CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this section of the dissertation, the methodology used to fulfill the objectives will be presented. In order to determine the relationship between the building ETTV and the E_c consumption, the mixed development case study used is presented. Thereafter, the method to obtain the building ETTV will be presented. Following to that, methods to obtain the E_c consumption of the building will be discussed and addressed. Lastly we will present method to relate two values and how the two values can be correlated. The correlation found however will be specific to the case study building.

3.2 THE CASE STUDY

The case study used for this paper is a medium scale mixed development building involving the restoration of a four-storey conservation chophouses and the development of a new six storey rear extension. The project is wholly owned and developed by an established private owned developer M/S Hong How Group. The development was given the name 36 38 Armenian Street serves as a mixed use commercial featuring SOHO style boutiques office units, retail shops and restaurants. The four storey conservation shop house is addressed as 38 while the new six storey rear extension is addressed as 36.

The development started in September 2008 and was completed by June 2010. The total development cost is expected to be approximately S$ 80 million (RM 200 million). The development boasts a total strata area of 5,301 m^2 where the four store conservation block occupies 1,274 m^2. In total, the development consist of an impressive entire en-block of private art gallery for Block 38, while Block 36 houses 24 unit of boutique office units (SOHO) and 13 units of retail units. Further to that, the development is a Green Mark certified project and has also won numerous award for its conservation, green and energy efficiency effort.

Being a conservation building, the façade of the building adopted the same feature from the previous 1920s treatment with the use of improved green glass, wooden features mixed with modern brick walls and reinforced concrete. These were done to ensure minimal absorption of building heat gain without compromising the unique features and requirement to maintain its conservation status.

Apart from that, the development also adopted the use of Variable Refrigerant Volume (VRV) flow air conditioning system to cater for its diversified usage and tenants. Although the use of VRV system does not contributes to a high energy saving as in chilled water plant system, studies were done to justify the best air conditioning system to be used for the development in term of space utilization, development size and initial investment cost and payback period. Nevertheless the VRV used has a Coefficient of Performance (COP) of 3 which is still very relevant for a development of this size. Thus given the diversity in use for the development and the equipment in place, it is ideal that the development is chosen as a case study to for our research to study the relationship between the building thermal transfer and cooling energy consumption.

To better understand the case study building, the building plan and elevation of the case study building of medium scale mixed development is presented in Appendix A courtesy from M/S Hong How Investment Pte Ltd.

3.3 DETERMINING BUILDING ENVELOPE THERMAL TRANSFER VALUE (ETTV)

As the development chosen is a mixed use development, it neither falls into commercial nor residential category. This is because for a commercial regardless as an office, retail or hotel, the development consideration for general space planning would be stringent in term of its buildability and the operation will be peak as long as the premise is in operation. For a residential however the building characteristics would be totally the opposite with lesser consideration for general space planning and peak usage mainly at night.

The chosen case study is a combination of all both commercial and residential. The nature of the building occupancy and usage nevertheless mimics a 24 hour commercial building. Thus the ETTV calculation for the building can be considered using the commercial model. The model proven by Chou (2009) which is also widely used in Singapore context under the Building Construction Authority (BCA) is adopted in this dissertation to calculate the ETTV value for commercial building with a maximum permissible value of 50 W/m^2.

However, there are 3 parameters that shall need to be predetermined first:

i. Envelope Area Calculation

ii. Thermal Transmittance (U-Value) Calculation

iii. Shading Coefficient Value (SC- Value) Calculation for glass fenestration

3.3.1 Envelope Area Calculation

The envelope area considered for the calculation of ETTV shall only take in account of air conditioned space. Thus kitchen and toilet's wall and windows where it is non-air conditioned are not taken into the calculation.

To determine the envelope area of a respective building, the elevations of the building must first be obtained. This shall be for all façade of the building. The façade facing for each elevation shall be determined to be North, South, East, West or any of the in between.

Then the number of type of wall and fenestration with different configuration shall be determined. It is vital to assign each type of wall and fenestration individually for ease of calculation at later stage. Area of each wall and fenestration type where the area is air conditioned is then measured and shaded on the elevation. This shall include any windows and walls regardless of the location and floor. These area measured shall then be tabulated in a table in accordance to the façade facing of the building for each elevation.

Thereafter the Window to Wall Ratio (WWR) value can be obtained. By using WWR, the façade and glass that impact the ETTV most significantly can be determined.

$$WWR_{NW} = \frac{\sum AG}{\sum A_{NW}} \quad (3.1)$$

3.3.2 Thermal Transmittance (U-Value) Calculation

The thermal transmittance or U-Value is the amount of heat that is able to flows through a unit area of a building or material section under steady state condition in unit time per unit temperature difference of the air on either side of the section. The unit for this value is expressed in W/m^{2}K as follows:

$$U = \frac{1}{R_T} \quad (3.2)$$

$$R_T = R_O + \frac{b_1}{k_1} + \frac{b_2}{k_2} + \cdots + \frac{b_n}{k_n} + R_i \quad (3.3)$$

The above calculation is also applicable for air space resistance using the same methodology. The set of R values for basic materials can be obtain from various references, publication of material science, manufacturer or as per in this paper from the Singapore's Building and Construction Authority Code on Envelope Thermal Performance for Buildings.

3.3.3 Shading Coefficient Value (SC-Value) Calculation

Shading coefficient is rate of solar heat gain measured when transmitted through a 3mm clear glass. In general, any glass selected shall come with a U-Value and SC-Value from the manufacturer. However with the different fenestration system and shading device configuration, a new SC-Value for the glass will need to be calculated for each system. This new SC-Value differs from the initial selected glass rate of solar heat gain due to the shading coefficient of the fenestration system and is expressed as follows:

$$SC = \frac{Solar\ heat\ gain\ of\ any\ glass\ and\ shading\ combination}{Solar\ heat\ gain\ through\ a\ 3mm\ unshaded\ clear\ glass} \tag{3.4}$$

Alternatively, the SC-Value for any fenestration can be calculated using the following formula.

$$SC = SC_1 \times SC_2 \tag{3.5}$$

The effective shading coefficient of the glass; SC_1 shall be based on the manufacturer value.

Using predetermined tables for effective shading coefficient of horizontal projection at various angles of inclination, the shading coefficient of the external shading devices; SC_2 can be easily obtained. Unless the type of shading is not available from any predetermined values or tables, this effective shading coefficient SC_2 (annual) can be calculated from the basic solar data using the following expression.

$$Effective\ SC_2 = \frac{\sum Q}{\sum I_T} \quad (3.6)$$

$$= \left[\frac{2\times\sum_M(G\times I_D+I_d)+\sum_J(G\times I_D+I_d)+\sum_D(G\times I_D+I_d)}{2\times\sum_M(I_T)+\sum_J(I_T)+\sum_D(I_T)}\right] \quad (3.7)$$

where

Q = G x I_D + I_d (3.8)

G = A_e / A_w (3.9)

A_w = A_e + A_s (3.10)

= I_D + I_d (3.11)

3.3.4 Envelope Thermal Transfer Value (ETTV) Calculation

To determine the ETTV value of the building, the type of building shall be determine. Using BCA guideline, as mentioned a mixed development building shall be calculated as a commercial building. The following general equation shall be adopted.

$$ETTV = 11.9(1 - WWR)U_w + 3.37(WWR)U_f + 210.9(WWR)(CF)SC \quad (3.12)$$

However as there will be more than a single material and fenestration, the respective terms will need to be expanded to cover all elements of the facade.

$$ETTV = 11.9\frac{(A_{w1}\times U_{w1}+A_{w2}\times U_{w2}+\cdots+A_{wn}\times U_{wn})}{A_o} + 3.37\frac{(A_{f1}\times U_{f1}+A_{f2}\times U_{f2}+\cdots+A_{fn}\times U_{fn})}{A_o} + 210.9\frac{(A_{f1}\times SC_{f1}+A_{f2}\times SC_{f2}+\cdots+A_{fn}\times SC_{fn})(CF)}{A_o} \quad (3.13)$$

Using the above Equation 3.11, each individual wall facade ETTV shall be computed and then the average ETTV value using weightage averaging of the exterior wall shall be taken as the building ETTV as walls at different orientation receive different heat gain.

$$ETTV = \frac{A_{o1} \times ETTV_1 + A_{o2} \times ETTV_2 + \cdots + A_{on} \times ETTV_n}{(A_{o1} + A_{o2} + \cdots + A_{on})} \tag{3.14}$$

3.4 DETERMINING TOTAL COOLING ENERGY (E_c) CONSUMPTION

In order to determine the required energy used for cooling, the required cooling load shall first need to be determined. The total cooling load, E_{cl} required for the building is a combination of external and internal load. External load of building consist of heat transferred through building envelope while internal load consist of heat generating sources as such occupants, equipment, etc.

The required cooling load shall be design for the worst case scenario to cater for maximum heat load gain for the space in accordance to the usage. It is vital to takes into account of all loads experienced by the building under a specific set of assumed conditions for a properly designed load. The assumptions used for E_{cl} calculations are but not limited to the following:

i. Weather condition selected from a long term statistical database for the specific location as such tabulated by ASHRAE
ii. Solar load of the building is assumed to be on a clear day
iii. The building occupancy is assumed to be at maximum or design occupancy

iv. The ventilation rates are assumed either on specific air changes or maximum occupancy expected

v. All building equipment and appliances are considered to be operating as expected of a typical day of designed occupancy

vi. Latent as well as sensible loads are considered. According to the ASHRAE regulations, the sensible heat gain from people is assumed 30% convection (instant cooling load) and 70% radioactive (delayed portion).

vii. Heat storage in building envelope and interior materials are considered.

viii. Peak load calculations to consider the maximum load to size and select the refrigeration equipment.

Thereafter, using the calculated cooling load required, the type of air-conditioning equipment to be used can be selected. The selection of the equipment will depend on the type and capacity of the cooling load. In our study, the selected air conditioning system used is VRV system.

Using the calculated E_{cl} required and equipment schedule, the required E_c can be calculated using the COP of the VRV system selected. The E_c used by the development is obtained by adding all the energy consumption of the air conditioning equipment.

Using the same concept, a program named E-20 which is an Hourly Analysis Program (HAP) by Carrier will be used to determine the total heat load and required cooling load based on the calculated heat load. This program (E-20) calculates heat load is in accordance to ASHRAE standard with weather data simulation specific to the location and countries. The program is also capable of comparing the total energy use at a certain period with various alternatives in order to determine the optimum one.

3.5 DETERMINING THE CORRELATION BETWEEN ENVELOPE THERMAL TRANSFER VALUE (ETTV) AND TOTAL COOLING ENERGY (E_c) CONSUMPTION

Based on the above methodology to determine the ETTV value and E_c consumption, we shall adopt and relate it to our case study for the purpose of determining the relationship between ETTV and E_c consumption. Using the above methodology however, only 1 set of data for both ETTV and E_c consumption will be obtained based on the selected building material and its required E_c consumption.

Thus to obtain a set of data for the purpose of our study, we shall run the calculation with different set of parameters for both the ETTV calculation and cooling load calculation. Nevertheless for the purpose of obtaining a set of ETTV value, varying 1 parameter from the entire set of parameters in the calculation of ETTV will suffice.

For the simplicity of calculation, the most significant factors towards an ETTV calculation shall be selected; the glass performance. This is also the fact that the glasses performance is the underlying factor for the cooling loads calculation and E_c.

Table 3.1: Summary of Glass Type Used

Item	Description	U-Value	SC-Value
1	12 mm Clear Glass	4.84	0.91
2	6 mm Asahimas Green Glass	5.37	0.62
3	6 mm Asahimas Frosted Green Glass	5.6	0.56
4	13.52 mm Clear Glass (6mm Sunergy Clear + 1.52mm Clear PVB + 6mm Light Green)	5.3	0.51
5	13.52 mm Translucent Glass (6mm Sunergy Clear + 1.52mm Clear PVB + 6mm Light Green with Silk Screen White 30%)	5.3	0.46
6	13.52 mm Opaque Glass (6mm Sunergy Clear + 1.52mm Clear PVB + 6mm Light Green with Silk Screen White 100%)	5.3	0.32

Out of the 6 types of glasses used in our case study building, the most impactful glass will be selected for variation on the performance to show the effect that one glass can do; 13.52 mm Sunergy Clear Glass as follows:

Table 3.2: Variation of Glass Performance for 13.53mm Sunergy Clear Glass

Item	Description	U-Value	SC-Value
1	13.52 mm Sunergy Clear Glass 1	5.3	0.2
2	13.52 mm Sunergy Clear Glass 2	5.3	0.4
3	13.52 mm Sunergy Clear Glass 3	5.3	0.51
4	13.52 mm Sunergy Clear Glass 4	5.3	0.6
5	13.52 mm Sunergy Clear Glass 5	5.3	0.8

Using the set glass performance selected, the E_{cl} is calculated for each glass performance value using E-20 program.

By doing so, a set of ETTV value with its corresponding E_{cl} is obtained. Using the COP of the selected air conditioning system, the E_c can be calculated.

With the available data, a graph of ETTV vs E_c can be plotted to determine the relation between the two. The graph shall then be interpreted and a better understanding of ETTV impact on the cooling load and E_c can be revealed. The result obtained however will only be applicable to the case study building. However the findings will general and applicable to any building.