

# Formulating an Alternative Methodology for Singapore's Envelope Thermal Transfer Value Calculation

## Accounting for non-conventional shading strategies

CLARICE FONG<sup>1</sup>, WU XUCHAO<sup>2</sup>, ERY DJUNAEDY<sup>3</sup>

<sup>1</sup>Arup Singapore Pte Ltd, Singapore

<sup>2</sup>Arup Singapore Pte Ltd, Singapore

<sup>3</sup>University of Idaho, Boise, Idaho, USA

**ABSTRACT:** Singapore's building regulations require the submission of Envelope Thermal Transfer Value (ETTV) calculations for new buildings. The current ETTV method accounts for the thermal contributions of conventional external shading devices, such as overhangs or fins. For complex façade design solutions, a longer and more complicated calculation process is required. This additional method is based on manual calculations, and can be a deterrent to pursuing more advanced shading strategies. As a response, this paper presents a modified computer-based methodology for ETTV calculation. The study looked into quantifying the shading contribution of different strategies, including inter-block shading. Research focused on defining correction factors that can be plugged into the current ETTV equation. These feed into three aspects of thermal heat gain through a building skin – heat conduction through opaque wall, heat conduction through transparent window, and solar radiation through transparent window. The revised methodology was then applied to a case study, to exhibit its ideal application in accounting for non-standard shading devices.

**Keywords:** ETTV, external shading, building façade

### INTRODUCTION

In Singapore, new buildings are required to submit Envelope Thermal Transfer Value (ETTV) calculations as part of statutory compliance. By definition, the ETTV quantifies solar heat gain through a building's external envelope. The standard calculation method takes into account thermal contributions of conventional shading devices, such as horizontal overhangs or vertical fins. However, more complex sunshading solutions require additional geometric and trigonometric calculations, which can be tedious and prone to errors. This approach may become a deterrent to exploring more innovative design solutions.

Furthermore, the ETTV standard formula does not account for shading contributions from neighbouring buildings. The rationale is that these buildings may not be present at a later time, and therefore cannot be relied on to provide constant shading. However, in large-scale developments where there is only one owner and designer for multiple blocks, shading between adjacent towers becomes more constant. This should allow architects to explore self-shading as a climatic response to reduce solar gain.

This study presents procedures for advanced assessments supporting ETTV calculation for non-

standard shading strategies. The proposed methodology is expected to supplement the standard ETTV calculation procedure whenever this standard procedure is found to be inadequate in dealing with complex façade features.

A worked example is presented at the end of the paper to demonstrate the proposed alternative ETTV calculation methodology.

### THE CURRENT ETTV METHODOLOGY

The ETTV formula sums up the three basic components of heat gain through building envelope. These are:

- Heat conduction through opaque walls;
- Heat conduction through transparent window; and
- Solar radiation through transparent window

The ETTV formula is given as follows:

$$\text{ETTV} = 12(A_w)U_w + 3.4(A_f)U_f + 211(A_f)(CF)(SC)$$

where

ETTV	envelope thermal transfer value
$A_w$	area of opaque wall
$U_w$	thermal transmittance of opaque wall
$A_f$	area of fenestration
$U_f$	thermal transmittance of fenestration
CF	correction factor for solar heat gain through fenestration due to orientation and inclination
SC	shading coefficient of fenestration

The formula's determinants are window-to-wall ratio (WWR), thermal transmittance (U-values) of wall and fenestration, façade orientation and inclination (CF), and shading coefficient of fenestration (SC). This shading coefficient is the effective shading coefficient of the fenestration system. It is obtained by multiplying the shading coefficient of the glass and the shading coefficient of external sun-shading devices.

$$SC = (SC_1)(SC_2)$$

where

- |                 |  |
|-----------------|--|
| SC              | shading coefficient of the fenestration system   |
| SC <sub>1</sub> | shading coefficient of glass or effective shading coefficient of glass with solar control film |
| SC <sub>2</sub> | shading coefficient of external shading devices (2)  |

The ETTV Code specifies shading coefficients of three most commonly used types of external shading – the horizontal overhang, vertical fin and egg-crate. Where these shading devices are used, the given figures can be plugged into the standard formula easily. However, in cases of non-standard shading devices, the effective shading coefficient shall be calculated from basic solar data. The methodology, as stipulated in the Code, requires averaging the hourly solar gains of four representative days: March 21, June 22, September 23 and December 22. This methodology presumes the use of a solid, opaque material for the shading device.

The Code's alternative methodology allows some flexibility in the design of solid shading devices. However, it does not consider some of the contributions by non-conventional shading strategies. This can come in the form of complex shading devices, shading of opaque construction, and shading from adjacent buildings in the same development. All these strategies contribute to the building's thermal performance by reducing exposure to diffused radiation or reducing thermal heat transfer due to lower surface temperatures.

## REVISED METHODOLOGY 1

In order to accurately account for the contributions of different design strategies, a revised methodology relying on solar modelling and computer simulation was developed. This work was based on a four-step process, which looked into the different contributing factors not accounted for in the standard methodology. The factors looked into were:

- Inter-block shading, denoted as  $G_s$ ;
- Direct shading provided by unconventional shading devices, denoted as  $G_D$ ;
- Diffused shading provided by unconventional shading devices, denoted as  $G_d$ ; and
- Reduced surface temperature due to direct and diffused shading, denoted as  $U_{eq}$ .

The first three factors relate to radiation through glazed surfaces, while the last factor relates to heat gain through the opaque building envelope. The notations for these factors are based on those used in the Code, where  $G$  is the fraction of area exposed to direct solar radiation.

**Inter-Block Shading** In a highly urbanised and dense environment, it is common to have neighbouring buildings overshadowing another. This will inadvertently affect the heat gains through the façade. Singapore's ETTV methodology does not consider the shading from neighbouring buildings. This is mainly because there is no assurance that the adjacent building will remain for the entire lifespan of the building that is shaded. This assumption changes when dealing with multi-block developments. Buildings within the same project or development are expected to have the same lifespan. In such instances, inter-block shading then becomes a valuable design tool in reducing solar heat gains.

To quantify inter-block shading, the factor  $G_s$  was determined by dividing the unshaded window area over the total window area:

$$G_s = \frac{\text{unshaded window area}}{\text{total window area}} \quad (3)$$

This fraction is also equal to the amount of solar radiation incident on the surface over the total solar radiation. Both are expressed as yearly averages, and can be derived through solar modelling on the four representative days (solstices and equinoxes).

**Direct Shading** To quantify the contribution of bespoke shading devices such as perforated screens, the factor  $G_D$  was determined by dividing the amount of direct solar radiation incident on the glazed surface over the total direct radiation. Numbers are taken from yearly averages based on solar modelling of four representative days.

**Indirect Shading** The Code's standard procedure for determining the effective shading coefficient ignores reduction in diffuse radiation provided by external shading devices. However, as seen in computer simulations, external shading devices also reduce exposure to diffuse radiation by reducing view of the sky (Fig. 1). This is especially true for perforated screens.

To account for indirect solar radiation, the sky factor was used as a benchmark figure. This is the percentage of sky view from the unshaded glazed surface. The  $G_d$  or indirect shading factor was determined through the reduction in sky view or change in sky factor when the surface was shaded.

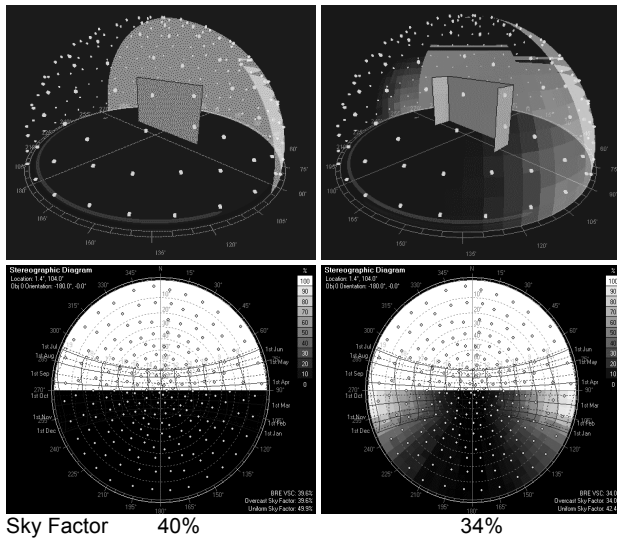


Figure 1: Simple solar models showing the change in sky factor as a result of introducing vertical fin shading.

**Reduced Conduction Heat Gain** The standard ETTV formula uses a fixed factor of 12 to account for the thermal transfer through the building skin's opaque surfaces. This works on the assumption that the opaque walls are completely exposed to the sun, which results in surface temperatures falling within a specific range of values. However, when the opaque elements are shaded, there is also a corresponding drop in surface temperatures. This affects the temperature differentials between external and internal surfaces, and the heat flow through the building skin.

To address this discrepancy, a factor for reduced heat conduction gain through the opaque building fabric  $C_w$  was introduced. This value will be multiplied by the first term in the standard ETTV formula ( $12 \cdot A_w \cdot U_w$ ), and will account for the difference in conduction heat flow through opaque walls.

Similarly, conduction heat gain through glazed surfaces is expected to be lower due to reduced incident diffuse radiation. This reduction shall be accounted for by the factor  $C_F$ . This value will be multiplied by the second term in the ETTV formula ( $3.4 \cdot A_F \cdot U_F$ ).

## CASE STUDY – RESIDENTIAL COLLEGES

The National University of Singapore is developing a new campus that is primarily composed of student accommodation. The new University Town will house five Residential Colleges (RC's), one of which is the basis of this case study. The RC block was designed with a unique shading device – a perforated metal screen

parallel to the façade – that could not be easily accounted for under the standard ETTV calculation (Fig. 2).

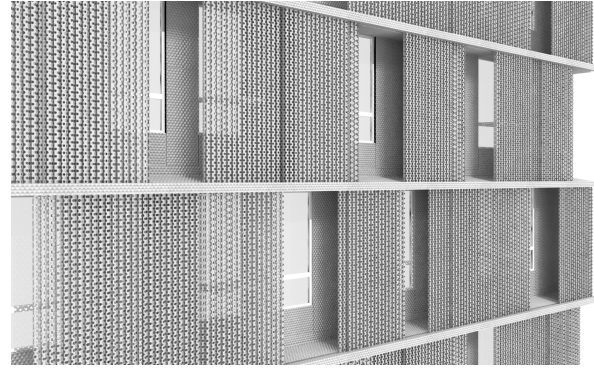


Figure 2: Perspective of the proposed Residential Colleges, showing sliding perforated screens used for shading. Image courtesy of SOM New York.

Solar and thermal simulations have confirmed the effectiveness of the screen, not only in blocking direct solar radiation from the sun, but also in reducing exposure to diffuse radiation. These contributions were quantified through a performance-based calculation methodology for ETTV. The first three steps discussed earlier were applied to the RC block being investigated. However, due to project time constraints, this exercise did not include quantifying contributions to reduced conduction heat gain. This final part of the study was done in a separate exercise, and shall be discussed later.

**Methodology** The first step is to quantify inter-block shading. A model was built and imported into ECOTECT for solar simulations. As shown in Fig. 3, the lower part or podium of the southwest facing façade shaded by the block opposite at specific hours of day.

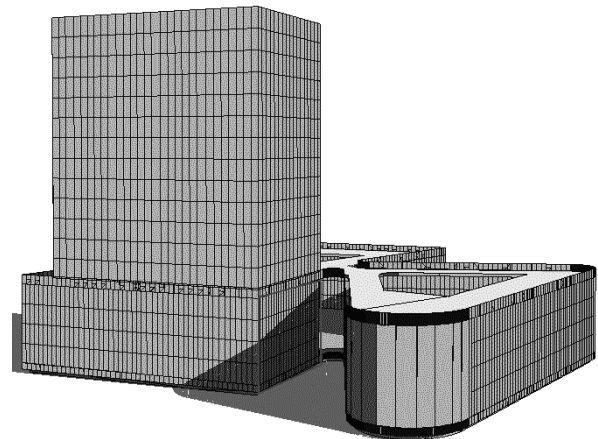


Figure 3: Solar model of Residential College as an example of inter-block shading.

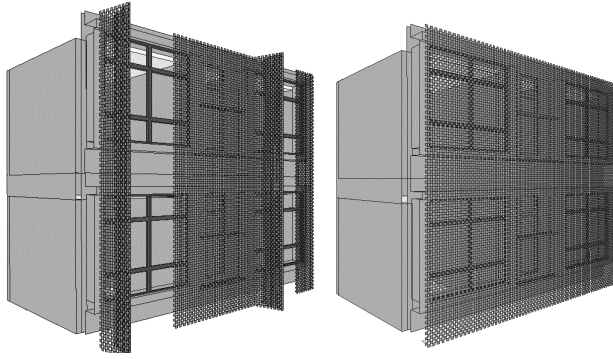


Figure 4: View of ECOTECT models with perforated bi-fold shutters in open and closed positions.

As the extent of shading varies throughout the year, computer simulations were used to derive the actual shaded area and self-shading factor  $G_s$ . Solar exposure was then calculated for three representative days of the year: March 21, June 22 and December 22. (The sunpath for September 23 is almost identical to that of March 21, and was excluded from the calculations. This is done according to the guidelines in the Code.)

From simulation results, the Shading Coefficient for each design day was calculated, taking the fraction of the incident solar radiation over the total solar radiation throughout the day. The final effective SC for self-shading ( $SC_s$ ) for each orientation was then taken as the average of the three days. This effective SC was used in the final ETTV calculation to account for self-shading.

Direct shading from the perforated screens were also quantified using solar modelling in ECOTECT. The designers specified operable bi-fold screens that are 50% perforated. ECOTECT models for this option were constructed with shutters in both 'open' and 'closed' positions (Fig. 4). Note that there are also perforated panels that are fixed or non-operable, and remain in the 'closed' position throughout.

Given that the shutters are manually operated, it is impossible to predict the schedule and profile of the shutters' open and closed modes. For simplicity, the study assumed a 1:1 proportion of open and closed units. This means that the effective SC will be an average of the SC for open and closed shutters.

For diffused shading, an unshaded base case model was constructed to establish the benchmark level. The diffused shading factor  $G_d$  is then calculated by dividing the sky factor of the shaded model over the sky factor of the base case. The effective shading coefficient  $SC_D$  was calculated together with the results from the direct shading. The resulting  $SC_D$ , which takes both direct and

diffused shading into account, was then used in the final ETTV calculation.

Table 1: Total solar radiation  $Q$  on southwest façade with inter-block shading factor  $G_s$  taken on representative days

Southwest	21-Mar / 23-Sep		22-Jun		22-Dec	
Time	$G_s$	$Q$	$G_s$	$Q$	$G_s$	$Q$
7.00AM	0	23	0	23	0	30
8.00AM	0	48	0	63	0	88
9.00AM	0	76	0	86	0	119
10.00AM	0	98	0	98	0	136
11.00AM	0	136	0	106	0	146
12.00NOON	0	139	0	116	0.16	159.84
13.00PM	0	133	0	116	0.4	228.6
14.00PM	0.3	177	0	109	0.58	336.62
15.00PM	0.535	277.875	0.13	97.94	0.59	370.3
16.00PM	0.715	358.13	0.41	115.77	0.52	330.92
17.00PM	0.68	278.28	0.65	127.1	0.36	200.12
18.00PM	0.48	73.12	0.81	65.93	0.195	51.59
$Q$ (day)	1817.405		1123.74		2196.99	
$I_T$ (day)	2402		1264		3427	
$SC_s$ (day)	0.756622		0.889035		0.641083	
$SC_s$	0.73					

**Results** Simulations were run and results gathered for all orientations on the three representative days. These were used to arrive at corresponding SC's, which were then introduced to the ETTV calculation. The contribution of inter-block shading and the perforated screen can be clearly seen in the reduction of the final ETTV. The following discussion presents a few results from this study that quantifies the above process.

Table 1 illustrates how the effective SC for the southwest façade was derived based on solar exposure. The inter-block shading factor  $G_s$ , taken from hourly solar simulation results, was multiplied to the direct radiation component. This reduced the total solar exposure  $Q$  during hours when the southwest façade was partially shaded. The shading coefficient for inter-block shading  $SC_s$  was then obtained by dividing the total  $Q$  over the total solar radiation  $I_T$ . This effective  $SC_s$  is later factored into the final ETTV calculation, as part of the SC formula noted earlier (Equation 2).

The above process can also be applied when quantifying the effect of the perforated screens. Shading factors for both direct and diffused radiation were gathered through solar modelling, with shutters in the open and closed positions. These shading factors were multiplied to the direct and diffused radiation values accordingly, resulting in a reduced hourly  $Q$ . Again, the effective SC was taken as the sum of  $Q$  over the sum of  $I_T$  for all three test days. Results for open shutters and closed shutters were then averaged to arrive at the final shading coefficient for perforated shutters  $SC_D$ .

The results from the above exercise were plugged into the standard ETTV formula, either as SC2 values or as another multiplier to the U-value.



The resulting values used in the alternative ETTV calculation are shown on Table 2.

Table 2: Some of the resulting shading factors and how it was used in the alternative ETTV calculation

interblock shading SCs			screen shading SCd			
northeast	0.54		northeast	0.55		
southwest	0.89		southwest	0.53		
southeast	0.84		southeast	0.57		
given	Aw	159.18	Af	68.52	CF	1.06
	Uw	2.10	Ur	4.55	SC1	0.44
standard ETTV			51.89 W/m <sup>2</sup>			
[12 Aw·Uw + 3.4 Af·Ur + 211 Af·CF·SC1·SC2]/[Aw + Af]						
given	southwest façade		SC2	1		
alternative ETTV			39.12 W/m <sup>2</sup>			
[12 Aw·Uw + 3.4 Af·Ur·Cr + 211 Afp·CF·SC1·SCs + 211 Aft·CF·SC1·SCd]/[Aw + Af]						
given	southwest façade		Afp	5.64	SCs	0.89
			Aft	62.88	SCd	0.53

Note that inter-block shading is only applicable to the podium level of the building, and the screens are only applied to the tower. Hence, the area of fenestration is divided into two parts –  $A_{FP}$  (podium) and  $A_{FT}$  (tower). The derived shading coefficients are then applied to the respective sections.

## FURTHER STUDIES – METHODOLOGY 2

The NUS case study did not factor reduced conduction heat gain into the ETTV calculation. A secondary study was then conducted to determine the effect of reduced surface temperatures on the heat gain of a building. A base case model was built, using the parameters set forth in the BCA Code. The building has a square footprint of 25m x 25m, rising 10 storeys. The floor-to-floor height is 3.4m, with 1.5m high window on all façades. The external wall is made of concrete, with a U-value of 2.82 W/m<sup>2</sup>K. The glass has a U-value of 2.72 W/m<sup>2</sup>K and a SC of 0.49.

Simulations were carried out in eQuest, using the following boundary conditions:

- Outside air 7 CFM/person
- Cooling set point temperature 25°C
- Night setback temperature 37°C
- Chiller COP 4.5
- Lighting power 20.4 W/m<sup>2</sup>
- Infiltration 0.6 ACH (fans off)
- Heat of light-to-space ratio 0.8

A series of simulations were run to establish the base case heat gain and ETTV of the building (Table 3). Note that results are in kWh, which need to be integrated over a time period to derive the values in Watts. Given that, the resulting ETTV was calculated to be 64.3 W/m<sup>2</sup>.

Using the standard formula in the Code, the base case building has an ETTV of 68.4 W/m<sup>2</sup>. This figure varies by 6% from the computer-simulated ETTV. This margin Table 3: Heat gains and corresponding ETTV of the Base Case, from computer simulation results

	North	East	South	West
Wall Conduction (kWh)	50,572	59,073	50,014	58,371
Glass Conduction (kWh)	28,233	33,595	28,097	32,313
Solar Radiation (kWh)	61,044	77,402	61,499	75,432
Total (kWh)	139,849	170,070	139,611	166,116
ETTV (W/m <sup>2</sup> )	58.43	71.05	58.33	69.40

Envelope heat transfer (kWh) 615,645  
Overall ETTV (W/m<sup>2</sup>) 64.30

Table 4: Heat gains and corresponding ETTV of the building with perforated screen on west façade, from simulation results

	North	East	South	West
Wall Conduction (kWh)	50,572	59,073	50,014	35,852
Glass Conduction (kWh)	28,233	33,595	28,097	22,998
Solar Radiation (kWh)	61,044	77,402	61,499	23,611
Total (kWh)	139,849	170,070	139,611	82,461
ETTV (W/m <sup>2</sup> )	58.43	71.05	58.33	34.45

Envelope heat transfer (kWh) 531,990  
Overall ETTV (W/m<sup>2</sup>) 55.56

of error is due largely to the simplification that is built into the standard ETTV formula. The manual calculation method presumes that all orientations contribute equally to conductive heat gains. However, based on the above simulation results, there are differences in heat gain due to orientation.

To assess the contribution of the perforated metal shutters, a second model was built with the shading device installed on the west façade. Solar simulations were run using the same parameters as the base case. The resulting the heat gains and ETTV are found in Table 4.

Based on the results, there is a notable reduction in heat gains on the west façade. To obtain the conductive gain factors  $C_W$  and  $C_F$ , results from Table 4 were divided by results in Table 3. This gives the value of  $C_W$  as 0.614, and  $C_F$  as 0.712.

There is also a significant difference in the solar radiation heat gains through the glazing. This reduction can be translated into a new correction factor  $SC_{MOD}$ . This shall be the ratio of the reduced radiative heat gain to the base case. The  $SC_{MOD}$  factor shall replace the factor  $SC_D$  in the previous methodology.

The simulation-derived reduction factors  $C_W$ ,  $C_F$  and  $SC_{MOD}$  were then introduced into the standard ETTV formula. The resulting ETTV for the shaded building is

56.78 W/m<sup>2</sup>. This value shows a 3% variance from the simulation-derived ETTV in Table 4.

The above methodology presumes that the reduction in heat gain is the same across all the orientations. This can be verified through further computer simulation. However, it is believed that the difference will be insignificant, and will not greatly affect the calculated ETTV value.

### COMPARISON OF TWO METHODOLOGIES

The earlier discussion and case study shows how a performance-based ETTV calculation can effectively account for contributions of non-standard shading devices. The work done on the Residential Colleges clearly shows the difference between using the standard ETTV methodology, and the revised performance-based methodology. The worked example for the southwest façade shows a 25% improvement in the ETTV, from 51.89 W/m<sup>2</sup> to 38.48 W/m<sup>2</sup> – all simply through adjusting the existing ETTV formula.

The second follow-up study takes into account both the change in conductive heat gains for both opaque and transparent elements, as well as radiative heat gains through glazing. The example used shows a 17% reduction in the calculated ETTV. The difference is not as substantial as in the Residential Colleges case study, but is still notable. It should also be pointed out that this second study did not account for inter-block shading, as was in the RC case study.

Of the two revised calculation procedures presented, the second methodology is more comprehensive. It is also simpler, in that all heat gain factors are accounted for and computed using the same computer-based simulation results. This leaves less space for errors and possible overlaps. This in turn ensures that the actual contribution of the shading device is not overestimated in the calculation.

### SCOPE FOR FURTHER RESEARCH

The current study focused on the implications of inter-block shading and unconventional shading devices. Further study could be developed in determining shading or solar exposure in an urban context – that is, how a cityscape can contribute to shading effects. This may lead to new standards for building design within the urban context.

Further study and analysis of the standard ETTV equation can also be undertaken. This will help determine whether the current equation should be revised or updated to reflect changes in the building industry. Factors such as inter-block shading may be introduced into the equation as a standard term or coefficient.

### CONCLUSION

To arrive at a performance-based ETTV methodology, computer simulations definitely play a large part. It is therefore important to apply a highly methodical approach to this exercise, to ensure accuracy of the results. An understanding of the software and the boundary conditions is also critical in undertaking this type of exercise.

This study enables the proper evaluation of advanced shading strategies, and thereby encourages the design of such. This revised ETTV calculation methodology does not supplant the existing methodology; it should be used only in cases where non-tradition shading strategies are being used.

**ACKNOWLEDGEMENTS.** This study was undertaken with support from the Arup DTF for building physics. We would like to acknowledge the input from our external collaborator, Prof. SK Chou of the National University of Singapore, for his input and comments on our work.

### REFERENCES

1. Chou SK, Lee YK., (1988) A simplified overall thermal transfer value equation for building envelopes, *Energy*, 13(8): p. 657 – 670.
2. Yik F. W. H, Wan K. S. Y., (2005) An evaluation of the appropriateness of using overall thermal transfer value (OTTV) to regulate envelope energy performance of air-conditioned buildings, *Energy*, 30(1): p. 41 – 71.
3. Lam, J. C., Hui, S. C. M. and Chan, A. L. S., (1993). Overall thermal transfer value control of building envelope design part 1 - OTTV limits, *Hong Kong Engineer*, 21 (8): 27-31, August.
4. Lam, J. C., Hui, S. C. M. and Chan, A. L. S., (1993). Overall thermal transfer value control of building envelope design part 2 - OTTV parameters, *Hong Kong Engineer*, 21 (9): p. 40-44, September.
5. Hui, S. C. M. and Lam, J. C., (1991). Overall thermal transfer value (OTTV) - a review, *Hong Kong Engineer*, 19 (9): 26-32, September.
6. Hui, S. C. M., 1997. Overall thermal transfer value (OTTV): how to improve its control in Hong Kong, In Proc. of the One-day Symposium on Building, Energy and Environment, 16 October 1997, Shangri-la Hotel, Kowloon, Hong Kong, HKIE BS Division/CIBSE/ASHRAE/PolyU, p. 12-1 to 12-11.