ARTICLE

Overall Thermal Transfer Value (OTTV) - a review

by **Sam C M Hui** and **Joseph C Lam**, *Building Energy Conservation Unit, Department of Building and Construction, City Polytechnic of Hong Kong*

Abstract

There has been growing concern about energy consumption in buildings and its implications to the environment. As a first step towards making buildings in Hong Kong more energy efficient, the Government commissioned a feasibility study on the introduction of Overall Thermal Transfer Value (OTTV) to air-conditioned buildings in Hong Kong in 1990. Since then, there has been an increasing interest in the OTTV approach to energy conservation in buildings. This paper reviews the basic concept of OTTV, some of the work carried out in other countries and their experience. It is hoped that the information presented will form a good introduction to OTTV for those who are interested in pursuing this subject.

Introduction

Because of the much publicized problems of global warming and ozone layer depletion, people have become more conscious of the environment and there has been a growing concern about energy consumption in Hong Kong and its environmental implications. The recent event in the Persian Gulf and the subsequent rise in fuel costs highlight the need for energy conservation. In the UK, building stock consumes about 50% of all UK energy [1] and similar situations are envisaged in most developed countries.

In Hong Kong, with an expanding economy and an increase in living standard, there has been a 146 % increase in electricity consumption over the 12-year period (1978-1989) (see Fig 1) [2, 3]. A significant proportion of the electricity is used for air-conditioning in buildings, particularly commercial buildings in summer. In an effort to conserve energy and as a first step towards encouraging more energy-efficient building design, the Government has commissioned a consultancy study on energy conservation in buildings, with the focus on the Overall Thermal Transfer Value (OTTV) approach.

This paper examines the characteristics of the OTTV method and analyses its implications to energy conservation in buildings. Experience in the formulation of OTTV standards and its implementation in other countries will also be discussed.

Concept of OTTV

The OTTV concept originates from the first energy conservation standard of the "American Society of Heating, Refrigerating and Air-Conditioning Engineers", ASHRAE Standard 90-75 "Energy Conservation in New Building Design", later revised as ANSI/ASHRAE/IES Standard 90A-1980 [4], in which the cooling criteria set maximum allowable OTTVs for mechanically-cooled buildings. Basically, OTTV is a measure of average rate of heat transfer from the outdoor environment into a building, through the building envelope (walls and roof) - the higher the OTTV, the greater the heat gain. The OTTV requirement specified in building envelope section of energy conservation standards applies to air-conditioned (or mechanically cooled) buildings. It is aimed at achieving the design of an adequately insulated building envelope so as to cut down external heat gain and hence reduce the cooling load of the air-conditioning system.

OTTV is an index of the overall thermal performance of the building envelope. Provided that the same method and the same thermal environmental figures are used in the calculation of OTTVs, the thermal performance of various buildings can be compared and related to a specified standard or an OTTV limit. However, it should be noted that an OTTV is merely a measure of comparative performance and not an indicator of the total energy that will be consumed for cooling, or how close to the optimum a particular envelope design comes.

Conceptually, OTTV of a building envelope can be expressed as follows :

$$OTTV = \frac{Q}{A} \qquad (1)$$

where Q = heat gain through the building envelope (W)
A = gross area of the building envelope (m^2)

Each facade (eg a south-facing external wall or an horizontal roof) can have its own OTTV. The usual practice is to have two separate OTTVs - one for exterior walls (including windows) and the other for the roof (including skylights).

OTTV equation for walls

Heat gain through exterior walls can be broken down into three components - heat conduction through opaque parts of the wall, heat conduction through glass windows and solar radiation through glass windows. As walls at different orientations receive different amounts of solar radiation, the general procedure is to calculate first the OTTVs of individual walls with the same orientation and construction, then the OTTV of the whole exterior wall is given by the weighted average of these values. Thus :

$$OTTV_i = (Q_w + Q_g + Q_s) / A_i$$
$$= \frac{(A_w x U_w x TD_{eq}) + (A_f x U_f x DT) + (A_f x SC x SF)}{A_i} \qquad (2)$$

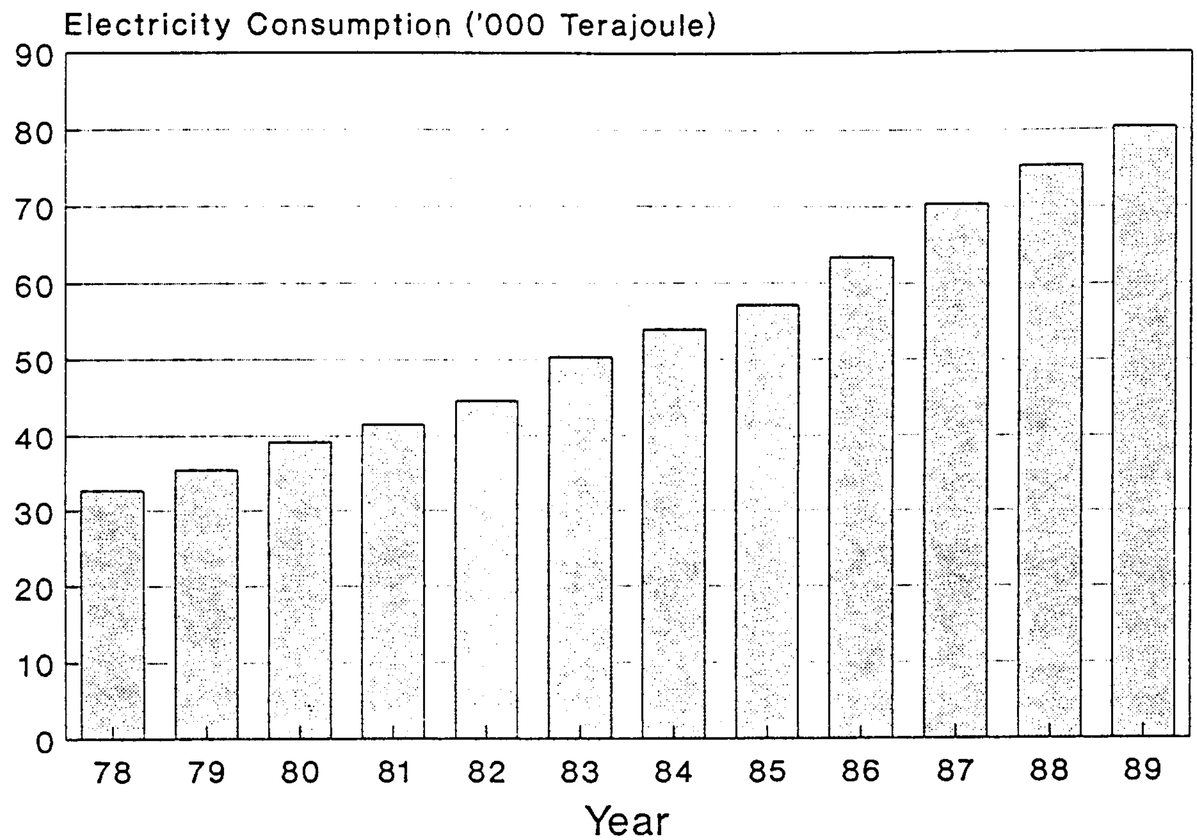
where $OTTV_i$ = overall thermal transfer value of walls with same orientation and construction (W/m^2)
Q_w= heat conduction through opaque walls (W)
Q_g= heat conduction through glass windows (W)
Q_s= solar radiation through glass windows (W)
A_w= area of opaque wall (m^2)
U_w= U-value of opaque wall ($W/m^2.K$)
TD_{eq}= equivalent temperature difference (K)
A_f= area of fenestration (m^2)
U_f= U-value of fenestration ($W/m^2.K$)
DT= temperature difference between exterior and interior design conditions (K)
SC= shading coefficient of fenestration
SF= solar factor for that orientation (W/m^2)
A_i= gross area of the walls (m^2) = $A_w + A_f$

$$\text{and, } OTTV_{wall} = \frac{\sum (OTTV_i x A_i)}{A_o} \qquad (3)$$

where $OTTV_{wall}$= $OTTV$ of the whole exterior wall (W/m^2)
$A_o = \sum(A_i)$ = total gross exterior wall area (m^2)

Parameters TD_{eq}, DT and SF depend on the climatic conditions of particular locations. TD_{eq} also varies with the types

Figure 1 Electricity Consumption in Hong Kong (1978 - 1989) (Excluding street lighting and export to China)



(densities) of construction. Table 1 compares some of the values used/suggested by different publications. If the *OTTV* of a particular design is more than the maximum allowable value, say, in Singapore 45 W/m^2, the design team would have to reduce the OTTV by adopting one or a combination of the following design options :

(a) Reduce the glass area.
(b) Use glass with lower shading coefficient.
(c) Provide shading.
(d) Reduce the U-value of glass (e.g., use double glazing).
(e) Reduce the U-value of opaque wall (e.g., add insulation).

OTTV equation for roof

The approach and equations for calculating roof OTTV are similar to those for walls. The calculation for roof is often much simpler because the roof does not typically contain large amount of glazing (except for skylights in atria).

OTTV parameters and averaging period

OTTV is a measure of the average rate of heat gain through the envelope. The averaging period depends on how TD_{eq}, DT and SF have been obtained. If TD_{eq}, DT and SF have been averaged over a year, then strictly speaking, these parameters are only applicable to be used in equation (2) for calculating OTTVs for buildings with continuous operation (i.e. 365 days, 24 hours per day, such as hotels). The total annual heat gain (Q_t) through the envelope can be estimated by :

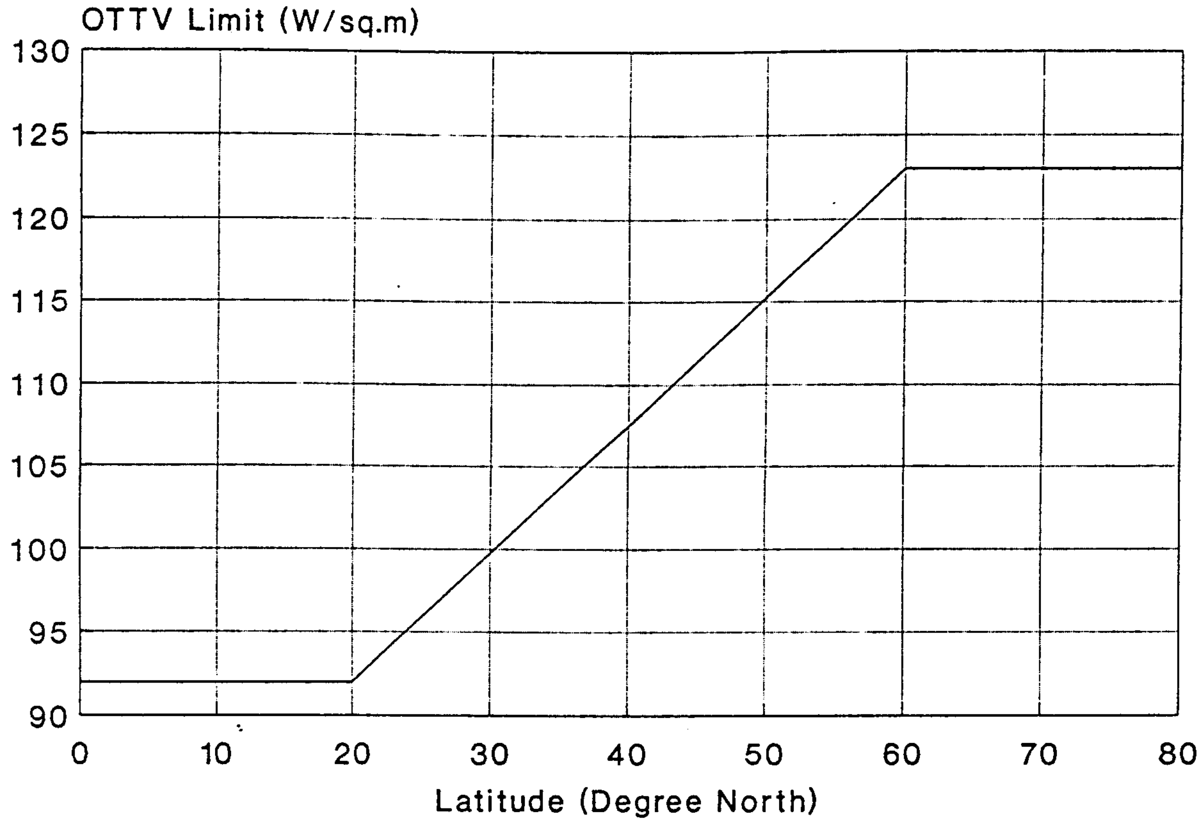
$$Q_t = \frac{OTTV \ x \ 8760}{1000} \text{ (in kWh/m}^2\text{)} \qquad (4)$$

Both ASHRAE [4] and Singapore [5] Standards do not have different parameters for buildings with different hours of operation whereas Shillinglaw & Chen [8] adopted a 12-hour (0700-1800 hrs) and eight-month cooling season (March to November) approach. Research work on parameters and averaging periods for Hong Kong is being carried out by the Building Energy Conservation Unit, Department of Building and Construction, City Polytechnic of Hong Kong and preliminary research report [6] is being drafted.

ASHRAE Standards

In the mid '70s, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) took the responsibility to develop a national voluntary consensus standard for conserving energy in new building design. The first energy conservation standard, ASHRAE Standard 90-75 was published in 1975. This was later revised as ANSI/ASHRAE/IES Standard 90A-1980 [4], in which the idea of specifying an OTTV for building envelope control is introduced via the 'cooling' criteria in the exterior envelope section of the standard. The objective of the criteria is to provide minimum requirements for building envelope construction in the interest of energy conservation.

Figure 2 OTTV Limit for Buildings at Different Latitude [4]



The cooling criteria state that any building that is mechanically cooled shall have an OTTV for the gross area of the exterior not exceeding a particular limiting value. For exterior walls, the limiting OTTV is a function of latitude (see Fig 2); and for roof 26.8 W/m^2. The effect of external shading is not considered.

The ASHRAE Standards are voluntary energy standards but they have been modified by many states in the US and were adopted into their mandatory state energy codes. Experience with the standards indicated that they have been effective in reducing energy costs in buildings.

Through years of extensive research and practical applications, it was recognized that significant cost-effective improvement could be made to the ASHRAE Standard 90A-80 [4]. The latest upgraded edition ASHRAE Standard 90.1-1989 [7] was published in 1989. An important point to be noted is that the approach and structure of its building envelope section has been revised substantially and that the OTTV method is no longer used. A new approach based on a combination of system performance, prescriptive requirements and energy cost budget is introduced to specify the building envelope requirements.

Recognizing the advances in the performance of various building components, equipment and systems, ASHRAE has attempted in its updated Standard [7] to encourage innovative energy conserving designs by allowing the building designer to take into consideration the dynamics that exist between the many components of a building through the use of the System Performance Method or the Building Energy Cost Budget Method compliance paths.

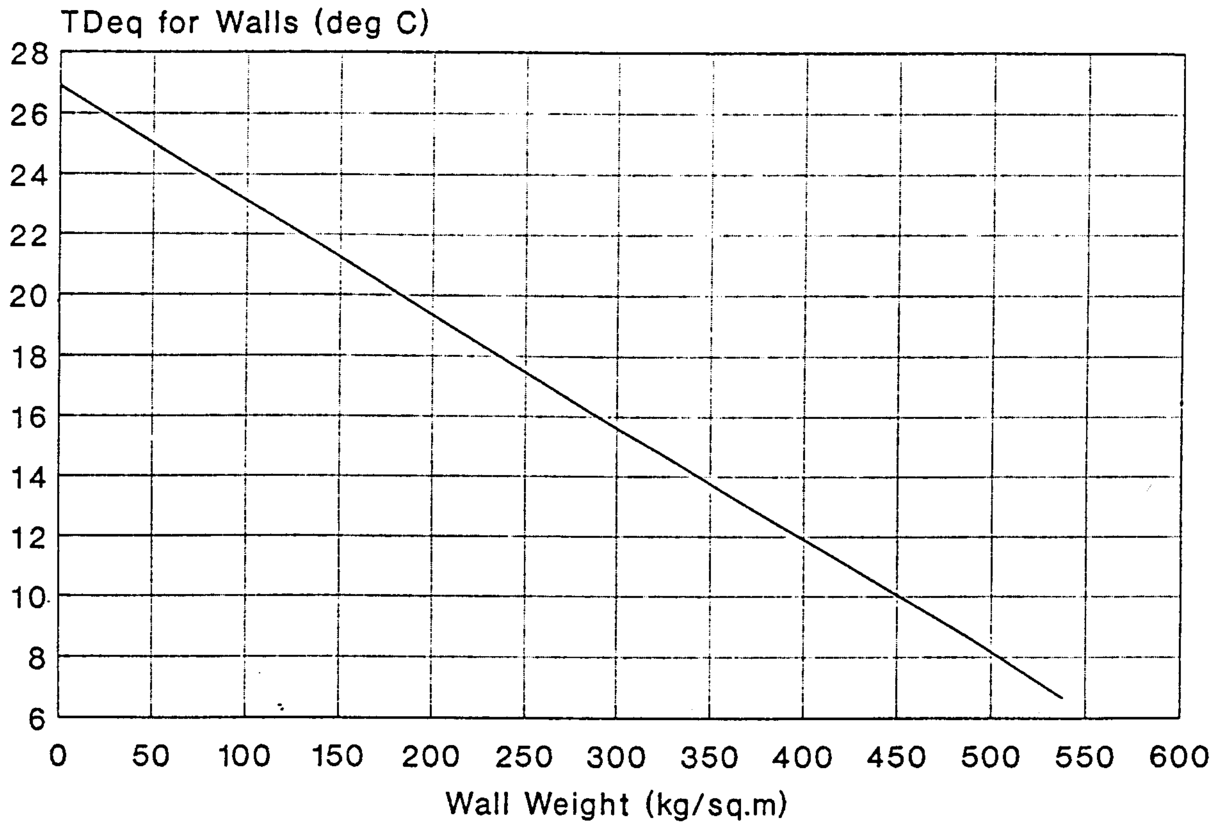
Singapore Building Regulation

In 1979, in an effort to reduce energy consumption in air-conditioned buildings, the Singapore Government introduced the Building Control (Space, Light and Ventilation) Regulation 1979, which sets a maximum permissible OTTV of 45 W/m^2 for both exterior walls and roof. In addition, the regulations prescribe maximum allowable thermal transmittance values (U-values) for different types of roof constructions for air-conditioned buildings as well as those not air-conditioned. Provision is also made to calculate the effective shading coefficient where external shadings are employed.

In preparing the regulations and the supplementary handbook [5] that contains details of calculation methods and submission procedures, reference was made to the ASHRAE 90-1975 and ASHRAE 90A-1980 [4] regarding OTTV concept and standard. The OTTV limit and parameters used in the OTTV equation were derived from local weather data, and the effect of external shading devices, not included in the ASHRAE Standard, was investigated and included in the OTTV formulation to suit local conditions in Singapore.

When the Building Regulations were introduced in 1979, the Singapore OTTV Standard was also applied to existing buildings with a grace period for them to be upgraded. Schemes involving a surcharge on electricity consumption for buildings

Figure 3 Equivalent Temperature Difference for Walls [4]



that do not meet the OTTV Standard, tax incentive for building owners to retrofit their buildings to be more energy-efficient, and accelerated depreciation allowance for expenditure (both new and existing buildings) on approved energy-saving equipment have been introduced [9].

Hong Kong situation

In the early '80s, a Joint Steering Committee on Energy Conservation in Buildings was set up to consider ways to conserve energy. The committee recommended the adoption of OTTV to be applied through legislation and that a consultancy study should be commissioned to carry out the necessary research work. In late 1990, a consultancy was commissioned and it was envisaged that the study would be completed by mid 1991.

Actually, before the current consultancy study, some work on OTTV had been carried out in Hong Kong. In 1987, Shillinglaw and Chen [8] published the work carried out by OTTV Sub-Committee of the Hong Kong Branch of the Chartered Institution Building Services Engineers on OTTV formulation for Hong Kong. A grading system for building OTTV was proposed - an OTTV of 22 or less, 23 to 30, and 30 or more were considered good, average, and below average, respectively. Proposed data for calculating OTTV for buildings in Hong Kong are shown in Table 1. Provision was made to adjust the SF for buildings with external overhangs.

Discussion and conclusion

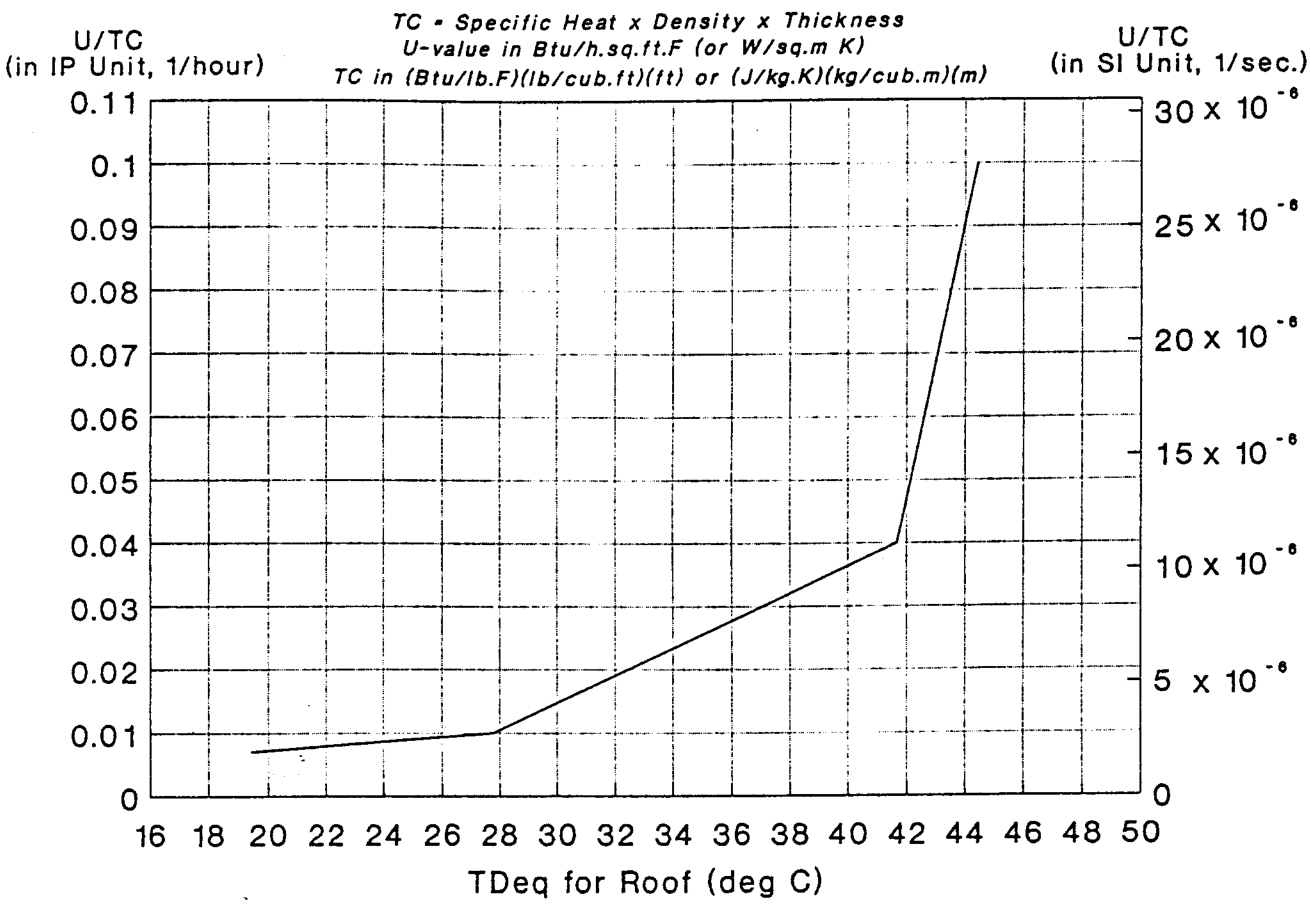
OTTV is a measure of average rate of heat gain through the building envelope into a building. It can give a good indication to the comparative performance of different building designs and constructions - higher OTTV implies larger heat gain and more cooling requirement. It cannot, however, show the actual cooling load nor the actual energy consumption. Despite some shortcomings of the OTTV method, it has been proved to be effective in reducing energy consumption for air-conditioning. It is relatively easy to establish, legislate and implement.

It seems that in the area of energy-efficient design and energy conservation in buildings, Hong Kong is behind the US and her Asian neighbours, but better late than never. The OTTV approach would be one step in the right direction. With the growing concern about energy and the environment among the public and in Government, the climate has never been better for designers (architects, engineers and other building professionals) to create a more energy-efficient environment and to come up with designs that can meet user needs in the most energy-efficient way while being kind to our environment.

References

[1]Lorch, R, "Energy and Global Responsibility", *RIBA Journal*, March, 1990, pp. 50-51.

Figure 4 Equivalent Temperature Difference for Roof [4]



Note : TC is calculated as the sum of the TC's for each layer in the roof construction.

[2]"Hong Kong Energy Statistics 1978-1988", Industrial Production Statistics Section, Census and Statistics Department, Hong Kong, 1989.

[3]"Hong Kong Energy Statistics 1979-1989", Industrial Production Statistics Section, Census and Statistics Department, Hong Kong, 1990.

[4]ASHRAE Standard 90A-1980, "Energy Conservation in New Building Design", American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 1980.

[5]*Handbook on Energy Conservation in Buildings and Building Services*, The Development & Building Control Division, Ministry of National Development, Singapore, 1979.

[6]Hui, S C M and Lam, J C, "Overall Thermal Transfer Value and Its Implications to Energy Conservation in Buildings in Hong Kong", Research Report (in preparation), Department of Building and Construction, City Polytechnic of Hong Kong.

[7]ASHRAE Standard 90.1-1989, "Energy Efficient Design of New Buildings except New Low-Rise Residential Buildings", American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 1989.

[8]Shillinglaw, J A and Chen, K T, "Overall Thermal Transfer Value - Skin-Deep Quantifying of Energy Gain and Conservation", *Building Journal Hong Kong China*, April, 1987, pp. 84-93.

[9]Chou, S K, "Using Building Regulations and Standards to Save Energy", private communication, 1990.

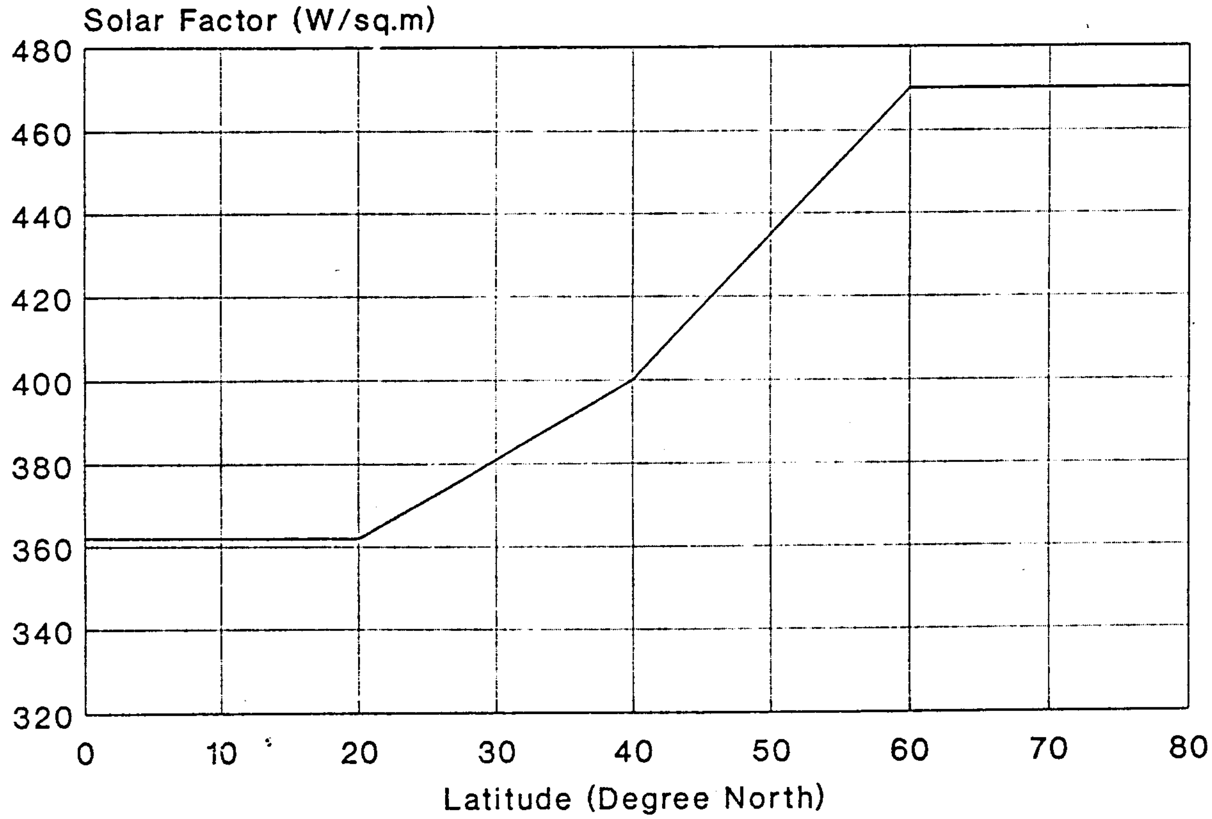


Figure 5 Solar Factor for Buildings at Different Latitude [4]

Table 1 - Comparison of OTTV methods

		ASHRAE	Singapore	HK (Trial)
		Ref [4]	Ref [5]	Ref [8]
OTTV Limit (W/m^2)	Walls	Fig 2	45	Section 5
	Roof	26.8	45	Section 5
TD$_{eq}$ (K)	Walls	Fig 3	Table 2	Table 6
	Roof	Fig 4	Table 3	Table 6
DT (K)		(*)	5	3.1
SF (W/m^2)	Walls	Fig 5	130 x CF (Table 4)	Table 7
	Roof	434.7	320 x CF (Table 5)	Table 7
External Shading Considered ?		No	Yes	Yes

Note:(*) temperature difference between exterior and interior design conditions

Table 2 - Equivalent temperature difference for walls (Singapore [5])

Wall construction (Mass per unit area)	TD$_{eq}$ (walls)
0 - 125 kg/m^2	15 K
126 - 195 kg/m^2	12 K
above 195 kg/m^2	10 K

Table 3 - Equivalent temperature difference for roof (Singapore [5])

Roof construction (Mass per unit area)	TD$_{eq}$ (roof)
0 - 50 kg/m^2	24 K
50 - 230 kg/m^2	20 K
over 230 kg/m^2	16 K

Table 4 - Solar Correction Factor (CF) for wall (Singapore [5])

Slope Angle	Solar Correction Factor for wall at different orientation							
	N	NE	E	SE	S	SW	W	NW
70°	1.32	1.63	1.89	1.65	1.32	1.65	1.89	1.63
75°	1.17	1.48	1.75	1.50	1.18	1.50	1.75	1.48
80°	1.03	1.33	1.59	1.35	1.04	1.35	1.59	1.33
85°	0.87	1.17	1.42	1.19	0.89	1.19	1.42	1.17
90°	0.72	1.00	1.25	1.02	0.74	1.02	1.25	1.00

Table 5 - Solar Correction Factor (CF) for roof (Singapore [5])

Slope Angle	Solar Correction Factor for roof at different orientation							
	N	NE	E	SE	S	SW	W	NW
0°	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5°	1.00	1.01	1.02	1.02	1.00	1.02	1.02	1.01
10°	1.01	1.03	1.04	1.03	1.01	1.03	1.04	1.03
15°	1.01	1.03	1.05	1.03	1.01	1.03	1.05	1.03
20°	1.00	1.03	1.06	1.03	1.01	1.03	1.06	1.03
25°	0.98	1.02	1.06	1.03	0.99	1.03	1.06	1.02
30°	0.96	1.01	1.05	1.01	0.97	1.01	1.05	1.01
35°	0.93	0.98	1.03	0.99	0.94	0.99	1.03	0.98
40°	0.90	0.96	1.01	0.96	0.91	0.96	1.01	0.96
45°	0.86	0.92	0.98	0.92	0.87	0.93	0.98	0.92
50°	0.81	0.89	0.95	0.89	0.83	0.89	0.95	0.89
55°	0.77	0.84	0.91	0.85	0.78	0.85	0.91	0.84
60°	0.71	0.79	0.86	0.80	0.73	0.80	0.86	0.79
65°	0.66	0.74	0.81	0.75	0.67	0.75	0.81	0.74

Table 6 - Equivalent temperature difference (Hong Kong [8])

Wall Weight (kg/m^2)	TD_{eq} at different orientation (K)								
	N	NE	E	SE	S	SW	W	NW	Horizon
< 100	3.0	5.0	7.0	6.0	5.0	6.0	6.0	4.0	7.0
100-300	2.0	3.0	5.0	5.0	4.0	4.0	4.0	3.0	6.0
> 300	0.6	2.0	4.0	3.0	2.0	2.0	2.0	1.0	6.0

Table 7 - Solar heat gain factor (Hong Kong [8])

	SHGF at different orientation (W/m^2)								
	N	NE	E	SE	S	SW	W	NW	Horizon
SHGF	41	102	153	130	84	130	153	102	374

Note: Solar Factor (SF) = SHGF x SSF
where SSF = solar shade factor (when no overhand, SSF = 1)