LIGHT SHELF GEOMETRY FOR DAYLIGHT AND LIGHTING ENERGY SAVING IN SMALL MEDIUM ENTERPRISE OPEN OFFICE PLAN IN MALAYSIA

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DEDICATION

This thesis is dedicated to my Lord and Saviour Jesus Christ, my late father, Elder John Abimaje, who made immeasurable sacrifices to make sure I am educated, my mother, Deaconess Elizabeth Abimaje and my lovely wife Rebecca Joshua.

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ABSTRACT

Open office plan are common due to their space efficiency. However, daylight, a cardinal design element which has a rendering that best matches the human eye with its attendant physiological, psychological, task performance improvement and the energy conservation merits are not enjoyed in most open office plans. This is due to the use of large unilateral side-lighting which results in excessive and low illumination at the work plane in area close to window and at the back of the office room respectively. This illuminance contrast causes visual discomfort, a situation which makes office tenants avoid available daylight with blind and depend on electric lighting. Light shelf (LS) is one of the daylighting systems which have been studied in the past, however, these research were done mostly in the temperate climate which is different from the tropical climate. Besides, there is a scarcity of the research on energy saving implication of daylighting with LS in the tropics, and as such, the thrust of this research is to study the daylighting performance of LS and its attendant lighting energy saving for open office plan in tropical climate. External LS of 0.6 m and 0.9 m depth placed at different angles with the clerestory window were combined with internal LS of 0.6 m depth at different tilt angles from the clerestory. Additionally, internal LS of 0.6 m depth was introduced at a distance of 0.6 m and 1.05 m from the internal LS to test the effect of additional shelves. Sixty-seven (67) LS test cases were studied using simulation with the application of Integrated Environmental Solution Virtual Environment. The result proved that LS cases improved the daylighting quantity by reducing excessive illumination at the area near the window opening of a unilateral side-lighting office and increasing it at the back where the illuminance level was low. LS was able to improve work plane illuminance (WPI) distribution across the whole room compared to the base case with the range of 65.22 % to 80.00 %. It also improved WPI distribution between the adjacent points in the room with the range of 17.06 % to 25.00 % and saved energy for electric lighting ranging from 11.70 % to 15.97 %. This study therefore, concluded that the depth and angle of the LS affect its efficiency. Hence, the finding of this study encourages the use of LS in the open office plan with unilateral side-lighting by recommending optimum LS geometries based on different orientations.

ABSTRAK

Pejabat pelan terbuka adalah biasa kerana kecekapan ruang tersebut. Walau bagaimanapun, pada waktu siang, elemen reka bentuk kardinal yang mempunyai persembahan yang paling sesuai dengan mata manusia dengan penambahbaikan prestasi fisiologi, psikologi, prestasi tugas dan manfaat penjimatan tenaga tidak dapat dinikmati di pejabat pelan terbuka. Ini disebabkan oleh penggunaan pencahayaan unilateral yang besar yang mengakibatkan pencahayaan berlebihan dan rendah di satah kerja di kawasan yang berdekatan dengan tingkap dan di bahagian belakang bilik pejabat masing-masing. Kontras pencahayaan ini menyebabkan ketidakselesaan penglihatan, keadaan yang membuat penyewa pejabat mengelakkan cahaya siang yang tersedia dengan tirai tingkap dan bergantung pada pencahayaan elektrik. Para cahaya (LS) adalah salah satu sistem pencahayaan siang yang telah dikaji pada masa lalu. Walau bagaimanapun, penyelidikan ini dilakukan kebanyakannya pada iklim sederhana yang berbeza dengan iklim tropika. Selain itu, terdapat kekurangan penyelidikan tentang implikasi penjimatan tenaga cahaya dengan LS di kawasan tropika. Oleh itu, tujuan penyelidikan ini adalah untuk mengkaji prestasi cahaya siang LS dan penjimatan tenaga pencahayaan yang ada untuk pejabat pelan terbuka dalam iklim tropika. LS luaran dengan kedalaman 0.6 m dan 0.9 m dipasang pada jarak 0.6 m dan 1.05 m dari LS dalaman untuk menguji kesan para cahaya tambahan. Enam puluh tujuh (67) kes ujian LS dikaji menggunakan simulasi melalui aplikasi *Integrated Environmental Solution Virtual Environment*. Hasilnya membuktikan bahawa kes LS meningkatkan kuantiti pencahayaan siang dengan mengurangkan pencahayaan berlebihan di kawasan berhampiran bukaan tingkap pejabat dengan pencahayaan sisi unilateral dan meningkatkannya di bahagian belakang di mana tahap pencahayaan adalah rendah. LS dapat meningkatkan taburan iluminasi aras kerja (WPI) di seluruh ruangan berbanding dengan kes asas dalam lingkungan 65.22% hingga 80.00%. Ia juga meningkatkan taburan WPI antara titik bersebelahan di ruang bilik dengan lingkungan 17.06% hingga 25.00% dan menjimatkan tenaga untuk pencahayaan elektrik antara 11.70% hingga 15.97%. Oleh itu, kajian ini menyimpulkan bahawa kedalaman dan sudut pemasangan LS mempengaruhi kecekapannya. Oleh itu, penemuan kajian ini mendorong penggunaan LS di pejabat pelan terbuka dengan pencahayaan sisi unilateral dengan mencadangkan geometri LS optima berdasarkan orientasi yang berbeza.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASEAN	-	Association of South-East Asian Nations
ASHRAE	-	American Society of Heating and Air-conditioning Engineers
ACM	-	Aluminium Composite Material
BC	-	Base Case
BLS	-	Bottom Light Shelf
BRE	-	Building Research Establishment
CIBSE	-	Chartered Institution of Building Services Engineers
CIE	-	International Commission on Illumination
CU	-	Coefficient of Utilisation
DF	-	Daylight Factor
DOE	-	Department of Energy, United States
DR	-	Daylight Ratio
DS	-	Diffusion Sheet
EO1	-	Estimated Outdoor Illuminance
EII	-	Estimated Indoor Illuminance
EPC	-	Energy Performance Certificates
GDDM	-	Graphic Daylight Design Method
IES	-	Illuminating Engineering Society
IESVE	-	Integrated Environmental Solution Virtual Environment
IRC	-	Internal Reflected Component
IT	-	Information Technology
LAT	-	Location-Awareness Technology
LBNL	-	Lawrence Berkeley National Laboratory
LCP	-	Laser Cut Pipe
LEED	-	Leadership in Energy and Environmental Design
LGS	-	Light Guiding System
LS	-	Light Shelf
LTS	-	Light Transporting System
MLS	-	Middle Light Shelf
MS	-	Malaysian Standard

NARM	-	National Association of Roof Light Manufactures
NSDC	-	National SME Development Council
PCM	-	Phase Change Material
PCM	-	Phase Change Material
PSALI	-	Permanent Supplementary Artificial Lighting
RM	-	Malaysian Ringgit
SME	-	Small and Medium Enterprise
USA	-	United States of America
UTM	-	Universiti Teknologi Malaysia
VALRA	-	Variable-area light-reflecting Assembly
VDT	-	Video Display Terminal
VT	-	Visible Transmittance
WPI	-	Work Plane Illuminance
WPIR	-	Work Plane Illuminance Ratio
WWR	-	Window-to-wall Ratio

LIST OF SYMBOLS

Ω	-	Solid Angle Subtended by the source
L_s	-	Source of Luminance
L_b	-	Average Background Luminance
P_{con}	-	Overall Connected Lighting Power
A_{room}	-	Floor Area
ω	-	Angular size of the source of light as seen by eye
E_{min}	-	Minimum Illuminance
$E_{average}$	-	Average Illuminance
E_{max}	-	Maximum Illuminance
Klx	-	Kilolux
GWh	-	Gigawatt hour

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Light is essential for human existence. Man has continuously sought to let in daylight into his dwelling using openings and window openings. The use of opening for admitting daylight can be traced to the prehistoric age when man was using cave as a form of shelter and this opening has undergone series of transformation resulting in different types for glazed windows of different sizes, colours and visible transmittance for different purposes today. As architecture advances so window design also advances. The variation in the intensity and directionality of daylight and its good colour rendering make it desirable in building. The aesthetic quality of a building is usually manifested through the interplay of light and shadow. Even with the advancement in electric light technology today, daylight is still preferable to electric light and other forms of artificial light.

The over-dependence on electric light in offices can be reduced with the application of daylight (Babu *et al.*, 2019; Calama-González *et al.*, 2018). This is because the office tenants operate between 08:00 to 17:00 when the daylight is available (Heng *et al.*, 2020; Lim and Heng, 2016; Mousavi *et al.*, 2018). In the tropics, there is adequate daylight (Yen, 2017), it does not have adverse effect on man, environment and it is free of charge (Lim *et al.*, 2012). Daylight also has good effect psychologically and physiologically on human (Lim and Heng, 2016). Jamrozik *et al.* (2019) and Meresi (2016) posited that the office users carry out their task better under daylight than electric light.

The external illuminance of a place in the tropic like Malaysia can be up to 120 Klx whereas external illuminance of about 20 Klx is attributable to the temperate areas. Nonetheless, Lim (2019) and Mousavi *et al.* (2018)expressed difficulty in daylight utilisation in offices in the tropics as a result of its instability. The external illuminance varies greatly within a short period due to the formation of cloud. Also, Lim (2011) observed that the available daylight was not well utilised in open offices plan in Malaysia as high dependence on electric light is an eloquent testimony of this situation.

Daylight is important for office spaces. However, achieving the desired daylight quantity and quality is a challenging task in open office plan where a number of office staff having different workstations with varying luminous environment (Abd-Kadir *et al*., 2016). This is usually the case with open office plan used for small and medium enterprises especially where unilateral daylighting is the only practical option.

Open office plan are uninterrupted office space with a depth between 6-12 m (Hongisto *et al*., 2016). Heng (2017) used an office depth of 12 m as a deep-plan office in the study of light pipe for office building in Malaysia. Hansen (2006) reported that an office plan layout free from obstruction up to 17 m and above is referred to as deep-plan office under the United Kingdom Property Services Agency and Department of Environment. There seems not to be a consensus on the depth of open office plan. However, most researchers used less than 12 m depth for open office plan. It can, therefore, be rationalised that the depth of open -plan office should not exceed 12 m whereas office depth of 12 m and above can be considered as a deep-plan office. This study uses open office plan with 9 m depth.

There is a rise in the use of open office plan nowadays by corporations to take advantage of large office space (Abdollahzadeh *et al.*, 2020; Chraibi *et al.*, 2016). However, the large area in open office plan also makes reliance on daylight difficult, a situation that necessitates the use of electric light (Abd-Kadir et al., 2016). The energy use by the building sector worldwide is about 40 % of the total energy (Omrany *et al.*, 2016; Yang *et al.*, 2014). Out of this, 25 % to 40 % is for electric lighting (Krarti *et al.*, 2005). This trend in energy use is similar to that of nations in Asia (Yang *et al.*, 2014). The buildings used for commercial activities in Asia have about 233 kWh/m^2/year as the building energy index (BEI) (Loewen *et al.*, 1992). Loewen *et al.* (1992) further maintained that an average building in Malaysia consumed 269 kWh/m^2/year and concluded that it was higher than that of other nations considered in the study. Further, in a relatively recent study, Hassan *et al.* (2014) lamented that 38, 645 GWh of electricity consumption is attributable to commercial building in 2012. Less than 135 $kWh/m^2/yr$ is the recommendation for energy use by Malaysian standard. Unfortunately, energy use of approximately 100 % beyond the said standard as was noted by Loewen *et al.* (1992) in commercial buildings in Malaysia. In a related study, Sadrzadehrafiei *et al.* (2011) conducted a study, which the result indicated that 19 %, 20 %, 58 % and 3 % of energy usage in Malaysian offices is for equipment, electric lighting, cooling and others correspondingly.

Also, Saidur (2009) submitted that heating and cooling account for 57 % of energy utilisation, light is responsible for 19 %, Pump uses 18 % while other services use 6 %. This research work revealed a substantial energy usage for lighting in the study area. The use of one-sided large window opening without shading devices in open office plan caused the occurrence of non-uniform distribution of illuminance between the rear area of the room and the area close to the opening of the window (Dogan and Stec, 2018; Indarto *et al.*, 2017). This causes discomfort to the office users visually. A situation that resulted in high reliance on electric light in the open office plan.

The employment of light-casting device like light shelf can improve daylighting performance and its attendant energy savings in open office plan in the tropical climate. Light shelf is simple and can easily be installed; this makes it cost effective than most other daylight reflecting and distributing systems. Besides, different geometries can be easily configured, and it can help to redirect light to the rear area of open office plan space in the building (Bahdad *et al.*, 2020; Mangkuto *et al.*, 2018; Moazzeni and Ghiabaklou, 2016; Zazzini *et al.*, 2020).

Achieving adequate daylight quantity and its distribution at the work plane through efficient light shelf geometry as well as the resultant reduction in reliance on electric lighting in open office plan in the tropical climate is the focus of this research.

1.2 Problem Statement

As a result of the desire for easy cooperation and collaboration among office workers, many organisations have embraced open office plan (Shafaghat *et al.*, 2015). These kind of offices are common places in Malaysia. For instance, Lim (2011) arrived at an average size of open office plan putting into consideration thirteen of these offices in Johor, Malaysia. However, most of these open office plans have unilateral lighting Lim *et al.* (2012). The unilateral lighting in open office plan is associated with excessive illumination at the work plane at the area close to the window while it diminishes towards the back to the extent that it becomes too low in quantity for any task to be performed (Abd-Kadir *et al.*, 2016; Lim *et al.*, 2012; Modaresnezhad and Nezamdoost, 2017).

There is abundant daylight in the tropical region. This is evidenced as the external illuminance in this region can be more than 100 klx (Bahdad and Fadzil, 2019; Lim *et al.*, 2012). This implied that there is a great potential for daylight utilisation in the office which operates within the day time usually from 8 am - 5 pm. However, the penetration of this daylight into the office room is not controlled in most cases with shading devices that can improve the daylight quantity and quality (Dogan and Stec, 2018; Mostofa, 2015). For instance, office with unshaded window can have as much as 11, 193 lux as the mean illuminance with very low uniformity less than 0.1 (Lim and Heng, 2016). This kind of high illuminance at the work plane without appropriate shading element that can also distribute it into the deeper interior part of the room brought about visual discomfort for office tenants.

There is high electric energy consumption for lighting in offices in Malaysia. For instance, Sadrzadehrafiei *et al.* (2012) researched on energy consumption in Malaysian offices. The study revealed among other things that 20 % and 58 % of energy consumption was for electric lighting and air conditioning respectively. This high energy consumption for electrical lighting was due to non-utilisation of daylight as a result of its poor quantity and quality across the entire room a situation that makes office occupants avoid the available daylight with blind and depend totally on electric light with its attendant energy consumption.

Therefore, it is necessary to employ innovative daylighting system such as light shelves which provides shading at the area of the room close to the window opening with excessive WPI, increasing it at the back where the work plane illuminance is low as well as improving daylight distribution across the entire room. Besides, electricity consumption for lighting can be minimised if improved daylighting is integrated with electric light.

1.3 Aim and Objectives of the Research

This work aims at proposing light shelf geometry that is efficient for daylight and electric light energy saving for small and medium enterprise (SME) open office plan in Malaysia. To achieve the research aim, the specific objectives are:

(i) To investigate the daylight condition of the SME open office plan,

(ii) To determine light shelf test cases with daylight utilisation potential using daylight factor (DF),

(iii) To evaluate the quantitative and qualitative daylight performance of the selected light shelves using DF, estimated indoor illuminance (EII) and work plane illuminance (WPI) uniformity,

(iv) To study the lighting energy saving due to daylight utilisation of the selected light shelves, and

(v) To propose efficient light shelf geometry for daylight and lighting energy saving.

1.4 Research Questions

The research questions for this study are as follows:

(i) What is the present condition of daylight in SME open office plan in Malaysia?

(ii) What are the performances of light shelf in SME open office plan in Malaysia in terms of daylight quantity and quality?

(iii) What amount of energy for lighting is saved from daylighting performance using light shelf integrated with window opening in SME open office plan in Malaysia?

(iv) What is the efficient light shelf geometry for best daylight performance as well as electric lighting energy saving?

1.5 Research Hypothesis

Efficient light shelf geometry should be able to illuminate open office plan and equally maintain illuminance distribution uniformity as illustrated in Figure 1.1. Further, it should be able to bring about a reduction in lighting energy consumption when daylight and electric light are integrated.

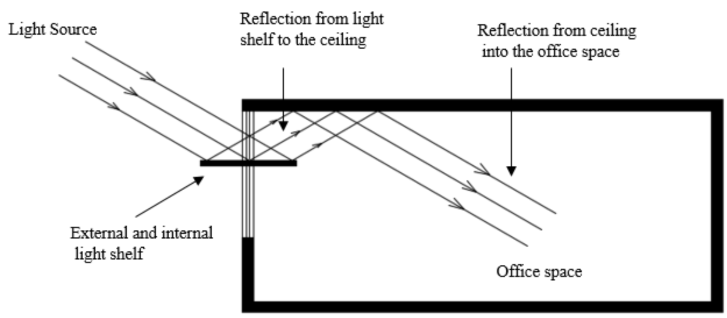

Figure 1.1 Illustration on the function of light shelf

1.6 Research Gap

Research has been done by several scholars on light shelf. These studies were mostly in the temperate climate (Kim *et al.*, 2019; Lee, 2019; Lee *et al.*, 2017a; Meresi, 2016). Daylighting in the temperate climate is different from the tropical daylight as explained in Section 2.5 with a particular reference to Johor Bahru, Malaysia. Also, the simulation software sky model uses temperate sky data which is at variance with the tropical sky data. Hence, the need for validation of the software under tropical sky condition of Malaysia before its application in this study. Further, Heng *et al.* (2020), Heng (2017) and Toledo *et al.* (2016) commented that most of the daylighting studies were done in shallow plan buildings with unilateral lighting. This was evidenced in Lee *et al.* (2017a) and Sherif *et al.* (2012)among others. However, the challenge of achieving efficient daylighting in shallow office plan is different from open plan office.

Many of the studies on light shelf involved south orientation. Some of these include but not limited to Heng (2017) , Berardi and Anaraki (2015) and Meresi (2016). Although locations in the tropic of cancer receive daylight for a longer period within the daytime, it is sometimes impossible to achieve this orientation due to site constrain and other architectural design limitations. Thus making the study of the daylighting performance based on the four cardinal orientations necessary.

The study of light shelf over the years is skewed to its daylight performance. However, it has energy saving potential which cannot be ignored (Moazzeni and Ghiabaklou, 2016). When daylight and electric light are integrated, the expectation is that there should be a reduction in the use of energy for electric light. However, there is a scarcity of the study on electric energy saving attributable to daylighting performance of light shelf generally, and this is more serious in the tropical climate.

Berardi and Anaraki (2015) stated that variables such as height, width of light shelf and orientation of building, among others affect daylighting performance. Previous studies used internal light shelf, external light shelf, internal and external light shelf with different tilt angles and depths (Kontadakis *et al.*, 2017a). However, in this thesis, addition of middle and bottom light shelves at different tilt angles to the clerestory changed the light shelf geometry from most of the previous ones. Also, the middle and bottom light shelves were expected to bring about an increase in daylighting performance associated with the increase in the height of the light shelf from the ceiling. This thesis, therefore, sets out to study the different light shelf geometries, their daylight performance and electric energy saving implications in a SME open plan office in Malaysia. The summary of the previous studies is shown in Table 1.1.

Table 1.1 Summary of some previous related studies and the present study

		CLIMATE TYPE		BUILDING TYPE		DESIGN VARIABLES									GEOMETRY OF INTERIOR SPACE			METHODOLOGY			DAYLIGHTING PERFORMANCE PARAMETERS OF LIGHT SHELF					
						EXT. LIGHT SHELF					INT. LIGHT SHELF															
S/N	AUTHOR/YEAR	Tropical Climate	Temperate Climate	Office Building	Others	Depth	Ceiling-Light Shelf Height	Horizontal Light Shelf	Curved Light Shelf	Other Light Shelf Geomet.	Depth	Ceiling -Light Shelf Height	Horizontal Light Shelf Height	Curved Light Shelf	Deep Plan Space	Open Plan Space	Others	Physical Scaled Model	Full-Scale Building	Computer Simulation	Daylight Factor	Work Plane Illuminance	Daylight Dist. Uniformity	Glare	Energy	Others
1	Bahdad *et al.* (2020)	■		■		■				■	■						■			■						■
2	Kurtay and Esen (2017)		■	■		■	■	■	■		■	■	■	■			■			■		■	■			■
3.	Lee *et al.* (2017a)		■	■		■		■											■			■	■		■	■
4.	Lim and Heng (2016)	■		■							■			■		■		■		■	■	■	■	■		■
5.	Meresi (2016)		■		■					■									■	■	■		■	■		
6.	Berardi and Anaraki (2015)		■		■	■	■	■	■		■	■	■	■	■				■	■						
7.	Ponmalar and Ramesh (2014)	■		■		■		■		■	■		■				■		■	■	■	■	■			
8.	Xue *et al.* (2014)	■			■													■		■		■	■			
9.	Lim *et al.* (2013)	■		■							■		■			■		■		■	■	■	■			
10.	Lim *et al.* (2012)	■		■				■	■				■	■	■				■		■		■			

Table 1.1 Summary of some previous related studies and the present study (continued)

		CLIMATE TYPE		BUILDING TYPE		DESIGN VARIABLES									GEOMETRY OF INTERIOR SPACE			METHODOLOGY			DAYLIGHTING PERFORMANCE PARAMETERS OF LIGHT SHELF					
						EXT. LIGHT SHELF					INT. LIGHT SHELF															
S/N	AUTHOR/YEAR	Tropical Climate	Temperate Climate	Office Building	Others	Depth	Ceiling -Light Shelf Height	Horizontal Light Shelf	Curved Light Shelf	Other light Shelf Geomet.	Depth	Ceiling-Light Shelf Height	Horizontal Light Shelf	Curved Light Shelf	Deep Plan Space	Open Plan Space	Others	Physical Scaled Model	Full-Scale Building	Computer Simulation	Daylight Factor	Work Plane Illuminance	Daylight Dist. Uniformity	Glare	Energy	Others
11.	Lim and Ahmad (2015)	■		■							■		■			■		■		■	■	■	■			
12.	Lee *et al.* (2018a)		■	■		■				■						■			■	■		■			■	■
13.	Lee *et al.* (2018b)		■	■		■		■								■		■	■	■		■	■		■	
14.	Kim *et al.* (2019)		■	■						■						■			■						■	
15.	Lee *et al.* (2017b)		■	■				■										■		■		■	■		■	
16	Present Study	■		■		■	■	■			■	■	■			■				■	■	■	■		■	

1.7 Scope and Limitations

The study is delimited to the daylighting performance of SME open office plan in Malaysia. Spaces in the office building like washroom, office that are partitioned and pantry are not part of this research work. Also, the office occupants and the furniture are excluded from this work because of many ways that the latter can be arranged in the room. Consequently, the result of this research work is based on an empty SME open office plan without the impact of the users and the furniture.

The daylight quantity and its distribution, as well as the electric lighting energy saving through dimming method, form the focus of this research, therefore on and off method was not used. Criteria like energy for cooling, cost of electrical lighting system, office users' perception of the daylighting condition of the office was not part of this study because of the exigency of time.

The tropical sky of Malaysia which is mainly intermediate was applied in this study. The dates for the solstices and equinox were used. These are the days when the angle of the sun path is critical. Hence, 21st March, 22nd June and 22nd December were used. 21st March and 23rd September are dates for the equinox but only 21st March was used since the sun path on these dates are similar. During equinox, the sun path is directly above the equator. 22nd June is the June solstice when the sun is furthest from the equator in the northern hemisphere while 22nd December is the date for the December solstice when the sun is furthest from the equator in the southern hemisphere.

North-east orientation was used for the validation of the software employed in this research. This was because the office used in the Eco-home of the Universiti Teknologi Malaysia has its window facing this orientation. There were no trees in this orientation to cause any obstruction. This same orientation was also modelled using Integrated Environmental Solution Virtual Environment (IES VE) for validation. However, the four cardinal orientations: north, south, east and west were used for the main simulation.

The research work focused on the light shelf geometry. Therefore, other design variables such as the surface reflectivity and colour were kept constant. The light shelf of 600 mm and 900 mm depth were used for external light shelves while shelf of 600 mm depth was mostly used for internal light shelves. The different shelves were combined at different angles and thus gave different geometries.

The data for this study was mainly obtained from the result of the simulation. Criteria of analysis like daylight factor, daylight ratio, estimated indoor illuminance, work plane illuminance ratio, and electric lighting energy as a function of daylight availability through dimming control were used for further analysis and discussions.

1.8 Importance of the Research

This study helps in improving daylight illumination and its distribution in the SME open office plan in Malaysia by exploring the different geometries of the light shelf. In this case, there will be more productivity among the office tenants as they work under preferred luminous interior office condition. Also, the issue of absenteeism will be minimised as unsatisfactory luminous office environment is often associated with this undesirable workers' attitude. Moreover, the improvement in the daylighting condition in the office will have positive physiological and psychological effects on the workers in the office.

The improved daylight performance, when harvested, will result in electric energy saving. This is very cardinal as the reduction in energy consumption will result in more economic gain since less money will be spent on energy. Further, in some cases, energy is obtained through the burning of fossil fuel. When this happens, greenhouse gases such as carbon dioxide, carbon monoxide, and sulphur dioxide among others which deplete the ozone layer are emitted into the atmosphere. Therefore, reducing energy consumption in offices implies reducing the rate at which the atmosphere gets polluted and improves the challenge of climate change.

The result of this research will be of benefit to architects, light shelf manufacturers, and other professionals in the building industry on efficient light shelf geometry in SME open office plan. Adopting the recommendations of this study will facilitate timely project delivery as decision on the choice of light shelf geometry will be faster.

This thesis will also serve as reference material for researchers interested in similar or related study thereby extending the frontiers of knowledge.

1.9 Organisation of the Thesis

This thesis has five chapters as presented in Figure 1.2. The first chapter which is **Chapter One** gave the background of this research work alongside with the problem statement, hypothesis of the research, research gap, aim and objectives, scope and limitation, and importance of the research. It equally covers the thesis organisation.

Chapter Two is the summary of previous studies on daylighting in architecture and its impact on man. It also reviews energy consumption in the building. The characteristics of daylighting in the tropical climate with a focus on Malaysia are also reviewed. Further, the characteristics of the open office plan buildings are reviewed. Finally, daylighting systems that comprised light transporting and guiding systems were reviewed.

Chapter Three focuses on the previous daylighting methodology and the one used in this thesis. It explains the validity of the method used. It also explains all the software simulation settings, criteria of analysis and the performance indicators.

Chapter Four covers the results, analysis as well as the findings based on the study of the daylight performance of light shelf geometries and the electric lighting energy saving implication under the four cardinal orientations. The quantitative daylighting performance was determined through DF, DR, and EII. The light shelves with high potential quantitative performance were selected for qualitative performance. The qualitative daylight performance was studied with WPI uniformity. This was followed by the study of electric energy saving performance.

Chapter Five is the conclusion of the entire study in this thesis. It summarises the aim, objectives and the methodology used in achieving these objectives as well as the findings. It also gives a highlight on the daylight and electric light energy saving situation in SME open office plan in Malaysia without and with light shelf. This chapter ended with the recommendations on light shelf geometries for different orientations and suggestion of areas of further research.

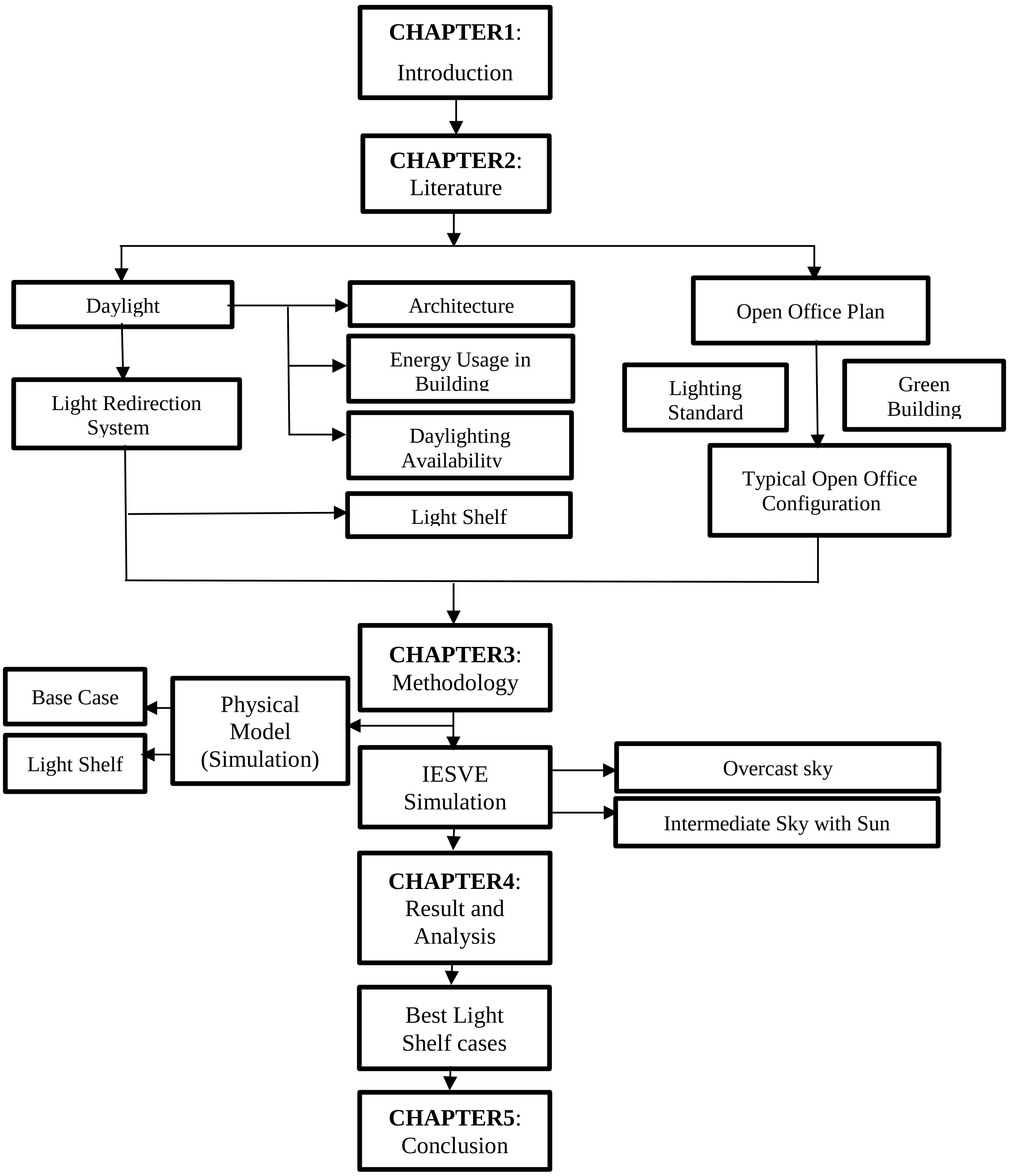

Figure 1.2 Research flow and thesis organisation

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