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

ABDULTAWAB MOHAMMED QAHTAN

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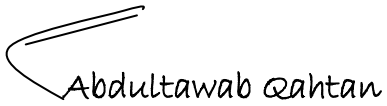
This thesis dedicated to the **Martyrs Souls** …

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.



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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).
$I^\perp$	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
α	The glass absorption coefficient
τ	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
τ_b,	The transmittance of the reference glazing for direct beam radiation;
α_b,	Absorptance of the reference glazing for direct beam radiation
τ_d	Transmittance of the reference glazing for diffuse radiation
α_d	Absorptance of the reference glazing for diffuse radiation
D_h	Hourly diffuse radiation on the plane of the horizontal glazing (W/m2
H_h	H direct beam radiation on the plane of the horizontal glazing (W/m2
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/m2);
G_v	Measured hourly global radiation on the plane of the vertical glazing (W/m2)
H_v	Hourly direct beam radiation on the plane of the vertical glazing (W/m2).
Δt	is temperature difference across the faces of the glass pane (°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 n1 into a second medium with refractive index n2, 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 (m3 /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 memaksimakan 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 dikonfigurasikan 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 inframereah 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 memaksimakan kepancaran cahaya solar (atau cahaya boleh dilihat) di dalam bangunan.

Daripada kajian ini, dapat disimpulkan bahawa jumlah tenaga yang signifikan boleh dijimatkan 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 pengcahayaan palsu.