LIGHTING ENCLOSED INTERNAL CORRIDORS BY BORROWED DAYLIGHT

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by

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May Allah reward all of you......!

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LIST OF ABBREVIATIONS

C	Celsius
cm	Centimetre
DF	Daylight Factor
FC	Foot Candle
IESNA	Illuminating Engineering Society of North America
CIE	International Commission on Illumination
lx	Lux
m	Metre
m/s	Metre Per Second
mm	Millimetre
OFCM	Office of the Federal Coordinator Meteorological
SQM	Square Metre

MENERANGI KORIDOR DALAMAN TERTUTUP DENGAN CAHAYA SIANG YANG DIPINJAM

ABSTRAK

Koridor dalaman tertutup adalah ruang sirkulasi yang panjang tanpa dibekalkan dengan tingkap, dan ia memerlukan pencahayaan buatan untuk dibekalkan 24 jam untuk kekal beroperasi. Bergantung kepada reka bentuk mereka, sesetengah koridor mempunyai bukaan di kedua penghujungnya, manakala yang lain mempunyai bukaan di bahagian tengah. Kebanyakan bahagian koridor ini sentiasa dalam keadaan gelap dan menggunakan banyak tenaga yang tidak boleh diperbaharui untuk pencahayaan buatan. Kajian ini meninjau bagaimana koridor dalaman tertutup boleh mendapat manfaat dari cahaya siang tertakluk kepada reka bentuk dinding koridor terbabit. Ia meninjau bagaimana nilai % DF (Faktor cahaya siang) yang kurang dari 1% terutamanya di Malaysia yang mempunyai langit yang cerah masih boleh memberi manfaat dan amat berguna. Piawaian pencahayaan untuk koridor menjadi penanda aras dan kajian lapangan mengukur %DF di beberapa titik terpilih di sebuah koridor tertutup bangunan asrama telah diambil pada hari yang cerah dan berawan. Model berskala dibina untuk dikaji dalam langit buatan untuk mendapat bacaan yang setara diikuti dengan simulasi menggunakan perisian Radiance. Keputusan menunjukkan kesemua bacaan menentukur dengan baik membandingkan dengan kajian lapangan dengan perbezaan kurang dari 10%. Dinding koridor kebiasaannya adalah legap mengakibatkan situasi yang sangat gelap dan bergantung sepenuhnya kepada cahaya buatan. Kajian ini seterusnya menilai sejauh mana cahaya siang boleh dipinjam untuk menerangi koridor dalaman tertutup. Ini dibuat dengan mengkaji beberapa jenis reka bentuk dinding koridor dengan menambahkan kawasan lutsinar dan kaca untuk membolehkan penembusan cahaya siang berlaku. Kajian ditambah dengan beberapa alternatif mendatar dan menegak. Impak reka bentuk koridor yang baharu dikaji menguunakan simulasi Radiance. Ia dibandingkan dengan kajian asal iaitu koridor yang biasa. Dapatan menunjukkan yang reka bentuk dinding koridor yang baharu dapat memperbaiki tahap pencahayaan pada koridor tertutup dengan signifikan. Walaupun peningkatan %DF sangat rendah dan minima, ia masih memberi manfaat kepada pencahayaan di koridor kerana pencahayaan di luar yang sangat tinggi. Dinding koridor dengan reka bentuk 50% kaca melalui empat jalur mendatar didapati reka bentuk yang terbaik untuk membenarkan cahaya siang untuk dipinjam.

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LIGHTING ENCLOSED INTERNAL CORRIDORS BY BORROWED DAYLIGHT

ABSTRACT

Enclosed internal corridors are long circulation areas with no window provisions, and they require electric lighting to be switched on for 24 hours continuously to operate. Depending on the designs, some corridor designs have openings for daylight at the ends, while others supplement daylight at the middle. Most parts of these corridors, however, are usually dark and consuming a lot of non-renewable energy from artificial light. This research explores how enclosed internal corridors could get the benefits of daylight depending on the corridor wall designs. It explored how %DF (Daylight Factor) less than 1%, especially in Malaysia where the skies are bright, could still be beneficial and useful. The standard illumination required for corridors is benchmarked. Fieldwork for %DF measurements was conducted in selected points at an enclosed corridor of a hostel building on a typical overcast day. A scaled model of similar design was built and experimented with in the artificial sky to get the same set of readings; followed by simulation using Radiance. Results showed that the readings calibrate well between fieldwork compared to the scaled model and simulation, with less than 10% differences. Corridor walls are usually opaque resulting in very dark situations relying solely on artificial lighting. The study further investigated the extent of daylight that can be borrowed to illuminate the internal enclosed corridors. This was carried out by experimenting on the various types of corridor wall designs with added transparent or glazed areas to enable daylight penetration. The designs experimented with various horizontal and vertical alternatives. The effects of these new corridor wall design on daylight distribution in corridors are investigated by Radiance simulations. Results were compared to the normal base case. The findings showed that the newer designs of corridor walls could provide daylight to corridors with significant levels of improvements. Even though the %DF found were very low, outdoor illuminance in tropics is high therefore it was sufficient for corridor lighting. Corridors with 50% glazed areas in a four strips horizontal design were found to perform the best for allowing borrowed daylight to occur.

CHAPTER 1

INTRODUCTION

1.1 Introduction

A corridor is typically a narrow hallway or gallery connecting different parts of a building and has an entry point to all rooms located along the corridor (Luckhurst, 2019). In the late 17th century, corridors became common in building design regardless of corridors are found in many modern buildings. It was found that corridors were commonly introduced to buildings in the 19th century. Before that, people would flow or walk from one room into another (Neufert, E., 2012).

Socio-economic factors and evolving moral attitudes were found to be the main reason behind the propagation of corridors in buildings. Corridors were used to separate building's occupants, such as supervisors from workers, guards of prisons from prisoners, and so on. Privacy can be created by using corridors; therefore, it was no longer required to go through rooms but only corridors can be used to enter rooms (Mardaljevic, 2000). Besides, the efficiency of energy could be improved by corridors when people travel and move inside buildings.

The functions of the building primarily determine the design of the corridors. For example, corridors in hospitals required to be wide enough to smoothly allow the bi-directional flow of circulation, including wheelchairs and beds. Meanwhile, corridors in a hotel must be strong enough for baggage wheels and trolleys. Besides, to avoid dark corners and allow smooth circulation, natural light should be introduced to corridors using windows or illuminated by artificial lighting (Freewan, 2016).

Current studies in architecture design towards sustainable design imply practising green buildings (resource management, energy efficiency, passive design, renewable energy, etc) and producing a healthy environment for people (air quality, non-toxic materials, and occupant health) (McDonough, 2002). However, modern designs of large buildings, including office buildings, typically contradict these concepts.

Office buildings usually have deep plans corridors or large floor areas that rely almost entirely on electricity for lighting and air conditioning (McDonough, 2002). During daylight hours, when most office buildings are in use, electrical usage is highest when there is also the greatest abundance of natural light for lighting (Hawkes & Forster, 2002). This, therefore, results in a paradox as natural light should have been better utilised.

As a result, most office employees spend daytime hours almost fully exposed to artificial light. While artificial light provides adequate levels of illumination for visual tasks, it cannot provide the physiological and psychological benefits of natural light, and it is becoming increasingly proven that there are significant workplace health and productivity issues for artificially lit buildings (Boyce, 2004).

This study assesses the effect of borrowed daylight technique and investigates a new passive daylighting solution to bring natural light into deep plan buildings. The system proposed is using a translucent material which ~~are~~ can reflect, absorb, and diffuse the light into space, optimizing daylight comfortably.

However, corridors are often dark spaces and completely dependent on artificial lighting for 24 hours per day. Therefore, this consequently leads to a huge increase in energy consumption that has several direct and indirect harmful effects such as unhealthy and infertile environments, non-energy-efficiency, production of greenhouse gases and the use of non-renewable resources for the occupants of the building.

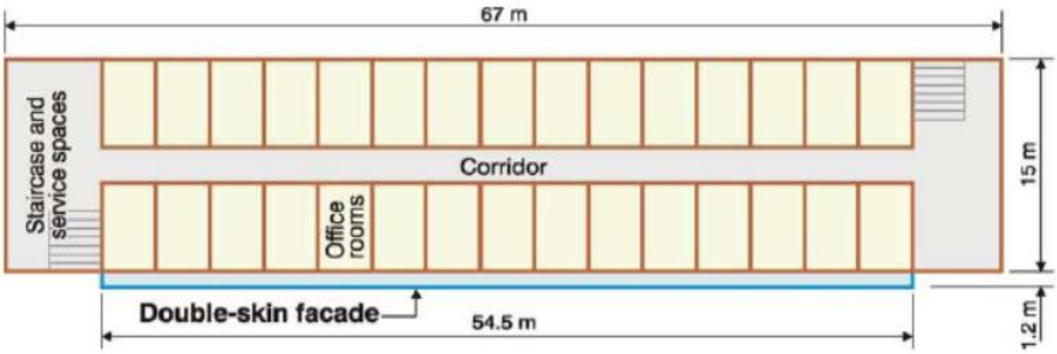

Figure 1.1 Building plan with an enclosed corridor

Source: (McKay, n.d.)

Due to the rising demand for energy utilization and the need for energy-saving, daylighting has been considered a key element in buildings' design and construction. A major challenge for architect/designer is to provide sufficient natural lighting into deep spaces of buildings. The main concern is how to bring daylight into the deep areas of office buildings to improve the visual comfort of office workers in workplace conditions and improve energy efficiency in indoor corridor spaces.

The energy used for lighting can be reduced by lessening the usage of indoor artificial lighting and optimize daylighting instead. One of the strategies used to optimize daylighting is the borrowed daylight technique. Borrowed daylight technique is mainly related to the illumination of an enclosed internal space using a window connected to an adjacent space with direct natural lighting.

However, less amount of daylight is provided into the internal space using this technique, a connection with the outside can be provided by the borrowed daylight technique. Besides, this technique can be useful when the required lighting in the internal space is lower than in the adjacent room with daylight such as corridors. Therefore, the purpose of this study is to examine how lighting internal corridors can be achieved by the borrowed daylight technique.

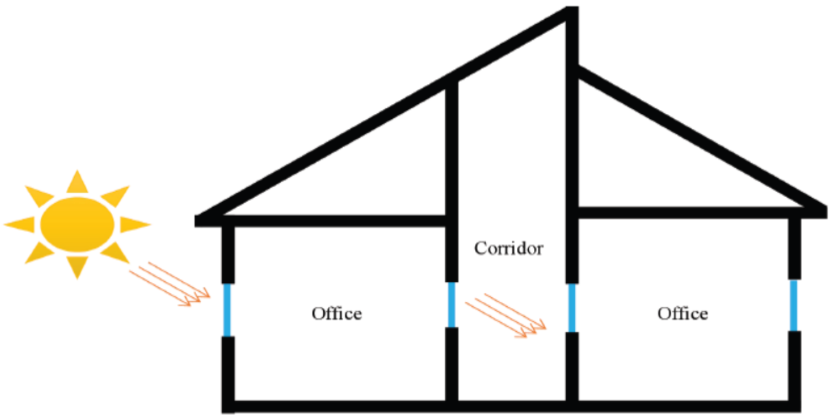

Figure 1.2 Borrowed Light with an enclosed corridor

Source: (WENDEL, n.d.)

1.2 Problem Statement

Corridors are the vital network inside buildings for people to move around. Besides that, they can also be part of the functional spaces such as for displaying artworks or awards. Therefore, corridors must be optimally illuminated to ensure safe orientation and movement within the space. However, most of today's corridors are often long, dark, and gloomy and this may lead to employees tripping and falling in some cases. For example, this could be occurring in emergencies when the main power supply is cut, and artificial illumination fails.

On the other hand, one of the major components of total energy consumption in buildings is the energy used by artificial lighting systems. Figure 1.3 demonstrated that about 20% of total energy consumption is related to the energy used by artificial lighting systems. Therefore, the proper implementation of daylighting principles during the initial design stage will reduce the usage of artificial lighting and improve the performance of the building as the cooling load decreased and consequently the energy consumption of the building is reduced.

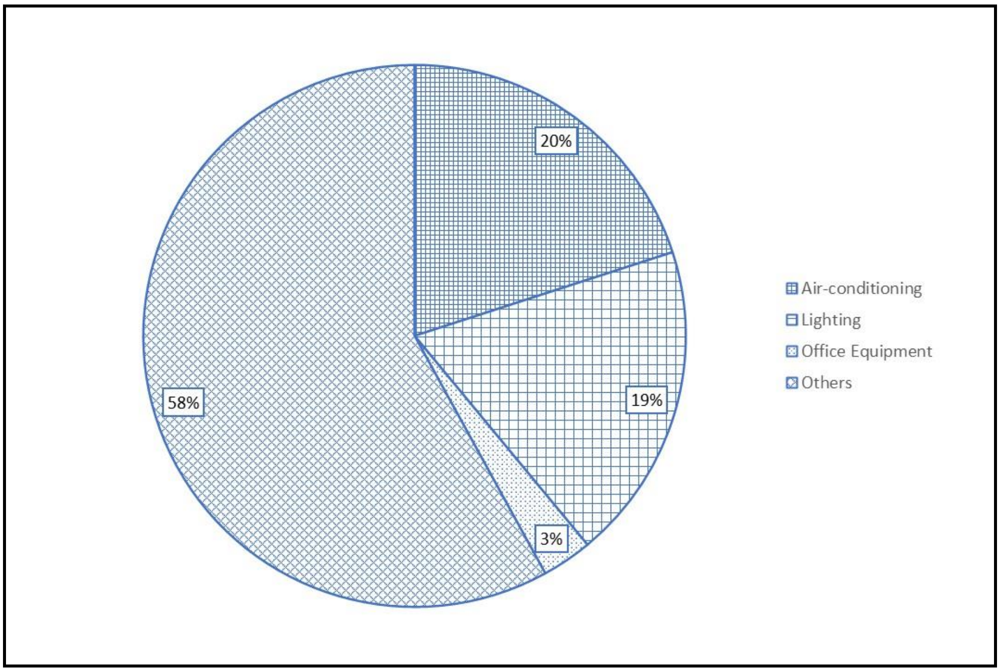

Figure 1.3 Energy consumption components in office buildings in Malaysia
Source: (Energy Commission, 2016)

The top lighting strategy from skylights is used in high-rise buildings to provide better distribution of daylight levels in the space. But, only the top floor of a building can be illuminated by skylights. Artificial lighting for illumination is required for corridors at further distances from the passive zones.

Moreover, most of today's lighting systems are designed to adjust to the corridor, other than just being turned on or off. This is because corridors are often viewed as more than just passageways into other areas of the building. However, hallways are not considered concerning its interior design, specifically its interior lighting.

Illuminating daylight into deep spaces such as long corridors or the core of a building is one of the essential characters of architectural design. It is an effort to increase energy-saving and at the same time improve the occupants' health and well-being.

This research intends to experiment with methods on how enclosed corridors can use borrowed daylight to solve the problem of the complete reliance on artificial light. In addition, this research also intends to solve the problem of how-to bring daylight into deep spaces to enhance the conditions of the workplace for buildings' occupants as well as reduce energy consumption.

The fact is that some innovative daylighting techniques can provide daylight further to the deep spaces in buildings. Therefore, this study focuses on providing daylight into internal enclosed corridors with better quality and quantity using borrowed daylight technique.

This type of research aims to meet global design goals for green architecture through the reduced dependence on electricity and most importantly, to create healthier work environments for their occupants. The new findings provide insights for architects, engineers, and scientists in the built environment to achieve the full potential of the borrowed daylight technique in visual comfort as well as energy saving.

1.3 Objectives of the Study

This study mainly aims to prove there are opportunities to utilize borrowed daylight to the internal corridors. This study also examines the effect of borrowed daylight on the design of the dark corridors in buildings. The main objectives of this study are to:

1) To identify the extent of daylight levels which can be borrowed from the external walls with windows to illuminate the internal corridors.
2) To improve the level and distribution of daylight via corridor wall.
3) To determine the extent of daylight factor (DF) that is acceptable for corridor light.

1.4 Research Questions

The research questions were specified according to the proposed research objectives and they are:

a) What is the range of daylight illumination levels which can be obtained from a borrowed daylight technique to light the corridor?
b) What is the role of corridor interior design in improving the level and distribution of daylight into internal corridor?
c) What is the extent of daylight factor (DF) that is acceptable for corridor light?

1.5 Research Methodology

The methodology of research used is experimental research with simulation modelling (radiance). The experiments are conducted at the environmental laboratory of the Universiti Sains Malaysia (USM) using the artificial sky. Fieldwork measurements are carried out for validation of research.

1.6 Significance of the Study

Recently, innovative ideas for daylighting have been a widely hot topic in scientific research areas. Borrowed daylight is a system that provides daylight via windows glass or transparent materials, a design technique that allows daylight from exterior windows to be filtered into interior dark spaces of buildings. Therefore, this research is essential to improve borrowed daylight for internal corridors of deep buildings in tropical regions particularly Malaysia as the selected location for this study.

The recommended strategy can improve the visual comfort of the building's occupants and result in better productivity and performance. Additionally, energy consumption by the usage of artificial lighting can be reduced by optimum borrowed daylight.

1.7 Limitation of the Study

This study focuses on the efficiency of daylight in double-loaded corridors of the long building by using borrowed daylight technique and the borrowed daylighting systems are studied under the artificial sky. Besides that, this research focuses on how borrowed light can be utilised under the worst sky conditions which are the overcast sky. Therefore, clear, and intermediate sky conditions will not be used for the study.

The area of current studies is specified for daylight in long corridors as they are vital to achieving a better visual environment. Daylighting should be highly considered to be used more efficiently in this type of corridors. Two research methods are employed in this study. These methods are the physical scale model and the modelling simulation process. The study requires the corridor walls to go through extrusive modification which requires time and many permissions from building owners.

1.8 Thesis Outline

The thesis comprises five chapters which are organized as follows:

Chapter One: This chapter presents an introduction and general overview of the topic of this study. It highlights the problem statement, the scope and limitation of this study, research objectives, and the significance of this study. It also provides a brief on the outline of the chapters of this study.

Chapter Two: A review of the daylight theory is discussed in this chapter to provide an understanding of the basic principles of light and human vision. Additionally, the components of daylight and expected benefits from efficient use of daylight, as well as advantages and disadvantages of daylighting are discussed. Design strategies for borrowed daylight are discussed to provide an understanding of the method. Elaborate literature from previous researchers on daylight in deep spaces of buildings provide the opportunity to propose the improved borrowed light for an office building and may benefit when being studied and designed.

Chapter Three: This chapter discusses the proposed methodology used in this study. It includes lighting measurement in a physical scaled model and modelling and simulation for daylight using the proper software.

Chapter Four: This chapter presents the results including the validation process of daylighting results of the simulation model and the physical scale model.

Chapter Five: This chapter presents and main conclusions of this study and proposes recommendations and suggestions for future research.

Figure 1.4 below explains the framework of the research which has altogether five phases that will be elaborated in the coming chapters.

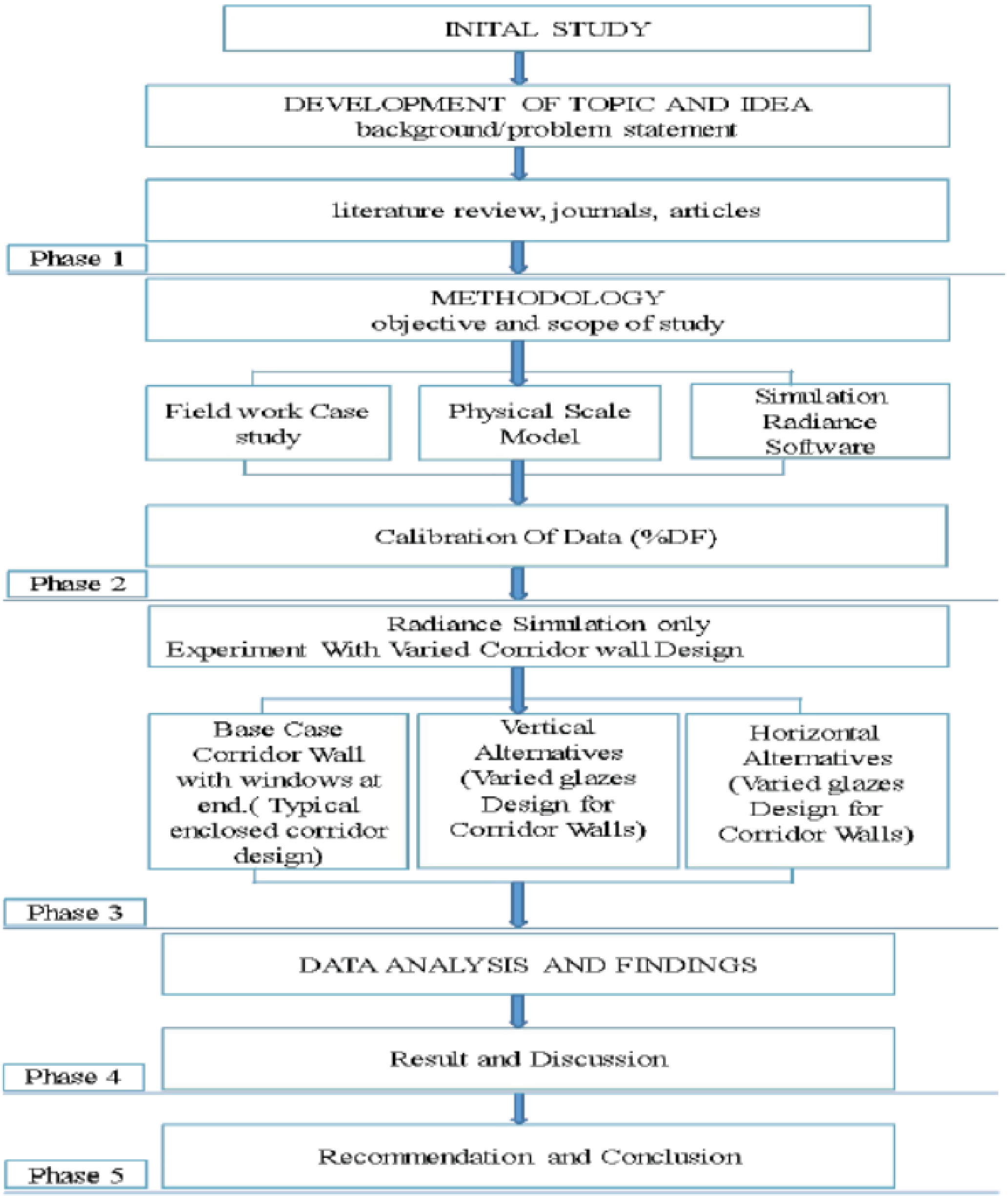

Figure 1.4 Research framework

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A review of daylight design in office building design and the main principles of daylighting systems are presented in this chapter. Besides, the theory of light is highlighted in this chapter to provide an understanding of light characteristics and vision. In addition, the components and the advantages and disadvantages of daylighting are discussed.

The next section consists of the definitions of corridors, interior design, elements, and envelopes in interior design. The types of lighting in corridors are highlighted and the consideration of lighting design is explained. Finally, the lighting requirements for corridors are discussed.

2.2 Building and Daylighting

The envelope of a building comprises everything that separates the building interior from the outdoor environment, including the walls, roof, windows, and floors. Windows admit daylight to spaces and provide a direct view and connection with the outside environment. Therefore, it is important to provide acceptable conditions of daylight in buildings. This can be achieved through the proper design of windows including different windows design elements. This includes the window position, window area and window shape, and materials. Moreover, the proper integration of daylight can reduce the use of artificial lighting and consequently, helps decrease total energy consumption (Majumdar, 2001).

2.2.1 Lighting Definition

Lighting can be defined as the electromagnetic spectrum part that is visible by human eyes and has wavelength values between 780 and 380 nm. See Figure (2.1) (ZUMTOBEL, n.d.).

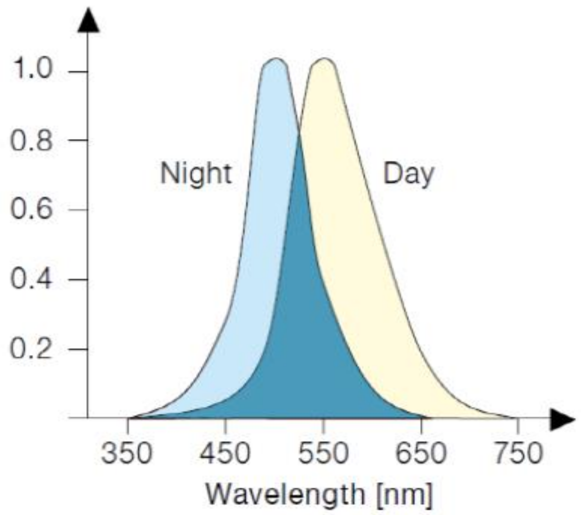

Figure 2.1 Wavelength range for lighting

Source: (ZUMTOBEL, n.d.)

Figure 2.2 shows that infrared radiation is beyond red and it is invisible to the human eye and detected as heat. Ultraviolet radiation is at the end of the visible spectrum and beyond the violet. It is also invisible and causes damage to the eye, the skin and various fabrics. Then, the visible wavelengths represent the white light which breaks up into its constituent colours (Philips, 2008).

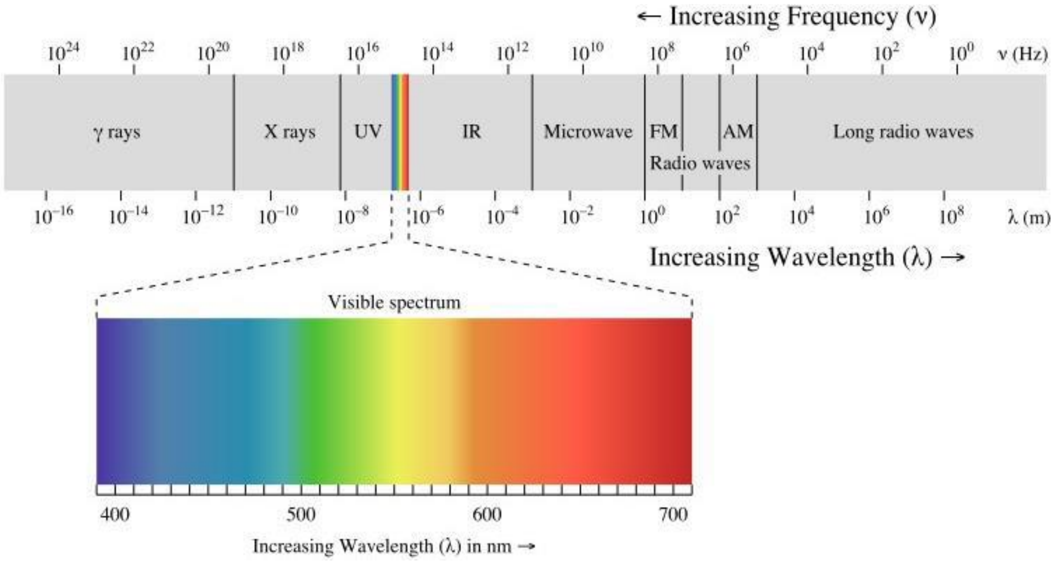

Figure 2.2 The electromagnetic spectrum

Source: (Cummins, 1983)

Quality of lighting is a target of excellence that lighting designers, architects and engineers are eager to achieve. There is currently no clear definition of the term lighting quality that is recognized by official institutions. Nevertheless, through discussion in their papers, several researchers have tried to make this definition simple and more understandable (Veitch, 2005; Dehoff, 2014). It can be inferred by generalizing different methods that the definition of lighting quality involves mainly the parameters relevant to human needs, economics, the environment, and architecture. (See Figure 2.3).

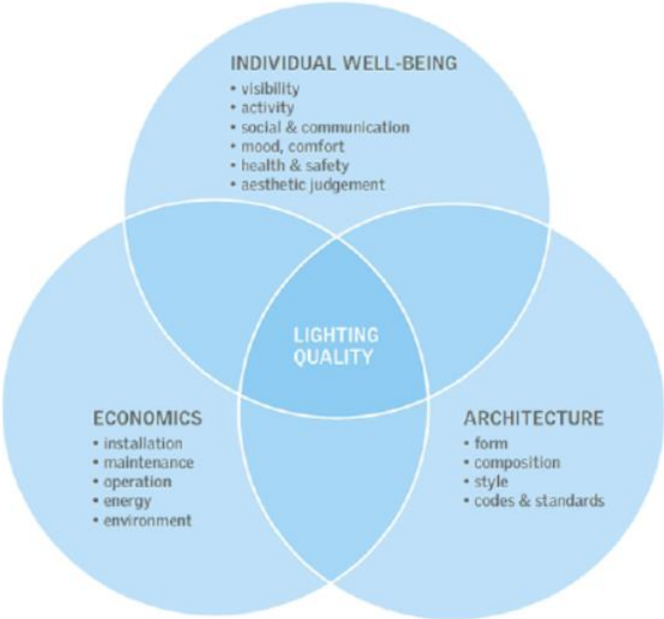

Figure 2.3 Lighting Quality: the integration of individual well-being, architecture, and Economics

Source: (Veitch, 2005; Dehoff, 2014)

The right combination of these dimensions helps to achieve good quality lighting (Veitch, J. A., 2005). The CIE (Veitch et al., 1998) acknowledged this definition of the term lighting quality and it is also represented in The IESNA Lighting Handbook: Guide & Application (Rea, M. S., 2000). Besides, due to the mutual relationship of light with forms, the lighting quality is a deciding factor in the appearance of the forms and spaces (Katunský, & Dolníková, 2017).

Even though the amount of artificial light may be measured because the perceived appearance of shapes differs from person to person, the quality of light is also regarded subjectively in many studies. Some variables need to be understood in this context which affects the quality of light through perception in space as listed below:

- Size: The amount of light and the intensity of light that illuminates a certain volume is influenced by the size and number of light sources. A light source's size can lead to shadow variations. The effective size of a light source depends on both the physical size and the location and distance of the light source concerning objects or spaces (Bhusal, et al., 2006).
- Position: About its distance from exhibits, the spatial position of a light source influences the quantity of light and its angle and direction. Light created from luminaires near an illuminated surface referred to as "grazing light," enhances the highlights and shadows (Gordon, 2015; Phillips, 2000).
- Colour: Light source colour influences the quality of light in a space. The use of a natural colour (e.g. white) in interiors often influences the perceived light quality; the fact associated with daylight is added (Bhusal, et al., 2006).
- Direction: The direction and distribution of light in interior spaces can alter the perception of surfaces and objects (Gordon, 2015).

According to Gordon (2015), luminaires are characterized by the way light is distributed:

a) Direct distribution: Describes light leaving a fixture and entering the illuminated space without first bouncing from any architectural elements such as the ceiling or walls.
b) Semi-direct: A light distribution pattern in which 60% or more of the light is directed downward and 40% or less is directed upward.
c) Direct/indirect: A light distribution pattern or luminaire in which 40–60% of the light is directed downward and upward.

d) Semi-indirect: A light distribution pattern in which 40% or less of the light is directed downward and 60% or more is directed upward.

e) Indirect: A light distribution pattern in which all the light is directed upward to bounce off the ceiling.

f) Diffuse: A light distribution pattern in which light is dispersed in all directions.

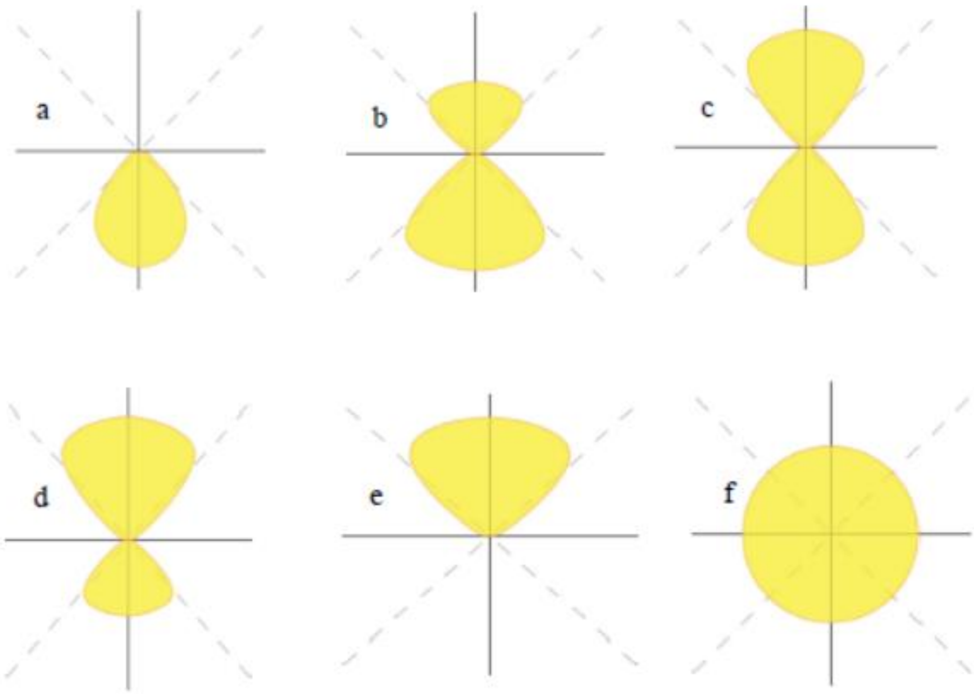

Figure 2.4 Lighting distribution types

Source: (Gillette & McNamara 2019)

2.2.2 Basic Parameters used in Lighting

There are four basic photometric quantities that lighting professionals use for light measurement as shown in Figure 2.5. They can be briefly defined as follows:

1- Luminous flux

It is the total quantity of light radiated from a light source per second. Luminous flux is measured in *lumen (lm)*

2- Luminous intensity (I)

It is the light flux emitted from a light source in a specific direction. C*andela (cd)* is the luminous intensity measurement unit.

3- Illuminance (E)

Illuminance or illumination level is the amount of light that is received on the unit area of the working surface. Illuminance is measured in lumen/m^2, or *lux (lx).*

4- Luminance

It is the light emitted from a surface in a specific direction. luminance is measured in *cd/m2* (Philips, 2008).

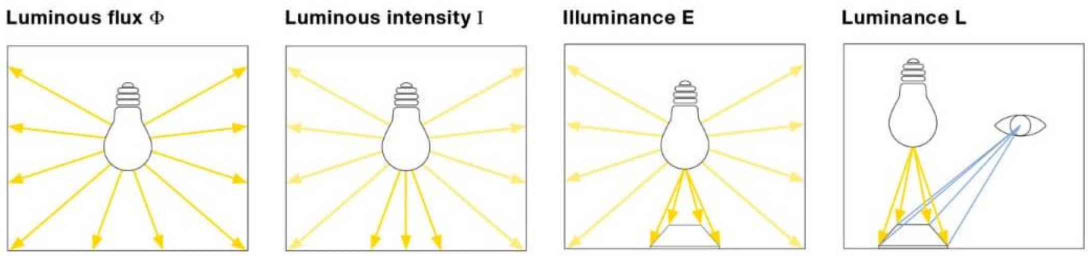

Figure 2.5 Basic parameters used in lighting

Source: (Philips, 2008)

2.2.3 Daylighting

Daylight is a light source that can create a pleasant visual environment for the building's occupants as well as minimize energy consumption when properly utilised. According to the Illuminating Engineering Society of North America (IESNA), daylighting is a technique to admit daylight into space to achieve a suitable illumination level to perform the intended function in this space. A visually stimulating and productive environment for the building's occupants can be achieved by good daylighting design (Husin & Harith, 2012).

Daylighting can be also defined as is the proper use of direct, reflected, or diffused natural light to partly or fully illuminate or the interior spaces in buildings (Abboushi, 2013). According to Reinhart and Galasiu (2006), as cited in (Reinhart et al., 2006), the focus of different professions on different daylighting aspects is one of the major difficulties of good daylighting determination. Five sample lists of daylighting definitions were reported by participants of a survey that addressed the use of daylighting in sustainable building design (Reinhart & Galasiu, 2006).

1) Architectural definition: the manipulation of building form and natural light attributes to provide an interior environment with visually stimulating, productive, and healthy conditions.
2) Lighting Energy Savings definition: using daylight as a replacement for artificial lighting to illuminate the indoor spaces, resulting in a reduction of lighting energy consumption.
3) Building Energy Consumption definition: reduce overall required building energy (lighting, cooling, heating) through the proper design of fenestration systems integrated with a responsive lighting control system.

4) Load Management definition: manage and control building loads and electric demand through the control of the fenestration system and lighting systems.
5) Cost Definition: reduce the operational costs and increase productivity, output, or sales by the efficient design and integration of daylighting strategies.

The objective of daylight design is to supply visual variety with controlled brightness contrasts in which variety is a principal characteristic of daylight. The cleanliness of the atmosphere is depicted via the inter reflection of surrounding objects. It affects the change of colour of daylight which changes with time. Besides that, time of day, the time of year and the latitude of the site are the main factors that affect the intensity of sun variations.

The amount of daylight passing within a space is influenced by (Phillips, 2004):

- Space geometry, planning, and orientation.
- The fenestration orientation and dimensions which natural light will pass through. Figure 2.6 shows the type of opening.
- The interior surface characteristics and location of partitions may affect the daylight reflection and distribution.
- The shading devices form, dimensions, and location can protect from too excessive light and unwanted glare.
- The glazing materials thermal and visible properties.

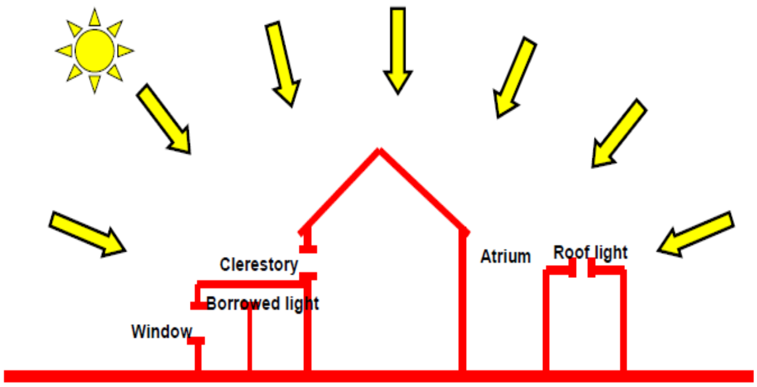

Figure 2.6 Type of opening in a building's

Source: (Phillips, 2004)

2.2.4 Daylight Factor

Daylight factor values are utilized to measure and evaluate the required illumination levels resulted from natural lighting in a space for the users to perform their daily activities. It is the ratio of internal illumination level to the external illumination level and defined as follows:

· Ei = illumination level at a point on the working plane due to daylight,

· Eo = outdoor illumination level on a horizontal plane from an unobstructed overcast sky (Shikder et al., 2010).

DF = (Ei / Eo) x 100%

2.2.5 Daylighting Sources

Daylight sources may be classified as

- **Direct** (includes direct and diffuse sunlight).

➢ **Indirect** (include reflected or transmitted light from reflective or translucent diffusers).

2.2.6 Components of Daylight

It is essential to understand the components of daylight for the design of windows and opening and material selection. There are three components of daylight illuminance:

❖ **Sky Component (SC)** - Directly from the sky, through an opening such as a window.

❖ **Externally Reflected Component (ERC)** - Reflected off the ground, trees, or other buildings.

❖ **Internally Reflected Component (IRC)** - The inter-reflection of 1 and 2 off surfaces within the room.

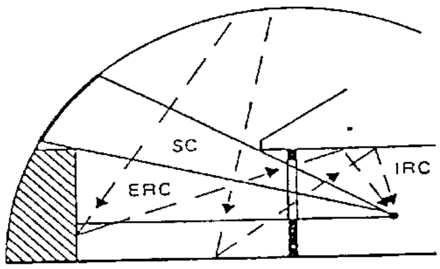

Figure 2.7 Components of Daylight.

Source: (Szokolay, 2004)

2.2.7 Benefits of Daylight in Buildings

The proper design and integration of natural light in buildings can result in different advantages and benefits. This includes the aesthetic aspects as well as economic and physiological aspects.

Various benefits can be achieved from daylighting, such as daylighting can significantly reduce energy consumption. According to Boyce et al. (2003), artificial lighting may result in redundant electricity usage. Thus, the concerns are to find appropriate sustainable alternatives that can reduce energy consumption. Two prospects suggested by Boyce et al. (2003) to reduce lighting energy consumption are: 1) Mainly using daylight and 2) Energy-efficient lighting technology should be developed.

Natural lighting is perceived to have significant advantages on people and the indoor environment. These advantages include significant savings in the cost of energy used, as well as improving indoor visual comfort. Moreover, it is described as the optimal lighting source as it is the only light source that closely matches human visual response and it has good colour rendering (Li & Tsang, 2008). As daylight transmitted to space, a pleasant atmosphere is created while a connection with the outside environment is maintained. According to Roche et al. (2000), people prefer and anticipate good daylight in the environment they work or stay in. “The main question that has been addressed in previous studies is to find a balance between daylight provisions and reduction in energy consumption or demand through appropriate control of solar gains” (Beltrán et al., 1997).

Research has pointed out that the proper use of daylighting can considerably affect energy consumption in various buildings types in all forms. This is because artificial lighting is no longer required when there is sufficient daylight. Therefore, energy efficiency can be achieved. More architects/designers have been recently integrating daylighting principles into the design of their buildings due to the increase of information and research data that are currently collected regarding the efficient use of natural lighting. The aim of using daylight is to improve building performance and consequently resulted in energy-efficient design. The benefits of natural lighting are far-reaching, as the following schematic illustrates.

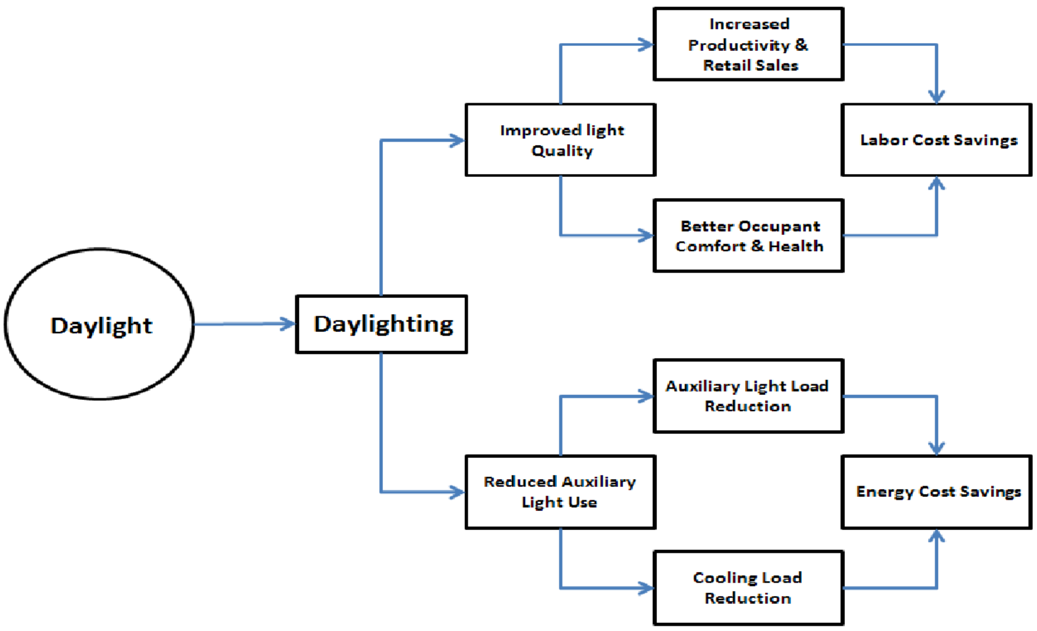

Figure 2.8 Benefits of daylighting

Source: (Boyce et al., 2003)

People can perform their visual tasks utilizing available daylight especially if electricity is not available during the daytime. Furthermore, the integration of daylight control systems is crucial to reduce the lighting energy consumption as there is sufficient available illumination level from daylight (Ul-Haq et al., 2014). Using the control system, which is a switching or dimming method can decrease the use of artificial lighting as daylight is transmitted into space.

According to Ul-Haq et al. (2014), It was reported that adequate light levels required for the task performed in the room can be maintained by the lighting control system. There are many tools are used in buildings design to evaluate daylight including design guidelines, manuals, computer calculation, simulation software, and scale models. They can be used to:

1) Examine the illumination levels at specified points in the room from daylight for specified sky conditions.

2) Estimate annual savings in energy consumption under different control strategies.

3) Predict light distribution's in the room through the design and construction of the openings.

4) Examine the time and location of the direct sun within a space. This can be useful in shading devices design and evaluation.

5) Evaluate the interaction of light and the proposed space aesthetically.

After reviewing natural lighting as the best source of light, it is important to address the integration of daylighting as one of the major strategies which are responsible for a better environment. This kind of strategies has achieved a lot of attention and focus in the building design industry. Professionals must evaluate the advantages and drawbacks of daylighting before applying it in the early design stages.