An Overall Thermal Transfer Value (OTTV) -based approach in analysing the energy efficiency of buildings: A Review

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Abstract

A building envelope thermal heat gains plays a big part in the energy consumption and the buildings energy performance. Several thermal heat gains forecasting of a building envelope has been developed such Overall Thermal Transfer Value (OTTV) to help strategize the design of a building envelope and to reduce the energy consumption of a building. An OTTV is a measuring method of the energy consumption of building envelope. This paper provides a review on the role of OTTV in its approach to analyse the energy efficiency of buildings. Previous works concerning the mathematical calculation on analysing energy consumption using OTTV is also introduced. Other related methods for measuring energy consumption performance of buildings may also be presented.

Keywords: OTTV, energy consumption, building envelope

1.0 Introduction

According to the 2013 Survey of World Energy Resources, published by World Energy Council, global primary energy demand may increase 50% by 2050 and 80% of the increase is by the developing countries (Hong, Koo, Kim, Lee, & Jeong, 2015). In another report by the International Energy Agency (IEA) 2007, the building sector in developed nations accounts for 40% of the primary consumption. Areport by United Nation Environment Programme (UNEP) further vindicates this report as it also stated that 30-40% of the energy in the world is consumed in buildings (Najihah, Bakar, Yusri, & Abdullah, 2015). In view of this matter, the government of Malaysia has initiate several programs to ensure the efficient use of energy through the Ninth Malaysia Plan. These programs though mainly focus on the industrial, transportation and commercial sectors(Chandran, Sharma, & Madhavan, 2010). In the Tenth Malaysia Plan, the government has follow-up the initial initiatives on the energy efficient plans and has added the government buildings to its plan (Economic & Unit, 2011).
As the building sector contributes to nearly half of the primary consumption, it has been identified that 60% energy consumption of building is for space heating and air-conditioning (Huang et al., 2014). In countries with tropical climates such as Malaysia, Heating, Ventilation and Air-condition system (HVAC) is used in every commercial building to achieve thermal comfort, hence to contribution towards 60% of energy consumption. A method for a building to be more energy efficient is to look into the building envelope as it is where the thermal gain is. If the thermal gain could be decrease, thus the cooling load needed by HVAC would be less.
In 1975, the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) originated the use of overall thermal transfer value (OTTV) as a thermal performance index for the envelope of air-conditioned building (Yik & Wan, 2005). OTTV is used in many Asian countries such as Malaysia, Singapore, Hong Kong and Thailand as an approach in achieving energy saving in buildings. The usage of OTTV as a regulator in building energy efficiency has been researched to examine its capability as a regulator and its effect towards the building envelope design. This paper will attempt to provide a review of researched done on the role of OTTVand its parameters.

2.0 Overall Thermal Transfer Value

The Overall Thermal Transfer Value (OTTV) is a design parameter for building envelopes and has been commonly used as means to restrict excessive external heat gains into air-conditioned buildings. The concept of OTTV is to estimate the amount of building envelope heat gains based on the building parameters such as U-value, window-towall ratio, etc. Formulation of OTTV is different from one country to the other as the parameters in OTTV are climate depended.

In Singapore an OTTV limit of 45 W/m^2 is stipulated in it building regulation as a means to control the cooling-energy requirement of a building(Chua & Chou, 2010). In Malaysia Standard 1525:2007, a handbook for

Malaysia Code of Practice on Energy, an OTTV limit of 50 W/m² has been specified. Difference in OTTV limits shows the difference of OTTV formulation and this paper will attempt to discuss the formulation OTTV in Malaysia, Singapore as well as Hong Kong. The formulation of OTTV was also compared with energy simulation This paper will attempt to (1) discuss the different formulations of OTTV of Hong Kong, Singapore and Malaysia, and (2) review the study of OTTV and its comparison towards energy stimulation tool DoE-2.

2.1 OTTV Difference of Formulas

OTTV formulation generally is estimation on the rate of average heat-transfer to the building envelope divided by the time of operation of the air-conditioning system and the envelope area:

$$\text{OTTV} = \frac{\text{Total heat gain through building envelope } (Q_e)}{[\text{Total operating time of air-conditioning system } (T_{op}) \text{ x envelope area } (A_e)]} \tag{1}$$

In the paper by Chow and Chan, extensive simulation is required to derive Q_e, T_{op} and A_e. In their paper, six parameters of the OTTV was studied which are wall-to-window ratio (WWR); the glass-shading coefficient (SC); the window *U*-value (U_r); the opaque wall *U*-value (U_w); the opaque wall heat capacity (H_w) and the wall surface absorptance (α). These parameters are all affected by the local climate. From this formulation, the formulation of the OTTV external wall of a building could be written as follows:

$$\text{OTTV} = \frac{\text{Heat conduction through opaque wall x Heat conduction through window x solar heat gain through windows}}{[\text{Total opaque wall + window area}]} \tag{2}$$

The heat conduction and solar heat gain is as follows:

Heat conduction through opaque wall $= A_{wi} \text{ x } U_w \text{ x } TD_{eq}$ (3)

Heat conduction through window $= A_{fi} \text{ x } U_f \text{ x } \Delta T$ (4)

Solar heat gain through windows $= A_{fi} \text{ x SC x SF}$ (5)

Thus, the formula could further be simplified as per the following

$$\text{OTTV} = TD_{eq}(1\text{-WWR})U_w + \Delta T\,(\text{WWR})U_f + \text{SF(WWR)(SC)} \tag{6}$$

A_{wi}	Total area of opaque wall
U_w	U-value of opaque wall
U_f	U-value of fenestration/window
TD_{eq}	equivalent temperature difference
A_{fi}	Area of fenestration
U_f	U-value of fenestration
ΔT	Temperature difference of outdoor and indoor conditions
SC	Solar coefficiency
SF	Solar factor
WWR	Wall-to-window ratio
CF	Solar correction factor
α	Absorptivity of wall

Figures for the TD_{eq} ,ΔT and SF differs as it depends on the countries climate. As Hong Kong consist of a four distinct seasons, including a hot and humid summer and a cool and dry winter a different summer formula is proposed. While Singapore and Malaysia has the same tropical climate which are hot and humid climate throughout the year yet its formula are different as these countries are at different latitude from each other. As per the paper by Chow and Philip, Hong Kong denotes the OTTV formula as fig. (9) but in summer operation the cooling energy consumption increases thus derived by Chow and Chan as fig. (10). For curtain-walled commercial buildings with window-to-wall ratio more than 0.5, over 70% of space heat gain will be due to fenestration, hence the equation is simplified as fig. (11). Table 1 shows the formulas from the three different countries that has been formulated thus the figure TD_{eq} ,ΔT and SF is constant. All of the formula are only assessing the building envelope and does not include terms for the roof heat gain.

Table 1: Summary of OTTV formula in Malaysia, Singapore and Hong Kong

Country	Formula
Malaysia	OTTVmsia = 15α(1-WWR)*U*w+6(WWR)*U*f+(194xCFxWWRxSC)
Singapore	OTTVspore = 11.88α(1-WWR)*U*w+3.39(WWR)*U*f+210.92(WWR)SC
Hong Kong	OTTVhk= 1.96(1-WWR)*U*w+2.62(WWR)*U*f+143.4(WWR)SC OTTVsm= 11.4(1-WWR)+2.6 (WWR)*U*w+204.2(WWR)SC OTTVsm= 204.2(WWR)SC

2.2 OTTV and Simulation Studies

Several papers were published such as Chow and Chan, Chua and Chou as well as Chow and Philip, comparing the energy usage figure produced by OTTV to be sufficient and whether it has any deficiencies. Table 2 compiles the findings on OTTV.

Table 2: Finding on OTTV

Paper	Country	Findings
(Chow & Chan, 1995)	Hong Kong	• WWR, Sc and α parameters plays an important in the OTTV, these parameters could provide guidelines for designers to optimize thermal performance of the envelope. • Some modification towards the TDeq should be made.
(Chow & Philip, 2000)	Hong Kong	• OTTV has many limitation and does not address total building energy control, thus can only be regarded as a preliminary step. • The OTTV values calculated using equations by Chow and Chan is to be found closest to those simulated by computer programs compared to other formulation.
(Yik & Wan, 2005)	Hong Kong SAR	• In a sub-tropical climate such as Hong Kong, acceptable correlation between OTTV and energy use for air-conditioning could be achieved if only the cool months was ignored thus it remains an inadequate measure for an envelope performance. • For flexibility in meeting control requirements in most economical manner, a second route such as computer simulation should also be part of compliance demonstration.
(Chua & Chou, 2010)	Singapore	• Envelope Thermal Transfer Value (ETTV) has a strong correlation with the annual cooling energy consumption. • SC and WWR has a strong influence towards the ETTV and the reducing of Uf even if rather insignificant, the slight appreciation would influence if there is an increase in WWR which would attribute towards the increase in fenestration. • It is possible to lower ETTV by 30% in buildings by incorporating cladding in walls.

		• Load correlations for the energy-estimating methodology for commercial buildings have been updated to reflect the effects of absorptance on cooling energy;
(Chua & Chou, 2011)	Singapore	• A new correlation factor has been proposed to relate annual cooling load to envelope heat gains by taking into consideration the effects of outdoor ventilation air rate γ. • By using the new correlation factor γ, comparison of energy consumption VAV system versus CAV system could be made and VAV system proves to have better cooling efficiency. • Extending the design day concept to buildings experiencing sub-tropical climate, the cooling energy consumption of buildings in Hong Kong during the cooling months were found to be in good agreements with simulated results.

3.0 Discussion on Research Findings on OTTV

These papers mostly compared OTTV values and computer stimulation findings in its findings. The computer simulation tools used wereDOE-2.1D program developed at the Lawrence Berkeley Laboratory, with the year 1980, BLAST 3.0 and TRANCE 600 which was used to predict annual energy heat gain. The case studies used were of a single zone building with volumes ranging from 4000m³ to 40,000m³.

From these papers, it was highlighted the skepticism the usage of OTTV as a building energy regulator in building compliance as Hong Kong and Singapore makes it mandatory for building submission to include the OTTV calculation in its building submission (Hui, 1997). OTTV calculation was compare to buildings simulation for its value and the OTTV formula is scrutinized to formulate calculation most closely related to the computer simulated value.The paper by Chow & Chan and Chow & Philip research closely towards these thus a simplified formula of OTTV by Chow & Chan was formulated whereby it was close to the simulated computer value. The paper by Yik& Wan whereby does acknowledge this, still stands by that computer simulation is still necessary as part of to meet building control requirement as OTTV still has many limitation.

One of the limitations identified is the absence correlation factor of outdoor ventilation rate researched by Chua & Chou. The research done on the outdoor ventilation rate proves with different usage of air-condition system it could affect the cooling efficiency of the building whereby affecting energy consumption.

In 2 of the papers, it does highlight the ranking of the OTTV parameters wherebyWWR, Sc and α plays the most important role in the OTTV formula while $U_f$would be significant if the building envelope consist mostly of fenestration whereby it would increase the WWR.

From the OTTV formula it is also apparent that the solar heat gain through the fenestration play a part in the energy consumption as the SF figure is bigger than the TD_{eq} and ΔTfigure (Consumption, 2009). This would play a part when considering the preliminary design for the building envelope.

4.0 Conclusion

These objectives of these papers mostly were to compare OTTV values and computer stimulation findings to reinforce the usage of OTTV as compliance in the building regulation whether it is adequate. As proven, OTTV has many limitations but as findings and researches are made, OTTV formulation could be rectified to establish its accuracy. Thus, it is understandable to that OTTV should not be the only tool to establish a building efficiency as many other parameters of the building are ignored such as a building management system.

With these arguments, it may have influence Malaysia to partake OTTV as a voluntary tool and not a mandatory tool as in Singapore and Hong Kong in its building compliance as it is stated in MS1525:2007.Though without enforcement of such tool, there is no enforcement in developing an energy efficient building or development. A step takento encourage the energy efficiency in buildings, non-governmental organization such as PersatuanArkitek Malaysia has developed an assessment tool which is Green Building Index (GBI) in 2009. It is a self-assessing system and is a voluntary tool (www.greenbuildingindex.com, 2014). In complying towards this self-assessing system, there are several parameters to investigate as it will determine the overall score of the building whereby one of it is using the OTTV tool.

Though OTTV is a small fraction in the GBI assessment, it can be a major influence to the whole building energy usage. As proven by the papers, OTTV and the computer simulation does give a close result on the building energy usage thus the usage of OTTV could not be entirely ruled out and enforcing its usage will ensure energy efficiency in every development.

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