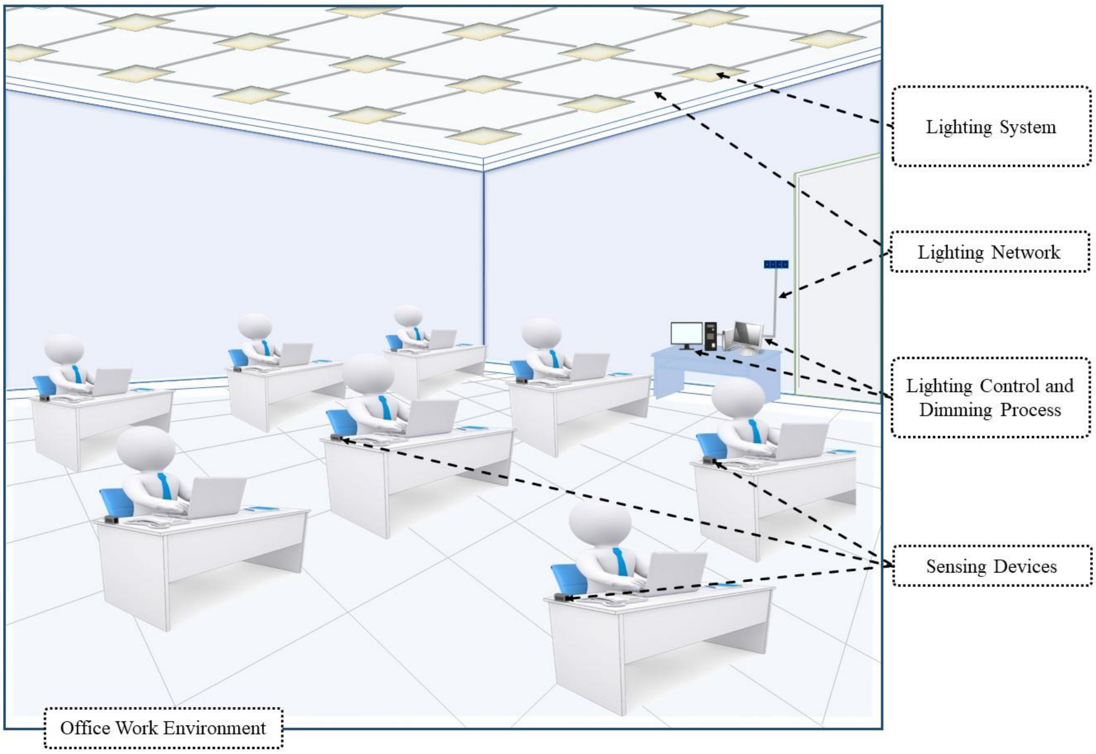



*Figure 2-6: Example of the essential elements of intelligent lighting in the office work environment.*

The intelligent lighting system has three processing parts of using the lighting system in the office, as shown in Figure 2-7. The integration of the innovation models combines in all the parts of the intelligent lighting system phases and components. Each processing phase has a different state of handling the data of the system or user experience. The integration and developing each part find various module of the intelligent lighting system [29], [64], [65]. However, some other operating components require at least a specific level of integration with the intelligent lighting system [49].

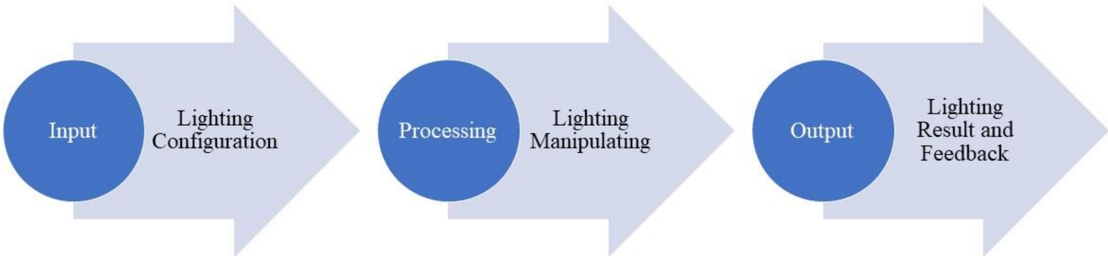



*Figure 2-7: The processing phases manipulate the user data and system information in the intelligent lighting system.*

In the processing phase, the optimization functions or lighting automation is another part of the computerized innovation models. The lighting automation considers several factors to provide the lighting for each user [40], [62]. For instance, the time and lighting speed of the realized target is a significant factor in the intelligent lighting system efficiency in the office. In automation processes, convergence methodologies are used by traditional approaches to reducing errors between results and input variables. Additional methods are developed based on the design of the intelligent system.

The lighting results in the third phase considers the feedback of the user to achieve the target in the office [42]. Studying the behavior of the system in line with the user in the office requires innovative methodologies to avoid the consumption of lighting, which increases the energy loads in the office [23], [42], [66]. The consistency of the lighting results in the input achieves the appropriate quality for each worker in the office [34].

## 2.6 New Perspective Design of the Model

The modeling perspective in the intelligent system design has various views and conceptualizations of the implementation and system development [6], [48]. The new concept design of the intelligent lighting system in practical office work environments requires to regulate the target of each worker in the office [67]. The processes of integrating components of the system for office work context, requires a visualization about the application of the concept of intelligent design in the work environment [68], [69].

A new perspective of utilizing the intelligent lighting system to boost the office work environment has been introduced by using three concepts combined, as shown in Figure 2-8. The office workplace is the environmental border of applying the concept. There are different sizes and limited capacities of the office design, and the stakeholders plan to make the best use of the lighting system in the workplace that enhances performance and achieves the preference for each worker in the office.

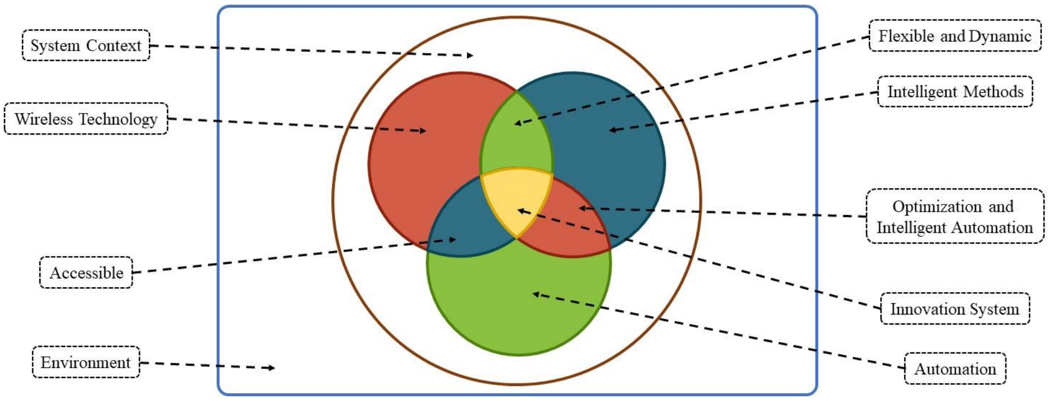



*Figure 2-8: The new perspective design states utilizing the intelligent lighting system in the office work area.*

The size of the office work environment influences to the intelligent lighting system design [34], [48]. The office space impacts affect the speed of converging to realize the target luminance for each worker in the office [70], [71]. Therefore, the lighting system development plays an active role in the automation and dimming process of the lighting [8], [37]. Also, the computerized algorithms perform the vital players to minimize the time of preparing the lighting system to provide the lighting service for each worker as desire [69].

In other words, each worker in the office has a different target illuminance, and the intelligent lighting system achieves the target lighting for each worker on time accepted in the office. Realizing the target or the visual lighting for each worker is a significant factor and getting personal lighting at the desk is how the result is acceptable for each worker in the office. However, the time of converging for each worker in the office is another significant factor [72]. For instance, the time of the large size of the office space is not the same for the small area. In all cases, the workers cannot recognize the speed of the converging target in the desk, and the intelligent lighting system realizes the target in a short time in the office [14], [73].

The ambient indoor lighting system is the system context in the office work area. There are different workplace areas, and the lighting system is widely applied to various aspects of workplace environments [12], [17]. Therefore, the lighting system supposes in the system development stage to provide the lighting for each worker who has an individual work desk inside the office [74].

The first concept revolves principally throughout automation and lighting process computing [50], [56]. The lighting automation process enables the user to utilize the lighting operations or services instead of changing the brightness levels and toggling the lighting needed manually on the desk. The second concept is the use of intelligent methods and algorithms that make the best hire of the lighting system in the office, in addition to reducing waste in energy consumption [26], [75]. The third concept is related to the utilization of communication services, wireless technology, Bluetooth, and the internet of things [58], [65]. Wireless technology with lighting control system services plays a vital role in saving time of the automation, information sharing, data processing, and technology accessibility.

Integrating several components of technology involves the integration of functions into a comprehensive platform to work together. High-level characteristics, better system performance, improved productivity is obtained by integrating components and subsystems and utilizing the innovative model of the intelligent lighting system [4], [33], [65].

## 2.7 Remarks

The philosophy of intelligent system design is a fully comprehensive concept that applies to the smart innovation system for each office work area. The intelligent lighting system is the best application and practice to use in office design systems. Whatever, the innovation in the lighting control system contributes to enhancing the productivity of the workplace environment, increases performance, and provides a comfortable work environment for each worker in the office area.

The concept of the innovation system is key to the smart and automated operations that promote the personal ergonomic ecosystem to regulate the office work environment. Further, hiring the concept to be applied appropriately, the definition of the system scope is required in the office work context. Each office work area has a singular philosophy to utilize the concept for each worker.

The intelligent system design in the office areas has specific functions to use in the workplace. Therefore, the intelligent lighting system, as one of the best practices of providing a suitable work environment for each user, the system has limited functions and features. The integration of the functions creates a work environment that helps each worker to increase performance and adopt smart lighting with high efficiency and effectiveness in the office areas.

Systems integration and the combination of various functions to interact as one system leads to a comprehensive unit that cooperates in reaching one purpose. Furthermore, a lot of the office work areas utilize different technology components in the intelligent lighting system in a way to make the best use of the lighting system and boost the work environment for each user. Moreover, involving the behavior of the users into the work systems design regulates and creates an ecosystem of the office work areas.

# CHAPTER THREE

## Literature Review & Related Works

A lot of related papers has found in the literature of intelligent and optimization area [3], [8], [76], [77]. All of them have tried to develop a proper intelligent lighting system for workplace; or improve the quality if lighting system by using different optimization methods. The next sections highlight many ideas which can be the base of the research. As well, the goal of the section to compile a listing of the literature that is commonly cited for showing last topic in intelligent lighting system and the impacts in workplace environment.

While proven and effective, advanced lighting control strategies have not really made their way to commercial buildings the world over [5], [7], [29]. The goal of office comfort space is to design your office work station that fits and allows each user for a comfortable working environment for maximum productivity and efficiency [59], [78], [79].

Many research and related works have been done to improve the output performance of intelligent lighting systems [6], [20]. All of the works contribute to develop a new intelligent lighting system and improve efficiency of the system for all users as a main contribution in automated lighting control system [80], [81]. The contributions have been achieved to make a quality of lighting system or enable the system to carry out the optimal lighting output for all users in different workplace environments [9], [66].

The overall purpose of intelligent lighting system is to eliminate waste while providing a productive visual environment for workplace [23], [34]. Smart lighting system used to be more fixable for workers, as users can adjust the proper illuminance [11], [82]. By the basic functions of intelligent lighting system, the worker will have the desired target which satisfied or flexible for people [73]. Thus, power consumption of smart lighting in workplace can also be reduced and improved in matching the automation and sustainability of energy [49].

Designs of ergonomic workplaces cover all elements of a working system and the relevant environmental factors [9]. Basically, lighting systems have affected in workplace environment in different ways: visual functions; emotional perception; and biological effects [3].

One experiment [9] had been conducted to provide individual illuminance and color temperature for users in workplace. The experiment has used regression coefficient to estimate the basic factors for intelligent lighting system in workplace. The experiment has addressed the problem of target illuminance as well the required color temperature of workplace without using a chroma meter in the environment. In the way, personal lighting system for workers have been provided, as the power consumption has been reduced to save the energy of lighting.

The proposal method in previous work had to estimate color temperature. Estimated approach used the luminance of lamps to control illuminance based on the estimated color temperature. A new approach has been improved instead of using simplified method, and without a chroma meter.

In a similar way, an evolutional optimization algorithm was proposed [10] as a new approach to estimate influence coefficient factors of lighting control system, and illuminance sensors by using regression analysis methods. The paper has inferred that the lighting environment cannot be suited for each worker. The paper has proposed an Adaptive Neighborhood Algorithm using Correlation Coefficient (ANA/CC) as a control algorithm for intelligent lighting systems which enable to convergence the illuminance in stable.

The new approach used the regression coefficients to change the luminance of lighting system, as well to change the illuminance of sensors system [10]. The experiment deduced that the luminance was increased to be optimal for each worker in range 200 lux up to maximum 800 lux, and it found the consumption of energy was reduced around 40% of total.

Another system and model [4] which had been proposed to estimate illuminance based on achieving personal illuminance and self-distribution algorithm. Each light has been changed individually by using regression analysis to estimate the influence coefficient between sensor and light; and to realize the target illuminance for user.

Whatever, the paper as well has proposed a method to solve the problem which become due to increase the error rate of regression method by expand the number of lights in workplace. Thus, the researchers have proposed a method by using the distance between light and sensor. The method which had proposed in the experiment improve the result to be more optimized, and convergence fast. Moreover, the proposed method enables user to control lights appropriately compared with conventional method; as well reduce the power consumption in the workplace.

Meanwhile, another intelligent control system has been conducted by applying another particle optimization for controlling system during system operations [11]. The experiment had used an intelligent algorithm to finds the optimal solutions for power consumption and customer comfortable.

On other side, another experiment which had conducted for intelligent lighting system to realize personal illuminance for users [12]. The experiment has applied in multiple real office in Tokyo area, as well in large-scale workplace which the number of lighting fixtures and illuminance sensors have been increased in the environment, also the time is increased. A new technique has been proposed by this experiment to reduce time of converging target illuminance, to save the energy consumption by lights [12].

In a similar way, the experiment of paper is extended [6] to develop another method and improve power consumption by extracting a method for influential lighting of illuminance in large office. By the proposed method, power consumption is reduced drastically in using regression coefficient for the optimization and based on Hill Climbing method.

The approach in previous paper proposed a new technique to avoid any temporary correlation phenomenon through the change of luminance intensity during new generation which affect to energy efficient lighting system. Thus, the researchers have determined a rank for all influence factors by using a Map to workplace, which enable the system to identify near all lights for sensors and recognize it in groups.

On another hand, some papers choose the optimization methods based on the environment which enable to improve the fitness of function or minimize the objective function of intelligent lighting system. General design optimization has been chosen based in specific criteria as use some algorithm based in machine learning and statistical analysis. The potential for delivering better designs to be optimum or more efficiency compared to another optimization approaches for intelligent lighting system makes automated design optimization more attractive from different viewpoints.

By the way, some papers present strategies to save the power consumption of lighting. The strategy [13] to distribute the consumption of energy for lighting has been proposed to meet the illuminance requirements of users. This strategy is developed based on a message passing for status between users and lamps, and it has been considered to capture the personal preferences for the recommendation of required levels of lighting parameters. As a result of the work, the level of luminance is temporal changed based on users.

Next paper [14] has used a distributed control algorithm to determine dimming levels of lights to achieve illumination rendering, under different occupancy conditions, as well to minimize the power consumption of rendering the lights. A weighted average of simplex dimming level has been set for the dimming level which received from neighboring luminaires of lights and communicated to the respective luminaires. The simulation of the paper is conducted in open office with the resulting that the power consumption is higher than the obtained by using an optimum centralized control algorithm.

Posteriorly, other systems have been proposed for desk by using an imaging sensor and intelligent light emitting diode lighting system [24], [27]. The paper defined an objective lighting effect evaluation metrics and developed the control system to realize optimal luminance tuning. By using the proposed system, the lighting effect of a desk application has been effectively improved.

## 3.1 Remarks

All these studies and research are interested in developing and improving intelligent lighting system using different optimization techniques. There is no optimum solutions or methods which enable the system to be more convenient for all users in workplace, but the intelligent lighting system integrating the convenient technology may effect on the office environment.

The research and all previous one has used different approaches to provide individual illuminance and color temperature for workplace to make the optimum solution for the best environment for workplace as required, as well as to improve the productivity of workers, and reduce the consumption of energy.

All the above studies and experiments are meant to provide a solution in one viewpoint which will help to propose a solution useful for many optimization problems, and convenient based on the objective of workplace environment.

# CHAPTER FOUR

## Proposed of the New Model Configuration for Intelligent Lighting System

The design of the intelligent lighting system is a considerable part of building smart office working systems. Many smart work offices endeavor to optimize the use of resources and tools in the office workplace environment, including providing a comfortable work environment through the intelligent lighting system.

Each office workplace area has a different technique of using the intelligent lighting system. However, the office areas have the same base in building the blocks needed for the lighting control system. Lighting system components and adjusting control settings have become a principal function that affects the performance and productivity of the office working area. Therefore, the intelligent lighting system and lighting control features need to correspond to the setting or configuration of the office design.

System architecture, settings, and system operations are a primary component of the dimming operations. Also, the system integration between models affects the automation processes and operating mechanisms of the office. Therefore, building an intelligent lighting system concerns the system settings and configuration. Control system works incorporate communication for different lighting models or parties related to the lighting control system. The impact and importance extend and expand depending on the size of building the intelligent lighting system in the office areas.

In this section, the intelligent lighting system architecture is discussed to build a conventional intelligent lighting system in the office area. The base components of the intelligent lighting system are illustrated, in addition to the structured elements and control properties. The system settings are configured to stand on the significance of the shape in the lighting system architecture. Furthermore, the system operational scenarios are explained and examined for the events and phases to transfer the data in all lighting stages. Finally, the potential area design is discussed and showed up the implied effects on the intelligent lighting system.

## 4.1 System Architecture

Enable the intelligent lighting systems in the office work environments requires to be known the lighting model components of the system, besides defining the functional structure of the system to enable the model to perform functions and offer the features based on the user needs.

The intelligent lighting system has the base components connected to a network and required for each office work environment, as shown in Figure 4-1. The ceiling lighting fixture is the first module of the lighting control system, and it consists of the smart lights, which are the flameless or high-quality modern string lights fixtures. The controller module or the dimming process is for dominating the amount of energy supplied to the lighting source. The sensing device is the occupancy sensors that are the intermediate unit for each worker to interact with the intelligent lighting system. The power meter is also an intermediate device for the signals from the controller module to the lighting unit.

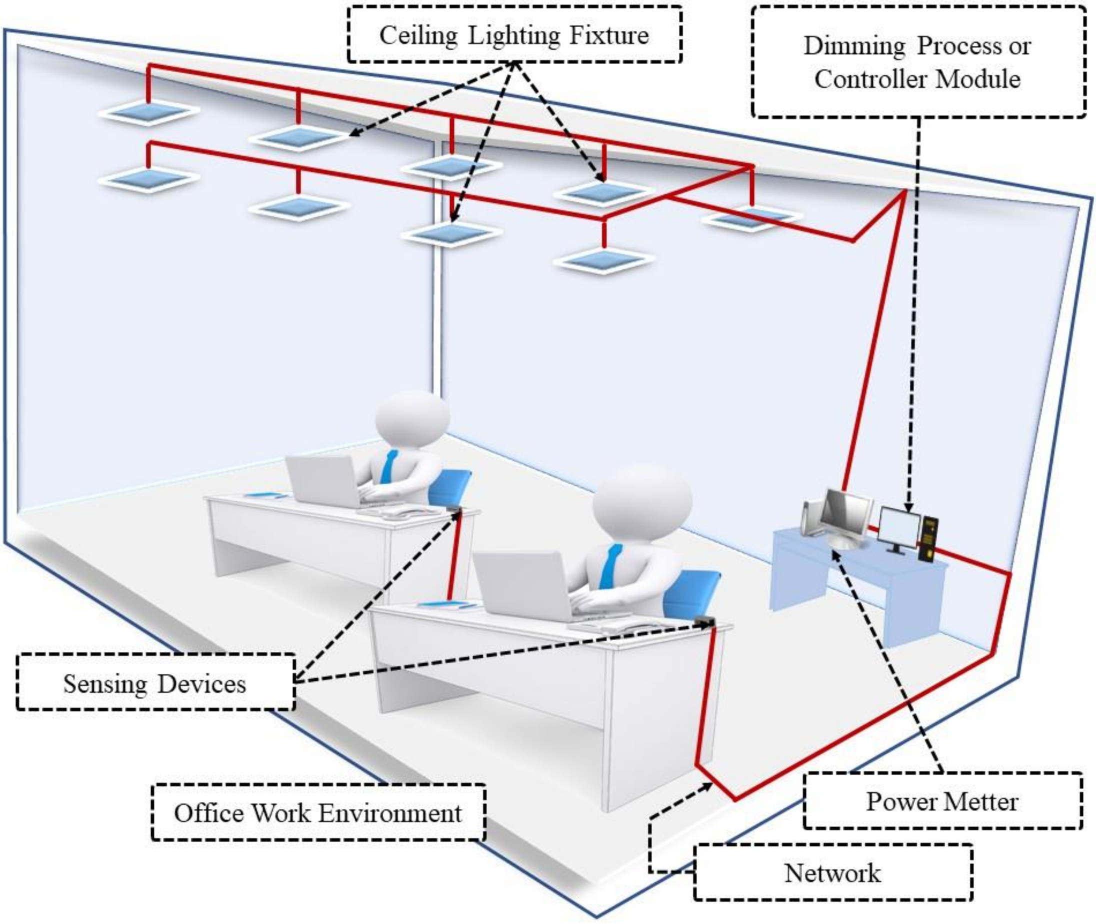



*Figure 4-1: Example of the essential components of intelligent lighting connected with the network of the office work environment.*

The intelligent lighting system has equipped ceiling lighting fixtures with lighting units that address the functions of brightness and color appearance on the desk, as illustrated in Figure 4-2. The lighting units must be a model of dimmable lights with more durable and low energy consumption. Each lighting mode has a scale of adjustable brightness options to eliminate all unpleasant shadows as the user desire. Besides, the lighting units have two styles of color appearance, which are the white color cooling mode and the orange color warming mode. Configuring the functions of the ceiling lighting fixtures and the lighting unit features are handled in the control unit of the intelligent lighting system in the office.

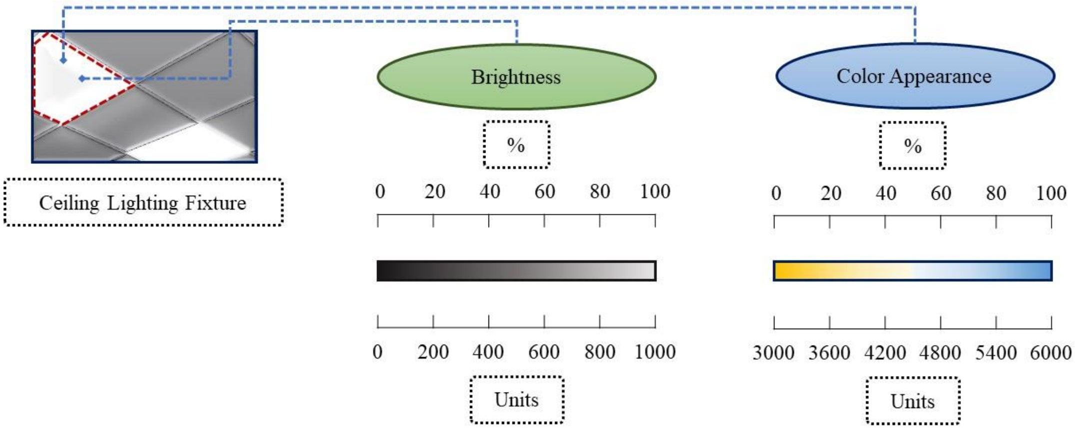



*Figure 4-2: The lighting units equipped in the ceiling lighting fixtures configure the features and modes of the lighting in the office.*

The ceiling lighting fixture and lighting system attaches to the energy meter system connected to the controller module. The energy meter connects between the controller and the ceiling lighting fixture system. Besides, the controller module connects to the sensing devices in the office work environment.

The energy meter or power quality meter is a small device connected to the intelligent lighting system for measuring the power of lighting. The power meter monitors the energy of the lighting system control. However, luminance is the largest efficient element in the energy consumption of the lighting system. The luminance measurement comes from the amount of light-emitting passing through or reflected from a surface from a solid angle [52].

The energy meter system and the controller module gradually start the dimming process after receiving the value from the sensing devices in the office. The control system receives the values and sends the rate of brightness for each light, and the lighting system adjusts the luminance per light based on the rate values of the controller and energy meter system, as shown in Figure 4-3.

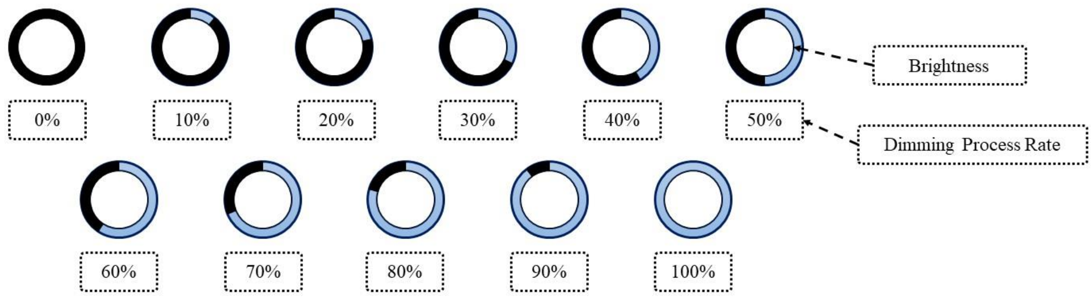



*Figure 4-3: The dimming process rate is for each light individually to adjust the brightness and luminance for each worker in the office work environment..*

The sensing devices in the intelligent lighting system are an interface of the communication between the worker and the lighting control system. Each worker in the office environment has one sensing device on the desk. However, the sensing device has three functions, and two phases of usage in the desk, as illustrated in Figure 4-4.

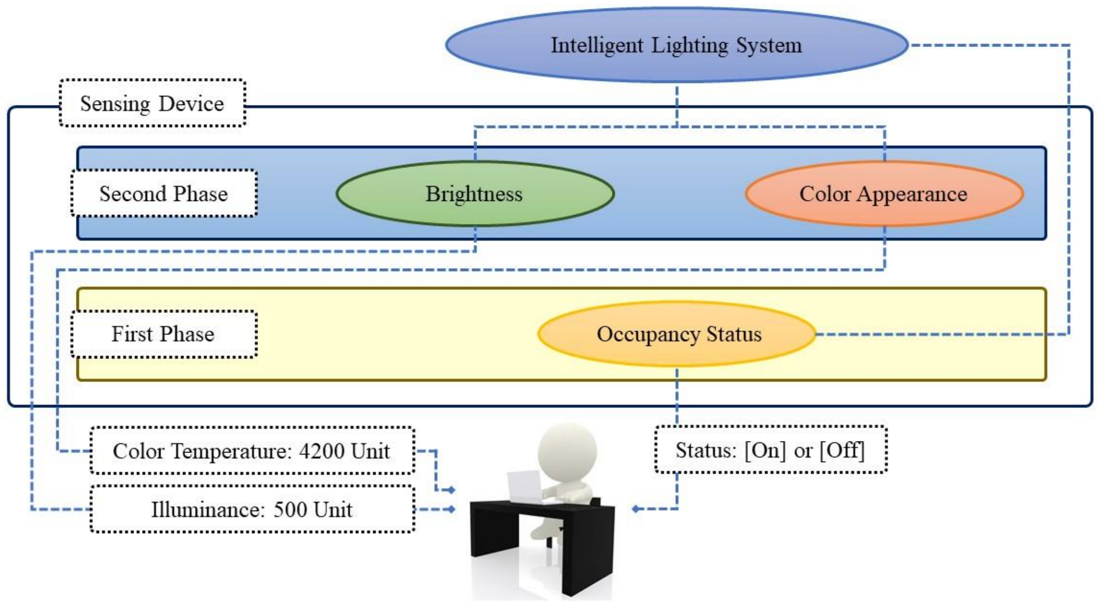



*Figure 4-4: The sensing devices located on each desk exist, and the functions of the sensing devices in the office work environment..*

The first function of the sensing devices is to toggle the status of the occupancy. The occupancy status is the first phase of each worker to use the intelligent lighting system.

In the second phase of usage, there are two features that each worker can use it. The first feature is the adjust the illuminance desire and change the brightness of the lighting. The second feature is to choose the color appearance using the sensing device and set the value of the color appearance as desired.

Limited sensing devices are available and exist to measure the illuminance and the color appearance of the lightings. Some office work environments consider reasonable factors to equip the sensing devices for the intelligent lighting system in the office. For instance, the constituents are easy to use and install, reasonable cost, availability of the sensing devices and find, and other factors depend on each office work environment.

## 4.2 System Configuration

The system configuration of the intelligent lighting model defines the processes of the system. The lighting control configuration prescribes how the components operate together and transfer the data between the elements. The intelligent lighting system configuration illustrates the system elements and the architecture of the parts that compose the boundary of the lighting system.

There are three processing phases in the intelligent lighting system, as illustrated in Figure 4-5. The first processing part is called the input parameters of the lighting system. Then, the lighting system received the input parameters and used it for processing in the second part of the lighting control system. The third part is the realized lighting quality, and it is the lighting output and the result. All the phases of lighting processing have different situations and scenarios in multi cases. Therefore, feedback is a factor of importance, especially in smart systems applications. The lighting system can learn and modify its operating behavior based on the behavior of the worker in the office.

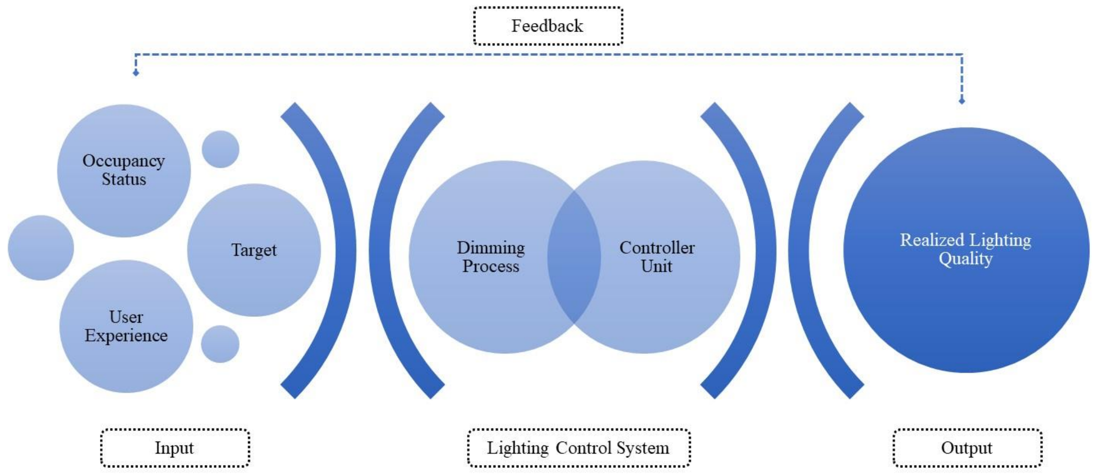



*Figure 4-5: The principal stages of the intelligent lighting system operate in the office work environment.*

In the input phase of the lighting process stages, three elements are the different input parameters for each worker and sensing devices. The affected input elements are the occupancy status, user target, and user experience. The occupancy status identifies the activity space for each worker. Also, each worker specifies the lighting target in the sensing device after toggling the occupancy status of the desk. Besides, the user experience depends on the user situation and the behavior of the system.

In the lighting control system phase, two stages perform the control unit functions of the intelligent lighting system. The first part is the stage of processing user data and required lighting inputs. The second part is the stage of dimming the lighting. Therefore, the controller unit receives the input parameters and manipulates the data according to the situation of the lighting system. Then the intelligent lighting system starts the dimming process of the lights to realize the value according to the user input values.

The output phase of the intelligent lighting system is the result and the realized lighting quality. Each worker in the office has got the expected lighting values as required. Therefore, the lighting system connects to the user and sends the feedback information. Then the lighting system prepares individually the lighting data for each worker.

## 4.3 System Properties

The system properties of the intelligent lighting system are a part of the system configuration that examines how to use the properties objects before the manipulation and control processing of the lighting system. In the system properties, the information for each worker in the office is processed and pre-configured for the control unit in the intelligent lighting system.

Figure 4-6 shows the properties of the lighting system. Lamps are portable lighting fixtures, which are the foremost indoor source of lighting in the office [19]. The luminance and lighting must be compatible according to the standards used in the design of the office environments. For instance, the lamps can provide two types of color lighting sources, which are cool white lighting and warm orange lighting.

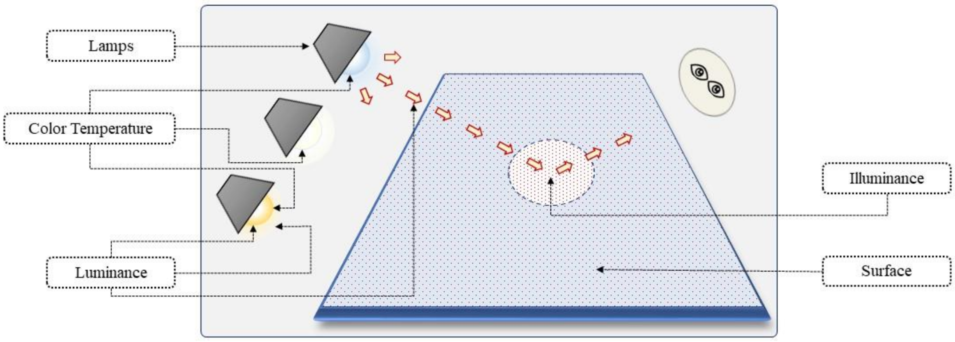



*Figure 4-6: The system properties of the lighting fixtures in the office, and the difference between emitted light and the luminous flux falling on a surface.*

Luminance is the amount of light-emitting or reflected off the office surface. For different purposes, luminance is the brightness in which the human eye perceives the luminous intensity. Further, each light has a quality of being intense to cover the area, and it is affected by several factors in the office. Also, luminance reflects the visible lighting from point to another point on the surface of the desk work area. Then, the luminance or the brightness defines the luminous intensity per unit apparent area of lighting source.

In the intelligent lighting system, the lamps are a lighting model that can adjust the luminance as requested. Therefore, the controller unit in the intelligent lighting system sent the signal request to the lighting unit to adjust the luminance as required. Consequently, luminance is a part model that accepts the dimming process features.

On another side, illumination is another element of lights occurred when lights turn on in the surrounding environment. Illuminance describes the quantity of lighting intensity falling on a surface area to become illuminant. Hence, human eyes perceive the visual lighting of the illuminated area. The illuminance spreads from the brightness or luminance of the lights. For instance, the luminance is the first point of the luminance beam, and the illuminance is the last point of candela falling onto the given area.

On the other side, the illuminance level is affected by the number of lights and luminance with different levels. For instance, each lighting has a different level of illuminance based on the falling point in the cover area. The falling point on the surface is affected by distance to the lights. Besides how much the light is close to the illuminating point on the surface.

The candela unit (cd) per square meter refers to the luminous intensity onto a surface. The illumination level resulting from the light beam is measured in lux (lx). Hence, the illuminance value is affected by the number of lights used and the distance from each luminance separately.

In the color lighting science, the spectral power distribution (SPD) defines the color characteristics of the lighting that reflect the properties of the color appearance of the surface. The spectral power distribution is a curve that depicts the power per unit area per unit wavelength of an illumination [78]. Whatever, there are two properties of the color lighting to describe the color appearance of the surface, namely the correlated color temperature (CCT) and the color rendering index (CRI).

The color temperature of illuminance describes the lighting appearance provided by lamps. Further, the color temperature is a vital factor in choosing the color appearance of illuminance in the office. Besides, the color temperature refers to the correlated color temperature, which indicates whether the light has a warm, midrange, or cool color lighting appearance, as shown in Figure 4-7. Therefore, the correlated color temperature is a gauge of color lighting emitted from the lamp appears. However, the Kelvin (K) degrees refer to the correlated color temperature of the lighting appearance.

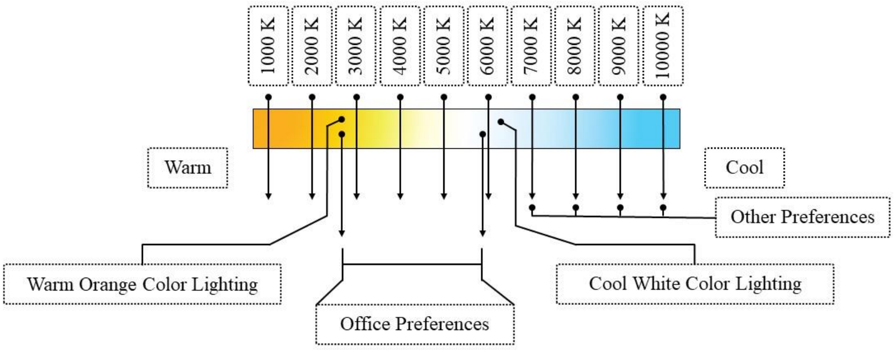



*Figure 4-7: The correlated color temperature scale chart describes the measurement degree of the color appearance in Kelvin from the lowest warm color lighting to the highest cool color lighting.*

In the intelligent lighting system, the office preferences of the color lighting system are both warm orange or cool white color lighting, and the combination of both colors on the scale. Therefore, the intelligent lighting system has a limitation in the lighting fixture installation, which provides the color lighting as requested, and it does not affect other surfaces area in the office.

There is a computational relationship for both illuminance and correlated color temperature. Therefore, obtaining a degree of the correlated color temperature of lighting is determined by adjusting the appropriate amount of illuminance onto the surface. The mathematical relationship of the correlated color temperature lighting ratio is processed on the controller unit of the intelligent lighting system.

Thus, determining the amount of illuminance and adjusting the correlated color temperature on the surface affect the amount of luminance and brightness emanating from the lamps. The process of the lighting amount required for illuminance is a part of the operations process on the energy consumption of the lighting system. Therefore, the intelligent lighting system specifies how much power is needed to provide the required amount of luminance in the office. The luminance has a big part of the measures affecting the energy consumption of lighting fixtures, in addition to the intelligent lighting system.

## 4.4 System Process & Control Settings

The control process of the intelligent lighting system operates in the control unit. Besides, each stage of the intelligent lighting system components has control settings of the lighting system from preparing the data to getting the expected result. Figure 4-8 illustrates the details of the control settings in each stage of the lighting system. Three stages of the control setting exist in the intelligent lighting system.

The first stage is on the sensing devices or other devices equivalent to the same purpose. The user control settings of the initial staging are identified by each worker in the office, namely, toggle the occupancy status, set the required illuminance, and required color temperature. To illustrate that, the default status that the desk is unoccupied. The identity of each worker is not recognized to use the system, while the occupancy status of the desk is inactive. Therefore, the worker should turn on the lighting system once using the desk; otherwise, the lighting has turned off to save energy.

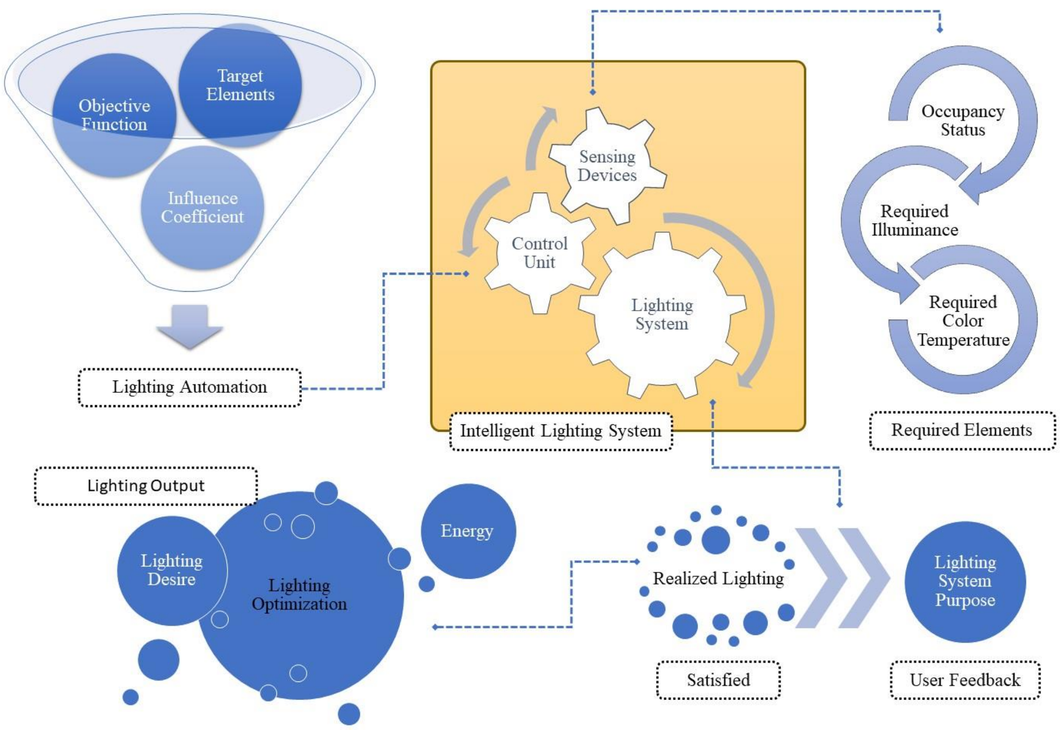



*Figure 4-8: The lighting settings and configurations operate on the control unit of the intelligent lighting system.*

After toggling the status of the occupancy, the intelligent lighting system prepares the lighting system for usage and expecting for the required values of the illuminance and the color temperature to start the dimming process for each light. Each worker put the desired amounts of illuminance and color temperature in the sensing device. Otherwise, the intelligent lighting system affords the same default values of illuminance and color temperature for each worker.

After receiving the data of each worker in the office, the intelligent lighting system performs three basic operations sequentially. The operations functions are the basis of each conventional lighting system. However, the method or processes change according to the integrated model with the lighting control system. Integrating and interconnecting processes between required models require other additional processes that there is no effect on the control unit operations of the lighting control system.

The first function of the controller unit is to manipulate the influence coefficient of the lighting onto the sensing devices. Each sensing device connected to the lighting system has different influence coefficients. The influence coefficient is a crucial factor that refers to the coupling stiffness between the light and surface of the office [21]. In other words, the influence coefficient refers to the distance of each lighting to the sensing device on the desk. Each sensor has several influence coefficients equivalent to the receiving illuminance in the office. The influence coefficient moves according to the position of the sensing device on the desk.

Figure 4-9 illustrates that the power of the influence coefficient obtains in the distance between the lights and the sensing device. For instance, the influence coefficient to the close light is higher than other lights. Besides, the illuminance in the covered areas by lights is higher than that area covered by individual lighting.

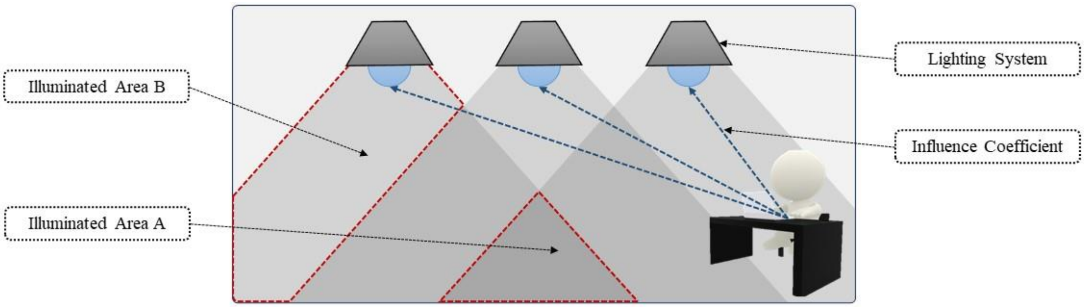



*Figure 4-9: The influence coefficient of the lights on the sensing device is available, and the relationship of the distance to the illuminating areas.*

The second function in the control unit determines the luminance operations and calculating the required illuminance operations to realize the target. Each worker has the desired lighting, and the intelligent lighting system offers the necessary luminance for all workers in the office. To illustrate that, each worker expects that the lighting system provides the required lighting in the desk when the worker sets the value in the sensing device as expected.

The lighting process is automated individually in considering several important factors. The factors represent in providing target lighting within a short time in which office work productivity is not affected. Besides, achieving the required target for each worker using the minimum requirement of energy.

The third function of the control unit is to present the expected lighting results to each worker in the office. Further, the system operates the output of the lighting automation and optimization methods in the dimming process of the lighting system. The lighting system operation leads to make a convergence of the expected lighting with the target system. The expected outputs of the lighting system take a way to meet the needs and desires of each worker, in addition, to achieve the goals of the intelligent lighting system in the office. Realizing the objectives method is performed through the feedback and whether the user needs have been met more precisely and accurately in the office environment.

The lighting convergence and improvement are carried out through the following main issues: providing target adequate lighting and achieving the user desire, improving lighting optimization, and reducing energy consumption. Therefore, intelligent lighting requires the exchange and sharing the information between worker behavior and the output of the lighting system in the office. Information exchange provides better lighting and quality to achieve the target of the intelligent lighting system.

## 4.5 System Operation Scenarios

The intelligent lighting system operational scenarios describe the sequence of the events and the control process data from the user to verify and validate the lighting system. Figure 4-10 illustrates the system operation scenarios of the intelligent lighting system.

The sequence of the events distributes the operations within five phases, namely, the launch-up phase, the preparation phase, the operations phase, the process phase, and the resulting phase. Another block is added for the integration phase through adopting the combination within other blocks.

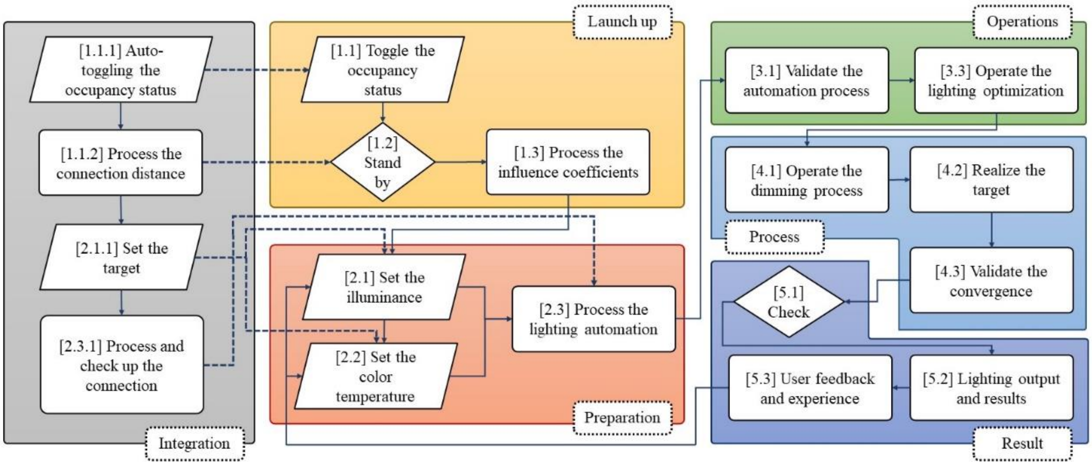


*Figure 4-10: Operational scenarios of the intelligent lighting system operate in the merest base case.*

The launch-up phase starts with each worker in the office to toggle the occupancy status of the intelligent lighting system. When the lighting system moves to the standing-by, processing the influence coefficients of each light proceed. Next, the lighting system process the influence coefficients of each lighting to the sensing device used to change the occupancy status.

The previous conventional way of the launch-up phase can be replaced in different approaches using such the integration models of the lighting system. For instance, auto toggling the occupancy status is used by wireless technology instead of the manual way. Besides, processing the connection distance between the worker and the desk enables more efficiency of the intelligent lighting system to save energy.

Through the preparation phase, each worker adjusts the values of the illuminance and the color temperature using the sensing devices. On the side of the system, the control unit receives the lighting values and processes the automation for each value. However, the new model of the intelligent lighting system replaces the way of adjusting values by regular sensing devices to other devices like smartphone devices, following with another process to check up the connection of the smartphone devices and the lighting systems with the wireless. The previous method enables each worker to adjust the lighting values before launching up the work.

After the operations start, the intelligent lighting system verifies the lighting automation processes and drives the convergence of the dimming process to the required lighting values of each office worker. The convergence process is realized based on the optimization method of the intelligent lighting system. After that, the control unit transfers the best outcomes to demonstrate the output on the lighting unit of the system separately. The process of converging the required lighting values to achieve the target for each user operates in a short time that is not discerned by the user in the office.

In the result phase, the intelligent lighting system compares the results and display the output for each user. Therefore, user feedback has been used depending on user experience. For instance, the system operates to realize the target based on the previous lighting values used. Otherwise, the worker can change the lighting values as desire.

## 4.6 Potential Area Design Effects

The office environment reflects and reinforces any solutions for using innovative technology in the smart office. Smart office design is the next generation of workplace environments. Therefore, the office environment design should be compatible with achieving the requirements of using the ergonomic concepts for each user, especially installing intelligent lighting control in the office area.

The office design plays an efficient role in the performance of the intelligent lighting system. Each worker has the favorite lighting, and the choice of the preferred individual lighting complies with the requirements of the office design. For example, choosing a low lighting influences on another high lighting in the next of previous preferences. Figure 4-11 shows the impact of office design on the intelligent lighting system.

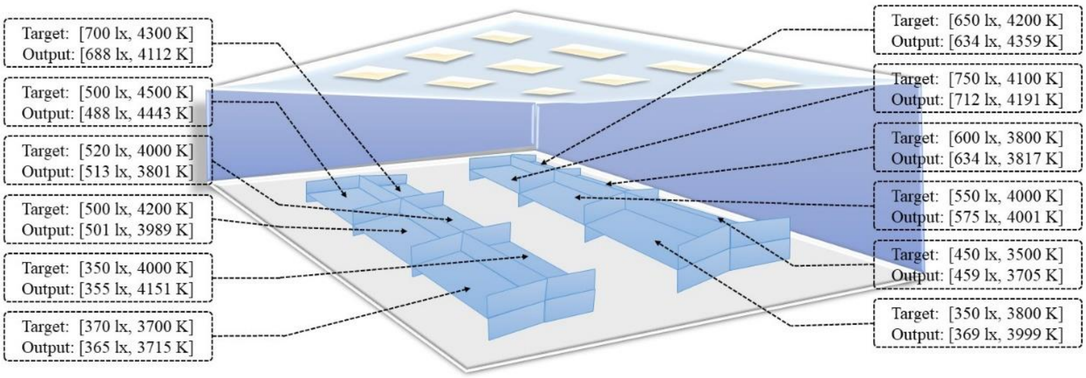



*Figure 4-11: The effects of area design occur on the intelligent lighting system in the office work environments.*

The implications of the design on the lighting system are to provide proper lighting in the office, to achieve the target lighting of each worker, and time to converge to realize the target. Therefore, smart approaches and intelligent methods play a vital role in the operations of the intelligent lighting system in office work environments.

## 4.7 Remarks

The intelligent lighting system has a base structure for use in office environments. The structure and office design play an active role in the utilize of the lighting system in work office areas. Each office employs the properties of the lighting system in the office. Therefore, the office work area has the challenge to configure the intelligent lighting system and adjust the control settings to achieve the purpose of the system in the office.

The intelligent lighting system should be a solution for each worker. However, the system is only one shared for all the workers in the office. For instance, each worker in the office has used the same lighting control system, so that the intelligent lighting system finds the best solution not only for each worker but the best solution for the workplace. Therefore, the workplace and office environment should be creative and dynamic as the office design affects the solutions of the intelligent lighting system for the user in the office.

Smart office design plays an efficient factor in using the innovative technology, beginning on the installation of the system to using the technology and providing an ergonomic workplace for users inside the office. The term of the smart office design exceeds the concepts of utilizing creative environments with the tools to support the various types of work tasks. However, the structure design of the smart office is a mandatory requirement to make the environment more dynamic for the office and use the intelligent lighting system to boost the office area.

# CHAPTER FIVE

# Performance Method of the Intelligent Lighting System

In this section, the intelligent lighting system methods is discussed to build a conventional intelligent lighting system in the office area. The base components of the intelligent lighting system are illustrated, in addition to the structured elements and control properties. The system settings are configured to stand on the significance of the shape in the lighting system architecture. Furthermore, the system operational scenarios are explained and examined for the events and phases to transfer the data in all lighting stages. Finally, the potential area design is discussed and showed up the implied effects on the intelligent lighting system.

## 5.1 Assumptions & Constraints

The assumed procedures are available according to the office design requirements and the simulation experiments of the system. Some limited assumptions are considered based on conducting the experiments and running the system simulation to avoid any external influences on the intelligent lighting system. Besides, reducing the differences between the actual and real measured values to minimize any bias affecting the office work environment.

Furthermore, the research assumes that the intelligent lighting system has an influence on worker attitudes and behavior based on the lighting preferences. For instance, each worker has the desired lighting, and the lighting system provides the values according to the individual choose. Office performance has many aspects, and this study assumes that the choice of each worker will affect intellectual productivity in the office. Therefore, this study assumes that the intelligent lighting system offers the quantitative values of visual lighting, personal lighting, and health lighting based on the desire of each worker in the office.

## 5.2 Impact Factors

The main impact factors of the intelligent lighting system are the outcome lighting features to apply in the office working area. Further, the impact factors on lighting automation are devoted to the conditions and controls of the office working environment. For example, each obtained illuminance is related to the availability of the lighting source in the office area, and to the situation surrounding the illumination zone.

There are some limited influencing indirect factors in the intelligent lighting system, represented in the number of required lighting sources, the distance between the lighting sources to each worker, the number of lights required, and in addition to the design of the work area. However, the direct impact factors of the intelligent lightings system, which are the basic variables and parameters of the system, come through determining the inputs and outputs of the lighting system. The inputs and outputs variables of a lighting system determine the source and the expected outcome.

Figure 5-1 shows that the elements of luminance and illuminance are the base of the lighting source and outcome. Each lighting element extends to several other lighting elements and characteristics that boost the intelligent lighting system in the office. Further, there is an existing relationship between the lighting source and the outcome. Therefore, the relationship between luminance and illuminance is handled and manipulated in the controller unit of the lighting system.

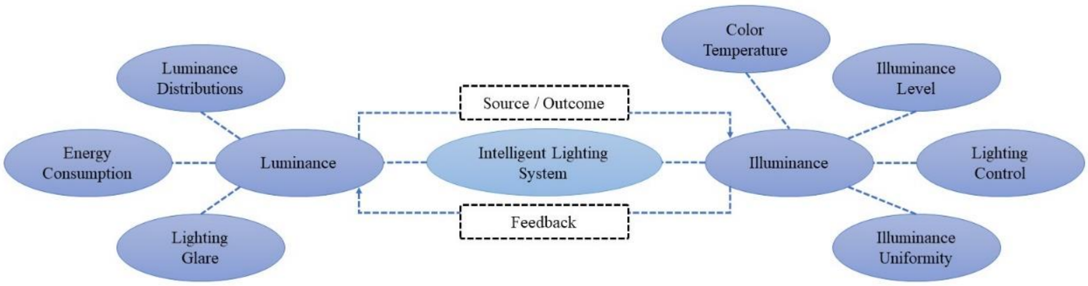



*Figure 5-1: The influencing factors affect the intelligent lighting system in the indoor office area.*

Each element is calculated and measured mathematically or through practical experiments in the automation process of the intelligent lighting system. Concerning best results, each lighting element has assumptions and restrictive to some conditions in the ideal work environment without any biases that affect the results and lighting outcomes.

## 5.3 Direct Parameters & Arguments

Once used the lighting system in the office, a beam link exists between the light source and the lighting outcome. The beam link or the lighting relationship establishes according to the area that the light falls on. However, there is one lighting source called luminance in the office work environment, but each space in the office has a different lighting outcome called illuminance.

The illuminance is directed based on the impact relationship of luminance in the office. For instance, the level of illuminance in each area comes when the number of lights or luminance worked in the same space. The relationship has an impact factor called, in the lighting automation, the influence coefficient of the luminance to the illuminance in each area. The influence coefficient is a statistical method to calculate the target distribution responses of luminance levels to current illuminance onto a specific space [21].

In the lighting automation engineering, the luminance of a perfect diffuser is assumed by the computations control for the office area. Office illumination no longer plays a critical role in refraction due to the use of materials to avoid bias refractions, in addition to the computerized control systems (cite). In contrast, the reflectance value has the influence to shape the illuminance and luminance image while using the lighting models in the office.

Figure 5-2 illustrates the reflectance of the illuminance in the office area. The lighting system generates more than one illuminance zone in the office. Further, the location and the closed position to the light has a high illuminance level more than other zones. Due to the different influence coefficient, there are different zones of illuminance. Therefore, the effect of the influence coefficient affects and response control system of the intelligent lighting system and the occupancy status of each worker.

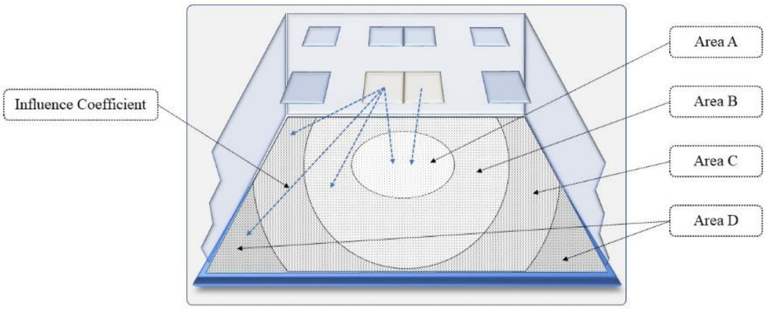



*Figure 5-2: Part of the office work environment illustrates the different zones of illuminance based on the influence coefficient of the luminance.*

Three primary parameters play a vital role in lighting automation, namely luminance, illuminance, and the influence coefficient. The luminance and illuminance have a relationship depend on the influence coefficient. All the primary parameters are calculated theoretically and measured empirically by experiments. Equation (1) illustrates the linear relationship between the direct parameters of lighting, where the parameters $E$: is the illuminance, $L$: is the luminance, and $R$: is the influence coefficient.

$$E = R \times L \tag{1}$$

Theoretically, the illuminance is a function of luminance, and the illuminance has a normal distribution. There are several techniques to estimate the parameters. Figure 5-3 shows the linear relationship between the values of luminance and illuminance and how to estimate the influence coefficient values.

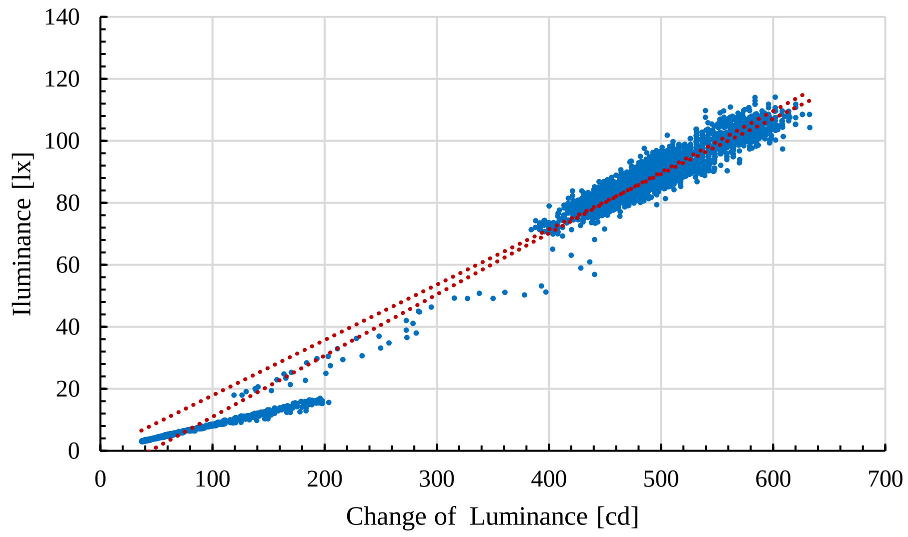



*Figure 5-3: An illustration panel shows the relationship between the illuminance and luminance measurement made with a given time in the office. Besides, the movement of one luminance changes the illuminance values.*

Practically, in the office, there is one sensing device, at least, in each working area to measure the illuminance and more than one light. Therefore, illuminance is a result of all the lighting systems in the office. Equation (2) illustrates the total illuminance in the sensing device, where the parameters $E_i$: is the illuminance $E$ in the sensing device $i$, $L_j$: is the luminance $L$ for the lighting number $j$, and $R_{ij}$: is the influence coefficient between the sensing device $i$ and the lighting number $j$. The total illuminance $E_i$ is calculated based on the summation of each illuminance for $n$ lights.

$$E_i = \sum_{j=1}^{n} \left( R_{ij} \times L_j \right) \tag{2}$$

Illuminance is an element that is affected by the change in luminance and the dimming process of the lightings. Also, the illuminated area is affected by how close the illuminance is to the luminance source and lighting levels. Each illuminance or illuminated area in the office has a different value based on the influence coefficient between the sensing device in the illuminating area and each lighting in the office.

Figure 5-4 shows the method to find the relation between each lighting and the illuminance sensing device in a specific given area.

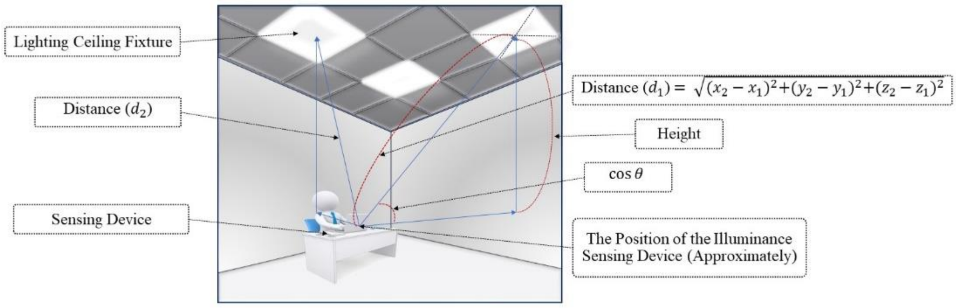



*Figure 5-4: An illustration shows the method to calculate the influence coefficients between lights and sensing devices on the surface.*

The influence coefficient $R$ from the lighting number $i$ to the illuminance sensing devices number $j$ is calculated theoretically by using the angle of the luminous beam $\theta$ to the square of the distance $d$, as indicated in Equation (3).

$$R_{ij} = \cos\theta/d^2 \tag{3}$$

Practically, the influence coefficient is calculated based on using illuminance $E$ and luminance $L$ from the light number $i$ to the sensing devices $j$, as in Equation (4).

$$R_{ij} = E_j/L_i \tag{4}$$

By using simple two methods to determining the influence coefficient for each light to the sensing device, the factor figures the shape of the illuminance distribution in the office. Figure 5-5 illustrates the influence coefficients rating and the relationship of the illuminance sensing device to the luminance for a sample distributed randomly in the office working environment. The rate of the influence coefficient is high whenever the illuminated area or sensing device is very close to the lighting source.

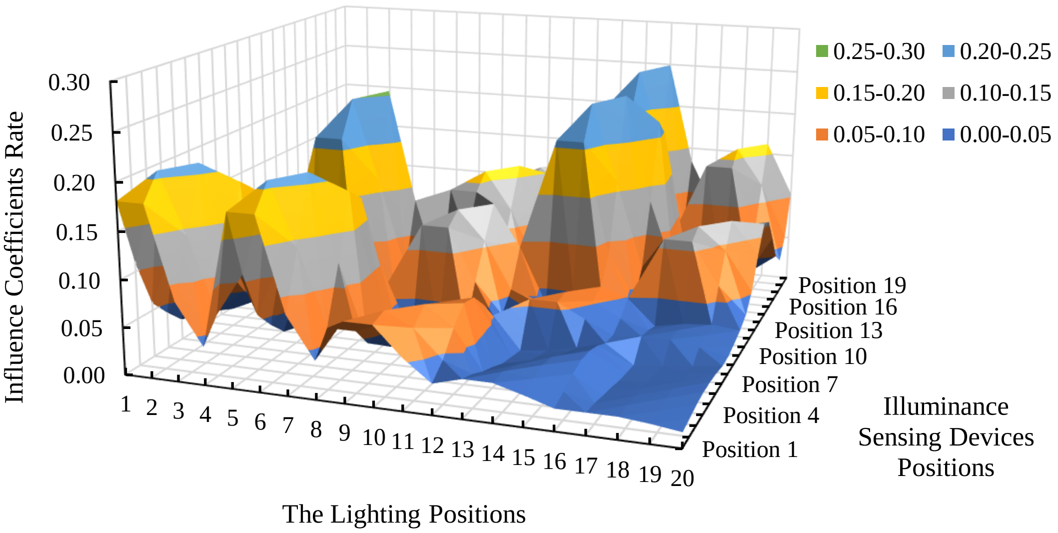



*Figure 5-5: A sample distributed randomly of the sensing devices illustrates the importance of the influence coefficient between illuminance and luminance in the office.*

Furthermore, the influence coefficient relationship has power in concluding the dimming processes for lighting and realizing the user target in a short time. The influence coefficient determines the speed of convergence of lighting to make the target, which helps to the normal distribution of luminance and contributes to saving energy in the office.

Empirically, some limiting factors have been considered based on the influence coefficients. For instance, the quality of sensing devices affects the accuracy of the measurement. Further, the time of illuminance measurement shapes the ideal calculation in addition to the dimming process of the lights. Finding close average illuminance to the real calculated values comes by conducting a lot of the measurements to reduce the gap between the calculated values and the measured values of the illuminance.

Equation (5) indicates to minimize the predicated error or the gap difference received in the calculation and measurement values of the illuminance, where the parameters

$\varepsilon_i$is the predicated error, $\widehat{E_i}$ is the measured value, and $E_i$ is the calculated value for the sensing device $i$.

$$min(\varepsilon_i) = \widehat{E_i} - E_i \qquad (5)$$

From the luminance to illuminance, lighting control operates the automation and the optimization to achieve the user target. Other direct affected elements are influenced based on the values of luminance and illuminance in the office.

## 5.4 Formulation of the Control System

In the intelligent lighting system, the control unit operates the lighting automation to reduce the gap of the estimated value to the real value of illuminance. The optimization process realizes the target besides to minimize energy consumption using the method of regression analysis [22]. Based on the result, the control unit operates the dimming process to set the value for each lighting in the office.

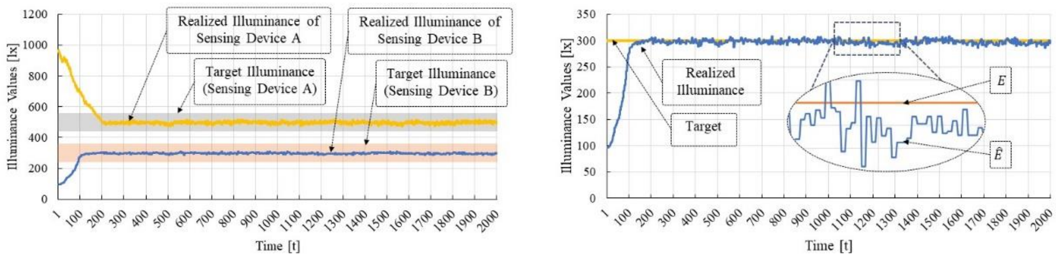
The objective function of the optimization method works to find what is the best solution for using lighting in the office. The best status of the lighting is that each light achieves the target with a minimum requirement of energy. Equation (6) illustrates, in general, what is the goal of the objective method in the intelligent lighting system. The equation argues that the objective function of each light $i$ is to reduce the volume of energy $p$ in the presence of achieving the illuminance target $E_i$ in the sensing device $j$.

$$min\, f(i) = f\big(min(p_i), E_j\big) \qquad (6)$$

Each part of the optimization objective function requires limited constraints to find the optimal value of the parameter without the effect in the presence of other parameters. The main parameter is the energy consumption $p_i$ of the light $i$, and the objective function reduces the rate to the lowest case. Besides, the estimation of the method brings to find the best state of target illuminance $\hat{E}_j$ in the sensing device $j$, which is close to the required target $E_j$. Equation (7) illustrates the conditions of the objective function.

$$min\, f(i) = \begin{cases} p_i & min(p_i) := 0 \\ \hat{E}_j & \hat{E}_j := E_j \end{cases} \tag{7}$$

The illuminance constraint brings the estimated illuminance in the sensing device to the target illuminance. Figure 5-6 has two panels of illuminance history. The first panel is to illustrate the realized illuminance for two cases of the sensing devices in the office. The second panel shows the illuminance panel and how the objective function brings the estimated values to the target. Whatever, all cases converge the goal to the accepted range of the target.




*Panel (A)* *Panel (B)*

*Figure 5-6: A sample of illuminance history explains the realized states for two cases of the sensing devices, in addition to how the objective function brings the estimated values to the target.*

Equation (8) explains the objective function of the intelligent lighting system in another way by using the energy consumption and the illuminance constraints. Each element is a function calculated or measured in the time of the dimming process. The essential dependent variables are quantitative values in work time.

$$f(i) = p + \sum_{j=1}^{n} \left| \hat{E}_j - E_j \right| \tag{8}$$

The observations are generated by the dimming process of the intelligent lighting system to find the best lighting solution. The dimming process in the control unit receives the best case of the luminance to adjust the values of each light. Therefore, the optimization method depends on the lighting automation process before achieving or finding the optimal solution for each lighting in the office.

In the optimization method of the intelligent lighting system, the convergence part hires a weighting factor $\omega$ for increasing the illuminance priority in the office. The weighting factors enable the changes for the preferences of power consumption and the constraints of the lighting system. The weighting factors are hired depending on the priorities of the office work environment. Equation (9) shows the function and how to use the weighting factors to optimize lighting solutions.

$$f(i) = p + \omega \times \sum_{j=1}^{n} \left| \hat{E}_j - E_j \right|, \omega > 0 \tag{9}$$

Furthermore, the influence coefficient $R_{ij}$ is utilized based on the illuminance constraint to increasing the power of the realizing target in the sensing devices. Realizing the illuminance target is the current value in the sensing device $j$ for each time $n$. Besides, the objective function minimizes the difference between the current illuminance $Ec$ value and the target value $Et$ as possible. Equation (10) illustrates the objective function of luminance optimization.

$$f(i) = p + \omega \times \sum_{j=1}^{n} \left( R_{ij} \times \left( Ec_j - Et_j \right)^2 \right) \tag{10}$$

The influence coefficient is an efficient variable in the objective function to realize the illuminance target. The effectiveness of the objective function is an essential factor in the convergence time of the illuminance values. The convergence process is operated based on how much the influence coefficient has the power between illuminance and luminance in the office.

The objective function recognizes the illuminance sensing device in groups. Each group has power and different coverage time. There are threshold values used to classify the illuminance sensing device in the office, namely, high convergence, medium, and low convergence process. The threshold values are decided based on the experiments and the demonstration to find the best case of the office work environment. Office design plays a vital role in classifying the illuminating areas in the office space. Therefore, threshold values are recognized based on office design.

According to the experiments, the best practice of using the threshold values is to recognize the influence coefficients values into three groups. For instance, two threshold values are located based on the range of 10% to 20%. All the influence coefficients are classified in which the influence coefficients are less than the first threshold; the convergence time is low. Also, if the values of the influence coefficient are larger than the second threshold, the convergence time is high. Otherwise, the medium case of the convergence process is applied.

Consequently, the objective function of the intelligent lighting system affects other parameters and elements which could be added or modifies based on the lighting solutions. For instance, the objective function utilizes the color temperature element or organize the control method of the illuminance distribution in the office.

## 5.5 Control Operations

The control operations of the system automation and the optimization runs based on the Ordinary Least Squares (OLS) approach. The usage of the regression coefficients adapts the realized values of illuminance to the real targets on the regression slope.

The ordinary least squares reduce the difference gap of estimated illuminance values to make the convergence to the target values. The method of the intelligent lighting system to achieve the luminance convergence declares the process of an Adaptive Neighborhood Algorithm using Regression Coefficient (ANA/RC) to realize the luminance intensity in respect of each received target for each user.

Equation (11) illustrates that the objective function of the luminance improvement model is a function in time. The achieved luminance is dependent on the current dimming processes. The optimization process is cumulative and dependent on the previous state of luminance convergence operations. In other words, the current luminance improvement model is covered based on the state of the past luminance. The optimization system changes the convergence techniques based on the luminance convergence status.

$$f(i)_t = \beta_0 + \beta_{11} \times g_{11t} + \beta_{12} \times g_{22t} + \cdots + \beta_{ij} \times g_{ijt} + \varepsilon_t \qquad (11)$$

Equation (12) explains that the optimization model starts to achieve luminance convergence according to the data of the previous case. Therefore, the mechanism depends on how convergence achievement varies for each luminance to reduce energy consumption and save the time of the luminance convergence.

$$f(i)_{(t)} = \beta_0 + \beta_{11} \times g_{11(1t-1)} + \beta_{12} \times g_{22(2t-2)} + \cdots \qquad (12)$$

$$+ \beta_{ij} \times g_{ij(t-1)} + \varepsilon_{(t-1)}$$

The mechanism of the objective function in the system automation is to find the optimal solution depending on the derivation of the function on the time. The change of luminance during the dimming process uses the Hill Climbing method to find the next value and sort the range of the luminance movement. Generating the range values of the luminance movement, or in a different way, finding the adaptive neighborhood of the luminance depends on performing the regression coefficients for each observation on the regression slope.

Therefore, an Adaptive Neighborhood Algorithm using Regression Coefficient (ANA/RC) is applied based on obtaining the optimal solution close to the target. The convergence of the luminance state to the next luminance ensures the stability of lighting during working time, in addition to the changes that may occur during work time. Further, the algorithm applies to each function parameter to find the optimal solution of the variable.

Figure 5-7 shows a spot of the illuminance history in the office while realizing the desired user target. The illuminance variation exists in the processes to approximate the illuminance to the required target. The adaptive neighborhood algorithm is used based on how much to achieve the lowest error ratio between the estimated values and the required illuminance values. Part of the illuminance spot has a high convergence, while another part has lower or medium based on the illuminance state.

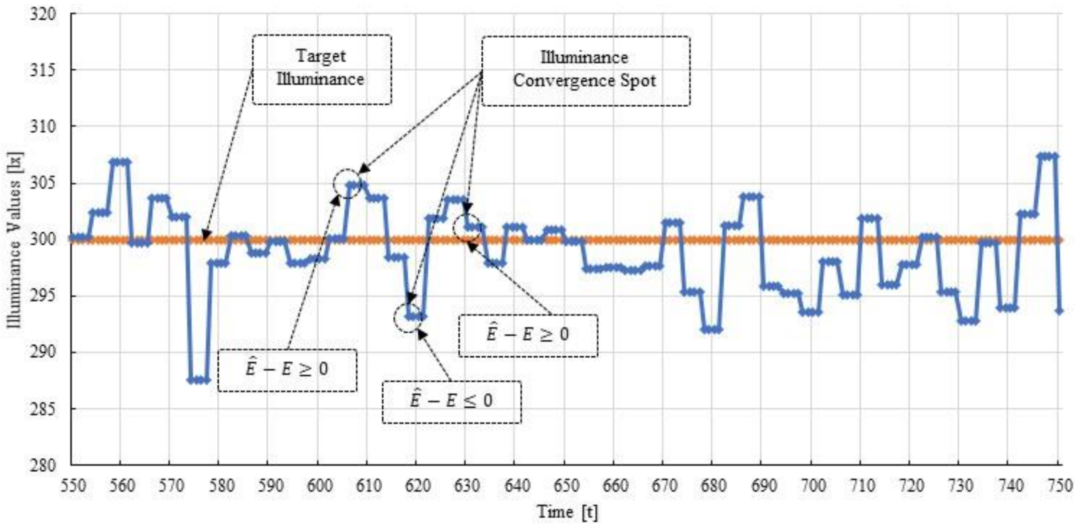
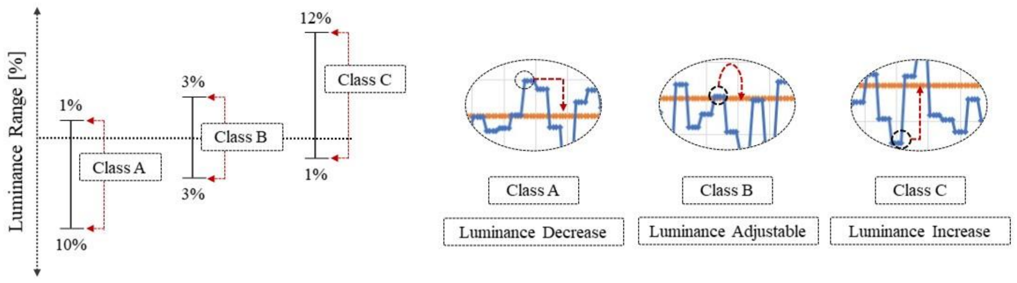



*Figure 5-7: A spot live of the illuminance history in the office while realizing the desired user target.*

The size of the office design plays a role in the choose the range of illuminance convergence. A wrong development of the luminance convergence range causes a problem of the lighting convergence to the target. Further, in the intelligent lighting system, luminance distribution is considered, which is not affect the visual lighting. All the luminance convergence is done based on the conducted experiments in the office. Moreover, the distribution of luminance has influenced to realize the balance of energy saving.

The range of luminance convergence for the adaptive neighborhood algorithm has three categories, namely: decrease the luminance convergence, adjust the luminance convergence, or increase the luminance convergence. However, another classification is used based on the office space size, but any new categories are classified based on the recognized levels. Figure 5-8 illustrates the basic classes of the luminance convergence range in the control operations of the intelligent lighting system. Each spot of the illuminance history has a different convergence class of convergence to realize the user target.




*Panel (A)* *Panel (B)*

*Figure 5-8: The classes of the luminance convergence range exist as basic categories, and each spot of the illuminance history is applied based on the requirement of the luminance convergence.*

The control operation in the intelligent lighting system decides the class level of the luminance convergence range depending on the office criteria. There are two criteria to choose the class level after developing the luminance convergence range system. The first factor is the influence coefficient of the lighting on each sensing device. For instance, the luminance convergence is high when the influence coefficient has the power. The luminance convergence is low when the influence coefficient has not the strength. Otherwise, the medium range of the luminance convergence is applied based on other estimated values. Equation (13) explains the influence coefficient criteria.

$$R_{ij} = \begin{cases} High & R_{ij} > Threshold_1 \\ Medium & Threshold_1 \leq R_{ij} \leq Threshold_2 \\ Low & R_{ij} < Threshold_2 \end{cases} \quad (13)$$

According to the experiments, the best practice of using the threshold values is to recognize the influence coefficients values into three groups. For instance, two threshold values are located based on the range of 10% to 20%. All the influence coefficients are classified in which the influence coefficients are less than the first threshold; the convergence time is low. Also, if the values of the influence coefficient are larger than the second threshold, the convergence time is high. Otherwise, the medium case of the convergence process is applied.

The second criteria are the illuminance constraint on each sensing device. The illuminance constraint factor has three levels to decide the luminance convergence range, and there are two thresholds to recognize the classes. Choosing the inceptions values considers some bounded criteria like the time of realizing the target and avoiding fluctuation in luminance frequencies. Besides that, there is a limited range acceptable of the luminance convergence to achieve the personal lighting for each user. Equation (14) illustrates the classes of the acceptable luminance convergence range in the lighting system. According to the experiments, the acceptable twofold of the thresholds values comes to ±7% of the illuminance target.

$$\left|\hat{E}_j - E_j\right| = \begin{cases} High & \hat{E}_j > Threshold_1 \\ Medium & Threshold_1 \leq \hat{E}_j \leq Threshold_2 \\ Low & \hat{E}_j < Threshold_2 \end{cases} \qquad (14)$$

Developing the rules of using the luminance convergence range is considerable on how to prioritize the influence coefficient and the illuminance constraint at the same time. Table 5-1 explains the convergence rules of the luminance operations to converge the user target. However, the rules are expanded based on the luminance convergence range and the office space design.

*Table 5-1: The design of the classification rules for distributing luminance convergence while the dimming process operates.*

| **Rules** | | **Illuminance Constraint** | | |
|---|---|---|---|---|
| | | High | Medium | Low |
| **Influence Coefficients** | High | C | B | A |
| | Medium | B | B | A |
| | Low | B | A | A |

The control operations of the intelligent lighting system use the luminance convergence rules for the adaptive neighborhood algorithm. Thus, the rules help the lighting system to reduce energy consumption based on the distribution of the luminance inside the office.

## 5.6 Remarks

The control method plays a vital role in performing the intelligent lighting system. The result s of the lighting is affected. Using the appreciate method affect the optimization function of the intelligent lighting system. In addition, the useful approach of the automation method has an influence to provide lighting for each user in the office. Therefore, the method may have affected to the user behavior and the also the energy consumption in the office.

# CHAPTER SIX

# Effect of the System Properties on the System Automation

The section aims to study the effect of the system properties on the control automation. This section explains the calculated elements of the intelligent lighting system and the directly affected elements in the input or output phase of the control operations. Also, the illuminance and luminance distribution has been reviewed based on some conducted experiments in the office.

Therefore, the calibration method of the color appearance is discussed, and how the correlated color temperature performs in the optimization method. Also, some examinations and investigations of utilizing the color temperature are conducted empirically and by the computerized simulation.

## 6.1 Direct Affected Elements

In the intelligent lighting system, other elements are affected by the results of the control process automation. Illuminance and luminance play an efficient role in influencing some other lighting elements affecting user target or the automation of the control operations. The affected lighting elements are luminance distributions, energy consumption, lighting appearance, and automated lighting control, in addition to other lighting elements.

In the intelligent lighting system, the control method distributes the luminance based on the adaptive approach used for luminance convergence to the target. Figure 6-1 illustrates the luminance distribution based on the illuminance target. Some lights have a high level of luminance, while other lights adjust the illuminance to the target. The previous state explains how much the intelligent lighting system manages the luminance distribution with a low level of energy consumption.

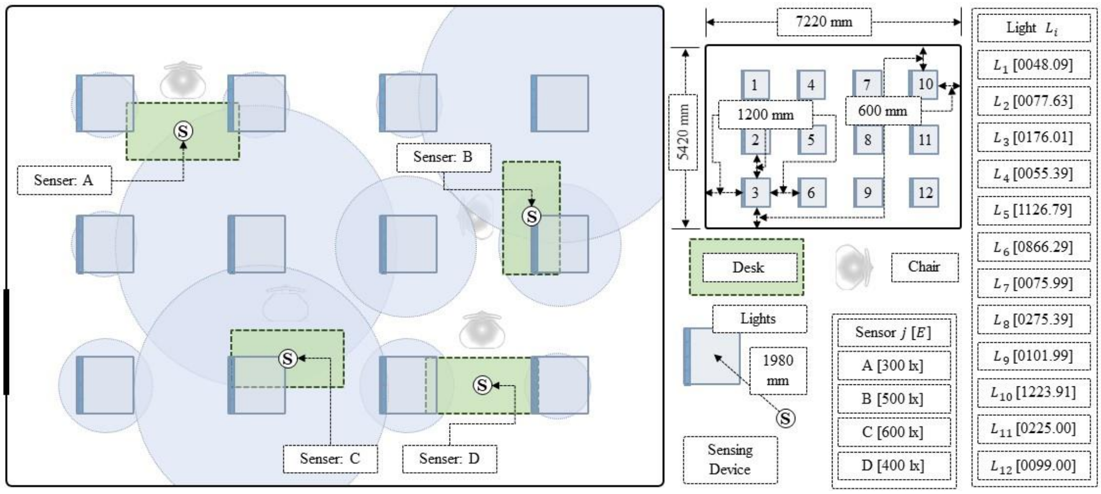



*Figure 6-1: An illustration shows the luminance distribution in the office.*

Figure 6-2 shows that each worker in the office has the target, and the intelligent lighting system has realized the target as requested. Therefore, the intelligent lighting system considers the luminance distribution in the control method of the luminance convergence.

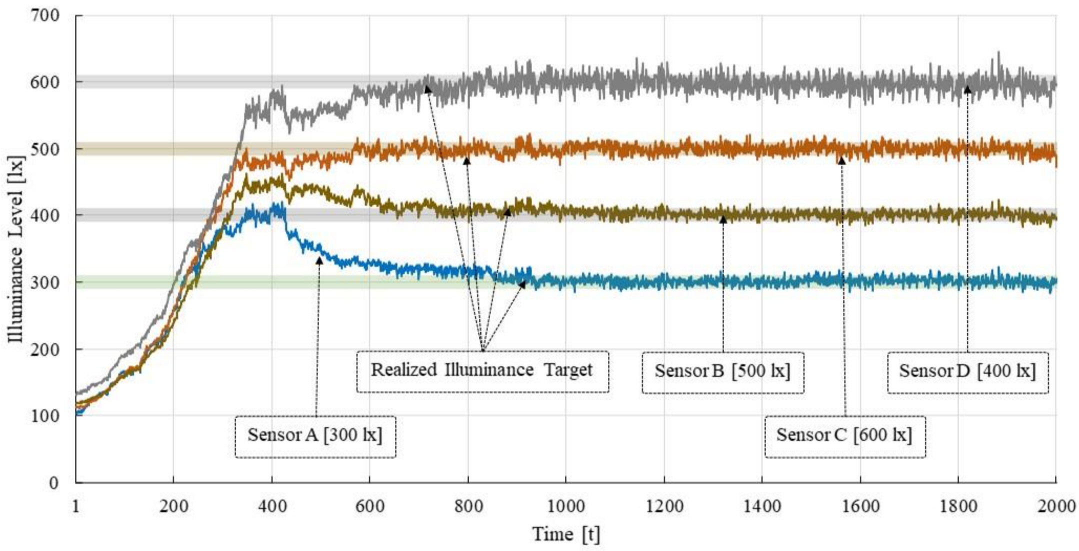



*Figure 6-2: An explanation shows the realized illuminance for each worker in the office.*

## 6.2 Calibration Method for the Color Temperature

In the color appearance of the lighting system, the correlated color temperature (CCT) is estimated based on the method of nonlinear regression. However, in the examination of the correlated color temperature in this research, linear regression is the best method to estimate the correlated color temperature function. Figure 6-3 illustrates the function of correlated color temperature. Both colors lighting source shape the total color appearance of the lighting.

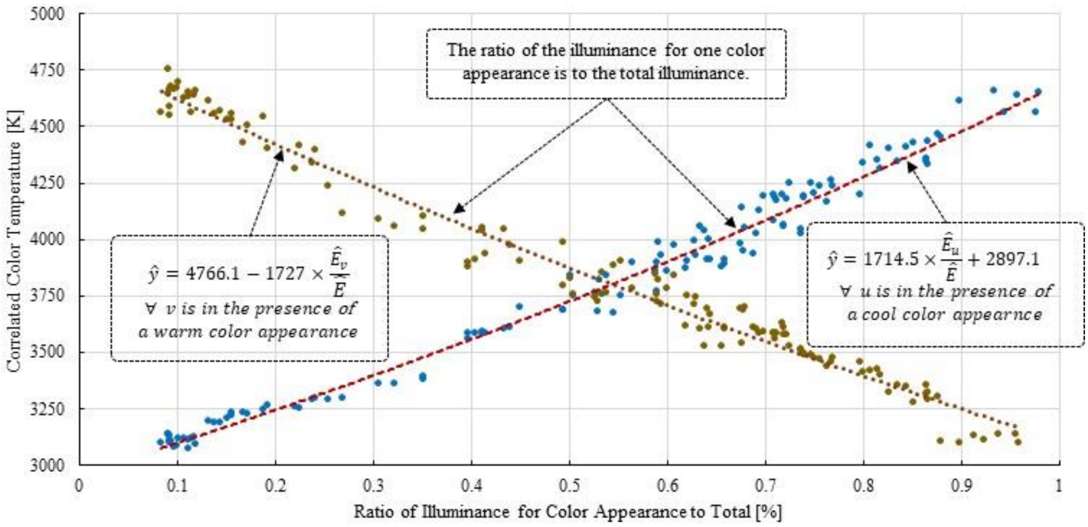



*Figure 6-3: A linear function estimates the correlated color temperature associated with the ratio of illuminance in color appearance.*

The reasons taken in formulating the color appearance function are that the error range is still acceptable for each user. For instance, each user has a target of the color temperature, and the optimization function of realizing the target is to the nearby value of the desired target within the limited accepted range.

Equation (15) explains the function of the color temperature, and the estimation of the method is to drop the value onto the slope. Each color lighting source $CT$ has an illuminance $\hat{E}_{CT}$ that is a ratio of the total illuminance $\hat{E}$. The slope line is driven based on the ratio value for one color appearance in the presence of the total illuminance. For instance, the ratio of the cooling white color temperature is different from the ratio value of the warming orange color temperature, and both color appearance shapes the lighting source.

$$f(CCT) = \beta_0 + \beta_1 \times \frac{\widehat{E}_{CT}}{\widehat{E}} \quad (15)$$

On the practical side, each sensing device has a correlated color temperature. Besides, the illuminance sensing device recognizes the total color temperature from all lighting appearance. Equation (16) illustrates the released color temperature from all the lights.

$$CCT_j = \sum_{j=1}^{n} \left( \beta_0 + \beta_1 \times \frac{\widehat{E}_{j_{CT}}}{\widehat{E}_j} \right) \quad (16)$$

Each light has a color appearance beside the illuminance, so the sensing device receives the combining values from all the lights. For instance, in the office, the sensing device recognizes combining two color lighting sources in one color appearance value, in case a warm orange and cool white color lighting existence. Figure 6-4 shows the practical value of the correlated color temperature.

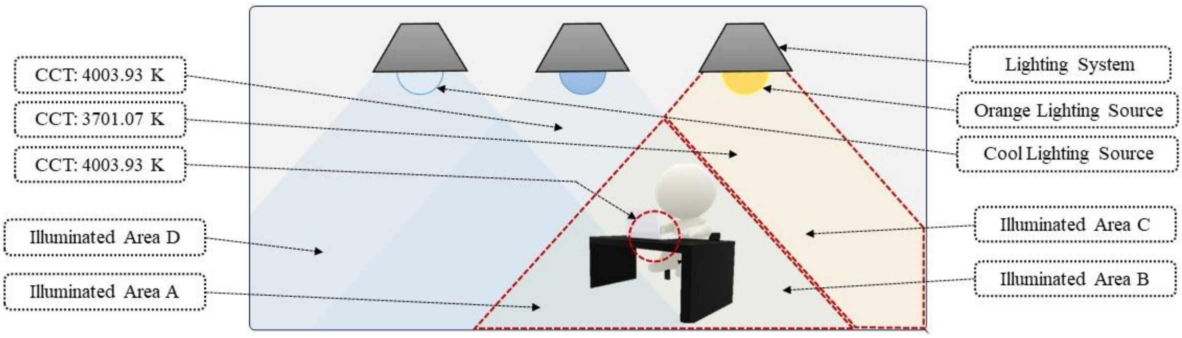



*Figure 6-4: An illustration of the lighting system performs while using the color appearance and how the sensing device recognizes the correlated color temperature in a given area.*

The color appearance is affected by each light on the desk. Each lighting fixture offers the amount of the color temperature in the office, in which the sensing device measures all the amount received from all lights. In general, the intelligent lighting system considers the issue of the color temperature as the same as the issue of the individual illuminance in the office.

## 6.3 Utilizing the Color Temperature on the Control System Method

As a possible solution to providing personal comfort to boosting the performance in the workspaces, the correlated color temperature is one of the solutions that help to change the color appearance for each worker in the office. Despite the existence of sensing devices for measuring the color temperature, sometimes the measurement of the color temperature is considered not preferable due to commercial reasons. Preferences available to provide lighting automation systems instead of the manual or the conventional approaches in the intelligent lighting system.

In the automation control of the intelligent lighting system, system automation can involve the correlated color temperature as a parameter in the objective function of the system. Therefore, the optimization function of the system estimates the correlated color temperature to realize the target for each user in the presence of the illuminance parameters. Equation (17) illustrates the new model of the intelligent lighting system and the objective function for each lighting $i$ using the correlated color temperature $CCT$ in the presence of the energy $p$ parameter to achieving the illuminance target $E$ in the sensing device $j$.

$$min\, f(i) = f\left(min(p_i), E_j, CCT_j\right) \tag{17}$$

The correlated color temperature constraint is the same for the illuminance constraint. Further, both conditional requirements bring the estimated values to both targets each. Equation (18) illustrates the new conditions of the objective function.

$$min\, f(i) = \begin{cases} p_i & min(p_i) :=\ 0 \\ \hat{E}_j & \hat{E}_j := E_j \\ \widehat{CCT}_j & \widehat{CCT}_j := CCT_j \end{cases} \tag{18}$$

Further, the objective function of the intelligent lighting system expands to include more than one parameter in the objective function. The influence of the new parameter is not affected on operating time for realizing each target (cite). However, each parameter has a weighting factor used, while the convergence process is finished based on the office size. The weighting factors figure the balance in each element of the objective function. Equation (19) illustrates the new model of the intelligent lighting system using the correlated color temperature in the presence of the illuminance for each user. As considered, the weighting factor $\omega_g$ is for illuminance constraint and $\omega_h$ for color temperature constraint.

$$f(i) = p + \omega_g \times \sum_{j=1}^{n} g_{ij} + \omega_h \times \sum_{j=1}^{n} h_{ij} \quad , \omega_g \; and \; \omega_h > 0 \qquad (19)$$

The innovative model of the intelligent lighting system involves the correlated color temperature as a direct parameter in the model. Therefore, the new objective function has the illuminance constraints $g$ and the correlated color temperature constraint $h$ for each lighting $i$ to each sensing device $j$. The optimization method of the intelligent lighting system converges the illuminance target and the color temperature target concurrently. Equation (20) illustrates the illuminance constraint. The function of the illuminance constraints converges the estimated illuminance to the target.

$$g_{ij} = R_{ij} \times \left(Ec_j - Et_j\right)^2 \qquad (20)$$

Further, the new parameter of the color temperature converges the estimated the estimated color temperature to the target for each light to each sensing devices. Equation (21) illustrates the corelated color temperature constraint used in the new model of the intelligent lighting system.

$$h_{ij} = R_{ij} \times \left(CCTc_j - CCTt_j\right)^2 \tag{21}$$

In the control operations of the intelligent lighting system, the process of an Adaptive Neighborhood Algorithm is used to realize the illuminance and the color temperature at the same in respect of each received target for each user. The algorithm runs to reduce the gap between each value of the estimation. Besides, the convergence techniques are used based on the illuminance, in addition to the color temperature.

## 6.4 Examination of Performed Method

In order to examine the performed previous method, some experiments and computerized simulations have been conducted to check the performance of the method. In this examination, three stages or different scenarios have been determined of the work time in the office and different situations and conditions. The target values for illuminance and color temperature for each worker has set randomly. The office space is designed based on real workspace using the same distances.

Figure 7-4 shows the office design space to examine the method for the color appearance and the correlated color temperature in the intelligent lighting system. In the experiment, there are twelve lights, and each lighting has two appearance types of lighting color sources. The experiment room shows that there are five workers in the office distributed randomly, and each worker has a personal illuminance and color temperature in the office.

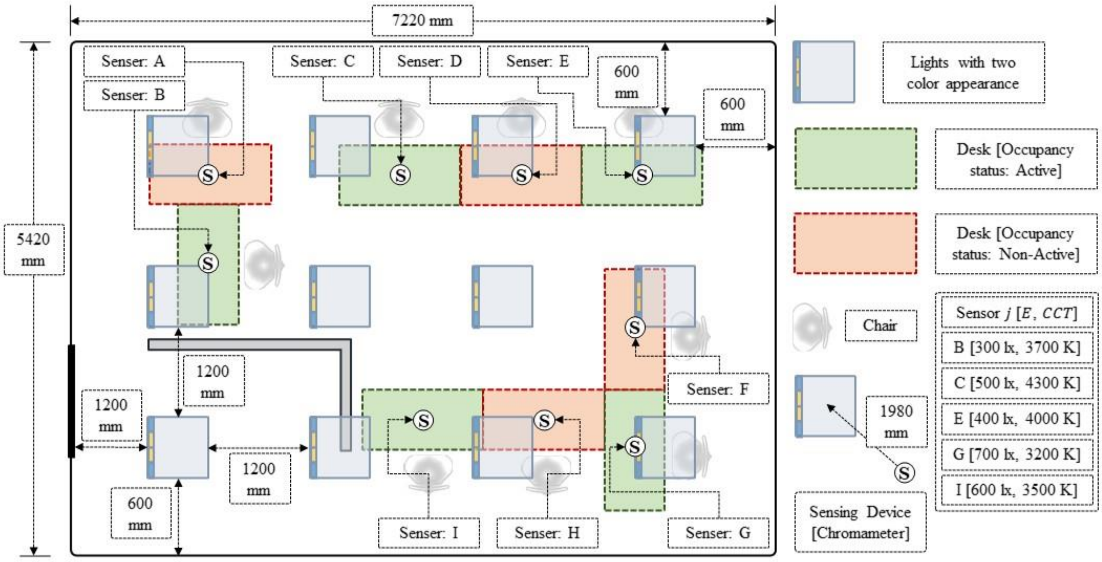



Figure 6-5: The shape of the office design space illustrates the experiment room based on a real workspace in one stages of the work time.

In the process examination of the experiment, the intelligent lighting system is operated based on the target values of each worker in the office. Therefore, each worker has the realized illuminance and the color temperature based as requested. Figure 6-6 shows the realized target illuminance for each worker in the office.

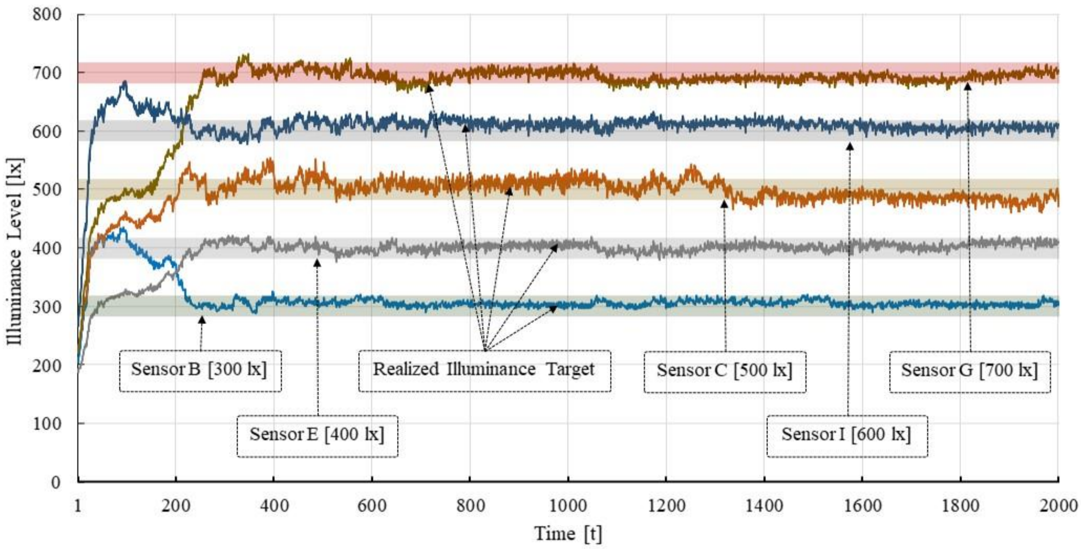



Figure 6-6: The illuminance history of the intelligent lighting system is illustrated for five active workers in one stages of the work time.

The intelligent lighting system is not affected by other parameters used on the objective function of the system. The illuminance element is not biased, while the intelligent lighting system hired the color temperature as a function parameter in the proposed method of the system. Figure 6-7 shows the outcome of the achieved target of the color temperature for five active workers in the office. Each worker has realized values of the color temperature close to the user target.

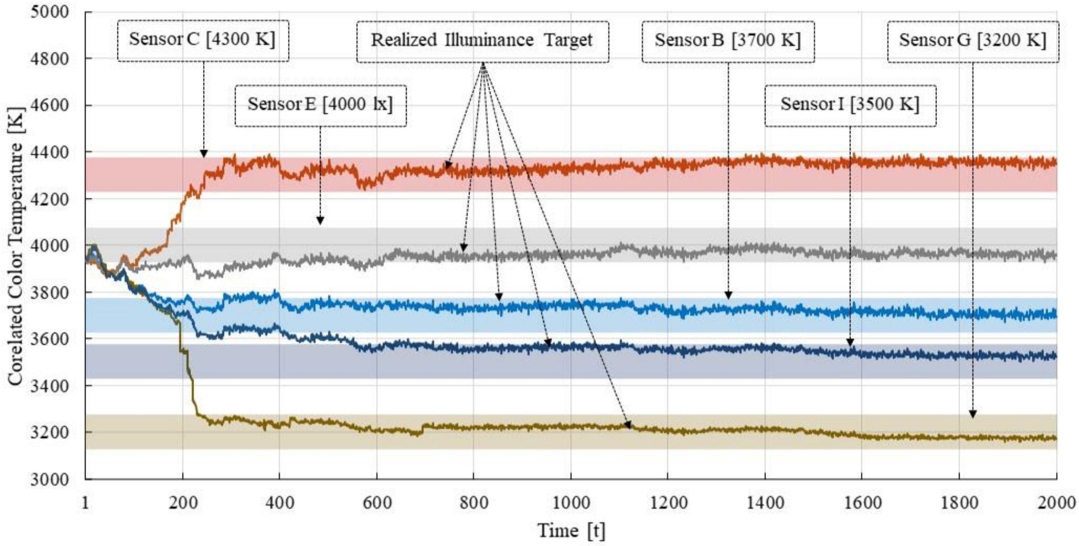



*Figure 6-7: The correlated color temperature history in the intelligent lighting system for five workers in one stages of the work time.*

Figure 6-8 shows the luminance distribution of the first stage of work time in the office. The luminance has two colors of light sources, namely cool white light, and warm orange light. The luminance level of both colors is distributed based on the target of the sensing devices.

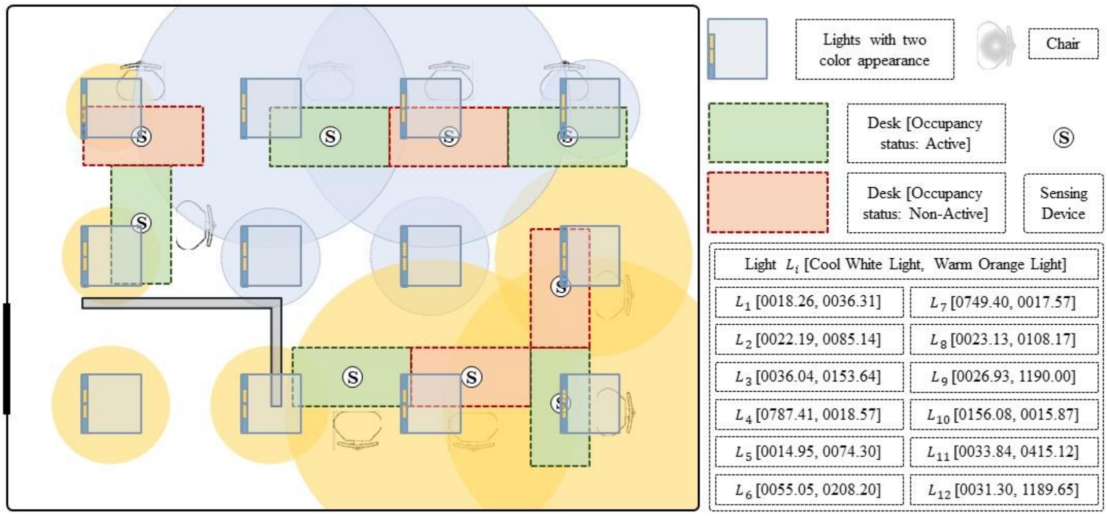



*Figure 6-8: An illustration explains the luminance distribution of the first stage of the work time in the office*

For instance, a sensing device has 500 lx and 4300 K, so the intelligent lighting system realizes the target as requested. The lights close to the previous state cover the amount of the illuminance and the correlated color temperature. The required lighting to covers the target for cool white light are 787.41 cd and 747.4 cd, in addition to other amounts of luminance around the sensing devices. The required adjustable lighting covers the rest of the target in a small amount of luminance, which is enough to adjust the illuminance target. In another case, two close sensors have 3200 K and 3500 K respectively. Therefore, the required lighting to covers the warm orange lights is 1190 cd, 415.12 cd, and 1189.65 cd. Besides, the rest of the adjustable lighting is covered based on the target and other lights state.

In the next examination of the experiment, there is a change in office design. Figure 6-9 shows the change in office design. The experiment design has six available active workers, and each worker has a different individual illuminance and color temperature. Some workers in the previous experiment left the office, while other workers come to the office and use the intelligent lighting system. Also, other workers change the preferences of the illuminance and the color temperature.

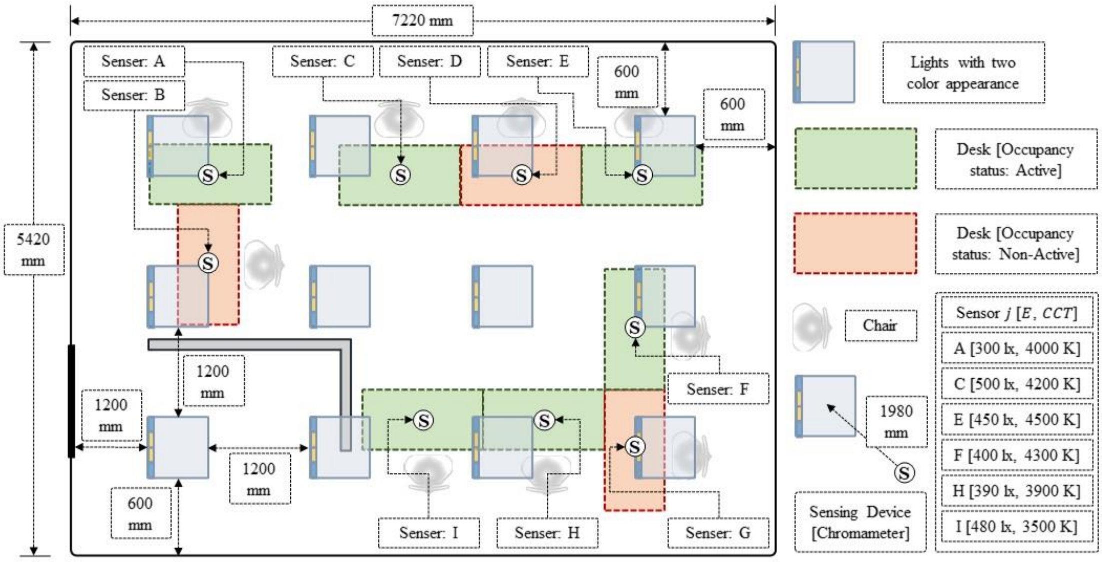



*Figure 6-9: The shape of the office design space illustrates the experiment room based on a real workspace in two stages of the work time.*

Figure 6-10 shows the illuminance history for six workers in the second stage, while there are five workers in the first stage of work time in the office. Besides, the intelligent lighting system moves from the inactive work time stage to the active work time stage. Each worker has realized the target illuminance. Further, the intelligent lighting system adjusts the target for each user as requested. For instance, one worker in the office has 600 lx, and the worker changes the level of illuminance to 480 lx. Then the intelligent lighting system provides the level of illuminance based on the request of the worker. Also, there is no effect on other sensing devices. For another example, another worker in the office has 500 lx all the work time, and the illuminance value is not affected in the presence of other sensing devices.

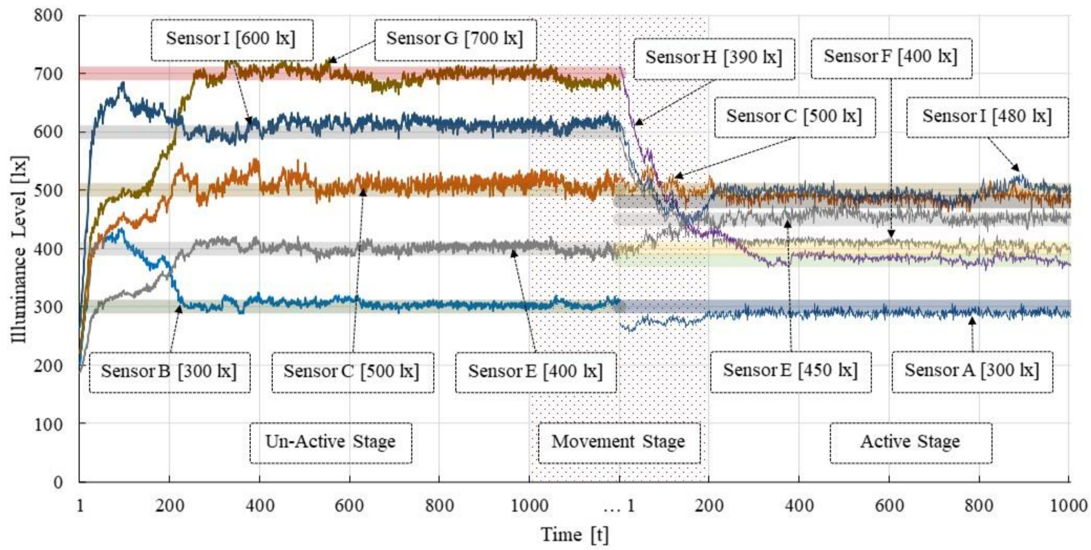



*Figure 6-10: The illuminance history of the intelligent lighting system is illustrated for five active workers in two stages of the work time.*

In the color appearance of the lighting, the intelligent lighting system realizes the correlated color temperature for each work. Figure 6-11 shows the history of the correlated color temperature for eight workers in two stages of work time in the office. The first stage has five workers, and the second stage has six workers. Some workers move out of the office, and other workers change the values of the correlated color temperature, while other workers keep the same amount of color appearance. Some workers come back to the office and starts using the intelligent lighting system.

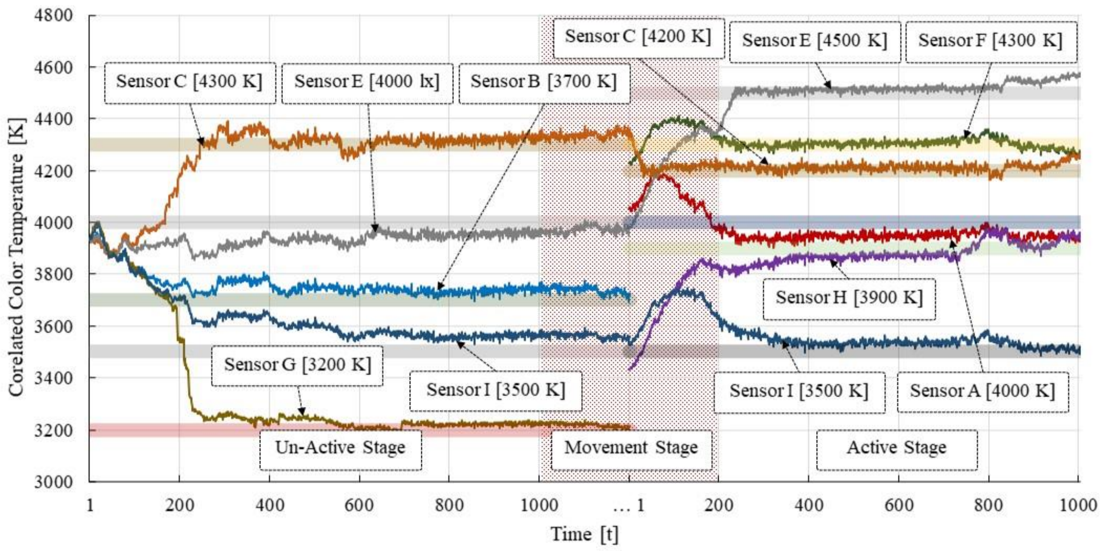



*Figure 6-11: The correlated color temperature history in the intelligent lighting system for five workers in two stages of the work time.*

For instance, one worker has started using the intelligent lighting system at the second stage of the work time due to some reasons with 4000 K, while some workers left the office. Another worker has started using the lighting system with 3900 K. Also, some workers change the amount level of the color temperature to another level in the next stage of the work time. All the target values have been realized by the intelligent lighting system as requested.

Figure 6-12 shows the luminance distribution of the second stage of work time in the office. The luminance level is distributed based on the target of illuminance and color temperature on the sensing devices. The cool white light color is distributed on one side as all the workers have the amount of cool white color. The warm orange light color has the same distribution based on the target on the sensing device.

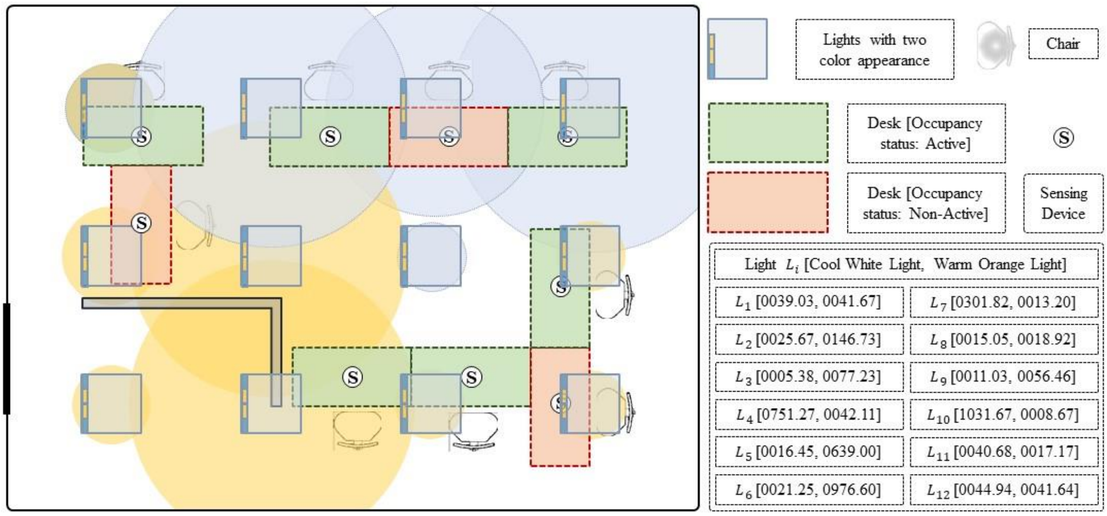



*Figure 6-12: An illustration explains the luminance distribution of the second stage of the work time in the office.*

In the next examination, another stage of the experiment is conducted based on different states. Figure 6-13 shows the change in the office. All the workers have been left the office except three workers with different situations and different amounts of illuminance and color temperature. The intelligent lighting system moves to realize the target for each user based on each condition in the office.

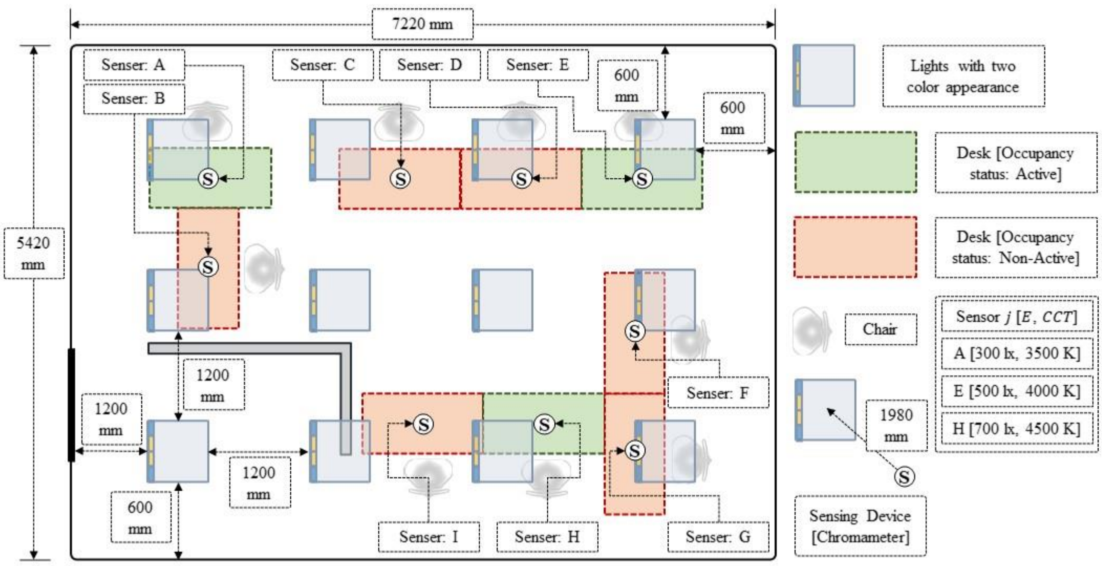



*Figure 6-13: The shape of the office design space illustrates the experiment room based on a real workspace in three stages of the work time.*

There are three stages of illuminance history during work times. In the last stage, there are three workers, and other workers move out of the office. Figure 6-14 shows the illuminance history for five workers in the first stage, and six workers as a second stage of the work time, then there are three workers as a third stage in the office. Each work has individual illuminance and different conditions. For instance, in the first stage, one worker has started the illuminance target with 400 lx. The work has changed the desire luminance to 390 lx in the second stage of the work time, and the same worker has asked to increase the amount of illuminance to 700 lx in the next stage of the work time.

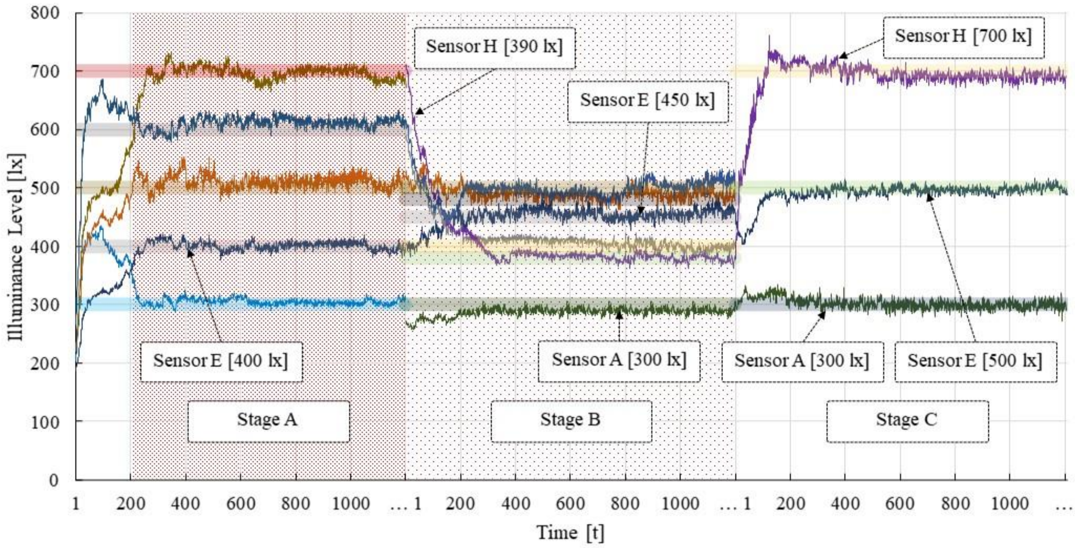



*Figure 6-14: The illuminance history of the intelligent lighting system is illustrated for five active workers in three stages of the work time.*

The intelligent lighting system provides all the illuminance amount and realizes the target as requested. Other illuminance targets for other workers have not been affected. Also, the intelligent lighting system has achieved all the illuminance targets as ordered. In the second stage, another worker has 450 lx for illuminance, and the same worker has got 500 lx once requested on the third stage of the work time.

On the side of the color appearance, each worker has desired values of the correlated color temperature in different stages of the work time. Figure 6-15 shows the history of the correlated color temperature for some workers in some conditions on three stages of the work time. In the first stage, one worker has started using the intelligent lighting system at the amount level 4000 K for the color temperature. In the second stage, the same worker has increased the amount level of the color temperature to 4500 K, and in the third stage, the same worker has come back to the same amount of the color temperature in the first stage of the work time.

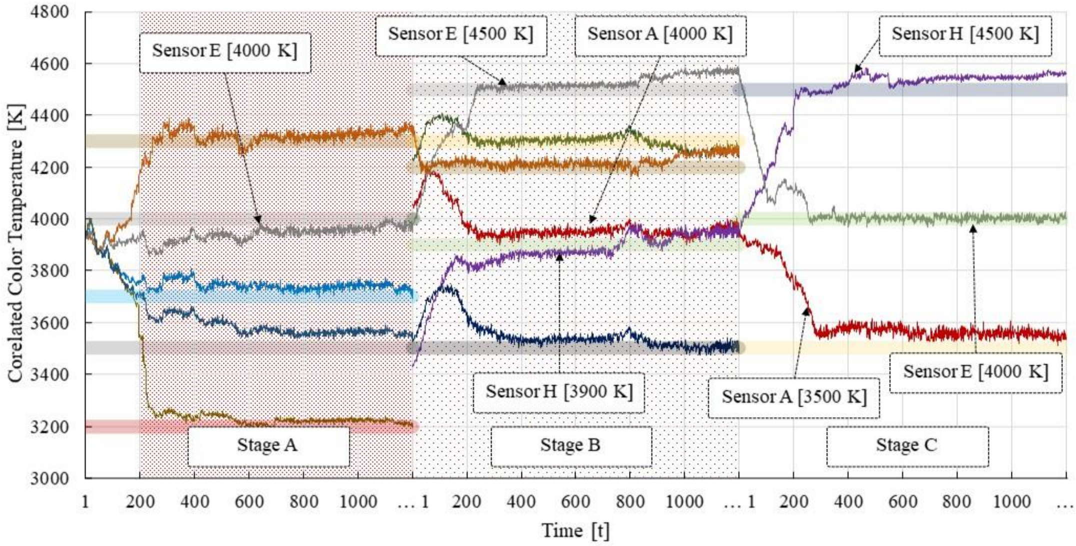



*Figure 6-15: The correlated color temperature history in the intelligent lighting system for five workers in three stages of the work time.*

Another case for another worker that the worker has started using the intelligent lighting system at the second stage in the degree of 4000 K. The same worker has changed the degree to 3500 K in the third degree on the next stage. Also, another case for another worker has started with 3900 K and increased the amount level of the color temperature to 4500 K for the next stage of the intelligent lighting system. As the same of the illuminance issues, the intelligent lighting system has realized all the targets for the color temperature.

Figure 6-16 shows the luminance distribution of the third stage of the work time in the office. The luminance distribution has been changed based on the new conditions of the third stage of the work time.

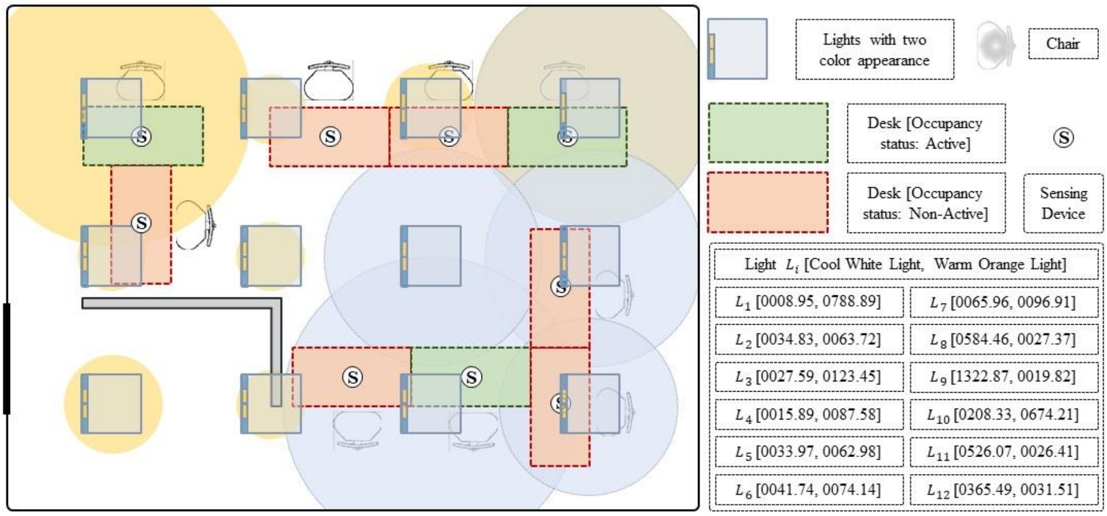



*Figure 6-16: An illustration explains the luminance distribution of the third stage of the work time in the office.*

All luminance levels are changed based on the new requirement and new condition in the office. Each stage has a different distribution, and the control method of the intelligent lighting system adjusts all the luminance amounts, which reduces the energy in the office. However, the office environment affects to realize the close target for each worker.

## 6.5 Remarks

According to all previous cases and scenarios of the intelligent lighting system, the observations find that the system realizes each user target for illuminance and color temperature. The method of color temperature works in different cases. However, the examination has been conducted based on the assumption of the intelligent lighting system. The ideal time for the experiments has been considered based on the simulation criteria. The proposed method of calibration for the color appearance has influenced the system automation in the intelligent lighting system. The intelligent lighting system has achieved the target for each worker in the office, with different conditions and situations. The method helps each worker to have the color appearance as desire in the desk space.

# CHAPTER SIX

## Intelligent Lighting System Solutions on the Energy Consumption

Energy consumption is a source that influenced the performance of the workers [50]. Today, energy consumption causes concern for the designs of the workplaces and the office environment [3]. In the comfortable office, the intelligent lighting system is one of the solutions that reduce the amount of energy in the office. In the control operations, the intelligent lighting system hires the lighting components, smart optimization method, and utilizes the best use of the resources to provide the lighting services as requested for each worker in the office.

A lot of the technological advancements have been applied in the workspaces to reduce the energy consumption in the office [53], [83]. The advanced model of the intelligent lighting system encompasses how the system provides a comfortable space for each worker, besides improving the high energy consumption of the office [6]. The available technological solutions in commercial environments have not adequately capture the relationship between energy efficiency and visual comfort of the luminance [60]. For instance, the typical improvements include how to decrease the energy consumption of the intelligent lighting system using remote sensing technology and utilizing the automation process on the system [58].

In this section, the situation of the energy consumption is discussed and how the intelligent lighting system contribute as a solution to reduce the energy in the office.

## 7.1 Energy Consumption Factor

Energy consumption is one of the top issues for the intelligent lighting system. Therefore, the control operations utilize the smallest amount of energy to realize the target for each worker. The rate of energy consumption is expressed based on how much of watts unit in each time. There are different ways to measure and calculate the energy consumption in the office, but to examine the assumption of the research, the luminance influences energy consumption in the presence of other constant factors. Therefore, the most element that affects energy consumption is the amount of luminance level used in the office. Equation (22) shows how to calculate the energy consumption based on luminance values $L$ for number $n$ of lights.

$$p = \sum_{i=1}^{n} L_i \tag{22}$$

Figure 7-1 shows the different energy consumption in the office environment based on office space design and workers using the intelligent lighting system. Energy consumption is related to the amount of lighting and the luminance available in the office. The amount of lighting level depends on the desire of each worker to use the lighting system. Each worker has a high illuminance desire, which required more luminance to cover the amount of the illuminance more than others.

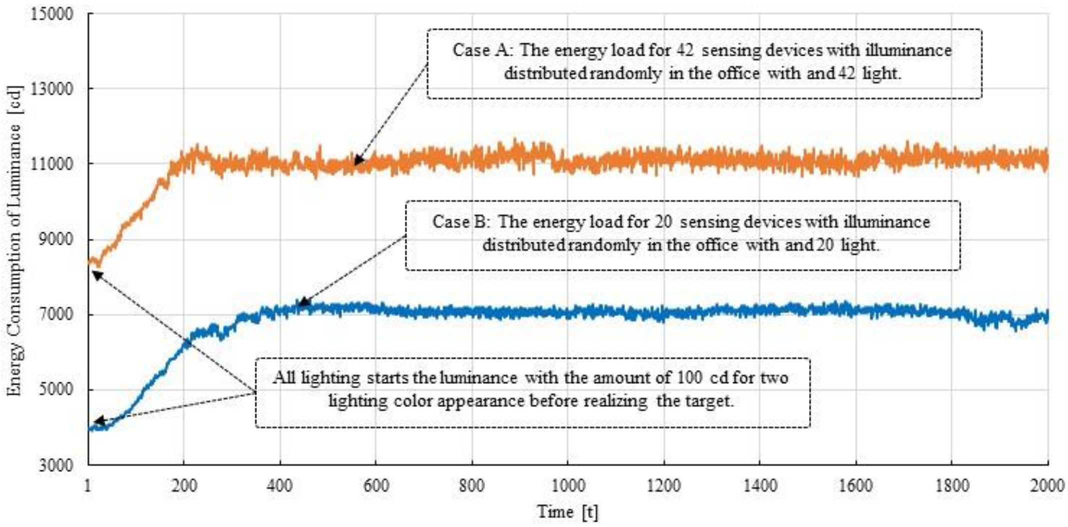



*Figure 7-1: The history of energy consumption in the office in different situations.*

## 7.2 Effect of the Lighting System on the Energy

Accordingly, the problem of high energy consumption for the intelligent lighting system used in the office is considered based on worker usage during work time. In this examination, the intelligent lighting system has a high effect on energy consumption for the office work environment. The conventional model of the intelligent lighting system using the illuminance sensing devices offers the services of lighting for each worker in the office. Each worker has the realized illuminance by the lighting system. However, the behavior of the user has a large effect on using the intelligent lighting system on energy consumption in the office environment.

Figure 7-2 illustrates a part of the experiment office room from 42 positions for the workers. The desks have random targets of 300 lx, 500 lx, and 700 lx for the preferred illuminance of the workers. The intelligent lighting system runs in distributing the illuminance based on the desired individual value for each user in the office.

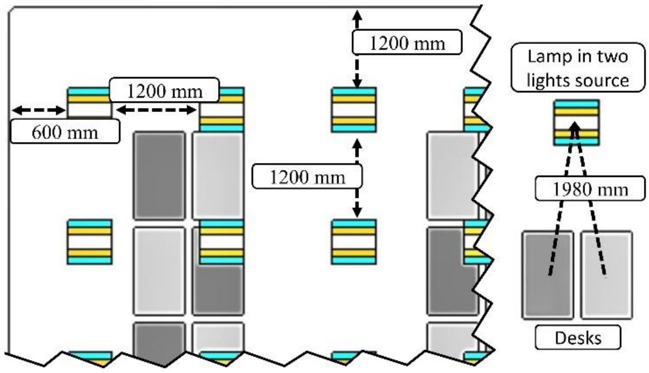



*Figure 7-2: A part of the experiment on the simulation for the office design.*

The influence of the traditional lighting system on energy consumption is not the same as the influence of intelligent lighting on energy consumption. The worker can change the illuminance in the intelligent lighting system, unlike the traditional lighting model. The standard level of illuminance provided for all the workers in the office is 700 lx.

All the workers have the same level of standard illuminance as recommended [50]. However, each worker has different preferences for the illuminance and the lighting. For instance, some workers prefer a medium level of illuminance, which is 500 lx. This examination assumes that around 20% of workers have illuminance at the level of 300 lx. Additionally, another 20% of workers have the illuminance of 700 lx each, while around 60% of workers get the level of 500 lx. This assumption is taken based on real cases on actual office spaces [50].

In the next examination, the energy effect is observed and monitored the impact of using intelligent lighting systems on the performance rate of energy consumption in the office. In the conventional intelligent lighting system, toggling the sensing devices have influenced the use of the lighting system. For instance, the assumption of the system has two scenarios for the status of the system affected by the usage of sensing devices during the daytime.

The first scenario of the experiment is related to the toggling status of the desk and sensing devices. The ratio of the occupancy status of the desk is the number of workers that used the intelligent lighting system and never left the office in the daytime. In this scenario, the intelligent lighting system has several cases when the workers are not in the office.

The examination assumes that 30%, 60%, and 90%, or all workers leave the office, respectively. The previous assumption is to study the behavior of the intelligent lighting system in the normal case and to monitor the effect of power consumption in different cases. The purpose of the assumption leads to check the overload of the energy in the office in different conditions.

The second scenario of the experiments checks the overload of the energy rate in the intelligent lighting system through the proper use of the sensing devices. The sensing devices toggle the status of the system by each worker before receiving the values. Toggle the status of the sensing device is done manually by each worker in the office. The proper use of sensing devices keeps the lighting system active for each worker while the worker was using the system before leaving the office. Whatever the intelligent lighting system has an active status or a non-active status, and the status depends on the toggling of the sensing device.

Occasionally, each worker activates the intelligent lighting system during work time or deactivates the system due to forgetting to toggle the status of the system in the office. Consequently, the ratio of forgetting to toggle the status of the intelligent lighting system is the number of workers to the total who neglect the sensing devices while leaving the office.

The experiments assume different causes of user behavior in the office. There are 20%, 40%, 60%, and 80% of workers for the case of forgetting to toggle the system after leaving the office, respectively.

The experiment and the investigation study the behavior of using the sensing device properly in different cases and the effect of energy consumption in the office. There are 42 workers and desks for each to use the intelligent lighting system. The energy of the intelligent lighting system becomes in full use of power in the case that the ratio of forgetting to toggle the status of sensing devices is 0%. In another case, the ratio of the occupancy status is 70%, while 30% of the workers leave the office, which assumes that 29 workers are still using the intelligent lighting system.

The overloaded energy status of the intelligent lighting system becomes higher than before the previous status based on the ratio of the forgetting status to toggle the sensing devices. For more clarification, the assumption is that the occupancy status of total workers is 10%, which corresponds to 38 workers left the office while the intelligent lighting system works.

However, if the assumption for the forgetting status of toggle the sensing devices ratio is 60%, so that there are 23 workers left the office and forgot to change the deactivate the intelligent lighting system. The energy consumption, in the previous case, will increase the power overload caused by the occupancy status of the desks. Furthermore, the system provides the energy for 27 workers, while the energy for this case is required for four workers. This case indicates that energy will become higher than before in the previous case.

Table 7-1 shows the ratio of occupancy and the ratio of forgetting toggle the status of the system for all the workers in the office. For instance, if the ratio of occupancy is

100% or the ratio of forgetting to toggle the status of the sensing devices is 100%, the total number of active illuminance sensing devices is 42 as well. In this case, the energy consumption will become high for the system.

*Table 7-1: The ratio of occupancy and the ratio of forgetting to toggle the status of the system for all the workers in the office.*

| **Cases** | | **The Ratio of Forgetting to Toggle the Status of the System** | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0% | 20% | 40% | 60% | 80% | 100% |
| **The Ratio of Occupancy** | 100% | 42 | 42 | 42 | 42 | 42 | 42 |
| | 70% | 29 | 32 | 34 | 37 | 40 | 42 |
| | 40% | 17 | 22 | 27 | 32 | 37 | 42 |
| | 10% | 4 | 12 | 19 | 27 | 35 | 42 |
| | 0% | 0 | 8 | 17 | 25 | 34 | 42 |

For the illustration, if the occupancy status of the office is 10%, it assumes that there are four workers using the intelligent lighting system in the office. On another side, if the ratio of forgetting to toggle the status of the system is 40% of the workers who left the office, it assumes that around 15 workers kept the sensing device in the active case. The overload of the energy in the previous figure increased by four times the normal case.

In the experiment, there 42 workers, and around 20% of workers have 300 lx and another 20% of workers have 700 lx each, while 60% of the workers had 500 lx for each. The intelligent lighting system tries to realize the target for each worker, and the energy consumption becomes as in Figure 7-3.

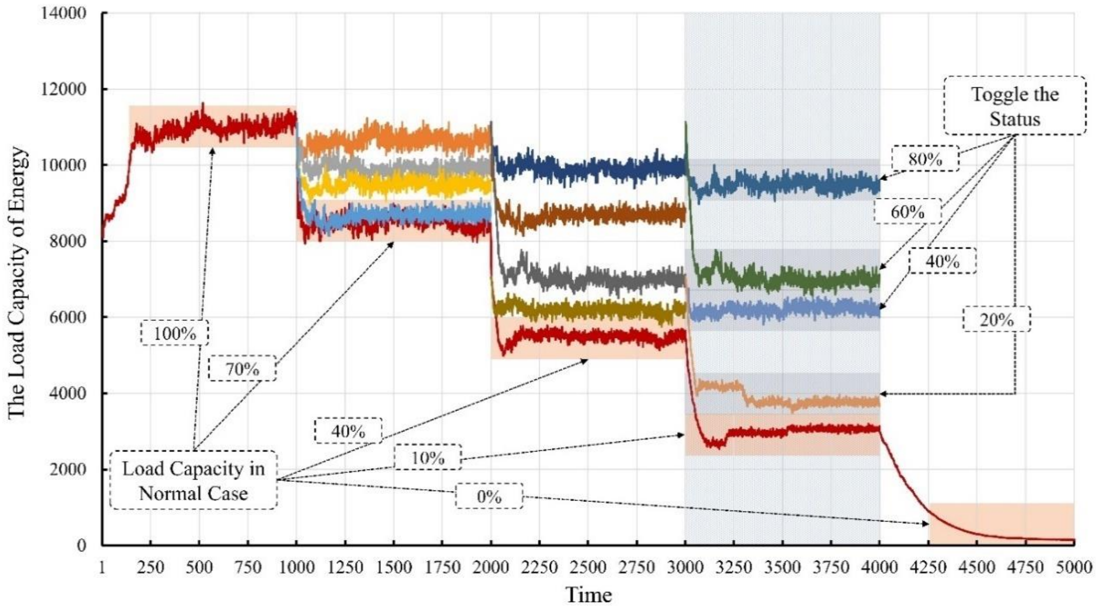



*Figure 7-3: The history of the energy consumption at the office.*

The energy overload reached the maximum amount of energy in the office. The energy rate becomes stable in around three to five minutes to realize the target for each user. The energy rate becomes stable in a very short time when the situation of the occupancy ratio is changed from 100% to 70% applied for all the situations for the occupancy status.

The ratio of forgetting to toggle the status of the system affected the energy consumption rate. The energy overloads more than the required energy for the occupancy status. To further illustrate, the occupancy status has around 3000 watts for 10% of workers inside the office, while 90% of workers deactivate the system after leaving the office. However, the ratio of energy consumption increased to 100% in the case where 10 of the workers were not using the intelligent lighting system properly.

Also, the ratio will increase more to 200% if the number of workers doubles. The occupancy status and the forgetting status of toggling the intelligent lighting system have a big influence on the energy consumption of the office, as depicted in Figure 7-4.

The occupancy ratio and the forgetting ratio of toggling the status of the system have a relationship with affecting the energy consumption rate in the office.

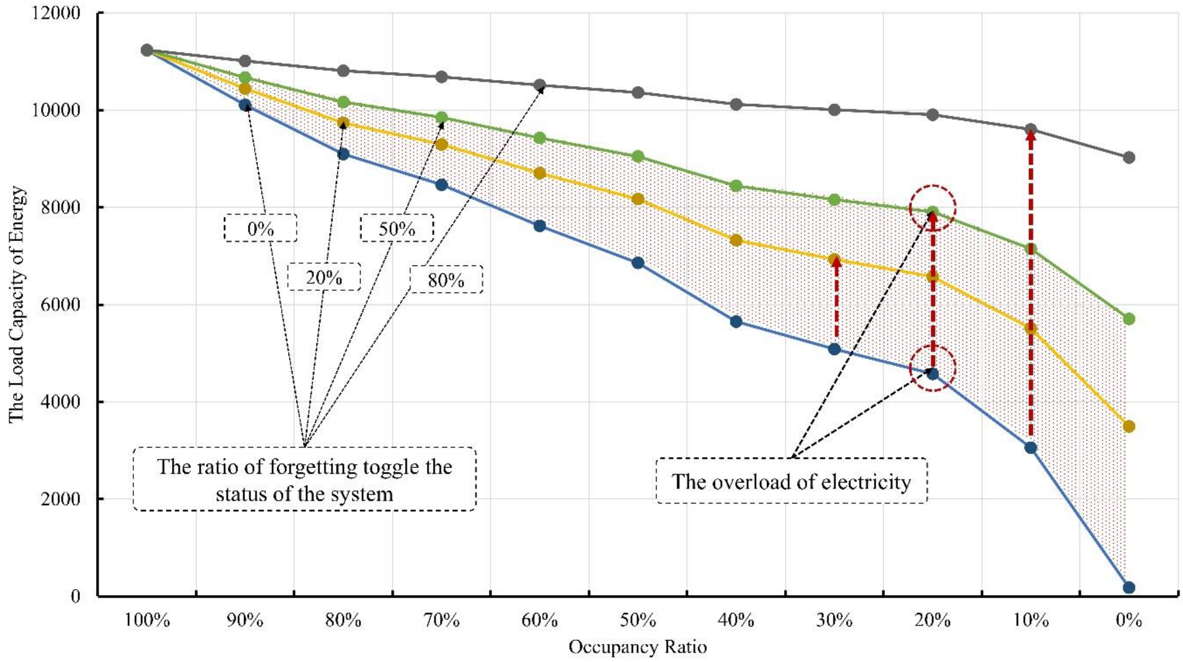



*Figure 7-4: The load capacity of energy for the occupancy status compared with forgetting to toggle the status of the intelligent lighting system.*

Utilizing the lighting control system by beacons instead of the traditional system tries to decrease the rate of energy consumption and fix the problem of activating the illuminance sensing devices manually. The proposed solution depends on the number of workers in the office as the beacon has a limited range of detecting the signal of smartphones and how wide the office is for workers.

For instance, two types of beacons are used: each user has one beacon at the desk and another beacon installed in the ceiling lighting fixture to detect the movement of the worker inside the office. Each beacon detects the signals of the smartphone by the distance and sends the received signal to the intelligent lighting system. Each worker will use the smartphone as an interface to change the target illuminance.

## 7.3 Lighting System Based on BLE Beacon

In the intelligent lighting system, sensing devices technology plays an efficient role in using the lighting system [65]. Each worker in the office has a sensing device to communicate with the intelligent lighting system. The worker toggles the occupancy status of the illuminance sensing device then. After the occupancy status, each work adjusts the amount of illuminance as desire.

The communication technology of wireless or BLE beacon is employed in the intelligent lighting system to enhance the accessibility and lighting control system. In the lighting configuration and the input phase of the system, the conventional model of the intelligent lighting system has utilized sensing devices for toggling the occupancy status of the system. However, BLE beacon technology is used instead of the sensing devices.

The intelligent lighting system consists of the sensing device of the smartphone with beacon technology to toggle the occupancy status of each user. Whatever BLE beacons transmit the signal radio waves, and the smartphone receives the signal from the beacons [65]. The data transferred includes an alerting signal mode of the device [64], [84].

A BLE beacon is a model of a one-way wireless technology standard to broadcasting a short message to other devices [85]. The message includes information about the device identification number and the services offered to other configured devices nearby [65]. The signal strength transmitted by the beacon has determined the occupancy status of the desk in the office.

For instance, each user has one beacon in the desk and another active beacon placed in the ceiling fixture of the office for efficiency measurement. Consequently, the intelligent lighting system has the accuracy of determining the occupancy status of each user at the office. The lighting system lies to provide the proper individual luminance for each user based on the occupancy status for each desk, which affects the energy consumption of the office.

The beacon used radio-frequency waves to transmit the signal values, including an information packet about the device in a short time and the regular interval range. Then, the smartphone estimates the distance from the beacons by using the information packets and received signal strength [65].

The received signal strength measured the signal energy for each received packet to quantize the received signal strength indicator (RSSI). The proposed intelligent lighting system works on the RSSI of the smartphone to determine whether the seat is occupied or unoccupied. RSSI identifies four parameters: range, accuracy, linearity, and averaging period [64], [84].

Therefore, the RSSI range is the smallest and largest transmission signal in dBm, in which the accuracy is the average error for each transmission signal [65]. The indicator linearity deviates the computed function of energy. RSSI is changed by the distance between the beacon and the smartphone, as in Figure 7-5.

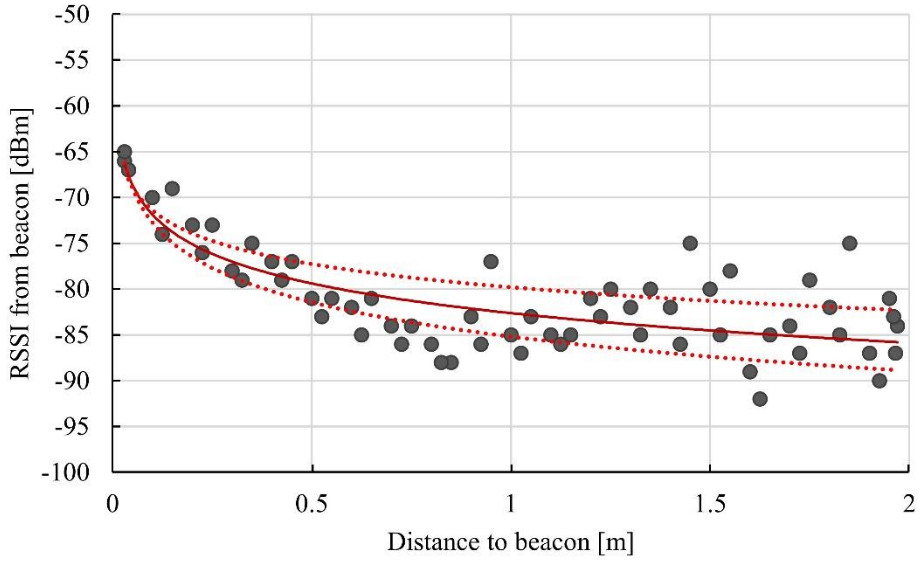



*Figure 7-5: The received signal strength indicator (RSSI) experiments of beacons.*

The RSSI computed in the receiver to the transmission energy indicates broadcasting by the beacons [64], [65]. The RSSI is affected by the location of the beacon and the mobile. Then, the mobile sends a signal to the control module of the intelligent lighting system to occupy the desk for the worker [65].

Figure 7-6 illustrates a topography of the workspace that installed different lighting fixtures types for various purposes. In the office space, two model of BLE installed in the lighting fixture, and one for each desk.

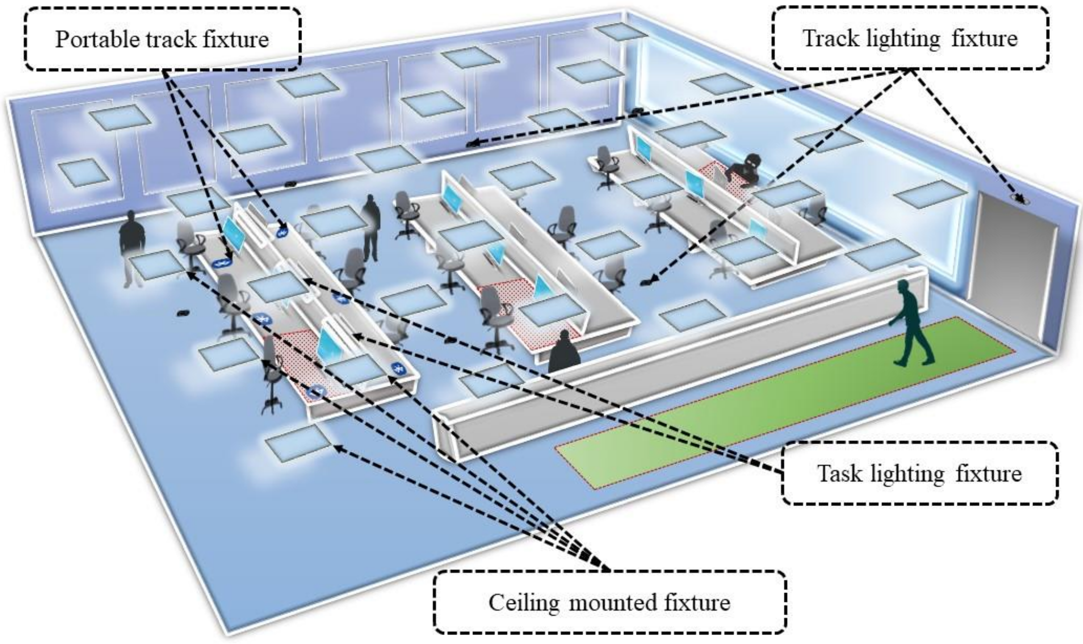



*Figure 7-6: The topography of the office work environment installed different lighting fixtures for various purposes.*

Figure 7-7 explains the experiment of four workers to validate the intelligent lighting system in realizing the target for each worker. The illuminance targets 350 lx, 500 lx, 400 lx, and 600 lx are distributed for each worker, respectively. Each worker changes the illuminance target using the smartphone, and the smartphone is close to the beacon on the desk. Based on RSSI, the smartphone received the signal from the close beacon. Then the system detects the beacon, and the intelligent lighting system realizes the target for each worker. The target is realized as 378.76 lx, 494.24 lx, 383.41 lx, and 581.45 lx for each worker, respectively.

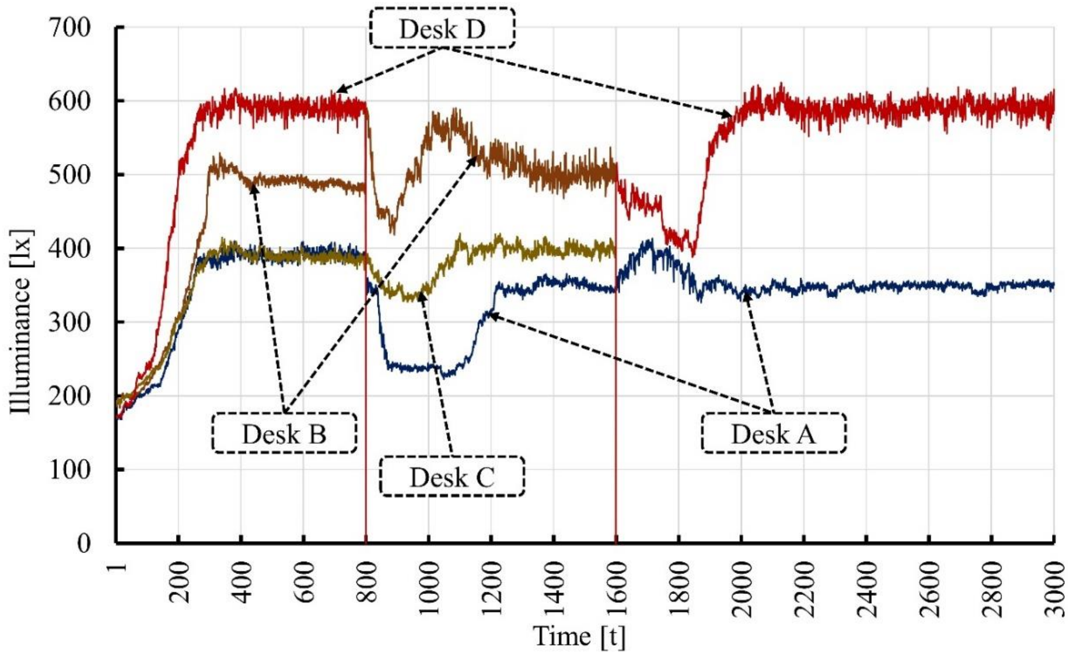



*Figure 7-7: The illuminance history of the sensor devices is during the different status of the occupancy inside the office.*

After that, each worker moves to change the position inside the office. For example, worker A moved to different places inside the office in a short time, and the worker came back to the desks. The workers B and C moved as well to different places in a short time, and then they left the office. Also, worker D left the office in a short time and came back later to the office.

Based on this scenario, the intelligent lighting system with beacons works properly, and the system was activated based on the user movement inside the office. In the first case of the workers, the intelligent lighting system does not detect the signals of beacons in the desks received by the smartphones of the workers. However, the system detected the signals of beacons in the ceiling lighting fixture received by workers A, B, and C, while the system did not receive the signal of worker D as the worker left the office.

The main purpose of the beacon on the ceiling lighting fixture is only to detect the user movement inside the office. After the workers B and C left the office, the system did not detect the signals of beacons in the ceiling lighting fixture received by workers B and C. However, worker D came back to the office, and worker A went back to the desk, and the intelligent lighting system changed based on the user movement. The system detected the signals of beacons in the desks received by the smartphones of the workers A and D.

The intelligent lighting system behavior changed dramatically based on the users' needs and movement. The system provides the target illuminance for each user in the office, while the system controls the toggle of the status of the illuminance sensing devices based on the user movement. In this solution, the system commands the energy of the lighting control system and changes the luminance based on toggling the occupancy status of the sensing device at the desk.

## 7.4 Smart Office Design

The office environment reflects and reinforces for any solutions of using the innovation technology on the smart office [55], [86]. Therefore, the office environment should be designed to achieve the requirements of using the ergonomic concepts for each user especially installing the intelligent lighting control on the office [39].

The intelligent lighting system should be a solution for each worker [6], [87]. However, the lighting control is only one system shared for all the workers in the office [72]. For instance, each worker in the office has used the same system of the lighting control, so that the intelligent lighting system finds the best solution not only for each worker, but also for the workplace [73]. Therefore, the workplace and office environment should be creative and dynamic as the office design affects to the solutions of the intelligent lighting system for user in the office [88].

Smart office design is a main factor to use the innovation technology beginning on the installation of the system to using the technology and providing an ergonomic workplace for users inside the office [14], [88]. Smart office design is not only about more than creating a creative environment that provides all the tools to support the various types of work tasks, but also the structure design of the smart office is a mandatory requirement to make the environment more dynamic for the office [74].

## 7.5 Remarks

A lot of the lighting solutions have been introduced in the workspaces to reduce the energy consumption from lighting systems. There have been a variety of techniques proposed to reduce the cost of energy. The integration of other models combines all the parts of the intelligent lighting system phases and components to work as one part. BLE beacon adds new value to enhance the use of the intelligent lighting system. The new model of the lighting control using BLE beacon performs a result satisfied for each user in the office.

# CHAPTER EIGHT

# Evaluation & Verification

This section argues the issues of data on the intelligent lighting system. The manipulation of data plays a vital role to consider the objective of the intelligent lighting system. Besides to acceptance solution of the data and the information which offer for the user based on the results and the lighting outcome. Therefore, the section discusses the assessment of the data on the user side. Furthermore, the data validation of the intelligent lighting system is evaluated to introduce the intelligent lighting system and compare the lighting outcome with the data from the actual workspaces.

## 8.1 Data Manipulation

A lot of the lighting fixture standard has been introduced based on the office space environment. However, all of them concentrate on lighting quality, which influences the elements of each visual lighting, personal lighting, and health lighting, as shown in Figure 8-1. Each affected element has several considered factors from different aspects. For instance, each worker has a specific level of lighting, and the intelligent lighting system able to provide the required visual lighting in a short time. Besides, the intelligent lighting system has abled to offer personal lighting in an acceptable range of required lighting. Additionally, the provided lighting is satisfied, which realized the health lighting for each worker.

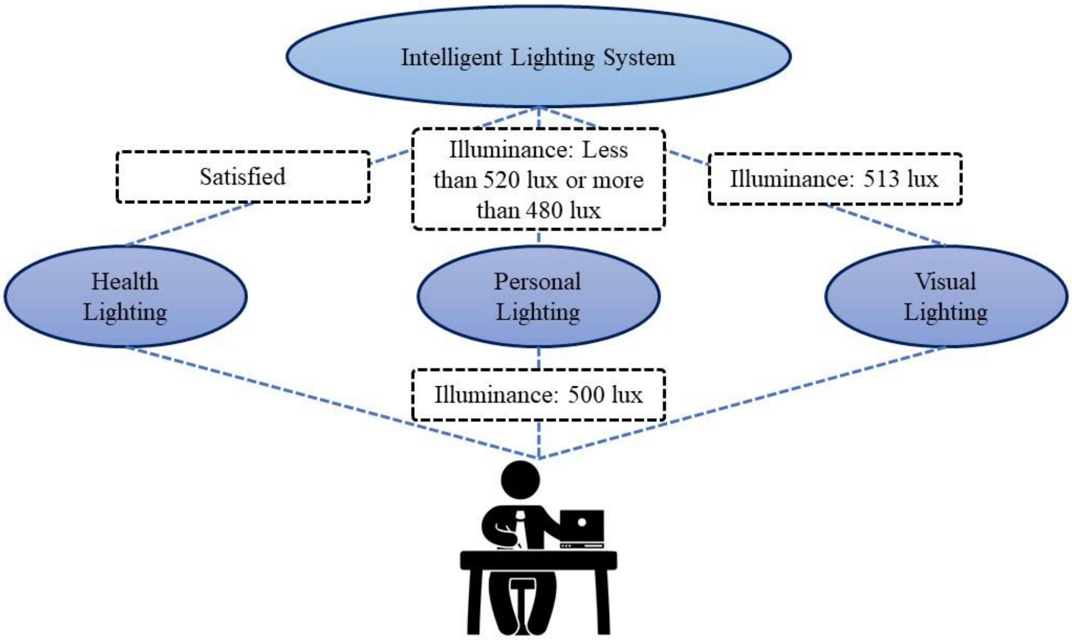



*Figure 8-1: The affected elements of the quality feature in the intelligent lighting system are shown in the three main parts with a real example in the office.*

## 8.2 Data Assessment

A few assessments have been considered based on the experiments and the simulation programs. The assessment analysis is a part of the requirements for performing the proposed method of the intelligent lighting system. In the intelligent lighting system, the measurement devices have an acceptable range of errors due to the age of the device and other issues. Besides, the experiment time affects the measurement. For instance, the other lights that come from the windows influence the office lighting fixture. Therefore, the ideal measurement of the lighting outcome has some assumptions which considering other factors that affect the measurements.

The next examination of the intelligent lighting system has six workers in the office. Each worker has the individual illuminance and desire comfort space of the desk. After running the intelligent lighting system, each worker has got the realized illuminance and color temperature. Figure 8-2 explains that the intelligent lighting system has achieved the target for each worker in the office.

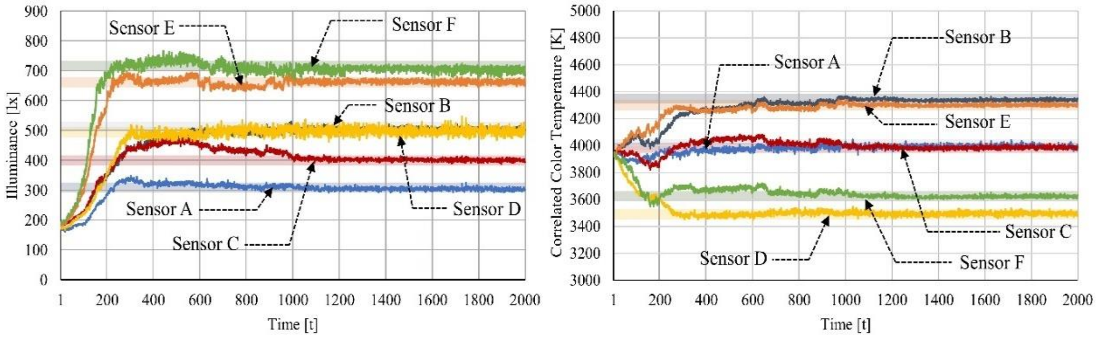



*Figure 8-2: An explanation shows the realized illuminance and the color temperature for six workers in the office.*

The intelligent lighting system finds the best state of the luminance that covers the amount of the target. In the illuminance history panel, each worker has got the illuminance value is close to the target as the desire. However, the acceptable range of the illuminance for the user is less or more than 30 lx to the target. The eyes of the user cannot recognize the gap between the realized illuminance and the target. In the color temperature history panel, the acceptable range of the color appearance for each user is around 200 K. The realization gap adequate and satisfies the comfort space for each user in the office.

## 8.3 Data Validation

In order to verify the experiments and the simulation of the intelligent lighting system, the measurement data of the intelligent lighting system is conducted in different scenarios and multi cases. Table 8-1 explains multi cases of the scenario to measure and validate the method of the intelligent lighting system. The data of illuminance and color temperature has got and extracted by the simulation and measurement experiments. Therefore, there are three levels to validate the performance of the intelligent lighting system, namely the real target, the measurement, and the computerized simulation data.

*Table 8-1: The data of the sensing devices for calculated and measured values with target values.*

| **Sensing Devices** | **Target Values** | | **Simulation** | | **Measurement** | |
|---|---|---|---|---|---|---|
| | $E$ | $CCT$ | $\hat{E}_1$ | $\widehat{CCT}_1$ | $\hat{E}_2$ | $\widehat{CCT}_2$ |
| Sensor 1 | 450 | 4000 | 470.81 | 4482.95 | 487 | 4270 |
| Sensor 2 | 300 | 4200 | 316.36 | 4019.73 | 279 | 3709 |
| Sensor 3 | 500 | 4300 | 487.14 | 4351.72 | 480 | 4069 |
| … | | | | | | |
| Sensor 11 | 300 | 3500 | 316.03 | 3756.98 | 322 | 3590 |
| … | | | | | | |
| Sensor 14 | 500 | 3500 | 456.59 | 3476.91 | 413 | 3254 |
| … | | | | | | |
| Sensor $N$ | 700 | 3200 | 644.39 | 3557.5 | 679 | 3401 |

Figure 8-3 shows the illuminance history data from the computerized simulation and the measurement data from the experiments. The data constraint and the gap between the real data and the simulation is small. The constraint gap is still in the range of user acceptance.

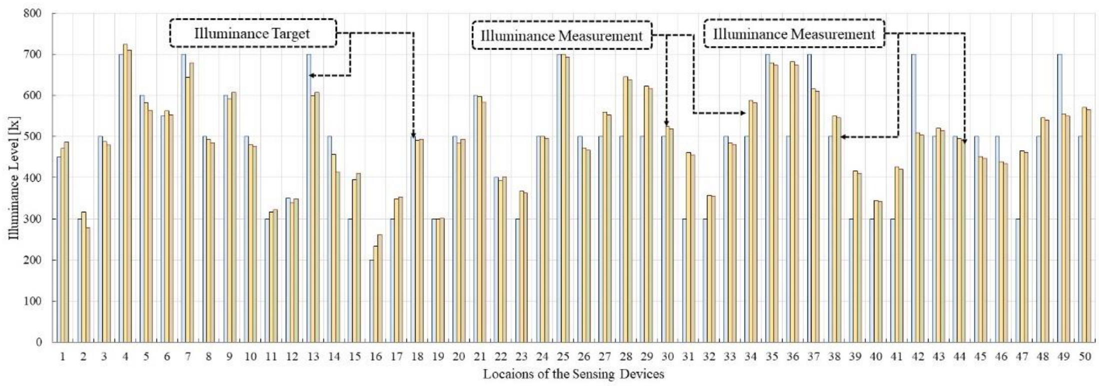



*Figure 8-3: The illuminance history data for calculated and measured values with target values.*

On another side, the correlated color temperature has the same difference between the calculated date and the date from the experiments. Therefore, the difference values between calculation and measured values are not high, and the gap is still in the average of user acceptance. Figure 8-4 shows the correlated color temperature history data for calculated and measured values with target values.

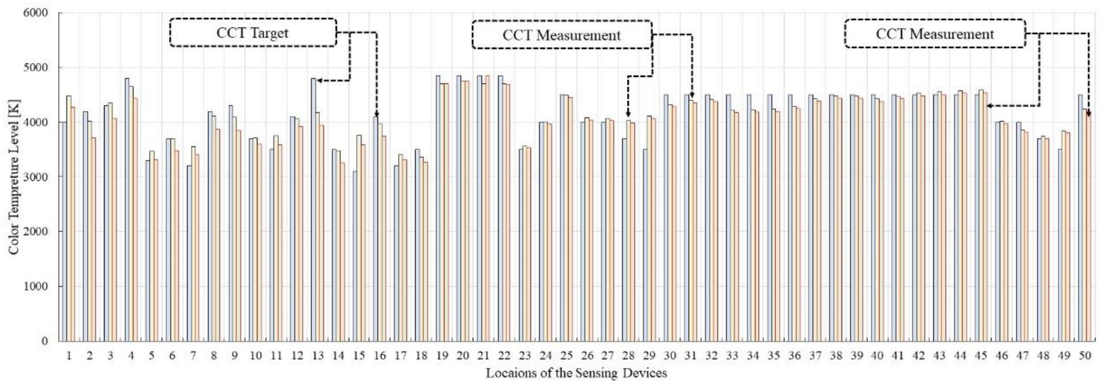



*Figure 8-4: The correlated color temperature history data for calculated and measured values with target values.*

In the intelligent lighting system, the outcome has been achieved, and the calculation results by experiments become closer to the simulation and the computerized system. Therefore, the illuminance target and the color appearance target are realized for each worker in the office. Further, the intelligent lighting system can be introduced based on office size.

The capacity of using illuminance sensing devices have not a big effect on the optimization and processing time. The adaptive method of processing convergence has different scenarios applied based on office size. Moreover, using the distributed lighting system for the large office affects to minimize the time of lighting processing.

## 8.4 Remarks

One of the proposed approaches to develop the method of the intelligent lighting system and reduce the error rate, the constraint gap between the real values and the actual values in the objective function is rated based on office space conditions. There are some limitations to the optimization method in the intelligent lighting system. However, other affected factors may influence the parameters of the objective functions. For instance, the quality of the equipment has some requirements considered for the experiments.

# CHAPTER NINE

## Discussion & Conclusions

The problem of the conventional intelligent lighting system is considered to obtain the target of illuminance and color temperature for each user while minimizing the energy at the workplace. In this paper, the new model of the automated lighting system without using the sensing devices has attained the target in advance for each user in the office. However, the performing model of the intelligent lighting system has provided personal illuminance and desired color temperature for each user in the workplace.

Most of the work offices provide the technology to enhance the environment, and the worker must use the afforded technology and adapted during the work. However, the worker has a routine feeling with the traditional use of technology once a mature system every day. Once the technology becomes flexible with involving the data of users, the modern office transforms to be a dynamic and a part of the lighting system that can be adapted with each user and contribute to the environment requirements.

Building a relationship between the worker and the system comes from how the data user involves feeding the data of the system. Therefore, the intelligent lighting system provides the required or desired work office space for each worker individually.

The lighting system energy has a part to affects performance besides the potency of the office design for each worker. The intellectual productivity of the office beside the worker is essential. It has been affected by the performance of the lighting system used in the office. The innovation design of the intelligent lighting system contributes to offer the lighting for each user as desire in the desk. Then, each worker can set the brightness and the luminance intensity in the working desk as needed. The comfortable space for each worker means the intelligent lighting system can offer an ergonomic based on the user data.

The comfort lighting system research concentrate on the behavior of the workers to deal with intelligent systems design in the office environment. Office ergonomics plays a principal role in ergonomics development of the ecosystem to boost the intelligent system for each worker in the office.

The innovation on the ergonomics generates a new concept of the intelligent system design in the office environment. The outline of the idea is the philosophy of the relationship based on the system performs with the user acts and behavior in the office. The relationship between the system and stakeholders helps with different aspects of the office covering technology resources tools, saving energy, and being healthy of the workers. The new concept leads to build a model of ergonomics ecosystem of office design and improve the intelligent system design to boost the productivity of each worker in the office.

The concept leads to build a model of ergonomics lighting system of office design and improve the intelligent system design to boost the productivity of each worker in the office.

The comfort lighting system use all technology parts of the office to work together to enhance the productivity of the office. The emerging workforce ergonomic system using the intelligent system design will impact the experience of the workers and boost the performance of the office.

The concept of innovation in the intelligent system design has expanded to boost the ergonomic system in the office. Therefore, the system value has used some principles such as ergonomic office design and office wellness for each worker. Besides that, the intelligent system has considered the saving energy of the office environment.

The intelligent lighting system is a part of the intelligent system design in the office. It is a part of the automated lighting control system, which refers to the automated office lighting control beyond the stationary brightness of the workplace.

The intelligent lighting system is one of the innovation technologies used to enhance the performance at the workspaces. The communication technology of wireless or BLE beacon is employed in the intelligent lighting system to enhance the accessibility and lighting control system.

For instance, the workers use the sensing devices technology to adjust the brightness level on the desk during the work time. Even so, smart houses use suitable technology tools to help in providing a comfortable daily life, such as switching on or off some devices using the wireless or the internet connection by smartphone devices.

The intelligent lighting system has some effective methods to validate the data outcome and enhance the user results. The feedback plays a role in boosting the comfort personal of user satisfaction. Besides, the intelligent lighting system contributes to the field of office designs.

Therefore, the office space is the best practice of the intelligent lighting system, as the system has affected all the stakeholders and the workplace environment. The system effect becomes to each worker, the energy consumption of the workplace, and ergonomic office design to keep the workers feeling well during the work in the office. Also, the intelligent lighting system is the best practice of the ergonomic system for each worker and a part of the ecosystem for the work office.

Despite the dominance of the lighting system in the office, some workplaces have not utilized the new stages of the lighting control systems, which helps for boosting an innovation personal ergonomic ecosystem of the workspace. The lighting system has been developed in the office using innovation and technology to become more satisfied and efficient as an application of the intelligent system design in the smart office environment.

The intelligent lighting control as a part of the intelligent system design plays a decisive role in the office environment. The system role is not only on the functional or practical tasks and intellectual productivity but also the human feeling well. The human sense, such as the emotional feeling, affects the performance of the workplace. The intelligent lighting system affects to achieve the desired atmosphere for each worker in the office.

The main factor of the office workspace is to utilize the lighting system to provide the health lighting for each worker besides using the lighting system, which not affected the power consumption of the office.

The automated lighting system becomes readily available to match individual preferences for different office environments. Using innovative technology is available with the lighting control system to design a smart ergonomic system and keep the office more comfortable for each worker. Towards ergonomic personal lighting system has become more compulsory for the appropriate interaction of stakeholders or workers, technology, and reciprocal information in the workplace.

The system design philosophy is how the new lighting model does cover the concepts that help to achieve the goals of the intelligent system design on the environment. In general, each working environment has specific goals for the stakeholders to develop or improve the business model or realize the sustainability of the business.

Therefore, all the principles support the utilizing of the intelligent lighting system in the working office. Each office considers the application of the intelligent lighting system for each worker. The intelligent lighting system contributes to boosting the office ecosystem design needs.

Each environment has specific goals for the stakeholders to develop or improve the best performance and increase the intellectual productivity of the environment. The concepts of reality, existence, and knowledge are the main issues of the system design that used to the circle philosophy needed for boosting an ergonomic system on the workspaces.

## 9.1 Beyond the Smart Lighting Development

A good lighting system in a workplace can have a significant effect on the performance of environment, as well the quality of lighting can play a main role to the productivity of workers. The stage after the smart lighting involves the system with some automation process and connects with control modules such as the computer or the smartphone devices. The stage after the smart lighting involves the system with some automation process and connects with control modules such as the computer or the smartphone devices.

The automated lighting control system hires the computerized system to adjust the level of lighting on the workspace. The automated model of the lighting system could probably be at the same level as the smart lighting control system. However, automated lighting is more related to connecting with the computer module and the dimming process of luminance intensity. Combining smart lighting control and the automation process becomes useful for office design. However, more efficient energy savings and employing an ergonomic system require the implementation of an advanced model of the lighting control systems, as known as the intelligent lighting systems

The conventional intelligent lighting system and the new model of the system depend on utilizing the computerized lighting control system and hiring the innovative technology to control the properties of the lighting system inside the office. For instance, the intelligent lighting system may hire the internet of things technology technology to provide the level of illuminance intensity for each worker inside the office.

The office space is the best practice of the intelligent lighting system, as the system has affected all the stakeholders and the workplace environment. The system effect becomes to each worker, the energy consumption of the workplace, and ergonomic office design to keep the users feeling well during the work in the office. However, the intelligent lighting system has the best practice of the ergonomic system for each worker and a part of the ecosystem for the work office.

The ecosystem work office revolves around the study of the worker data, and how the intelligent system design like the intelligent lighting system is affected by the feedback or the data of the worker. The philosophy of implementing the intelligent lighting system in the office is still developing and growing based on the working office designs, which are expanding and increasing the requirements of the work. The concept has a big challenge to apply in the office, and it has other complicated factors that should be considered by each office individually.

## 9.2 Development & Future Works

In the intelligent system, a lot of emerging techniques are appearing by the time to support the daily life of people. The first future work which can guide these ideas is merging the new technology with the intelligent lighting control system to create intelligent lights controllers for a variety of applications by using the mobile application, or wireless technology to control the system in a different way.

The second one, using biological information of workers is highly recommended to specify the favorite values of users. Biological information like human eyes or hand movement will help to develop intelligent lighting systems more dynamic and flexible which will be healthy for each user.

Finally, using a new method for optimization of machine learning and the artificial intelligent approaches are recommended for the estimation parts of intelligent lighting elements which help to save the energy, or may lead to consider more about biological information to study more the behavior of users in interacting the intelligent lighting system.

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# Appendixes & Annexes

## A. Calculating & Measurement Sensing Device Data

Table 9-1 illustrates the data sensing devices for the experiments in different cases and different situations using the calculated and measured lighting methods.

*Table 9-1: The data of the sensing devices for calculated and measured values with target values in details.*

| | **Target Values** | | **Simulation** | | **Measurement** | |
|---|---|---|---|---|---|---|
| | $E$ | $CCT$ | $\hat{E}_1$ | $\widehat{CCT}_1$ | $\hat{E}_2$ | $\widehat{CCT}_2$ |
| Sensor 1 | 450 | 4000 | 470.81 | 4482.95 | 487 | 4270 |
| Sensor 2 | 300 | 4200 | 316.36 | 4019.73 | 279 | 3709 |
| Sensor 3 | 500 | 4300 | 487.14 | 4351.72 | 480 | 4069 |
| Sensor 4 | 700 | 4800 | 724.68 | 4645.89 | 710 | 4434 |
| Sensor 5 | 600 | 3300 | 582.28 | 3472.99 | 564 | 3307 |
| Sensor 6 | 550 | 3700 | 561.89 | 3696.45 | 553 | 3480 |
| Sensor 7 | 700 | 3200 | 644.39 | 3557.5 | 679 | 3401 |
| Sensor 8 | 500 | 4200 | 493.36 | 4116.29 | 485 | 3865 |
| Sensor 9 | 600 | 4300 | 591.74 | 4095.24 | 607 | 3852 |
| Sensor 10 | 500 | 3700 | 480.46 | 3715.75 | 477 | 3592 |
| Sensor 11 | 300 | 3500 | 316.03 | 3756.98 | 322 | 3590 |
| Sensor 12 | 350 | 4100 | 339.35 | 4066.11 | 348 | 3925 |
| Sensor 13 | 700 | 4800 | 598.98 | 4180.43 | 607 | 3944 |
| Sensor 14 | 500 | 3500 | 456.59 | 3476.91 | 413 | 3254 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Sensor 15 | 300 | 3100 | 394.99 | 3763.75 | 410 | 3583 |
| Sensor 16 | 200 | 4100 | 233.82 | 3972.8 | 261 | 3738 |
| Sensor 17 | 300 | 3200 | 348.68 | 3404.94 | 353 | 3311 |
| Sensor 18 | 500 | 3500 | 490.62 | 3363.5 | 494 | 3264 |
| Sensor 19 | 300 | 4850 | 298.8979 | 4699.59 | 301 | 4701 |
| Sensor 20 | 500 | 4850 | 483.3693 | 4754.25 | 493 | 4755 |
| Sensor 21 | 600 | 4850 | 596.9527 | 4699.88 | 584 | 4853 |
| Sensor 22 | 400 | 4850 | 394.1087 | 4705.34 | 402 | 4697 |
| Sensor 23 | 300 | 3500 | 366.2299 | 3562.628 | 363 | 3527 |
| Sensor 24 | 500 | 4000 | 500.2331 | 4004.85 | 495 | 3965 |
| Sensor 25 | 700 | 4500 | 700.3118 | 4493.34 | 693 | 4448 |
| Sensor 26 | 500 | 4000 | 471.9262 | 4078.82 | 467 | 4038 |
| Sensor 27 | 500 | 4000 | 558.879 | 4066.931 | 553 | 4026 |
| Sensor 28 | 500 | 3700 | 644.91 | 4030.425 | 638 | 3990 |
| Sensor 29 | 500 | 3500 | 623.1763 | 4112.495 | 617 | 4071 |
| Sensor 30 | 500 | 4500 | 524.5293 | 4321.745 | 519 | 4279 |
| Sensor 31 | 300 | 4500 | 460.9099 | 4395.44 | 456 | 4351 |
| Sensor 32 | 300 | 4500 | 357.3291 | 4421.422 | 354 | 4377 |
| Sensor 33 | 500 | 4500 | 485.5391 | 4214.873 | 481 | 4173 |
| Sensor 34 | 500 | 4500 | 587.5277 | 4228.207 | 582 | 4186 |
| Sensor 35 | 700 | 4500 | 679.4866 | 4241.551 | 673 | 4199 |
| Sensor 36 | 500 | 4500 | 681.1897 | 4295.405 | 674 | 4252 |
| Sensor 37 | 700 | 4500 | 616.1166 | 4430.847 | 610 | 4387 |
| Sensor 38 | 500 | 4500 | 550.165 | 4479.396 | 545 | 4435 |
| Sensor 39 | 300 | 4500 | 415.5011 | 4480.026 | 411 | 4435 |
| Sensor 40 | 300 | 4500 | 344.8421 | 4425.051 | 341 | 4381 |
| Sensor 41 | 300 | 4500 | 425.5573 | 4473.28 | 421 | 4429 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Sensor 42 | 700 | 4500 | 508.4289 | 4529.57 | 503 | 4484 |
| Sensor 43 | 500 | 4500 | 519.797 | 4551.636 | 515 | 4506 |
| Sensor 44 | 500 | 4500 | 495.4743 | 4581.379 | 491 | 4536 |
| Sensor 45 | 500 | 4500 | 451.3235 | 4585.155 | 447 | 4539 |
| Sensor 46 | 500 | 4000 | 439.0339 | 4014.939 | 435 | 3975 |
| Sensor 47 | 300 | 4000 | 466.0144 | 3855.422 | 461 | 3817 |
| Sensor 48 | 500 | 3700 | 545.4031 | 3743.252 | 540 | 3706 |
| Sensor 49 | 700 | 3500 | 554.8999 | 3841.583 | 549 | 3803 |
| Sensor 50 | 500 | 4500 | 571.1354 | 4237.13 | 565 | 4195 |

## B. Tools and Equipment

All tools and equipment which have been used in the environment as below:

1. Chroma meter: Konica Minolta Ltd products.
2. LED Lighting fixture: Panasonic Ltd products.

**Quotes** "…"

However, the combination of concepts, tools, and techniques used generates additional features that enhance the lighting control system in the office work environment. For instance, the intelligent lighting system came from the integration of automation processes with intelligent methods. There are limited additional features generated, and in the intelligent lighting system, optimization processes based on intelligent automation increase the effectiveness of the lighting control system. The optimization process finds the best case for using the lighting system in the office to achieve the target of each worker and stakeholders.

The automation processes make each worker in the office to obtain the desired lighting and the illuminance target needed. The automation development of lighting operations is part of the automated and adaptive lighting systems in the office work areas.

The computerized methodologies depend on reducing the gap between the target required for each worker and the illumination level available to the worker on the desk. Also, intelligent approaches are based on analyzing behavior and worker data for realizing the desired lighting needs. Thus, the lighting control system adjusts the brightness levels based on the occupancy status and the presence of the worker in the office. In this case, the lighting system can maintain the required lighting levels and reduce energy consumption in the office.

On one side, wireless technology enables smart and easy access to system automation. The integration of technology with intelligent lighting systems makes the user interaction to become more dynamic and flexible with other system components. Though instantly, the worker has access to control the lighting system in the office, the worker has the availability to control the lighting system remotely with the smartphone through the wireless technology dynamically and flexibly.