UNIVERSITI PUTRA MALAYSIA

***NUMERICAL ASSESSMENT OF THE IMPACT OF SHADING ON OPAQUE WALL IN MALAYSIAN CONDITIONS***

**AMIRHOSEIN SOHRABIASL**

**FRSB 2015 8**

**NUMERICAL ASSESSMENT OF THE IMPACT OF SHADING ON OPAQUE WALL IN MALAYSIAN CONDITIONS**

**By**

**AMIRHOSEIN SOHRABIASL**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science**

**December 2015**

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

**NUMERICAL ASSESSMENT OF THE IMPACT OF SHADING ON OPAQUE WALL IN MALAYSIAN CONDITIONS**

By

**AMIRHOSEIN SOHRABIASL**

**December 2015**

**Chairman : Mohamad Fakri Zaki Bin Ja'afar, PhD**
**Faculty : Design and Architecture**

Solar radiation on building envelope is the main reason for heat gain and thermal discomfort. In the case of Malaysia being a tropical country with high solar radiation, solar heat gain through building envelope is the main reason for cooling requirement. The design criterion for minimizing solar heat gain into a building envelope is known as the Overall Thermal Transfer Value (OTTV), which consists of three main parts**:** heat conduction through walls, heat conduction through fenestration, and solar radiation through fenestration. Although various strategies such as wall insulation and shading with plants have been developed to control the heat transfer through opaque façades, these strategies have some disadvantages. However, there is no study about the effect of controlling direct solar radiation on opaque facades in Malaysian climate conditions via external fixed shading system. Moreover, since the current OTTV equation and coefficient for Malaysia were initially introduced to apply to buildings with bare envelope, building designers have the problem of computing the OTTV for buildings with external shading.

The purpose of this research is to examine impact on heat gain of buildings under Malaysian climate conditions by introducing external fixed shading system on opaque facades. To achieve this aim, a computerized simulation method was used and ECOTECT simulation software was selected as a simulation engine. First, an existing cell in the Faculty of Design and Architecture at Universiti Putra Malaysia camp‟s was selected to validate the model in the simulation package.

After preparing the base line model, solar analysis tool was run to assess the solar radiation on building envelope. Thermal analysis was run to consider the indoor thermal comfort condition and cooling requirement. After analyzing the base line model, the effect of external shading on opaque facades was evaluated by introducing the horizontal louver fixed shading devices to the base line model and reassessing the model with louver shading system. Finally, findings for the base line model without shading system and with shading system were compared and the effect of external

fixed shading on opaque facades was discussed. Based on the results of solar analysis, variations for solar heat gain through envelope and OTTV were calculated to present the external fixed shading effects on opaque facades.

The findings of this research show that the reduction of solar radiation on opaque facades achieved by external shading on opaque surfaces, decreases the solar absorption and as a result of this, there is less solar heat gain by buildings. Equivalent temperature differences ($TD_{eq}$) for opaque facades are affected by solar radiation and less direct solar radiation on building envelope reduces the $TD_{eq}$, Thus, heat conduction through opaque facades shows a decrease. It means less solar radiation on building envelope reduces the OTTV for Malaysian climate buildings. Moreover, the results for thermal analysis indicate that by rejecting excess solar radiation from walls, external fixed shading on opaque facades limits the mean radiant temperature (MRT). Therefore, indoor temperature comes down and PMV variation is low. Thus indoor thermal performances improve, and less cooling requirement is needed for providing thermal comfort.

The results of this study contribute toward finding optimal ways for architects to design buildings with better understanding of thermal transfer of building envelope as well as energy efficient standards in tropical regions especially in Malaysia for future research.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**PENILAIAN NUMERIC KE ATAS KESAN LINDUNGAN KE ATAS DINDING LEGAP DALAM KEADAAN MALAYSIA**

Oleh

**AMIRHOSEIN SOHRABIASL**

**Disember 2015**

**Pengerusi : Mohamad Fakri Zaki Bin Ja'afar, PhD**
**Fakulti : Rekabentuk dan Senibina**

Sinaran suria kepada sampul bangunan adalah sebab utama bagi peningkatan haba dan ketidakselesaan terma. Dalam kes Malaysia sebagai sebuah negara tropika dengan sinaran suria yang tinggi , peningkatan haba solar melalui sampul bangunan adalah sebab utama untuk keperluan penyejukan. Kriteria reka bentuk untuk mengurangkan peningkatan haba solar ke dalam sampul bangunan dikenali sebagai Nilai Keseluruhan Pemindahan Haba ( OTTV ), yang terdiri daripada tiga bahagian utama: konduksi haba melalui dinding , pengaliran haba melalui fenestrasi , dan radiasi solar melalui fenestrasi.

Walaupun pelbagai strategi seperti dinding penebat dan teduhan dengan tumbuh-tumbuhan telah dibangunkan untuk mengawal pemindahan haba melalui bahagian hadapan legap , strategi ini mempunyai beberapa kelemahan.Walau bagaimanapun, dalam pengetahuan penyelidik , tidak ada kajian dibuat mengenai kesan kawalan radiasi solar secara langsung pada facades legap dalam keadaan iklim Malaysia melalui sistem teduhan tetap luaran . Lebih-lebih lagi , kerana persamaan OTTV semasa dan pekali bagi Malaysia pada awalnya diperkenalkan untuk memohon kepada bangunan dengan sampul kosong , pereka bangunan mempunyai masalah pengiraan OTTV untuk bangunan dengan teduhan luar.

Tujuan kajian ini adalah untuk mengkaji peningkatan haba bangunan di bawah keadaan iklim Malaysia dengan memperkenalkan sistem teduhan tetap luaran pada facades legap. Untuk mencapai matlamat ini , satu kaedah simulasi berkomputer terpilih telah digunakan dan perisian simulasi ECOTECT telah dipilih sebagai enjin simulasi. Oleh itu, pada mulanya , sel yang sedia ada di Fakulti Rekabentuk dan Senibina di kem Universiti Putra Malaysia telah dipilih untuk mengukur suhu , kelembapan dan data ini kemudiannya dipindahkan kepada Microsoft excel untuk dianalisis .

Selepas menyediakan model asas, analisis solar telah dijalankan untuk menilai radiasi solar di sampul bangunan . Analisis terma dijalankan untuk mempertimbangkan keadaan haba dan penyejukan keperluan dalaman.

Selepas menganalisis model garis asas, kesan teduhan luar pada facades legap dinilai dengan memperkenalkan peranti louver mendatar tetap teduhan kepada model garis asas dan menilai semula model dengan sistem teduhan louver. Akhirnya, dapatan kajian bagi model garis asas tanpa sistem teduhan dan dengan sistem teduhan telah dibandingkan dan kesan bagi teduhan tetap luaran ke atas facade legap telah dibincangkan. Berdasarkan kepada hasil analisis solar dan terma, variasi bagi peningkatan haba menerusi sampul dan OTTV telah dikira untuk memaparkan kesan teduhan tetap luaran ke atas facade legap.

Dapatan kajian ini menunjukkan yang pengurangan radiasi solar ke atas façade legap mengurangkan penyerapan solat dan sebagai hasilnya, ianya kurang peningkatan haba daripada solar kepada bangunan. Perbezaan suhu setara ($TD_{eq}$) kepada façade legap telah memberi kesan oleh radiasi solar dan kurang kesan radiasi solar ke atas sampul bangunan mengurangkan $TD_{eq}$, Oleh itu , pengaliran haba melalui facades legap menunjukkan penurunan . Ini bermakna kurang sinaran solar di sampul bangunan mengurangkan OTTV untuk bangunan iklim Malaysia. Selain itu , keputusan untuk analisis terma menunjukkan bahawa dengan menolak sinaran suria yang berlebihan dari dinding, teduhan luar ditetapkan pada facades legap menghadkan suhu berseri min ( MRT). Oleh kerana itu , suhu tertutup turun dan PMV variasi adalah rendah. Oleh itu persembahan terma dalaman bertambah baik, dan keperluan penyejukan kurang diperlukan untuk menyediakan keselesaan terma.

Keputusan kajian ini menyumbang ke arah mencari cara optimum untuk arkitek untuk mereka bentuk bangunan dengan pemahaman yang lebih baik daripada pemindahan haba sampul bangunan dan piawaian cekap tenaga di kawasan-kawasan tropika khususnya di Malaysia untuk penyelidikan masa depan.

## ACKNOWLEDGEMENTS

As a student, I would like to express my deepest gratitude to my dear supervisor,Dr. Mohamad Fakri Zaki Bin Ja‟afar and Special thanks to my supervisory committee member, Dr. Mohd Fairuz Bin Shahidan for assisting me in many ways to complete this Master‟s thesis.

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

**Mohammad Fakri Zaki Bin Ja'far ,PhD**
Senior Lecturer
Faculty of Design and Architecture
Universiti Putra Malaysia
(Chairman)

**Mohd Fairuz Shahidan, PhD**
Senior Lecturer
Faculty of Design and Architecture
Universiti Putra Malaysia
(Member)

**BUJANG BIN KIM HUAT, PhD**
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

**Declaration by graduate student**

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ________________________ Date: __________________

Name and Matric No.: Amirhosein Sohrabiasl, GS31826

**Declaration by Members of Supervisory Committee**

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- Supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: ______________________________

Name of Chairman of Supervisory Committee: Dr. Mohammad Fakri Zaki Bin Jaʻʻfar

Signature: ______________________________

Name of Member of Supervisory Committee: Dr. Mohd Fairuz Shahidan

**TABLE OF CONTENTS**

## LIST OF TABLES

## LIST OF FIGURES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| ASHRARE | America society of Heating Refrigerating and Air-Conditioning Engineers |
| $A_W$ | Area of walls ($m^2$), |
| $A_F$ | Area of fenestration ($m^2$). |
| C | Degree Celsius |
| OF | The solar orientation factor, |
| $R_{SE}$ | External surface resistance. |
| $Q_W$ | Heat conducted through the opaque walls (W). |
| $Q_F$ | Total rate of heat transfer through windows (w), |
| SC | Shading coefficient of windows (SHGC is the solar heat gain coefficient where SHGC =SC ×0.87). |
| $T_{SOLR-AIR}$ | sol-air temperature(˚C) |
| $T_{INSIDE}$ | Indoor temperature (ºC). |
| $T_e$ | Ambient temperature, |
| WWR | The windows to gross wall area ratio for the orientation under consideration $A_f/A_i$ |
| U | Overall heat transfer coefficient ($W/m^2k$), |
| $\phi$ | thermal radiation to the sky |
| α | Absorptance of surface, $I_{sol}$ global solar irradiance |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of the Study

Air conditioners are used in many buildings in a tropical country like Malaysia to provide a cool and desired thermal comfort condition for occupants. This is as result of solar radiation, which is absorbed by people and buildings and this accumulation of hot air in envelopes which is transmitted indoor (Mahlia et al., 2007). However, cooling is the main reason for energy consumption in buildings and the fact that such cooling utilizes 30-60% of the building‟s energy makes it the highest energy consumer for cooling and dehumidification (Lam et al., 2003). Studies show air conditioners in commercial buildings in Malaysia consumed around 42% of energy, while residential buildings constitute 30% of the total (Saidur et al., 2009). Although an air-conditioning system is useful for providing a cool indoor, the $CO^2$ production by this artificial system is harmful for the environment (Liu et al., 2014).

Passive strategies can contribute to the reduction of energy consumption (MS1525, 2014). When constructing buildings in a tropical climate with a high rate of radiation, thermal insulation and cutting down of solar radiation are used as effective ways of controlling direct gains into buildings and reducing the energy consumption (Moldovan et al., 2014).

External walls as a major part of the building envelope are exposed to solar radiation and receive much heat from the sun. So, controlling sunlight on opaque surfaces will be effective for the purpose of reducing heat gain (Ghaffarianhoseini et al., 2012). Thus, many strategies for controlling of solar energy such as wall insulation and green facades shading have been created by designers (Givoni, 1994). Furthermore, there are numerous studies about the controlling of solar radiation on fenestration by external shading systems (Guohui et al., 2014).

Studies have shown that shading devices reduce the cooling demand in constructions, while at the same time they increase the heating loads due to loss of beneficial solar gains (Dubois, 1997). According to studies by Kumar et al. (2005), shading strategy for countries with high temperature and high radiation is significant to control the solar radiation and provide visual and thermal comfort. Hence, Samanta et al. (2014) indicated appropriate an external shading device could manage the rate of incident solar radiation a building, which could significantly reduce cooling loads and improve indoor thermal comfort condition.

In Malaysia, the main reason behind the high energy consumption for the purpose of cooling is that heat from solar radiation is conducted through windows, walls, and roofs (Al-Tamimi et al., 2011). On the other hand, there have been different strategies used in this country to control high solar radiation effects on building surfaces such as, thermal insulation (MS1525, 2014) and green facades (Sulaiman, 2013). However, analyzing these techniques shows that they have some limitations in providing the desirable indoor thermal comfort. For example, studies show increase in insulation thickness in order to achieve the optimum rate of insulation which may cause the walls to get thicker, hence it reduces indoor space and results in additional cost for building construction, which is energy-efficient (Mahlia et al., 2007). Meanwhile, Tang (2013), in relation to thermal comfort indicates that *"In the Malaysian climate, it is possible to provide suitable insulation to external walls, windows or roofs to reduce the mean radiant temperature in a building to match the air temperature of the space. But, it is not possible to reduce mean radiant temperature below the air temperature using insulation alone".*

Contrary to this idea, green shading system by intercepting the amount of solar radiation toward external opaque facades to reduce heat gain will promote a more comfortable living environment and energy efficiency (Wong & al, 2010). However, it causes increasing humidity between the plants and walls, which is a detrimental for building longevity (Jaafar et al., 2013; Pérez et al., 2011). On the other hand, it is difficult to cover 100% of the wall with greenery facades (Sulaiman, 2013; Wong, Hien, et al., 2010). Meanwhile, (Ottelé et al., 2011; Šuklje et al., 2013) in their research indicate that *"Despite modern architectural solutions, green façades are difficult to maintain due to their need for constant irrigation, fertiliser, organisms in the foliage, and the fabrication of a support construction for the greenery, which represent additional costs".*

Additionally, there have been a number of researches carried out to show the impressive impacts of external shading devices on fenestration of buildings (Atzeri et al., 2014). However, upon examining existing literature, the author could not find any studies that investigated the effects of external physical shading devices on the opaque surfaces of buildings.

## 1.2 Problem Statement

Heat conduction through opaque facades is affected by the radiation heat transfer coefficient at the exposed facades. Solar incident stored by building envelope and released to indoor at night time resulted in thermal discomfort and this is the main reason for requiring cooling system in buildings (Kreider, 2002). In fact cooling requirements as results of solar gains represent more than half of cooling loads in residential buildings and almost half in non-residential buildings (Sciuto, 1994). As solar radiation intensity is not constant and periodical, any changes in solar intensity cause temperature fluctuations of opaque walls (Onbasioglu et al., 2002). Hence, passive design strategies are the primary and basic techniques to control the heat gain of buildings (Lechner, 2009). Therefore different techniques like as thermal insulation and greenery facades systems to reduce heat gain through building envelope were reviewed and their limitation form the background of this study. A review of the external fixed shading devices indicates that external fixed shading on fenestration has impressive effects on reducing of solar heat gain and improving indoor thermal condition (Al-Tamimi et al., 2011). However there has been no study done on fixed shading devices effect on opaque surfaces. The effect of fixed shading devices on opaque surfaces is crucial so that current research would be able to find the most optimized passive strategy against heat gain.

In Malaysia high solar radiation on building envelope is the main reason of indoor thermal discomfort and increasing the cooling requirement, hence, building envelope has to block out solar radiation (MS1525, 2014) as one of the effective means to reduce heat gain.

In order to compare the thermal performance of buildings, overall thermal transfer value (OTTV) as a design criterion of building envelope heat gain was developed in mid of 1980‟s for this country to measure the average heat gain into a building through building envelope (GBI, 2009). However, solar intensity fluctuations on opaque facades were not considered in this model. This study will investigate the impact of external fixed shading device on opaque wall on heat gain. By quantifying the effect of shading on minimizing solar heat gain through walls, this study might offer new insight in passive design strategy.

## 1.3 Research Questions

The aim of this research is to study the impact of physical external shading on opaque surfaces on heat gain in buildings under Malaysian climate conditions, and so the main question and sub-questions of this research are as follows:

**Main-research question**

> "What is the effect of physical external shading on opaque surfaces on heat transfer under Malaysian climatic conditions?"

**Sub- research questions**

> "What is the effect of external shading of opaque wall on Malaysian air conditioning buildings indoor thermal comfort condition?"
> "What is the impact of external shading on opaque surfaces on energy use on Malaysian buildings?"'

## 1.4 Research Purpose and Objectives

Based on the aim of this research, that is, to study the impact of physical external shading on opaque surfaces on heat gain in buildings under Malaysian climate conditions, the objectives of this research are presented as follows:

**Objectives**

- To assess the effects of shaded walls on thermal comfort in air conditioned room under Malaysian climate condition.

- To assess the effects of external fixed shading on opaque surfaces on cooling energy demand in Malaysian buildings

## 1.5 Methodology and Data Collection

In order to address the set of objectives of the study, a quantitative research approach was applied. Since the focus of the present study is to evaluate the effect of external fixed shading on opaque facades on heat gain under Malaysian climatic conditions, a computerized simulation method is suggested and explained below:

The specifications of an existing cell at the Faculty of Design and Architecture in Universiti Putra Malaysia were measured for the purpose of studying and understanding the solar radiation effects on indoor thermal condition. Then, the measured data were exported to Microsoft Excel for evaluation. ECOTET simulation software was used as a simulation engine to develop a base line model based on the existing cell. After matching the base line model characteristics with those of the existing cell, in order to ensure the accuracy of the ECOTECT software findings, indoor temperatures on specific dates were compared between the existing cell and the base line model. After preparing the base line model, solar analysis and thermal analysis tools were run on ECOTECT to evaluate the base line model. Solar analysis tool shows solar radiation, and solar absorbed on building envelope. Indoor thermal condition for the base line model was developed based on ASHRAE 55 standard and Malaysian standard (MS1525). The thermal analysis tool revealed the indoor thermal condition for the base line model, Predicted Mean Vote (PMV) and Mean radiant temperature (MRT) could be examined with this tool. In the next step, in order to examine the effects of external fixed shading on opaque facades, an external horizontal louver system was introduced to the base line model. The base line model with louver shading system was reassessed as a base line model without a louver system. In the final step, solar data were used to compute heat gain and OTTV for the cell without shading and with shading. Findings for the base line model without the louver system and with the louver system were compared to understand the effect of the external fixed shading on opaque facades.

## 1.6 Scope of Study and Limitations

The aim of this research is to assess the impact of fixed shading on opaque walls on heat gain in Malaysian climatic condition. This section explains the scope of this research.

Current research is focused on the solar heat gain in the building envelope and it comprises a detailed analysis regarding heat exchange through opaque facades. Of particular importance is the study of controlling of radiation and heat balance, since the total heat gain and thermal transfer will determine the amount of the solar radiation needed to minimize the energy consumption. Moreover, it will be valuable for implementing efficient energy savings in the future.

Indoor thermal comfort is affected by heat transfer through wall or roof sections that are exposed to direct solar radiation (Kreider, 2002). The other importance of current study is evaluating the indoor thermal comfort condition which is affected under direct solar radiation. This part of study focused to improve the thermal comfort condition in air conditioning room and cooling energy requirement with managing the solar radiation on building envelope and balancing the thermal transaction.

According to Saidur et al. (2009) windows to wall ratio (WWR) of residential buildings in Malaysia is very low and it is only %6. Hence, equation for overall thermal transfer value (OTTV) which is a factor for air-conditioning buildings (MS1525, 2014) is not affected by Windows to wall ratio in aforementioned sector. Also, simulated by Datta (2001) about effect of external fixed louver shading on heating and cooling of Italian buildings was done in a south windows of a single test cell. Therefore, similarly in current study, shading on opaque facades has been assessed to find out (OTTV) modification for a single test cell that windows to wall ratio is low and solar radiation on opaque facades is the main reason of thermal discomfort. Thus, the result of this study can be new insight for considering the external fixed shading of opaque facades on OTTV for air-conditioning residential buildings in Malaysia.

Palmero-Marrero et al. (2010) indicates main aspects for louver system are depth, offset, height and tilt of array. Offset is distance between the louvers and the building that affects the amount of solar energy that incident on building envelope. Also, louvers on building envelope without distance conduct the temperature to building facades. Hence, current research evaluated the external louver shading on building opaque facades with 0.1m offset. Additionally, some constraints and considerations were required in various aspects of this work to narrow it down.

In some studies with limited times, researchers carried out experimental measurement but during the critical times of the year in some sample area besides corresponding simulation (Rajapaksha et al., 2003). The duration of time allocated for data collection for this study was from Solstices and Equinox (21 march, June, September, December). Studies on solar effects on built environment can be successfully have been done for solstices and Equinox because it is possible to generalize both situation throughout the year (Lechner, 2009). A similar time was adopted in this study wherein simulation process was conducted through aforementioned days.

Studies about physical external shading effect on indoor thermal performance by Datta (2001) has simulated on south windows of a simple room in Italy. Similar case study in this research has been evaluated. Hence, in assessing the physical external shading of opaque facades on heat gain, a single test cell in faculty of Design and Architecture at University Putra Malaysia has been selected as field measurement. Due to dimensions of test cell facades, in order to optimize the shading on building envelope, current research is limited to consider the 100% shading on opaque surfaces.

## 1.7 Contributions and Significance of the study

The knowledge contribution of this study is the introduction of the external fixed shading devices for Malaysian buildings in a humid tropical climate, which would provide insights into building design for designers and architects to modify or alter the heat gain of the building. Through the heat modification process demonstrated in this study, the thermal transfer rate and cooling requirements of Malaysian buildings is represented. This can enhance design guidelines so that more buildings with less-energy consumption can be designed and built for the Malaysian tropical climate. Furthermore, this study also creates awareness of sustainable buildings and highlights the fundamentals of controlling solar radiation on opaque facades of buildings.

## 1.8 Research Framework

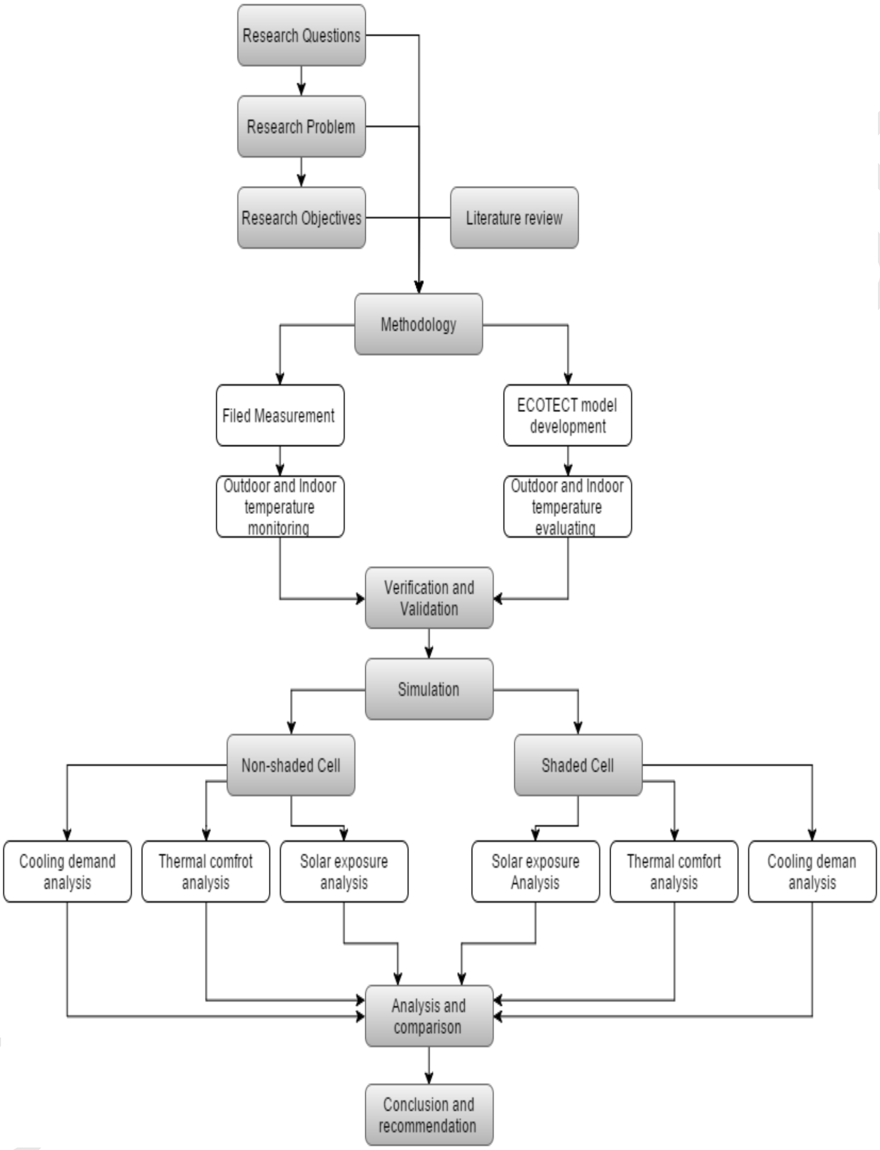


**Figure 1.1: Research Framework**

## 1.9 Organization of the Thesis

This thesis consists of five chapters. The organization of the chapters is clarified below:

Chapter 1 provides an overview of this research such as the, research background, problem statement, research questions, formulation of the purpose and objectives, expected outcomes, importance and benefits of the research, determination of the scope and limitations of research and the research methodology.

Chapter 2 presents the literature review that discusses previous studies in the field of radiation, shading and heat gain. This chapter investigates previous studies on the variety of options that affect research results which are utilized to guide the preparation of the research.

Chapter 3 indicates the method of research for data collection. The simulation processes, as well as the variables such as indoor conditions, operation times, building models, and analyzing tools, are also explained in detail in this chapter.

Chapter 4 presents conclusive outcomes arising from the analysis of the methodology and data for calculating heat gain and OTTV. The analysis of the information from simulation shows the behavior of buildings affected by shading on external walls. Tables and diagrams illustrate the information for each model and show their reactions to architectural strategies.

Chapter 5 summarizes the major outcomes of the study and offers suggestions and recommendations for future research.

## REFERENCES


Abdullah, A. H., Bakar, S. K. A., & Rahman, I. A. (2013). Simulation of Office‟s Operative Temperature Using ECOTECT Model. *International Journal of Construction Technology and Management, 1*(1), 33-37.

Al-Tamimi, N. A., & Fadzil, S. F. S. (2011). The Potential of Shading Devices for Temperature Reduction in High-Rise Residential Buildings in the Tropics. *Procedia Engineering, 21*, 273-282.

ASHRAE. (2011). *2011 Ashrae Handbook: Heating, Ventilating, and Air-conditioning Applications*: ASHRAE.

ASHRAE. (2013). Standard 55-2013. Thermal environmental conditions for human occupancy. ASHRAE. *Atlanta, USA*.

Aste, N., Angelotti, A., & Buzzetti, M. (2009). The influence of the external walls thermal inertia on the energy performance of well insulated buildings. *Energy and Buildings, 41*(11), 1181-1187. Atmaca, I., Kaynakli, O., & Yigit, A. (2007). Effects of radiant temperature on thermal comfort. *Building and Environment, 42*(9), 3210-3220.

Atzeri, A., Cappelletti, F., & Gasparella, A. (2014). Internal Versus External Shading Devices Performance in Office Buildings. *Energy Procedia, 45*, 463-472.

Auliciems, A., & Szokolay, S. V. (1997). *Thermal comfort.* Paper presented at the Passive and Low Energy Architecture International

DESIGN TOOLS AND TECHNIQUES.

Azhari, A. W., Sopian, K., Zaharim, A., & Al Ghoul, M. (2008). A new approach for predicting solar radiation in tropical environment using satellite images-case study of Malaysia. *WSEAS Transactions on Environment and Development, 4*(4), 373-378.

Bedford, T. (1951). Equivalent temperature. *What is it*, 87-91.

Bensalem, R. (1997). leanring from the past and exploring contemporary concepts in the context of Algeria. Accessed on 20th OCT 2007. *Climate Resopnsive Architecture*.

Brennan, C. J. (2012). Analysis of passive louver shading systems andimpact on interior environment. *Masters Theses. Paper6941. Missuri University of scince and technology*

Castleton, H., Stovin, V., Beck, S., & Davison, J. (2010). Green roofs; building energy savings and the potential for retrofit. *Energy and Buildings, 42*(10), 1582-1591.

Chan, A. L. S., & Chow, T. T. (2013). Evaluation of Overall Thermal Transfer Value (OTTV) for commercial buildings constructed with green roof. *Applied Energy, 107*(0), 10-24. Ching, F. D. (2014). *Building construction illustrated*: John Wiley & Sons.

Choi, J., Lee, T., Ahn, E., & Piao, G. (2014). Parametric louver design system based on direct solar radiation control performance. *Journal of Asian Architecture and Building Engineering, 13*(1), 57-62. doi: 10.3130/jaabe.13.57

CIBSE. (2006). Environmental design. *The Chartered Institution of Building Services Engineers, London*.

Dahlan, N., Jones, P., Alexander, D., Salleh, E., & Dixon, D. (2008). Field measurement and subjects' votes assessment on thermal comfort in high-rise hostels in Malaysia. *Indoor and Built Environment, 17*(4), 334-345.

Datta, G. (2001). Effect of fixed horizontal louver shading devices on thermal perfomance of building by TRNSYS simulation. *Renewable Energy, 23*(3), 497-507.

De Dear, R., & Brager, G. S. (1998). Developing an adaptive model of thermal comfort and preference. *Center for the Built Environment*.

Dekay, M., & Brown, G. (2013). *Sun, wind, and light: Architectural design strategies*: John Wiley & Sons.

Deru, M. P., & Torcellini, P. A. (2005). *Standard definitions of building geometry for energy evaluation*: National Renewable Energy Laboratory.

Dubois, M.-C. (1997). Solar Shading and Building Energy Use. *Lund University*.

Dubois, M.-C. (2000). *A method to define shading devices considering the ideal total solar energy transmittance.* Paper presented at the Proceedings of the Eurosun 2000 Conference.

Fanger. (1970). Thermal comfort. Analysis and applications in environmental engineering. *Thermal comfort. Analysis and applications in environmental engineering.*

Feng, G., Zhang, Q., Sha, S., & Wang, Z. (2014) The energy consumption analysis for the windows with external shading influenced on the green building. *Vol. 263 LNEE. 8th International Symposium on Heating, Ventilation, and Air Conditioning, ISHVAC 2013* (pp. 515-521). Xi'an.

GBI. (2009). Applying MS1525:2007 Code of Practice on Energy Efficiency and Use of RenewableEnergy for Non-Residential Buildings. *Pertubuhan Arkitek Malaysia CPD Seminar 14th February 2009*.

Ghaffarianhoseini, A., Berardi, U., GhaffarianHoseini, A., & Makaremi, N. (2012). Intelligent facades in low-energy buildings. *British Journal of Environment and Climate Change, 2*(4), 437-464.

Givoni, B. (1994). *Passive low energy cooling of buildings*: John Wiley & Sons.

Givoni, B. (1998). *Climate considerations in building and urban design*: John Wiley & Sons.

Guohui, F., Zhang, Q., Sha, S., & Wang, Z. (2014). *The Energy Consumption Analysis for the Windows with External Shading Influenced on the Green Building.*

Paper presented at the Proceedings of the 8th International Symposium on Heating, Ventilation and Air Conditioning.

Hui, S. C. (1997). *Overall thermal transfer value (OTTV): how to improve its control in Hong Kong.* Paper presented at the Proc. of the One-day Symposium on Building, Energy and Environment.

Hui, S. C., & Lam, J. C. (1991). Overall thermal transfer value (OTTV)-a review. *Hong Kong Engineer, 19*(9), 26-32.

Iqbal, M. (1983). *An introduction to solar radiation*: Elsevier.

ISO. (2007). 10211: Thermal bridges in building construction–Heat flows and surface temperatures–detailed calculations (ISO 10211: 2007): CEN.

Jaafar, B., Said, I., Reba, M. N. M., & Rasidi, M. H. (2013). Impact of Vertical Greenery System on Internal Building Corridors in the Tropic. *Procedia - Social and Behavioral Sciences, 105*(0), 558-568.

Jain, S., Creasey, R., Himmelspach, J., White, K., Fu, M., Vangimalla, P. R., . . . Hinze, J. (2011). VALIDATION OF AUTODESK ECOTECTTM ACCURACY FOR THERMAL AND DAYLIGHTING SIMULATIONS.

Jensen, M., & Larson, S. L. (2014). Annual Solar Motion and Spy Satellites.

Kapur, N. K. (2004). A comparative analysis of the radiant effect of external sunshades on glass surface temperatures. *Solar Energy, 77*(4), 407-419.

Kreider, J. (2002). *Heating and Cooling of Buildings: Design for Efficiency*: UNIV OF COLORADO BOULDER

Ari Rabl, PRINCETON UNIVERSITY.

Kumar, R., & Kaushik, S. (2005). Performance evaluation of green roof and shading for thermal protection of buildings. *Building and Environment, 40*(11), 1505-1511.

Lam, C, J., Tsang, C., Li, D. H., & Cheung, S. (2005). Residential building envelope heat gain and cooling energy requirements. *Energy, 30*(7), 933-951.

Lam, Joseph C, & Hui, S. (1996). A review of building energy standards and implications for Hong Kong. *Building Research and Information, 24*(3), 131-140.

Lam, Li, D. H., & Cheung, S. (2003). An analysis of electricity end-use in air-conditioned office buildings in Hong Kong. *Building and Environment, 38*(3), 493-498.

Lechner, N. (2009). *Heating, cooling, lighting: sustainable design methods for architects*: John Wiley & Sons Hoboken, NJ, USA.

Li, D. H., & Lam, J. C. (2000). Solar heat gain factors and the implications to building designs in subtropical regions. *Energy and Buildings, 32*(1), 47-55.

Liu, X., Jiang, Y., & Zhang, T. (2014). *Temperature and Humidity Independent Control (THIC) of Air-conditioning System*: Springer Science & Business Media.

Loutzenhiser, P., Manz, H., Felsmann, C., Strachan, P., & Maxwell, G. (2007). An empirical validation of modeling solar gain through a glazing unit with external and internal shading screens. *Applied Thermal Engineering, 27*(2), 528-538.

Maamari, F., Andersen, M., de Boer, J., Carroll, W. L., Dumortier, D., & Greenup, P. (2006). Experimental validation of simulation methods for bi-directional transmission properties at the daylighting performance level. *Energy and Buildings, 38*(7), 878-889.

Mahlia, Taufiq, B. N., Ismail, & Masjuki, H. H. (2007). Correlation between thermal conductivity and the thickness of selected insulation materials for building wall. *Energy and Buildings, 39*(2), 182-187.

Marsh, A. (2003). ECOTECT and EnergyPlus. *Building Energy Simulation User News, 24*(6), 2-3.

MetMalaysia, R. o. M. D., Malaysain Metrological Department Petalying Jaya Station, Kuala Lumpur. (2009).

Moldovan, M. D., Visa, I., Neagoe, M., & Burduhos, B. G. (2014). Solar heating & cooling energy mixes to transform low energy buildings in nearly zero energy buildings. *Energy Procedia, 48*, 924-937.

MS1525. (2014). Malaysian standard. In D. o. M. standard (Ed.): Ministry of scince, Technology and innovation.

Muneer, T. (2007). *Solar radiation and daylight models*: Routledge.

Nysan, S. C. (2012). A Hunter Douglas Contract Company. Sun Louvers. hurev2withchange.pdf>.

Onbasioglu, H., & Egrican, A. N. (2002). Experimental approach to the thermal response of passive systems. *Energy conversion and management, 43*(15), 2053-2065.

Ottelé, M., Perini, K., Fraaij, A., Haas, E., & Raiteri, R. (2011). Comparative life cycle analysis for green façades and living wall systems. *Energy and Buildings, 43*(12), 3419-3429.

Palmero-Marrero, A. I., & Oliveira, A. C. (2010). Effect of louver shading devices on building energy requirements. *Applied Energy, 87*(6), 2040-2049.

Pargana, N., Pinheiro, M. D., Silvestre, J. D., & de Brito, J. (2014). Comparative environmental life cycle assessment of thermal insulation materials of buildings. *Energy and Buildings, 82*(0), 466-481.

Peci López, F., & Ruiz de Adana Santiago, M. (2015). Sensitivity study of an opaque ventilated façade in the winter season in different climate zones in Spain. *Renewable Energy, 75*(0), 524-533.

Pérez, G., Rincón, L., Vila, A., González, J. M., & Cabeza, L. F. (2011). Green vertical systems for buildings as passive systems for energy savings. *Applied Energy, 88*(12), 4854-4859.

Puteh, M., Ibrahim, M. H., Adnan, M., Che"Ahmad, C. N., & Noh, N. M. (2012). Thermal Comfort in Classroom: Constraints and Issues. *Procedia - Social and Behavioral Sciences, 46*, 1834-1838.

Rajapaksha, I., Nagai, H., & Okumiya, M. (2003). A ventilated courtyard as a passive cooling strategy in the warm humid tropics. *Renewable Energy, 28*(11), 1755-1778.

Rayner, J., Raynor, K., & Williams, N. (2010). Façade greening: a case study from Melbourne, Australia. *Acta horticulturae, 881*.

Safikhani, T., Abdullah, A. M., Ossen, D. R., & Baharvand, M. (2014). A review of energy characteristic of vertical greenery systems. *Renewable and Sustainable Energy Reviews, 40*(0), 450-462.

Saidur, R Hasanuzzaman, M., Hasan, M., & Masjuki, H. (2009). Overall thermal transfer value of residential buildings in Malaysia. *Journal of Applied Sciences, 9*(11), 2130-2136.

Samanta, A., Saha, S., Biswas, J., & Dutta, A. (2014). Evaluation of Impact of Shading Devices on Energy Consumption of Buildings in Tropical Regions. *Journal of Energy Resources Technology, 136*(2), 024503.

Sciuto, S. (1994). Model development subgroup report, vol. 2 solar control. *Conphoebus SC rI, Catania, Italy*.

Shekarchian, M., Moghavvemi, M., Rismanchi, B., Mahlia, T. M. I., & Olofsson, T. (2012). The cost benefit analysis and potential emission reduction evaluation of applying wall insulation for buildings in Malaysia. *Renewable and Sustainable Energy Reviews, 16*(7), 4708-4718.

Shoubi, M. V., Shoubi, M. V., Bagchi, A., & Barough, A. S. (2014). Reducing the operational energy demand in buildings using building information modeling tools and sustainability approaches. *Ain Shams Engineering Journal*. doi: 10.1016/j.asej.2014.09.006

Šuklje, T., Medved, S., & Arkar, C. (2013). An Experimental Study on a Microclimatic Layer of a Bionic Façade Inspired by Vertical Greenery. *Journal of Bionic Engineering, 10*(2), 177-185.

Sulaiman, M. J. M. F. M. Z. (2013). *shading performance of tropical climing plant: Anemopaegma chamberlaynii on green facades*. Paper presented at the international sustainable tropical environmental design confrence 2013, faculty of design and architecture , University Putra Malaysia 43400. UPM serdang selangor , malaysia.

Szokolay, & V, S. (2014). *Introduction to architectural science: the basis of sustainable design*: Routledge.

Tang, N. C. (2013). *Building Energy Eficiency Technical Guideline for Passive Design*. Malaysia: the Building Sector Energy Eficiency Project (BSEEP), Malaysia. © BSEEP. All rights reserved.

Tarara, J. M., Lee, J., Spayd, S. E., & Scagel, C. F. (2008). Berry temperature and solar radiation alter acylation, proportion, and concentration of anthocyanin in Merlot grapes. *American Journal of Enology and Viticulture, 59*(3), 235-247.

Taylor, T., Counsell, J., & Gill, S. (2014). Combining thermography and computer simulation to identify and assess insulation defects in the construction of building façades. *Energy and Buildings, 76*(0), 130-142.

Vangimalla, P. R., Olbina, S. J., Issa, R. R., & Hinze, J. (2011). *Validation of Autodesk Ecotect™ accuracy for thermal and daylighting simulations.* Paper presented at the Simulation Conference (WSC), Proceedings of the 2011 Winter.

Vijayalaxmi. (2010). Concept of Overall Thermal Transfer Value (OTTV) in Design of Building Envelope to Achieve Energy Efficiency. *Int. J. of Thermal & Environmental Engineering, 1, No. 2 (2010) 75-80.*

Vijayalaxmi, J. (2010). Concept of overall thermal transfer value (OTTV) in design of building envelope to achieve energy efficiency. *Int. J. of Thermal & Environmental Engineering, 1*(2), 75-80.

Wong, & al, e. (2010). Thermal evaluation of vertical greenery systems for building walls. *Building and Environment, 45*(3), 663-672.

Wong, Hien, N., Chen, Y., Ong, C. L., & Sia, A. (2003). Investigation of thermal benefits of rooftop garden in the tropical environment. *Building and Environment, 38*(2), 261-270.

Wong, Hien, N., Tan, A. Y. K., Chen, Y., Sekar, K., Tan, P. Y., . . . Wong, N. C. (2010). Thermal evaluation of vertical greenery systems for building walls. *Building and Environment, 45*(3), 663-672.

Wong, Hien, N., Tan, A. Y. K., Tan, P. Y., & Wong, N. C. (2009). Energy simulation of vertical greenery systems. *Energy and Buildings, 41*(12), 1401-1408.

Yang, L., He, B.-J., & Ye, M. (2014). Application research of ECOTECT in residential estate planning. *Energy and Buildings, 72*(0), 195-202.

Yik, F., & Wan, K. (2005). An evaluation of the appropriateness of using overall thermal transfer value (OTTV) to regulate envelope energy performance of air-conditioned buildings. *Energy, 30*(1), 41-71.

Zhu, P., Huckemann, V., & Fisch, M. N. (2011). The optimum thickness and energy saving potential of external wall insulation in different climate zones of China. *Procedia Engineering, 21*(0), 608-616.