ANALYSIS ON THE PERFORMANCES OF AUTOCLAVED AERATED CONCRETES (AAC) FOR BUILDINGS IN A TROPICAL REGION

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ABSTRACT

Nowadays, with the development of the economy in recent years, the people standard quality of living also increases as the Malaysia has been maintaining high economic growth and thus, contributed to the rapidly rising of the energy consumption. About 45% of the total electricity used in the residential building sector for cooling accounts of air conditioning. This study deals with the optimum thickness of Autoclaved Aerated Concrete (AAC) of building constructions and the thermal performances of buildings with different wall systems in a Tropical Region. The results show that the optimum thickness of AAC wall orientation was 66mm varies from standard common practice of 100mm with the total annual cooling loads of 84957Wh and 79138Wh with the annual electricity costs of RM2209 and RM2062 per year respectively. While, the standard sand cement brick with and without insulation wall orientation with thickness of 209mm and 152mm, the total annual cooling loads was 87819Wh and 97604Wh with annual electricity costs of RM2283 and RM2538 per year respectively.. This research uses Autodesk Revit for building modeling and Autodesk Ecotect Simulation software to analyze the building energy performances in terms of cooling loads. The investigation is carried out for the building with the climatic condition of Malaysia. The results are compared between the four different wall systems of AAC with optimum thickness, AAC with standard common practice thickness, standard sand cement brick with insulation and standard sand cement brick without insulation wall systems in terms of optimum thickness and thermal with the costs performances and payback period of the building.

ABSTRAK

Kini, dengan perkembangan ekonomi dalam tahun-tahun kebelakangan ini, standart kualiti taraf hidup orang di Malaysia meningkat kerana Malaysia telah mengekalkan pertumbuhan ekonomi yang tinggi dan dengan itu, menyumbang kepada peningkatan pengunaan tenaga yang semakin pesat. Kira-kira 45% daripada jumlah tenaga elektrik yang digunakan dalam sektor bangunan kediaman untuk akaun penyejukan penghawa dingin. Kajian ini membincangkan ketebalan optimum Autoclaved Aerated Concrete (AAC) bangunan pembinaan dan prestasi haba bangunan dengan sistem dinding yang berbeza di Wilayah Tropika. Keputusan menunjukkan bahawa ketebalan optimum orientasi dinding AAC adalah 66mm berbeza dari standart amalan biasa 100mm dengan jumlah beban penyejukan tahunan 84957Wh dan 79138Wh dengan kos elektrik tahunan RM2209 dan RM2062 setahun masing-masing. Manakala, orientasi dinding standart bata pasir simen dengan dan tanpa penebat dengan ketebalan 209mm dan 152mm, jumlah beban penyejukan tahunan adalah 87819Wh dan 97604Wh dengan kos elektrik tahunan RM2283 dan RM2538 setahun masing-masing. Kajian ini menggunakan Autodesk Revit untuk membina model dan perisian simulasi Autodesk Ecotect untuk menganalisis prestasi tenaga bangunan dari segi beban penyejukan. Siasatan itu dijalankan bagi bangunan dengan keadaan cuaca di Malaysia. Keputusan dibandingkan antara empat sistem yang berbeza dinding AAC dengan ketebalan optimum, AAC dengan standard ketebalan amalan biasa, standard bata pasir simen dengan penebat dan standard bata pasir simen tanpa sistem dinding penebat dari segi ketebalan optimum dan kos prestasi bangunan serta tempoh pulangan balik.

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LIST OF ABBREVIATIONS

AAC	Autolaved Aerated Concrete
SBS	Sick Building Syndrome
EPI	Energy Performances Index
Pcf	Pound per cubic foots
CMU	Concrete Masory Unit
PWF	Present Worth Factor
ADH	Annual Degree Demand Hour
COP	Coefficient of performance
PBP	Payback Period

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

The development of the world technologies nowadays cannot be denied. But the movement of the technologies is concurrently with the side effects to the human beings and the environment also. This situation will make the burden especially to the earth residents; the humans, the animals and the plants that have to face all the effects from that. So, nowadays everyone is busy seeking for their comfort and at the same time they are also concern about the energy utilization on how to use that efficiently.

Recently, the standard quality of living is getting higher from time to time following the current economic weather. In order to have comfort condition, peoples use air conditioning in daily life activities such as during working or even resting. But then, the using of air conditioning frequently will contribute to the ozone depletion layer rapidly. Thus, it will increase the global warming effects and may results in uncomfortable condition for the human.

The study of cooling loads is very important as it is one of the ways on how to overcome he energy related issues. Nowadays, the using of air conditioning is not an option but it is a need for human due to the unstable weather condition. But the using of air conditioning use more energy for cooling load that contribute to higher costs for the users.

So, the study of cooling loads is important to find the alternatives ways to reduce the energy consumptions and the costs that consumed for the energy used besides to overcome the energy depletion issues.

Thus, with the great development of technologies today, a lot of R & D on the efficient energy utilization is done in order to find new alternative ways to solve the problems regarding to the human comfort. Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation, because by maintaining this standard of thermal comfort for occupants of buildings or other enclosures is one of the important goals of HVAC (heating, ventilation, and air conditioning) design engineers.

The buildings are where the humans express their comfort. So, the energy efficient buildings need to be designed. Energy efficient buildings can be defined as buildings that are designed to provide a significant reduction of the energy needed for heating and cooling, independently of the energy and of the equipments that will be chosen to heat or cool the building (Isover-Saint Gobain, energy efficiency, 2008).

1.2 PROBLEM STATEMENT

There is also a problem in determining the best design of the residential buildings in terms of the building performances. In determining the building performances, the whole structure of the building plays an important roles such as the wall thickness, the wall materials and the design of the building itself. AAC is a type of concrete block which have good thermal properties and efficiency. AAC is further considered a sustainable building product because of its excellent insulating qualities resulting in increased energy efficiency. AAC's thermal efficiency stems for three factors. First, AAC structures result in solid wall construction with integrated insulation. Entire wall coverage prevents the thermal bridging associated with conventional stud-framed walls, which essentially leave cold gaps around the stud and header. Second, the solid wall construction of AAC structures creates an air thigh building envelope, minimizing uncontrolled air changes while helping maintain desired temperatures and maximizing the efficiency of HVAC equipment.

Thirdly, AAC structures benefit from the added value of thermal mass and low thermal conductivity. The benefits of thermal mass however, vary by location, and are greatest in regions where outdoor temperature fluctuate above and below the desired indoor temperature over a 24-hour period.

Thus, in this case, the study on the optimum thickness of AAC wall for buildings in tropical region is important since the optimum thickness in this region still not clarified and the using of too thick of AAC blocks may increase the construction costs. The AAC block is widely used in other regions throughout the world but less practice in tropical region. Even in regions where the cost of building with AAC may currently be higher than conventional building methods, this higher initial cost must be balanced against savings due to lower operating maintenances costs, the structure's longer lifespan, lower initial outlays for required heating and cooling costs compared to conventional block building. Therefore, comprehensive study on the optimum thickness of AAC wall is needed to give the solution regarding to the building's performances.

Besides that, the performances of the building also can be designed to give a better surrounding to the humans. So, several steps can be executed to ensure the comfort condition of the buildings. For instance, by analyzing the building's cooling load of AAC buildings which can helps to identify the best thermal performances of the building in terms of the efficient energy utilization. In addition, the ways also can be multiply by analyzing the buildings with different materials. So, the best result of the performances can be decided when the analysis on the residential buildings in tropical region model is analyzed using the Ecotect Analysis 2010 software.

1.3 OBJECTIVES

i. To analyze the optimum thickness of AAC block for residential buildings in a tropical region.

ii. To analyze the cooling load and costs performances of residential buildings with different materials used in a tropical region.

1.4 PROJECT SCOPE

There are several parameters in order to control this research flow. This means that the parameters in which the boundary of the research is focused on. Therefore, the scopes of this research are as follow:

i. Identifying the optimum thickness of AAC walls by considering the standard requirements.
ii. Analyzing the thermal performances on the basis of the building's cooling loads.
iii. The building's materials for the walls construction, which are AAC and standard sand cement bricks only.
iv. Only focusing on the residential buildings in Malaysia for the tropical region climate country.

By applying this scope of project, the analysis can be done in order to get the best result of this research.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This paper describes the analyzing on the performances of Autoclaved Aerated Concrete (AAC) in buildings in tropical region for the efficient energy utilization and analyzing on the cooling load of residential buildings with different materials used. Various sources including journal, thesis, and reference books have been carried out and revised in writing this chapter.

Buildings, energy and the environment are key issues facing the building fraternity worldwide. With the increasing population and living standards, energy issues are becoming more and more important today because of a possible energy shortage in the future (Yilmaz 2007). Worldwide, the World watch Institute estimated that buildings consume at least 40% of the world's energy and 16% of the water used annually (Roodman and Lenssen 2005).

Although air-conditioning has played a positive role for economic development in warm climates, its image is globally mixed. Field studies demonstrate that there are substantial numbers of dissatisfied people in many buildings, among them those suffering from Sick Building Syndrome (SBS) symptoms, even though existing standards and guidelines are met. A paradigm shift from rather mediocre to excellent indoor environments is foreseen in the 21st century (P Ole Fanger, 1999). It has also been reported that more than 40%of the energy consumed by Malaysian buildings can be reduced if energy efficiency is practiced and sustainable technologies are applied to building envelope (Azni Zain, 2008).

Besides that, according to the Ninth Malaysia Plan, energy conservation culture must be inculcated. Buildings should be designed to optimise energy usage. Such resources need to be prudently and carefully utilised while the Malaysian government is adopting measures to reduce wastage by enhancing energy efficient buildings and increasing energy sufficiency (9th- Malaysia- Plan, 2006).

In most countries, the buildings account for energy consumption is about 40%, yet their potential for energy efficiency is huge. By using adapted insulation and energy savings techniques, up to 80% of a building's energy consumption for heating or cooling can be saved. Cheung had conducted a study to reduce the cooling energy for high-rise apartments through an improved building envelope design (Cheung, Fuller et al. 2005). Consequently, in order to solve the problems regarding to the human comfort, the buildings need to be designed to fulfil the human comfort besides provides an efficient energy utilization or energy saving practice.

2.2 AUTOCLAVED AERATED CONCRETE (AAC)

AAC is applied as a material for wall construction in residential and commercial buildings. It is a building material widely used in Europe for many years and now it is finding its place in the Malaysia market as well. is a unique building material made from quartzite silica sand, water, lime, cement and anhydrite, which are processed with a gas-forming aluminium paste, to create a highly porous, lightweight, insulating mineral product. The manufacturing process of AAC is a precast product manufactured by combining silica (either in form of sand or recycled flyash), cement, lime and water, and pouring it into a mold. The AAC is cut into blocks or panels which are then steam and pressure-cured in an autoclaved (Stefan Schnitzler, October 2006). AAC's structural appearance resembles that of Styrofoam – a solid matrix skeleton surrounding thousands of pores (Georgiades et al. 1991). Besides that, these pores form from the most distinguishing and important feature of the AAC and the total porosity (by volume) for the most common AAC approaches percentage of between 75 and 90 (Wagner et al. 1995).

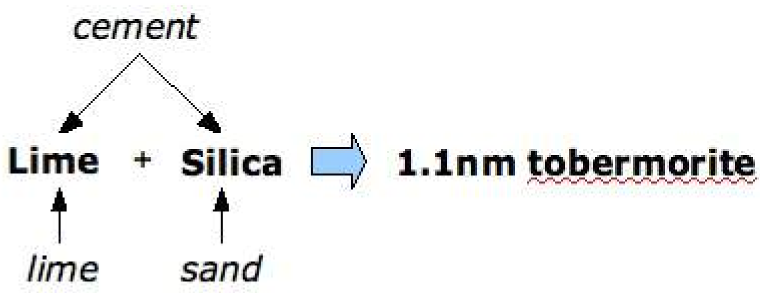

Figure 2.2.1: Chemistry notation of AAC composition

Source: WHD Microanalysis Consultants Ltd 2005-2012

The AAC was invented since a long time ago. It was developed by a Swedish architect and inventor Johan Axel Eriksson and then was patented in 1924. At that time, the architect was looking for building material that had the properties of wood-good thermal insulation, solid structure, easy to work with and handle but without the disadvantages of combustibility, decay and the termite damage. In the early 1950's the first residential applications became popular with the introduction of a home construction division called Hebel Haus (Hebel: History of AAC, 2010).

According to Stefan Schnitzler, (October 2006), AAC is not a new building materials that developed in Sweden in response to increasing demands on the timber supplies. AAC is a lightweight manufactured building stone which comprised of all natural raw materials. AAC is used in wide range of commercial, industrial, and residential applications and has been in use in Europe for over 70 years, the Middle East for the past 40 years and South Africa and Australia for over 70 years.

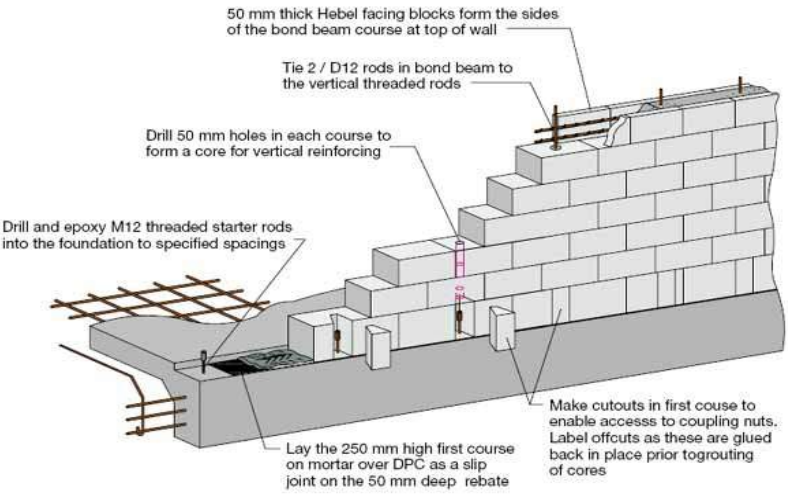

Figure 2.2.2: General arrangement of wall construction

Source: Hebel Products, October 2006

The using of AAC for building gives more advantages. The ability of a product material use, utilize recycled product and avoid toxic emissions are the key factor in determining whether a product qualifies as “green” or can be used in a sustainable manner besides reduces the additional material use and minimizes waste and pollution.

2.3 AAC THERMAL PERFORMANCES

AAC is an unique building concept since it helps to save on CO_2 pollution by lowering the cooling or heating cost by more than half. The AAC materials provide a comfortable environment which satisfies other demands required for today’s building materials. The block’s structure of the buildings which contains air pockets will give the same thermal properties in all directions since the air is one of good insulator. According to the Energy Performances Index (EPI) which the index cannot exceed the value of 100, a comparison have been made between the AAC home with Concrete Masory Unit (CMU) home. The result from the comparison shows AAC received a value of 84.4 and the CMU house received 89.71 and this shows that AAC is 5% more energy efficient than CMU house (MHE International, LLC 2004-2012).

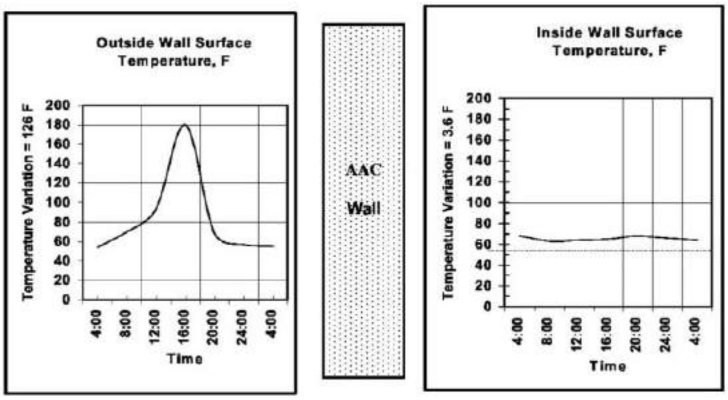

Figure 2.3.1: AAC Wall Temperature Difference

Source: Global Modular Concepts, 2006

The thermal performances of any building material may determine several factors and may not be assumed either effective of ineffective on the basis one of the thermal performances factors such as the thermal conductivity, K, material resistance, R and the heat transmission coefficient, U.

A previous study on AAC from MHE International shows the results regarding to the thermal performances of AAC. For thermal conductivity, K which measures the conductivity of the building material where the major factors is the density. AAC with 32 pcf "pound per cubic foot" of design density weight performs 10 times better than 150 pcf concrete and as half as good as polystyrene insulation board. While the R-value depends on the material thickness and the density where it shows the resistance of a material to conduct or allow heat flow which an 32 pcf AAC material, 8" thick, performs again 10 times better than a 150 pcf concrete wall 8" thick. But their 8" AAC wall performs up to 70% as good as 3 ½ batt insulation. For the heat transmission coefficient U-value, which is defined as how much heat transmits through 1 sqft of a building envelope in 1 hour. The results of the study shows heat is required to raise 1 lbs of material by 1 degree Fahrenheit it shows clearly that it takes 20% more heat to raise the temperature of an AAC building than of an concrete building and it takes 35% more heat to heat up an AAC building then an 3 ½ batted insulated wood frame house (MHE International 2004-2012).

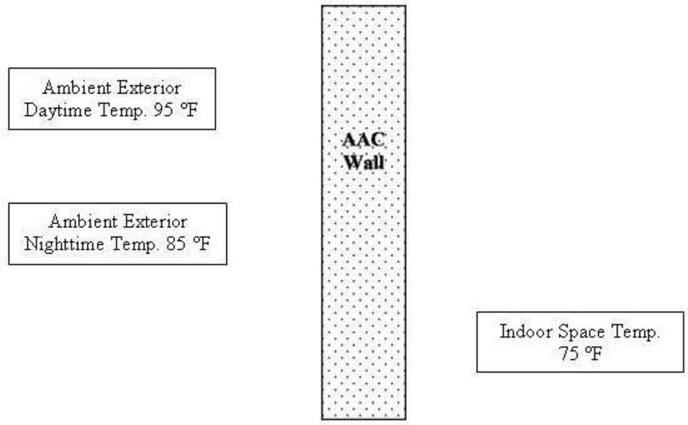

Figure 2.3.2: Example of delayed heat flow

Source: Global Modular Concepts, 2006

2.4 COOLING LOAD OF BUILDING

According to Pita (1998), the air inside a building receives heat from a number of sources during the cooling session and it must be removed in order to maintain the temperature and humidity of the air at comfortable condition. The amount of heat that must be removed to achieve comfortable level is called cooling load. The cooling load must be determined due to the basis for the selection of proper size of air conditioning equipment and distribution system. Besides that, the cooling load calculation also used to analyze energy usage and conservation.

In designing the buildings, it is a vital thing to be considered about the cooling loads during the design process. It is because the cooling loads will determined the human comfort. A study by Yu *et al*. (2008) investigated the effects of building envelope components on cooling energy load in a high-rise apartment in the hot summer and cold winter zone of China. The results indicated that envelope shading and exterior wall thermal insulation were the best strategies to reduce cooling energy, which achieved a saving of 11.3 and 11.5%, respectively. The study also showed a saving of 8% on the annual electricity consumption by replacing the 3mm normal clear glass of the base case windows with a double glazing one with low-e, electro and reflective glass. The previous study had proved that the energy can be saved by making mini adjustment windows.

But this time, the research will prove about the adjusting the entire design of the buildings by using different materials. A previous study by Al-Mofeez (2007) reported a study on energy saving from retrofitting a one-storey house located in Dhahran, Saudi Arabia, which is in a hot–humid climate. The study recorded the actual monthly bills for 72 months before, and 72 months after, retrofitting. The results show that savings in electrical consumption due to a building envelope reached 40.3% on average and 34.3% in peak months.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will describe further about the analysis of the optimum thickness of AAC wall and the residential building cooling load in a tropical region. Methodology part is one of the most important that need to be considered in order to complete the analysis project. The main point of methodology is to make sure that the project is running smoothly on schedule.

Besides that, all the details and related discussion on the process and methods tat involved in this project are described in this chapter. The process flow and timeline of the project is illustrated by using flow chart and Gantt chart. The both charts are the fundamental for this project as both charts explained every step to achieve the objective of the project. The project starts with working on literature review and end by submitting the complete thesis to the faculty.

3.2 RESEARCH FLOWCHART

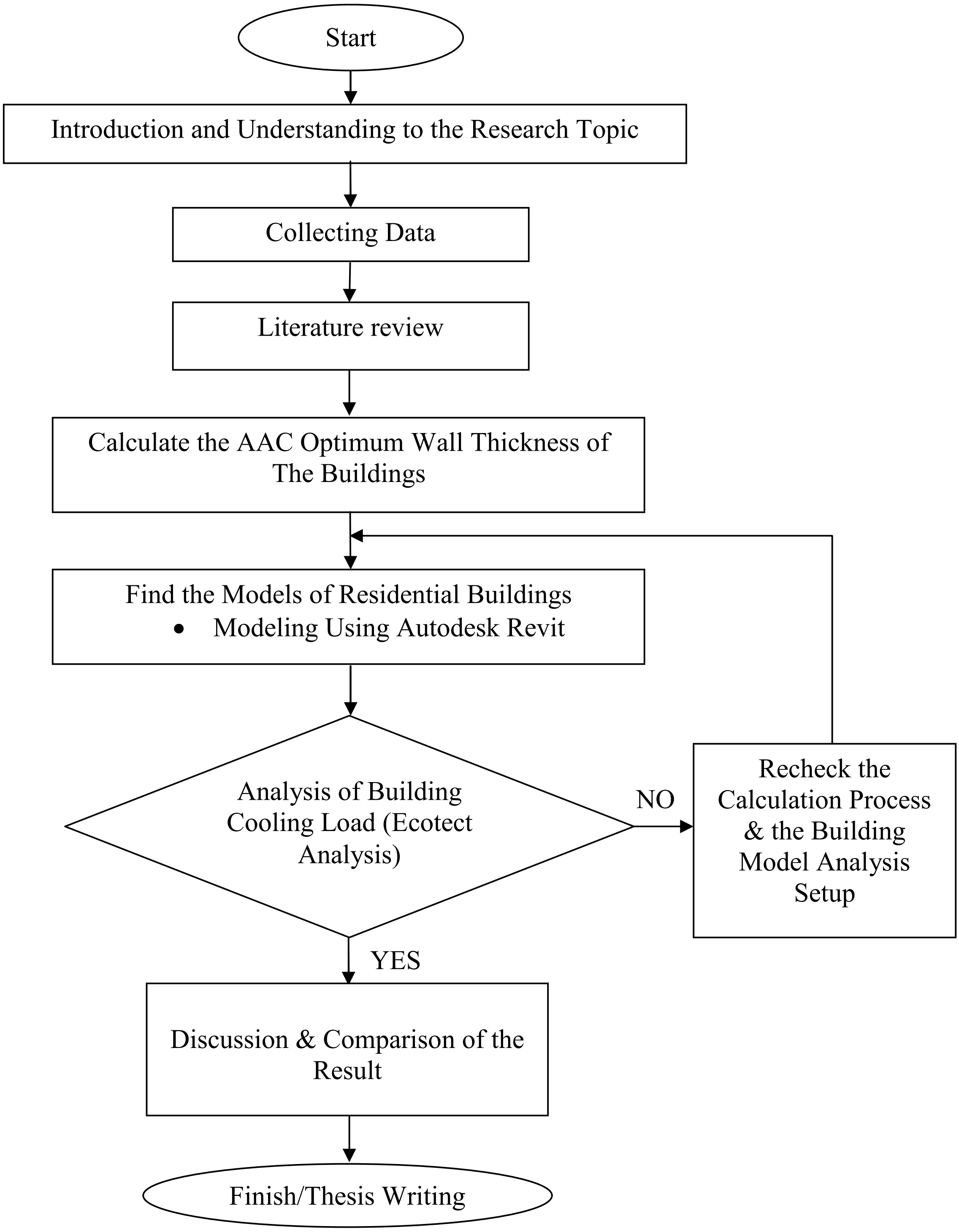

Figure 3.2.1: Framework of Methodology

3.3 FLOWCHART DESCRIPTION

Figure 3.2.1 shows the research flow chart for every process that is needed to accomplish the project goals. At the early stage, the project starts with understanding the topic given then starts to determine the project scope and general background of the project. After that, the objective of the project is determined.

Next, the stages proceed by writing the literature review of the project. The sources of the information of the literature review came from the books, journal and research from the internet. By doing the literature review, it gives better understanding regarding to the project. Besides that, the data and the information from previous research and studies can be used to gain new idea and concept to be used in the project.

In this project, it starts with calculating the optimum thickness of AAC wall system and then continues with finding the suitable model of the residential building in a tropical region. For this case, Malaysia is chosen for this research as it is located in a tropical region as stated in the research topic. The model of the residential buildings is chosen by considering about the following considerations such as the dimension, materials and the type of the houses. In this case, a single-storey house was chosen as in Malaysia there are a lot of this house type.

After all the information regarding to the project already gathered, the presentation slide for Final Year Project 1 presentation is prepared. For instance, the residential building model, the climate data in tropical region, the buildings materials and other parameters that should be included for the analysis in this project.

Then, the next stage of methodology is continued with the Final Year Project 2 where the analysis of the residential building will be analyzed by using the Autodesk Ecotect Analysis 2010 software. In this stage, the cooling load of the building will be analyzed then discuss and compared for further step.

3.4 OPTIMUM AAC BLOCK THICKNESS x_{block} CALCULATION

In this project, there are some simple equations that used for calculating the optimum thickness x_{block} of the minimum AAC block wall system. To determine the x_{block}, several equations that related with the calculation such as the life cycle cost analysis and heat transfer through the wall which includes the heat losses through the wall per unit area $q_{/A}$, the overall thermal coefficient *U,* the annual energy required for space cooling per unit area $E_{/A}$, the cost of block per unit area C_{block}, the cost of electricity per unit area C_{ele}, and the factor of present worth of fuel consumed for the entire life cycle *PWF.*

So, by following the calculation step below, the x_{opt} can be determined.

Heat Transfer Through The Wall

Heat is losses through the wall per unit area $q_{/A}$ via the conduction process and can be calculated by Eq. (1):

$$q_{/A} = U(t_{out,ave} - t_{in}) \quad (1)$$

Please note that the value of t_{in} was assumed to be 21[°C], while the value of $t_{out,ave}$ is determined by the time of the operation time of buildings and it was found that the $t_{out,ave}$ is 25.6 [°C] averagely. The overall thermal coefficient U [kW/m^{2}K] can be calculated by Eq. (2):

$$U = \frac{1}{\left(\frac{1}{h_1}+\frac{1}{h_2}+\frac{x_{block}}{k_{block}}\right)} = \frac{1}{\left(R_{total}+\frac{x_{block}}{k_{block}}\right)} \quad (2)$$

where both h_1 and h_2 were assumed to be 0.0047 [kW/m^{2}K]. the details on the building type, average temperature difference, operating time and annual degree demand hours are shown in the Table 1. Besides that the details of AAC block and sand cement brick properties that are available in Tropical region are shown in Table 2.

Table 1: Details on the building type, average temperature difference, operations time and annual degree demand hours

Building Type	Average Temperature Difference [°C]	Daily Operation Hour (Total Operating Hours) [h]	Annual Degree Demand Hours [h]
Residential Building	6.158	7am – 10pm, 1am – 6am (20hrs)	7300

Table 2: Details on materials available in Malaysia

Materials	Thermal Conductivity [10^{-3} kW/mK]	Price [Rm/m^3]
AAC Block	0.160	330
Sand Cement Brick	0.711	180

Next, the annual energy required for space cooling per unit area can be calculated by Eq. (3):

$$E_{/A} = \frac{q_{/A}}{COP} . ADH \tag{3}$$

For this research, the COP was assumed to be 2.93 [-]. Besides that, Eq.(3) can also be expressed as the following equation:

$$E_{/A} = \frac{(t_{out,ave} - t_{in})\, ADH}{\left(R_{total} + \frac{x_{block}}{k_{block}}\right) COP} \tag{4}$$