OPTIMUM OVERHANG GEOMETRY FOR HIGH RISE OFFICE BUILDING ENERGY SAVING IN TROPICAL CLIMATES

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A thesis submitted in fulfillment of the
requirements for the award of the degree of
Doctor of Philosophy

Faculty of Built Environment
Universiti Teknologi Malaysia

SEPTEMBER, 2005

To:

My Beloved Father, Mother and Brother

ACKNOWLEDGEMENT

My deepest gratitude goes to my main thesis supervisor Assoc. Prof. Dr. Mohd Hamdan Ahmad for his valuable and close supervision, guidance, comments, resources, encouragement, motivation, inspirations and friendship rendered throughout the study. I am also very thankful to my co-supervisor Assoc. Prof. Dr. Nor Haliza Madros for her critics advice, guidance, motivation and friendship. Without their continued support and interest, this thesis would not have been the same as presented here.

The author wishes to acknowledge the Public Service Department, Malaysia and the Malaysian Government for the scholarship. I also acknowledge the Malaysia's High Commissioner and the staff (year 2001-2002) of the Malaysian High Commission in Sri Lanka for offering the opportunity and information regarding the Malaysian Commonwealth Scholarship and Fellowship Plan. My thanks also go to Mr. T. K. Azoor and the steering committee members of COSLAM for their encouragement and support in obtaining the scholarship. I would also like to express my gratitude to the Universiti Teknologi Malaysia and the Department of Architecture for accepting me as one of their doctorate students.

A special thanks to Mdm. Halimah Yahya for her assistance in obtaining the required weather data and also for her friendship and support. Many thanks also go to Agung Murti for helping with the graphics and Roshida with the translations.

My sincere gratitude also goes to those who have provided assistance in many ways at various occasions: Dr. R. Emmanuel from University of Moratuwa, Sri Lanka; Prof. Dr. Najib Ibrahim, Assoc. Prof. Syed Zainol Abidin Idid and family and Dr. Mohd. Tetsu Kubota from UTM. Thank also due to Shahzarimin and his family, Azril and his family, Dr. M. Mukhlis, Dr. Monzurul Alam, Kamarudzaman, Syed Hossin, Adil, Asif, Ashiq, Rumi, Jami, Kayser and Arif for their brotherhood and friendship. I am also grateful to Tilak and family, Praveena and her family, my cousins Suzaniya & Remano and Mr. & Mrs. Ramzan for their constant concern and moral support.

My heartiest and utmost gratitude goes to my dear father, mother and brother for their patience, sacrifices, understanding, constant concern, moral support and prayers during the course of my study. Finally, I thank Almighty Allah for giving me patience, courage, strength, mercy, guidance and blessings to face all challenges in life and to complete this thesis successfully.

ABSTRACT

Intercepting the radiant heat wave using external solar shading before penetrating to the internal environment through the envelope openings is the main criterion to prevent solar heat gains into the building. In hot and humid climates, one draw back of using the external shading device is the risk of reducing daylight level in the interior space, which in turn increases the use of artificial lighting. Therefore, it is important to understand the magnitude of energy consumption for cooling and lighting when shading devices are adapted in order to propose optimum external horizontal shading device strategies as design solutions in hot and humid climates. This study investigates the effect of six different depths of external horizontal shading device on incident solar radiation, transmitted solar heat gains, natural-light penetration, building cooling and energy consumption. The experiment was carried out using a standard, single fenestration perimeter office room in a typical high-rise office building. The investigation is conducted using the eQUEST-3 dynamic energy simulation program supported by the DOE2.2 calculation engine. The results showed that overhang ratios of 1.2, 1.6, 0.6 and 0.8 reduced the incident direct solar radiation more than 80% on the east, west, north and south orientations respectively. The target illuminance of 500lux for internal lighting was obtained for overhang ratios of 1.0, 1.3, 0.2 and 1.0 on respective orientations. Further, findings indicated that deeper natural light penetration can be achieved through the bare window under Malaysian sky conditions compared to the common rule of thumb of 2.5 times the window height on all orientations considered. The findings also revealed that optimum energy savings of 14%, 11%, 6% and 8% were achieved by optimum overhang ratios of 1.3, 1.2 and 1.0 on the east, west and north, south orientations respectively. This study concludes, considering the trade off between total heat gain and natural-light penetration to optimize the total energy consumption as the best option in designing external solar shading in hot and humid climates.

ABSTRAK

Pemintasan pancaran haba dari matahari menggunakan alat redupan luaran sebelum menembusi persekitaran dalaman melalui bukaan adalah ciri-ciri utama bagi mengelakkan pertambahan haba solar di dalam bangunan. Dalam iklim panas dan lembap, satu kelemahan menggunakan alat redupan adalah risiko terhadap pengurangan kadar cahaya siang yang mana boleh sebaliknya meningkatkan penggunaan cahaya buatan pula. Oleh itu adalah penting bagi memahami magnitud penggunaan tenaga untuk penyejukan dan pencahayaan apabila alat redupan digunakan bagi mencadangkan strategi menggunakan alat redupan mendatar luaran yang optimum sebagai penyelesaian rekabentuk dalam iklim panas dan lembap. Kajian ini juga menilai kesan enam perbezaan lebar alat redupan mendatar luaran terhadap insiden gelombang suria, penambahan transmisi kepanasan suria, kemasukan cahaya semulajadi, penyejukan bangunan dan penggunaan tenaga. Kajian ini dijalankan melalui simulasi fenestrasi sebuah bilik pejabat dalam bangunan tinggi yang dianggap tipikal. Penilaian ini dikendalikan menggunakan eQUEST – 3, satu program simulasi tenaga yang dinamik berbantukan mesin pengiraan DOE2.2. Keputusan menunjukkan nisbah unjuran 1.2, 1.6, 0.6 dan 0.8 dapat mengurangkan penerimaan pancaran haba terus matahari lebih daripada 80% pada arah timur, barat, utara dan selatan. Sasaran illuminasi 500lux untuk pengcahayaan dalaman dicapai pada nisbah unjuran 1.0, 1.3, 0.2 dan 1.0 pada arah yang sama. Seterusnya, penemuan mendapati kemasukan cahaya semulajadi melalui tingkap yang terdedah di bawah keadaan awan Malaysia adalah lebih jauh berbanding dengan 2.5 kali ketinggian tingkap ygmenjadi kebiasaan pada semua arah yang diambil kira. Penemuan juga mendedahkan bahawa penjimatan tenaga yang optima pada 14%, 11%, 65 dan 8% dapat dicapai dengan nisbah unjuran yang optima 1.3 dan 1.2 untuk 1.0 pada timur dan barat untuk utara dan selatan. Kajian ini menyimpulkan bahawa penggunaan alat redupan dengan mengambil kira imbangan jumlah penambahan haba dan pancaran cahaya semulajadi bagi mencapai jumlah penggunaan tenaga yang optima adalah pilihan terbaik bagi rekabentuk redupan luaran dalam iklim panas dan lembap.

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ASEAN	-	Association of South East Asian Nations
ASEAM	-	A Simplified Energy Analysis Method
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
CBIP	-	Commercial Building Incentive Program
CIBS	-	Charted Institute of Building Service
CIBSE	-	Chartered Institution of Building Services Engineers
CIE	-	International Illumination Commission
COSLAM	-	Conference of Sri Lankan Malays
CTBUH	-	Council on Tall Building and Urban Habitat
DBT	-	Dry Bulb Temperature
DDM	-	Degree-Day Method
DewPT	-	Dew Point Temperature
DEU_{CL}	-	Differential Energy Use (cooling)
DOE	-	Department of Energy (United States)
DOE.wf	-	Department of Energy weather file
EC_{LT}	-	Energy Consumption (lighting)
EC_{CL}	-	Energy Consumption (cooling)
EC_{TOT}	-	Energy Consumption (total)
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
IES	-	Integrated environmental Solutions
IEU	-	Incremental Energy Use
IEU_{CL}	-	Incremental Energy Use (cooling)
IEU_{LT}	-	Incremental Energy Use (lighting)
IEU_{TOT}	-	Incremental Energy Use (total)
LEO	-	Low Energy Office
LEED	-	Leadership in Energy and Environmental Design
MBE	-	Mean Bias Error
MDD	-	Modified Degree-Day method
MECM	-	Ministry of Energy, Communications & Multimedia (Malaysia)
MEWC	-	Ministry of Energy, Water and Communication (Malaysia)
MS	-	Malaysian Standards
NFRC	-	National Fenestration Rating Council
NI	-	Nebulosity Index
NRA	-	Net Rentable Area
OHR	-	Overhang Ratio
$OHR_{é}$	-	Overhang Ratio (Side extension *é*)
OHR_{fin}	-	Overhang Ratio vertical fins
ORI	-	Façade Orientation
OTTV	-	Overall Thermal Transfer Value
PC	-	Personal Computer
PF	-	Projection Factor
PSALI	-	Permanent Supplementary Artificial Lighting of Interiors
PWD	-	Public Works Department
RMSE	-	Root Mean Square Error
SHGF	-	Solar Heat Gain Factor
$SHGF_{v}$	-	Solar Heat Gain Factor vertical surface

$SHGF_{sh}$	-	Solar Heat Gain Factor shaded window
SMS	-	Subang Meteorological Station
SIR	-	Sun Illuminance Ratio
TMY	-	Typical Metrological Year
THG	-	Total Heat Gain
TRY	-	Test Reference Year
UMNO	-	United Malaya National Organization
USAID	-	Unite States Agency for International Development
UTM	-	Universiti Teknologi Malaysia
VE	-	Virtual Environment
VSA	-	Vertical Shadow Angle
WBT	-	Wet Bulb Temperature
WWR	-	Window-to-Wall Ratio
WYEC	-	Weather Year for Energy Calculations

LIST OF SYMBOLS

A	-	Surface Area (m^2)
α	-	Absorptance (dimensionless)
A_1, A_2, A_3	-	Coefficients of absorptions (constants)
A_4, A_5, A_6	-	Coefficients of absorptions (constants)
A_{cog}	-	Projected area center of glass (m^2)
A_{eog}	-	Projected area edge of glass (m^2)
A_{frame}	-	Projected area of frame (m^2)
A_G	-	Fraction of window area exposed to the sun (m^2)
A_r	-	Rayleigh scattering coefficient
A_{sun}	-	Area of window exposed to the sun (m^2)
α_b	-	Absorptance of reference glazing for direct beam
α_{diff}	-	Absorptance of reference glazing for diffuse radiation
B	-	Atmospheric extinction coefficient (dimensionless)
β	-	Solar altitude angle above the horizontal (^{0})
C	-	Diffuse sky factor
C_1, C_2, C_3	-	Coefficients of transmission (constants)
C_4, C_5, C_6	-	Coefficients of transmission (constants)
C_d	-	Compensation factor for window dirt (DF calculation)
C_f	-	Compensation factor for frame (DF calculation)
C_g	-	Compensation factor for glazing (DF calculation)
C_n	-	Clearness number of the atmosphere (dimensionless)
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)
DF	-	Daylight Factor

$\dot{E}_{diff,cl}$	-	Clear sky diffuse illuminance (lux)
E^{d}_{sky}	-	Direct illuminance from sky (lux)
$E^{r(ext)}_{sky}$	-	External reflected component from sky illuminance (lux)
$E^{r(int)}_{sky}$	-	Internal reflected component from sky illuminance (lux)
Ei^{d}_{sun}	-	Internal direct illuminance from sunlight (lux)
Ei^{r}_{sun}	-	Internal reflected illuminance from sunlight (lux)
$E_{o,sun}$	-	Exterior illuminance from sunlight (lux)
$E_{o,sky}$	-	Exterior illuminance from sky (lux)
Ei	-	Interior illuminance (lux)
Eo	-	Exterior illuminance (lux)
E_t	-	Equation of time
e	-	Projection side ways from the window vertical edge (m)
e^1	-	Length of the shading device over the window (m)
é	-	Awning width exceeding window width on each side (m)
ϕ	-	Latitude of the location (^{0})
F_{fl}	-	Flue loss factor, equipment
F_{ra}	-	Radiation factor, equipment
F_s	-	Lighting special allowance factor
F_{sg}	-	Angle factor between the surface and the sky
F_{ss}	-	Angle factor between the surface and the sky
F_u	-	Light use factor, lighting
F_{ua}	-	Use factor, equipment
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
$G_{sunshade}$	-	G-value for corresponding shading device (dimensionless)
G_{system}	-	G-value for corresponding window system with shading (dimensionless)
G_{window}	-	G-value for window (dimensionless)
η_1, η_2	-	Regression coefficients for total energy (dimensionless)
H_{fen}	-	Height of fenestration (m)
H_i	-	Inside air enthalpy, (kJ/kg) (dry air)

H_o	-	Outside air enthalpy, (kJ/kg) (dry air)
h	-	Horizontal projection of the awning (m)
h_i	-	Heat transfer coefficient, inside glazing surface (W/m^2 K)
h_o	-	Heat transfer coefficient, outside glazing surface(W/m^2 K)
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
φ	-	Awning slope (^{0})
K	-	Luminous efficacy (lm/W)
K_B	-	Beam luminous efficacy (lm/W)
K_{cc}	-	Cloud cover ratio
K_D	-	Diffused luminous efficacy (lm/W)
K_G	-	Global luminous efficacy (lm/W)
k	-	Fraction of diffuse radiation obstructed by the shading device

L	-	Awning length (m)
λ_1	-	Regression coefficient for lighting energy (dimensionless)
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)
m	-	Optical air mass
μ_1, μ_2	-	Regression coefficients for cooling energy (dimensionless)
N	-	Cloud amount
N_i	-	Inward flowing fraction of the absorbed radiation
N_o	-	Number of people
N_t	-	Cloud type
n	-	Daily sunshine duration
n_o	-	Maximum possible sunshine duration
p_a	-	Atmospheric pressure
Q	-	Ventilation air flow (L/s)
θ	-	Incident angle (^{0})
θ_h	-	Angle of incidence on horizontal surface (^{0})
θ_v	-	Angle of incidence on vertical surface (^{0})
Q_c	-	Conduction heat flow rate (w)
Q_{cl}	-	Cooling energy use (W/m^2)
Q_{el}	-	Heat gain from electric lighting (w)
Q_{eq}	-	Appliances heat gain (w)
Q_i	-	Occupants heat gain (w)
$Q_{s,win}$	-	Total solar heat gain flow rate, window (w)
Q_v	-	Convection heat flow rate (w)
Q_{win}	-	Thermal heat gain, window (W/m^{2}K)
ρ	-	Reflectance (dimensionless)
R_{gap}	-	Thermal resistance of gap between panes (m^{2}K/W)
R_{gl}	-	Thermal resistance of glass pane (m^{2}K/W)
R_{si}	-	Internal surface resistance (m^{2}K/W)
R_{se}	-	External surface resistance (m^{2}K/W)
R_{tot}	-	Total thermal resistance (m^{2}K/W)

R^2	-	Coefficient of determination
S	-	Relative sunshine duration
SC	-	Shading coefficient
$SC_{clearglass}$	-	Shading coefficient of clear glass
$SC_{shadingdevice}$	-	Shading coefficient of shading device
SC_{net}	-	Net shading coefficient for partially shaded window
S_{df}	-	Sky diffusive factor
S_{ec}	-	Solar extinction coefficient
ΔT	-	Temperature difference (^{0}C)
τ	-	Transmittance (dimensionless)
T_d	-	Dew point temperature (^{0}C)
T_{dt}	-	Out door dry-bulb temperature (^{0}C)
T_{sol}	-	Local solar time
T_{std}	-	Local standard time
T_{wt}	-	Out door wet-bulb temperature (^{0}C)
τa	-	Secondary heat transmittance (dimensionless)
τ_b	-	Transmittance of reference glazing for direct beam (dimensionless)
τ_{diff}	-	Transmittance of reference glazing for diffuse radiation
t_i	-	Daily mean indoor temperature (^{0}C)
t_o	-	Daily mean out door temperature (^{0}C)
U	-	Thermal transmittance value (W/m^{2}K)
U_{cog}	-	Thermal transmittance center of glass (W/m^{2}K)
U_{eog}	-	Thermal transmittance edge of glass (W/m^{2}K)
U_{frame}	-	Thermal transmittance frame (W/m^{2}K)
UPD	-	Average lighting unit power density (W/m^2)
U_{win}	-	Thermal transmittance of window (W/m^{2}K)
V_d	-	Wind direction
V_s	-	Wind speed
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)
W_o	-	Outside humidity ratio, kg (water)/ kg (dry air)
W_i	-	Inside humidity ratio, kg (water)/ kg (dry air)
ψ_{edge}	-	Linear heat transmittance coefficient (W/mK)
ζ	-	Surface tilt angle (^{0})

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CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

Protection of buildings against the influences of the climate and its forces had been a challenging task throughout history. In modern scenario the task has been more challenging by the fact that this protection should not categorically eliminate all climatic influences, thus rendering the interior space independent from the external environment. The most important facet of a building's internal environment is the control of the physical conditions- light, temperature, humidity, airflow and noise within the building (Codella et al, 1981). Unbalancing any of these conditions will prevent the proper functioning of the building, as the comfort level for people engage in the type of activity that the building is intended will be affected. However, rapid pace of urbanization and development of technology played a part in neglecting valuable experience of climate adopted building technology and often controlled by artificial means. This is evident by the fact that intensive use of electricity for lighting and air-conditioning to improve comfort levels has been major consuming issues in high-rise office buildings.

The intensity of solar radiation in hot and humid climates such as Malaysia is generally high and consistent throughout the year. Records of hourly solar radiation data for altitude 3.7^0 north and latitude 101.3^0 east (Subang Jaya Meteorological Station), received a maximum of 1055 W/m^2 for the year 2001. This is about 75-80% of the solar radiation intensity outside the earth's atmosphere. Further, annual maximum intensity of solar radiation falling on horizontal is about 1000 W/m^2 and on vertical surface is about 850 W/m^2 for east and west facing surfaces. Thus, in tropical hot and humid climates, solar radiation prevention is one of the crucial factors in climate design criteria.

Daylight is one of the passive design strategies that architects and designers can utilize in building design. What makes daylight utilization so interesting is that it can be used to replace artificial lighting. Thus, it has two advantages in terms of building energy use; firstly it reduces the electricity consumption for lighting and secondly reduces the cooling demand through reduction of internal heat load from lights. Other than energy saving and economical benefits, there are other advantages and also potential drawbacks in daylight utilization. Use of daylight implies the presence of windows in the immediate surrounding which has psychological and physiological benefits. The quality of natural illumination may also be highly desirable.

According to Nor Haliza (2002), Azni Zain-Ahmed (2002a) and Hamdan (1996) the abundance of daylight in the tropics that has not been utilized to the maximum, nor has it been considered as design criterion. The main drawback is maximum daylight availability is usually concurrent with intense solar heat gain, especially in hot and humid climates, like in Malaysia. Further, the sky conditions in Malaysia can vary significantly throughout the day from overcast to clear sky, due to formation of clouds (Hamdan, 1996). Therefore, availability of sunlight and daylight can fluctuate significantly throughout the day. In this context, top lit concept for daylight is not desirable and side lighting is the main source of daylight into the building. The side daylight system produces a non-uniform light contribution from window to wall at deep end of the room. Steep depth in ‘plan form’ also creates gloomy interior where daylight penetration is limited. Another main concern is glare caused by extreme contrasts or unsuitable distribution of luminance. In order to avoid unbalanced conditions, artificial lighting is used to create a brighter internal environment.

The high-rise buildings have significantly larger façade and fenestration area than their low building counter part. The building vertical surface area is a major variable in determining the impact of the climate forces, practically which cannot be covered by a roof. The roof plays a significant role in controlling the climatic forces in low rise buildings. Hence, high-rise buildings are more exposed to the full impact of external temperatures, radiant heat and wind forces. Consequently by nature the high rise buildings are energy intensive. The necessity to reduce energy use is further challenged by the use of large glazing area for office buildings. Whether this is the result of improvement in the glazing technology or to increase daylight levels of the interior or aesthetic trend remains to be determined (Dubois, 2001c). Glass facades create problems of overheating and high air-conditioning cost, excessive brightness and discomforting glare problems.

Daylight and solar heat are two components directly affecting building fenestration design. The main climate and energy conscious design initiatives in hot and humid climates is to achieve a balance between solar radiation prevention and daylight utilization (Lam and Li, 1999; Lee et al, 1998). The solutions remain in thermal resistance of building envelope, preventing solar radiation falling on the façade and allowing beneficial daylight in. Although use of tiny windows and tinted glazing reduce heat gain through fenestration, they also cut off the view from the window and tend to reduce the penetration of daylight into the space. Studies also have shown that reducing window sizes do not prevent glare, but reduce amount of daylight in the interior (Chauvel et al, 1982). But, heat reduction is best achieved by excluding unwanted heat rather than removing it later, often by air-conditioning. Previous researches (Dubois, 2000; Givoni, 1981; Harkness, 1978; Olgyay, 1957) suggest that the use of appropriate solar shading devices can give better solutions to solve the overheating, lack of daylight and glare problems in modern offices.

External shading devices also have a few advantages over other options like different glazing types and reduction of window sizes. They can improve the light distribution in the room and reduce the discomfort glare problem. Further, use of shading devices are often more attractive to the architect than reducing the glazing area or using reflective or tinted glazing, which may alter the architectural character intended for the building (Dubois, 2001c).

Review by Abdul Majid (1996) and Nor Haliza (2002) of solar shading designs in high-rise buildings in two major cities in Malaysia, Kuala Lumpur (Latitude 3.7^0 N) and Johor Bahru (Latitude 1.38^0 N), showed that inappropriate attentions given to the shading and daylight problems. According to Hassan, KAKU (1996) most designers incorporate shading devices as an aesthetic element rather than a useful climatic design element. The reasons may be of little knowledge on solar radiation and daylight penetration and the energy implication often used to achieve internal thermal and visual comforts. In this context it can be argued that the role of external shading strategies required a rethinking in terms of reducing the impact of solar radiation, obtain a better daylight distribution and energy consumption for cooling and lighting.

1.2 The Problem Statement

Local climatic conditions affect the energy consumed by a building. In Malaysia, buildings are subject to significant cooling requirements due to high intensity of solar radiation penetration through fenestration. Previous works on energy audits and surveys of office buildings for Malaysia indicated that the energy consumed to cool the building is about 68% of the total electricity use (Loewen, J.M et al 1992). The external solar shading devices can substantially reduce the cooling load of buildings and large energy savings can be achieved.

However, a total shading to cut off unwanted solar radiation may reduce the daylight level in buildings. A reduction in the use of daylight will increase in the use of artificial lighting. This again results in the cooling load to remove the internal heat gains from light as well as consume electricity on artificial lighting. Apart from energy consumption, oversized shading devices reduce view out through building which is a primary function of a window. In hot and humid climates, the problem is emphasized by the fact that it is important to understand the magnitude of solar heat gain, daylight penetration and high energy consumption in high-rise office buildings in order to determine energy efficient shading strategy.

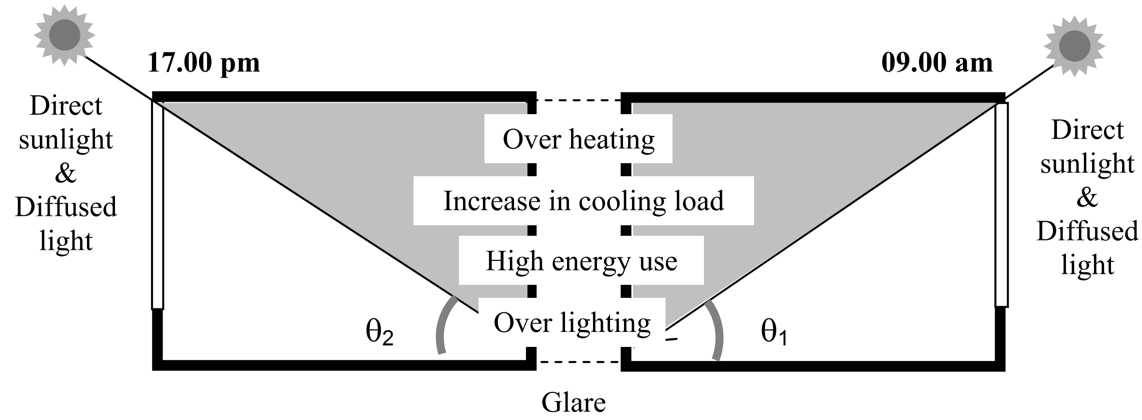

Figure 1.1: The Problem: A Typical Fully Glazed Office Space Section.

1.3 Research Hypothesis

The hypothesis of this study is that an optimum depth of a horizontal shading device will achieve the following:

i. Reduction of solar heat gain into the building
ii. Obtain adequate daylight quantity at deep end of the interior space.
iii. Thus reduce the total energy consumption from cooling and lighting and predict an optimum energy saving.

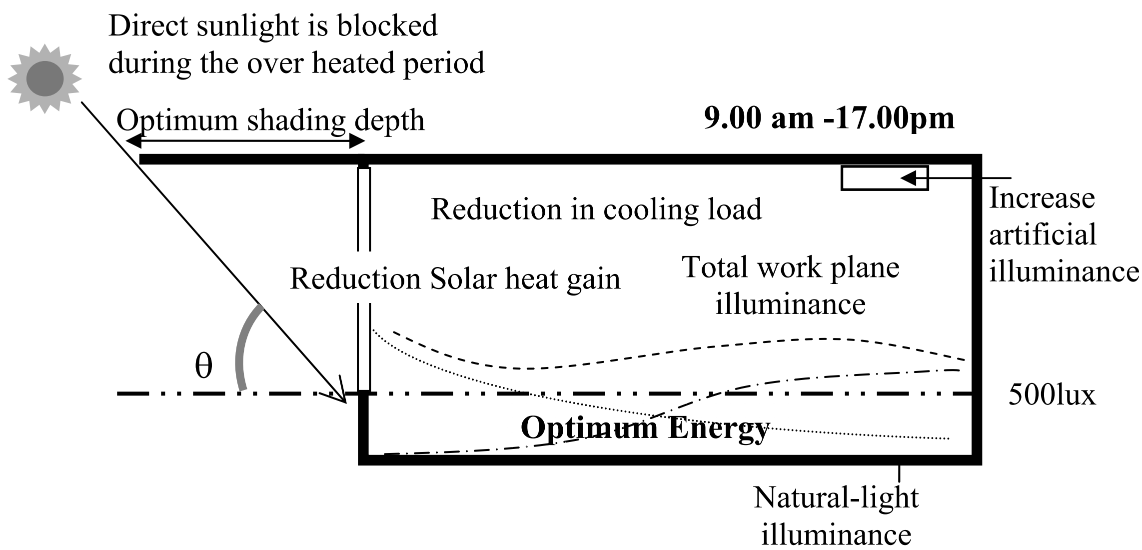

Figure 1.2: The Proposition: Optimum shading during over heated period to reduce total heat gain and obtain target illuminance

The term “optimum depth” refers to the external horizontal shading device depth which will reduce maximum heat gain and provide target illuminance to obtain an optimum energy saving, by correlating between them.

1.4 Research Questions

The following questions will be addressed in this thesis:

1. Does the orientation of the fenestration influence the solar heat gain and daylight penetration into the building and the depth of the shading device?
2. What are the effective overhang ratios to intercept the maximum direct and diffuse incident solar radiations during the over heated period from 9:00 am to 17:00 pm?
3. What is the effective overhang ratios for the maximum reduction of transmitted heat gains during the over heated period from 9.00 am to 17.00 pm?
4. What is the effective overhang ratio to obtain adequate work plane illuminance at deep end of the space considered?
5. Does the effective depth obtained at (2), reduce the work plane illuminance below the target level?
6. What is the trade off between the transmitted heat gain and the shading depth to achieve target work plane illuminance?
7. What is the optimum shading geometry to obtain an optimum energy saving in relation to cardinal orientations?

1.5 Research Gap

Previous researches on solar shading were reviewed in order to get a clear understanding of the state-of –art knowledge in the field and identify the areas which had not been covered in the past. The review revealed that research on solar shading had been focused mainly on five issues: impact on solar radiation, impact on daylight quality and distribution, impact on energy use, shading design methods, and impact on human comfort and perception. Few studies during the summer time and under hot humid tropical climate suggested that use of external shading strategies significantly reduce impinging solar radiation on the fenestration than the internal shading devices (Olgyay and Olgyay, 1957; Givoni, 1998; Hassan KAKU, 1996). Previous studies on external shading devices in hot and humid tropical climates (Hassan KAKU, 1996; Sharifah and Sia, 2001) only concentrated on the incident solar radiation (direct, diffused and reflected) and expressed the capacity of shading device to cut out the impinging solar radiation. Yet they do not indicate amount of solar heat gain transmitted into the space when different external shading strategies were applied in order to understand the energy implication of employing such strategies.

Though it was stated in many research works and publication that the external solar shading reduces daylight distribution into the space, there were only few researches done on this aspect in hot and humid tropical climate conditions (Sharifah and Sia, 2004 Hamdan, 1996). Also, little is known about the relationship between external shading device geometry and the daylight distribution, especially under high illuminance global sky conditions like in Malaysia.

Review also suggested that shading strategies have a significant impact on the energy consumption for cooling, heating and lighting. Few studies have looked into this aspect under different climate conditions and with different shading strategies (Bojic et al, 2002; Bülow-Hübe, 2001; Dubois, 1999; Huang et al 1992; Bordart et al, 2002; Li & Lam, 1999; Lee, E. S et al, 1998). Studies by Huang et al (1992) in office buildings in Singapore, were dependent on other variables (different illuminance levels, lighting power requirements, window-to-wall ratio) as well, therefore it is difficult to derive clear conclusion on the effect of solar shading on total energy consumption. Further they do not indicate an optimal shading strategy for any particular climate. Hence, there is room for further research on relationship between external shading device geometry and on the electric consumption for cooling and lighting.

Table 1.1: Summary of previous research related to solar shading, daylight and energy use

		Design Variables														Performance Variable								
		External				Internal			Nat-ural		Geometry					Thermal			Visual					
Research	**Climate zone**	**Horizontal**	**Vertical**	**Egg-crate**	**Awnings**	**Blinds**	**Screens**	**Glazing**	**Build. orientation**	**vegetation**	**Window-to-wall**	**Depth**	**Width**	**Angle**	**Color**	**Solar radiation**	**Solar transmit**	**Temperature**	**Illuminance**	**Glare**	**Uniformity**	**Energy**	**Design Meth**	**Others**
Olgyay (1957)	T	*	*	*				*								*	*		*				*	
Hassan, KAKU (1996)	HH	*	*	*								*				*								
Givoni (1981/1998)	T	*	*									*	*			*	*							
Dubois (1999)	T				*							*	*	*								*		
Dubois (1998)	T				*			*								*	*					*	*	
Dubois (2001c)	T	*			*	*	*								*				*		*			
Sharifah & Sia (2001)	HH	*																					*	
Sharifah & Sia (2004)	HH	*																	*					
Raeissi & Taheri (1997)	HA	*										*	*									*		
Azni Zain-Ahmad (2002)	HH										*						*		*					
Al-Shareef (2001)	HA					*						*		*	*				*					
Robbins (1986)	T	*										*							*			*		
Chirarttanano n (1996)	HH	*						*			*	*							*			*		*
Dinapradipta (2003)	HH							*			*								*					
Huang (1992)	HH	*						*			*	*										*		*
Bojic (2002)	HH							*	*			*										*		
Present Study	*HH*	√										√				√	√		√			√		

T = Temperate climate HA = Hot and arid climate HH = Hot and humid climate

Table 1.1 gives a summary of related research work and their variables. Thus, the above review suggest that effect of solar shading on solar heat gain, internal daylight level and on energy consumptions have been dealt as separate issues. There is no specific research done to study the relationship between external shading devices and the correspondence solar heat gain, daylight level and energy consumptions. Therefore, this thesis attempts to focus on the application of external horizontal solar shading device and to asses their performance with respect to the impact of solar radiation, internal daylight illuminance level and the optimal energy saving.

1.6 Research Objective

The main objective of this study is to assess and evaluate the impact of external horizontal shading devices in reducing the unwanted solar heat gain and the amount of daylight penetration into the building. Thereby, to determine the geometry of horizontal shading device to optimize the energy savings for cooling and lighting for buildings in hot and humid climates.

Other specific objectives of the study are as follows:

1. To determine the amount of direct, diffuse and reflected solar radiation incident on the window pane and transmitted solar radiation through window.
2. To determine the depth of external horizontal shading device considering the window solar angle dependent properties.
3. To determine the direct, diffuse and reflected solar radiation incident on the window pane and transmitted solar radiation through the window for the proposed external horizontal shading devices described in (2).
4. To determine the work plane illuminance for the proposed external horizontal shading devices described in (2).
5. To determine the potential trade-offs involved between the solar heat gain and daylight penetration into the interior space to optimize the depth of the external horizontal shading devices described in (2).
6. To determine the energy performance of proposed external horizontal shading devices described in (2).

7. To compare the energy performances of proposed external horizontal shading devices with a base-case model (without shading device) and results obtained from (3), (4) and (6) for determining the optimum overhang depth to achieve optimum energy saving.
8. To determine the influence of building orientation on the external horizontal shading strategy.

1.7 Scope and Limitations

There are several necessities for using shading systems in buildings, ranging from individual level (better thermal and visual comforts, low energy bills) to national or global levels (reducing energy consumptions). However, scope of this study is to evaluate the solar heat gain and daylight penetration in order to optimize the energy consumption for cooling and artificial lighting when external solar shadings are applied.

The thermal performance of a building largely depends on two parameters: unsteady climatic parameters and building design variables (Bouchlaghem, 2000). The thermal analysis is mainly focused on the amount of direct, diffuse solar radiation and transmitted and retransmitted solar heat gain through fenestration. Although, there are other means of solar heat gain into the building such as, conduction through wall and infiltration, assumptions are made that heat gain from these modes are constant for all the tested shading strategies. Further, relative humidity and wind flow also can effect on the building thermal performances, but these parameters were not considered in this experiment.

The thermal comfort aspect is not dealt within this thesis as a major issue. This is because there are other parameters effecting thermal comfort, for e.g. air temperature, humidity, air velocity, clothing and metabolic heat production (Givoni, 1981; Sharifah, 1995). It is assumed that by setting the indoor temperature at recommended comfort value, will provide the required thermal quality for that space.

The daylight evaluation is limited to determining the work plane illuminance at 0.9 meter from the ground level. Uniformity of daylight distribution, luminance ratio between the surfaces of the space, effects on color rendering and effect on glare, which contribute to the determining the qualities of daylight of a space are not dealt in this thesis. Although evaluation of daylight quality is not within the scope of this study, assumptions were made, by providing an optimum shading strategy so that these criteria were acknowledged, thus provide appropriate visual comfort for the user.

The energy performance of a building largely depends on three parameters; building design variables, mechanical and technical system efficiency and efficient management of systems. An approach focusing on architectural form and envelope are directly under the control of the architect and also provides a visual picture of the impact of environment on people and architecture. In this study energy analysis is carried out for different external horizontal shading geometry only. Other building design parameters such as, properties of building materials, location and size of fenestration, surface treatment and insulation were kept as constant to all shading cases tested.

Mechanical and technical system operating conditions were also kept identical to all experiments tested. The working schedule for the office is considered from 9:00 am to 17:00 pm.

A standard office room with a single fenestration was selected for the experiment, with a typical room configuration capturing the variety of solar heat gains and lighting distributions found in typical high-rise office buildings in Malaysia. Therefore, analysis of data and energy is performed and discussed as reference to the base case model and as a ratio to the base case values. The base case office room is developed to comply with the Malaysian MS 1525 Standards. Due to above stated reasons; no comparisons were made with any existing building energy estimates.

This study is entirely carried out by using computer simulation program eQUEST-3 DOE 2.2 (Version 3) and thus bears the limitations of the simulation tool used. In chapter 4, a review on common research methods used by previous researches and justification for the selection of the present tool are discussed.

Finally, the simulation is performed under clear sky conditions and the main cardinal orientations, East, West, North and South, were considered. The following days were chosen for hourly analysis; 21 March, 22 June, 24 September and 21 December. Since Malaysia receives similar climatic condition throughout the year, the selected dates do not represent extreme days or average days, but suggest the position of the sun related to certain façades at certain orientations. During 21 March and 24 September the sun is within the plane of the equator and in tropical regions, a high amount of solar radiation is received on these dates. In 22 June and 21 December the sun is in the equinox and it is at farthest point from the tropical region. Therefore it is assumed the impact of solar radiation is less on these two dates compared to other dates of the year.

1.8 Importance of the Research

The out come of the study is expected to show that, the effectiveness of the solar shading system depends on the relative balance between solar heat gain reduction and adequate daylight in the building. The study also expect to suggest that appropriate design decisions on solar shading systems can significantly reduce the high energy consumption in office buildings in Malaysia.

Apart from the protection against harsh solar radiation and energy conservation, the use of solar shading has benefit on various other aspects as shown in figure 1.3. The most important aspect is the thermal and visual comforts, which determines the human behavior. Hence, findings of this study will enable and provide the building designer with wider range of options in selecting an appropriate shading strategy for achieving the balance between desired daylight level and optimum energy consumptions for space cooling and lighting.

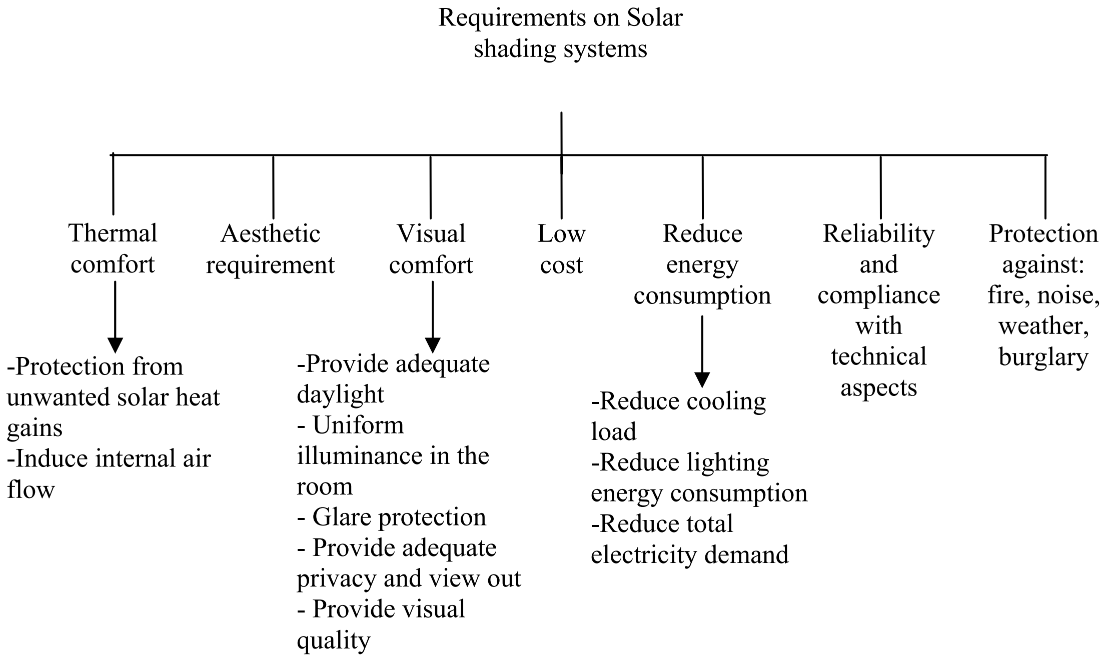

Figure 1.3: User requirements for solar shading systems

1.9 Thesis Organization

The thesis is organized into eight chapters as summarized bellow.

Chapter one introduces the main issue of this research. This chapter also contains the proposed hypothesis of the study, 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 theory of solar radiation and the sky conditions of Malaysia, particular to Kuala Lumpur (Latitude: 3.12^0; Longitude: $+101.6^0$; Time zone: +7). Review on solar radiation includes the geometry of solar movement, solar intensity and its computations for different radiation types in order to understand their influence on the building. Also, a critical evaluation is carried out between measured weather statistics for the location considered and data obtained from the simulation weather file in order to clarify the validity of the latter to be used in the study.

Chapter three is divided into three sections. Section one reviews the energy consumption patterns in Malaysia in general and in office buildings in particular. The building standards for energy control in commercial buildings are also reviewed to understand the energy scenario in Malaysia. The high-rise office building and basic principles of energy efficient high-rise building are discussed. Based on the review initial design conditions for the present study are also presented. Section two reviews the principles of heat gains, types of heat transfer and factors influencing heat gains in the building. A method to compute the solar heat gains are explored. Finally, in section three, different shading devices are analyzed to understand their implication as a shading element. Their basic functions as a solar radiation control device are discussed to get a clear understanding of the state-of-the-art knowledge in the field. Aspects determining the effectiveness of the shading are presented in order to find a suitable energy efficient shading strategy. Methods for designing shading device are reviewed and a new method is proposed to determine the shading depth in hot and humid climate conditions.

Chapter four discuss the methodology implemented in this present study. Initially, the energy evaluation methods and common research methodologies used by previous researchers are reviewed. Thus, an appropriate methodology to be employed in this thesis is formulated. Further, development of the base model, experimental procedures, assumptions, limitations and the overall sequence of the selected experiment method are described. Finally, the data analysis criterions are discussed, which is used to analyze the results of the experiment.

Chapter five presents the results and analysis of the incident solar radiation transmitted solar heat gain and work plane illuminance for the tested external horizontal shading strategies. The principle findings of the simulation are also summarized. The results of the simulation are analyzed as follows:

- Assess the impact of shading strategies on incident solar radiation (direct & diffused).
- Assess the impact of shading strategies on transmitted solar heat gain into building.
- Assess the influence of shading strategies on target illuminance level at deep end of the room to determine the optimum shading strategy for natural-lighting.
- Assess the relationship between natural-light penetration and the office room geometry.

Chapter six investigates the influence of the external horizontal overhang strategies on building cooling load and energy consumptions. The results of the experiments are analyzed as follows:

- Assess the impact of shading strategy on annual building cooling load.
- Assess the impact of shading strategy on annual energy consumption for cooling, lighting and on total consumption to determine the optimum energy consumption.
- Assess the natural-light level and annual energy consumption to determine the optimum shading strategy.

Chapter seven presents the overall review of the thesis objectives and research questions, followed by the conclusion remarks of the major findings of the experiment. Finally, suggests further works to complement with the thesis findings.

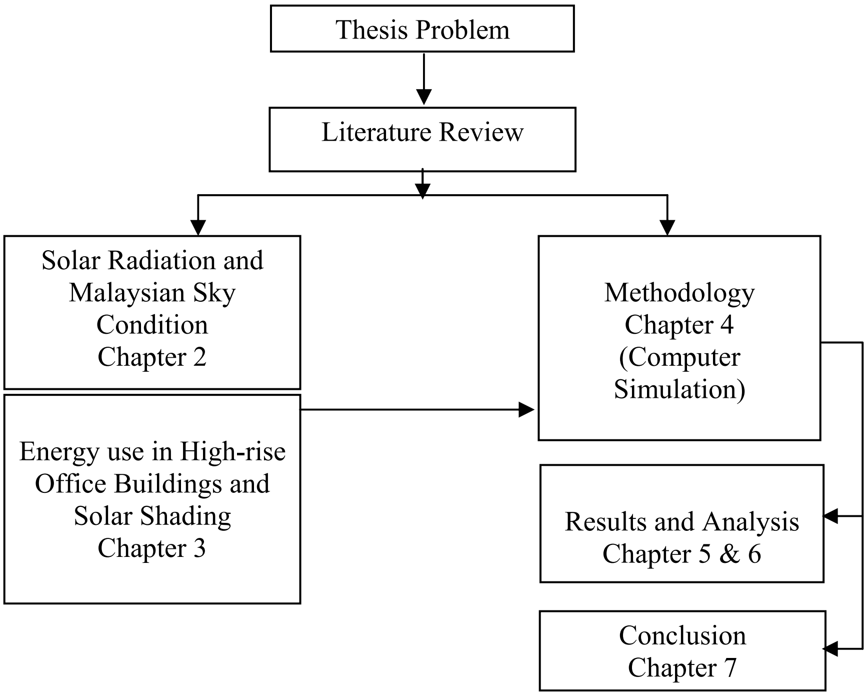

Figure 1.4 The flow of research process and thesis structure

internal natural lighting and to optimize energy savings. In other words little had been known about the relationship between the energy use and the external horizontal shading device geometry. Therefore, the solar shading design strategies require a rethinking in light of energy efficiency. However, several areas of study need further investigation, to develop the knowledge of the shading strategies in Malaysia and regions with similar climates. The following are some suggestions:

1) Investigation on the effectiveness of the geometry. Apart from the depth of the overhang, the other factors need to be investigated are; the impact of angle and the width of the overhang with respect to, daylight, solar heat gain and overall energy consumption.

2) Investigation on the effectiveness of surface material and colour of shading devices on energy consumption. Effectiveness of shading device also depends on the material and surface colours as they affect on thermal and daylight reflection. Therefore, these aspects need to be studied in terms of surface texture, light and dark colours etc. It may also contribute to the aesthetics of the shading device.

3) Further investigations are required to determine the effects of external shading strategy on deep plan office buildings and on various building forms.

4) In terms of daylight, the influence of energy efficient shading strategy on daylight quality and glare need to be explored. In hot and humid tropics, glare from window create visual discomforts on the inhabitants and quality of daylight is not incorporated as design criteria in buildings. Therefore, information on relationship between shading strategies, daylight quality, glare and energy consumption are very important.

5) Investigation of other different external shading devices and their influence on energy consumption. A detail study should be carried out to look into the impact of horizontal fins, vertical and egg-crate external shading devices on daylight penetration, solar heat gain and on energy consumption.

6) Further studies need to be carried out to develop a method to define shading devices by considering the total solar energy transmittance. In hot and humid tropics influence of diffuse component of solar radiation on thermal effects are significant. Therefore, considering the total solar energy transmittance may be an important aspect in determining different shading strategies. Considering the total solar energy transmittance may also be a better replacement for defining shading devices rather than based on shading coefficient. Studies on solar transmittance properties can be used to develop a design method to determine different shading strategies for the tropics.

7) Investigation on the influence of solar shading strategies on the OTTV (overall thermal transfer value) standards. The standard design criterion for non-residential building envelope is determined by the OTTV, which is developed based on solar heat gain through the building envelope. The scope may extend to determine the influence of solar shading strategy on building OTTV and on the overall energy consumption of the building. By investigating this aspect, it would alleviate the problem of trade off between daylight, solar heat gain, use of artificial lighting and overall energy consumptions.

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