Overall Thermal Transfer Value Control of Building Envelope Design Part 1 – OTTV Limits

Joseph C. Lam,
Sam C. M. Hui
and Apple L. S. Chan

Building Energy Conservation Unit
Department of Building and Construction
City Polytechnic of Hong Kong

Energy consumption from 1981 to 1990 has been analyzed. Buildings account for nearly half of the total energy consumption in Hong Kong. Background leading to possible legislative control of building envelope design via the overall thermal transfer value (OTTV) method is outlined. There has been concern about the proposed OTTV limits for air-conditioned buildings. This is the first part of a series of articles on the OTTV study. Several key issues relating to OTTV methodology are discussed. A reference building envelope has been developed for air-conditioned non-residential buildings for Hong Kong. Based on this envelope, OTTV limits less stringent than those recommended by the Building Authority are proposed.

Introduction

IN HONG KONG, as the economy grows and living standard improves, so does energy consumption. Figure 1 shows the growth in gross domestic product (GDP) and total primary energy requirement (PER) in Hong Kong during the 10-year period from 1981 to 1990. It can be seen that GDP rose from HK$ 150 billion in 1981 to HK$ 259b in 1990, an increase of 73% [1]. During the same period, total PER increased by 98% from 216,929 terajoule to 430,153 terajoule [2]. Increase in PER was 25 % more than growth in GDP, implying that, by the end of the 10-year period, Hong Kong consumed more energy to produce the same amount of goods and provide the same services.

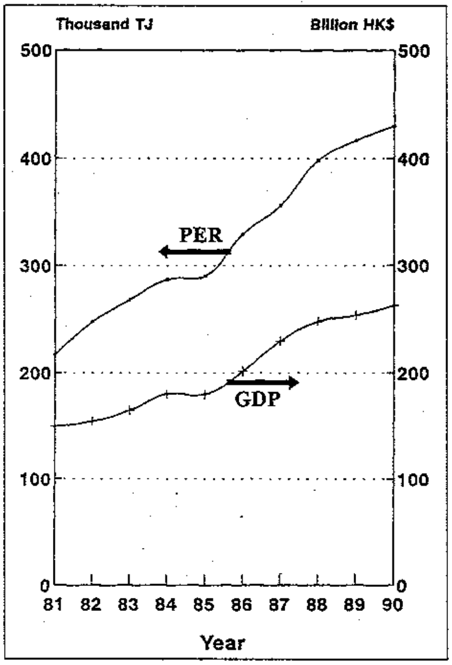

Fig. 1 Total Primary Energy Requirement and Gross Domestic Product in Hong Kong (1981-1990) GDP at constant (1980) market prices

Most of the PER is for electricity generation. In 1990, energy (mainly coal) required for electricity generation accounted for 69% of the total PER. There are three main electricity end-users: industrial, commercial and residential sectors. A small percentage is for street lighting and export to China.

As the Hong Kong economy becomes more service-oriented in the '80s, there has been a steady increase in the demand for high quality, fully air-conditioned commercial buildings, which results in a steady rise in the proportion of electricity consumed in commercial buildings. Figure 2 shows commercial buildings accounted for 45% of the total electricity consumption in buildings in 1990, while the residential sector remained steady at 21%. In other words, energy (electricity) consumption in buildings accounted for 45.5% of the total energy consumed in Hong Kong in 1990.

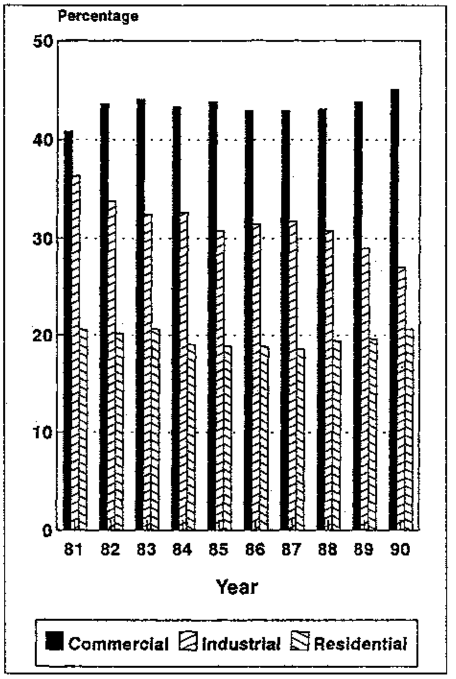

Fig. 2 Percentage of Electricity Consumption in Commercial, Industrial and Residential Sectors (1981-1990)

A significant proportion of the electricity is for air-conditioning in summer. Figure 3 shows the electricity consumption profiles for the residential and commercial sectors in Hong Kong in 1990. It can be seen that consumption begins to rise in May/June and falls off in October/November. In Hong Kong most people (particularly in residential buildings) operate air-conditioning equipment during the six hot summer months from May to October.

As a first step to encourage more energy-efficient design of building and building services systems, in October 1990 the Hong Kong Government commissioned a consultancy study on the possibility of legislative control of new design of air-conditioned commercial buildings via the overall thermal transfer value (OTTV) method. The consultancy study was completed in a few months and the final report [3] was submitted in August 1991 to the Working Party on Energy Conservation in Buildings. In September 1992, a draft handbook [4] was

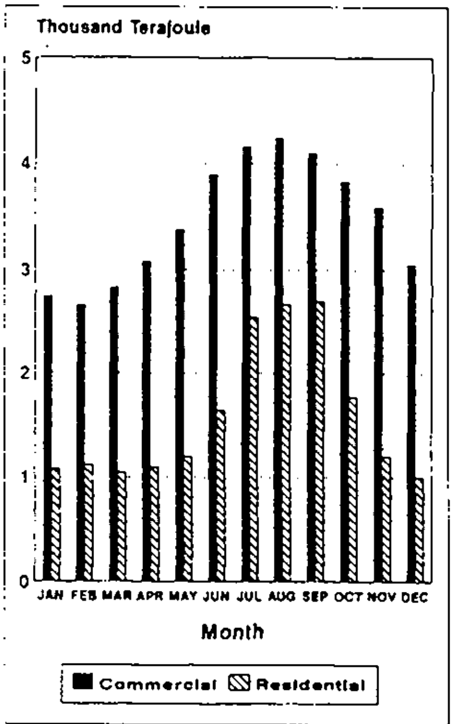

Fig. 3 Electricity Consumption Profiles for the Commercial and Residential Sectors in Hong Kong (1990)

	OTTV Limit (W/m²)	
	Wall	Roof
Commercial Buildings	16	11
Hotel Buildings	30	17

Table 1 OTTV Limits Recommended in Consultancyu Study [3]

	OTTV Limit (W/m²)				
	Whole Building	Roof	Wall*		
			R=0.5	R=1	R=10
Commercial Buildings	16	11	26	21	16.5
Hotel Buildings	30	17	56	43	31.3

* Interpreted from Draft Handbook with different R
R = total gross wall area / total gross roof area

Table 2 OTTV Limits Set in Draft Handbook [4]

sent to the building professions for trial and comments. It is hoped that feedback from the building professions would help evaluate and finalize the proposed OTTV standard, before it becomes statutory control.

There has been concern about the OTTV study, particularly the proposed OTTV limits for commercial buildings (see Tables 1 and 2). These limits are considered too stringent, and would impose too much constraints on architectural design and construction practice [5,6,7]. This paper discusses some of the key issues relating to OTTV study and suggests a more relaxed OTTV limits for air-conditioned buildings for Hong Kong.

Recap of the OTTV concept and OTTV equations

Key features of the OTTV concept are outlined here. Details have been published elsewhere [8]. Basically, Overall Thermal Transfer Value (OTTV) is a measure of heat transfer from the outdoor to indoor environment through the external envelope of a building. Three components of heat gain are considered – conduction through opaque surface, conduction through glass and solar radiation through glass.

OTTV is an index of the overall thermal performance of the building envelope. Smaller the OTTV value, less will be the energy use for cooling. OTTV can be used to compare the thermal performance of different building schemes. For example design A with an OTTV of 40 W/m² would admit twice as much heat as design B with an OTTV of 20 W/m², and hence would consume more energy for cooling. The usual practice is to have two separate OTTVs – one for external walls (including windows) and the other for the roof (including skylights, if any).

OTTV equation for walls

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:

$$OTTV_i = (Q_w + Q_g + Q_s) / A_i$$

$$= \frac{(A_w \times U_w \times TD_{eq}) + (A_f \times U_f \times DT) + (A_f \times SC \times SF)}{A_i} \qquad (1)$$

where

$OTTV_i$ = overall thermal transfer value of walls with same orientation and construction (W/m²)

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 (m²)

U_w = U-value of opaque wall (W/m²)

TD_{eq} = equivalent temperature difference (K)

A_f = area of fenestration (m²)

U_f = U-value of fenestration (W/m²-K)

DT = temperature difference between exterior and interior design conditions (K)

SC = shading coefficient of fenestration

SF = solar factor for that orientation (W/m²)

A_i = gross area of the walls (m²) = $A_w + A_f$

and,

$$OTTV_{wall} = \frac{\Sigma (OTTV_i \times A_i)}{A_{ow}} \qquad (2)$$

where

$OTTV_{wall}$ = OTTV of the whole exterior wall (W/m²)

A_{ow} = $\Sigma (A_i)$ = total gross exterior wall area (m²)

Alternatively, Equation (1) can be expressed in terms of window-to-wall ratio, WWR. Thus:

$$OTTV_i = (1 - WWR) \times TD_{eq} \times U_w + WWR \times DT \times U_f + WWR \times SC \times SF \qquad (3)$$

where

WWR = the ratio of window area to gross wall area = A_f / A_i

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 roof usually does not contain large amount of glazing (except skylights over an atrium).

Key issues about OTTV methodology

There has been concern about some areas in the recommendations on OTTV outlined in the consultancy study [3] and the draft handbook [4]. Some of the key issues are discussed as follows:

Separate OTTV limits for different types of building

Should different OTTV limits be applied to buildings with different functions and operations? In the Draft Handbook [4], different OTTV limits have been proposed for commercial and hotel buildings. Why should hotels be allowed to have higher OTTVs, and hence admit more heat gain than commercial buildings (see Tables 1 and 2)? How about other types of air-conditioned building such as tertiary institutions, airport terminal buildings, etc.?

As mentioned earlier, OTTV is a measure of heat gain through the building envelope; and is used for comparative study of different building designs in terms of their abilities to limit heat gain into air-conditioned buildings. Setting OTTV limits for the wall and roof is to ensure that the building envelope will not admit too much heat from the external environment, and hence demand for air-conditioning during summer will not be excessive.

Different types of buildings cater for different activities with different requirements and operations. For instance, hotels and hospitals operate on a 24-hour basis, whereas most commercial buildings only operate 11 hours (08:00-19:00) per day and 5 ½ days per week. Strictly speaking, the requirement to limit heat gain into a building should be different. However, as most of the heat gain occurs during the day, buildings with 11-hour and 24-hour operations would be exposed to similar level of heat gain from the external environment.

It is, therefore, argued that to be simple and practicable, the requirement to limit heat gain into a building should be the same for air-conditioned non-residential buildings. In other words, same OTTV limits should be applied to both commercial buildings and hotels with same OTTV parameters (i.e. TD_{eq}, DT and SF) and calculation pro-cedure. Indeed, the ASHRAE Standard on OTTV [9] was developed for all non-residential buildings and the Singapore OTTV requirement [10] is applied to all commercial buildings including hotels.

It is proposed that other air-conditioned buildings with operation schedules similar to those for commercial buildings and hotels should be classified as a non-residential buildings and subject to the same OTTV limits set for commercial and hotel buildings. One would then ask, which set of OTTV limits, commercial or hotel, specified in the Draft Handbook [4] should be used for air-conditioned non-residential buildings in Hong Kong?

OTTV Limits for Air-Conditioned Buildings in Hong Kong

Setting OTTV limits for air-conditioned buildings in Hong Kong depends on a number of factors such as the prevailing climatic conditions, the likely energy savings, implications to the design and construction process, acceptance within the building professions and building industry; and whether it can be achieved given the current design technique and construction technology. It also has to be easily legislated, implemented and enforced.

Among the three components of heat gain considered in the OTTV equation, solar radiation through windows is by far the most significant one. The building variables controlling solar heat gain are window-to-wall ratio and shading coefficient.

Survey conducted by Goodsall and Lam [11] indicates that WWR for commercial buildings vary from 30% to 65%, with an average value of 47%. It is interesting to note that similar finding has been reported in the consultancy study on OTTV commissioned by the Hong Kong Government [3]. To keep a balance between limiting solar heat gain and the need for external view and natural light, a WWR of 44% is proposed in the present study for developing an appropriate OTTV limits for wall. For a typical floor-to-floor height of 3.4 m, this represents 1.5 m high window. This WWR was used by researchers in their OTTV study for Singapore [12,13]. As for the roof, a skylight-to-roof ratio (SRR) of 15% is suggested. This is considered typical in most buildings with skylight roof.

Broadly speaking, there are three types of glass used in commercial buildings – clear, tinted and reflective. In recent years, most commercial buildings have reflective glass with shading coefficients ranging from 0.2 to 0.4. A few buildings use tinted glass with shading coefficients ranging from 0.5 to 0.7. Average daylight transmittance for reflective glass is about 20% whereas tinted glass is about 50%.

Having considered factors such as solar heat gain, daylighting and current trend in architectural design, it is proposed that reflective glass with a shading coefficient of 0.35 would be reasonable (most of the reflective glass has a shading coefficient between 0.3 and 0.4). A U-value of 2.5 W/m² is proposed for the opaque wall (e.g. typical concrete wall with tiles and rendering and with no insulation), and 0.6 W/m²K for roof (e.g. typical roof construction with 50 mm insulation). For glazing, actual U-value depends mainly on the inside and outside surface resistances. For simplicity, a U-value of 6 W/m²K is assumed for single glazing in the present study. These proposed building variables are summarized in Table 3.

Based on this proposed reference building envelope and the OTTV parameters from the draft handbook [4], OTTVs for the wall and the roof have been found to be 28.5 W/m² and 18.6 W/m², respectively (see Table 4). Both the wall and roof are assumed to be medium/heavy weight. Although the reference building envelope is based on survey and analysis for commercial buildings, it is envisaged that this could be applied to other air-conditioned non-residential buildings to ensure no excess heat gain will be admitted into the building interior, without imposing too much constraints on the architectural design and construction practice.

From Table 4, it can be seen that roof OTTV (based on the reference building envelope) is higher than commercial buildings by 7.6 W/m² (i.e. 70% less stringent) and hotels by 1.6 W/m² (i.e. 9% less stringent). OTTV for whole building (based on reference building envelope) is higher than commercial buildings by 12 W/m² (i.e. 75%

Wall				
Opaque Wall		Window		WWR
U-Value (W/m²K)	Absorptivity	U-Value (W/m²K)	Shading Coefficient	
2.5	0.7	6	0.35	44%
Roof				
Opaque Roof		Skylight		SRR
U-Value (W/m²K)	Absorptivity	U-Value (W/m²K)	Shading Coefficient	
0.6	0.7	6	0.35	15%

Table 3 Summary of Variables for Proposed Reference Building Envelope

	OTTV (W/m^2)			Percentage Difference between Ref. Bldg. Env. and Limits in Draft Handbook	
	Reference Building Envelope	Limits (Draft Handbook)			
		Commercial	Hotel	Commercial	Hotel
Wall	28.5	–	–	–	–
Roof	18.6	11	17	+70%	+9%
Whole Building	28.0*	16	30	+75%	-7%

* Assume high-rise building with R = 20, where R = total wall area/total roof area

Table 4 Comparison of OTTV for Reference Building Envelope and OTTV Limits Set in Draft Handbook [4]

less stringent), but 2 W/m^2 lower than hotels (i.e. 7% more stringent).

On average, in terms of meeting the OTTV limits set in the draft handbook [4], these OTTVs are closer to those for hotels than commercial buildings. In the present study, OTTV limits of 29 W/m^2 and 19 W/m^2 are proposed for wall and roof, respectively. Building envelope meeting these limits are considered reasonably energy-efficient, in terms of its ability to limit heat gain into the building. It should be pointed out that these limits are based on OTTV parameters (TD_{eq} and SF) given in the Draft Handbook [4], so that OTTV limits proposed in the present study can be compared directly with limits set in the draft handbook. A different set of OTTV parameters would give different OTTV limits. Indeed, a different set of OTTV parameters, which is considered more representative of the external climate in Hong Kong, has been derived [15].

Limits for whole building and roof or wall and roof

In the consultancy report [3] and in-house study conducted by the Building Ordinance Office (BOO) [14], OTTV limits have been set for wall and roof as shown in Table 1. In the Draft Handbook [4], OTTV limits, however, are set for whole building and roof (see Table 2). Should the OTTV limits be set for the whole building and roof or for wall and roof? From Tables 1 and 2, it can be seen that for high-rise buildings where total gross external wall area is very much bigger than total gross roof area, it will not make much difference.

For low-rise buildings, the OTTV limits set in the Draft Handbook [4] are less stringent than the original limits recommended in the consultancy [3] and BOO [14] studies. Was it a conscious attempt to relax the OTTV limits for low-rise buildings, or was it simply a mistake (say, a typing error)?

The aim of OTTV control is to ensure building envelopes will be well insulated against external heat gain during the hot summer months. Such requirement will be similar to air-conditioned buildings with different ratios of wall area to roof area. For simplicity and practicability, it is, therefore, proposed that OTTV limits should be set for wall and roof, rather than whole building and roof. Again, this is indeed the approach taken by ASHRAE Standard [9] and Singapore OTTV Standard [10].

To have more design flexibility, it is also proposed that trade-off between wall and roof OTTVs be allowed. In other words, either the wall or roof OTTV limit can be exceeded, provided the following is met:

$$OTTV_{wall} \times A_{tw} + OTTV_{roof} \times A_{tr} \leq OTTV_{w,limit} \times A_{tw} + OTTV_{r,limit} \times A_{tr} \quad \ldots\ldots (4)$$

where

$OTTV_{roof}$ = OTTV for the entire roof

A_{tr} = total roof area

$OTTV_{w,limit}$ = OTTV limit for wall

$OTTV_{r,limit}$ = OTTV limit for roof

Evaluation of OTTV limits based on the reference building envelope

To gain some idea about how the proposed OTTV limits of 29 W/m^2 for wall and 19 W/m^2 for roof (based on the reference building envelope and OTTV parameters given in the draft handbook [4]) would fare when compared with requirements stipulated in OTTV standards in other places with similar climate or latitude, OTTVs for the reference building envelope have been calculated using parameters given in four other OTTV standards. These are summarised in Table 5. It can be seen that the proposed reference building envelope meets the ASHRAE [9] wall limit but exceeds that for the roof. It meets the Singapore [10] roof limit but exceeds the wall limit of 45 W/m^2 by about 2 W/m^2. For the Malaysian Standard [16], the proposed envelope exceeds both the wall and roof OTTV limits. Comment on Thailand [17] is similar to that on Singapore.

On average, the proposed limits of 29 W/m^2 for wall and 19 W/m^2 for roof are comparable to OTTV limits in places such as Singapore, Malaysia and Thailand, where the climate is similar to the Hong Kong summer (i.e. hot and humid). The wall OTTV limit is also close to the ASHRAE Standard for location with latitude similar to Hong Kong.

It has been found that cooling requirement due to heat gain through building envelope usually represents 10 – 20% of the total cooling load. The rest is mainly due to fresh air requirement and heat gain from people, lighting and equipment. As an initial step to encourage more energy-efficient design, it is not appropriate to set the OTTV limits too stringent, since the savings in energy might not justify the constraints that might be imposed on building design. The proposed OTTV limits based on the reference building envelope are considered reasonable in terms of keeping a balance between limiting heat gain into buildings and flexibility in building design.

To illustrate that these limits can be achieved without imposing too much constraints on architectural design, building

	OTTV, Wall (W/m^2)		OTTV, Roof (W/m^2)	
	Limit	Reference Building Envelope	Limit	Reference Building Envelope
ASHRAE [9]	92 (22.3°N Latitude)	90.0	26.8	40.8
Singapore [10]	45	47.1	45	29.5
Malaysia [16]	45	48.5	25	38.3
Thailand [17]	45	54.3	45	34.1
HK* (Present Study)	29	28.5	19	18.6

* Based on OTTV parameters (TD_{eq} and SF) given in Draft Handbook [4]
Different set of OTTV parameters would give different OTTVs

Table 5 Comparison of OTTV Limits and OTTV of the Reference Building Envelope

variables for designs that meet the proposed OTTV limit of 29 W/m² (for wall) are summarised in Table 6.

Wall Construction	Opaque Wall	Window		Window-To-Wall Ratio (%)
	U-Value (W/m²K)	Shading Coefficient	U-Value (W/m²K)	
Reinforced Concrete (Reflective Glass, No Insulation)	2.5	0.35	6	44
Reinforced Concrete (Tinted Glass, No Insulation)	2.5	0.6	6	26
Reinforced Concrete (Tinted Glass, No Insulation, 0.5m Deep Overhang)	2.5	0.6	6	32
Curtain Wall (Reflective Glass Spandrel with 25mm Insulation)	1	0.35	6	56
Curtain Wall (Tinted Glass, Spandrel with 25mm Insulation)	1	0.6	6	36
Curtain Wall (Reflective Glass with low shading coefficient, Spandrel with 25mm Insulation)	1	0.26	6	70

Notes
- Typical medium colour external surface with an absorption coefficient of 0.7 is assumed.
- Typical thermal conductivity of 0.036 W/mK is assumed for the insulation material.
- 70% WWR represents full floor-to-ceiling height window (based on 2.4m floor-to-ceiling height and 3.4 m floor-to-floor height).

Table 6 Summary of Wall Designs Meeting the 29 W/m² OTTV Limit for Wall

Discussion and Conclusion

There has been concern about the Government's OTTV study and OTTV limits. The Energy Efficiency Advisory Committee (EEAC) has asked the building professions to send in their comments and suggestions by 30 April 1993. The final shape and form of OTTV control of new building design will not be known until the EEAC has time to study all the comments and suggestions in mid 1993.

A reference building envelope has been developed. This envelope is considered reasonably energy-efficient in terms of its ability to limit heat gain into a building. Based on this reference building envelope, OTTV limits of 29 W/m² and 19 W/m² have been proposed for wall and roof, respectively. OTTV parameters given in the Draft Handbook have been used in calculating these OTTV limits. A different set of OTTV parameters would give different OTTV limits.

It has also been suggested that same OTTV limits should be applied to air-conditioned non-residential buildings such as commercial buildings and hotels; and limits should be for wall and roof, rather than whole building and roof.

To achieve energy savings and conservation in buildings, it should always be borne in mind that there are, broadly speaking, three key areas to address – building envelope, building services and building operation and maintenance. For optimum energy-efficient building design, building services and subsequent control and operation should also be considered; and the dynamic interactions between envelope, services and operation need to be analysed. Research work on these issues are being conducted by the Building Energy Conservation Unit at City Polytechnic of Hong Kong, as part of an on-going research project to arrive at energy indices (in terms of kWh/m² floor area) for air-conditioned buildings in Hong Kong.

Although OTTV method only deals with the building envelope, it has proved successful in reducing cooling demand in buildings when complemented with specific guidelines on lighting and air-conditioning design. The introduction of a moderate OTTV standard to building design together with guidelines on lighting and air-conditioning would be an initial step in the right direction to create a more energy-conscious design environment.

Acknowledgements

Work presented in this paper is funded by the Croucher Foundation.

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