MINIMIZING SOLAR INSOLATION IN HIGH-RISE BUILDINGS THROUGH SELF-SHADED FORM

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ABSTRACT

High-rise buildings experiences overheating conditions especially in hot humid tropics. For a high-rise built form, vertical surfaces receive the most critical impact from solar radiation. This study examines the effect of geometric high-rise forms against the amount of solar insolation received by the external surfaces, and the generation of self-shading strategies where high-rise buildings form are self-shaded from solar insolation during the required period. The study is divided into two main parts and conducted using building simulation program 'ECOTECT V5.2b'. The first part is on the evaluation of the effect of geometric shapes based on annual total solar insolation received on the entire exposed vertical surfaces. Circular and square generic shapes with their variations in width-to-length ratio and building orientations are generated. Circular and square shapes with width-to-length ratio 1:1 received the lowest annual total solar insolation. They are selected as the optimum shapes. The second part is the modification of stepped inverted geometry method involving four different depths of self-shading projections to building height. Each floor are experimented based on direct and diffuse components of solar insolation received on vertical surfaces for three different design-days. The simulation results revealed that significant reduction of 60% direct solar insolation could be achieved by self-shading projection ratio of 1.00, 0.75 and 0.25 on east, west, north and south wall respectively. Circular shape with varying wall orientations and curvatures performed better compared to square shape. With appropriate attentions given to the proportion of geometric shapes and self-shading projection ratio, the impact of solar radiation on high-rise building shape can be minimised. Hence, it can be assumed that the energy consumption used for cooling load can also be reduced.

ABSTRAK

Bangunan tinggi mengalami keadaan pemanasan yang melampau terutamanya dalam iklim panas dan lembap. Permukaan menegak bagi bangunan tinggi menerima kesan pancaran matahari yang paling kritikal. Kajian ini dijalankan untuk menyelidik kesan bentuk geometri bangunan tinggi terhadap jumlah insolasi solar yang diterima oleh permukaan luaran bangunan tersebut. Strategi pembentukan secara teduhan sendiri membolehkan bangunan tinggi memperolehi perlindungan insolasi solar daripada bentuknya sendiri pada tempoh masa yang diperlukan. Kajian ini dibahagikan kepada dua bahagian utama dan dikendalikan menggunakan program simulasi bangunan '*ECOTECT V5.2b'*. Bahagian pertama merupakan penilaian tentang kesan bentuk geometri bangunan berdasarkan jumlah tahunan insolasi solar terhadap seluruh permukaan luaran bangunan tersebut. Bentuk tipikal bangunan iaitu bulatan dan segiempat dengan pelbagai variasi dari segi nisbah lebar kepada panjang bangunan termasuk orientasi bangunan telah dihasilkan. Bentuk bulatan dan segiempat yang mempunyai nisbah lebar kepada panjang 1:1 menerima jumlah tahunan insolasi solar yang paling rendah dan dipilih sebagai bentuk optima untuk simulasi yang seterusnya. Bahagian kedua melibatkan pengubahsuaian geometri bertingkat songsang melibatkan empat perbezaan lebar bagi nisbah unjuran teduhan sendiri. Semua pengubahsuaian dikaji berdasarkan pancaran haba terus dan baur matahari yang diterima pada permukaan menegak bagi tiga hari rekabentuk yang berlainan. Keputusan menunjukkan pengurangan yang nyata iaitu sebanyak 60% daripada pancaran haba terus boleh dicapai dengan nisbah teduhan sendiri 1.00, 0.75 and 0.25 masing-masing pada dinding timur, barat, utara dan selatan. Bentuk bulatan dengan pelbagai orientasi dinding dan lengkuk adalah lebih baik berbanding dengan bentuk segiempat. Dengan perhatian yang setimpal diberi kepada bentuk geometri dan nisbah unjuran teduhan sendiri, kesan pancaran matahari pada permukaan luaran bangunan tinggi boleh diminimumkan. Andaian boleh dibuat bahawa penggunaan tenaga untuk menampung beban penyejukan bangunan dapat dikurangkan.

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LIST OF ABBREVIATIONS

ASHRAE	-	American Society of Heating, Refrigerating and Air Conditioning Engineers
BC	-	Base Case
BDL	-	Building Description Language
BLAST	-	Building Loads Analysis and System Thermodynamics
CAD	-	Computer Aided Design
CC	-	Circular shape
CTBUH	-	Council on Tall Building and Urban Habitat
DOE	-	Department of Energy (United States)
DOE.wf	-	Department of Energy weather file
EEM	-	Energy Efficient Measures
eQUEST	-	Quick Energy Simulation Tool
GFA	-	Gross Floor Area
GIA	-	Gross Internal Area
HVAC	-	Heating, Ventilation & Air-Conditioning
HSA	-	Horizontal Shadow Angle
IB	-	Intelligent Building
IES	-	Illuminating engineers society of North America
IES	-	International Energy Standards
KL	-	Kuala Lumpur
MBE	-	Mean Bias Error
MS	-	Malaysian Standards
NRA	-	Net Rentable Area
OHR	-	Overhang Ratio
PF	-	Projection Factor
RMSE	-	Root Mean Square Error
SIG	-	Stepped Inverted Geometry

SMS	-	Subang Meteorological Station
SQ	-	Square shape
SSP	-	Self-shading Projection
TMY	-	Typical Metrological Year
TRY	-	Test Reference Year
UTM	-	Universiti Teknologi Malaysia
VE	-	Virtual Environment
VSA	-	Vertical Shadow Angle
2103	-	Design-day: 21 March
2206	-	Design-day: 22 June
2112	-	Design-day: 21 Decemebr

LIST OF SYMBOLS

A	-	Surface Area (m^2)
β	-	Solar altitude angle above the horizontal (^{0})
C	-	Diffuse sky factor
CR	-	Cloud Ratio
D	-	Depth of the horizontal projection (m)
δ	-	Solar declination angle (^{0})
d	-	Horizontal projection of the distance between the awning's lower corner and its shadow on the vertical wall (m)
E_t	-	Equation of time
ϕ	-	Latitude of the location (^{0})
f	-	Depth of the vertical fin (m)
f_r	-	Fraction of diffuse radiation obstructed by the shading device
γ	-	Surface solar azimuth (^{0})
G-value	-	Total fraction of incident solar energy transmitted (dimensionless)
G_{ref}	-	Reflectance of the ground
H_{fen}	-	Height of fenestration (m)
I_{sc}	-	Solar constant
I_o	-	Extraterrestrial solar radiation (W/m^2)
I_{bn}	-	Direct beam normal solar radiation (W/m^2)
I_{bh}	-	Direct beam solar radiation on horizontal surface (W/m^2)
I_{bv}	-	Direct beam solar radiation on vertical surface (W/m^2)
$I_{diff,h}$	-	Diffused solar radiation on horizontal surface (W/m^2)
$I_{diff,v}$	-	Diffused sky radiation on vertical surface (W/m^2)
I_{Gh}	-	Global irradiance horizontal surface (W/m^2)
I_{Gv}	-	Global irradiance vertical surface (W/m^2)
I_r	-	Ground reflected radiation (W/m^2)
$I_{t,\theta}$	-	Total horizontal radiation strikes the ground surface (W/m^2)

$I_{tot,h}$	-	Total solar radiation on horizontal surface (W/m^2)
$I_{tot,v}$	-	Total solar radiation on vertical surface
$I_{cl,diff}$	-	Diffused solar radiation clear sky (W/m^2)
$\dot{I}_{dv}$	-	Diffused & reflected radiation on vertical glazing (W/m^2)
$\dot{I}_{bv}$	-	Direct beam radiation on vertical plane (W/m^2)
$\ddot{I}$	-	Apparent extraterrestrial irradiance (W/m^2)
$\acute{I}_{dr}$	-	Direct solar radiation transmitted through standard 3mm clear glass
$\acute{I}_{df}$	-	Diffused solar radiation transmitted through standard 3mm clear glass
$\acute{I}_{tot}$	-	Total (direct + diffused) solar radiation transmitted through standard 3mm clear glass
K_D	-	Diffused luminous efficacy (lm/W)
K_G	-	Global luminous efficacy (lm/W)
L_{edge}	-	Length of window frame edge (m)
L_{loc}	-	Longitude of the location (in degree)
L_{std}	-	Standard meridian for the local time zone (Longitude of the time zone)
L_{tot}	-	Total Length (m)
n_o	-	Maximum possible sunshine duration
θ	-	Incident angle (^{0})
θ_h	-	Angle of incidence on horizontal surface (^{0})
θ_v	-	Angle of incidence on vertical surface (^{0})
S	-	Relative sunshine duration
SC	-	Shading coefficient
S_{df}	-	Sky diffusive factor
T_{sol}	-	Local solar time
T_{std}	-	Local standard time
v	-	Vertical projection of the awning/ horizontal shading device (m)
W	-	Total light wattage
ω	-	Solar hour angle (^{0})
W_{awn}	-	Width of the awning (m)
W_{fen}	-	Width of fenestration (m)

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CHAPTER 1

INTRODUCTION

This thesis investigates the effect of various geometric high-rise forms against the amount of solar insolation received by their external surfaces towards the potential of using self-shading strategies. The ultimate aims to minimise total heat gains and reduce cooling load in the effort to promote low energy office building in Malaysia.

1.1 Background and Statement of Problem

In Malaysia, around 514 high-rise buildings are built since 1970 (source: www.emporis.com). However, Knowles (1981) stressed that large or tall buildings around the world often built to appear the same, block to block and even from one geographical region to another regardless the energy cost. Thus, the question is whether they really response to the local climate. This shows that the climate today is not influencing the design of high-rise building anymore. It is now becoming more crucial to find out concerning energy conserving high-rise building shape for tropical climate as energy consumed by building is directly influenced by the climate conditions (Knowles, 1981).

Since Malaysia is in the tropical region, it is undeniable that we are facing design challenge in terms of sun and wind. Unlike the temperate climate, tropical region can be said as having summer all year round, which means that building in the tropics gains unnecessary excessive solar radiation. More solar radiation means more total solar heat gain and hence increases demands for cooling loads. Therefore, it is important to prevent solar radiation from overheating external façade of the buildings, especially for high-rise building.

Due to their height, high-rise building envelope are exposed to the full impact of global solar radiation and the outdoor temperature compare to low-rise or medium-rise buildings, which can be easily shaded by the roof and vegetation (Arvind, 1995). The high-rise buildings have significantly larger façade and fenestration area than low-rise building. The vertical surface area is also a major variable in determining the impact of climate forces, practically which can not be covered by a roof (Ossen, 2005).

Ken Yeang (1996) suggested that architecture design of high-rise has remained unchanged since its invention. Its technology and engineering have become far better and much more sophisticated, but most of the high-rise buildings constructed today remain fundamentally similar in term of their built configuration. Conventional high-rise is like a concealed box of geometrical form that segregates users from the external natural environment. Users of the high-rise buildings live in an artificially controlled environment and these artificial environments are expected to fulfil the basic needs of users such as lighting, ventilation and thermal comfort. In fulfilling these requirements, high energy on mechanical system is used, thereby increasing energy consumption in office buildings.

Energy studies in commercial buildings in Southeast Asia were first initiated under the ASEAN-USAID Building Energy Conservation project in 1992. The results showed that office buildings in this region have an energy consumption of 233kWh/m^2/year on average. Comparison among the participating countries revealed that Malaysia has the highest energy consumption (269kWh/m^2/year) among the office buildings surveyed. According to MS1525:2001, code of practice for non-residential buildings on energy efficiency and use of renewable energy, the non-residential building should comply with an annual energy consumption of less than 135kWh/m^2/yr. However, the previous energy audit by ASEAN-USAID in

1992 showed that the average energy consumption for office building could be almost 100% more than the suggested new requirements. Then, it is a challenge for the government agencies, architects and engineers to reduce energy consumption particularly in office buildings to meet the MS1525:2001 Code of Practice.

In order to reduce this energy load, the understanding of the overall architectural design features of high-rise office buildings in hot tropics is important. Efforts to reduce cooling load can be done by blocking and filtering solar radiation from entering the building. The prediction of maximum irradiance value is primarily of interest for computing peak indoor temperatures and for sizing of air-conditioning plant. While the prediction of average solar insolation for any day, month, season or year are needed in estimating the cooling load arising from radiation received on walls or transmission through windows. Further, as solar insolation refers to the total amount of cumulative incident solar radiation on a point or surface over a specified period, the understanding of the characteristic of solar insolation strikes on different geometric shapes and orientations are crucial. Figure 1.1 illustrates the issue and the statement of the problem for this study.

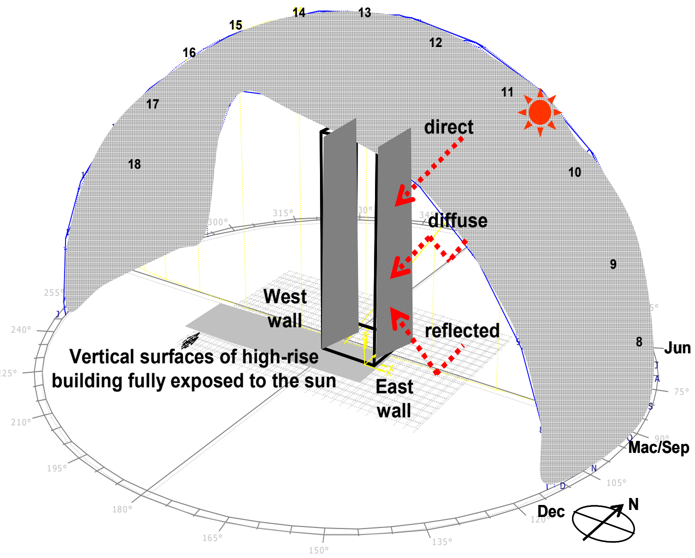


Figure 1.1: The issue and problem: influence of solar insolation on vertical surfaces of high-rise building.

One of the possible solutions is the high-rise built form to be self-protected from the tropical sun. Capeluto (2003) suggests self-shading building envelope for solar prevention at the building scale. This is a concept exactly opposite to the concept promoted by Knowles (1981) called a "solar envelope" which normally applied at urban scale. Self-shading strategy has been applied for low and medium-rise building in temperate climate (Capeluto, 2003). Generation of self-shading strategy in a way that high-rise building form is self-shaded from impact of solar radiation is important during the required period should now be investigated. Further design modification on the self-shading strategies is also needed to fulfil the appropriate design issue before it can be applied for high-rise building design especially in the tropics. Figure 1.2 illustrates the proposition of this study.

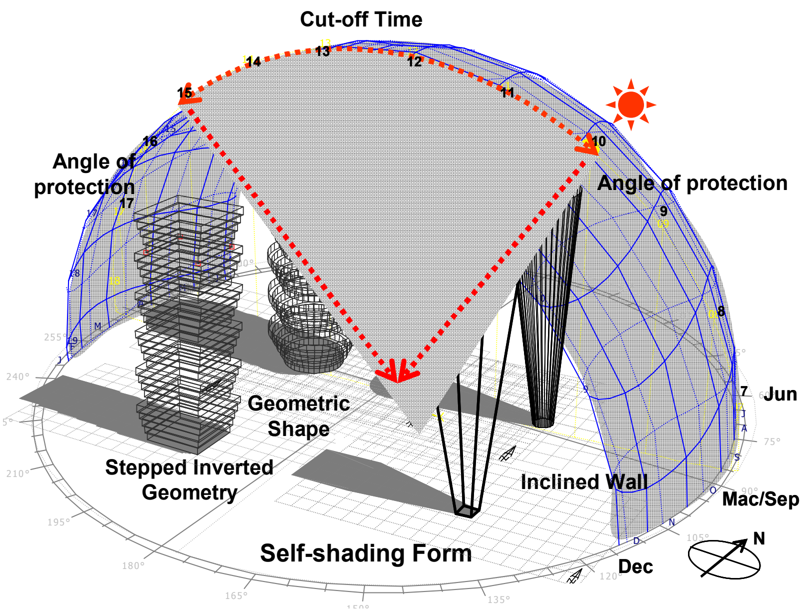


Figure 1.2: The thesis proposition: self-shading strategy to minimise the impact of solar insolation on vertical surfaces of high-rise building

1.2 Research Question

The following questions will be addressed in this thesis:

Q1. Does vertical exposed surfaces of high-rise built form received more impact of solar insolation as compare to low-rise and medium-rise built form?

Q2 What are the relationships between the geometric characteristics of high-rise built form: (a) geometric shape, (b) width-to-length ratio (W/L ratio) and (c) building orientations towards minimizing annual total solar insolation on vertical surfaces?

Q3. What is the optimum geometric shape of high-rise building towards minimising annual total insolation on vertical surfaces?

Q4. What are the implications of the self-shading strategies: (a) inclined wall and (b) stepped inverted geometry, in order to adapt these strategies into high-rise built form?

Q5. What is the effectiveness of self-shading projection ratios (SSP ratio) in reducing direct and diffuse components of solar insolation on varies wall surfaces of the selected optimum shapes for three different design-days?

1.3 Research Gap

Review on previous research can be divided into to two main parts. First, it describes the relationship between climate impacts and building shapes. The review revealed that research on building shape had been focussed mainly on low-rise and medium-rise built form towards various climatic impacts. Studies from Olgyay, (1963); Markus (1980) and Ken Yeang (1994) defined optimum building shape according to their specified area of concerns. Markus (1980) suggested the cylinder form is the optimum shape on minimising the impact of heat gain and heat loss for temperate climate. Olgyay (1963) recommended that rectangular form with width-to-length ratio 1:1.7 was optimum shape for tropical climate in considering the heating and cooling factors through out the year. Ken Yeang (1994) defined that optimum tropical high-rise built form should have the north-south orientation with its width-to-length ratio of 1:3. After reviewing all the above said studies, efforts of looking for the optimum geometric high-rise built forms where minimizing solar insolation is the main design concern is crucial and timely.

After the optimum geometric high-rise building, the second part reviews the finding of the appropriate solar shading strategies for high-rise built form in hot-humid tropic. For tropical climate, solar shading strategy is most crucial to prevent unwanted solar radiation compared to other climatic zones. Most of the studies focus on using the external shading devices (Ossen, 2005; Cheung, et al., 2004; Dewi, 2004) and internal shading devices (Tilmann 2005) to reduce the solar heat gain, or optimise the availability of daylight to the internal space.

Capeluto (2003) suggested self-shading building envelope for solar prevention at the building scale. This study aims to look for high-rise built form to be self-protected from the tropical sun. Self-shading strategy has been applied on low-rise and medium-rise building in temperate climate. Its application on high-rise building is yet to be found. Therefore, further design modification on the self-shading strategies is needed to fulfil appropriate design issue before it be applied for high-rise building design.

Table 1.1: Summary of previous research related to climate impact and building shape. (Appendix A)

		Built Form			Building shape			Form indicator			Climate impact				
	climate	High-rise	Medium-rise	Low-rise	Built form	geometric	Compact-ness	S/V	B/S	W/L	Solar radiation	Air velocity	Air Tem-perature	Thermal	Energy load
W. Pessenlehner A. Mahdavi (2003)	t		√			√	√	√		√			√		
T.N. Stasinopoulos (1999)	v	√	√	√	√	√			√		√				√
Vladimir Matus (1988)	t		√	√	√	√	√	√		√	√	√	√		
Ralph L. Knowles (1974)	t		√	√	√		√	√			√				
Markus T.A, Morris E.N. (1980)	v		√	√	√			√				√	√	√	
P.Depecker et al (2000)	v		√		√		√	√		√	√				√
Ken Yeang (1996)	v	√				√					√	√		√	√
PRESENT STUDY		√			√	√		√	√	√	√				

*Climate: t: temperate climate, v: various Climates, hh: hot and humid climate, ha: hot and arid climate.
Form indicator: S/V: exposed surface-to-volume ratio; B/S: base floor area-to-exposed surface ratio; W/L: width-to-length ratio

Table 1.2: Summary of previous research related to solar radiation and shading design strategy. (Appendix B)

	climate	Design variable										Solar radiation				
		Built Form			Geometric		Shading strategy									
		High-rise	Medium-rise	Low-rise	Bldg. shape	Orientation	Solar envelope	Core position	External Shading	Internal shading	Self shading	Solar heat gain	Daylight	Insolation	distribution pattern	Energy load
Capeluto (2002)	ha		√		√	√	√			√	√			√		√
Ahmad A., Mohd Gadi (2003)	ha			√		√						√		√	√	
Tilmann (2005)			√	√		√				√		√	√			√
Jahnkassim (2005)	h	√				√		√	√							√
Ossen (2005)	h	√				√			√			√	√	√		√
Ken Yeang (1996)	hh	√			√	√	√	√	√				√	√		√
PRESENT STUDY	hh	√			√	√					√			√	√	

*Climate: t: temperate climate, v: various Climates, hh: hot and humid climate, ha: hot and arid climate.

1.4 Research Objective

The primary intention of this study is to explore the possibility of application of self-shading strategy in high-rise building in order to minimise further the impact of solar insolation on its external facade. The influence of various geometrical high-rise forms against the amount of solar insolation need to be further discussed before investigating the possibility of the self-shading strategy.

Some of the accompanying objectives of this research are listed as follows:

1. To compare the impact of total solar insolation on varies geometric shapes through width-to-length ratio (W/L ratio) and building orientation in order to determine the optimum shape.
2. To determine the appropriate cut-off period and protection angle for self-shading forms in relation to the solar geometry
3. To determine the implication of stepped inverted geometry and inclined wall considering the design configuration for high-rise built form, for example floor efficiency and perimeter depth.

4. To determine the impact of daily total direct and diffuse solar insolation on varied wall surface of the selected optimum shape
5. To compare the effectiveness of self-shading projection ratio (SSP ratio) and solar insolation on various wall surfaces of the selected optimum shapes

1.5 Scope and Limitation

This study only focuses on the incident solar radiation received on the external vertical building façades before it enters into the internal space of the high-rise building. The energy received by the entire exposed surfaces with the given volume is estimated as the sum of the solar radiation on its facets, acting like flat collectors. All forms are considered as opaque and zero reflectivity. This means that the exposed surface will receive all of the solar radiation strikes on it without reflecting it.

The maximum depth of self-shading projection is 4.0m for each typical floor. It is because of the limitation of economical structural system and constructability of the high-rise office building. Due to the height constrain, application of full inclined wall strategy on high-rise building is impossible. Low solar altitude for the tropical sun produces extra large roof area as compared to the base floor area (typical floor area). Therefore, stepped inverted geometry is chosen as the appropriate shading strategies for this study.

The study is entirely carried out by using computer simulation program ECOTECT version 5.2b and thus bears the limitation of the simulation tool used. In chapter 3, a review on common research methods used by previous researchers and justification for the selection of the present tool will be discussed. Finally, the simulation is performed using solar radiation data from WeatherTools 1.0. There are three design-days chosen for average daily total analysis at 21 March, 22 June, and 21 December. Since Malaysia receives similar climate condition throughout the year, the selected dates do not represent the extreme days or average days, but suggest the position of the sun related to certain facades at certain orientations.

1.6 Research Methodology

In answering the research questions and achieving the research objective, the following methodologies have been identified and carried out in three main parts. The overall thesis flow is shown in Figure 1.6.

a. Theoretical research, which covers the basic understanding on the impact of solar radiation towards the high-rise building shapes. Review is made on the relationship between solar insolation and high-rise building. Further investigation on effects of solar shading design, especially self-shading strategy on high-rise building will be described.

b. The studies of the physical characteristic on high-rise building in Kuala Lumpur, Malaysia using satellite images from Google Earth are carried out. The general high-rise building descriptions available on internet are later deliberated. Further modifications of self-shading design alternatives are needed in order to fulfil related high-rise building design considerations, such as floor efficiency, structural stability and site constraints.

c. Computer simulation studies to investigate the impact of cumulative solar insolation on vertical surface of the high-rise building. Simulations to investigate the relationship between high-rise building shape and annual total solar insolation received by the entire vertical surfaces are conducted. Then, examinations on the effectiveness of self-shading projection ratio (SSP ratio) on various walls of selected optimum shape are carried out.

1.7 Importance of the Research

During the preliminary stages of designing high-rise building, architect deals with lots of design issue not only physical and climatic factors, but also by economic, social and cultural factors. Architect should not just ignore the importance of geometrical configuration and adopting solar shading from the beginning of the design process. This study can be the guidance in designing high-rise building when sun prevention is the main concern by choosing the appropriate strategies: optimum geometric shape, placement of the building and effective solar shading strategies.

1.8 Definition

In this thesis, there are important principles and key words that need to be clarified and defined. However, additional definitions will be explained in appendix C: glossary.

1.8.1 Solar Insolation

Solar insolation refers to the total amount of cumulative incident solar radiation on a point or surface over a specified period. Solar insolation integrated by three components: direct, diffuse and reflected solar insolation strike on an exposed surface. The values are generally expressed in kWh/m^2/day or MJ/m^2/day. This is the amount of solar energy on a square metre of the earth's surface in a single day.

1.8.2 Self-shaded form

Generation of building form in a way the form is self-shaded from impact of solar radiation during the required period. Further description can be found on Section 2.4.

1.8.3 High-rise Building

'Dictionary of Building' defined high-rise as tall building with more than eight storeys and at least 28 metres from the street level to the roof top (MacLean, 1993). ASHRAE (1997) categorises high-rise building as which its height (H) is more than three times its cross wind width (W): H>3W (Figure 1.3).

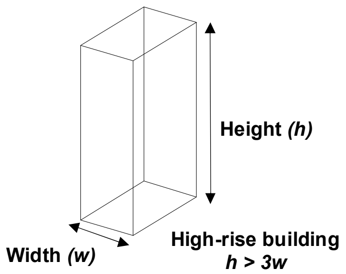
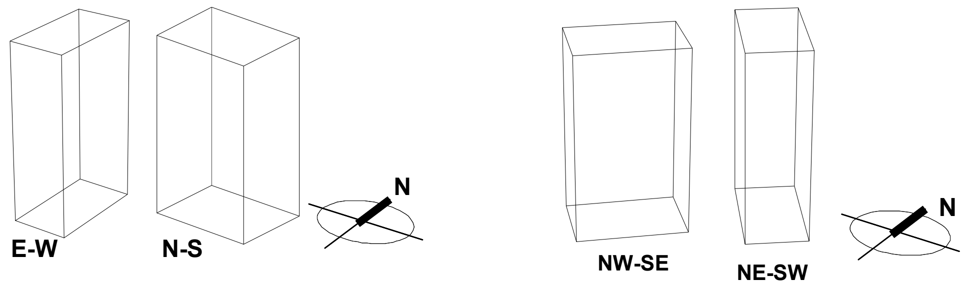


Figure 1.3: High-rise definition by ASHRAE (1997)

1.8.4 Building orientation

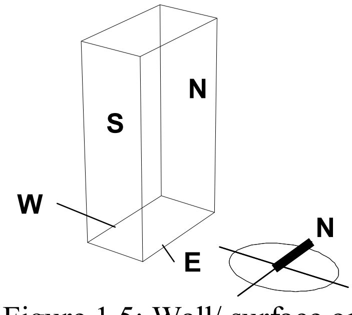
Building orientation refer to the major axis of the building , generally used to refer to solar orientation which is the sitting of building with respect to solar access. For an example when building orientation of high-rise building is north-south elongated (N-S) is means building with longer length is facing north and south. Figure 1.4 illustrates the building orientation for a high-rise building.



a) North-south (N-S) and East-west (E-W) elongated

b) Northeast-Southwest (NE-SW) and Southeast-Northwest (NW-SE) elongated

Figure 1.4: Building orientation



north wall, N
south wall, S
east wall, E
west wall, W

Figure 1.5: Wall/ surface orientation

1.8.5 Wall / Surface orientation

Surface orientation refers to the azimuth of the particular surface facing towards north. A surface facing east has an azimuth of 90°. A surface facing south has an azimuth of 180°. A surface facing west has an azimuth of 270°. Figure 1.5 shows the surface orientation for a high-rise building.

1.9 Thesis organisation

This thesis is organized into five chapters as summarized below:

Chapter One introduces the main issue of this research. This chapter also contains the proposed hypothesis of the study, the research questions and objectives of the study. Further, the research gap, scope and limitations of the study and the overall thesis structure are also presented in this chapter.

Chapter Two reviews the influence of solar insolation in high-rise office building design. This chapter covers the basic theory of solar radiation, solar geometry and solar diurnal pattern in hot humid equatorial tropic, particular to Subang, Malaysia. The review of high-rise office building design includes basic configuration, its geometric characteristic and application of solar shading design. The study also covers the concept of self-shading strategy and its application on building design.

Chapter Three discusses the methodology used in investigating the effectiveness of self-shading high-rise building form in minimising solar insolation. Initially the reviews of research methodology used by previous researchers have been studied. The justification of selecting the methodology of this study is also elaborated. Further, development of the base model, experimental procedures, limitations and overall sequence of the selected experiment method are described. Finally, the results obtained from the simulation are presented in the following chapter.

Chapter Four evaluates the simulation results obtained for cumulative solar insolation on generic geometric shape and effectiveness of self-shading strategies applied for high-rise building. The summary of the major finding is also presented in this chapter. The results of the simulation are analyzed as follows:

- Assess the influence of total solar insolation on two generic geometric shapes with variation in width-to-length and building orientation in order to determine optimum shape for both generic shapes.
- Assess the influence of direct, diffuse component of average solar insolation on the selected optimum shape
- Assess the effectiveness of self-shading strategy on the selected optimum shape

Chapter Five concludes the thesis. The overall review of the thesis objectives and research questions, followed by major finding of the experiment are presented in this chapter. It also outlines the suggestions for future research to complement with the thesis findings.

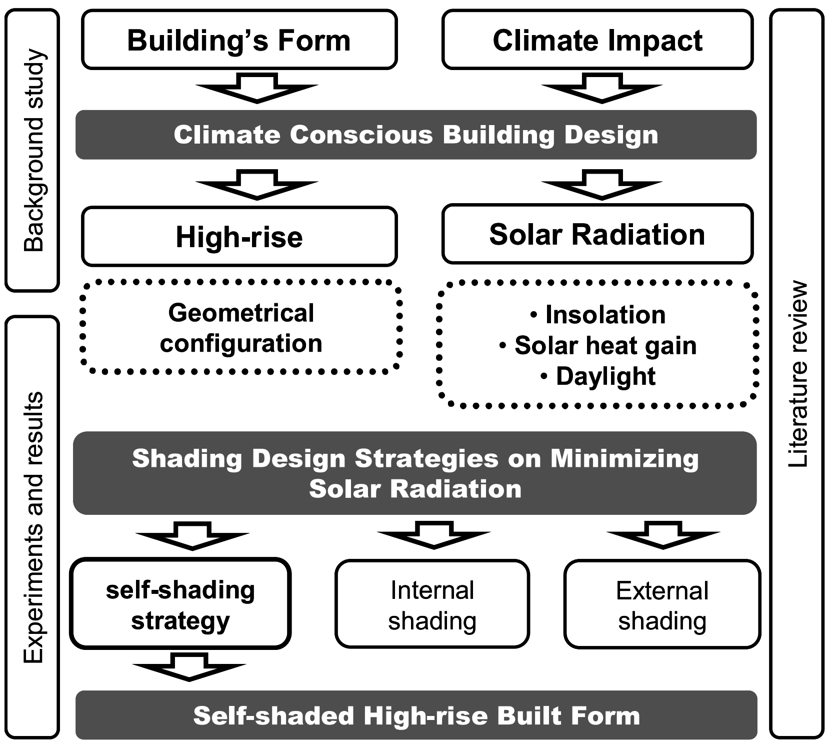


Figure 1.6: Thesis flow