# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

In this section of the dissertation, previous works and researches done in relation to the topic we are presenting will be reviewed. Besides having a better understanding from what have been done, this portion of dissertation gives the theoretical background study and review to help establish a frame work of the topic to ensure that the topic presented is relevant and unique. The 3 main area of this chapter are Building Envelope Thermal Transfer Value (ETTV), Total Cooling Energy ($E_c$) Consumption and Relationship between Envelope Thermal Transfer Value (ETTV) and Cooling Energy ($E_c$) Consumption.

## 2.2 BUILDING ENVELOPE THERMAL TRANSFER VALUE (ETTV)

A building ETTV is a performance measure of the building envelope by averaging the heat gain into a building for commercial building in Singapore. Using concepts of OTTV criterion, building external wall envelopes can be designed to take cater for a reduction in external heat gain hence required cooling load.

ETTV formulation takes into account the following three basic contributions to heat gain through the external wall of a building only namely (Chou; 1996):

i) heat conduction through opaque wall

ii) heat conduction through fenestration

iii) solar radiation through fenestration

The first building envelope thermal transfer value concept was presented in 1975 by the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) as Overall Thermal Transfer Value (OTTV) and was widely accepted worldwide. Since then, the concept of OTTV has been widely used by countries all over the world with modification and formula improvement to suit their own specific usage and conditions. Many countries all over the world has also make OTTV calculation mandatory and part of the building legislative in the effort to promote energy efficient buildings. This was inline with the effort to improve and promote energy efficient and sustainable in buildings.

In ASEAN context, the ASEAN – USAID Building Energy Conservation Project (1982-92) was an essential research basis for supporting the standard development in ASEAN countries (Deringer & Busch; 1992). Although many modification has been made to the original formula used for the OTTV calculation to suit various condition and building specification, the concept of OTTV remain as it was first presented in 1975 by the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE).

From ASHRAE Standard 90 (1975), the OTTV formula can be expressed as:

$$OTTV = TD_{eq}(1 - WWR)U_W + \Delta T(WWR)U_f + CF \times SF(WWR)SC \qquad (2.1)$$

The equation shall be applied to every external wall of a given air conditioned building to obtain the OTTV of the entire building envelope by using the weighted average values of all the walls.

In Asia, Singapore was the first country to develop an OTTV standard with some refinement to suit the local climate and construction practices as such the building mass (PWD; 1979). The initial OTTV calculation included 2 different formulas to calculate external wall and roof thermal transfer value respectively as follows:

$$OTTV_{wall} = 10\ (1 - WWR)U_w + 5(WWR)U_f + 130(WWR)SC \qquad (2.2)$$

$$OTTV_{roof} = \frac{[(A_r \times U_r \times 16) + (A_{sl} \times U_{sl} \times 5) + (A_e \times SC \times 320)]}{A_o} \qquad (2.3)$$

The maximum permissible values of both OTTV calculations were set at 45 W/m$^2$.

However studies done has shown that the existing formulation was not accurate and is inadequate to correlates the total heat gain through a building envelope and hence not reliable in determining the annual cooling energy use (Turiel; 1988 and Chou and Lee; 1988).

Thus a more accurate new formula was formulated in 1988 by S.K. Chou (National University Of Singapore) in collaboration with Singapore's Building Construction Authority to replace the OTTV formula and was renamed Envelope Thermal Transfer (ETTV). A similar review was also done to replace the OTTV formula for roof and it was renamed Roof Thermal Transfer Value (RTTV).

$$ETTV = 11.9(1 - WWR)U_w + 3.37(WWR)U_f + 210.9(WWR)(CF)SC \quad (2.4)$$

$$RTTV = 12.5(1 - SKR)U_r + 4.8(SKR)U_{sl} + 485(SKR)(CF)SC \quad (2.5)$$

The maximum permissible value of both ETTV and RTTV calculations are set at 50 W/m$^2$. Nevertheless limitation to the formula still exist where the formula is designed for commercial buildings where the averaging of annual sum of the building loads over specific working operation hour (Chou; 2010) was mainly during the day where the heat gains are at its peak.

In 2008, the ETTV concept was extended to overcome this limitation and cover residential buildings and was named Residential Envelope Transmittance Value (RETV). The maximum permissible value of RTTV is set at 25 W/m$^2$. This due to the parameters of the operation for residential buildings differs from commercial building where most energy usage occurs during night time. Thus from the correlation done to average the total heat gain of the building from the day time load, the following RETV formula was obtained (Chou; 2010).

$$RETV = 3.41(1 - WWR)U_w + 1.3(WWR)U_f + 58.6(WWR)(CF)SC \quad (2.6)$$

Based on the above formulations done, it is clear that no formulation was done to determine the building envelope thermal transfer value of mixed development buildings. This is essential because the operation of these buildings again differs from commercial and residential building. At present, the building envelope thermal transfer value of building in Singapore is represented as follows (BCA; 2004):

i) Envelope Thermal Transfer Value (ETTV) for commercial buildings

ii) Roof Thermal Transfer Value (RTTV) for roof

iii) Residential Envelope Transmittance Value (RETV) for residential buildings.

However to date in Singapore, any mixed development building are classified as commercial buildings and shall use the ETTV formulation.

## 2.3 TOTAL COOLING ENERGY ($E_c$) CONSUMPTION

The use of energy for any buildings is inevitable as the demand for comfort is unavoidable. Energy in buildings is used for a majority of activities as such HVAC, lighting, vertical transportation, pumps of all sorts and equipment. In fact the highest energy consumption from any building would be the air-conditioning equipment. This was reported by (Kinney and Lee; 2000) where an energy audit was performed on a five-star Singapore hotel which is similar to most commercial developments.

Thus, the heat gain from the building has a direct impact on the $E_c$ consumption of any building especially commercial and mixed developments in term of both operational and building efficiency design as these buildings operate everyday all year round.

The total cooling energy consumption, $E_c$ is defined as the total energy used by an air conditioning system to cool a space. Conventionally to obtain $E_c$, the total cooling load required will need to be determined. This can be done using 3 method originally mentioned in ASHRAE:

i. Transfer Function Method (TFM)
ii. Cooling Load Temperature Different /Cooling Load Factors (CLTD/CLF)
iii. Total Equivalent Temperature Differential / Time Averaging (TETD/TA)

However studies have been done to alternatively determine this required cooling load. Use of OTTV and cooling day concept was introduced for large scale commercial by developing a set of cooling load and energy estimating equation (Chou & Chang; 1993). Several studies using new assessment of modified method to determine cooling were also done. Among them are modified bin method from 1983 (ASHRAE; 1983) up to the latest in 2010 using modified TFM method (Fouda & Melikyan; 2010). In 2011 however, use of data intelligent approach as such probabilistic entropy based neutral (PENN) model to predict the cooling load of a building was introduced (Kwok & Lee; 2011). This is done by introducing 2 parameters, the dynamic occupancy area and dynamic occupancy rate.

By knowing the required cooling load, the equipment can be properly selected. As there are various systems available in the industry nowadays, the selection of the types of air conditioning system is vital to ensure the consumers and building owners choose the most suitable system for their respective building. These system may range from big scale air conditioning system as such chilled water system, condenser water system complete with cooling towers and expansion tanks to small scale systems such as multi split and split system. The determining factors of choosing the proper system would involve a study of the initial investment, payback, operation and maintenance cost, life cycle and etc.

Studies done by various air conditioning system suppliers namely Daikin, Mitsubishi, Carrier and e. show that the energy consumption for air conditioning system, $E_c$ per kilowatt (kW) is lower using big scale air conditioning system is to small scale air conditioning system when the required cooling load is high. However for a low required cooling load, small scale air conditioning system would be most economical besides being able to eliminate any requirement for a plant room. The total energy consumption of the equipment can be determined by using the COP of the equipment. This also means that the cooling energy consumption for a particular building may differs depending on the type of air conditioning system used.

In the study to determine the cooling energy consumption, it was demonstrated that it can be estimated using modified degree day method for cooling (Chou; 1986).

$$E_{ce} = \frac{(c)(Q_d)(24)(D)(\alpha)(\beta)}{\Delta t(COP)^n} \tag{2.7}$$

The cooling degree day is defined as the difference between the daily mean outdoor temperature and reference temperature and is expressed (Chua & Chou; 2010) as:

$$D = \sum_{i=1}^{n}\left(T_m - T_{ref}\right) {}^{\circ}C.day \tag{2.8}$$

The annual cooling energy consumption was formulated as the total yearly cooling load. (Chua and Chou; 2010).

$$E_{ac} = Q_{env} + Q_{int} + Q_{misc} \tag{2.9}$$

## 2.4 RELATIONSHIP BETWEEN ENVELOPE THERMAL TRANSFER VALUE (ETTV) AND TOTAL COOLING ENERGY ($E_c$) CONSUMPTION.

Based on a study done in Singapore showcasing a group of building, it was shown that the $E_C$ consumption constitute from 45.1% up to73% from the total building energy consumption (Lee: 2009). This clearly shows that $E_C$ consumption being the main contributor to high energy usage in buildings. There are a several methodologies to reduce these numbers mainly with the use of high efficiency equipment and better energy management program and also with a reduced ETTV value.

As proved by Chou and Chang (1993), ETTV has a direct linear relationship with the cooling energy consumption. Using Equation 2.7, a simplified equation was further developed by Chou and Chang (1993) incorporating the ETTV as follows:

$$E_{ac} = \frac{(\gamma)(ETTV)A(24)(D)(\alpha)(\beta)}{\Delta t(COP)^{n}} \qquad (2.10)$$

Therefore in order to reduce the cooling energy load significantly, the ETTV value shall need to be reduced as well aside from higher efficient equipment used and improve energy usage program. This can be achieved using better building orientation, glass value and wall thickness and shading design to reduce the overall building heat gain. Building envelope thermal transfer value with a lower value tends to absorb lesser heat gain thus require lesser cooling load to cool down the building which eventually translates to a reduced energy required for cooling purposes.

However a separate study was done in 2005 to evaluate the appropriateness of using building thermal transfer value to regulate envelope energy performance of air conditioned buildings (Yik and Wan; 2005). It was found that OTTV do not reflect the thermal performance of the building envelope for sub-tropical climate region and region with cool months.

Thus in this paper, the relationship between ETTV and $E_c$ will be study with the use of a case study located in a tropical climate region, Singapore to determine if ETTV can be used to estimate cooling energy consumption of a building.