

**PERFORMANCE OF THE GLAZED FACADES WITH A  
FLOWING SUSTAINABLE WATER FILM EXPOSED TO  
DIRECT SOLAR RADIATION UNDER  
THE MALAYSIAN CLIMATE**

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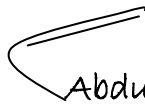
## DEDICATION

This thesis dedicated to the **Martyrs Souls** ...

*of my country...*

*of my nation...*

Those who gave their life out of passion as peacefully struggling for maintaining the dignity of the human and dreaming for a better future.

  
Abdultawab Qahtan

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## TABLE OF CONTENTS

Original Literary Work Declaration.....	i
DEDICATION .....	ii
ACKNOWLEDGEMENTS .....	iii
TABLE OF CONTENTS .....	iv
LIST OF APPENDICES .....	xvi
LIST OF ABBREVIATIONS USED IN THE THESIS .....	xvii
GLOSSARY.....	xviii
ABSTRACT.....	xix
ABSTRAK.....	xxi

### CHAPTER 1

INTRODUCTION .....	1
1.1    Introduction.....	1
1.2    Towards Sustainable Architecture in the Tropics.....	2
1.3    Passive Solar Control for Glazed Building.....	3
1.4    Building Orientation and Shading .....	3
1.5    Advanced Glazing.....	4
1.6    Glazing for Tropical Solar Control.....	5
1.7    Alternative Glazing Systems and Research gap .....	7
1.8    The Research Problem .....	8
1.9    Objectives of the Research .....	8
1.10   Research questions.....	10
1.11   Methodology .....	10
1.12   Research Design .....	11

### CHAPTER 2

CLIMATE OF MALAYSIA.....	13
2.1    Introduction.....	13
2.2    Solar Radiation .....	13
2.3    Rainfall.....	17
2.4    The Malaysian Sky Condition .....	18
2.5    Air Temperature Data .....	20
2.6    Relative Humidity.....	23
2.7    Wind Speed.....	24
2.8    Summary .....	26

## CHAPTER 3

SOLAR CONTROL FOR GLAZED BUILDINGS IN THE TROPICS .....	28
3.1 Introduction .....	28
3.2 Solar Radiation Fundamentals .....	28
3.2.1 Solar Geometry .....	28
3.2.2 Diffuse and direct solar radiation.....	30
3.2.3 Intensity of solar radiation .....	30
3.2.4 Solar radiation spectrum .....	31
3.2.5 Solar radiation on horizontal surface .....	32
3.2.6 Solar radiation on vertical surface .....	33
3.3 Solar heat gain through glazings .....	33
3.3.1 Direct solar radiation on glazings (or “near infrared”).....	34
3.3.1.1 Estimating of the shade coefficient .....	34
3.3.1.2 Solar Heat Gain Coefficient SHGC.....	36
3.3.2 Heat transfer through the glazing (or “far infrared”).....	38
3.3.2.1 Conductive heat .....	39
3.3.2.2 Convective heat .....	40
3.3.2.3 Radiant heat .....	40
3.3.2.4 Light to Solar Gain Ratio LSG .....	41
3.3.2.5 Heat sink.....	42
3.3.2.6 The green house effect.....	43
3.4 Passive solar control for glazed building in tropics .....	43
3.4.1 Shading devices and east/west orientation.....	44
3.4.2 Glazing technology in the tropics .....	46
3.4.2.1 Clear glass .....	47
3.4.2.2 Tinted glazing (heat absorbing glazing).....	48
3.4.2.3 Heat Reflective glazing .....	49
3.4.2.4 Low-e glazing.....	50
3.4.2.5 Spectrally selective glazing .....	52
3.4.2.6 New glazing systems .....	53
3.4.2.7 Discussion on the recommended glazing in the tropics .....	53
3.5 Summary .....	55

## CHAPTER 4

THE CHALLENGES OF THE GLAZED BUILDINGS IN THE GREEN ERA IN THE TROPICS .....	57
4.1 Introduction .....	57
4.2 Glazing in architecture. ....	57
4.2.1 Survey on Mid-rise glazed-office-buildings in Klang-Valley .....	59
4.2.2 Buildings and Energy consumption.....	59

4.2.3	Energy efficient design in the tropics .....	61
4.3	Potentials of green design for glazed buildings in Kalang-Valley, Malaysia .....	61
4.3.1	Green building index .....	62
4.3.2	Glazed and Green certified office buildings in Malaysia .....	63
4.3.2.1	The G-Tower building, Kuala Lumpur .....	63
4.3.2.2	The Securities Commission building, Kuala Lumpur .....	65
4.3.2.3	The Menara Mesiniaga building, Subang Jaya.....	67
4.4	A Case Study to Assess the Workspace Thermal Performance of glazed building in the tropics, Malaysia .....	68
4.4.1	Introduction.....	68
4.4.2	The Building and Passive Solar Control Elements.....	69
4.4.3	Methodology.....	72
4.4.4	Results and discussion .....	74
4.4.5	Conclusion .....	79
4.5	Chapter Summary.....	80
4.6	Research gap .....	81

## CHAPTER 5

	THE POTENTIALS OF WATER AS A SUSTAINABLE SOLAR GAIN CONTROL FOR GLAZED-BUILDINGS IN THE TROPICS.....	83
5.1	Introduction .....	83
5.2	Rainwater harvesting systems .....	83
5.3	Rainwater harvesting in Malaysia and the tropics .....	84
5.4	Impact of water on solar radiation transmittance .....	84
5.4.1	Optical properties of water .....	85
5.4.2	Estimating the solar radiation on the water surface.....	86
5.4.3	Water temperature.....	87
5.5	Applications of the water for Cooling and solar controlling in the buildings.....	87
5.5.1	Radiant cooling .....	89
5.5.2	Evaporation cooling .....	89
5.5.2.1	Direct evaporation cooling.....	90
5.5.2.2	Indirect evaporative cooling .....	90
5.5.3	Water-flow window .....	91
5.5.4	Building surface cooling.....	92
5.5.4.1	Water spray on an atrium roof in the tropics .....	92
5.5.4.2	Water film on a Superhydrophilic of the TiO <sub>2</sub> -coated surface .....	93
5.5.5	Water Film flows down over the glazing surfaces .....	94
5.6	Summary and research hypothesis .....	94

CHAPTER 6	
METHODOLOGY .....	96
6.1 Introduction .....	96
6.2 Architectural research methods .....	96
6.2.1 Experimental research in architecture.....	97
6.2.2 Knowledge gap and the research questions .....	98
6.3 Research methods for the SGWF .....	99
6.3.1 Experimental design and set up .....	100
6.3.2 Design of the test and the control rooms .....	101
6.3.3 Forming even flow of water film on the glass surface .....	106
6.3.4 The instrumentation and the sensors.....	110
6.3.5 The setting of the treatments and the outcome measures .....	114
CHAPTER 7	
RESULTS AND DISCUSSION .....	116
7.1 Introduction .....	116
7.2 DETERMINATION OF THERMAL PERFORMANCE OF GLAZED-FAÇADES WITH WATER FILM, UNDER DIRECT SOLAR RADIATION IN THE TROPICS 117	
7.2.1 Temperature difference inside the rooms .....	119
7.2.2 Temperature variation on glazing surfaces.....	125
7.2.3 Heat flux through SGWF .....	129
7.3 DETERMINATION OF THE SOLAR ENERGY TRANSMITTANCE OF SGWF UNDER THE DIRECT SOLAR RADIATION IN THE TROPICS.....	131
7.3.1 Theory of the total solar energy transmittance within the SGWF facade...	133
7.3.2 Test Rooms' calibration.....	135
7.3.3 Solar radiation transmittance through the SCGWF .....	137
7.3.3.1 Solar radiation intensity .....	137
7.3.3.2 Solar heat gain coefficient “SHGC” of SCGWF facade.....	141
7.3.4 Solar radiation transmittance through the STGWF .....	144
7.3.4.1 Solar radiation intensity.....	146
7.3.4.2 Solar heat gain coefficient “SHGC” of STGWF facade .....	149
7.4 THE LABORATORY AND CALCULATION VALIDATION OF THE SOLAR OPTICAL PERFORMANCE OF THE SGWF FACADE .....	153
7.5 Water film thickness .....	163
7.6 Relevant Significance of SGWF for Glazed Office Buildings in the Tropics ...	166
7.6.1 Reducing the building energy operation cost .....	167
7.6.2 Reducing the heat island effect.....	168
7.6.3 Contributing to the sustainable and green building .....	169
7.6.4 The low cost and high performance of glazed building insulation .....	170



7.6.5	Improving the level of the indoor air temperature and the daylighting .....	170
7.6.6	Increased in the rentable spaces .....	170
7.6.7	Self-cleaning ability .....	171
7.7	Water volume flow supply .....	171
7.8	Limitations of the study .....	173
7.9	Disadvantages of the SGWF facades .....	173

## CHAPTER 8

CONCLUSION AND FUTURE STUDIES .....		175
8.1	Introduction .....	175
8.2	Conclusion of the field study .....	176
8.3	Conclusion of the SGWF .....	177
8.3.1	Thermal performance of SGWF .....	177
8.3.2	Solar radiation transmittance of SGWF.....	178
8.3.3	Spectrally selective solar control of SGWF.....	178
8.4	Contributions of the study .....	179
8.5	Recommendations for further research .....	180
8.5.1	Integration of SGWF with PV buildings envelope .....	181
8.5.2	Glazed-building solar and thermal simulation with SGWF; the effect of SGWF on the urban heat island in Malaysia .....	181
8.5.3	Thermal and optical simulation of SGWF; the effect of SGWF on the energy consumption of office glazed-buildings in the tropics .....	182

## REFERENCES

## APPENDICES

## LIST OF FIGURES

Figure 1.1: The relationship of the issues of sustainability in glazed building (adapted from: Lechner, 2009). .....	2
Figure 1.2: The Research Frame Work .....	9
Figure 1.3: Flowchart of the study. ....	12
Figure 2.1: Sun path diagram of 22nd of June, Kuala Lumpur (Author).....	14
Figure 2.2: Sun path diagram of 21st March, Kuala Lumpur (Author) .....	15
Figure 2.3: Hourly Average DBT with its relation to the solar radiation kW/m <sup>2</sup> , in particular days; the shortest and longest days (2004 to 08 average, Subang Jaya Meteorological Station).....	16
Figure 2.4: Hourly average of solar radiation (kWh/m <sup>2</sup> ) (2004 to 2006, Subang Jaya Meteorological Station).....	17
Figure 2.5: Monthly total rainfall mm, 2004 to 2008, Subang Jaya Meteorological station. ....	18
Figure 2.6: Annual total rainfall mm, 2003 to 2008, Subang Jaya Meteorological station .....	18
Figure 2.7: Cloud cover and solar radiation, average monthly to 8 years (Subang Jaya Meteorological Station).....	19
Figure 2.8: Monthly cloud cover and solar radiation (average 10 years Subang Jaya Meteorological Station).....	19
Figure 2.9: Annual occurrences of different sky types at Subang Jaya, Malaysia (source: Zain-Ahmed <i>et al.</i> , 2002) .....	20
Figure 2.10: Monthly temperature variation (average 10 years, Subang Jaya) .....	21
Figure 2.11: Monthly average to 24 hours. The maximum of air temperature occurred during the month of March (Subang Jaya, 2004 to 2008).....	21
Figure 2.12: Average hourly dry bulb temperature in a day (Subang Jaya, 2004 to 2008) .....	22
Figure 2.13: Average hourly dry bulb temperature with its relation to solar radiation kWh/m <sup>2</sup> , in particular days; shortest and longest day (Subang Jaya, 2004 to 2006) .....	22
Figure 2.14: Monthly average of relative humidity and its relation to average temperature (for the period 10 years at Subang Jaya Meteorological Station) .....	23
Figure 2.16: Wind direction is mainly from the north-west to the southwest throughout the year Kuala Lumpur wind rose (Ahmad <i>et al.</i> , 2007). ....	25
Figure 2.17: Monthly wind speed for 10 years as recorded at Subang Jaya Meteorological Station .....	26

Figure 3.1:The Varying Solar Angles (source: modified from Bansal (1994b) )	29
Figure 3.2:The solar spectrum at the Earth's atmosphere, (modified from Button and Waldron (1993))	32
Figure 3.3: Solar reflection, transmission and absorption: standard 3mm clear sheet glass (Hassall, 1977).	35
Figure 3.4:Chilled water tubes are embedded into the floor slabs acting as a heat sink, in GEO building	42
Figure 3.5: The east and the west shading devices: (a) Wall Fence, PJ Trade Centre and (b) Screen Wall, Putrajaya	46
Figure 3.6:The performance of low-e glazing that reduces radiant heat transfer (long-wave infrared) (U.S. DOE, 1994)	50
Figure 3.7:Low-E Glass Penetration Rate in Major Countries where climates are cold in winter (Research In China, 2010)	52
Figure 3.8:Double glazing system, integrating low-e and spectrally selective glazing in GEO Building, a certified green office building in Malaysia (Source: PTM)	53
Figure 3.9:Different glazing performance, the light/heat ratio. (Source: modified from Button and Waldron, 1993)	54
Figure 4. 1The Fagus factory in Germany, the early glazed facade in 1911	58
Figure 4.2: G-Tower building, north facades 2009	64
Figure 4.3: G-Tower, the green planting throughout the building to improve air quality	64
Figure 4.4: G-Tower, the recycle timber used for wall decorating	64
Figure 4.5: The site plan of the Securities Commission Building, (Kasturi, 2006)	66
Figure 4.6: Perspective view for the Securities Commission Building	66
Figure 4.7: The glazing cavity which is a buffer and service route, the shading devices also illustrated	67
Figure 4.8: View from the lift lobby towards the west double skin showing the braking glass due to the temperature differences	67
Figure 4.9: North-west view of the Menara Mesiniaga with external shading	68
Figure 4.10: View of the vertical landscaping	68
Figure 4. 11The site view of the ST Diamond building. And 4.11,b : The north-west view (Reimann, 2010)	70

Figure 4. 12Self-shading facades from the direct sun-beam (Reimann, 2010). And 4.12,b : Fixed louvers and blinded to reduce the glazing ratio.....	70
Figure 4. 13The green roof provides an insulation to the ST Diamond building. And 4.13,b: Spectrally selective Glazing.....	70
Figure 4. 14About 40% of the cooling is delivered by floor slab cooling (Source: IEN Consultants).....	71
Figure 4. 15The water film flows down the glass at the ST Diamond building entrance.....	71
Figure 4. 16Diffuse light is redirected into the workspace by light-shelf and window sill (Reimann, 2010).....	71
Figure 4.17: ST Diamond building (a) plan of the level four, (b) section.....	72
Figure 4.19: Setting up the measurements in ST Diamond Building.....	73
Figure 4.18: Sun paths on the ST Diamond Building site of the measuring.....	73
Figure 4.20: Set up of the indoor Data logger.....	74
Figure 4.21: Set up of the outdoor data logger.....	74
Figure 4.22: The differences between the indoor and the outdoor temperatures near glazing.....	76
Figure 4.23: The relationship between the direct solar radiation, the glazing surface temperature and the heat flux values for all measuring days in ST Diamond Building.....	76
Figure 4.24: Measurement results during working days.....	78
Figure 4.25: Measurement results during non-working days.....	78
Figure 4.26: The passive solar control options for the glazing in the tropics.....	82
Figure 5.1:View of the British Pavillion with S-shaped photovoltaic shading panels and water flow film over the west façade (source: Expo, 1992)	88
Figure 5.2:The water flow film over the glazing of the main entrance of ST Diamond Building Putrajaya, Malaysia, (Author)	88
Figure 5.3: Water-flow double-glass window (source: Chow <i>et al.</i> , 2010).....	91
Figure 5.4:Forming water film: (a) surface with contact angle <90. (b) Surface with the Superhydrophilicity of the TiO <sub>2</sub> -coat that increase the wetting of the glass surface (source: modified from Takata <i>et al.</i> , 2004).	93
Figure 6.1: Variables examined for SGWF.....	101
Figure 6.2: The rooms' laboratory drawing .....	103

Figure 6.3: View of experiment site: reference room (left) and test room (right). .....	103
Figure 6.4: Schematic view of the reference room at single glazed façade.....	104
Figure 6.5: Schematic view of the SGWF .....	104
Figure 6.6: The stereographic diagram of 21st March, to the experiment site. ....	105
Figure 6.7: Sun path diagram of 21st March, to the experiment site.....	105
Figure 6.8: A layer of 100mm Rockwool insulation for the wall and internal roof ....	106
Figure 6.9: The variation of the water film application within glazed facades.....	107
Figure 6.10: During experiments, the water reservoir was shaded by an aluminum foil .....	108
Figure 6.11: Feeding the water to the system comes through a t-junction with a pipe going right and left with both ends capped off. ....	109
Figure 6.12: Feeding the water to the facade comes through a stainless steel gutter to form spill-over flow. ....	109
Figure 6.13: Set up of the “Babuc/A” data loggers in one room to check if there are any reading differentiations in order to minimise data errors.....	111
Figure 6.14: Set up of the indoor data logger in the test room.....	111
Figure 6.15: The vertical solar radiation monitoring sensors, which are attached to the wooden tripod. ....	112
Figure 6.16: Set up of the weather station for measuring the outdoor experiment’s variables .....	112
Figure 6.17: UV/VIS/NIR spectrophotometer to measure water spectrum.....	113
Figure 7.1: Flow chart for Chapter 7.....	117
Figure 7.2: (a) The schematic view of the present problem at single glazed façade and (b) the schematic view of the experiment with SGWF facade.....	118
Figure 7.3: Indoor air temperature difference with CG vs. CGWF 1.7m <sup>3</sup> /h.....	121
Figure 7.4: Air temperature variation outdoor – indoor, TG reference room vs. STGWF test room, (sunny hours).....	123
Figure 7.5: Air temperature variation, outdoor – indoor, TG reference room vs. STGWF test room.....	126
Figure 7.6: Surface Temperature difference, CG vs. SCGWF-f 1.7m <sup>3</sup> /h. ....	128
Figure 7.7: The temperature variation of glass surface, TG reference room vs. STGWF test room with two flow-rates during sunny and cloudy hours.....	128

Figure 7.8: The temperature distribution on SCGWF and heat flux through, sunny hours.....	130
Figure 7.9: The temperature distributions on different configurations of STGWF and heat flux through, sunny hours.....	131
Figure 7.10: Comparison of the east and the west outdoor vertical solar radiation at the experiment site .....	132
Figure 7.11: The solar radiation at the experiment site on the 21st of March where the equator receives the largest amount of the solar radiation. ....	132
Figure 7.12: The schematics of the experimental set-up of the solar transmittance within the SGWF.....	134
Figure 7.13: The schematics of solar energy performance within components of SGWF facade .....	134
Figure 7.14: The solar radiation data in the two rooms (test room and control room) on the control day without any treatments in both rooms.....	135
Figure 7.15: The equalization of the solar radiation data in both rooms at a control case .....	136
Figure 7.16: The difference between the two rooms without treatments (rooms' calibration) .....	136
Figure 7.17: The solar radiation transmittance through SCGWF and CG for the different sunny and cloudy hours of February .....	138
Figure 7.18: The increase in the solar radiation with the water film (the sunny hours of 22nd February) .....	139
Figure 7.19: The effect of SCGWF on the solar radiation transmittance at the peak of the sunny hours 22nd February .....	139
Figure 7.20: The increase in the solar radiation with the water film (the cloudy hours of 26th February).....	140
Figure 7.21: Solar transmittance of SCGWF on the cloudy at 13:00 – 15:00, 26th February. ....	141
Figure 7.22: The view of the tested west facade showing the pyranometers that measured the internal/external vertical solar radiation of the CG façade. ....	142
Figure 7.23: The difference between CG and SCGWF with respect to the exterior solar radiation in both cases (14th and 15th February).....	142
Figure 7.24: The peak difference in the solar radiation indoor/outdoor; (a) with water film SCGWF and (b) without water film CG.....	143
Figure 7.25: The differences in the total solar energy transmittance between the CG facade on 6th March and SCGWF facade on 7th March .....	144

Figure 7.26: The difference in the solar radiation transmittance between the tinted glass and the clear glass .....	145
Figure 7.27: The solar radiation comparison on different days .....	147
Figure 7.28: The performance of the solar radiation transmittance with the presence of the water film over the tinted glass on the sunny hours .....	148
Figure 7.29: The difference of the solar transmittance between TG and STGWF on the cloudy hours.....	149
Figure 7.30: The difference of the solar radiation between the outdoor and the indoor within TG and STGWF.....	150
Figure 7.31: Comparisons between outdoor solar radiation and indoor solar radiation within TG and STGWF.....	150
Figure 7.32: The difference of the total solar energy transmittance between the TG facade on 28th of March and the STGWF facade on 27th of March.....	151
Figure 7.33: The calibrated day without water film in both rooms .....	154
Figure 7.34: The decrease in the indoor air temperature and the increase in the solar radiation behind the STGWF .....	154
Figure 7.35: The set up of the “spectrophotometer” for measuring the solar optical properties of water.....	156
Figure 7.36: The optical glass of a standard “Quartz Cuvette” that was used for testing the water transmittance .....	156
Figure 7.37: The solar optical properties of the water for regular incident solar radiation (Author).....	157
Figure 7.38: The divergent solar beam in water at the regular transmittance.....	157
Figure 7.39: The transmittance of the solar radiation through the SGWF facade (Author) .....	160
Figure 7.40: The water transmittance of a beam of light as it travels through a cuvette of width $X_1=10\text{mm}$ .....	163
Figure 7.41: Overall transmittance of the wavelength of the solar radiation through the water film (Author). .....	165
Figure 7.42: Rainwater harvesting for forming the SGWF, not to scale (Author) .....	167

## LIST OF TABLES

Table 2.1: Monthly average of solar radiation and sunshine hours for Kuala Lumpur, Malaysia (Subang Jaya Meteorological Station throughout the years 2004 to 2008).....	15
Table 2.2: Hourly solar radiation (kW/m <sup>2</sup> ) for the longest and shortest days (average throughout the years 2004 to 2008, Subang Jaya Meteorological Station) .....	16
Table 2.3: Monthly sum of rainfall intensity for the year 2004 to 2008, recorded by the Subang Jaya Meteorological Station.....	17
Table 3.1: The Altitude and azimuth angles, 21st March, Kuala Lumpur, orientation 0.0° (source: Author by Sun-tool) .....	29
Table 3.2: Thermophysical properties of some building materials (Bansal, 1994b) .....	39
Table 3.3: The characteristics of glasses available in Malaysia, Pilkington products (MSG, 2009) .....	48
Table 3.4: Characteristics of low-e glass, imported to Malaysia. (MSG, 2009).....	48
Table 4.1: Energy consumption in the Malaysian buildings (%) (Zain-Ahmed, 2008)...	61
Table 4.2: Summary of GBI rating system (adapted from GBI( 2010) .....	63
Table 4.3: Summary of the passive solar control elements which are employed in the ST Diamond building .....	70
Table 5.1: Summarises the applications of water cooling for glazing in the buildings ..	94
Table 6.1: Restatement of research objectives and research questions.....	99
Table 6.2: The characteristics of glasses used in experiments (MSG, 2009) .....	106
Table 6.3: The control comparison design.....	114
Table 6.4: The one group pre-test - post-test design.....	115
Table 7.1: Heat transfer performance of 10mm Clear Glass (CG) with a thin film of water under the exposure to direct solar radiation .....	120
Table 7.2: Heat transfer performance of 10mm Tinted Glass (TG) with a thin film of water under the exposure to direct solar radiation .....	122
Table 7.3: The amount of the solar radiation transfer towards the interior of SCGWF as opposed to the CG facade .....	137
Table 7.4: The amount of the solar radiation transfer towards the interior of STGWF compared to TG facade .....	146
Table 7.5: The characteristics of the glasses used in the experiments.....	162
Table 7.6: The solar control parameters evaluated for the glazing types used in the experiment, following the system suggested by this study i.e. the SCGWF and STGWF .....	163



## **LIST OF APPENDICES**

Appendix A: Publications

Appendix B: Case Study

Appendix C: Instrumentation

Appendix D: Samples of Experiments Data

Appendix E: Experiments' Daily Progress Report

## LIST OF ABBREVIATIONS USED IN THE THESIS

SGWF	Sustainable-Glazed-Water-Film
CG	Clear Glass
TG	Tinted Glass
SCGWF	Sustainable Clear-Glazed-Water
STGWF	Sustainable Tinted-Glazed-Water-Film
f	Flow-rate
GBI	Green Building Index
IR	Infrared
SIR	Short wave infrared
LIR	Long wave infrared
UV	Ultra violet
VL	Visible light
I	Direct solar radiation intensity on the surface which is perpendicular to the incident direction of sunlight ( $W/m^2$ ),
$I_0$	Solar constant ( $W/m^2$ )
P	The atmospheric transparency
$h_s$	The solar altitude angle
$I^-$	The direct solar radiation intensity on the horizontal surface ( $W/m^2$ ).
$I^+$	The direct solar radiation intensity on the vertical surface ( $W/m^2$ )
SC	Shading coefficient
$SC_{SGWF}$	Shading coefficient of the SGWF facade
$SC_g$	Shading coefficient of the glazing
$SC_w$	Shading coefficient of the water film
$\alpha$	The glass absorption coefficient
$\tau$	The glass transmission coefficient
r	The glass reflection coefficient
SHGC	Solar heat gain coefficient
$N_i$	Inward-flowing fraction of absorbed radiation on the glazing
NFRC	National Fenestration Rating Council
$\tau_b$ ,	The transmittance of the reference glazing for direct beam radiation;
$\alpha_b$ ,	Absorptance of the reference glazing for direct beam radiation
$\tau_d$	Transmittance of the reference glazing for diffuse radiation
$\alpha_d$	Absorptance of the reference glazing for diffuse radiation
$D_h$	Hourly diffuse radiation on the plane of the horizontal glazing ( $W/m^2$ )
$H_h$	H direct beam radiation on the plane of the horizontal glazing ( $W/m^2$ )
$N_i$	Inward flowing fraction of the absorbed radiation
$I_v$	The sum of the hourly diffuse and reflected radiation on the plane of the vertical Glazing ( $W/m^2$ );
$G_v$	Measured hourly global radiation on the plane of the vertical glazing ( $W/m^2$ )
$H_v$	Hourly direct beam radiation on the plane of the vertical glazing ( $W/m^2$ ).
$\Delta t$	is temperature difference across the faces of the glass pane ( $^{\circ}C$ )
LSG	Light to Solar Gain Ratio
BEI	Building Energy Index
GBI	Malaysia's Green Building Index
BCA	Singapore Building and Constriction Authority Green Mark
X	The water film thickness
V	volume rate of the designed facade

## GLOSSARY

Beer–Lambert law	The absorbance and transmittance of light through a sample (glass) can be calculated by measuring light intensity entering and exiting the sample.
Fresnel’s law	When light moves from a medium of a given refractive index $n_1$ into a second medium with refractive index $n_2$ , both reflection and refraction of the light may occur. The Fresnel equations give the ratio of the reflected and transmitted electric field amplitude to initial electric field for electromagnetic radiation incident on a dielectric.
Heat island effect	The term "heat island" describes built up areas that are hotter than nearby rural areas. The “heat island effect” is a temperature phenomenon in which heat-absorbing buildings, especially those with dark roofs and non-reflective surfaces, release heat absorbed from sunlight into the surrounding atmosphere
Heat sink	Process, or region, in which energy is removed from the atmosphere in the form of heat.
Hydrophilic coat	Or “water loving coat”: a coat on glazing that significantly attracts water with a large adhesion force between the glass surface and the water.
Long-wave infrared	Starts at the spectrum of 3000nm and ends at the beginning of the microwave.
Long-wave radiation	Is a term used to describe the heat radiation with wavelengths greater 3000nm.
Reflection	a physical phenomenon in which a part of radiant energy falling on a body reflects off the body
Shortwave infrared	Is electromagnetic radiations emitted by the Sun with a wavelength longer than that of visible light, measured between 780nm and 3000nm.
Shortwave radiation	Is a term used to describe the radiant energy emitted by the Sun in the near-ultraviolet, visible light and near infrared wavelengths, between about 100nm and 3000nm.
Spectrally selective coating	Spectrally selective coatings are optically designed to reflect particular wavelengths but remain transparent to others. Such coatings are commonly used to reflect the infrared (heat) portion of the solar spectrum while admitting a higher portion of visible light.
Visible light	A part of the electromagnetic spectrum visible by a human eye. The term "visible light" typically refers to a wavelength range of 400 – 780nm, thus lying in the electromagnetic spectrum between the infrared waves and the ultraviolet waves.
Volume flow rate	Or rate of fluid flow: is the volume of fluid which passes through a given surface per unit time; for example cubic meters per hour ( $m^3 /h$ ).

## **ABSTRACT**

On the east and west orientations of the glazed buildings in the tropics where the solar altitude is low, the solar energy transmittance can not be effectively controlled by shading, except by blocking most of the glazed facades. Wherein, the daylight would be sacrificed. Based on this premise, to reduce the transmittance of solar energy without sacrificing daylight, the appropriate solution is the use of high performance insulated glazing system with spectrally selective coatings that distinguish between visible range (daylight) and infrared range (heat). Nevertheless, the drawback is its high capital cost.

This study seeks to improve the control of total solar energy transmittance by exploitation the potential of recycled elements in such tropical countries combined with low cost glazing. The study examines the effectiveness of Sustainable Glazed Water Film (SGWF) in reducing the solar heat transmittance and maximizing the solar light transmittance indoors.

The Malaysian climate and green-glazed buildings have been discussed to provide a direction to select the appropriate alternative solar control that copes with the east and west glazed facades in the tropical countries. SGWF was suggested as an alternative solar control and was numerically and experimentally investigated on glazed facades of west orientation, in the University of Malaya's campus. The experiments involved a study of three parameters namely: water flow rate, types of glazing, and the solar radiation intensity. The effect of water film thickness was also discussed. Two full-scale rooms were used, one as a reference room, with a fixed configuration, and the other as a test room, which could be configured in different ways.

It was found that the flowing water film on the glazed facades lowers the glazing surface temperature by 7.2 to 14°C (average) and absorbs a portion of the solar energy

thus resulting in a decrease in the indoor temperature by 2.2 to 4.1°C (average). On the other hand, although about 70% of the short infrared ranging between 1300nm and 2500nm are totally absorbed by the thin water film, the solar radiation transmittance behind the SGWF facade increased by 2% to 6.8% compared to the facade without water film. This is because the water film acts as an anti-reflective coat to transmit the entire visible light range hence reducing its reflection outwards compared to dry glass. It was concluded that the sustainable spectrally selective feature of the SGWF improved the performance of glazed buildings by reducing the solar heat (or infrared) transmittance and maximizing the solar light (or visible light) transmittance indoors.

From the study it can be summarised that significant energy could be saved by adopting the SGWF facade. It was observed that, (a) a reduction of 24.6% of the total energy cooling could be achieved as compared to an identical system without water film; (b) the reduction in glass surface temperatures contributed to the reduction of surrounding temperature (heat island effects) that affects the indoor environment; and (c) the increase in the visible light transmittance resulted in the reduction of the energy required for artificial lighting.

## **ABSTRAK**

Di orientasi timur dan barat bangunan-bangunan yang dipasang dengan kaca di negara-negara tropika di mana altitud solar adalah rendah, kepancaran tenaga solar tidak dapat dikawal dengan penggunaan pelindung, melainkan dengan menghalang sebahagian besar daripada permukaan kaca tersebut. Dengan ini, cahaya matahari dikorbankan. Berdasarkan premis ini, bagi mengurangkan kepancaran tenaga solar tanpa mengorbankan cahaya matahari, penyelesaian yang sesuai adalah penggunaan pemasangan kaca berprestasi tinggi dengan salutan selektif spectral yang membezakan antara ruang boleh dilihat (cahaya matahari) dan ruang inframerah (kepanasan). Walaubagaimanapun, kekurangannya adalah kos modal yang tinggi.

Kajian ini bertujuan untuk memperbaiki pengawalan kepancaran tenaga solar sepenuhnya dengan mengkaji potensi penggunaan elemen-elemen kitar semula di negara-negara tropika tersebut digabungkan dengan pemasangan kaca berkos rendah. Kajian ini mengkaji keberkesanan filem air berkaca yang mampan (SGWF) dalam mengurangkan kepancaran kepanasan solar dan memaksimumkan kepancaran cahaya solar di dalam bangunan.

Cuaca Malaysia dan bangunan-bangunan yang dipasang dengan kaca hijau telah dibincangkan dapat mengemukakan arah tujuan untuk memilih alternatif pengawalan solar yang sesuai dan berpatutan dengan hala permukaan kaca tersebut di timur dan barat di negara-negara tropika tersebut. SGWF telah dicadangkan sebagai pengawalan solar alternatif dan telah diujikaji secara bilangan dan melalui eksperimen terhadap permukaan berkaca berorientasikan barat, di kampus Universiti Malaya. Ujikaji-ujikaji tersebut membabitkan tiga parameter iaitu: kadar pengaliran air, jenis pemasangan kaca, dan kepadatan radiasi solar. Kesan ketebalan filem air juga dibincangkan. Dua bilik berskala penuh telah digunakan, satu sebagai bilik rujukan, dengan konfigurasi yang

tetap, dan satu lagi bilik sebagai bilik ujian, yang boleh dikonfigurasi dengan cara berlainan.

Hasil mendapati bahawa pengaliran filem air terhadap permukaan kaca merendahkan suhu permukaan kaca sebanyak 7.2 sehingga 14°C (secara purata) dan menyerap sebahagian daripada tenaga solar dan menyebabkan penurunan suhu di dalam bangunan sebanyak 2.2 sehingga 4.1°C (secara purata). Selain itu, walaupun hampir 70% daripada inframerah pendek sekitar antara 1300nm dan 2500nm telah diserap sepenuhnya oleh filem air nipis, kepancaran radiasi solar di sebalik permukaan SGWF naik sebanyak 2 sehingga 6.8% berbanding dengan permukaan tanpa filem air. Ini adalah kerana filem air bertindak sebagai salutan anti-reflektif bagi memancarkan keseluruhan ruang cahaya boleh dilihat selanjutnya menurunkan refleksinya ke luar berbanding kaca kering. Telah disimpulkan bahawa sifat selektif spektral mampan SGWF tersebut telah memperbaiki persembahan bangunan-bangunan yang mempunyai permukaan kaca dengan menurunkan kepancaran kepanasan solar (atau inframerah) dan memaksimumkan kepancaran cahaya solar (atau cahaya boleh dilihat) di dalam bangunan.

Daripada kajian ini, dapat disimpulkan bahawa jumlah tenaga yang signifikan boleh diijamatkan dengan menggunakan permukaan SGWF. Dapat diperhatikan bahawa, (a) pengurangan sebanyak 24.6% daripada keseluruhan penyejukan tenaga dapat dicapai berbanding dengan system yang sama tanpa filem air; (b) pengurangan suhu permukaan kaca telah menyumbang kepada pengurangan suhu sekeliling (kesan pulau kepanasan) yang member kesan kepada persekitaran dalaman; dan (c) menaikkan kepancaran cahaya boleh dilihat yang menghasilkan pengurangan tenaga yang diperlukan untuk pencahayaan palsu.