DAYLIGHT DRIVEN DESIGN IN ENHANCING ENERGY EFFICIENCY OF OFFICE BUILDING IN TROPICAL CLIMATE

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To my beloved parents and siblings

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ABSTRACT

The aim of this research is to establish a daylight driven office building design that improve the energy efficiency of office building in Malaysia. To achieve this aim, the key principles of daylighting are to be establish. The daylighting key principles are solar heat gain minimization, glare prevention, deep penetration of daylight, uniform daylight distribution, electrical light response to harvested daylight, interior planning and design consideration. The research methodology chosen are computer simulation and comparative analysis of case studies. Computer simulation is carried out to determine the optimum building form with minimal solar radiation and the effectiveness of light shelf to harvest daylight in relation to its width. While comparative analysis of case study is carried out to identify the daylighting strategies that implemented and its effectiveness. The results of the research can be categorise as three part that is comparative analysis of case studies, solar radiation simulation and daylighting simulation. Firstly, the three selected case studies show that consideration of all daylighting key principles is crucial to achieve high energy efficiency office building in Malaysia. Secondly, result of six cases of solar radiation simulations show that building form that has podium and tower with self-shading facades has less solar heat gain compared to other building form that do not have those characteristics. Lastly, the results of six cases for daylighting simulation shows that implementation of light shelf of 1500mm width enable to reduce glare effectively but slightly reduced desirable illuminance of 300-400 lux. Therefore, integrated approach that is introduction of reflective ceiling is required to increase the floor area with desirable illuminance of 300- 400 lux for healthy working environment.

ABSTRAK

Kajian ini bertujuan untuk mewujudkan reka bentuk bangunan pejabat yang didorong oleh prinsip pencahayaan semula jadi untuk meningkatkan kecekapan tenaga bangunan pejabat. Prinsip-prinsip utama pencahayaan semula jadi perlu dikenalpasti untuk mencapai matlamat ini. Prinsip-prinsip utama pencahayaan semula jadi merangkumi pengurangan sinaran suria, pencegahan silau, penembusan cahaya semula jadi yang mendalam, pengedaran cahaya dengan seragam, lampu elektrik yang bertindak balas dengan pencahayaan semula jadi, perancangan ruang dalaman dan pertimbangan reka bentuk. Metodologi kajian yang dipilih adalah simulasi komputer dan analisis perbandingan kajian kes. Simulasi komputer digunakan untuk menentukan bentuk bangunan yang optimum dengan radiasi solar yang minimum dan keberkesanan rak cahaya untuk mendapatkan pencahayaan semula jadi berkaitan dengan lebarnya. Analisis perbandingan kajian kes digunakan untuk megenal pasti strategi pencahayaan semula jadi yang dilaksanakan dan keberkesanannya. Hasil kajian ini boleh dikategorikan kepada tiga bahagian iaitu analisis perbandingan kajian kes, simulasi sinaran suria dan simulasi pencahayaan semula jadi. Pertama, tiga kajian kes yang dipilih menunjukkan bahawa pertimbangan untuk semua prinsip utama pencahayaan semula jadi adalah penting untuk mencapai pejabat bangunan yang mempunyai kecekapan tenaga yang tinggi. Kedua, keputusan enam kes untuk simulasi radiasi solar menunjunkkan bentuk bangunan yang mempunyai podium dan menara dengan fasad yang mampu meneduhkan diri sendiri mempunyai haba solar yang kurang berbanding bentuk bangunan lain seperti bentuk bangunan yang tidak mempunyai ciri-ciri tersebut. Ketiga, keputusan enam kes berkaitan dengan simulasi pencahayaan semula jadi menunjukkan bahawa pelaksanaan cahaya rak 1500mm lebar dapat mengurangkan silau dengan berkesan tetapi mengurangkan keterangan yang diperlukan iaitu 300- 400 lux. Oleh itu, integrasi siling yang reflektif diperlukan untuk meningkatkan kawasan lantai dengan keterangan 300- 400 lux dan menghasilkan persekitaran kerja yang sihat.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Daylight availability in Malaysia can be considered numerous in amount throughout the year, but energy usage for typical office building remain high with average Building Energy Index (BEI) of 200 to 250 kwh/m^2/year (Chan, 2009) as shown in Figure 1.0. Without taking daylighting as part of the design consideration, the building design will lead to a typical deep building plan design that rely heavily on artificial light despite of having large window opening.

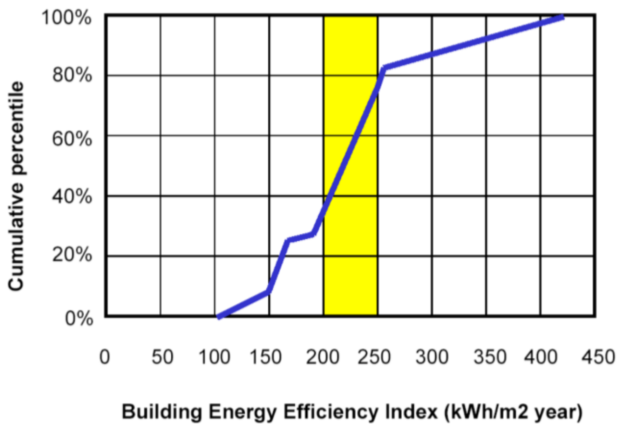

Figure 1.0: Average of building energy efficiency in Malaysia (Source: Chan, 2009)

Furthermore, despite of high direct solar heat gain of high rise facades, intends usage of expensive glazing caused emerging forest of “glass boxes” office building design which further worsen urban heat island effect and lead to high energy consumption for cooling. As energy efficiency is one of the key to sustainable future therefore through passive daylighting principles, building performance and working environment in office building can be enhanced and hence achieving energy efficient in office building.

By prioritizing the key principles of daylighting harvesting which are solar heat gain minimisation, glare prevention, deep penetration of daylight, uniform daylight distribution, electrical light response to daylight harvested and lastly interior designing will aid designer to design building that are more sustainable and efficient in the future.

The average minimum daylight available in Malaysia is above 10,000 lux during daytime and with office spaces only required daylighting of 300 lux to 400 lux during working hour. Thus, this shows that there is potential in harvesting daylight in Malaysia. Therefore, buildings should be designed to maximise the amount of natural light that enters the building, particularly workplaces. This can lead to significant energy savings by reducing the need for artificial lighting and furthermore has been shown to improve productivity (Edwards & Torcellini, 2002).

1.2 Background Studies

According to Green Tech Malaysia (2010), office building is the third highest energy consumption building typology after the hospital and hotel building in second and first respectively as shown in Figure 1.1. When building consumed high energy, it also represents the high carbon emission to the environment. Green Technology Corporation (2011) stated in the Clean Development Mechanism (CDM) Report, every

0.747kg of CO^2 equals to 1kWh of electricity generated by power plant in Peninsula Malaysia.

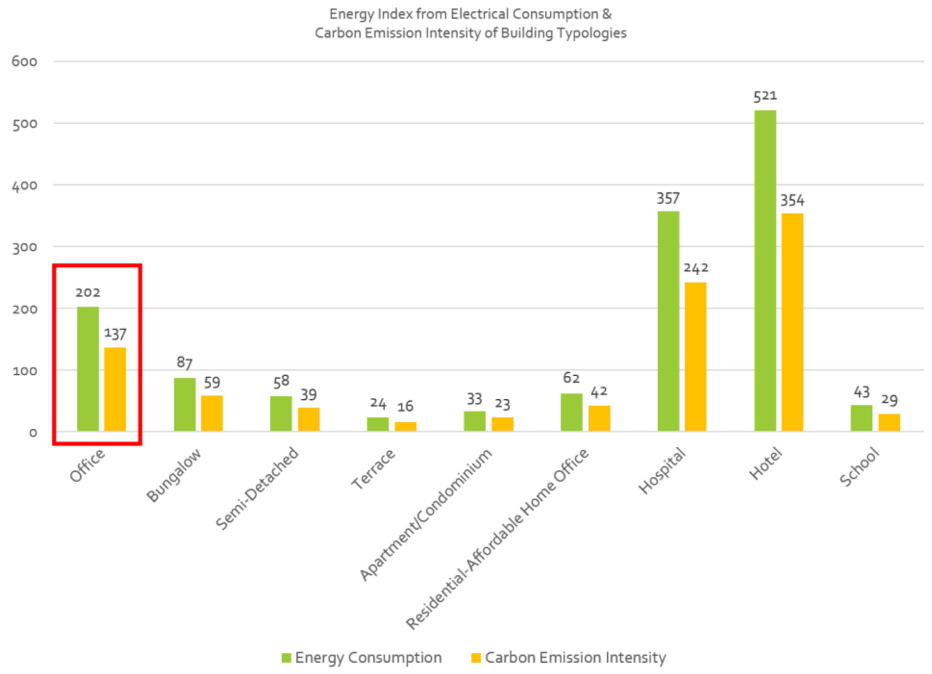

Figure 1.1: Energy index from electrical consumption and carbon emission intensity of building typologies in Malaysia (Source: Green Tech Malaysia ,2010)

Figure 1.2 shows that Malaysia is the highest CO^2 emission per capita compared to neighbouring countries such as Singapore and Indonesia (World Bank, 2016). World Resources Institute (WRI) suggested that 2 tons of CO^2 per capita per year must be targeted for a sustainable living on earth while currently Malaysia is on 7.9 tonnes per capita which exceeded the suggested CO^2 emission per capita.

As Malaysia's voluntarily committed to reduce 40% if its greenhouse gas (GHG) emissions from 1990 levels by 2020, announced at the 2009 United Nations Climate Change Conference in Copenhagen (COP-15). Therefore, it is crucial for office building in Malaysia to be energy efficiency to significantly reduce energy consumption and carbon emission.

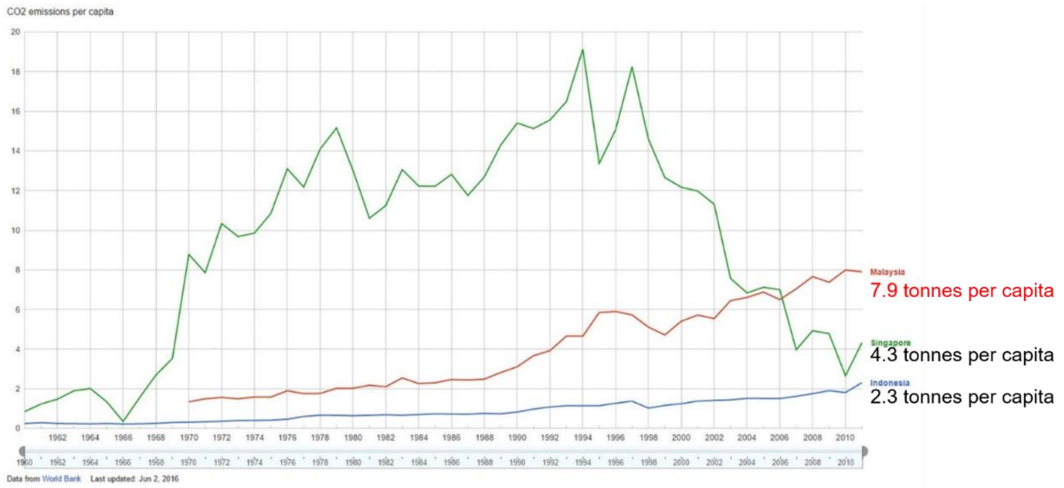

Figure 1.2: CO^2 emission per capita of Malaysia, Singapore and Indonesia from year of 1952 to 2010 (Source: World Bank, 2016)

1.3 Problem Statement

Typical office building in Malaysia is ranked as the top three building typology of high energy consumption and carbon emission (Green Tech Malaysia, 2010). As shown in Figure 1.3, the energy consumption during the operational stage by artificial light is second highest (20%) after the HVAC (58%). Therefore, by implementing the key principles of daylighting during the initial design stage will enhance the building's performances as it reduces the usage of artificial lighting and hence reduce the energy consumption of the building.

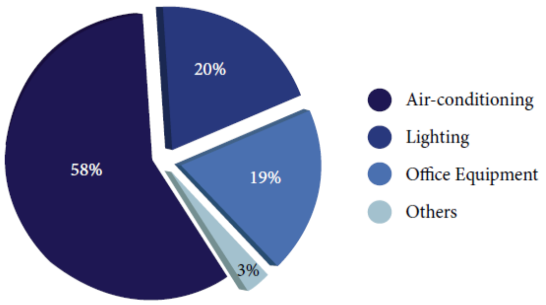

Figure 1.3: Typical electricity usage in office buildings in Malaysia (Source: Energy Commission, 2016)

1.4 Research Aim

The aim of the research is to establish a daylight driven office building design that improve the energy efficiency of office building in tropical climate.

1.5 Objectives of the Study

There are three main objectives that are targeted to be achieved in this research which stated as below: -

i. To identify the daylight strategies in achieving optimum daylight penetration into the building.
ii. To determine the building form through daylight principles.
iii. To develop integrated daylighting strategies for optimum working environment and hence enhancing energy efficiency of building.

1.6 Research Questions

The research questions are established and is interrelated to the objective of the study are stated as below: -

a) What are the possible daylight strategies that can be implemented to enhance daylight penetration into the building in tropical climate?
b) How daylighting enhances the working environment and enhancing the energy efficiency of building?
c) How daylight principles affect the building forms?

1.7 Significance of the Study

This research is crucial in understanding the important role of daylighting and integrated the strategies into design consideration especially during the initial stage of building design. This can significantly improve the energy performance of the building. By taking solar as the design driving force, it will establish a solar and environmentally responsive architecture design which will enhance the energy efficiency as well as the working environment of the building. Finally, the findings of this research will be implemented and integrated into the design thesis as part of the design strategies.

1.8 Research Methodology

The research methodology employed primary is through computer simulation. Software such as Insight 360 Revit solar simulation will be used to analyse the solar heat gain of six building forms and Velux simulation software is used to analyse the daylight's quantity and quality the six cases regarding light shelf and reflective ceiling.

Apart from computer simulation, three case studies of energy efficient office buildings in Malaysia are selected to compare and analyse the daylighting strategies that implemented and their performances. Further information regarding research methodology and the framework of research will be elaborated in Chapter 3.

1.9 Structure of Thesis

Referring to Figure 1.4, it shows the structure of the thesis which developed from objectives to data collection then followed by data analysis and lastly conclude with expected findings.

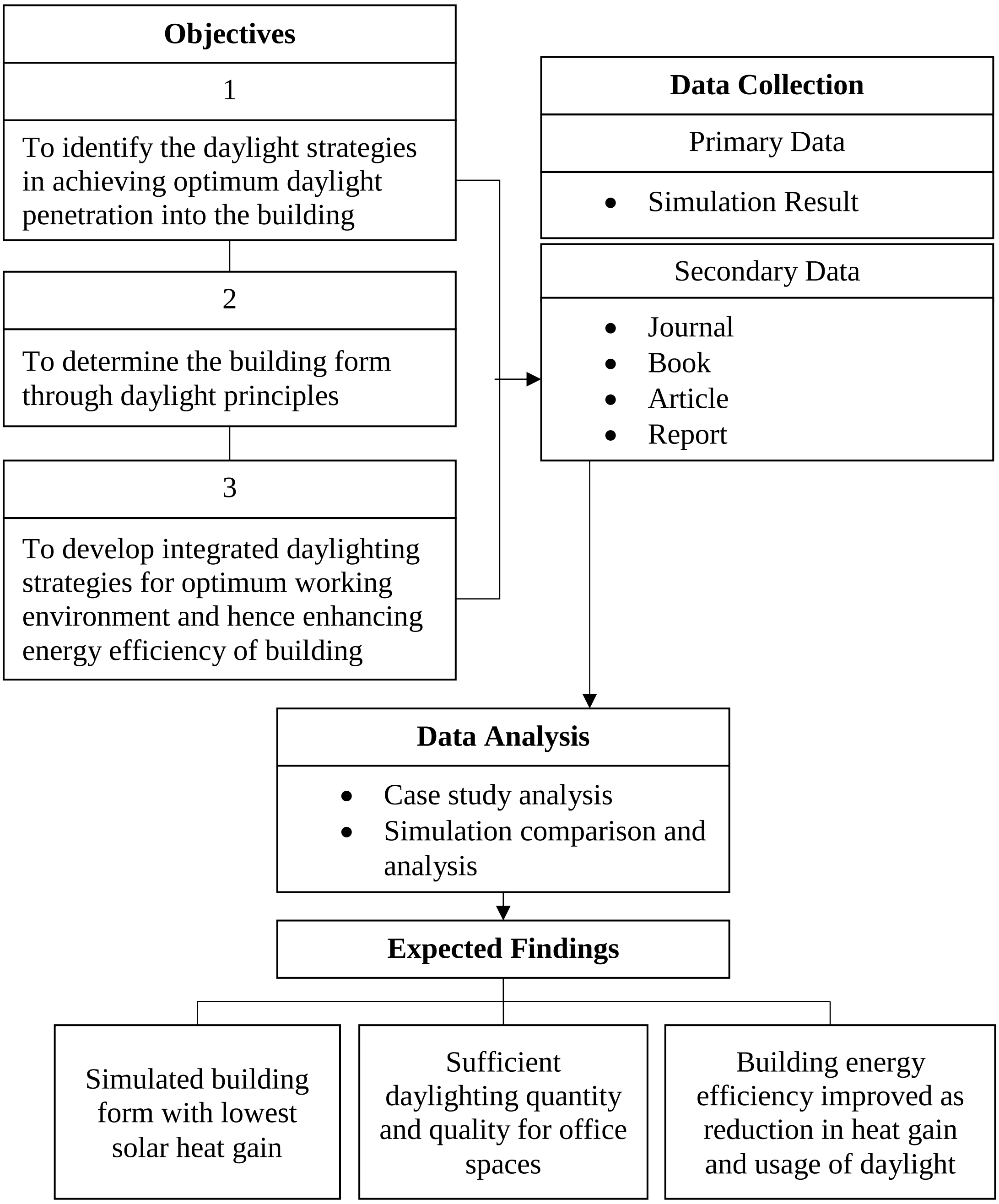

Figure 1.4 Structure of Thesis

REFERENCES

Ander, G. D. (2003). *Daylighting Performance and Design* (2nd ed.). Hoboken, New Jersey: John Wiley & Sons, Inc.

Autodesk . (2017). *Sustainability Workshop Glazing Properties*. Retrieved 22 March, 2017, from https://sustainabilityworkshop.autodesk.com/buildings/glazing-properties#SHGC

Autodesk. (2011). *Sustainability workshop*. Retrieved 15 March, 2017, from http://sustainabilityworkshop.autodesk.com/buildings/massing-orientation-daylighting

Autodesk. (2017). *Autodesk INSIGHT 360*. Retrieved 11 March, 2017, from http://www.autodesk.com/products/insight-360/overview

Autodesk Education Community. (2011). *Autodesk Sustainability Workshop*. Retrieved 11 June, 2015, from Passive Design Strategies | Sustainability Workshop: http://sustainabilityworkshop.autodesk.com/buildings/massing-orientation-cooling

Bainbridge, D., & Haggard, K. (2011). *Passive Solar Architecture: Heating, Cooling, Ventilation, Daylighting and More Using Natural Flows* (1st ed.). United State: Chelsea Green.

Battisto, D., & Franqui, D. (2013). A Standardized Case Study Framework and Methodology to Identify "Best Practices". Clemson,South Carolina: Clemson University.

Beltran, L. O., Lee, E. S., Papamichael, K., & Selkowitz, S. (1994). The design and evaluation of three advanced daylighting systems: light shelves, light pipes and skylights. Berkeley, CA: Lawrence Berkeley National Labotory.

Bleicher, P. D.-I. (29 May, 2014). *Climate Responsive Building Design- ZEO Building in Kuala Lumpur, Malaysia.* Retrieved 14 December, 2016, from en.e4g.org: http://en.e4g.org/wp-content/uploads/2015/07/E4G-Climate-responsive-building-design-----Malaysia-project-Volkmar-Bleicher-ENG.pdf

Boyce, P., Hunter, C., & Howlett, O. (2003). *The benefits of dayligt through windows.* Troy (NY): Rensselaer Polytechnic Institute.

Bright Shelf. (2015). *BrightShelf® vs. Traditional Flat Shelf*. Retrieved 3 May, 2017, from http://www.brightshelf.com/light_shelf_comparison.html

Carmody, J., Selkowitz, S., Lee, E. S., Arasteh, D., & T., W. (2004). *Window system for high performance building.* New York: Norton & Company.

Chan, S. A. (14 February, 2009). *GREEN BUILDING INDEX – MS1525 Applying MS1525:2007 Code of Practice on Energy Efficiency and Use of Renewable.* Retrieved 20 May, 2017, from http://www.greenbuildingindex.org/Resources/20090214%20-%20GBI%20MS1525-2007%20Seminar/20090214%20-%20GBI%20MS1525-2007%20Seminar%20(CSA)%20Notes.pdf

Chen, T., P.E., ENG, C., Ashrae, F., & P.E, A. I. (2013). Malaysia's Green Diamond. *High Performing Building Fall 2013*, 20-32.

Chia, C. P. (2004). The Performance of Daylighting with Shading Device. *Tamkang Journal of Science and Engineering, VII*(4), 205-212.

Department of Standard Malaysia. (2007). *MS 1525.* Malaysia: Department of Standard Malaysia.

Edwards, L., & Torcellini, P. (2002). *A Literature Review of the Effects of Natural Light on Building Occupants.* United States: National Renewable Energy Laboratory.

Egan, D. M., & Olgyay, V. (2003). *Architectural lighting* (Architectural lighting 2nd ed.). Troy (NY): Lighting Research Center.

Energy Commission. (2016). *Guidelines on No-Cost and Low-Cost Measures for Efficient Use of Electricity in Buildings.* Putrajaya: Suruhanjaya Tenaga (Energy Commission).

Evans, B. H. (1961). *Natural Lighting and Skylights.* Texas: A&M University.

Evans, B. H. (1981). *Daylight in Architecture* (Architectural Record ed.). America: McGraw-Hill Publication Company.

Garcia Hansen, V., & Edmonds, I. (2003). Natural Illumination of Deep-Plan Office Buildings: Light Pipe Strategies. Sweden: Research Gate.

Garde, F., Mara, T., Laure, A. P., Boyer, H., & and Celaire, R. (2001). Bringing Simulation to Implementation: Presentation of Global Approach in the Design of Passive Solar Buildings under Humid Tropical Climates. *Journal of Solar Energy*(71), 109-120.

GDP Architect. (2015). *KKR2 Tower*. Retrieved 23 May, 2017, from http://gdparchitects.com/2015/?project=kkr2-tower

General Services Administration (US). (2016). *Integrated Daylight System*. Retrieved 23 May, 2017, from https://www.gsa.gov/portal/content/193339

Google. (2017). *Google Map*. Retrieved 23 May, 2017, from https://www.google.com.my/maps/@3.1531586,101.6904303,275m/data=!3m1!1e3?hl=en

Green Building Index Sdn Bhd. (2013). *WHAT IS A GREEN BUILDING?* Retrieved 4 March, 2017, from http://www.greenbuildingindex.org/why-green-buildings.html

Green Tech Malaysia. (29 March, 2010). *Common Carbon Metric Report.* Putrajaya: Green Tech. Retrieved 20 May, 2017, from https://www.slideshare.net/asetip/common-carbon-metric-in-buildings-in-putrajaya

Hopkinson, R. G., & Longmore, J. (1959). Lighting Research & Technology. *The Permanent Supplementary Artificial Lighting of Interiors, 24*(3), 121-148.

IEN Consultants. (27 August, 2015). *Daylight Strategies and Case Studies.* Retrieved 23 March, 2017, from http://www.ien.com.my/downloads/Daylighting-Strategies-and-Case%20Studies-By%20Gregers%20Reimann-IEN%20Consultants.pdf

Lechner, N. (2014). *Heating, Cooling and Lighting: Sustainable Design Methods for Architects* (4th ed.). Canada: John Wiley & Sons, Inc.

Lee, E. S., & Selkowitz, S. (1995). The Design and Evaluation of Integrated Envelope and Lighting Control Strategies for Commercial Building. *ASHRAE Transaction 95, 1*(101), 326-342.

Lightway Crysrtal Tubular Skylights. (2010). *What are Light Pipes*. Retrieved 4 May, 2017, from http://www.lightway.cz/en/sunlight/what-are-light-pipes/

Mardaljevic, J., Heschong, L., & Lee, E. (2009). Daylight metrics and energy saving. *Lighting Res. Technol, 41*(3), 261-283.

NBI, IDL, & Architect, I. I. (2014). *Daylighting Guide For Office Interior.* Retrieved 16 March, 2017, from http://www.advancedbuildings.net/files/advancebuildings/DaylightingGuideOfficeInteriors.pdf

Ng, B. H., & Zainal, A. b. (2011). An Overview of Malaysia Green Technology Corporation Office. *Journal of Sustainable Development,* 212-228.

Oberlin College . (8 September , 2009). *Chapter 6: Windows, Light, and Heat Gain* . Retrieved 3 May, 2017, from http://www.oberlin.edu/physics/Scofield/p268/library/Ch-06%20Windows.pdf

Philip, L. (2010). Introduction to Daylighting. Sun Cam.

Ransen, O. F. (2017). *Candelas, Lumens and Lux* (2nd ed.). Owen Ransen.

Rea, M. S. (2000). *IESNA Lighting Handbook: Reference and Aplication* (9th ed.). New York: Illuminating Engineering Society of North America.

Reinhart, C., & Otis, T. (13 March , 2009). *Daylighting "Rule of Thumb"*. Retrieved 3 May, 2017, from http://isites.harvard.edu/fs/docs/icb.topic539779.files/Diffuse%20Daylighting%20Design%20Sequence.pdf

Roche, L., Dewey, E., & Littlefair, P. (2000). Occupant reactions to daylight in office. *Lighting Reseach and Technology, 32*(3), 119-126.

Rungta, S., & Singh, V. (2011). *Design Guide: Horizontal Shading devices and Light Shelves.* Retrieved 22 March, 2017, from http://studylib.net/doc/18142586/table-of-contents

Saddam Hussin, 3. D. (10 December, 2014). *KKR2.* Retrieved 23 May, 2017, from https://www.slideshare.net/MUHAMMADHUSSIN4/kkr-2

Singh, M. C., & Garg, S. N. (2011). Suitable Glazing Selection for Glass Curtain Walls in Tropical Climate of India. *ISRN Renewable Energy, 2011*, 11-23.

Smith, P. (2005). *Architecture in a climate of change* (2nd ed.). London: Oxford: Architectural Press.

Sonia, A., & Valerian, M. (2005). Development Of An Integrated Building Design Information Interface. Montreal, Canada: Ninth International IBPSA Conference.

Suruhanjaya Tenaga. (2013). *Energy Commission Diamond Building [The Gem of Putrajaya]*. Putrajaya: ENERGY COMMISSION (SURUHANJAYA TENAGA).

Tang, C., & Chin, N. (2013). *Building Energy Efficiency Technical Guideline for Passive Design.* Kuala Lumpur: Building Sector Energy Efficiency Project (BSEEP).

The Society of Light and Lighting. (2002). *Lighting Guide 7: Office Lighting* (7 ed.). England: Chartered Institution of Building Services Engineers.

Trimble Inc. (2017). *Sketchup*. Retrieved 23 May, 2017, from http://www.sketchup.com/products/sketchup-pro/new-in-2017?gclid=Cj0KEQjwmIrJBRCRmJ_x7KDo-9oBEiQAuUPKMlK5b5ozXne4-FPMLpRT903EGEPbnvL0FZFOy11b22oaAnHj8P8HAQ

U.S. Department of Energy. (2007). *National Best Practices Manual For Building High Performance Schools.* United State: Office of Energy Efficiency and Renewable Energy.

VELUX Group. (2005). *VELUX Daylight Visualizer*. Retrieved 11 March, 2017, from http://www.velux.com/article/2016/daylight-visualizer

Von, C. E. (6 December, 2015). *Project 1: Lighting & Acoustics Performance Evaluation & Design* . Retrieved 23 May, 2017, from https://issuu.com/cheaheevon/docs/building_science_menara_kkr2

WAUSAU . (2010). *Understanding U-Factor.* Retrieved 3 May, 2017, from http://www.wausauwindow.com/resources/education/ufactors/ufactor.pdf

Wilkinson, M. A. (1992). Lighting Research and Technology. *The effect of glazing upon energy consumption withing buildings*, *24*(2), 99-101.

World Bank. (2016). *CO2 emissions (metric tons per capita)*. Retrieved 20 May, 2017, from http://data.worldbank.org/indicator/EN.ATM.CO2E.PC?locations=MY

Zumtobel Group. (2013). *The Lighting Handbook* (4th ed.). Austria: Zumtobel .