INTERIOR RETROFIT FOR EFFICIENT TROPICAL DAYLIGHTING IN HOME OFFICE WORKSPACES

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To the World without Border...
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ABSTRACT

Home office workspaces have substantially increased all over the world and Malaysia is not an exception. However, existing residential buildings (ERBs) in Malaysia have been designed mostly for the purpose of accommodation, but not for office working, as far as daylighting is concerned. This situation is even more critical here as it is a tropical country with intense solar radiation and excessive sky luminance. This causes discomfort glare in many typical ERBs, which are mostly without external shadings. Due to limited flexibility for modification of the existing residential units by residents, interior retrofit can play a significant role in improving the visual environment. Not much research has been done focusing on interior retrofit in ERBs regarding visual comfort. This thesis aims to optimize tropical daylighting efficiency through interior retrofit in home office rooms (HOR) located in the ERBs in Malaysia. A questionnaire survey was conducted to find out the current scenario of HORs in terms of interior design profile in 11 ERBs in Johor Bahru. Based on the findings, a base model was derived to simulate daylight using the Radiance program in the Integrated Environmental Solution-Virtual Environment (IES-VE) software. Prior to the simulation experiments, a field measurement in a typical room was conducted to validate the software under the tropical sky. Then different design parameters including furniture layout, window glazing film, surface reflectance, internal light shelf and venetian blind were experimented through daylight simulation. Estimated work plane illuminance (EWPI) and standard daylight zone (SDZ) were evaluated for quantitative performance, while work plane illuminance uniformity ratio (IUR), Guth visual comfort probability (GVCP) and CIE glare index (CGI) were considered for qualitative performance. Findings showed that partial blind at upper window was the optimum design model for efficient daylighting in a room with indirect or reflected sunlight for all cardinal orientations. However, integration of a light shelf with partial blind at lower window was the best in a room with direct sunlight. In conclusion, this study provides evidence that a dynamic integrated model of light shelf and partial blind can be an effective alternative to the conventional interior shading devices. The finding of the study has shown how to improve the visual environments in home office workspaces in ERBs by changing the pattern of internal shading device in tropical areas.
ABSTRAK

Ruang kerja kediaman pejabat telah meningkat dengan ketara di seluruh dunia termasuk Malaysia. Bagaimanapun, bangunan kediaman yang sedia ada (ERBs) telah direka bentuk kebanyakkan untuk tujuan penginapan yang tidak berfungsi sebagai pejabat sebagaimana pencahayaan dititik beratkan. Situasi ini lebih kritikal di sini kerana merupakan negara tropika dengan sinaran suria yang sengit dan pencahayaan langit yang berlebihan. Ini menyebabkan ketidakselesaan silau dalam banyak ERBs biasa, yang kebanyakannya tanpa peneduhan luar. Oleh kerana kefleksibelan yang terhad untuk pengubahsuaian unit kediaman sedia ada oleh penduduk, retrofit dalam boleh memainkan peranan penting dalam meningkatkan persekitaran visual. Tidak banyak penyelidikan yang telah dijalankan untuk memberi tumpuan kepada perubahan retrofit di dalam bangunan untuk memberikan keselesaan visual. Tesis ini bertujuan untuk mengoptimumkan kecekapan pencahayaan tropika melalui retrofit dalaman di bilik pejabat kediaman (HOR) yang terletak di ERB di Malaysia. Tinjauan soal selidik telah dijalankan untuk mengetahui senario HOR semasa dari segi profil reka bentuk dalaman di 11 ERB di Johor Bahru. Berdasarkan dapatan kajian, satu model asas telah diperolehi untuk mensimulasikan siang menggunakan program Radiance dalam perisian Integrated Environmental Solution-Virtual Environment (IES-VE). Sebelum eksperimen simulasi, ukuran lapangan di bilik khas telah dijalankan untuk mengesahkan perisian yang di bawah langit tropika. Kemudian parameter reka bentuk yang berbeza termasuk tata letak perabot, filem kaca tingkap, refleksi permukaan, rak cahaya dalaman dan sejenis bidai telah diuji melalui simulasi siang hari. Anggaran pencahayaan permukaan kerja (EWPI) dan standard siang zon (SDZ) telah dilakukan untuk prestasi kuantitatif, sementara nisbah permukaan kerja pencahayaan keseragaman (IUR), Guth kebarangkalian visual keselesaan (GVC) dan CIE indeks silau (CGI) telah dipertimbangkan untuk prestasi kualitatif. Penemuan menunjukkan bahawa sejenis bidai separa pada tetingkap atas adalah model reka bentuk optimum untuk pencahayaan yang efisien di dalam bilik dengan cahaya matahari yang tidak langsung atau pantulan cahaya matahari untuk semua orientasi kardinal. Walau bagaimanapun, penyepaduan rak ringan dengan sejenis bidai separa pada tetingkap yang lebih rendah adalah yang terbaik di dalam bilik dengan cahaya matahari langsung. Kesimpulannya, kajian ini membuktikan bahawa satu model bersepadu dinamik rak ringan dan sejenis bidai separa boleh menjadi alternatif yang berkesan untuk peranti peneduhan dalaman konvensional. Dapatan kajian ini menunjukkan bagaimana untuk meningkatkan persekitaran visual di ruang kerja pejabat kediaman di ERBs dengan mengubah corak peranti teduhan dalaman di kawasan tropika.
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<td>3D</td>
<td>Three-dimensional</td>
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<tr>
<td>BLAST</td>
<td>Building Loads Analysis and System Thermodynamics</td>
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<tr>
<td>BGI</td>
<td>BRS (Building Research Station) Glare Index</td>
</tr>
<tr>
<td>BZ</td>
<td>Bright Zone (&gt; 500 lux)</td>
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<tr>
<td>CIBSE</td>
<td>Chartered Institution of Building Services Engineers</td>
</tr>
<tr>
<td>CIE</td>
<td>International Commission on Illumination</td>
</tr>
<tr>
<td>CGI</td>
<td>CIE Glare Index</td>
</tr>
<tr>
<td>DF</td>
<td>Daylight Factor</td>
</tr>
<tr>
<td>DGI</td>
<td>Daylight Glare Index</td>
</tr>
<tr>
<td>DOE</td>
<td>Department of Energy, United States</td>
</tr>
<tr>
<td>DR</td>
<td>Daylight Ratio</td>
</tr>
<tr>
<td>DSL</td>
<td>Direct Sunlight</td>
</tr>
<tr>
<td>DZ</td>
<td>Dim Zone (&lt; 100 lux)</td>
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<tr>
<td>EDB</td>
<td>Economic and Development Board</td>
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<tr>
<td>EPC</td>
<td>Energy Performance Certificates</td>
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<tr>
<td>ERB</td>
<td>Existing Residential Building</td>
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<tr>
<td>e-HBB</td>
<td>electronic Home-Based Business</td>
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<tr>
<td>EWPI</td>
<td>Estimated Work Plane Illuminance</td>
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<td>FAB</td>
<td>Faculty of Built Environment</td>
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<td>GBI</td>
<td>Green Building Index</td>
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<td>GDGR</td>
<td>Guth Disability Glare Rating</td>
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<tr>
<td>GVCP</td>
<td>Guth Visual Comfort Probability</td>
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<tr>
<td>HB</td>
<td>High-rise Building</td>
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<tr>
<td>HBB</td>
<td>Home-based Business</td>
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<td>HOR</td>
<td>Home Office Room</td>
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<tr>
<td>HVAC</td>
<td>Heating, Ventilation &amp; Air-Conditioning</td>
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IEQ - Indoor Environmental Quality
IES <VE> - Integrated Environment Solution <Virtual Environment>
IESNA - Illuminating Engineering Society
IUR - Illuminance Uniformity Ratio
IT - Information Technology
JB - Johor Bahru
LEED - Leadership in Energy and Environmental Design
LSR - Light Shelf Depth Ratio
MS - Malaysian Standard
MUFL - Mostly-Used-Furniture-Layout
NGO - Non-Governmental Association
NI - Nebulosity Index
RD - Relative Difference
RGB - Red/Green/Blue
RNC - Residential New Construction
SAZ - Suitable Area Zone
SDZ - Standard Daylight Zone (100 – 500 lux)
SHGC - Solar Heat Gain Coefficient
SOHO - Small Office Home Office
SR - Surface Reflectance
THO - Technopreneur Home Office Scheme
UBBL - Uniform Building By Laws
UGR - Unified Glare Rating
UTM - Universiti Teknologi Malaysia
VDT - Video Display Terminal
VELUX DV - VELUX Daylight Visualizer
VLT - Visible Light Transmittance
VT - Visible Transmittance
WFR - Window-to-Floor Ratio
WPI - Work Plane Illuminance
WWR - Window-to-Wall Ratio
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<td>B</td>
<td>Blind</td>
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<tr>
<td>Ds</td>
<td>Depth of Shelf</td>
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<tr>
<td>E</td>
<td>External Illuminance</td>
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<tr>
<td>E₁</td>
<td>Incident Light</td>
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<td>E₂</td>
<td>Reflected Light</td>
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<tr>
<td>Eₘᵢₙ</td>
<td>Minimum Work plane Illuminance</td>
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<tr>
<td>Eₐᵥᵍ</td>
<td>Average Work plane Illuminance</td>
</tr>
<tr>
<td>E₉ₘ</td>
<td>Measured Daylight Indicator</td>
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<tr>
<td>E₈ₜ</td>
<td>Simulated Daylight Indicator</td>
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<tr>
<td>Hc</td>
<td>Clerestory Height</td>
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<td>Ho</td>
<td>Height from sill</td>
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<td>hr</td>
<td>Hour</td>
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<tr>
<td>Hs</td>
<td>Height of sill</td>
</tr>
<tr>
<td>klx</td>
<td>Kilo Lux (1000 Lux)</td>
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<tr>
<td>L</td>
<td>Light shelf</td>
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<tr>
<td>LB</td>
<td>Integrated Light shelf and Blind</td>
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<tr>
<td>M</td>
<td>Measurement</td>
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<tr>
<td>P</td>
<td>Measurement Point</td>
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<tr>
<td>Rgh</td>
<td>Roughness</td>
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<td>S</td>
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<td>Spec</td>
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CHAPTER 1

INTRODUCTION

1.0 Introduction

The prospect of working from home has gained credibility over the years. Nowadays, due to the rapid development of communication technology, including computer capabilities, Internet services, and digital drawing, many people moved their own offices into their residential units (Whitehead, 2009). Home office workspace is a space inside a house that can be used for desk-related tasks (computer work, paperwork, study, etc.). This workspace can be exclusively devoted an entire room or may be occupied other spaces in a house (Kanarek, 2001). Home has many benefits for home office workers, such as saving time and money, decreasing expenses of daily commuting and furniture, increasing productivity, flexibility, and independence during working, reducing vehicular and human traffic, etc. (Bateman, 2000; Kanarek, 2001; Sulaiman and Shariff, 2012; Sulaiman et al., 2009). In this thesis, home office worker referred to a person who performs at least a type of desk-related tasks at his/her home office workspace during daytime.

There can be various terms used for home office tasks, such as home-based business, while each one may be formally or informally operated, all run from the owner’s home office. Working from home has remarkably increased worldwide and is taken much more serious in recent years. According to different conservative estimations, one in ten households in the UK, Australia, and the USA operates a
In Singapore, the government took some measure, such as Technopreneur Home Office Scheme (THO), to encourage entrepreneurs to use their dwelling as home offices (Rahim, 2010). Home office is also a new focus initiative of the Malaysian government to persuade people working from their homes. Accordingly, business associations, non-governmental associations (NGOs), private agencies such as Johor Corporation are also playing a major role in developing the concept of home office (Rahim, 2010; Sulaiman, 2011).

1.1 Background of Study

Due to increase of computer services and video display terminals (VDT), visual comfort has become a significant issue for the design of office workplaces (Guzowski, 2000). The quality of daylight is an essential reason to employ daylighting in order to design home office workplaces. Kanarek (2001) remarked that natural lighting is a vital part of any home office workspace since poor lighting can cause eyestrain, fatigue and irritability. The significance of daylighting is also highlighted for residential constructions in the Green Building Index (GBI, 2013). In this case, daylighting as well as air quality, has been devoted the highest points in the category of indoor environmental quality (IEQ) for residential sectors. Thus, efficient daylighting design needed to be investigated in order to improve visual comfort for home office workers in residential constructions. An esteemed American architect, Louis Kahn defined:

“…Natural light is the only light that makes architecture, architecture.”

(Louis I. Kahn, 1966)

The visual world can be experienced by human being through the presence of light. Previous research showed that the development of human eye is indeed based on daylight (Gugliermetti and Bisegna, 2006; Wang, 2009). Daylight as the natural source of light is the combination of sky light and sunlight. It is the visible
electromagnetic radiation that allows human to perceive luminous environment subjectively (Ander, 2003). Daylighting as a passive architectural design strategy has many benefits, such as saving energy by reducing the dependency on electric lighting (Ander, 2003; Robbins, 1986). Daylighting does not only contribute towards designing more energy-conscious buildings, but it can also influence human physiology and psychology. It provides healthy indoor environments, higher productivity and lower absenteeism for users (Athienitis and Tzempelikos, 2002; Bluyssen, 2010; Konis, 2013). Daylight as an aesthetical design element can also create sense of spaciousness to a building (Lechner, 2014). Daylight tends to produce less heat for the same amount of light compared with electric lighting because of its higher quality of luminous efficacy (Lam, 2000; Lam and Li, 1998). Thus, daylighting is a significant design strategy for many architects.

While daylighting is an effective way to save energy, poor daylighting installations may cause unwanted solar heat gain and glare problems. This is even more critical in tropical climate with extremely high daylight availability that the outdoor illuminance can be as high as 140,000 lx (Zain-Ahmed et al., 2002a). Intense sunshine, dynamic cloud formation within a few minutes, and excessive outdoor illuminance of tropical sky can create unpredictable indoor daylight availability and visual discomfort for occupants (Lim et al., 2008a; Mohd Hamdan, 1996; Tzempelikos, 2005). Therefore, tropical daylight needed to be utilised in order to avoid intense solar heat gain, non-uniform daylight distribution and glare problems in buildings. Zain-Ahmed et al. (2002b) indicates that at least 10 % energy savings can be achieved by using daylighting strategies alone.

In tropical climate, big windows that directly exposed to sky can cause thermal discomfort and glare problem. On the other hand, small windows or extreme use of shading devices can ignore daylight distribution that resulted in gloomy indoor environment. This increases dependency on electric lighting for illuminating interior spaces in buildings. Previous daylighting research in tropical regions focused on preparing sufficient amount of daylight (Chaiwiwatworakul et al., 2009; Shahriar and Mohit, 2007; Sharifah and Sia, 2004). However, in order to have energy efficient and architectural designs, it is essential to keep the balance between the daylight harvesting and the prevention of solar heat gains in buildings (Lim, 2011). In tropical
climates with the high outdoor illuminance, daylight efficiency is not just providing high daylight quantity, because it cannot promise acceptable daylight quality for visual comfort and may cause glare problem (Lim and Mohd Hamdan, 2010). Consequently, both quantitative and qualitative performances of tropical daylighting needed to be controlled in order to increase daylighting efficiency in buildings (Lim et al., 2009; Tzempelikos and Athienitis, 2007).

1.2 Problem Statement

The fast development of IT and computer services all over the world, resulted in increase of home office workspaces (Kanarek, 2001). This made a number of office workers to transfer their workplaces from office buildings to their homes. Because of the growing trend of home office, a residential unit should not be used only as a bedroom, but also a place for home office workers to do their desk-related tasks. However, existing residential buildings were not designed for office working but only planned for accommodation. In addition, existing residential buildings do not have potentials to cover various human’s need, especially visual comfort that is significant to be provided for home office workers in their residential units. Kanarek (2001) claimed that natural lighting is a vital part of any home office workspace since poor lighting causes eyestrain, fatigue and irritability. Thus, efficient daylighting strategies needed to be investigated in residential buildings in order to provide visual comfort for home office workers.

Excessive global illuminance, high sky luminance, and dynamic cloud formation of tropical skies resulted in non-uniform distribution of daylight in buildings. Malaysia is located in equatorial region; hot, humid and cloudy with dull grey sky condition that causes heat and glare problems for occupants (Sharifah and Sia, 2004; Zain-Ahmed et al., 2002a). However, high availability of tropical daylight is not optimised in the existing buildings in Malaysia. This is even more serious in the buildings without external shadings or well-designed shading devices on their facades that causes direct penetration of sunlight into such buildings. However, the
use of electric lighting and air conditioner are seen as a solution to overcome heat gain from daylighting (Jamaludin et al., 2013). Although indoor daylight quantity is higher than the required level in tropical regions, daylighting design is not effective in buildings because of poor indoor daylight quality. This condition is more critical for home office workspaces where visual comfort needs to be provided for home office workers.

Benefits of daylighting increased attention of architects and designers to consider daylighting for designing new buildings (Labib, 2013). In this case, review of previous studies revealed that researchers mostly investigated daylighting strategies that were only applicable for new building design such as building orientation, building shape, window size, external solar controls, etc. However, these strategies may not be economical or feasible to be retrofitted by users after occupancy in their residences (Cheng et al., 2007; Mayhoub and Carter, 2011). Therefore, they are not appropriate to be used in existing buildings. As many existing buildings were not designed for daylighting, it is essential to explore the possibility of improving daylighting design in existing buildings by developing guidelines to transform them into energy-efficient and productive environments. While living is the only function in the existing residential buildings, the issue is that how to change the typical indoor environment in order to support the home office needs. When the building already exists, a retrofit is the only approach to increase daylight efficiency through building design. It is because the existing buildings are more constrained in comparison with new buildings in applying the energy-efficient design strategies (Lim et al., 2012). Maier (2016) indicates that the successful deployment of daylighting retrofitting strategies in residential buildings will reduce energy use, provide attractive dwellings and financial gains and significantly impact climate change.

Huff and Huff (2011) claimed that internal light shelf as a daylighting strategy can be used for both new constructions and retrofit applications. While external light shelf is more efficient to reflect daylight deeper into room, the application of internal light shelf is simpler and more flexible to be installed (Jamaludin, 2014). Venetian blind as an adjustable internal shading device has potential to prevent direct sunlight, control daylight and avoid glare problems so it
plays a major role to prevent visual discomfort inside buildings (Koo et al., 2010; Sanati and Utzinger, 2013). Jamaludin et al. (2015) claimed that tinted window glass and glare protection should widely be implemented either for retrofit or as new designs of any residential building in tropical climate. A study by Konis (2013) defined the solar control film as an interior retrofit to evaluate daylighting effectiveness and occupant visual comfort in buildings. One of the considerations for daylighting systems in retrofit project is room surfaces (Brain, 2015). Jughans (2008) stated that the surface of room contributes to the level of reflectance in controlling glare and light distribution in the room. Interior layout is one of the other considerations for daylighting systems in retrofit project. Furniture and partitions impact the flow of light in a space. During a retrofit, rearranging the interior layout can create a more efficient daylighting design (Brain, 2015).

As it was mentioned in the above paragraph, retrofitting interior spaces for daylighting can be done through internal shading devices, including venation blind and light shelf, window glazing films, surface reflectance, and furniture layout. These daylighting strategies have potentials to be modified by end users and the feasible retrofits can be done with less cost effects. Thus, these parameters were investigated in this thesis to retrofit interior spaces of existing residential buildings for tropical daylighting.

### 1.3 Research Gap

There are many daylighting studies for Malaysia’s tropical climate that were mostly investigated in office buildings. Jamaludin et al. (2015) indicated that there is lack of studies performed at the residential buildings especially in the tropical climate region, as compared to the office or commercial buildings in the temperate climate region. However, due to increase of home office concept, efficient daylighting strategies need to be also investigated in residential buildings in order to provide visual comfort for home office workers. In addition, most of previous tropical daylighting research focused on daylight quantity so they measured the quantitative performance indicators of daylight in buildings (Athienitis and
Tzempelikos, 2002; Cheng et al., 2007; Chou, 2004; Ghasemi, 2015; Roshan, 2014; Sharifah and Sia, 2004; Zain-Ahmed et al., 2002b).

**Table 1.1** Summary of previous daylighting research in tropical climate

<table>
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<tr>
<th>Tropical Daylighting Research</th>
<th>Design Variable</th>
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<td>Building Form</td>
<td>Atrium Design</td>
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<tr>
<td>Zain-Ahmed et al. (2002b)</td>
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<td>Sharifah and Sia (2004)</td>
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<td>Fuziah et al. (2004)</td>
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<td>Ossen (2005)</td>
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<td>Mansour et al. (2006)</td>
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<td>Ibrahim et al. (2006)</td>
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<tr>
<td>Shahriar and Mohit (2007)</td>
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<td>Chia (2008)</td>
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<tr>
<td>Lim et al. (2009)</td>
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<td>Linhart et al. (2010)</td>
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<tr>
<td>Wang et al. (2010)</td>
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<td>Lim (2011)</td>
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<td>Husin and Harith (2012)</td>
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<td>Nikpour et al. (2013)</td>
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<td>Mahdavi et al. (2013a)</td>
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<td>Roshan (2014)</td>
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<tr>
<td>Ghasemi (2015)</td>
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<tr>
<td>Lim and Heng (2016)</td>
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<tr>
<td>Present Study (2017)</td>
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However, study on qualitative performance indicators of daylight, such as glare index, is also necessary to provide visual comfort and efficient tropical daylighting in buildings. Review of previous daylighting research in tropical climates (Table 1.1) shows that researchers usually evaluated daylighting strategies which were only applicable for designing new buildings. Lack of research on tropical daylighting strategies for existing buildings compared with new buildings is obvious. Accordingly, this thesis focused on some passive daylighting strategies that can be useful to retrofit interior spaces within the existing residential buildings (ERB).

Due to lack of long-term daylight data and research in Malaysia, most of researchers have used computer simulation tools to assess daylighting performance under tropical skies. Although computer simulation tools are very helpful techniques for daylighting research, most of these simulation tools use CIE sky models (Labayrade et al., 2009; Lim et al., 2013; Reinhart and Breton, 2009). However, CIE skies are very different from tropical skies in which the outdoor illuminance value is extremely high and the cloud’s formation is not uniform. Accordingly, the usage of each daylighting simulation tool needs to be validated under the tropical skies. In this thesis, real field measurement of daylight under the Malaysia’s tropical sky was conducted to validate the results of simulation tool for tropical climates.

1.4 Research Aim

The aim of this research is to optimise tropical daylighting efficiency through interior retrofit for home office workspaces within the existing residential buildings in Malaysia.
1.5 Research Questions

The following questions are addressed in this research:

1. What is the current scenario of the typical home office rooms (HOR) in the existing residential buildings in Malaysia?

2. How does furniture layout influence daylighting performances in tropical regions?

3. How do internal shading devices, window glazing film, and surface reflectance influence daylighting performances in tropical regions?

4. How to optimise quantitative and qualitative performances of daylight in a typical HOR under the tropical sky?

1.6 Research Objectives

The following objectives support the main aim of this thesis:

1. To investigate the current scenario of (HOR) in the ERBs in terms of interior design profile.

2. To evaluate the impact of furniture layout in HORs on the quantitative and qualitative performances of tropical daylight.

3. To assess the impact of internal shading devices, window glazing film, and surface reflectance in HORs on the quantitative and qualitative performances of tropical daylight.

4. To propose an effective daylighting design model to be used in HORs in tropical regions.
1.7 Research Methodology

Figure 1.1 depicts the methodology flowchart that was used in this thesis. A general observation and the questionnaire survey were conducted in 11 conventional residential buildings in Johor Bahru to record the required data for daylighting analyses. Then, the real field measurement of daylight was done to validate the computer simulation (Radiance-IES) under the Malaysia’s tropical sky. Subsequently, a huge number of simulation experiments were run to analyse the impact of various design parameters on the quantitative and qualitative performances of daylight in a typical HOR. Finally, based on the daylighting results for all orientations, an interior retrofitted model was proposed for efficient tropical daylighting in the existing residential buildings.
1.8 Research Hypothesis

The hypothesis of this research is that interior retrofit can increase tropical daylighting efficiency for home office workspaces through improving the qualitative and quantitative performances of daylight by:

1) Reducing the extremely high daylight level in the interior spaces under the Malaysia’s tropical sky.
2) Increasing the effective daylight zone within the recommended range of work plane illuminance (100 – 500 lx).
3) Distributing daylight uniformly throughout the interior spaces.
4) Reducing glare problems to improve visual comfort.

Thus, efficient interior retrofit for tropical daylighting can provide visual comfort for home office workers and also save electric lighting in the existing residential buildings.

1.9 Scope and Limitations

This thesis targets the daylighting efficiency for visual comfort. While daylight is usually related with direct sunlight that causes undesirable solar heat gain, so energy consumption and thermal comfort are not significant issues in this research. However, the justification is that providing sufficient indoor daylight can decrease the dependency on electric light which helps to save electricity.

Due to rapid development of residential buildings in major urban areas in Malaysia, this type of housing, which consumes high electricity for the buildings’ lighting and cooling, was chosen in the thesis. Daylight penetration in the ERBs is only dependent on the perimeter windows because of their multilevel design. Therefore, the use of daylight in the ERBs is only limited to their perimeter façades. The facades of ERBs in Malaysia are directly faced to the sun and sky which resulted
in big glare problems. Thus, the term ‘ERB’ in this thesis referred to an unobstructed building, irrespective of its height, which is not blocked by adjacent buildings and vegetation and has direct access to sunlight. While there are different rooms and spaces in the ERBs, a typical HOR was considered in this study that included desk-related tasks. However, this room may be used for other household activities.

This thesis focused on interior retrofit through various design parameters to improve tropical daylight efficiency and visual comfort in the typical HORs within the ERBs. Usage of daylight is very limited and needs to be improved in such buildings. There can be many daylight-efficient solutions for new building design that may not be applicable for the existing buildings. However, there are a great number of existing buildings that were built without any daylighting considerations. Hence, the existing buildings need further investigations to improve indoor daylighting efficiency. The computer simulation tool (IES-VE) was used to assess quantitative and qualitative performances of daylight in a typical HOR with different design parameters. The limitations and assumptions of the simulation experiments are discussed in chapter 3.3.6 and chapter 3.4.1.6.

The scope of this study is limited to tropical daylighting. Accordingly, the sky condition which used in the thesis is for hot-humid tropical climates. Since the intermediate sky is the predominant type of Malaysia’s topical sky, this sky type was used in the simulation experiments. However, the overcast sky was only used for the DF method. In addition, clear sky was not employed in this research because there is no possibility of this sky type for tropical climates (Lim, 2011).

1.10 Research Significance

This study claimed that besides accommodation, the existing residential buildings may be used for other tasks such as home office. Thus, these buildings need to have potentials to support flexible functions and provide visual comfort for home office workers. However, there is a lack of available design guideline for
daylighting efficiency in the ERBs in tropical climates. This study is significant to specify the critical design parameters of interior retrofit for improving the quantitative and qualitative performances of daylight in a typical HOR. This research proposes an interior retrofitted model for daylighting efficiency that can be implemented in typical HORs within the tropical regions, especially Malaysia. Finally, the proposed design model has potential to improve visual environments for home office workers. It can also help to save electric lighting that resulted in the reduction of buildings’ carbon emission and global warming.

1.11 Thesis Organisation

This research comprised of 5 chapters. Chapter One represents the major issues and focus of this thesis. This chapter explains the research hypotheses, research questions, gap and objectives of the research. In addition, the limitations and scope of the research are also discussed. Finally, the significance of the research and the overall thesis organisation are determined.

Chapter Two is divided into 7 parts. The first part discussed about the development of home office workspaces and the benefits of working from home. The second part was focused on daylighting and its significance for home office workspaces in the existing residential buildings (ERB). In the third part, daylighting through architectural design strategies for new building design and retrofitting existing buildings were pinpointed. Apart from that, review of previous research on daylighting and architecture was discussed. The fourth part described the characteristics of tropical sky and issues in tropical daylighting. Techniques for daylighting analysis, review of daylight simulation tools and daylighting performance indicators were explained in the next sections.

Chapter Three illustrates the methodologies employed in the thesis. This chapter describes the methodologies that were used in the thesis. It comprised of 4 sections. The first section explained the overall methodological flowchart of the
thesis. The second section described the filed survey to achieve data about the current scenario of the typical HORs in the ERBs in Johor Bahru. The third section described the procedure of validation test for Radiance-IES under a real tropical sky through the field measurement of daylight in real context. The last section illustrated all the three phases of daylight simulation experiments.

**Chapter Four** firstly evaluates interior layout of the typical HORs within the ERBs in Johor Bahru by focusing on the users’ response. In addition, the typologies of MUFL were configured based on the desk location in the HOR. The results of validation test through field measurement and simulation test of daylight were described. Then, simulation experiments were performed in the three phases to analyse quantitative and qualitative performances of daylight in a typical HOR with various design parameters. Accordingly, the illuminance-related indicators (DR, EWPI, IUR, and SDZ) and the glare-related metrics (GVCP and CGI) were calculated in the room with various conditions. Afterwards, an interior retrofitted model for tropical daylighting for home office workspaces was proposed.

**Chapter Five** indicates the overall thesis findings achieved through the previous chapters. The implications and contributions of the thesis results are also discussed for tropical daylighting efficiency in the existing residential buildings. Lastly, some future studies are suggested related to this research. Figure 1.2 depicts the flow of research process and the thesis organisation.
Figure 1.2 Research flowchart
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