KINETIC SHADING DEVICES FOR MULTI-STOREY OFFICE BUIDLINGS IN THE TROPICS

LEE SIEW JING

UNIVERSITI TEKNOLOGI MALAYSIA

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LEE SIEW JING

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DEDICATION

This thesis is dedicated to my family, who have always loved and supported me unconditionally throughout my graduate school journey. I also dedicating my supervisor and university friends for their encouragement and assistance in helping me finish this thesis during the Covid-19 pandemic.

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ABSTRACT

In tropical climate regions, daylighting is abundant but is not fully utilized in building design due to the undesirable solar heat gain. Shading systems are crucial in building design particularly for multi-storey office buildings in the tropics. However, the internal daylighting level in office buildings of Malaysia was insufficient due to the improper use of fixed shading devices. Kinetic shading systems are capable to improve the quality and quantity of daylighting in multi-storey office buildings in the tropics as the kinetic shading devices can respond to the dynamic sky condition. The objectives of the study is to identify the factors that would affect the performance of kinetic shading device of multi-storey office building in the tropics, to implement a kinetic shading system that interacts with the dynamic sky conditions and to improve the daylighting performance of the workplace with providing optimum indoor illuminance level. The methodology used in this study is mixed method research. Literature review and case studies contributed to the design parameters of kinetic shading devices by observation and comparison. Six types of shading devices are proposed and being assessed through the daylighting analysis simulation. An experiment is conducted using Velux Daylight Visualizer and SketchUp. The daylighting performance of the proposed shading devices are assessed through the computer simulation software, Velux Daylight Visualizer. The findings identified the kinetic shading devices which could provide optimum daylighting performance at each orientation and times under tropical sky. This study contributes to the exploration of kinetic shading devices design and the implementation of kinetic shading devices on office buildings in the tropics. Nevertheless, further studies are needed to consider the energy consumption of kinetic shading systems and daylighting performance analysis using real climate data.

ABSTRAK

Di kawasan iklim tropika, pencahayaan siang adalah banyak tetapi tidak digunakan sepenuhnya dalam reka bentuk bangunan kerana penambahan haba suria yang tidak diingini. Sistem teduhan adalah penting dalam reka bentuk bangunan terutamanya untuk bangunan pejabat bertingkat di kawasan tropika. Walau bagaimanapun, tahap pencahayaan dalaman dalam bangunan pejabat di Malaysia tidak mencukupi disebabkan oleh penggunaan peranti teduhan tetap yang tidak betul. Sistem teduhan kinetik mampu meningkatkan kualiti dan kuantiti pencahayaan siang di bangunan pejabat bertingkat di kawasan tropika kerana peranti teduhan kinetik boleh bertindak balas terhadap keadaan langit yang dinamik. Objektif kajian adalah untuk mengenal pasti faktor-faktor yang akan mempengaruhi prestasi peranti teduhan kinetik bangunan pejabat berbilang tingkat di kawasan tropika, untuk melaksanakan sistem teduhan kinetik yang berinteraksi dengan keadaan langit yang dinamik dan untuk meningkatkan prestasi pencahayaan siang hari. tempat kerja dengan menyediakan tahap pencahayaan dalaman yang optimum. Metodologi yang digunakan dalam kajian ini ialah kajian kaedah campuran. Kajian literatur dan kajian kes menyumbang kepada parameter reka bentuk peranti teduhan kinetik melalui pemerhatian dan perbandingan. Enam jenis peranti teduhan dicadangkan dan dinilai melalui simulasi analisis pencahayaan siang. Satu eksperimen dijalankan menggunakan Velux Daylight Visualizer dan SketchUp. Prestasi pencahayaan siang peranti teduhan yang dicadangkan dinilai melalui perisian simulasi komputer, Velux Daylight Visualizer. Penemuan mengenal pasti peranti teduhan kinetik yang boleh memberikan prestasi pencahayaan siang yang optimum pada setiap orientasi dan masa di bawah langit tropika. Kajian ini menyumbang kepada penerokaan reka bentuk peranti teduhan kinetik dan pelaksanaan peranti teduhan kinetik pada bangunan pejabat di kawasan tropika. Namun begitu, kajian lanjut diperlukan untuk mempertimbangkan penggunaan tenaga sistem teduhan kinetik dan analisis prestasi pencahayaan siang menggunakan data iklim sebenar.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Daylighting is very important to maintain human health on both physical health and psychological health (Wirz-justice et al., 2020). Daylighting is the primary source of Vitamin D which is crucial for the human's body internal system, especially for the absorption of calcium (Mirrahimi et al., 2012). In additions, daylighting regulates the human circadian system, which governs the physical health and physiological activity such as sleep's quality and cognitive abilities (Ward et al., 2019). In terms of psychological influence, natural daylighting increase satisfaction, facilitates stress recovery and improve creative problem solving. According to the studies conducted by Rot et al., (2008) and Zadeh et al.(2014) the participants who exposed to natural lighting showed improvement in mood and sociability. Workplace with sufficient natural lighting and pleasant view towards outdoor helps to improve productivity of the employees (Ward et al., 2019).

Moreover, daylighting is not only important for human health but also contributes to energy efficiency in buildings. The use of daylighting is one of the most effective strategies to improve indoor comfort and energy efficiency of the office building as daylighting is abundant in the tropical climate (Y. W. Lim, 2014). In tropical regions, the annual average hours with sunlight is 8 hours per day. However, the daylighting in the tropics often associated with intense solar heat gain which causes thermal discomfort. In additions, excessively high global illuminance and sky illuminance in the tropics often causes non-uniform indoor illuminance distribution and visual discomfort due to the unpredictable illuminance pattern (Y. W. Lim et al., 2013).Thus, the most appropriate daylighting approach for office building in the tropics is to conduct dynamic daylighting harvesting with solar control (Y. W. Lim et al., 2013).

In the response to the green building movement in Malaysia, the sustainability of buildings in Malaysia are evaluated with various aspects such as energy efficiency, water efficiency, and sustainable site management (G. H. Lim et al., 2017). However, the daylighting performance of the building is being evaluated barely based on the Daylight Factor without the consideration of other lighting issues such as glare problem and non-uniform distribution of light (G. H. Lim et al., 2017). According to the study conducted by G. H. Lim et al. (2017), the daylighting performance of the green buildings in Malaysia showed a missing "design gap" between the architect and the interior space usage by the client (G. H. Lim et al., 2017). Although both of the office buildings are being recognized as green building, the occupants don't satisfy with the visual comfort in the workplace (G. H. Lim et al., 2017). Consequently, the daylighting design of office buildings in Malaysia face the problem of lack of interaction between occupants with daylighting with low flexibility of daylighting control by the occupants.

Shading systems are one of the most efficient bioclimate strategies for buildings in tropical regions (Al-Masrani et al., 2018). Thus, the design of building envelope for solar control is very important to improve the daylighting performance and indoor visual comfort (Al-Masrani et al., 2018). Shading devices serve as a regulator of solar radiation flow by convert direct sunlight to diffuse light (Al-Masrani

& Al-Obaidi, 2019). Based on the study conducted by Ossen et al.(2005), the performance of the fixed shading device is different at different orientation. The study carried out by Y. W. Lim et al. (2012) claimed that the internal daylighting level in the building was insufficient due to improper use of fixed shading device. Furthermore, the fixed shading devices are unable to response to the dynamic sky conditions in the tropics, resulting in inconsistency illuminance levels between direct and diffuse light in internal spaces (Al-Masrani et al., 2018). The external factors such as site constraints and aesthetic needs also reveal the weakness of the fixed shading devices (Al-Masrani et al., 2018). The fixed shading device exhibit limitation in daylighting performance due to the inflexible operation method (Al-Masrani et al., 2018).

The limitation of fixed shading system can be overcome by integration of shading devices with responsive design elements (Al-Masrani & Al-Obaidi, 2019). Moveable and kinetic shading system need to be integrated with the building envelope to improve daylighting performance of the office buildings. Kinetic shading devices should be control by the intelligent system which enable the shading devices to response to the internal and external conditions (Al-Masrani et al., 2018). The daylighting quantity and quality in the building throughout various periods of time with varying sun angles need to be used to evaluate the capabilities of kinetic shading systems (Al-Masrani & Al-Obaidi, 2019). In short, this study will focus on the design of kinetic building envelope to improve the daylighting performance of multilevel office building in the tropics.

1.2 Problem Statement

In tropical climate, the main problem to harvesting daylighting is the high intensity of solar radiation, which caused in undesirable solar heat gain(Y. W. Lim et al., 2012). According to data from the Subang Jaya Meteorological Station, the yearly maximum intensity of solar radiation falling horizontally is around 1000W / sqm, and on vertical surfaces (east and west facing surfaces) is around 850W / sqm. The occupants could experience discomfort glare if there are lack of control of the daylighting especially for computer work (Y. W. Lim et al., 2012). Due to the direct

glare problem in the office spaces, many multi-storey offices in Malaysia chose to cover up their window to avoid glare using window blinds. As a result, the energy consumption increased as the offices became more reliant on artificial lighting (Kandar et al., 2011). According to Y. W. Lim et al.(2012), the 5 chosen multi-storey buildings were not designed for daylighting utilisation as the average daylight factor lower than 1.5% and poor daylight distribution uniformity. Furthermore, the performance of daylighting in individual room is better than the open plan office with deep plan. Thus, proper consideration for daylighting performance is needed for energy savings and visual comfort for multi-storey office buildings in Malaysia (Kandar et al., 2011).

The daylighting assessment for multi-storey government buildings carried out by Y. W. Lim et al.(2013) found that the fixed external shading device such as overhang and vertical screen for all orientation could reduce direct solar radiation but not able to maintain the visual comfort in the office spaces due to glare and poor distribution of daylight. This is because the fixed shading devices are non-responsive to the predominantly intermediate tropical sky with dynamic cloud formation. Thus, the design of shading system in tropical climate need to integrate with kinetic mechanism and adaptable design elements to overcome the restriction of the conventional static shading system (Al-Masrani et al., 2018). The harvesting of daylighting in tropical climate need to emphasis on quality instead of quantity. The kinetic shading devices need to be able to control effectiveness of sunlight levels at different period of time, particularly response to the sun angle (Al-Masrani & Al-Obaidi, 2019). The performance of kinetic shading systems are designed based on two main objectives namely glare reduction and sufficient indoor illuminance(Al-Masrani & Al-Obaidi, 2019).

1.3 Research Aim

The aim of the study is to investigate the daylighting performance of kinetic based shading devices in the multi-storey office in tropical climate.

1.4 Research Questions

The questions of the research are :

(a) What is the significance of shading devices for multilevel office in the tropics?

(b) What is the design configuration of shading device to achieve the optimum daylighting performance for multi-storey office in the tropics?

(c) What is the design parameter to optimize the daylighting performance with kinetic shading device?

1.5 Research Objectives

The objectives of the research are :

(a) To identify the factors that would affect the performance of kinetic shading device of multi-storey office building in the tropics.

(b) To implement a kinetic shading system that interacts with the dynamic sky conditions.

(c) To improve the daylighting performance of the workplace with providing optimum indoor illuminance level.

1.6 Scope of Thesis

This research will focus on the design and performance of kinetic shading devices in daylighting harvesting with solar control. The design elements of kinetic shading devices will be determined based on the principle and theory of daylighting harvesting in the tropical climate. The design elements of kinetic shading devices are categorized into two components namely architectural component and mechanical component. The architectural components including the geometric shapes and movement of the shading devices while the kinetic components referred to the mechanism to control the movement of the shading devices. The study also including the understanding of tropical sky. Sky conditions of tropical climate particularly in Malaysia is determined and the solar angle on each orientation are identified. Illuminance (lux) of the office spaces with different layout and daylight factor (%) of the interior spaces are the parameters to assess the daylighting performance of various kinetic shading devices. The relationship between the physical appearance of the shading device and the ability of daylighting harvesting will be investigated through simulation with using "Velux", a software to assess daylighting performance.

1.7 Significance of Study

The kinetic shading devices as building envelope is an innovative solution for improving daylighting performance of office building but yet to be applied on office building in Malaysia. This research contribute to the development of kinetic shading devices design through identify the important design elements. The daylighting performance assessment as the tool for analysing the ability of kinetic shading devices to provide optimal daylighting and improve indoor visual comfort. The findings of the research can be used as a design guide for designers and policymakers.

1.8 Research Methodology

The research framework is to evaluate the daylighting performance of kinetic shading devices in multi-storey office in tropical climates. This research conducted a mixed research method which is qualitative and quantitative approaches. Literature review is used to collect information and knowledge of the daylighting design strategy used in the tropics. Case study was also conducted to explore the form and aesthetic aspects of the building envelope design. The quantitative method is used to determine the daylighting performance of the indoor spaces through computer software.

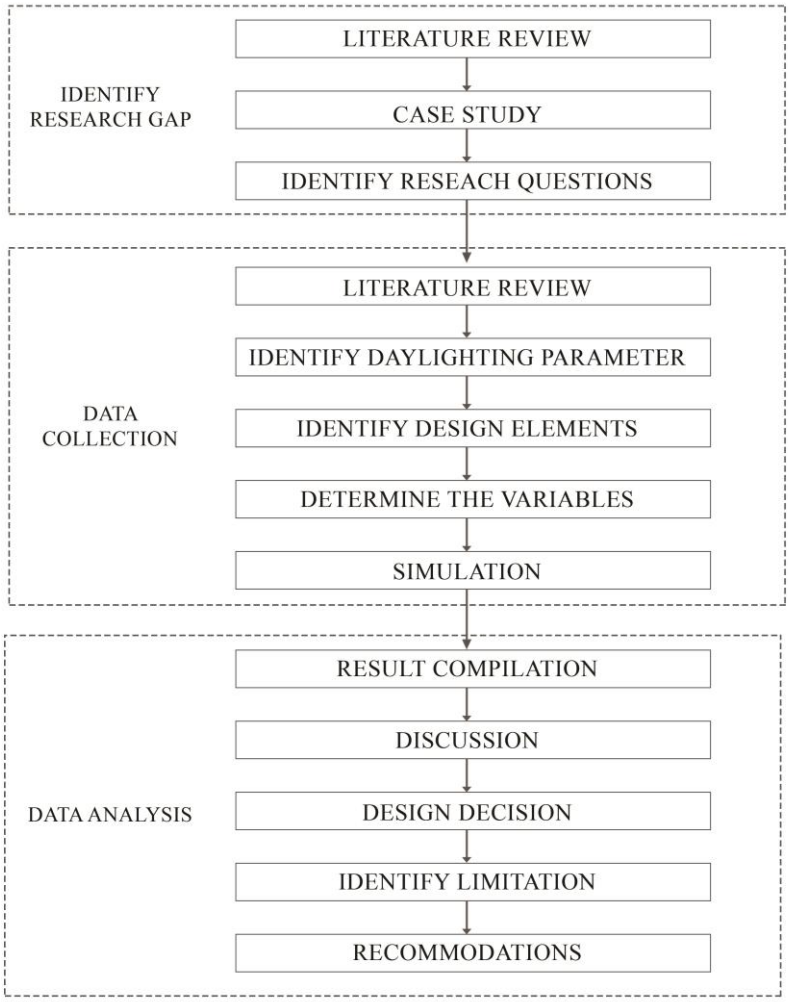

Figure 1.1 Research Methodology Flow Chart

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