KINETIC LIGHT SHELF DESIGN AND THE IMPACTS ON DAYLIGHTING PERFORMANCE IN TROPICAL CLIMATE

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KINETIC LIGHT SHELF DESIGN AND THE IMPACTS ON DAYLIGHTING PERFORMANCE IN TROPICAL CLIMATE

by

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ADS	Active Daylighting System
ID	Internal Parts Depth Ratios of Light Shelf
ASE	Annual Sunlight Exposure
BC	Base Case
Config	Configuration of light shelf
DAcon	Continuous Daylight Autonomy
CFsim	Corrected Factor Simulation
CF	Correction Factor
Msim	corresponding simulated illuminance value
DA	Daylight Autonomy
DF%	Daylight Factor
DGP	Daylight Glare Probability
DGS	Daylight Guiding System
DR%	Daylight Ratio
DTS	Daylight Transporting System
DS	Daylighting Systems
Mexp	Experiment Measured Illuminance Value
EA	Exterior Part Rotation Angle of Light Shelf
ED	Exterior Parts Depth Ratios of Light Shelf
EO	External Illuminance
Lo	external illumination measurement point
Ext	External Light Shelf Location
FDT	Fixed Daylight Techniques
GA	Genetic Algorithm
HL	Horizontal Location of Light Shelf
IDS	Innovation Daylight Systems
Li	Internal Illuminance Measurement Point
Int	Internal Light Shelf Location
IA	Internal Part Rotation Angle of Light Shelf
LEED	Leadership in Energy & Environmental Design
LS	Light Shelf

MSM	Malaysian Sky Model
DAmax	Maximum Daylight Autonomy
Mid	Middle Light Shelf Location
PDS	Passive Daylighting Systems
PIV	Percentage of Daylight Illuminance Variation
PIVR	Percentage of Daylight Illuminance Variation Ranges
HP	Position Height of Light Shelf
RE	Relative Error

LIST OF APPENDICES

REKABENTUK RAK CAHAYA KINETIK DAN IMPAK TERHADAP PRESTASI PENCAHAYAAN SIANG DI IKLIM TROPIKA

ABSTRAK

Salah satu keutamaan yang penting bagi ruang kerja dalaman adalah mengekalkan keseimbangan antara penggunaan cahaya siang secara maksima dari satu segi, dan minimakan impak negatif pencahayaan seperti pencahayaan terlebihan dari segi yang lain. Kajian ini bertujuan untuk memperkenalkan ruang kerja pejabat yang optima yang memenuhi kriteria pencahayaan siang yang mencukupi dengan menggunakan sistem rak cahaya yang dikawal secara manual. Kajian ini mengenalpasti parameter rak cahaya yang dikawal dan diubahsuai, yang boleh diaplikasi di bawah iklim tropika mengikut pembolehubah berikut: lokasi mendatar boleh ubah, posisi ketinggian, kedalaman bahagian luaran dan dalaman, sudut condong luaran dan dalaman. Eksperimen menggunakan model fizikal berskala dan simulasi parametrik optima berkomputer telah dijalankan dalam penyelidikan ini menggunakan injin pencahayaan siang Radiance. Model fizikal berskala (1:10) telah digunakan untuk mengesahkan simulasi dan untuk mengenal pasti konfigurasi rak cahaya kekal yang sesuai. Contoh ruang pejabat kecil yang tipikal telah dijalankan untuk menguji dan mengesahkan keberkesanan proses pengoptimuman tersebut. Analisis keputusan kajian lapangan untuk kuantiti pancahayaan siang telah dibuat berdasarkan pencahayaan satah kerja, faktor cahaya siang, nisbah cahaya siang, manakala pencahayaan siang berkesan telah digunakan untuk analisis keputusan dari simulasi. Dari eksperimen kajian lapangan, boleh dirumuskan rak cahaya yang diletakkan di luar keseluruhan dan di tengah dengan ketinggian yang berbeza bertindak lebih baik berbanding rak yang diletakkan keseluruhan di dalam. Rak cahaya bertindak lebih baik pada orientasi Timur dan Selatan berbanding Utara dan Barat disebabkan keadaan langit tempatan dan laluan matahari. Dalam langit mendung, rak cahaya didapati gagal membawa pembaikan peningkatan cahaya di dalam, tetapi pembalikan dalaman masih berlaku dengan cahaya terserak dengan ruang belakang menunjukkan perbezaan yang minima. Untuk kaedah simulasi, parameter rak cahaya yang dikawal secara manual telah dioptimakan pada 3 soltis solar yang berbeza mengikut laluan matahari Malaysia. Setelah proses optima, prestasi pencahayaan siang dalam Pencahayaan Siang yang Berkesan berbanding dengan model-model rujukan lain meningkat secara urutan dengan nilai purata 10.6% dan 4.8% pada 21 Jun, dengan nilai purata 13.6% dan 5.2% pada 21 Mac dan dengan nilai purata 12.0% dan 9.8% pada 21 Disember.

KINETIC LIGHT SHELF DESIGN AND THE IMPACTS ON DAYLIGHTING PERFORMANCE IN TROPICAL CLIMATE

ABSTRACT

One of the top priorities in the interior workspace design process is maintaining the balance between the maximization of daylight harvesting on one hand and the minimization of negative impacts of the illuminance in terms of over-illumination and poor daylight distribution on the other. This research aims to introduce an optimized office workspace that meets the sufficient daylight availability by using a manually controlled kinetic light shelf system. This research determines the light-shelf controlled parameters that can be manually adjusted and are applicable under tropical climate according to these variables: modified horizontal locations, height positions, external and internal parts depth, and external and internal parts tilt angles. Experimental physical scaled-model and parametric computer simulation and optimization were employed in conducting the research using the Radiance daylight engine. The physical scale model (1:10) was used to validate the simulation tool and to determine the appropriate fixed configuration of light shelf. An example small typical office space was conducted to test and verify the effectiveness of the optimization process. The analysis of fieldwork results for daylight quantity was done based on absolute work-plane illuminance, daylight factor, and daylight ratio, while useful daylight illuminance was used for the analysis of the simulation results. From the fieldwork experiments it can concluded that the light-shelves positioned totally outside and at the middle with different heights were found to work better than the ones positioned totally inside. Light shelf was found to work better in the East and South orientations compared to North and West due to local sky characteristics and sunpath. In totally overcast conditions, light shelf fail to bring any improvement to increase the illumination inside, but some inter-reflections of the diffused light still occur when the back of space showed minimal differences to base case. For simulation method, the parameters of the manually controllable kinetic light-shelf design were optimized in three different solar solstices of the Malaysian sun path diagram. The optimization results indicate that the optimal design options of controlled light shelf parameters have great potential for illuminance improvement. After the optimization, the daylighting performance of useful daylight illuminance was compared to reference base case models and were found to increase respectively with an average values of 10.6% and 4.8% on the 21st of June, and by 13.6% and 5.2% on 21st of March, and by 12.0% and 9.8% on 21st of December.

CHAPTER 1

INTRODUCTION

1.1 Research Background

During the last decades, there has been a trend of increasing cooling demand in buildings. This has particularly been the case for commercial buildings, where high internal loads combined with high solar gains through extensive glazing have resulted in significant cooling loads, even in moderate and cold climates (Guo et al., 2019). The designers and architects also make important decisions that have a significant effect on energy efficiency and indoor comfort (thermal and visual) when designing and selecting the building's external facades, fenestration systems during the early design phases (Halawa et al., 2018; Tzempelikos et al., 2007). Current façade design trends in architecture have moved towards transparency facade designs, where the utilization of glass has become an attractive envelope choice in high-rise construction, especially in office buildings (Kirimtat et al., 2019). Designing highly glazed office façades provides views and the possibility of an excellent availablty levels of daylight and and openable windows for natural ventilation (Azarbayjani, 2014).

Fully glazed facade systems have been increasingly used in an external office building envelope design for more daylight entry to indoor space (Palarino and Piderit, 2020). This has caused undesirable effects such as glare, heat losses during the winter, excessive heat gains in summer and increased demand for air conditioning (Vanhoutteghem et al., 2015). The construction industry records the highest amount of energy usage. They are responsible for approximately 40% of heat loss in winter and excess heat gains in summer (Barozzi et al., 2016). In energy consumption, the building sector records the highest amount of energy consumption. It is represented by almost 40% of global primary energy use (Kim et al., 2016b). Field measurements that were conducted in buildings show the energy consumption between 20%–40% in the United States, and more than 20% for Indian buildings (Sudan et al., 2015). In Europe, around 41% of the total energy consumed was used in the construction and building management field (Barozzi et al., 2016).

Office buildings in tropical regions such as Malaysia have given researchers interest because of energy concerns. Aun (2009) reported that many of the Malaysian office buildings recorded energy consumption exceeding the energy index of 180 kWh/m2/yr (Al-Masrani et al., 2018). In the study by Tang and Chin (2013) noted that the average energy consumption in Malaysian office buildings is 50% for air conditioning, 25% for artificial lighting and 25% for low-power systems. They outlined the better energy-saving solutions for Malaysia's office buildings focused on building form, orientation, and layout as shown in Figure 1.1; The first is selecting the right orientation to control solar loads, and the second designing the appropriate size for openings to reduce the heat gain whilst providing a good view to outside (Tang and Chin, 2013). However, as noted above, most energy use in office buildings is used for environmental comfort (thermal and visual) through air conditioning systems and artificial lighting (Yu and Su, 2015).

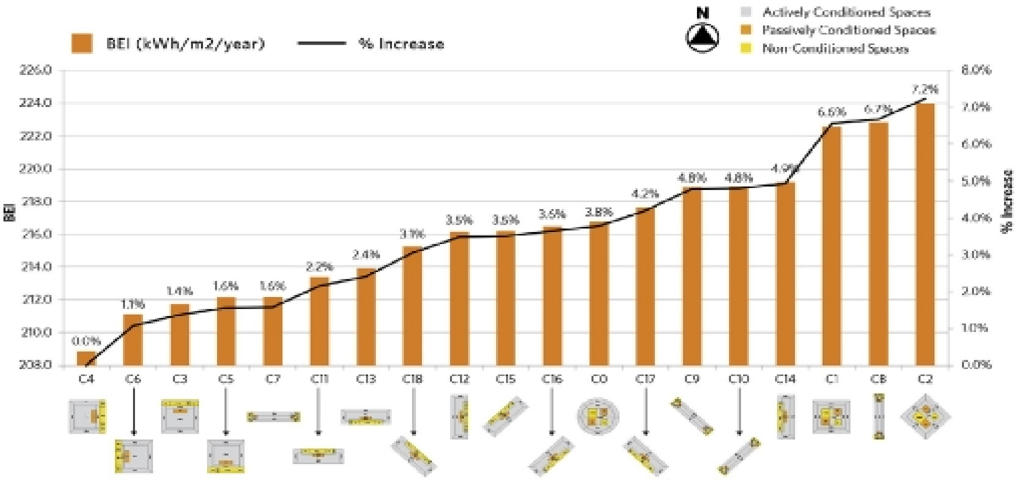

Figure 1.1 Energy used in an office building in Malaysia based on their designs. (Tang and Chin, 2013)

Today the contribution of daylight has been concentrated on energy saving in buildings. Daylight in the building is an important resource for improving energy efficiency (Samadi et al., 2020). The use of daylight in an office building has become a design strategy to improve the quality of environmental and energy efficiency by decreasing heating and cooling loads (depending on the climate) and minimizing artificial lighting energy consumption (Aghemo et al., 2008). According to previous studies, artificial lighting contributes up to 40% of the annual building energy consumption, 20% – 30% of overall energy use in commercial buildings, 35% of the total electric load in conventional office buildings (Wong, 2017).

In this regard, daylight is considered the best light source and is more effective in lighting the indoor spaces compared to electric lighting, because it generates less heat for the same amount of electric light (Lim et al., 2013). Increasing the daylight in indoor spaces will save energy and increase productivity in the workplace. The approximately minimum energy saving that can be accomplished by using the concepts of daylight strategies alone is around 10% (Lim et al., 2012).

Currently, there has been a growing interest in incorporating daylight into architectural and building designs as a means of reducing energy consumption in buildings (Li and Tsang, 2008). Recent highlighted the major influence of facade design on indoor daylighting quality (Al-Masrani et al., 2018). Daylight represents an important strategy in modern architecture by creating an attractive visual and lively environment (Li and Lam, 2003). Daylight is one of the passive design strategies of the green buildings, besides, it is a key aspect of building rating systems such as Leadership in Energy and Environmental Design System (LEED), Green Building Index (GBI), and Building Research Establishment Environmental Assessment Method (BREEAM) (Elghazi et al., 2014).

To achieve a successful design for better user performance, building façade design, and daylighting design should be always be integrated into the design process aiming to generate appropriate architectural and technical solutions to enhance optimum daylight distribution in indoor spaces while reducing building energy consumption (Aghemo et al., 2008). In the modern architectural design of office building, the new trend is to use large glass surfaces in the façade to guarantee wide exterior views and high levels of natural daylight (Berardi and Anaraki, 2015). This requires methods of reducing the side effects of glare and energy loss. Avoidance of glare, uniformity of daylight distribution and reducing the electric lighting sources are some of the main criteria considered by the designers to generate a high-quality illuminance area in buildings (Bodart and Cauwerts, 2017; Kensek and Hansanuwat, 2011).

Increased attention to daylight penetration into the deeper areas and spaces has been focused to provide better illuminance distribution (Berardi and Anaraki, 2015). Thus, offering the optimal amount of daylight and improving the quality of the indoor environment, implementing the right daylighting systems and strategies is quite necessary (Karizi, 2015). Much passive static or kinetic, and active dynamic daylight techniques in building envelopes have been developed serving as environmental design solutions to save energy and enhance daylighting distribution in indoor spaces.

As a result of climate change and complex facade design, static daylight devices cause a conflicting situation between the need for shading to avoid glare and the need for daylight to avoid using artificial lighting in a daytime (Schuster, 2006). Static daylight systems can only work enough for sun protection and harvesting of daylight under specific conditions. Moreover, today's new challenge is to create more advanced integrated solutions to optimize the daylight penetration through building facade, adapting to the external environmental conditions to achieve high levels of daylight (Konstantoglou and Tsangrassoulis, 2016).

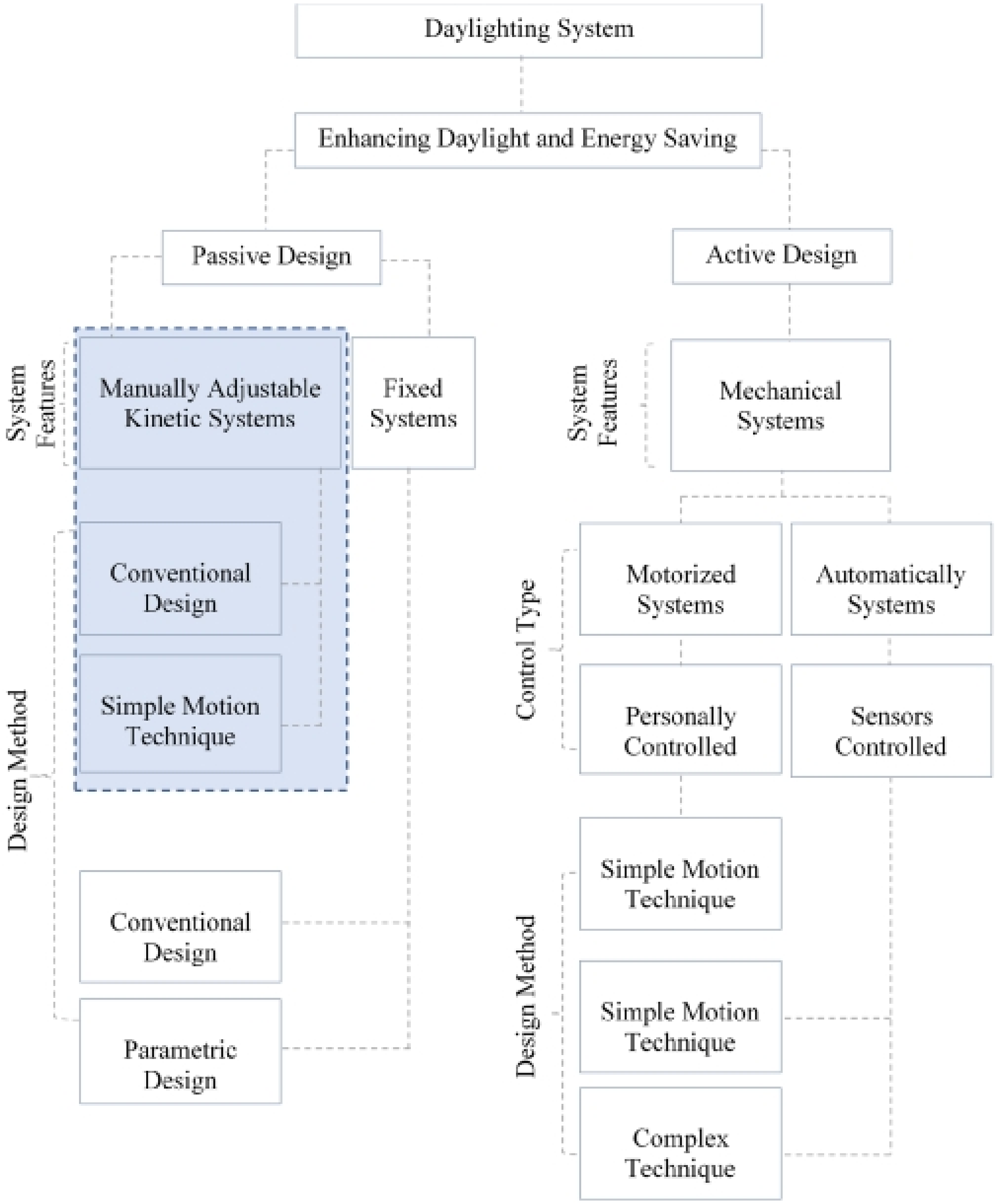

Figure 1.2 Classification of daylight controlling systems and the location of this research.

There was a major shift on facade daylighting design systems from static solutions to kinetic/dynamic trying to optimize daylighting levels and daylight quality indoor spaces (Hammad and Abu-Hijleh, 2010). However, daylighting systems are divided into two basic categories as shown in Figure 1.2: the first, active dynamic daylighting systems depending on the electronic mechanism of tracking the sun either using photo sensors or an algorithm that predicts the position of the sun for a location and date. The second, passive daylighting systems, are stationary devices or manually adjustable kinetic/movable systems (Javed, 2014).

Active daylight harvesting technologies available in the market often suffer from widespread market acceptability because of their high cost and imperfect performance. Whereas static systems cannot harvest higher potentials of daylight, which is dynamic over days, months, and seasons, because of their static nature (Javed and Reichard, 2014). ***This research looks at the potential of manually controllable kinetic daylight harvesting techniques, which in this case are light shelf technologies which can be manually controlled and can provide higher daylighting performance in it is efficacy***.

The passive design of kinetic light shelves with manually controllable techniques has been developed in this study to avoid the conflicts mentioned before and to make the facades more responsive and interactive for natural lighting. Kinetic shelves can redirect sunlight into the deep spaces, by manually controlling its positions, locations, widths, and tilt angle and different other variables according to the position of the sun (Kontadakis et al., 2017a). Light shelf techniques are one of the most common design choices in contemporary buildings and are often suggested as effective systems that can improve the quality of lighting in an interior spaces (Kontadakis et al., 2017b). Besides, light shelves techniques are one of the daylight guiding systems in building the façade, which was developed for attempting to achieve two major functions. First, it can reflect light deeper into the interior space, and second, it can block the direct light (Azarbayjani, 2014; Kurtay and Esen, 2017).

The effectiveness of kinetic light shelf systems regarding the distribution of daylight in interiors has become a major research issue, especially as regards how a kinetic light shelf system performs in daylight or what position and height or angle leads to get better illumination there at far areas from the window, and providing uniform daylight distribution under tropical sky conditions. Such inquiries should be dealt with during the early stages of design by research and calculation. Thus, a light shelf model with manually controlled adjustable features was developed in this study to answer the questions above.

This research was carried out to test the performance of manually controllable kinetic light shelf to achieve an optimal daylight distribution quality, and to give a clear perception of the effective or vice versa ineffective role of this system and its ability to improve or not to improve the internal conditions by measuring the levels of natural lighting. This will become a guide for architects and designers who want to adapt light shelves with manually controlled in the building envelope in their design according to the tropical areas. This light shelf system is a hybrid of the active and passive as it is a manually controllable light-harvesting device that allows for quick adjustment based on the sun path and interior space requirement for daylight and user's needs. To find answers to the questions which have related a research gap as mentioned above, a literature search was carried out to document what has been done so far, and to clarify the original contribution this research attempts to make in daylight harvesting systems especially in the tropical region.

1.2 Problem Statement

A carefully and effectively designed and built facades is one of the most significant factors influencing energy efficiency in a building. Building facades plays a crucial role in maintaining the occupants' comfort levels (Abdullah et al., 2016). They have a significant role in delivering daylight optimizing and maintaining the quality level to indoor spaces. Comprehension of daylight quality in indoor spaces requires information on the appropriate level of light distribution according to the space function, lighting spread, and visual discomfort of shade and shadow (Omidfar et al., 2015). Adjusting daylight level in indoor space require uniform daylight with an appropriate light level and controlling the glare through space (El-Dabaa, 2016). Recent years have seen a rise in understanding of the benefits of using optimal daylighting and designs of many buildings considering daylight. Including daylighting in designing results in better day-lit interior environment and thus decreases visual discomfort (Mohapatra et al., 2018).

There is an abundance of daylight in tropical regions but yet to be used. Most Malaysian office buildings currently do not use natural daylight because of designs inappropriate despite the abundant daylight from the diffused sky (Lim et al., 2013). The penetration of direct sunlight can become excessive, and it may create a non-uniform spread of natural illuminance, glare, and high gain of solar heat gain, impacting both visual and thermal comfort. A good daylighting strategy is necessary to decrease energy consumption for artificial lighting and to provide effective internal illumination (Husin and Harith, 2012).

Daylighting in high-rise office buildings, especially in the tropics, is facing a serious challenge due to the difficult daylighting situation. Natural light is abundant in tropical areas due to the high intensity of sunlight and its long period of daytime illumination. Given this ability, a lack of understanding of the sky conditions in this area can lead to underutilization. Due to the complex and varied sky conditions the nature of natural light utilization in tropical areas is challenging. Besides overheating problems that occur in large glazing areas and inappropriate orientations, such as east and west, an occupant’s lack of ability to control or manipulate the daylight within their environment may lead to increased energy usage from depending on electric lighting, and this eliminates positive outcomes related to daylight and views (Al-Masrani et al., 2018). Spaces that are unsuccessfully day-lit, because of the lack in user controls, allow excessive glare, and contribute to heat gain. This results in adverse effects upon occupant's performance and overall satisfaction. The adoption of daylight harvesting systems therefore seems to be an important strategy for reducing the energy usage of lighting and increasing the level of visual comfort (Day et al., 2012).

Today , conventional daylighting systems is not well integrated with the façade design and is frequently ignored due to the difficulties of successful performance and evaluation (Omidfar, 2011). Conventional daylighting devices also have some deficiencies in illuminating the deeper spaces (Javed and Reichard, 2014).

A variety of creative daylighting strategies have been suggested to tackle this issue, and there seems to be a trend to shift away from static to more dynamic approaches (Hashemi, 2014; Nair et al., 2014). The main difference between dynamic/kinetic and static ones is the capacity of the former to be modified to maintain both thermal and visual comfort within the recommended range and decrease the effects of the external loads (Elzeyadi, 2017). The fundamental challenges remain the same: how to admit enough daylight as deeply as possible into space, creating a high quality and productive environment for the occupants, while at the same time achieving increased energy savings (Alrubaih et al., 2013). Thus, there is an urgent need for a guide that will enable designers, architects, and researchers to predict daylight performance, especially in the deeper areas or areas far from apertures for the installation of the high-performance dynamic light shelf technologies. Many research on the use of static and dynamic strategies for daylighting have been performed (Fadzil and Sia, 2004; Konis and Lee, 2015; Lim and Ahmad, 2015; Lim et al., 2013; Lim and Heng, 2016). Some researchers have found that dynamic devices are more efficient in achieving adequate daylighting than static devices, which can be changed according to the position of the sun (Djamila et al., 2011; Koo et al., 2010; Lim and Ahmad, 2015). Dynamic devices can be controlled by the users manually or with automated system. Although many researchers looked into the use of automated shading devices as an effective solution, automated system might cause the users losing their sense of control and affect the users' satisfaction (Meerbeek et al., 2016).

This research explored the effectiveness of existing daylight solutions and investigates a new passive daylighting technique to bring natural light into deep plan buildings. The system proposed is a kinetic light shelf with manually controlled features. Manually controllable kinetic light shelves are a passive innovative daylight guidance system, it is a hybrid technique between active and passive systems. Few studies have tested the impact of passive design for the light shelf indoor daylight performance in high-rise office buildings on tropical areas (Mahmoud and Elghazi, 2016). Thus, because of this limited research, there is a gap that calls to tested and reevaluates such examples using modern analysis and assessment techniques. The development of manual controllable, low-tech, high-performance light shelf may be an alternative to active daylighting solutions in tropical areas.

In Malaysia, there has been very few kinds of research in this field. Most studies assessed the daylight levels indoor with passive and static light shelves, and there is a need to close the gap of using and exploring the feasibility and potential of the manually controlled kinetic light shelves to addressed the optimum distribution of daylighting in office spaces. This topic is selected because of the lack of studies on this type of light shelves and their method of motion design, and it is the ability to improve daylighting performance levels indoors. There is also a general lack of empirical evidence in the different tropical environmental conditions to test the performance of this type of light shelf .

1.3 Research Questions

In pursuing the aim addressed above, this research tries to build a ‘proof of concept’ by answering the fundamental questions related to manually controlled kinetic light shelves, thus, this research addresses the following research questions:

1. What is the improvement in daylight availability using manually controlled kinetic light shelf systems compared to the base case without light shelf?
2. Is it possible to improve daylight penetration deeper into indoor spaces and improve the uniformity of daylighting by manually controlled kinetic light shelves?
3. How do manually controlled kinetic light shelves affect daylight quality and quantity of indoor office spaces compared to conventional daylighting fixed techniques?

1.4 Research Aim and Objectives

This research aims to fill the knowledge gaps in the subject of manually controlled daylight techniques for the use of researchers and designers in their future studies and practices. The research is to explore the possibility of exploiting daylight to provide sufficient daylight illuminance in office environments by giving a critical evaluation of whether the design of various manually controllable kinetic light shelves configurations can play a significant role in concerning optimizing daylight distribution and enhancing the daylight performance of indoor spaces in office buildings in the tropics such as Malaysia. To achieve this general aim, it requires the following specific objectives to be carried out:

1. To investigate the potential of each design configurations of manually controllable kinetic light shelves for enhancing the availability of daylight in indoor spaces.
2. To evaluate the improvements of daylight availability into the back of space using manually controlled kinetic light shelves and understand the opportunities and obstacles which resulted under tropical sky.
3. To identify the features of the manually controlled kinetic light shelves and the parameters that contribute to daylight quality and quantity in the space. These features will then be used to suggest a general design design guide in tropical areas.

1.5 Research Methodology Overview

To assure reaching a successful daylighting availability in terms of quantity and quality by using kinetic light shelf which can be manually controlled is what the current research is all about. To understand the possibilities and limitations of creating manually controlled kinetic light shelf and its performance advantages over traditional building daylighting techniques. Therefore, a comprehensive methodology is required to fulfill the aims of this research that focus on daylighting availability and quality in office spaces, by using manually controlled kinetic shelf that will be able to control the sky changes in tropics by controlling illumination levels. To achieve this, This research introduces a methodology for designing, experiments, simulating and validating, aiming for addressing this integrated performance. The adopted method to achieve this purpose and answering the research questions is combine three steps; a literature review, experiments, and parametric analysis using numerical simulation (modelling, simulation and optimization).

Therefore, this research first, conducts a systematic review of the existing literature on the subject to configures background of study. The knowledge domains identified within this review are then categorized into groups and sub-groups to make it easier to extract the gist of what has been done so far, and the tools that allowed the architects and designers to create and simulate these models of daylight techniques. The second step, experimental approach, scale model has been modeled for testing and analytical the daylight penetration under the real and artificial environmental condition to measurements of daylight levels. The scale model experiment was used to validate the simulation tool and to determine the appropriate fixed configuration of light shelf. as for the last step, simulation approach, the experiments were supplemented with simulations studies by combines genetic algorithms and parametric simulation tools.

1.6 Significance of Research

The significance of this study stems from the lack of comparative studies for the use of various configurations of the manually controllable kinetic light shelves as design solutions. This study has taken a scientific method based on integrated methods between the real experiments and computer simulations by using scale models (small office model) to apply different configurations of light shelf based on the tropical climatic conditions. The differences in daylight performance and it is distribution within the interior spaces are explored. This study will simulate manually controllable kinetic light shelf to reach the optimum configuration design via parametric approaches that can achieve the optimum daylight performance. The results of the study will contribute to the understanding of the latest trend of building envelope design, especially with kinetic light shelf techniques.

1.7 Research Scope

In this research, the quality of daylight distribution is assessed by considering performance indicators that are linked with the manually controllable kinetic light shelves. To ensure that the study will be more focused and the results are more accurate and credible, the scope of the research focused on:

1. Typical office spaces with standard rectangular shape located in tropical climates with single-sided apertures.
2. The research focused on ensuring a successful daylight distribution in terms of quantity and quality by using light shelf with controlled and modified parameters only without focusing on other aspects such as thermal comfort, visual comfort (glare probability), and energy-saving.
3. Different design configurations and solutions based on several selected variables to find out the best design parameters by experiments using a scale model under the real sky as a first stage. Simulations analysis using parametric tools and optimization processes as a second stage.

1.8 Thesis Framework

The framework of research has been outlined in Figure 1.3, which can measure the effect of manually controllable kinetic light shelves on daylighting performance and comparing their effectiveness.

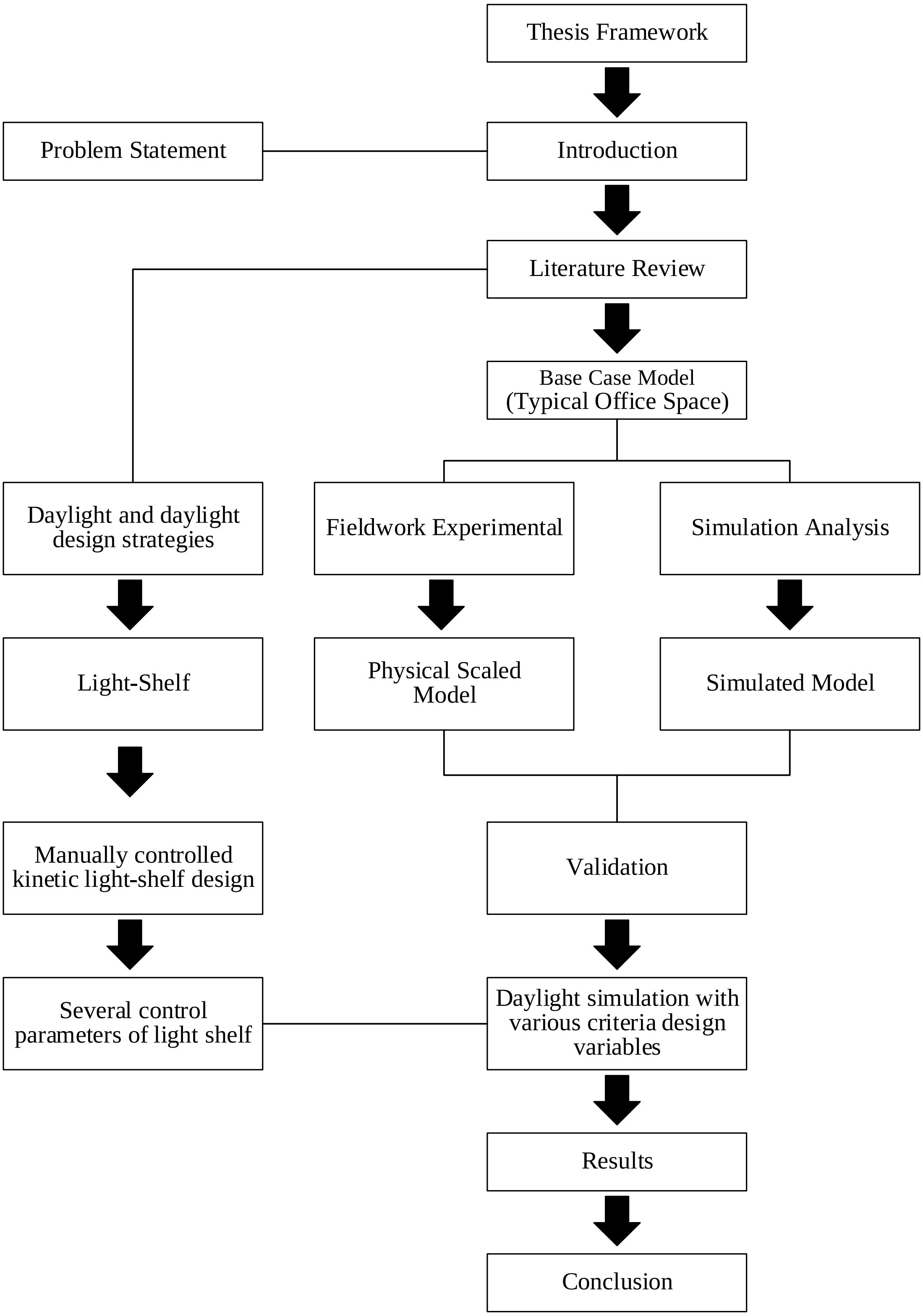

Figure 1.3 General research framework

1.9 Thesis Overview

The following section presents the different parts of the dissertation which consist of six chapters**. Chapter 1**: this chapter presented the introduction of the thesis, by providing the related general background about the topic, followed by the research problem statement, aims, and objectives, significance of this thesis, as well as the scopes and hypothesis of this research.

Chapter 2: discusses a literature review concerning previous works that have been carried out and their relation to the study. This chapter begins with key classifications associated with daylight strategies in building envelope and daylight systems. It then moves to the various classifications of daylight control systems. Followed by a detailed explanation about the daylight systems which were chosen in this study. It also explains daylighting measurement methods which are carried to the study.

Then the methodology followed as detailed in **Chapter 3**: experimental scale-model and computer simulation are the two main methods that were used to achieve the objectives of this research.

Chapter 4: focuses on field measurements of daylighting distributions by developed physical scaled-model testing. Different light shelves variables and configurations are extensively studied and discussed. Also, in this chapter, the experimental results were validated by comparing them with simulation results which are an important portion of this chapter

Chapter 5: presents the simulation results on the daylighting performance and the impact of different light shelf design variables using parametric simulation and optimization method. Finally, **Chapter 6**: provides the conclusions of this research and outlines the potential research topics in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Dynamism and constant change in tropical sky conditions are the two elements that characterize the regional environment, and they have a major effect in utilizing daylighting in a building's design and interior workspaces. Conversely, such dynamism can create unwanted lighting conditions in most daytimes such as discomfort and glare if it is ignored in the early design stages. Designing daylighting in tropics might still require a proper understanding of such dynamism. It also requires a lot of efforts to experiment with many solutions and techniques for designing daylighting, and these efforts must be the best it can be to create the optimum daylight solution.

However, in recent architectural design, especially in high-rise office buildings in Malaysia, daylighting systems are not well addressed in the early stages of design, because of inappropriate designs through the utilization of large glazing surfaces (Kirimtat et al., 2019). Therefore, when assessing indoor daylight environments, particularly in office spaces, it is essential to consider recent innovations that would help increase the daylight levels in the rear areas of the spaces and minimize visual discomfort in the front parts, without affecting the efficiency, health and comfort of the occupants (Al Waary, 2012).

A lot of studies address the importance of daylighting in office buildings. These studies help to provide additional knowledge of the subject and increase research awareness in developing various solutions that lead to the successful use of natural light in design. The literature review in this chapter is mainly focused in key classifications associated with daylight strategies and assessment methods. This literature focused on four main parts, including (1) Building facades and daylighting design, (2) Daylighting system and techniques, (3) Daylight assessment methods, and (4) Measurables daylight methods.

2.2 Building Facades and Daylighting Design

2.2.1 Building Facade Components (From Static to Kinetic)

Traditionally, the design of the façades of a buildings is 'static,' even though the continuously changing of the external environmental boundary conditions. Consequently, traditional façades can not adapt and react to different changes that they are exposed to (Sharaidin, 2014). However, there has been an interesting development in architecture that is interactive, responsive, and intelligent. This paradigm shift in architecture coincides with climate change and developments in computer science linked to architectural science through the advancement of software, cybernetics and building technology that have transformed the architecture from a static form to a more kinetic and dynamic form (Alotaibi, 2015).

Single or multi-layered building facades are now the place for new experiments on increasingly creative systems, technologies, smart materials and new technologies. This allows the achievement of moving surfaces that visually and physically interact with the environment, called "kinetic facades". A kinetic facade is constructed so that it, or it is main part, can move while maintaining the entire structural integrity (Formentini and Lenci, 2018). The development of kinetic building façade technologies that can be adjusted to variable outdoor or indoor conditions is seen as a critical step forward in achieving sustainable building (Favoino et al., 2014). Kinetic building facades could be defined as a facade that can change its properties and elasticity to control several elements of a building envelope in response to the changing climate conditions or changed interior environment behaviors. It is used to maintain the internal environment at an acceptable level, in other words, to improve the interior comfort. The change can be accomplished by several different methods: moving elements, introducing natural light or airflow to mention a few (Modin, 2014). Table 2.1 illustrates an overview of the main type of building facades categorised based on their key performances.

Table 2.1 Building façade categories and their performances. (Halawa et al., 2018).

Facade Categorization	Facade Type	Materials Made-Up Categories	Performance Evaluation
Single Layer	Stone façade	Brick masonry facade	High thermal mass performance
		Marble	Low-value of insulation.
	Metal façade	Aluminum facade	Thermal performance depends on the Manufacturing and design and fastening in building.
		Steel facade	Limited insulation performance.
	Glazing façade	Single-Glazing	Poor thermal performance and high energy used
	Solar Façade	Semi-transparent and Opaque facade	Significantly Improved interior environments
Multi-Layers	Double-skin façade	Double glazing facade	Provide better thermal performance than other glazing walls
	Kinetic façade	Double skin (different materials)	Enhancing interior environments by responding to micro-climatic variations. And Reduce over-lighting due to control of direct solar penetration

Kinetic components on building facades have appeared as an alternative design solution to enhance the building envelope over the past few decades. The main idea for designing the facades is to meet the increasing and complex demands related to the needs of space such as user comfort, energy consumption, and cost-efficiency

(Sharaidin, 2014). The kinetic term has been described in several ways, ranging from the usage of simple innovative components integrated with a facade system design, to highly complex designs and advanced technological application. It is also closely associated with different terms in the literature on this type of building envelopes such as, “Smart”, “Intelligent”, “Interactive”, “Adaptive” or “Responsive” etc (Ben Bacha and Bourbia, 2016).

Kinetic facade’s component is defined as all the elements of the building external envelope that adapt to the needs of users and changes in the environment. These components may be high-tech systems which use sensor networks and drives to track the environment and automatically control operating components. This term is often used to refer to the moveable, operable, often manually controlled elements of buildings that allowing the adjustment of the exterior and interior of the building to adapt the building’s performance to meet everyday needs (Meagher, 2015).

2.2.2 Kinetic Façade’s Components for Improving Daylighting

The physical environment influences the building user's well-being and directly influences their performance and productivity especially in office buildings, where they spend a lot of their time in. This is because the office temperature, air quality , lighting and noise conditions affect the concentration and productivity of work. It is often thought that workers who are more satisfied with the physical environment have a greater chance of achieving better work results (Kamarulzaman et al., 2011). Building facades are one of the most significant elements of building skin for displaying the building's architectural expressions and aesthetic design values. It plays a significant function in maintaining and protecting the indoor thermal conditions, whereas in general, it helps improve the sustainable performance of buildings. Briefly, facades are responsible for the outer form appearance of buildings, and also its performance. Due to this, building facades design is referred to as one of the most critical and technologically challenging in design, as it involves the multi-faceted and multi-functional components of a building (Halawa et al., 2018).

The new challenge in building design today is to provide a fully functional, integrated façade and lighting system that works properly in all environmental condition. A number of targets, including shading, must also be accomplished by cost-effective and practical approaches for long periods with minimal maintenance (Lee et al., 2004). The static design of conventional facade components has a disability in environmental performance, energy savings, and daylight achieving. This is because it is unable to take advantage of appropriate ambient conditions that would benefit the indoor environment continuously, as well as decrease the interior space features which hinders occupant's abilities to modify the envelope to their needs during all periods of the season (Gallo and Romano, 2017). However, there are also numerous problems related to utilizing conventional static building facades located in hot climatic regions. This includes low level of daylighting and thermal discomfort. Thus, static envelopes cannot provide consistent climate control without heating, ventilation and air conditioning system assistance due to continuous changes in the weather. These problems encourage many researchers in the architectural field to try and find a new style for improving the building facade by the utilization of new kinetic controls (Shameri et al., 2011).

The new application of kinetic elements in a building envelope plays an important part in a building’s process. Kinetic design as a sustainable building element is in its infancy, yet is a rapidly rising area of architectural research due to the need for a better building environmental efficiency. Kinetic facade components have the ability to add to a building's architectural appearance by visualizing the changeable environmental aspects (Nagy et al., 2016). Dynamic or kinetic facade components buildings may be adjusted according to current or expected conditions of the environment and comfort preferences. Such adaptation will contribute to substantial energy saving potentials as opposed to static building options (Bakker et al., 2014).

There are currently several research underway in the field of kinetic façade elements and their impact on the architectural design of buildings on several environmental aspects. Even so, several significant factors have yet to be confirmed such as the building design parameters and the selecting the most effective architecture design and control strategy for an adaptive façade according to the typology of the building and the surrounding environment (Favoino et al., 2014). Kinetic components in facades are a kind of creative or artistic building envelope that can contribute to the enhancement of the quality of the interior space through the provision of adequate tasks by their motion. The facades can serve a large scope to improve the indoor environment. However, such facades are currently not easy to be implemented in practice, due to the lack of information and precedents related to the performance (Lim et al., 2015). The unique feature of kinetic building facades is the ability to adjust and control their thermal and visual properties against ambient environment conditions (Loonen et al., 2017).

However, kinetic components in facades adapt to surrounding environmental behavior by measuring various information either from outdoor or indoor environmental conditions and user's needs, to address the developing environmental conditions to maintain the desired interior comfort level (Konstantoglou and Tsangrassoulis, 2016). The kinetic façade is usually distinct from a conventional one in the way they respond to surrounding factors in that it incorporates various tools that enable the building envelope to serve as a moderator for climate control. By using this type of facade, it is able to achieve indoor comfort and perform purposes that would not have been possible for a static facade structure. The abilities include accepting or rejecting the outdoor or indoor impacts, and responding or benefiting from external climatic conditions (Ben Bacha and Bourbia, 2016; Formentini and Lenci, 2018).

For dynamic climates such as the Malaysian region, the conventional building facades characterized with static or fixed elements may not be an optimal solution. Previous studies are referring to manifest the growing attention in kinetic elements technologies of the facade which are proposed for improving internal environment in several aspects (Ben Bacha and Bourbia, 2016). These features enabled the researchers to do complex simulations of the suggested systems to reach the best possible solution with daylighting and daylighting guiding systems by using various kinetic types (Miao et al., 2011). Recent literature has shown the major effect of kinetic facade design elements on daylight quality indoors. The application of this type of system will allow better performance compared to any other conventional system.

2.3 Daylighting and Daylighting Design Strategies

2.3.1 Daylighting Definition

Building envelope design might still require a lot of effort to experiment many solutions in different environmental fields, including daylighting. It is important, then, that this effort be as best as possible to reach the optimum solution. Daylighting is an important component that needs to be considered seriously in the approach to achieve energy efficiency and sustainability (Mangkuto et al., 2018). According to Alrubaih et al. (2013) Daylighting can be grouped into seven main categories based on various purposes; namely, daylighting and environmental pollution, daylighting, illuminance, luminance, daylight factor (DF), daylight glare, and lighting controls techniques. Baker

(2002), defined daylighting as ‘‘the combination of the diffused light from the sky and sunlight’’. Manning (2006) indicated that ‘‘daylighting is any method by which natural light is brought into a room to replace or supplement artificial lighting.’’ In addition, Mardaljevic (2013) defined daylight in buildings ‘‘is the natural illumination experienced by the occupants of any man-made construction with openings to the outside’’. Light can come from many types of glazing configurations, which are either vertical or horizontal and from the side or from the top (Alrubaih et al., 2013).

2.3.2 Daylighting Sources and Availability

2.3.2(a) Daylighting Sources

Sun is the source of natural light energy, and the sun track describes the sunlight available at a specific position of the building, according to the Illuminating Engineering Society of North America (IESNA) (Rea, 2000). The solar altitude and the solar azimuth are the two angles through which the position of the sun can be defined at a reference point on the surface of the earth. Three light conditions to be taken into account in the daylight design are overcast, clear and partially cloudy skies (Alrubaih et al., 2013). The sky is normally the brightest element in an exterior scene in the cloudy conditions, with a much lower light reflected from other surfaces. Lighting can exceed 2500 fc in the fully cloudy condition. Far more popular are partly cloudy skies, and there are frequent variations between direct sunshine and hazy daylight and fluctuations in intensity, distribution, and temperature of color. The sun is the brightest source of light under direct, sunny conditions, and is practically a point source of coherent, parallel rays creating sharp shadows. The strength of the sun varies with the thickness of the air mass through which light travels, which in turn is affected by the height, the