Energy Saving Potential of Thermal Broken Fenestration System in Hot Climate Counties

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ABSTRACT

The unprecedented volatility in energy prices of the last few years and rising global warming problems, has led the topic of "Energy Conservation" to become the most important and relevant topic worldwide. Building, Industrial and Transportation are the three major sectors contributing to the energy consumption globally. Building energy accounts for more than one third of the global consumption and thus, many countries take top priority in increasing the building energy efficiency.

Hong Kong is located in southern China with typical maritime subtropical climate. The long summer begins from April till October with hot and humid weather conditions, with occasional tropical typhoons. Temperatures in the afternoon are usually hottest, especially in July and August with an average temperature higher than 31°C, while it could be as high as 33°C in the New Territories. In addition, Hong Kong as a metropolitan city, with a high density of high-rise buildings, is affected by the heat island effect.

With greater awareness in building energy efficiency and green building codes, there is a rise in demand for high-performance window systems. However, the common fenestration systems used in Hong Kong combines high-performance glazing with non-thermal insulated frames. Such design combination results in a significantly lower overall thermal performance of a window system.

In this paper, we investigate how the thermal transmittance of frames (U_f value) has a direct influence on solar heat gain of fenestration system with a experimental and simulation analysis to understand the importance of using high performance fenestration system with low U_f value in tropical and sub-tropical countries such as Hong Kong.

Keywords: *U value, solar heat gain coefficient SHGC: overall thermal transfer value OTTV*

1. INTRODUCTION

1.1. Background

With the rapid economic development and increasing quality of living, Hong Kong's construction industry has developed rapidly and a comfortable living environment is essential to meeting the people's increasing demand for better living conditions.

Hong Kong is located in the South China region and is connected with mainland China in the northern part of the island, while the south faces in the direction of the South China Sea. Summer are hot and humid with temperature between 27 ~ 33°C with typical subtropical monsoons; winter are cool and dry, but rarely falls below 5°C. Hong Kong is a cosmopolitan city with the world's third highest population density. Crowded commercial and residential high-rise buildings form Hong Kong's urban landscape. This is a reason for the urban heat island effect.

In cities like Hong Kong, with a long period of high temperature. Building energy consumption accounts for more than 90% of the total energy consumption. Improvements should be made on the thermal performance of building envelope, thereby reducing the building air conditioning load, achieving better building energy efficiency.

At present, the OTTV is the only mandatory criteria to evaluate the thermal performance of building envelope; this evaluation includes the thermal transmission through the opaque walls and roofs, and the solar radiation through the window glass.

In the sub-tropical and tropical climatic regions, building envelope is constantly exposed to solar irradiation all year round. The traditional method of improving the thermal performance of fenestration is by adding a shading system to prevent sunlight from passing through the glazing, thereby reducing the solar heat gain through the fenestration.

However, building designer tends to neglect the solar heat gain effects through the overall fenestration system in the building envelope.

In this paper, we will find out how the solar heat gain coefficient SHGC is directly influenced by the Uf value of the fenestration system's opaque frames and how the thermal performance of building envelope can be effectively improved by the thermal broken aluminium fenestration system.

1.2. Concept of OTTV and development

The OTTV (Overall Thermal Transfer Value) concept was introduced by the US in the 70's. It was widely used to measure the thermal performance of building in Asia Pacific countries, and Hong Kong is one of them. According the "Code of Practice for Overall Thermal Transfer Value in Building 1995", the OTTV calculation equation is

$$OTTV = (Aw \times U \times \alpha \times TDeqDw) + (Afw \times SC \times ESM \times SF)/ Aow$$

Equation 1

The formula considers the heat gain through the opaque wall and roof, as well as the solar radiation through the glazing. However, it ignores the conductivity and solar heat gain effects from the fenestration system's frame.

Singapore is another Asia country which has implemented the OTTV concept and the country later modified it as ETTV (envelope thermal transfer value, the calculation equation is:

$$ETTV = 12 (1- WWR)Uw+3.4(WWR)U+ 211(WWR)(CF)SC$$

Equation 2

The formula considers three key criteria, the heat gain through the opaque wall, heat gain through the windows and solar radiation through the glazing. Basic concept is similar to OTTV's but the TDeq (annual equivalent temperature difference) and SF (annual equivalent solar factor) are simulated by actual climate condition.

The weather conditions and humidity levels between Singapore and Hong Kong are similar. Therefore, the experimental results for thermal broken fenestration system could give significance reference to Hong Kong.

2. ALUMINIUM PROFILES HEAT GAIN

2.1 Solar heat gain coefficient

With reference to the ETTV equation, we assume a room with a window wall ratio of 1 (window only, without opaque wall), and CF=1 (based on south-east facing vertical window), the ETTV equation can be expressed as:

$$ETTV=3.4U+211SC$$

Equation 3

From the above equation (3), it can be illustrated that the thermal transmittance of the window (U value) has a less significant influence to the ETTV than compared to the shading coefficient SC value. Based on this concept, it is understandable why building designers are more concerned with the SC value of the fenestration in hot climate areas. With this design concept, energy-saving windows and doors designs with low U-values are not often considered as an important design parameter.

In fact, there is a big misconception of designs taking into consideration only the SC values. The SHGC solar heat gain coefficient, also known as solar radiation admitted through a window, is the fraction of the solar radiation heat passing through the window. The SHGC includes two parts; solar radiation heat entering directly through the glass and the heat gain through the window frame component which absorbs and re-radiate inwards.

At present, both Hong Kong and Singapore both assumes that the U value and SC value of a window system is equal to the U value and SC value of the center-of-glazing. However, consideration of the solar heat gain through the window frames should be accounted for in evaluating the energy performance of the building. This can be done by converting the equation's SC value to SHGC value by dividing the SC value by a factor of 0.87.

2.2 Frames sample test

The following is a test conducted by Solar Energy Research Institute of Singapore (SERIS) to analyse the solar radiation absorption by the window frames and re-radiation inwards as a heat gain. Figure 1 is the actual test site, with its façade facing west and it is not shaded by trees or other structures. The room is air-conditioned during typical office hours. 10 aluminium profile samples with different colour and performance (with thermal break or without thermal break) were placed into the window opening as shown in Figure 2 and Table 1. All test samples are monitored by the many sensors located in the test facility, recording in 2 seconds intervals, and the data are then stored in the computer.

Figure 1: Test site

Figure 2: Aluminium profile samples

1	No thermal break, light color	AL_LC	2	No thermal break, dark color	AL_DC
3	With low performance thermal break, light color	TBL_LC	4	With low performance thermal break, dark color	TBL_DC
5	With moderate performance thermal break, light color	TBM_LC	6	With moderate performance thermal break, dark color	TBM_DC
7	With high performance thermal break, light color	TBH_LC	8	With high performance thermal break, dark color	TBH_DC
9	No thermal break, light color		10	No thermal break, dark color	

Table 1: Aluminium profile samples for testing

Figure 3 shows on a representative day during 14:00-18:00 hours, with solar radiation intensity being highest in the day. Outdoor air temperature was up to 38°C, while the indoor temperature maintained stable at 22-23°C by air-conditioning. Figure 4 shows the heat flux through the black aluminium non-thermally broken sample is the highest, with more than 400W/m², much higher than the light coloured high-performance thermal break aluminium samples which recorded a low heat flux of 60W/m².

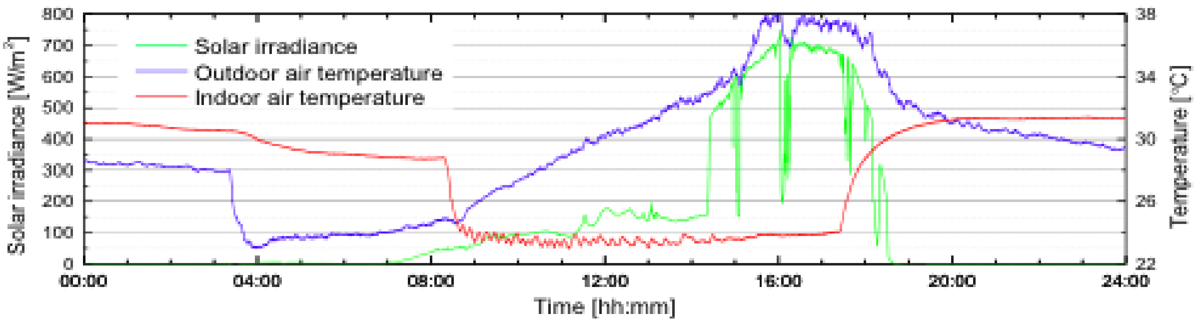

Figure 3: Solar irradiance and indoor/ outdoor air temperature

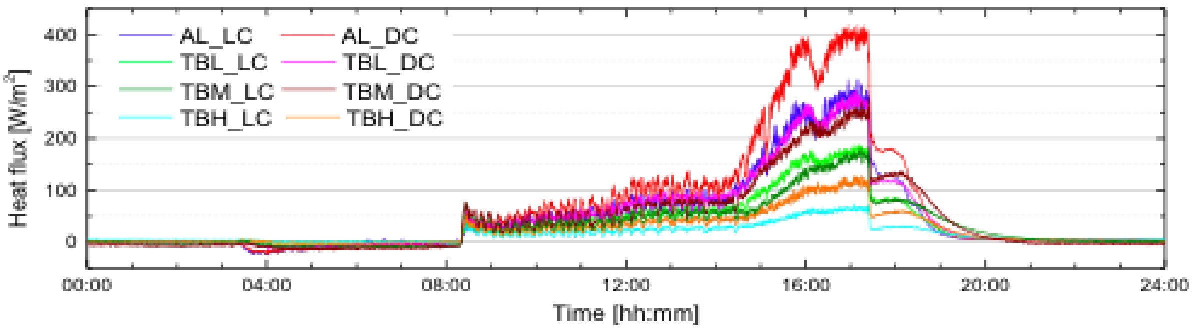

Figure 4: Heat flux through frame samples

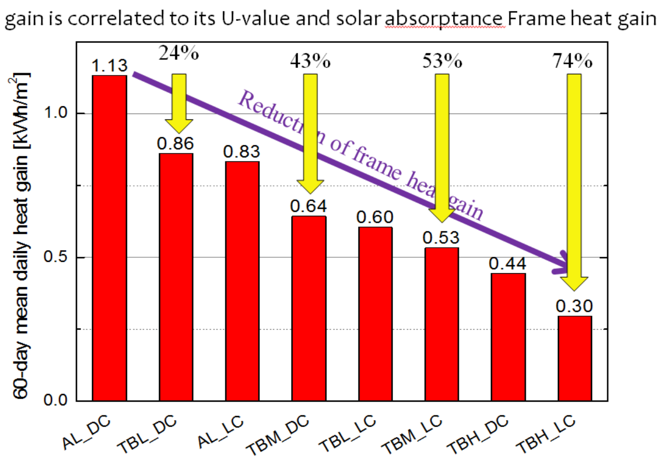

Figure 5: 60-day mean daily heat gain [kWh/m²]

By comparing the average daily heat of the non-thermal broken aluminium profiles in black colour with other thermally broken profiles, we could find that by using light-colour high-performance thermal broken profile the heat gain could reduce by 74%, relating to 0.83kWh/m².

This experiment proves that the solar radiation could be re-radiated to the interior through the absorption by the aluminium profiles. It is also affected by the surface colour and the thermal transmittance value of the profiles. The darker the surface colour, more solar radiation is being absorbed. The higher the thermal transmittance value of the profile, more heat flux per unit are, therefore more heat is transferred from the outside to the inside.

2.3 The relationship between U value and SHGC

In general, like Singapore, the SHGC only considers the centre-of-glazing and is then used to calculate the ETTV. But with reference to ISO 15099, NFRC200 or JGJ/T 151-2008, the solar heat gain coefficient of the frame is:

$$g_f = \alpha_f \cdot \frac{U_f}{\frac{A_{surf}}{Af} \cdot h_{out}}$$

Equation 4

And the SHGC of the whole curtain wall is:

$$g_{cw} = \frac{\sum g_g A_g + g_p A_p + g_f A_f}{A}$$

Equation 5

The above equation shows that the SHGC of the curtain wall is obtained by the area weighted average method of the solar heat gain from the frame, glass and the opaque panel.

After the conversion between shading coefficient SC and SHGC value, it can be substituted into the ETTV formula to calculate the thermal performance of the building envelope. The above formula shows that the U value and the shading coefficient were directly correlated, in the calculation process, the solar heat gain of the window frame is very important.

3. HIGH PERFORMANCE THERMAL BROKEN WINDOWS

3.1 Simulation analysis

By using the simulation software THERM, calculation of the U value of non-thermal broken aluminium profiles, thermal broken aluminium profiles and Passive Window profiles was done. We further substituted it into equation (4) to obtain the SHGC results as below:

	Non- Thermal Broken Aluminium Profile	**Thermally Broken Aluminium Profile**	**Passive Window Profile**
Uf value (W/m²K)	**6.96**	**2.02**	1.13
SHGC	0.18	0.05	0.03

Table 2: SHGC of different aluminium profiles

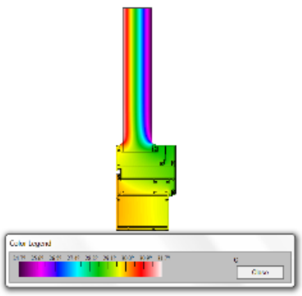

Figure 6: Non-thermal broken

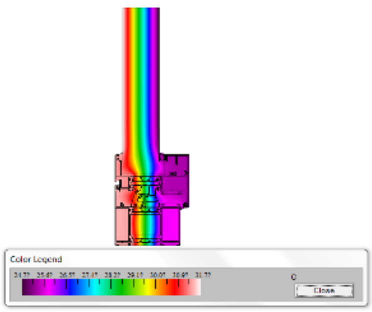

Figure 7: Thermal broken

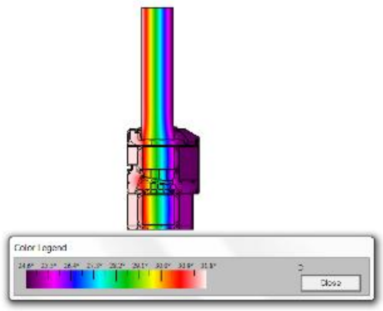

Figure 8: Passive window

The Uf value of non-thermal broken profile is 6.96 W/m²K and the SHGC is 0.18, while the Uf value of thermal broken profile is 2.02 W/m²K, the SHGC is 0.05, the Uf value is reduced by 71% and the SHGC is reduced by 72%. Similarly, the use of Passive windows, compared with the non-thermal broken profiles, Uf values and SHGC can be large reduced by 84% and 83% respectively.

3.2 Thermal performance of different windows

Below we evaluate the possible reduction of heat gain by high performance thermal broken windows. We assumed that other parameters of the windows are fixed, with a the glass to frame ratio is 75%, and with a single open sash.

	Non-thermal Broken Window	Thermal Broken Window	Passive Window
Project Area of the Frame Af	0.5m²		
Project Area of the Glass Ag	1.5m²		
Project Area of whole Window Aw	2.0m²		
Perimeter of glass vision area, lg	4.5m		
Glass Frame ratio	75%		
Solar absorptance of the outside the Frame Surface α_f	0.7		
Outdoor surface heat transfer coefficient h_{ex}	22W/(m²K)		
Frame Outside Area (m²) Frame Projected Area (m²) Asurf/Af	1.2		
U value of Glass	1.6W/(m²K)		
SHGC value of the glass	0.35		

Linear Thermal Transmittance ψ_g	0.05 W/(mK)	0.11 W/(mK)	0.11 W/(mK)
U Value of the Frame	6.96 W/(m²K)	2.02 W/(m²K)	1.13 W/(m²K)
SHGC Value of the Frame	0.18	0.05	0.03
U Value of the Window Uw	3.05 W/(m²K)	1.95 W/(m²K)	1.73 W/(m²K)
SHGC Value of the Window	0.31	0.28	0.27
ETTV (WWR=1， CF=1)	85.6 W/m²	74.5 W/m²	71.4 W/m²

Table 3: Parameter table of different windows

By the using the same SHGC glass, the results illustrated the following:

1. The SHGC value of window could show reductions of 9.7% and 12.9% by using thermally broken profile and Passive window profile respectively;

2. The ETTV of window could show reductions of 13.0% and 16.6% by using thermally broken profile and Passive window profile respectively.

The above results show that the window frame U value is closely related to the overall thermal performance of a window system. The use of thermal broken aluminium window can reduce the overall envelope heat gain more than 10%. With rational choice of window frame, reasonable configuration, the high performance thermal broken window can achieve the desired energy saving effect for the building.

4. CONCLUSION

The comparison shows that the U value of the window frame is an important factor in influencing the shading coefficient and the solar heat gain of the building envelope.

Today building energy consumption is the major part of Hong Kong total energy consumption and is increasing annually. However, awareness of building energy efficiency is low, while the concept of energy conservation is relatively weak. The primary task of reducing energy consumption can be achieved by increasing the energy efficiency of buildings; and we can start by improving the building envelope thermal performance.

Window frames, although only a small part of doors and windows, contributes significantly to the overall thermal performance of a window. High performance thermally broken window systems can effectively reduce the heat gain through the fenestration and thus reduce the energy consumption of the entire envelope to achieve the desired energy saving effect.

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