Investigating the Effectiveness of Self-Shading Strategy on Overall Thermal Transfer Value and Window Size in High Rise Buildings

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Abstract-So much energy is used in high rise buildings to fulfill the basic needs of users such as lighting and thermal comfort. Malaysia has hot and humid climate, buildings especially high rise buildings receive unnecessary solar radiation that cause more solar heat gain. Energy use specially electricity consumption in high rise buildings has increased. There have been growing concerns about energy consumption and its effect on environment. Building, energy and the environment are important issues that the designers should consider to them. Self protected form is one of possible ways against the impact of solar radiation in high rise buildings. The Energy performance of building envelopes was investigated in term of the Overall Thermal Transfer Value (OTTV). In this paper, the amount of OTTV reduction was calculated through OTTV Equations to clear the effectiveness of self shading strategy on minimizing energy consumption for cooling interior spaces in high rise buildings which has considerable envelope areas against solar radiation. Also increasing the optimum window area was investigated using self-shading strategy in designing high rise buildings. As result, the significant reduction in OTTV was shown based on WWR.In addition slight increase was demonstrated in WWR that can influence on visible comfort interior spaces.

Keywords—Self-shading strategy, high rise buildings, Overall thermal transfer value (OTTV), Window to wall ratio (WWR).

I. INTRODUCTION

E NERGY performance of the building envelopes was investigated in terms of the overall thermal transfer value (OTTV). Window area was represented by the window-towall ratio (WWR), defined as the ratio of the total area of windows to the overall gross external walls area. The main cooling load component is solar heat and the design of variables affecting on the building envelope which are shading coefficient and window area [1].

The OTTV is basically a measure of the heat transfer from outside to the indoor environment through external envelope of a building. Solar heat gain through fenestration is considered as the largest provider to building envelope cooling load and the most important parameter for OTTV determinations [2].

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Manuscript received December 31, 2010; revised January 31, 2011.

One way to reduce electricity consumption would be to limit heat gain into the buildings, and hence reduce the demand for air-conditioning during hot summer months. Key factors affecting heat gain through building envelopes into the buildings, are building orientation, exterior wall area and its construction type (i.e. thermal insulation and U-value) and surface finish (wall absorption coefficient), window area, glass type (U-value and shading coefficient), external shading, and roof area and its construction details [1].

One way to reduce the cooling requirement would be to have more energy-efficient building envelope (walls, windows and the roof) designs so that the amount of heat gains coming into the building interior could be limited.

A. Overall Thermal Transfer Value (OTTV) According to ASHRAE 90A- 1980.

The OTTV concept was introduced in the ASHRAE Standard 90A- 1980. OTTV shows the average heat gain through the building envelope. Smaller OTTV cause less energy consumption for cooling. Three components of the heat gain are considered, namely conduction through an opaque surface, conduction through glass window and solar radiation through glass window. The general OTTV equation can be expressed as [3].

$$OTTV_i = (Q_w + Q_g + Q_s)/A_i = [(A_w \times U_w \times TD_e q) + (A_f \times U_f \times DT) + (A_f \times SC \times SF)]/A_i$$

- A_f is the area of fenestration (m^2) ;
- A_i , the gross area of the walls $(m^2) = A_w + A_f$;
- A_w , the area of opaque wall (m^2) ;

DT, the temperature difference between exterior and interior design conditions (C);

- Q_g , the heat conduction through glass windows (W);
- Q_s , the solar radiation through glass windows (W);

 Q_w , the heat conduction through opaque walls (W);

- SC, the shading coefficient (dimensionless);
- SF, the solar factor (W/m2);

 TD_eq , the equivalent temperature difference (C);

 U_f , the U-value of fenestration (W/m2K);

 U_w , the U-value of opaque wall (W/m2K).

This equation can be expressed in terms of window-to-wall ratio, WWR. Thus

$$OTTV_i = [(1 - WWR) \times TD_e q \times U_w] + [(WWR) \times DT \times (U_f)] + [(WWR) \times SC \times SF]$$

Where, WWR is the ratio of window area to gross wall $area = A_f/A_i$. As walls at different orientations receive different amounts of solar radiation, the general procedure is to calculate the $OTTV_s$ of individual walls with the same orientation and construction first

 $OTTV_{wall} = [A_1 \times OTTV_1 + A_2 \times OTTV_2 + ... + A_n \times OTTV_n]/A_t w$ Where,

 $OTTV_{wall}$ is the OTTV of the whole exterior wall (W/m^2) and

 $A_t w = S(A_i) =$ total gross exterior wall area (m^2) [3].

It has been shown that among the three components of heat gain in the OTTV equation, solar radiation through the fenestration is the most significant [2]. The building variables controlling solar heat gain are SC and window-to-wall ratio (WWR), which are two parameters in the OTTVcalculation. Large WWR means high Q_q and low Q_w , and vice-versa. More solar heat gain contributes to more cooling requirements and hence larger air-conditioning plants for buildings [4]. Higher solar heat gain, however, could also mean more daylight available for a day lighting scheme [5]. One way to reduce electricity consumption would be to limit heat gain into the buildings, and hence reduce the demand for air-conditioning during hot summer months. Key factors affecting heat gain through building envelopes into the buildings included building orientation, exterior wall area and its construction type (i.e. thermal insulation and U-value) and surface finish (wall absorption coefficient), window area, glass type (U-value and shading coefficient), external shading, and roof area and its construction details [6].

B. Concept of OTTV According to Malaysian Standard 1525:2007

The solar heat gain through the building envelope constitutes an important part in cooling load in an airconditioned building. Solar heat gain into a building is a very important consideration in the design of an energy efficient building. The overall thermal transfer value (OTTV) is an indicator for envelope energy efficiency. The purpose of OTTV is to obtain the design of building envelope to reduce external heat gain and hence reduce the cooling load of the air-conditioning system. The OTTV of the building envelope for a building, having a total air-conditioned area exceeding $4000m^2$ and above should not exceed $50W/m^2$.

The OTTV of building envelope is given by the formula below [7]:

 $OTTV = [A_1 \times OTTV_1 + A_2 \times OTTV_2 + \dots + A_n \times OTTV_n]/[A_1 + A_2 + \dots + A_n]$

Where, A_i is the gross exterior wall area for orientation i; and

 $0TTV_i$ is the OTTV value for orientation i from below equation.

For a fenestration at a given orientation, the formula is given as below:

TABLE I Solar Correction Factor

CF
0.90
1.09
1.23
1.13
0.92
0.90
0.94
0.90

 $OTTV_i = 15 \times a \times (1 - WWR) \times U_w + 6 \times (WWR) \times U_f + (194 \times CF \times WWR \times SC)$

Where,

WWR is the window-to-gross exterior wall area ratio for the orientation under consideration;

 U_w is the thermal transmittance of opaque wall (W/m^2K) ;

 U_f is the thermal transmittance of fenestration system (W/m^2K) ;

CF is the solar correction factor [7];

Table 1 specifies CF for the various orientation of the fenestration. For the calculation of CF, It is recommended that the nearest predominant orientation be selected. Also a fenestration system may consist of a glazing material such as glass, a shading device and a combination of bothÅccoring to MS1525:2007 table 1 is based on updated (2006) data to match with the current test reference year (TRY) weather data for Kuala Lumpur. Data collected indicates that the average vertical East surface solar radiation is significantly higher than the vertical West surface. This trend is seen to be caused by the normally clear sky in the morning and cloudy sky in the afternoon.

SC is the shading coefficient of the fenestration system [7].

1) Shading Coefficient: The shading coefficient of a shading system is the product of the shading coefficients of its sub-systems, for example

$$SC = SC_1 \times SC_2$$

Where,SC is the effective shading coefficient of the fenestration system;

 SC_1 is the shading coefficient of sub-system 1 (e.g. glass); and

 SC_2 is the shading coefficient of sub-system 2 (e.g. external shading devices)

The shading coefficient for glass is the value assessed at an incident angle of 45 to the normal.

The shading coefficient of external shading devices can be obtained from table 2.

R1 in Table 2 is the ratio that is defined as the ratio of width of horizontal projection per height of fenestration.

C. Effective Factors on Energy Use in High Rise Buildings

The OTTV and day lighting are two parameters that control building energy use [1]. Chirarattanam (1996) assessed lighting and cooling-energy performance of a building envelope.

International Journal of Architectural, Civil and Construction Sciences ISSN: 2415-1734 Vol:5, No:2, 2011

TABLE II Shading coefficient of horizontal projections

Ratio(R1)	Orientation	Shading Coefficient(SC)
0.3 - 0.4	North/South	0.77
0.3 - 0.4	East	0.77
0.3 - 0.4	West	0.79
0.3 - 0.4	Northeast/Southeast	0.77
0.3 - 0.4	Northwest/Southwest	0.79
0.5 - 0.7	North/South	0.71
0.5 - 0.7	East	0.68
0.5 - 0.7	West	0.71
0.5 - 0.7	Northeast/Southeast	0.69
0.5 - 0.7	Northwest/Southwest	0.72
0.8 - 1.20	North/South	0.67
0.8 - 1.20	East	0.60
0.8 - 1.20	West	0.65
0.8 - 1.20	Northeast/Southeast	0.63
0.8 - 1.20	Northwest/Southwest	0.66
1.30 - 2.00	North/South	0.65
1.30 - 2.00	East	0.55
1.30 - 2.00	West	0.61
1.30 - 2.00	Northeast/Southeast	0.60
1.30 - 2.00	Northwest/Southwest	0.63

By choosing appropriate envelope parameters such as the WWR, optimum performance can be achieved [8]. Building and volume have important factors on energy efficiency. Building with larger floor space is smaller energy efficiency. Larger volume buildings tend to be more efficiency. Taller and narrower buildings are more energy efficient [9]. According to Capeluto (2002) self shading geometry forms provide the best solution for improvement energy performance in buildings [10]. According to Lam (2005) the amount of heat coming through the building envelope is proportional the total gross exterior wall area [1]. Ling (2007) revealed that vertical wall in high rise buildings received 86.6 percent of the annual solar insolation [11]. Self-protected form is one of possible ways against the impact of solar radiation in high rise buildings [10]. Self-shading building envelopes are suggested for solar prevention cite11. It's clear that self-shading strategies reduce solar insolation on vertical surfaces. Ling (2005) identified optimum self-shading projection ratio for high rise building in Malaysia (figure1) [11]. Lam (2005) indicated that important factors can effect on OTTV are WWR and shading coefficient and U-Values for the opaque walls and windows [1]. WWR and shading coefficient are the most important variables on solar radiation for most of the building envelope heat gain [6].

II. METHODOLOGY

This paper identified the amount of OTTV reduction in self-shaded high rise buildings in comparison with other high rise buildings with no shading strategies through OTTVcalculation to clear the effectiveness of self shading strategy on minimizing energy consumption for cooling interior spaces in high rise buildings which has considerable envelope areas against solar radiation. Also increasing the optimum window area was investigated using self-shading strategy in designing high rise buildings. According to Malaysian standard 1525:2007 In the second calculation process the amount of OTTV was considered fixed then the optimum ratio of WWR



Fig. 1. Self-shaded high rise building

was recalculated due to previous WWR optimization that is identified by Zain-Ahmed et al (1998).

III. FINDING AND DISCUSSION

A. OTTV Reduction Determination

To calculate the amount of OTTV reduction in each orientation OTTV equation was used.

$$OTTV = 15 \times a \times [(1 - WWR) \times U_w] + [6 \times (WWR) \times U_f] + [194 \times (CF) \times (WWR) \times (SC)]$$

According to Malaysian standard 1525:2007, the amounts of (CF) s solar correction factors for each orientation is given. Therefore CFs for different orientations are as follow: CF for North and south is 0.9.also CFs for East and West orientation are considered 1.23 and 0.94 respectively. SC (shading coefficient) for building that has no shading device equal to 1. Also according to ASHRAE 2005,

SHGC for 3mm clear glass is 0.87.

 $SHGC = 0.87 \times (SC)$

therefore with consideration both Malaysian Standard 1525:2007 and ASHRAE 2005, for those buildings that has no shading devices such as horizontal, vertical devices and egg-crates louvers, SC equal to 1.

that

Projecting floors in self shading buildings act as horizontal shading devices. According to Malaysian standard shading coefficients of horizontal projection depends on the ratio which is defined the width of horizontal projection per height of fenestration. For this case the ratio is 1.Therefore according to table 2, SC for North and South orientation equal to 0.67 and for East and West orientations were considered 0.60 and 0.65 respectively. For calculating the magnitude of OTTV reduction in self shading buildings, other parameters (like Absorptivity of opaque wall, U_w and U_f) were considered fixed to clear the effectiveness of self shading buildings on OTTV reduction. However these parameters are crucial but in this research were considered the same. Therefore

these parameters can be omitted in the calculation process. The ratio WWR was kept parametrically in the calculation process because the amount of reduction in OTTV depends on the WWR. Therefore the amount of OTTV reduction is a function of WWR. Where OTTV is OTTV for entire building envelope that has no shading strategy

and $OTTV_{ss}$ is OTTV for entire building envelope in self-shaded building.

The differences between OTTV and $OTTV_{ss}$ identified the amount of OTTV reduction in entire To calculate the amount of OTTV reduction, OTTV was calculated for two conditions with different SC for each direction. For example for North orientation;

 $OTTV_n = 15 \times a \times (1 - WWR) \times U_w + 6 \times (WWR) \times U_f + (194 \times 0.9 \times WWR \times 1)$

 $OTTV_{ssn} = 15 \times a \times (1 - WWR) \times U_w + 6 \times (WWR) \times U_f + (194 \times 0.9 \times WWR \times 0.67)$

Where $OTTV_n$ is OTTV for North orientation for building that has no shading strategy

and $OTTV_{ssn}$ is OTTV for North orientation of self-shaded building.

The differences between $OTTV_n$ and $OTTV_{ssn}$ identified the amount of OTTV reduction in North orientation with using self-shaded strategy in designing. Therefore;

 $OTTV_n - OTTV_{ssn} = (194 \times 0.9 \times WWR \times 1) - (194 \times 0.9 \times WWR \times 0.67)$

 $OTTV_n - OTTV_{ssn} = 57.61 \times WWR$

Also for other orientation the amounts of *OTTV* reduction are as follow:

For South orientation CF = 0.92 therefore;

 $OTTV_s = 15 \times a \times (1 - WWR) \times U_w + 6 \times (WWR) \times U_f + (194 \times 0.92 \times WWR \times 1)$

 $OTTV_{sss} = 15 \times a \times (1 - WWR) \times U_w + 6 \times (WWR) \times U_f + (194 \times 0.92 \times WWR \times 0.67)$

Where $OTTV_s$ is OTTV for South orientation for building that has no shading strategy.

and $OTTV_{sss}$ is OTTV for South orientation of self-shaded building.

The differences between $OTTV_s$ and $OTTV_{sss}$ identified the amount of OTTV reduction in South orientation with using self-shaded strategy in designing. Therefore

 $OTTV_s - OTTV_{sss} = (194 \times 0.92 \times WWR \times 1) - (194 \times 0.92 \times WWR \times 0.67)$

$$OTTV_s - OTTV_{sss} = 58.89 \times WWR$$

For East orientation CF = 1.23 therefore;

 $OTTV_e = 15 \times a \times (1 - WWR) \times U_w + 6(WWR) \times U_f + (194 \times 1.23 \times WWR \times 1)$

 $OTTV_{sse} = 15 \times a \times (1 - WWR) \times U_w + 6(WWR)U_f + (194 \times 1.23 \times WWR \times 0.60)$

Where $OTTV_e$ is OTTV for East orientation for building that has no shading strategy

and $OTTV_{sse}$ is OTTV for East orientation of self-shaded building.

The differences between $OTTV_e$ and $OTTV_{sse}$ identified the amount of OTTV reduction in East orientation with using self-shaded strategy in designing. Therefore

 $OTTV_e - OTTV_{sse} = (194 \times 1.23 \times WWR \times 1) - (194 \times 1.23 \times WWR \times 0.60)$

$$OTTV_e - OTTV_{sse} = 95.44 \times WWR$$

For West orientation CF = 0.94 therefore;

 $OTTV_w = 15 \times a \times (1 - WWR) \times U_w + 6 \times (WWR) \times U_f + (194 \times 0.94 \times WWR \times 1)$

 $OTTV_{ssw} = 15 \times a \times (1 - WWR) \times U_w + 6 \times (WWR) \times U_f + (194 \times 0.94 \times WWR \times 0.65)$

Where $OTTV_w$ is OTTV for West orientation for building that has no shading strategy

and $OTTV_{ssw}$ is OTTV for West orientation of self-shaded building.

The differences between $OTTV_w$ and $OTTV_{ssw}$ identified the amount of OTTV reduction in West orientation with using self-shaded strategy in designing. Therefore;

$$OTTV_w - OTTV_{ssw} = (194 \times 0.94 \times WWR \times 1) - (194 \times 0.94 \times WWR \times 0.65)$$

$$OTTV_w - OTTV_{ssw} = 63.82 \times WWR$$

For calculating the amount of OTTV reduction for whole building, OTTV for whole of building was calculated for two conditions. And then difference between two condition was investigated . for simplifying the result, the envelope areas for two condition and for each orientation were considered equal. Therefore $A_n = A_s = A_e = A_w = A$, Then

$$OTTV = [A_1 \times OTTV_1 + A_2 \times OTTV_2 + \dots + A_n \times OTTV_n]/[A_1 + A_2 + \dots + A_n]$$

$$OTTV = [(A \times OTTV_n) + (A \times OTTV_s) + (A \times OTTV_e) + (A \times OTTV_w)]/(A + A + A + A)$$

$$OTTV_{ss} = [(A \times OTTV_{ssn}) + (A \times OTTV_{sss}) + (A \times OTTV_{sse}) + (A \times OTTV_{ssw})]/(A + A + A + A)$$

Where OTTV is OTTV for entire building that has no shading strategy

TABLE III Reduction the amount of OTTVs in different orientation and whole building with using self-shading strategy

Orientation	OTTV Reduction
North	$57.61 \times WWR$
South	$58.89 \times WWR$
East	$95.44 \times WWR$
West	$63.82 \times WWR$
Whole Building	$68.94 \times WWR$

and $OTTV_{ss}$ is OTTV for entire of self-shaded building. The differences between OTTV and $OTTV_{ss}$ identified the amount of OTTV reduction in building with using self-shaded strategy in designing. Therefore;

 $OTTV - OTTV_{ss} = [A(57.61 \times WWR + 58.89 \times WWR + 95.44 \times WWR + 63.82 \times WWR)]/[4(A)]$

 $OTTV - OTTV_{ss} = 68.94 \times WWR$

The amounts of OTTV reduction in different orientation and whole of building are collected in the table 3.

The effectiveness of self-shading strategy on OTTV determining shows reduction the amount of OTTV in different orientation, especially in east orientation with $95.44 \times WWR$. However the self-shading strategy on OTTV has the least effect with $57.61 \times WWR$ reductions for the North orientation. Also it is obvious that the influence of the self-shading strategy depends on WWR. if the ratio of WWR are increased the amount of OTTV decrease significantly with using self-shading strategy in designing. The amount of OTTV reduction for different ratio of WWR varies between 0 W/m2 for no glazing envelope to $68.94W/m^2$ for whole glazing envelope.

B. Calculating Optimum WWR

Zain-Ahmed et al (1998) demonstrated that the solar gains increased as the WWR increased. The heat gains from lighting decreased from 10 to 25 percent WWR but increased again from 30 percent WWR, although no supplementary lighting was used. This shows that the optimum window opening for day lighting is 25 percent WWR. Any further increase in glazing size will actually increase the thermal gains. Therefore according to Zain-Ahmed et al (1998) the optimum window size is 25 percent WWR in Malaysia [12]. In this calculation process at first the amount of OTTV was calculated for WWR = 0.25 for building without shading device then the optimum WWR with using self shading device was found through equalization OTTV with new condition under shade of self-shading form. OTTV for each orientation should be calculated For determination the Amount Of OTTV for a whole building with no shading device and WWR = 0.25. Also a which is defined Solar absorptivity for opaque wall was considered fixed with 20 percent for white color wall in all calculation process.

 U_w , for 30mm common concrete wall is $2.4W/m^2K$ and U_f , for 3mm clear glass is $5.9W/m^2K$.

SF for all orientation was specified and SC = 1 for building has no shading device. So amounts of OTTV for different orientation are as follow:

$$OTTV = 15 \times a(1 - WWR) \times U_w + 6(WWR) \times U_f + [194 \times (CF) \times (WWR) \times (SC)]$$

 $OTTV_n = [15 \times (20/100) \times (1 - 0.25) \times 2.4] + [6 \times (0.25) \times 5.9] + [194 \times (0.90) \times (0.25) \times (1)]$

 $OTTV_s = [15 \times (20/100) \times (1 - 0.25) \times 2.4] + [6 \times (0.25) \times 5.9] + [194 \times (0.92) \times (0.25) \times (1)]$

 $OTTV_e = [15 \times (20/100) \times (1 - 0.25)2.4] + [6 \times (0.25) \times 5.9] + [194 \times (1.23) \times (0.25) \times (1)]$

 $OTTV_w = [15 \times (20/100) \times (1 - 0.25) \times 2.4] + [6 \times (0.25) \times 5.9] + [194 \times (0.94) \times (0.25) \times (1)]$

As areas in all orientation was considered same. Therefore OTTV for whole building is as follow:

$$OTTV = [A \times (57.9 + 58.87 + 73.90 + 59.74)]/4(A)$$
$$OTTV = 62.60W/m^2$$

Values for all parameters were set in OTTV Equation except WWR, to determine optimum size for window in self-shaded buildings. OTTV for different orientation in self-shaded building are as follow:

$$OTTV_{ssn} = 15(20/100)(1 - WWR)2.4 + 6(WWR)5.9 + [194(0.90)(WWR)(0.67)]$$

$$OTTV_{sss} = 15(20/100)(1 - WWR)2.4 + 6(WWR)5.9 + [194(0.92)(WWR)(0.67)]$$

 $OTTV_{sse} = 15(20/100)(1 - WWR)2.4 + 6(WWR)5.9 + [194(1.23)(WWR)(0.60)]$

 $OTTV_{ssw} = 15(20/100)(1 - WWR)2.4 + 6(WWR)5.9 + [194(0.94)(WWR)(0.65)]$

OTTV for whole self-shaded building are as follow:

 $OTTV_{ss} = [A \times [(7.2 + 145.18 \times (WWR)) + (7.2 + 147.78 \times (WWR)) + (7.2 + 171.37 \times (WWR)) + (7.2 + (146.73 \times (WWR))]]/4(A)$

 $OTTV_{ss} = 7.2 + 152.76 \times (WWR)$

The amount of OTTV that is determined as a function of WWR, is equaled to $62.60W/m^2$, Then WWR was calculated. Therefore

 $62.60 = 7.2 + 152.76 \times (WWR)$

WWR = 0.36

Since the optimum size of window was considered 0.25 in common buildings with no self-shading strategy.with using self-shading strategy the optimum size of window can be more with 0.36. However the amount of OTTV was considered the same.It means with using self-shaded strategy in buildings if WWR was considered 0.36 the amount of OTTV will be equal to OTTV buildings with WWR = 0.25 as while they have no shading device. Therefore we can infer from this, that Self-shaded strategy can increase optimum size of windows in buildings because however the amount of WWR in this case increased but the amount of OTTVdidn't increased. it means in designing process if the amount of WWR increased 11 percent and also self-shaded strategy was used, The amount of heat which transfer from outside to inside of building would not be changed. In addition not only this strategy doesn't more heat gain but also it causes more daylight enter to interior of buildings. Therefore probably it causes that electricity use for artificial lighting decrease. Finally occupants can use more from the view of outside of buildings.

IV. CONCLUSION

Self-shaded strategy in buildings especially in high-rise buildings effect on minimizing the amount of OTTV. This reduction is $68.94 \times WWR$ as a case in Malaysia. The effect of Self-shaded strategy is more significant if the amount of WWR increase .Also optimum size for window can be increased with using this strategy in designing buildings.Therefore self-shading designs are mainly to minimize solar radiant heat gain and meet the current code of practice for overall thermal-transfer value OTTV standard. This is an effective approach to allow architectural design to have a more flexible building facade design, and to enhance a more energy-efficient and greener building development. Energy savings mean not only low electric-lighting and reduced-peak electrical demands, but also reduced cooling loads and the potential for smaller heating, ventilating and air-conditioning (HVAC) plants The initial, running and maintenance costs of a building due to lower HVAC plant capacity and smaller peak electrical-demand can be saved.

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