

**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 lengkung 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.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	THESIS TITLE	i
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK (BAHASA MELAYU)	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xiv
	LIST OF FIGURES	xvii
	LIST OF ABBREVIATIONS	xxi
	LIST OF SYMBOL	xxiii
	LIST OF APPENDICES	xxv
Chapter 1	INTRODUCTION	
	1.1 Background and statement of problem	1
	1.2 Research question	4
	1.3 Research gap	5
	1.4 Research objective	7
	1.5 Scope and limitations	8
	1.6 Research methodology	9
	1.7 Importance of research	9
	1.8 Definition	10
	1.8.1 Solar insolation	10
	1.8.2 Self-shaded built form	10
	1.8.3 High-rise Building	10

1.8.4	Building orientation	11
1.8.5	Surface/ wall orientation	12
1.9	Thesis organisation	12
Chapter 2	SOLAR RADIATION IN HIGH-RISE BUILDING DESIGN	
2.0	Introduction	14
2.1	Solar radiation and hot humid climate	14
2.1.1	Solar geometry	15
2.1.2	Solar insolation or solar irradiance	17
2.1.2.1	Global solar irradiance	18
2.1.2.2	Beam irradiance	18
2.1.2.3	Diffuse sky irradiance	18
2.1.2.4	Ground reflected irradiance	19
2.1.3	Kuala Lumpur sky conditions	19
2.1.3.1	Solar radiation analysis of meteorological station	20
2.1.3.2	Diurnal pattern of global solar radiation	21
2.2	Influence of solar insolation on building shape	23
2.2.1	Solar insolation on solid surfaces	25
2.2.2	Solar insolation index, μ -index	25
2.2.3	Steps of computing μ -index	26
2.3	Geometric characteristic of high-rise building	26
2.3.1	Basic concept of geometrical shape	27
2.3.2	Exposed surface area-to-volume ratio (S/V ratio)	29
2.3.3	Width-to-length ratio (W/L ratio)	29
2.3.4	Building orientation	31
2.4	Solar shading strategies	31
2.4.1	Types of solar shading	32
2.4.1.1	Natural shading strategies	32
2.4.1.2	Solar control shading device	33
2.4.2	Effectiveness of solar shading devices	34
2.4.2.1	Geometry of the external shading device: depth, width and angle	34

2.4.2.2	Shading coefficient	35
2.4.3	Special features of solar shading strategies on high-rise building	36
2.5	Self-shading strategies in hot humid tropics	39
2.5.1	Design of self-shading strategy	40
2.5.1.1	cut-off time and protection angle	41
2.5.1.2	vertical shadow angle (VSA)	42
2.5.1.3	Self-shading projection depth	43
2.5.1.4	Self-shading projection ratio (SSP ratio)	44
2.5.2	Design alternatives of self-shading strategy	45
2.5.2.1	Inclined wall strategy	45
2.5.2.2	Stepped inverted geometry (SIG)	47
2.6	Summary	50
Chapter 3	METHODOLOGY	
3.0	Introduction	52
3.1	The need for experiment	52
3.2	Studies of high-rise building shape in Kuala Lumpur	53
3.2.1	Generic high-rise building shape	53
3.2.2	High-rise building configuration	57
3.3	Adaptation of self-shading strategy to high-rise built form	57
3.3.1	Possible adaptation	58
3.3.2	Procedure of generation of self-shading high-rise building	59
3.3.2.1	<u>Step A</u> : Generation base case model	59
3.3.2.2	<u>Step B</u> : Segmented high-rise form into groups	60
3.3.2.3	<u>Step C</u> : Modification on the projection depth	60
3.3.2.4	<u>Step D</u> : Alternative shading design	61

3.4	Development of geometric shape for high-rise building	67
3.4.1	Basic geometric shape in high-rise building	67
3.4.2	Design variables	68
3.4.2.1	Design variables for building shapes in various heights (base model 1)	69
3.4.2.2	Design variables for basic geometric shapes (base model 2)	70
3.4.3	Building assumptions and limitation	71
3.5	Development of self-shading strategy	72
3.5.1	Stepped inverted geometry for optimum shape	72
3.5.2	Design variables for base model 3	74
3.5.2.1	Self-shading projection ratio (SPP ratio)	74
3.5.2.2	Cut-off time for each SSP ratio	75
3.5.3	Evaluation on the self-shading strategies on various aspects	76
3.5.3.1	Floor efficiency	77
3.5.3.2	Parameter depth	77
3.5.3.3	Exposed vertical surfaces	79
3.5.4	Building assumptions and limitation	79
3.6	Method of evaluation of solar radiation on building external surfaces	81
3.6.1	Simplified design and calculation tools	82
3.6.2	Field measurement	82
3.6.3	Computer simulation	83
3.7	Selection of computer simulation programs	84
3.7.1	Experimental requirement	85
3.7.2	Review of energy simulation programs	86
3.8	The ECOTECT V5.0 computer simulation programme	87
3.8.1	Simulation procedure	87
3.8.1.1	Data requirement	87
3.8.1.2	Preparation of geometric modelling	88
3.8.1.3	Simulation parameter and perform simulation	88

3.8.1.4	Review Simulation Result	89
3.8.2	Simulation Limitation	90
3.8.3	Simulation Design Conditions	90
3.9	Comparison of horizontal global solar radiation data between WeatherTool and Subang Meteorological Station (SMS)	91
3.10	Simulation analysis criteria	93
3.11	Summary	95
Chapter 4	RESULT, ANALYSIS AND FINDINGS	
4.0	Introduction	97
4.1	Effect of building shape with various heights on minimising total solar insolation	98
4.2	Effects of geometric shape of high-rise building	99
4.2.1	Effect of geometric shape on circular shape (CC)	99
4.2.2	Effect of geometric shape on square shape (SQ)	100
4.2.3	Comparison between two basic geometric shapes (CC and SQ)	101
4.3	Influence of annual total solar insolation on varied wall surface of both optimum shapes (CC 1:1 and SQ 1:1)	102
4.4	Effectiveness of self-shading projection ratio (SSP ratio) on optimum shapes CC 1:1	104
4.4.1	Influence of direct and diffuse component on optimum shape (CC 1:1) with SSP ratio 0	105
4.4.2	Effectiveness of SSP ratio on direct component of CC 1:1	106
4.4.2.1	East-wall of CC 1:1	107
4.4.2.2	West wall of CC 1:1	108
4.4.2.3	North-wall of CC 1:1	109
4.4.2.4	South-wall of CC 1:1	110
4.4.3	Effectiveness of SSP ratio on diffuse component on varied wall surface of CC 1:1	111

4.5	Effectiveness of self-shading projection ratio (SSP ratio) on optimum shape SQ:11	112
4.5.1	Influence of direct and diffuse components on optimum shape (SQ 1:1) with SSP ratio 0	112
4.5.2	Effectiveness of SSP ratio on direct component of SQ 1:1	113
4.5.2.1	East-wall of SQ 1:1	113
4.5.2.2	West wall of SQ 1:1	114
4.5.2.3	North-wall of SQ 1:1	116
4.5.2.4	South-wall of SQ 1:1	117
4.5.3	Effectiveness of SSP ratio on diffuse component on varied wall surfaces of SQ 1:1	118
4.6	Comparison effectiveness of SSP ratio between both optimum shapes (CC 1:1 and SQ 1:1)	119
4.6.1	Effectiveness of SSP ratio on direct component	120
4.6.2	Effectiveness of SSP ratio on diffuse component	122
4.6.3	Effectiveness of SSP ratio on maximum obstruction of direct and diffuse components	124
4.7	Summary	125
Chapter 5	CONCLUSION	
5.0	Introduction	127
5.1	Review of thesis objectives and research questions	127
5.2	Thesis conclusion	128
5.2.1	Effect of building shape with varied heights towards minimizing total solar insolation	128
5.2.2	Effects of geometric shape of high-rise building	129
5.2.3	Optimum shapes (CC 1:1 and SQ 1:1)	130
5.2.4	Adaptation of self-shading strategies into high-rise built form	131
5.2.5	Effectiveness of self-shading projection ratio (SSP ratio) on CC 1:1 and SQ 1:1	133

5.3	Application of ECOTECH version 5.2b in Malaysian conditions	137
5.4	Suggestions for further research	139
5.5	Application and contribution	140
BIBLIOGRAPHY		142
APPENDICES		
A	Summary of building shape and climate impact related research	150
B	Summary of solar radiation and shading design strategy related research	154
C	Glossary	156
D	Vertical shadow angle (VSA) value for main cardinal surfaces for three design-days.	159
E	Summary of Computer Simulation Programs	162
F	Simulation data and results	165
F1	Summary of annual average daily total of total, direct and diffuse solar insolation on each wall orientation of CC 1:1	166
F2	Summary of annual average daily total of total, direct and diffuse solar insolation on each wall orientation of SQ 1:1	167
F3	Effectiveness of SSP ratio on direct solar insolation for CC 1:1.	168
F4	Effectiveness of SSP ratio on direct solar insolation for SQ1:1	172
F5	Effectiveness of SSP ratio on diffuse component of solar insolation	176
G	Architectural design solution: Self-Shading High-Rise Office (undergraduate thesis study by Chia Sok Ling)	178
H	Journal writing for Journal of Construction in Developing Countries (JCDC) 12(1), 2007: Effect of geometric shape and building orientation on minimising solar insolation on high-rise buildings in hot humid climate	180
I	Conference paper for 5 th International Seminar on Sustainable environment Architecture (SENVAR 5), 2004: Impact of solar radiation on high-rise built form in tropical climate	190

LIST OF TABLES

NO	TITLE	PAGE
1.1	Summary of previous research related to building shape and climate impact.	6
1.2	Summary of previous research related to solar radiation and shading design strategy	7
2.1	Monthly means of Global Solar Radiation at Subang Meteorological Station (SMS)	21
2.2	The protection angle and self-shading projection predicted based on incident angles of direct solar insolation according to the specified cut-off time	44
3.1	Generic Geometric Form and Plan Form Ratio of High-rise in the city of Kuala Lumpur	56
3.2	Average floor area of high-rise in the city of Kuala Lumpur	56
3.3	Overall building height of high-rise buildings in the city of Kuala Lumpur	57
3.4	Typical floor-to-floor of high-rise buildings in the city of Kuala Lumpur	57
3.5	Description of base case reference for generic office building	68
3.6	The design and performance variables for base model 1	69
3.7	The design and performance variables for base model 2.	71
3.8	Description for Self-shading projection depth of the experiments	73
3.9	Design variable and performance variables for Base Model 3A and 3B	74
3.10	Relationship between SSP ratios with cut-off time for various surface orientations on 21-March.	75
3.11	Relationship between SSP ratios with cut-off time for various surface orientations on 21-June.	76

3.12	Relationship between SSP ratios with cut-off time for various surface orientations on 21-December.	76
3.13	The floor efficiency (NFA) for every typical floor with varied SSP ratio of CC 1:1.	77
3.14	The floor efficiency (NFA) for every typical floor with varied SSP ratio of SQ 1:1.	77
3.15	Parameter depth for base model 3A (CC 1:1) with varied SSP ratio	78
3.16	Parameter depth for base model 3B (SQ 1:1) with varied SSP ratio	78
3.17	Summary of the variables and constants for base models 1 to 3.	80
3.18 (a)	Comparisons of monthly average solar insolation and MBE & RMSE values for SMS and WeatherTool.	93
3.18 (b)	Comparisons of daily total global solar radiation and MBE & RMSE values for SMS and WeatherTool.	93
3.19	Data analysis indicators and their interpretation	95
4.1	Comparison of the annual total solar insolation on circular and square shape with percentage values compared to the CC 1:1 (0%) as base reference for both basic geometric shapes	102
4.2	Summary of annual average daily total of total, direct and diffuse solar insolation on each wall orientation of CC 1:1	103
4.3	Summary of annual average daily total of total, direct and diffuse solar insolation on each wall orientation of SQ 1:1	103
4.4	Summary based on average daily total solar insolation (direct and diffuse) for CC 1:1 with percentage values compared to the respective components of solar insolation on horizontal surface.	106
4.5	Summary of average daily total solar insolation (direct and diffuse) for SQ 1:1 with percentage values compared to the respective components of solar insolation on horizontal surface.	112
4.6	Effectiveness of SSP ratio on direct solar insolation for CC 1:1 with percentage values compared to the respective components of solar insolation on horizontal surface.	121
4.7	Effectiveness of SSP ratio on direct solar insolation for SQ1:1 with percentage values compared to the respective components of solar insolation on horizontal surface.	122
4.8	Effectiveness of SSP ratio on diffuse component of solar insolation with percentage values compared to the respective components of solar insolation on horizontal surface.	124

4.9	The maximum obstruction of direct component of solar insolation	125
4.10	The maximum obstruction of diffuse component of solar insolation	125
5.1	The best and worst geometric shape in variation of width-to-length ratio (W/L ratio) and building orientation	130
5.2	The maximum and minimum solar exposure of direct solar insolation on both optimum shapes with SSP ratio:0	133
5.3	Effectiveness of optimum SSP ratio on direct solar insolation for CC 1:1	134
5.4	Effectiveness of optimum SSP ratio on direct solar insolation for SQ 1:1	135
5.5	The Percentage of Coverage of the Analysis Grid on Base Model 3A and 3B (SQ 1:1 and CC 1:1)	137

LIST OF FIGURES

NO	TITLE	PAGE
1.1	The problem: influence of solar insolation on vertical surfaces of high-rise building.	3
1.2 (a)	The proposition: self-shading strategy to minimise the impact of solar insolation on vertical surfaces of high-rise building: self-shading form	4
1.3	High-rise definition by ASHRAE (1997)	11
1.4 (a)	Building orientation: North-south (N-S) and East-west (E-W) elongated	11
1.4 (b)	Building orientation: Northeast-Southwest (NE-SW) and Southeast-Northwest (NW-SE) elongated	11
1.5	Wall/ surface orientation	11
1.6	The flow of research process and thesis structure	13
2.1	The sun's apparent position in the imaginary sky dome is given by the solar altitude and azimuth angles	16
2.2	Position of the sun at 12 noon local solar time for Kuala Lumpur (3.1°N, 101.7°E) from the horizontal surface and coming from the north and south wall	16
2.3	Global solar radiation patterns in Malaysia (source from: Othman et al, 1993).	22
(a)	Global solar radiation pattern for a clear day. Maximum instantaneous solar intensity can be reach a level of 1000W/m ²	22
(b)	Global solar radiation pattern for full cloudy day	22
(c)	Global solar radiation pattern for a partly cloudy day	22
(d)	Global solar radiation pattern with instantaneous intensity higher than solar constant	22
(e)	Global solar radiation pattern with afternoon rain	22
2.4	The percentages of global solar radiation pattern on 5 diurnal variations.	23

2.5	The components of a box.	27
2.6	The basic component of a building shape	29
2.7	Optimum high-rise building shape for various climates. (Source: Yeang, Ken (1994). " <i>Bioclimatic Skyscrapers</i> ". Artemis London Limited, London, UK.	30
2.8	The special feature can benefit the solar prevention to the high-rise building design.	38
2.9	Shadow umbrella. Source: Emmanuel (2005). <i>An Urban Approach to Climate-sensitive Design</i> .	39
2.10	Protection angle and cut-off time for hot humid tropics with special reference to Kuala Lumpur, Malaysia (3.1°N, 101.7°E).	41
2.11	Method of vertical shadow angle on vertical surface.	43
2.12	The determination of the maximum depth of self-shading projection so that the vertical wall is shaded by the horizontal surface or roof surface.	43
2.13	Example of Inclined wall generated according to the required period. (a) axonometric view, (b) and (c) view of the building's form from the sun point of view at 21 st September and 21 st December (source: Capeluto, 2003).	46
2.14	Tempe City Hall design by Michael and Kemper Goodwin	46
2.15 (a)	The proposed design alternatives for stepped inverted geometry: Full shaded wall	48
2.15 (b)	The proposed design alternatives for stepped inverted geometry: Partially shaded wall.	48
2.16	Images of Bank of Israel design by A and E. Sharon Architect. (Source: Capeluto, 2003)	49
2.17	Boston City Hall designed by McKinnel Kallmann and R.L. Knowles (Source: http://www.greatbuildings.com/buildings/Boston_City_Hall.html dated 31 st May 2006)	50
2.17 (a)	overall view	50
2.17 (b)	3-dimensional massing model	50
2.17 (c)	huge dentils as external shading devices	50
2.17 (d)	irregular composition between the attic floor and top office level	50
3.1	Example of satellite picture for Suria KLCC (Source: satellite images form Google Earth, dated at 20 th April 2006).	54

3.2	Generic plan form study for high-rise building in city of Kuala Lumpur (Source: satellite images form Google Earth, dated at 20 th April 2006)	55
3.3	Step A: Generation Base Case Model for Self Shading Strategies	63
3.4	Step B: Segmented High-Rise Form into Groups	64
3.5	Step C: Modifications on the Depth of Cantilever	65
3.6	Step D: Design Alternative for Full Shaded and Partially Shaded Wall	66
3.7	Base Case High-Rise Building Form	68
3.8	Comparison of insolation level on high-rise (a), medium-rise (b) and low-rise (c) built form	69
3.9	The geometric proportion of two basic geometric shapes.	70
3.10	Generation of self-shading building shape for base model 3A and 3B	73
3.11	Overall flows of the base models and simulation procedures involved	81
4.1	Annual total solar insolation on vertical surfaces (wall) and horizontal surfaces (roof) on building shape with various heights	98
4.2	Annual total solar insolation on circular shape (CC) with variation in W/L ratio and building orientation.	100
4.3	Annual total solar insolation on square shape (SQ) with variation in W/L ratio and building orientation.	101
4.4	The sum and percentage (%) of received average daily direct solar insolation incident on the east wall of CC1:1 as a function of SSP ratio on 3 design-days	107
4.5	The sum and percentage (%) of received average daily direct solar insolation incident on the west wall of CC1:1 as a function of SSP ratio on 3 design-days.	108
4.6	The sum and percentage (%) of received average daily direct solar insolation incident on the north wall of CC1:1 as a function of SSP ratio on 3 design-days.	109
4.7	The sum and percentage (%) of received average daily direct solar insolation incident on the south wall of CC1:1 as a function of SSP ratio on 3 design-days.	110
4.8	The sum and percentage (%) of received average daily diffuse solar insolation incident on vertical wall of CC1:1 as a function of SSP ratio on 3 design-days.	111

4.9	The sum and percentage (%) of received average daily direct solar insolation incident on east wall of SQ 1:1 as a function of SSP ratio on 3 design-days.	114
4.10	The sum and percentage (%) of received average daily direct solar insolation incident on west wall of SQ 1:1 as a function of SSP ratio on 3 design-days.	115
4.11	The sum and percentage (%) of received average daily direct solar insolation incident on north wall of SQ 1:1 as a function of SSP ratio on 3 design-days.	116
4.12	The sum and percentage (%) of received average daily direct solar insolation incident on south wall of SQ 1:1 as a function of SSP ratio on 3 design-days.	118
4.13	The sum and percentage (%) of received average daily diffuse solar insolation incident on vertical walls of SQ 1:1 as a function of SSP ratio on 3 design-days.	119
4.14	The sum of average daily total of direct solar insolation incident on east, west, north and south wall of CC 1:1 and SQ 1:1 as a function of SSP ratio on 3 design-days.	123
4.15	The percentage of received average daily total of direct solar insolation incident on east, west, north and south wall of CC 1:1 as a function of SSP ratio on 3 design-days.	123
4.16	Average daily direct total of solar insolation incident on all orientations of CC 1:1 and SQ 1:1 as a function of SSP ratio on 3 design-days.	124
5.1	Comparison of the annual daily total solar insolation on horizontal and vertical surfaces for optimum shape: (a) CC 1:1 and (b) SQ 1:1 of high-rise form.	131
5.2	Generation of Self-shaded High-rise Built Form in Hot and Humid Tropics	132
5.3	Example of the graphical result for east wall of optimum shape SQ1:1 with SSP ratio 0.25 on 21 st December.	138
5.4	Extension of building design parameter and performance variables	139

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 ($^{\circ}$)
C	-	Diffuse sky factor
CR	-	Cloud Ratio
D	-	Depth of the horizontal projection (m)
δ	-	Solar declination angle ($^{\circ}$)
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 ($^{\circ}$)
f	-	Depth of the vertical fin (m)
f_r	-	Fraction of diffuse radiation obstructed by the shading device
γ	-	Surface solar azimuth ($^{\circ}$)
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)
\dot{I}_{dr}	-	Direct solar radiation transmitted through standard 3mm clear glass
\dot{I}_{df}	-	Diffused solar radiation transmitted through standard 3mm clear glass
\dot{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 ($^\circ$)
θ_h	-	Angle of incidence on horizontal surface ($^\circ$)
θ_v	-	Angle of incidence on vertical surface ($^\circ$)
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 ($^\circ$)
W_{awn}	-	Width of the awning (m)
W_{fen}	-	Width of fenestration (m)

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Summary of building shape and climate impact related research	150
B	Summary of solar radiation and shading design strategy related research	154
C	Glossary	156
D	Vertical shadow angle (VSA) value for main cardinal surfaces for three design-days.	159
E	Summary of Computer Simulation Programs	162
F	Simulation data and results	165
	F1 Summary of annual average daily total of total, direct and diffuse solar insolation on each wall orientation of CC 1:1	166
	F2 Summary of annual average daily total of total, direct and diffuse solar insolation on each wall orientation of SQ 1:1	167
	F3 Effectiveness of SSP ratio on direct solar insolation for CC 1:1.	168
	F4 Effectiveness of SSP ratio on direct solar insolation for SQ1:1	172
	F5 Effectiveness of SSP ratio on diffuse component of solar insolation	176
G	Architectural design solution: Self-Shading High-Rise Office (undergraduate thesis study by Chia Sok Ling)	178
H	Journal writing for Journal of Construction in Developing Countries (JCDC) 12(1), 2007: Effect of geometric shape and building orientation on minimising solar insolation on high-rise buildings in hot humid climate	180
I	Conference paper for 5 th International Seminar on Sustainable environment Architecture (SENVAR 5), 2004: Impact of solar radiation on high-rise built form in tropical climate	190

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/m²/year on average. Comparison among the participating countries revealed that Malaysia has the highest energy consumption (269kWh/m²/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/m²/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.

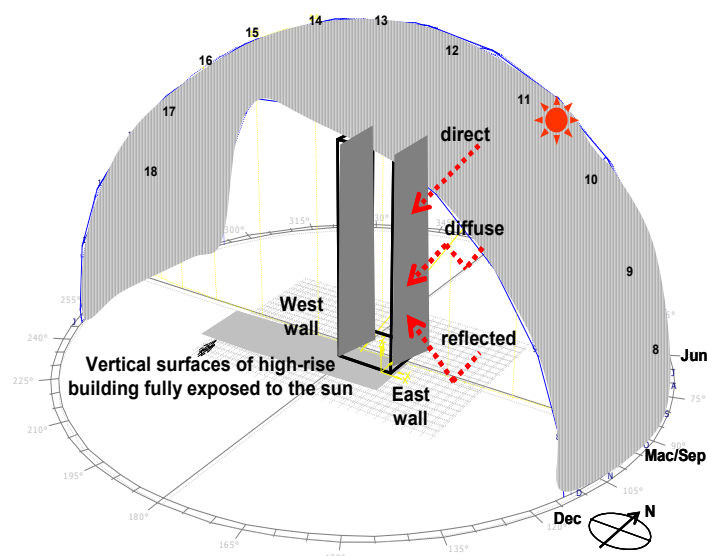


Figure 1.1: The issue and problem: influence of solar insolation on vertical surfaces of high-rise building.

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.

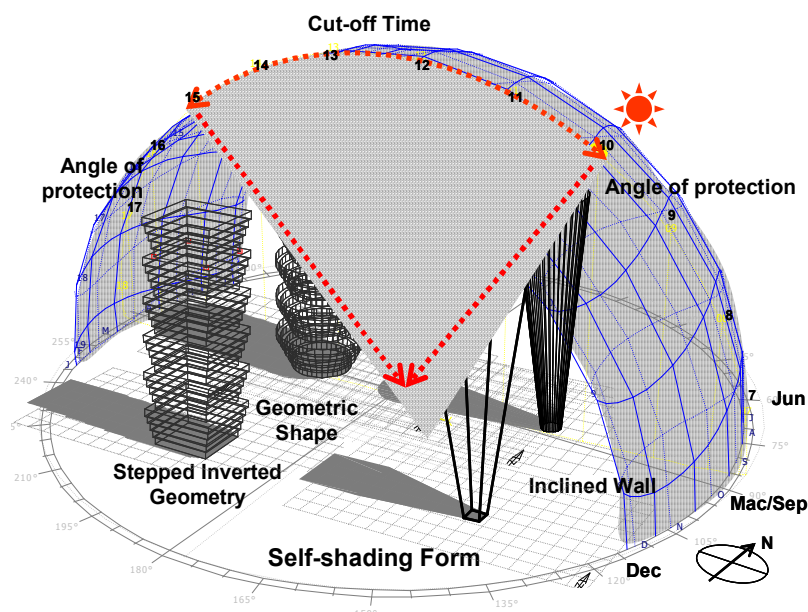


Figure 1.2: The thesis proposition: self-shading strategy to minimise the impact of solar insolation on vertical surfaces of high-rise building

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 various wall surfaces of the selected optimum shapes for three different design-days?

1.3 Research Gap

Review on previous research can be divided into 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 (Tilman 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)

	climate	Built Form			Building shape			Form indicator			Climate impact				
		High-rise	Medium-rise	Low-rise	Built form	geometric	Compactness	S/V	B/S	W/L	Solar radiation	Air velocity	Air Temperature	Thermal load	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				Energy load
		Built Form			Geometric		Shading strategy					Solar heat gain	Daylight	Insolation	distribution pattern	
		High-rise	Medium-rise	Low-rise	Bldg. shape	Orientation	Solar envelope	Core position	External Shading	Internal shading	Self shading					
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 ECOTECH 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 façades 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/m²/day or MJ/m²/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).

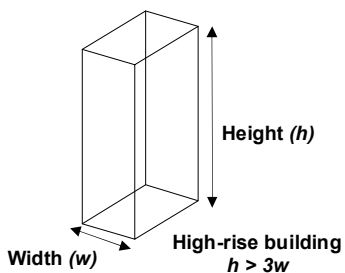
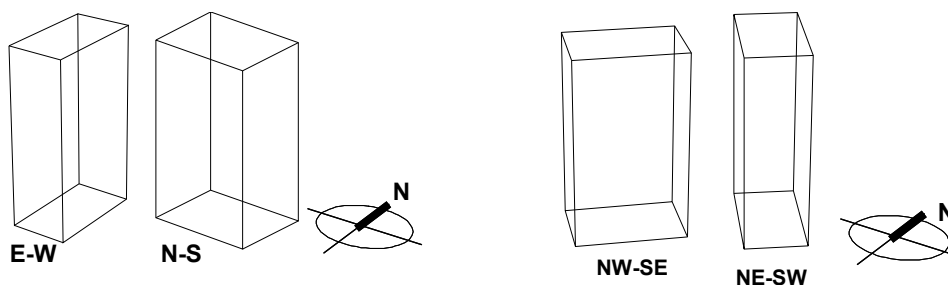


Figure 1.3: High-rise definition by ASHRAE (1997)

1.8.4 Building orientation

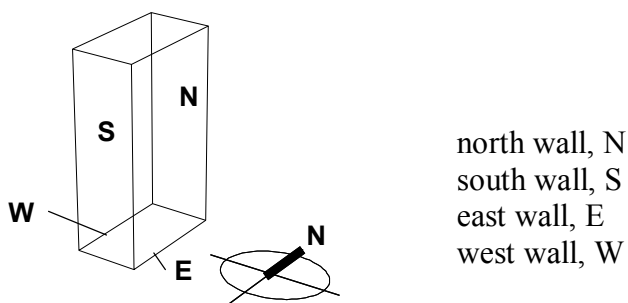
Building orientation refer to the major axis of the building , generally used to refer to solar orientation which is the sitting of building with respect to solar access. For an example when building orientation of high-rise building is north-south elongated (N-S) is means building with longer length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

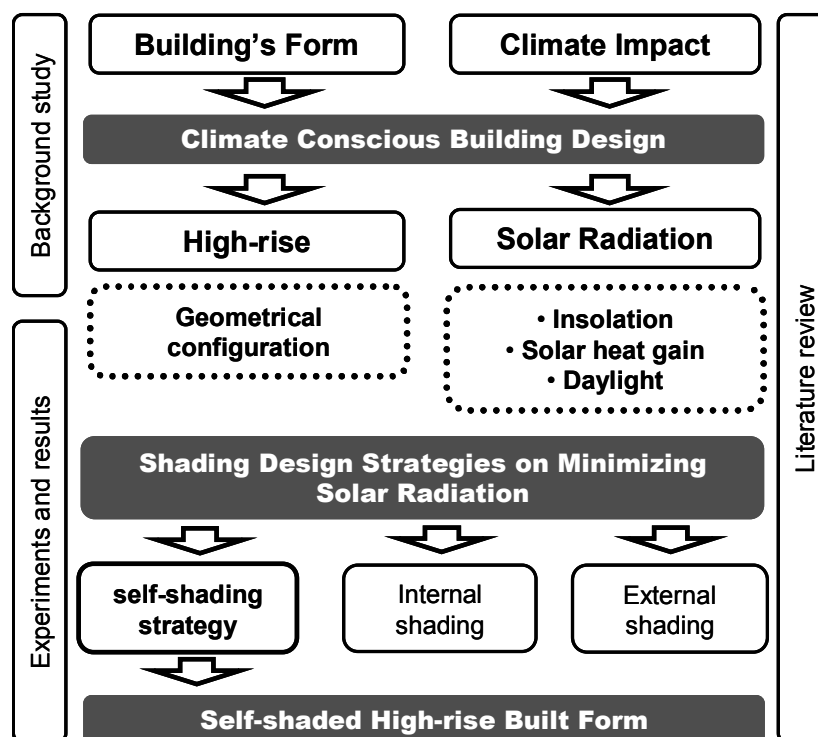


Figure 1.6: Thesis flow