COMPUTATIONAL ANALYSIS OF HEAT TRANSFER RATE USING THERMAL RESPONSE FACTOR METHOD

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We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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STUDENT’S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

A study of heat transfer rates through a wall of air conditioned buildings is presented in this thesis. The transfer of energy as heat is always from the higher temperature to lower temperature and the heat transfer stops when the two medium reach the same temperature or in equilibrium. The Microsoft Visual C++ software is used to analyze the heat transfer rate into wall building by using Thermal Response Factor method. The parameters and thermal physical properties of the material are obtained in the analysis. The local weather data for Kuantan City has been used for all the result presented, the data for temperature starting from January until December in year 2008. The temperature used in this project was the typical temperature for six days in one year. Each typical temperature represent for two month as January and February month. The parameters and thermal physical properties used were wall thickness, wall insulation, wind velocity and density of material. The comparison between result from ASHRAE Book and computer programming showed the percentage error is around about 36.98%. Thermal Response Factor method using Visual C++ software can be used to determine the heat transfer rate through a wall building which is has the differences of thermal physical properties.

ABSTRAK

Projek ini ialah kajian terhadap kadar pemindahan haba ke dalam sesuatu dinding bangunan yang berhawa dingin. Pemindahan haba ke dalam sesuatu bangunan berlaku daripada suhu yang lebih tinggi kepada suhu yang lebih rendah, walaubagaimanapun kadar pemindahan haba ini akan berhenti apabila keaadaan suhu adalah sama atau lebih dikenali mencapai satu tahap yang seimbang. Perisian Visual C++ digunakan dengan kaedah Sambutan Terma untuk mencari kadar pengaliran haba ke dalam permukaan bangunan. Keadaan parameter dan sifat terma fizikal bagi sesuatu bahan diambil kira di dalam kajian ini. Data suhu bagi bandar Kuantan daripada bulan Januari hingga Disember bagi tahun 2008 digunakan di dalam projek ini. Suhu harian yang digunakan di dalam projek ini ialah suhu 6 hari tipikal di dalam setahun. Setiap satu suhu tipikal ini mewakili 2 bulan seperti satu hari tipikal mewakili bulan Januari dan Februari. Parameter dan sifat terma fizikal yang digunakan di dalam projek ini adalah ketebalan dinding bangunan, penebatan pada bangunan , kelajuan angin dan ketumpatan bahan. Peratusan perbandingan di antara keputusan daripada buku ASHRAE dengan program komputer ialah sebanyak 36.98%. Ini menunjukkan kaedah Sambutan Terma boleh digunakan untuk mecari kadar haba pada sesuatu dinding bangunan yang mana mempunyai sifat terma fizikal yang berbeza.

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A	Area
Bi	Biot number
C_p	Constant pressure specific heat
crz,cry	Common ratio
Fo	Fourier number
h	Convection heat transfer coefficients
k	Thermal conductivity
Nu	Nusselt number
P	Period of time
Pr	Prandtl number
Q	Heat transfer rate
q	Heat flux
R	Resistance conductivity
Re_x	Reynolds number
TRF	Thermal Response Factor
t_o	Outside temperature
X,Y,Z	Thermal Response Factor
x	Wall thickness
	Thermal diffusivity
Δt	Change of temperature
Δx	Change of distance
ρ	Density of material

LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
TRF	Thermal Response Factor
CTF	Conduction Transfer Functions
ZTF	Z-Transfer Function
SG	Specific Gravity
RD	Relative Density

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

The first law of thermodynamics states that the energy of a closed system is conserved. Therefore, to change the energy of a system, energy must be transferred to or from the system. Heat and work are the only two mechanisms by which energy can be transferred to or from a control mass. Heat is the transfer of energy caused by the temperature difference. [Yunus, 2006]

Heat transfer is a path function (process quantity), as opposed to a point function (state quantity). Heat flows between systems that are not in thermal equilibrium with each other; it spontaneously flows from the areas of high temperature to areas of low temperature. When two bodies of different temperature come into thermal contact, they will exchange internal energy until their temperatures are equalized; that is, until they reach thermal equilibrium. [Yunus, 2006]

The hot is used as a relative term to compare the object's temperature to that of the surroundings. The term heat is used to describe the flow of energy. In the absence of work interactions, the heat that is transferred to an object ends up getting stored in the object in the form of internal energy. [Yunus, 2006]

1.2 PROBLEM STATEMENT

Heat transfer is commonly encountered in engineering systems and other aspects of life, and one does not need to go very far to see some application areas o heat transfer. In fact, one does not need to go anywhere. The human body is constantly rejecting heat to its surroundings, and human comfort is closely tied to rate of this heat rejection. From this problem, we try to control this heat transfer rate by adjusting our clothing to the environment condition.

Malaysia is a tropical country. Tropical country is a hot and wet country. Nowadays maximum temperature at Malaysia is about 33°C where this situation gives uncomfortable condition to peoples especially in a closed space with a large number of peoples. This situation makes the indoor space become hot and the peoples inside feel not comfortable with this condition. Therefore, the analysis of heat transfer should be done to decreases the heat to provide comfort the occupants.

1.3 OBJECTIVE OF PROJECT

The objectives of the project are:

i. To analyze the heat transfers rate through the wall based on the thermal physical properties.

ii. To develop the computer programming using C++ software.

1.4 SCOPE OF PROJECT

The scopes of this project are:

i. To develop the computer programming using the Microsoft Visual C++ software.

ii. To analyze the effect of heat insulator position in the wall.

iii. To analyze the heat transfer rate through a wall based on thermal physical properties.

iv. To find the heat transfer rate (heat flux) through a wall based on heat balance equation.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Study of literature or scientific studies on the heat transfer rate through a wall building are built to go deep into the concepts and find the declaration related to feature of this project. This study will be more to discuss about the scope projects that stated before.

2.2 HEAT TRANSFER MECHANISMS

A thermodynamic analysis is concerned with the amount of heat transfer as a system undergoes a process from one equilibrium state to another. The transfer of energy is always from the higher temperature medium to the lower temperature medium, and heat transfer will stops when the two medium reach the same temperature.

Heat can be transferred in three different modes as conduction, convection and radiation. All modes of heat transfer require the existence of a temperature different, and all modes are from the high temperature medium to a lower temperature medium.

Unsteady heat transfer for a solid wall is one way to find the changes in temperature against time between the wall nodes. The inner nodes distinction given the same distance between each other's and the temperature outside and temperature inside must note first. From here, the heat conduction equation and heat convection equation will be used to find the heat transfer rate to wall building. [Yunus, 2006]

2.2.1 CONDUCTION

Conduction is the transfer of heat by direct contact of particles of matter. The transfer of energy could be primarily by elastic impact as in fluids or by free electron diffusion as predominant in metals or phonon vibration as predominant in insulators. In other words, heat is transferred by conduction when adjacent atoms vibrate against one another, or as electrons move from atom to atom. Conduction is greater in solids, where atoms are in constant contact. In liquids (except liquid metals) and gases, the molecules are usually further apart, giving a lower chance of molecules colliding and passing on thermal energy. [Yunus, 2006]

Heat conduction is directly analogous to diffusion of particles into a fluid, in the situation where there are no fluid currents. This type of heat diffusion differs from mass diffusion in behavior, only in as much as it can occur in solids, whereas mass diffusion is mostly limited to fluids. [Yunus, 2006]

In the heat transfer by conduction calculation, the Crank-Nicholson method in one dimension will be used, the Crank-Nicholson methods is numbering method that requiring to find every inner node in the wall.

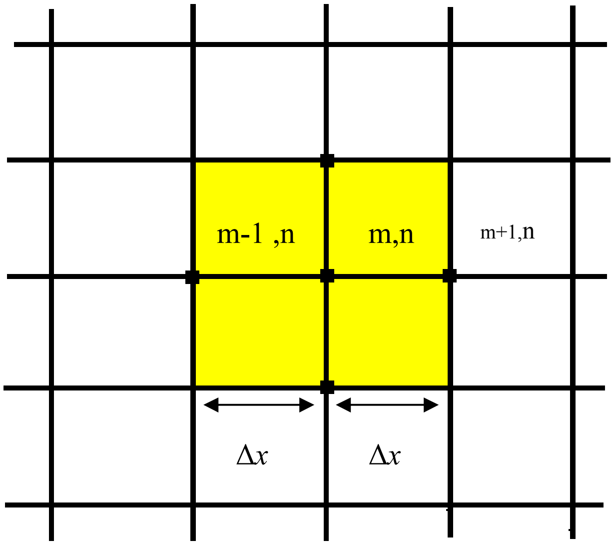

Figure 2.1: The inside node points in the wall, heat transfer by conduction

The increasing of this value is Δx in the direction x. Figure 2.1 shows the inner node in the wall. Let, a small letter m denotes as a direction of $\boldsymbol{x}$ and the lowercase n as a direction of y (Holman, 1992). With assume the properties of material is constant, then the equation of the heat flow in matter is

$$k\left(\frac{}{}+\frac{}{}\right)=\qquad\frac{}{} \tag{2.1}$$

but heat flow in the wall is in one dimension only, so

$$\frac{}{}=0 \tag{2.2}$$

the above equation becomes

$$k\left(\frac{}{}\quad\right)=\qquad\frac{}{} \tag{2.3}$$

and simplify to

$$\frac{}{}=\quad\frac{}{} \tag{2.4}$$

with,

$$=k\,/ \tag{2.5}$$

= thermal diffusivity (m^2/s)

k = thermal conduction (W/mK)

= density of material (kg/m^3)

= constant pressure specific heat (kJ/kg.K)

When solving the equation above, the equation becomes

$$T'_m = \frac{}{}\left(T_{m+1} + T_{m-1}\right) + \left(1 - \frac{}{}\right) T_m \tag{2.6}$$

$$= \frac{(\Delta \quad)}{\Delta} \geq 2 \text{ (for one dimension case)}$$

Clear here from equation above if M is less than 2, the situation is not suitable which the coefficient is of T_m will become negative. So the higher value of T_m, the value of T'_m will be smaller which is not correct. That why the value of M greater or equal to 2.

2.2.2 CONVECTION

Convection is the mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of conduction and fluid motion. The faster the fluid motion, the greater the convection heat transfers. In the absence of any bulk fluid motion, heat transfer between a solid surface and the adjacent fluid is by pure conduction. The presence of bulk motion of the fluid enhances the heat transfer between the solid surface and the fluid, but it also complicates the determination of heat transfer rates. [Yunus, 2006]

Apart from the heat transfer in each node through walls, heat transfer also happened at convection boundary on the surface of the walls outside and inside. It is dependent to the temperature inside and outside walls including the convection heat transfer coefficient, h (W/m^2.K) (Holman, 1992). Figure 2.2 show the heat transfer at convection boundary.

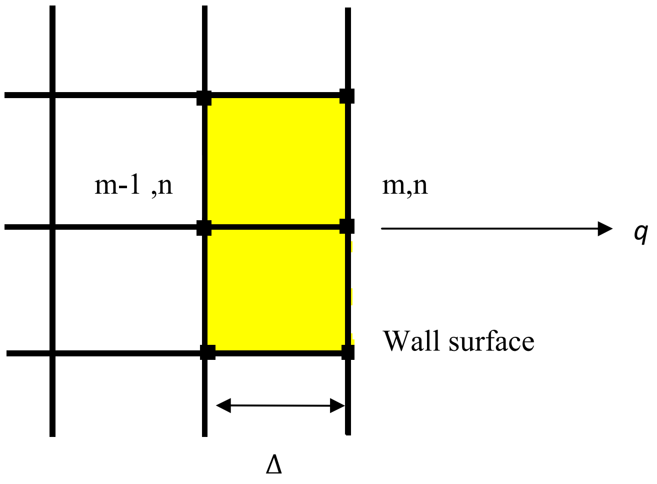

Figure 2.2: Node points at wall surface, heat transfer by convection

The solution for this problem is based on the equation 2.7 but involve the convection heat transfer coefficient, *h* (W/m^2.K), and the ambient temperature outside and inside of the wall. The relationship heat transfer by convection with one-dimensional case is written as follows

$$T'_m = \frac{\quad}{\quad}\left(2 \qquad {}_{\infty} + \left[\quad -2(\qquad +1)\right] T_m \right) \tag{2.7}$$

with,

$$= \frac{\Delta}{\quad} \tag{2.8}$$

$$= \frac{(\Delta \quad)}{\Delta} \tag{2.9}$$

= Biot number

h= convection heat transfer coefficient,(W/m^2.K)

k = thermal conduction, (W/mK)

Δ = change of wall thickness (m)

Δ = change of time (s)

Note that the selection of the parameters *M* for the node on the border of heat convection must be suitability requirements by requiring,

$$M \geq 2(\quad + 1) \tag{2.10}$$

After increasing the distance Δ*x* is selected, the values mentioned above for the M will limited the value Δ*t*. A higher value for *M* may be selected. This means a the value of Δ*t* will small and effect the value of Δ*x*, from this situation, the distance and time period used in calculation is long but it will give a more precise result.

Conversely, if the value *M* of smaller (although the value had more than limited value) this means the value of Δ*t* to be something big for the Δ*x*, from this, the distance will be decreasing and the period time that used in the calculation also decreasing but the decision precise (Incropera, 1996). It is clear here that the selection must be made the high accuracy of the calculation period or which less in this problem will depend on the situation.

The important things in the heat transfer by convection is convection heat transfer coefficients, h where it is dependent to the Reynolds Number, R .That means thet flow of heat transfer may occur as laminar or turbulent depending on the volume flow rate.

From the method above, the heat transfer rate into the wall building can be determine from the equation below,

$$= h \quad \Delta \tag{2.11}$$

where,

= heat transfer, (kJ)
h = convection heat transfer coefficients (W/m^{2}K)
= area (m^2)
Δ = temperature different (K)

2.3 THERMAL PHYSICAL PROPERTIES

2.3.1 THERMAL CONDUCTIVITY, *k* (W/m.K)

Thermal conductivity value is a measure of absorbed heat value and numbered heat thermal conductivity shows how the rate will flow in a material. Thermal conduction in one solid material may as one of heat flux change according to the direction and position in the materials. (Mohd Zainal, 1991)

Solid material can be divided into two groups, the metal and not metal, where there is a very big cliff on the thermal conductivity value. Table 2.1 and table 2.2 show some of the important material that usually used in industry.

The high value of high conductivity in the material is caused by spotlessness order that the crystal structure. The order of molecular lead will affect the heat transfer more quite. Metals such as copper is a good electricity conductor and also with a good heat stream

Table 2.1: Thermal properties of Metal (Holman, 1992)

Material	**(kg/m^3)**	C_p**(kJ/kg.K)**	**k (W/m.K)**
Aluminum	2707	896	204
Iron	789	452	72.7
Tin	7304	227	64
Copper	8954	385	111
Magnum	1746	1013	171
Molybdenum	8906	446	90
Zinc	7144	384	112
Lead	11370	130	34.6

Table 2.2: Thermal properties of Non-Metal (Holman, 1992)

Material	**(kg/m^3)**	C$_p$**(kJ/kg.K)**	**k (W/m.K)**
Bakelite	1273	1590	0.0232
concrete	1906	879	0.049
Plaster	1442	837	0.0413
Asbestoses	577	816	0.151
Glass	200	670	0.00398
Cotton	80.1	1298	0.0589

Non-metallic materials are very different because it does not have a structure that stacks neatly. Thus, the flow of heat transfer between molecules is limited value and the value for thermal conductivity is lower. The small hole in the material filled in by the air stream so will affect the heat transfer because gas is a bad heat conductor.

This is because the molecule gases in that position is more quite separate and the heat transfer is depend on the collision between molecules. (Mohd Zainal, 1991)

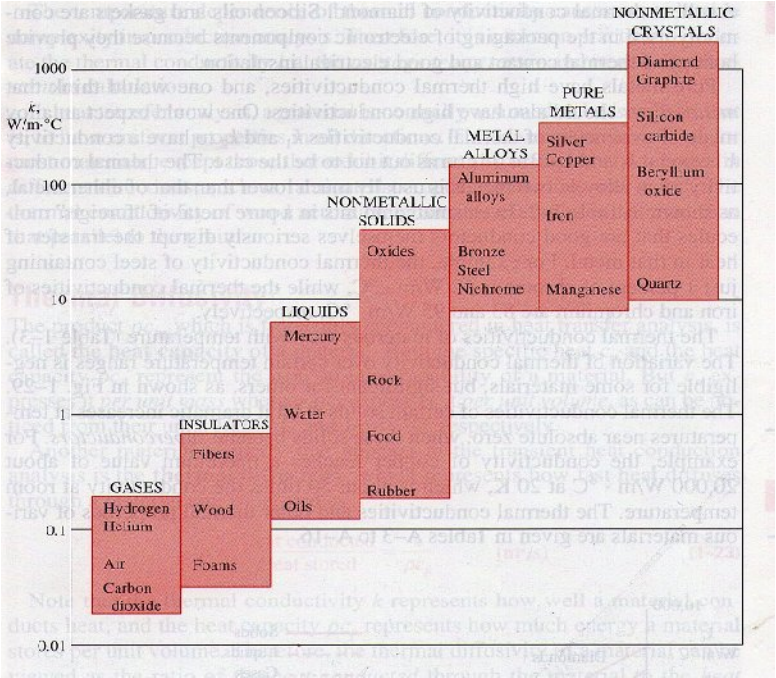

Figure 2.3: The range of thermal conductivity of various materials at room temperature. [Yunus, 2006]

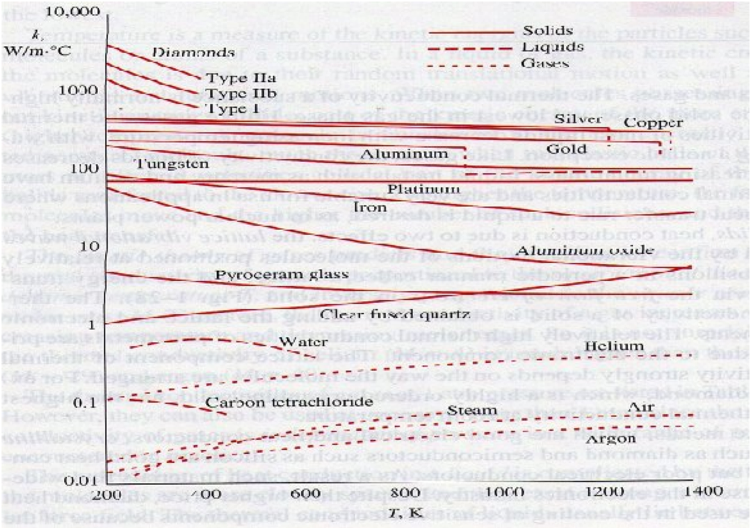

Figure 2.4: The variation of the thermal conductivity of various solids, liquids, and gases with temperature. [Yunus, 2006]

2.3.2 CONVECTION HEAT TRANSFER COEFFICIENTS, *h* (W/m$^{2\cdot}$K)

The heat convection coefficients, h is dependent to a volume flow rate that flow to the surface of wall material. For a flat plate, this value knowing from using the Reynolds number. That means the flow of heat transfer may occur as laminar or turbulence depend on the volume of flow rate. For laminar flow in the layer border, Reynolds number must less than 5 x 10^5. [Yunus, 2006]

For situations complex or turbulence flow, it must be determined from the test or experimental method .Table 2.1 shows the value of the convection heat transfer coefficients. There are two types of convection on the wall which are compulsion and free. For the real case, the force convection is often use. The value of convection heat transfer can be determine from the equation below, [Yunus, 2006]

$$h = - Nu \tag{2.12}$$

where,

Nu = Nusselt number

$$Nu = 0.332(\quad)^{/}(\mathrm{Pr})^{/} \tag{2.13}$$

and

Pr = Prandtl number

$$\mathrm{Pr} = - \tag{2.14}$$

Table 2.3: Typical values of convection heat transfer coefficient. [Yunus, 2006]

Types of convection	***h*,W/m^2°C**
Free convection of gasses	2-25
Free convection of liquid	10-1000
Forced convection of gasses	25-250
Forced convection of liquid	50-20000
Boiling and condensation	2500-100000

The solving that equation over the border of layer plate will allow us to get the convection heat transfer coefficients, *h*.

2.3.3 THERMAL DIFFUSIVITY (m^2/s)

The product c_p, which is frequently encountered in heat transfer analysis, is called the heat capacity of material. Both the specific heat c_p and the heat capacity c_p represent the heat storage capability of a material. [Yunus, 2006]

But c_p expresses it per unit mass whereas c_p expresses it per unit volume, as can be noticed from their unit J/kg.˚C and J/m^3. ˚C,respectively. Another material properties that appears in the transient heat conduction analysis is the thermal diffusivity, which represents how fast heat diffuses through a material and is defined as

$$= \frac{}{} = \text{heat conducted / heat stored}$$

Note that the thermal conductivity represent how well material conduct heat, and the heat capacity c_p represent how much energy of the material stores per unit volume.

Therefore, the thermal diffusivity of a material can be viewed as the ratio of the heat conducted through the material to the heat stored per unit volume.

A material that has a high thermal conductivity or a low heat capacity will obviously have a large thermal diffusivity. The larger the thermal diffusivity, the faster the propagation of heat into the medium. A small value of thermal diffusivity mean that heat is mostly absorbed by the material and a small amount of heat is conducted further.

Table 2.4: The thermal diffusivities of some materials at room temperature. [Yunus, 2006]

Material	**,m^2/s**
Silver	149×10^{-6}
Gold	127×10^{-6}
Copper	113×10^{-6}
Aluminium	97.5×10^{-6}
Iron	22.8×10^{-6}
Mercury (1)	4.7×10^{-6}
Marble	1.2×10^{-6}
Ice	1.2×10^{-6}
Concrete	0.75×10^{-6}
Brick	0.52×10^{-6}
Heavy soil (dry)	0.52×10^{-6}
Glass	0.34×10^{-6}
Glass wool	0.23×10^{-6}
Water (1)	0.14×10^{-6}
Beef	0.14×10^{-6}
Wood	0.13×10^{-6}

2.3.4 DENSITY OF MATERIAL, (kg/m^3)

Different materials usually have different densities, so density is an important concept regarding buoyancy, metal purity and packaging. In some cases density is expressed as the dimensionless quantities specific gravity (SG) or relative density (RD), in which case it is expressed in multiples of the density of some other standard material, usually water or air/gas.

$$= \quad / \tag{2.15}$$

Where,

= density of material

= mass

= volume

In general density can be changed by changing either the pressure or the temperature. Increasing the pressure will always increase the density of a material. Increasing the temperature generally decreases the density, but there are notable exceptions to this generalization.

From the table 2.1 and table 2.2 shows that when one material has a high density, the longer time that will take in heat transfer to flows into the wall building. This is because the thermal diffusivity α is inversely with the density of material, of building.

The materials that is denser and have a heavy crystal structure has a solid, that structure will gives impediment to slow the heat transfer rate into the wall building (Mohd Zainal, 1991).

2.3.5 SPECIFIC HEAT CAPACITY

Specific heat is defined as the energy required raising the temperature of a unit mass of a substance by one degree. In general, this energy depends on how the process is executed. Usually interested in two kinds of specific heats: specific heat at constant volume and specific heat at constant pressure, .

The specific heat at constant volume can be viewed as the energy required raising the temperature of a unit mass of a substance by one degree as the volume is held constant. The energy required to do the same as the pressure is held constant is the specific heat at constant pressure .The specific heat at constant pressure is than because at constant pressure the system is allowed to expand and the energy for this expansion work must also supplied to the system.

A common unit for specific heats is kJ/kg·˚C or kJ/kg·K.Notice that these two units are identical since Δ (C) = Δ (K), and 1˚C change in temperature is equivalent to a change of 1K.Also,

$$1\ \text{kJ/kg}\cdot{}^{\circ}\text{C} \equiv 1\ \text{J/g}\cdot{}^{\circ}\text{C} \equiv 1\ \text{kJ/kg}\cdot\text{K} \equiv 1\ \text{J/g}\cdot\text{K} \tag{2.16}$$

The different changes in the internal energy *u* and enthalpy *h* of an ideal gas can be expressed in terms of the specific heats as

$$du = \quad dT \quad \text{and} \quad dh = \quad dT \tag{2.17}$$

Constant pressure specific heat is the number of heat amount energy stored in the material in a pressure situation fixed. This may be explained based on equality below

$$= (dh/dT)_p \tag{2.18}$$

With h is the enthalpy of the material. P subscript means that it applies in the pressure. So the constant pressure specific heats of materials depend on the pressure and also the temperature. According to the equation 2.18, the constant pressure specific heat is inversely to the value of thermal diffusivity, .

Thus, for materials that have a high value of constant pressure specific heats, it will save a lot of energy and the heat transfer rate through a wall will be slow.
[Yunus, 2006]

2.4 WALL THICKNESS, L (m)

Each wall has a built own size and own thickness. The distance from the outside surface to the inside surface is the thick of the wall. The thickness f the wall will affect the heat transfer rate through a wall from outside to inside.

The wall is thick, then the longer the heat transfer rate will enter into the building and the heat transfer value will decreasing when up to the building ,this is because by the obstacles in the building and the propagation heat distance that take a long time in because of a long distance.

2.5 THERMAL INSULATION

Thermal insulation in buildings is an important factor to achieving thermal comfort for its occupants. Insulation reduces unwanted heat loss or gain and can decrease the energy demands of heating and cooling systems. It does not necessarily deal with issues of adequate ventilation and may or may not affect the level of sound insulation. In a narrow sense insulation can just refer to the insulation materials employed to slow heat loss, such as: cellulose, fiberglass, rock wool, polystyrene, urethane foam, vermiculite. But it can also involve a range of designs and techniques to address the main modes of heat transfer - conduction, radiation and convection materials.

The thermal insulation is a material or combination of various materials in which used to prevent drainage from heat situation like heat conduction, heat convection and the radiation. This material may consist of a composite material, metal, not metal or air. The thermal insulation order in the wall will affect the degree of heat removal from the outside surface to inside surface. [Yunus, 2006]

The insulation placed on the outside surface of the wall, the middle of the wall and the outlet wall surface will affect the heat transfer rate through the wall building from outside to inside. Besides that, the types of insulator using in material will affect the heat flow rate because of the thermal physical properties of that insulator. The effectiveness of insulation is commonly evaluated by its R-value. However, R-value does not take into account the quality of construction or local environmental factors for each building.

The thermal resistance concept can still be used to determine the rate of steady heat transfer through such composite walls. This is done by simply nothing that the conduction resistance of each wall is *L/kA* connected in series, and using the electrical analogy. That is, by dividing the temperature difference between two surfaces at known temperatures by the total thermal resistance between them. The equations 3.1 for heat conduction through a wall can be arranged as

$$R_{\text{wall}} = \frac{\qquad}{\cdot} \tag{2.19}$$

where,

$$R_{\text{wall}} = \frac{\quad}{\quad} \tag{2.20}$$

R_{wall} is the thermal resistance of the wall against heat conduction or simply the conduction resistance of the wall. Note that the thermal resistance of a medium depends on the geometry and the thermal properties of the medium.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, the development and analysis for computer programming for heat transfer rate through a wall building will discusses. The Microsoft Visual C++ will be used to analyze the heat transfer rate (heat flux) through a wall building.

3.2 DEVELOPMENT OF COMPUTER PROGRAMMING

In development of computer programming by using Microsoft Visual C++ for determine the heat transfer rate through the walls building, there are three major elements that solved among each other's which is the input data, computer analyzing and output data. Data entries represent the real weather data and the wall data have the different thermal physical properties is used to analyzing the process.

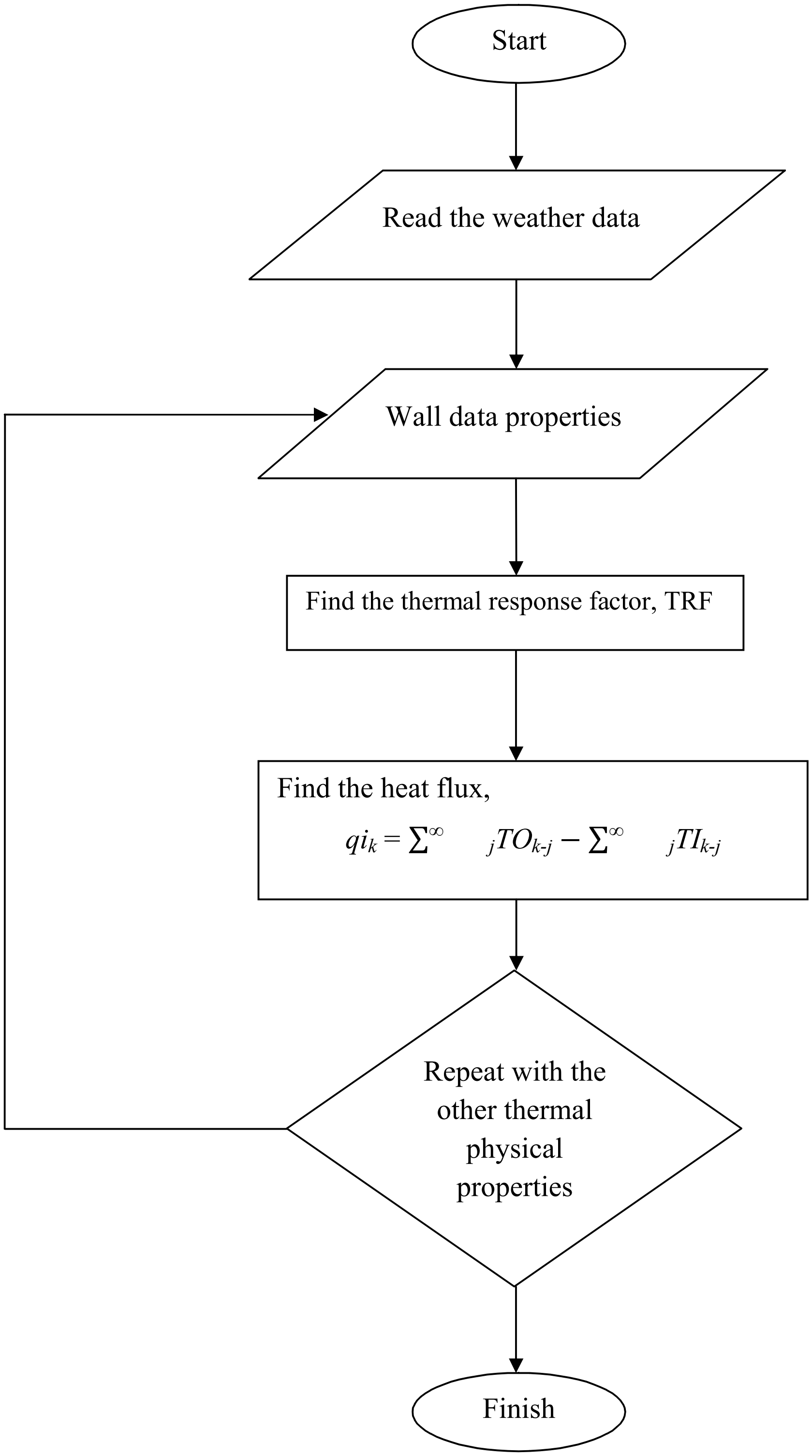

Figure 3.1: Flow chart of methodology

3.2.1 WEATHER DATA

The daily temperature for Kuantan City contain from January until December. The daily temperature there got from Jabatan Meteorology Malaysia located at Kuantan. The latitude and longitude for the Kuantan City are (3° 47’N) and (103° 13'E). The temperature will used in this project is the typical temperature for six days in one year. Each typical temperature represent for two month as January and February month. Note that, the daily rainfall amount (0800 - 0800 MST) for a particular day is the amount collected over the 24 - hour period beginning from 0800 a.m. on that day. For example, the daily rainfall amount for 25th. December, 2008 is the amount collected over the 24 - hour period from 0800 a.m. 25th. December, 2008 to 0800 a.m. 26th. December 2008.

Weather data can be seen in Appendix A.

3.2.2 WALL DATA

In this data, the data layer of the wall with the nature of the physical thermal properties will entered. The thermal physical properties including thermal conductivity, convection heat transfer coefficients, specific heat, and density of material and wall thickness. [Yunus, 2006]

3.3 THE ANALYSIS OF PROBLEM

The Microsoft Visual C++ software will be used to analyze the heat transfer rate into wall building by using Thermal Response Factor method. The parameters and thermal physical properties of the material are obtained in the analysis.

3.3.1 HEAT TRANSFER ANALYSIS USING THERMAL RESPONSE FACTOR METHOD

In this project, the analysis of heat transfer rate (heat flux) based on a reference wall with changes in the physical thermal properties and the position of wall insulation. The various methods will be used to complete the heat transfer rate problems through the wall building but only two methods usually used are z-Transfer Function (ZTF) and Thermal Response Factor Method (TRF).

The calculations of heat flux in this project by using the Thermal Response Factor Method (TRF).The method derivation of the conduction z-transfer function coefficients from the response factors for three-dimensional wall assemblies is presented.

3.3.1.1 THEORY OF THERMAL RESPONSE FACTOR METHOD

The thermal response factor method is a good method when we want to find the unsteady heat flows in one-dimensional calculation for the heat transfer rate through a wall building. From this method, the heat flux inside and outside surfaces such as walls in figure 3.1 can be calculated using the equation below

$$qi_k = \sum^{\infty} \quad {}_jTO_{k\text{-}j} - \sum^{\infty} \quad {}_jTI_{k\text{-}j} \tag{3.1}$$

$$qo_k = \sum^{\infty} \quad {}_jTO_{k\text{-}j} - \sum^{\infty} \quad {}_jTI_{k\text{-}j} \tag{3.2}$$

where.

qi_k = heat flux outwards from wall surface at time k,(W/m^2)

qo_k = heat flux enters to wall surface at time k, (W/m^2)

TO, TI = outside and inside temperatures, (˚C)

X,Y,Z = thermal response factor, (W˚C /m^2)

The problem encountered when using equations 3.1 and 3.2 are depends on the thermal response factor X, Y and Z. Specifically, the factors of each Y and Z are heat flux enter at the wall surface and exit at the outside slab surface.

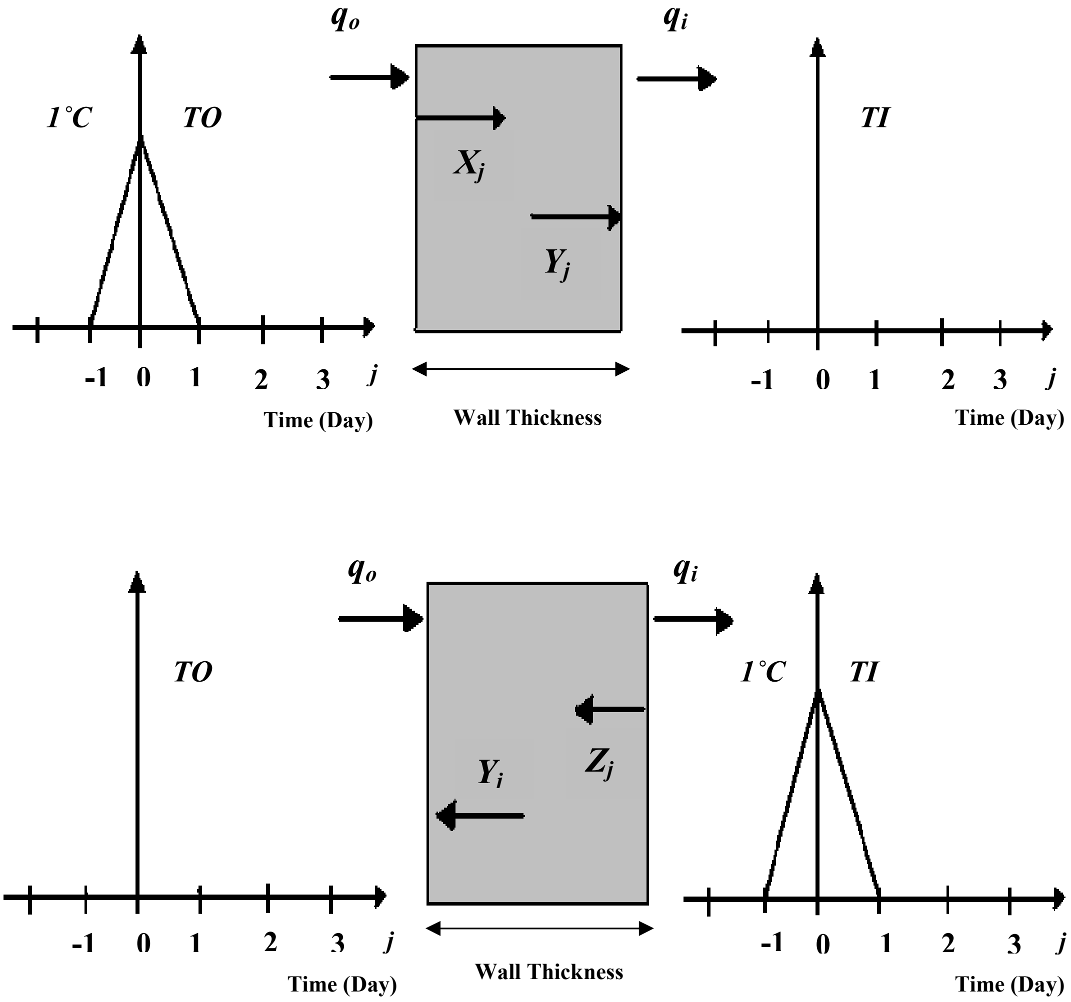

Figure 3.2: The model of thermal response factor (Kimura, 1977)

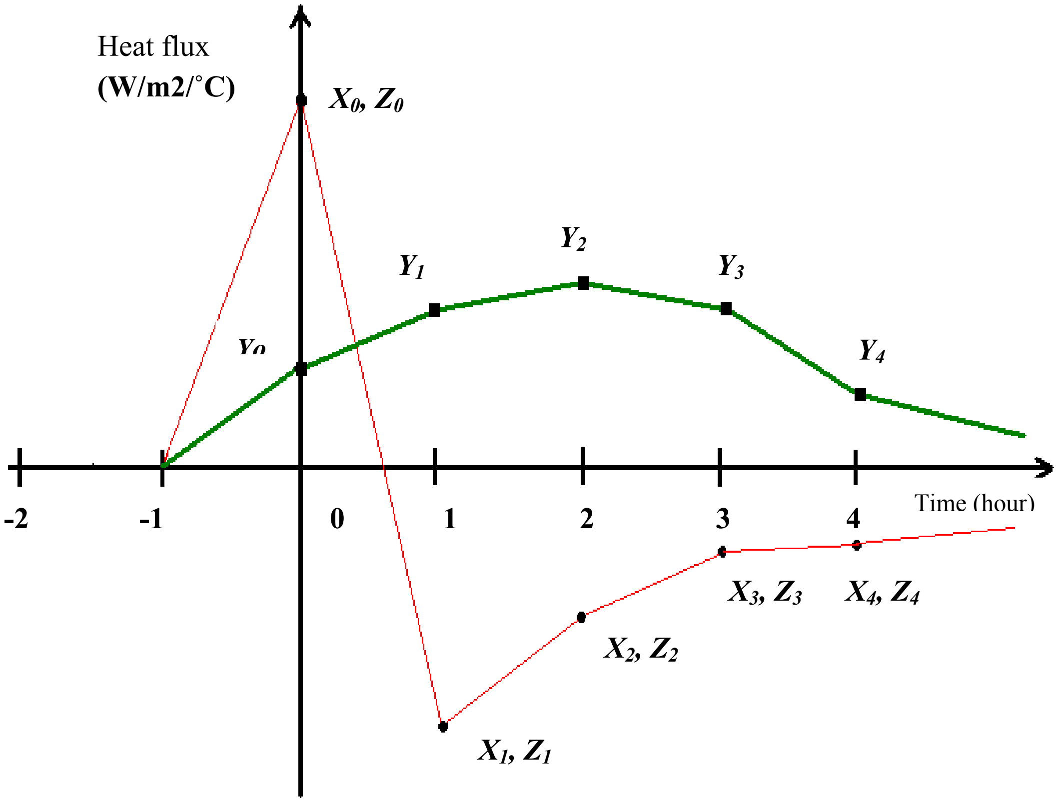

Figure 3.3: The graph of thermal response factor (Kimura, 1977)

3.3.1.2 THERMAL RESPONSE FACTOR AT HOMOGENEOUS SLAB

The thermal response factor at flat slab is obtained using the scheme Crank-Nicolson number implicit real and complete to the Fourier heat conduction equation in one-dimensional. The thermal response factor was obtained will compared with the appropriate analysis.

In the comparison about the affect of temperature increasing is also done for thermal response factor obtained with some of the finite difference time increments. For a homogeneous slab with a limited thickness, the equation as follows (Shih, 1981)

$$\frac{\quad}{\quad} = \frac{\qquad}{\qquad} \tag{3.3}$$

where,

T = temperature (˚C)

= thermal diffusivity, (m^2/s)

t = time (s)

x = thickness (m)

the equation above can be modified to get the Euler formula, from this equations the node temperature easily to find

$$T_{m,n} = F_0.T_{m-1,o}+(1-2F_0)T_{m,o}+F_0.T_{m+1,o} \tag{3.4}$$

where m is the node point as figure 3.2, n and o are the present time and time before. The criteria of Fourier number must be less and equal than 0.5 (shih, 1981).

$$F_0 = \alpha \frac{\qquad}{(\qquad)^2} \leq 0.5 \tag{3.5}$$

Where Δt is the increasing the time and Δx is the thickness of the wall.

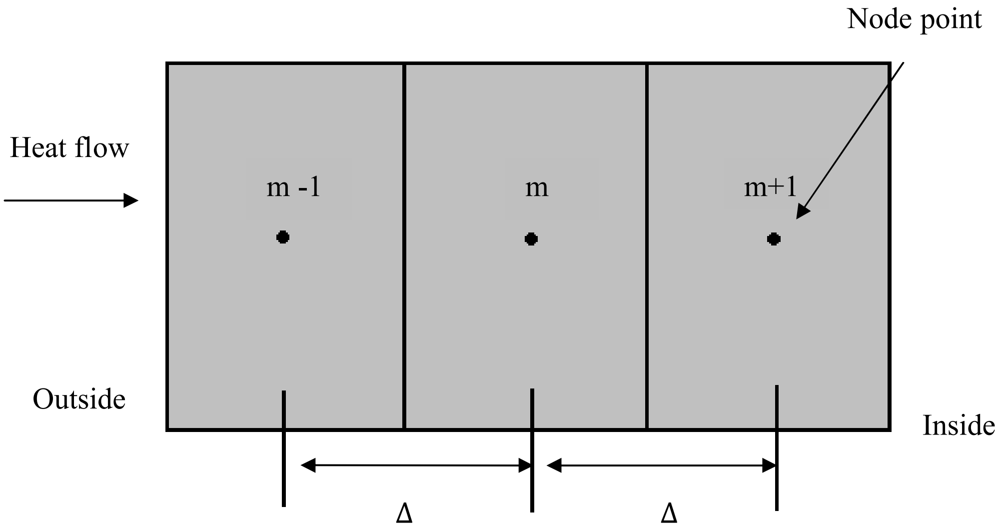

Figure 3.4: The node points at the homogeneous slab

The limited stability of the equation above can be eliminated by using Crank-Nicolson scheme in which he was stable, with no requirement for any value Fourier-positive. In this scheme, the latest nod temperature that unknown, described easily use the values that have been calculated, as follows the equation below (Shih, 1981)

$$-Fo.T_{m-1,n}+2(1+Fo)T_{m,n}-Fo.T_{m+1,n}= Fo.T_{m-1,n}+2(1-Fo)T_{m},n+Fo.T_{m+1,n} \quad (3.6)$$

In the calculation of thermal response factor, the beginning and at the border of the wall must be specify first. When the equation 3.4 used, the unknown temperature node easily calculated. If the equation 3.6 used, where it can be completed using the Thomas algorithm efficient (Shih, 1981).

For the calculation Y and Z factors, the temperature at wall surface inside will sets at 0˚C. The equation 3.4and 3.6 can be used to estimate the temperature at inner node, with guard in the period beginning on the j = -1(at this time the time at zero). When the time has passed 3600 (t = 3600, j = 0), the first thermal response factor will calculate with using the equation below:

$$Z_o=k\ (1-T_{N-1,t=3600})/\Delta \tag{3.7}$$

$$Y_o=k.T_{2,t=3600}/\Delta \tag{3.8}$$

where *k* is thermal conductivity and the N is the last node points. For the others thermal response factor (j=1, 2, 3…∞), this will be calculate using the equation below

$$Z_o=k\ (1-T_{N-1,t=3600j+3600})/\Delta \tag{3.9}$$

$$Y_o=k.T_{2,t=3600j+3600}/\Delta \tag{3.10}$$

This calculation can be eliminated when the general ratio (common ratio) reached a constant value. The general ratio as follows the equation below (Kimura, 1977)

$$crz_j=Z_j/\ Z_{j-1} \tag{3.11}$$

$$cry_j=Y_j/\ Y_{j-1} \tag{3.12}$$

with the *crz* and *cry* are the common ratio for the thermal response factor *Y* and *Z*.

$$\text{ABS}\{(crzj - crzj\text{-}1)\ /\ crzj\text{-}1\} \leq 0.00001 \tag{3.13}$$

$$\text{ABS}\{(cryj - cryj\text{-}1)\ /\ cryj\text{-}1\} \leq 0.00001 \tag{3.14}$$

for the rest TRF for this geometry series can be calculated using the:

$$Z_j = Z_{j-1}.crz \tag{3.15}$$

$$Y_j = Y_{j-1}.cry \tag{3.16}$$

When the *crz* and *cry* are the value crz_j and cry_j, so the equations 3.13 and 3.14 are fulfilled.

$$X_o = k\,(1 - T_{2,t=3600})/\Delta \tag{3.17}$$

$$X_j = -k.T_{2,t=3600j+3600}/\Delta \tag{3.18}$$

An important element in the thermal response factor is it must eligible state stability:

$$\sum^{\infty} \quad = \sum^{\infty} \quad = \sum^{\infty} \tag{3.19}$$

3.3.1.3 THERMAL RESPONSE FACTOR AT UNHOMOGENEOUS SLAB

In practical situations, buildings have the variety of wall layer with the different thermal physical properties. To any solid layer, the equation 3.4 can be used again for the inner node points. When the solid layer connected with small layer, the surface temperature on the node brush can be obtained by using the energy balance like the figure 3.5.The exchange in energy actually is the number of heat conduction with the density must have the same degree of power.

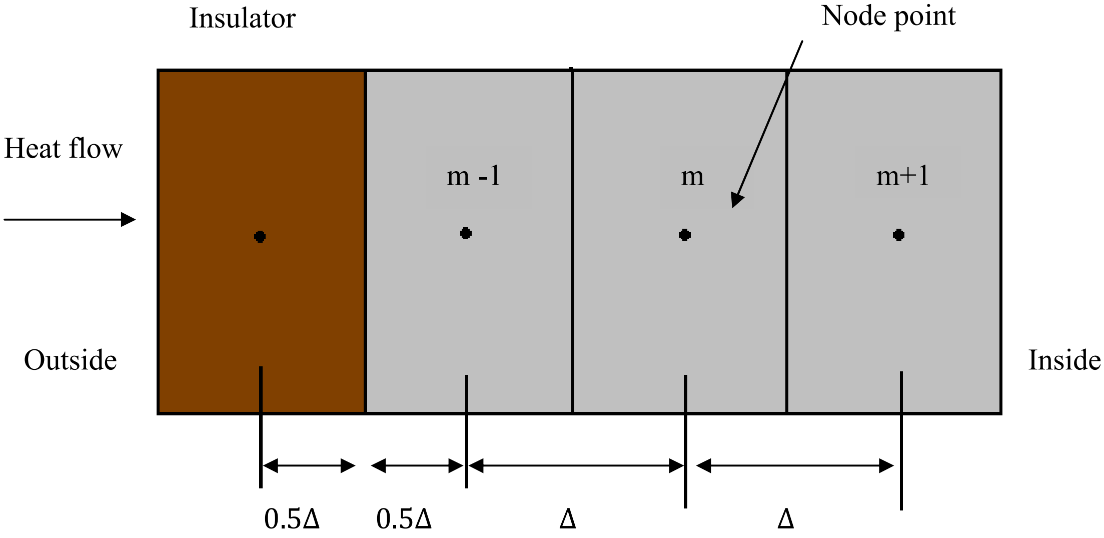

Figure 3.5: The small layer at the outside of wall

By using the concept of (Holman, 1992), the following equation can be written for a one unit surface area

$$U(T_{m-1,0}-T_{m,0})-k(T_{m,0}-T_{m+1,0})/\Delta x=0.5 \quad \Delta x(T_{m,n}-T_{m,o})/\Delta t \tag{3.20}$$

the equation above can be changed and stated clearly as

$$T_{m,n}=2Fo[T_{m+1,0}+BiT_{m-1,0}+(0.5/Fo-Bi-1)T_{m,0}] \tag{3.21}$$

the value of $T_{m,0}$ must be greater or equal the zero (Holman, 1992),so

$$Fo \leq 1/(2Bi+2) \tag{3.22}$$

But when the stability criteria are less than the criteria of equation 3.12, so published follows as

$$Fo \leq 1/\ \{(Bi^2+1)^{0.5}+1\} \tag{3.23}$$

In this project, the equation 3.22 will be used

When the layer is located on the left of a small solid layer, such as figure 3.5, the energy balance equation can be written as follows

$$K(T_{m-1,0}-T_{m,0})/\Delta x\ -U(T_{m,0}-T_{m+1,0})/\Delta x = 0.5 \quad \Delta x(T_{m,n}-T_{m,o})/\Delta t \tag{3.24}$$

The equation above can be change as follows

$$T_{m,n}=2Fo[T_{m+1,0}+BiT_{m-1,0}+(0.5/Fo-Bi-1)T_{m,0}] \tag{3.25}$$

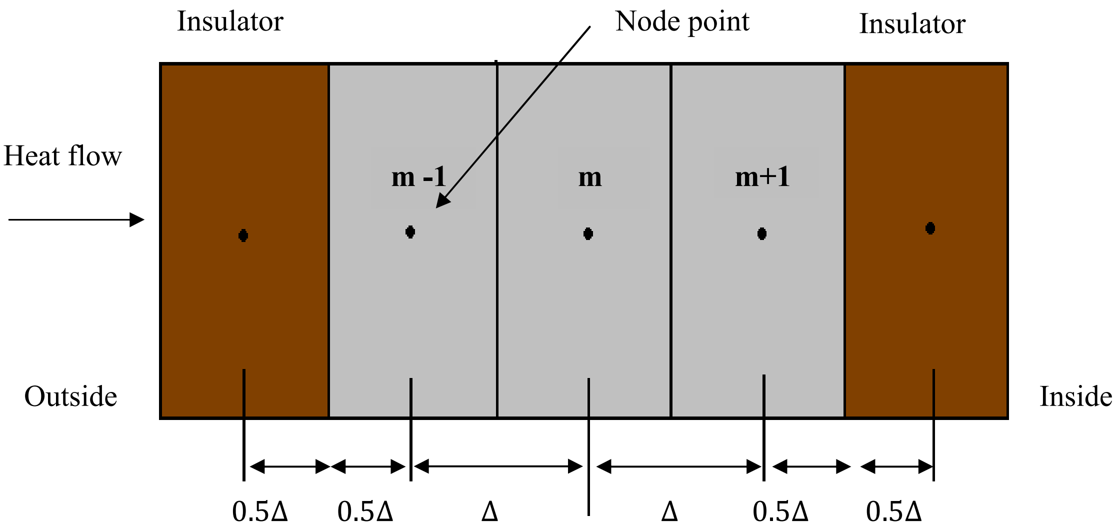

Figure 3.6: The small layer at the both side of wall

If the two surface solid layers meet the same as in figure 3.6, energy balance equation can be written as

$$k_L(T_{m-1,0}-T_{m,0})/\Delta x_L - k_R(T_{m,0}-T_{m+1,0})/\Delta x_R=0.5(\quad \Delta x_L+\quad \Delta x_R)(T_{m,n}-T_{m,o})/\Delta t \qquad (3.26)$$

with the subscript *L* and *R* refer to the left and the right material. This equation can be change as

$$T_{m,n}=r_L r_R[2T_{m-1,0}+2DT_{m+1,0}+(1/r_L+D/r_R-2-2D)T_{m,0}]\,/\,(Dr_L+r_R) \qquad (3.27)$$

with,

$$D=k_R\Delta x_L/k_L\Delta x_R \qquad (3.28)$$

r_L is Fourier number for the solid material at the left a horizontal surface and r_R is Fourier number of the solid material at the right horizontal. The value of $T_{m,0}$ must greater or equal to zero (Holman,1992).So that,

$$1/r_L+D/r_R-2-2D\geq 0$$

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter will discuss about the parameters and the thermal physical properties that affect the heat transfer rate into wall building. The analyses of heat transfer rate of the project are obtained by using the theory of thermal response factor method. The results are obtained by using Microsoft Visual C++ software and the findings are discussed.

4.2 RESULT OBTAIN BY MICROSOFT VISUAL C++

The Microsoft Visual C++ software is use to analyze the heat transfer rate into wall building by using Thermal Response Factor method. The parameters and thermal physical properties of the material are obtained in the analysis.

The temperature use to analyze the heat transfer rate into wall building taking temperature on February month in year 2008. Table and figure below shows the results of the analysis.

4.3 VERIFICATION

For case study approval, the comparison between the values of Heat Gain from Thermal Response Factor Method, TRF and CTF from ASHRAE Book will be considered first. The concrete wall data that have the value of temperature between 21.1 ˚C and 43.4 ˚C will be used, the value for room temperature will be considered at 21.1 ˚C. The thermal physical properties of wall such as L=203.2mm, k = 1.03842 W/mK and C_p = 837.4 J/kg.K, where these all values taking from wall number C8, Table 11 (ASHRAE, 1993).

Table 4.1: The Comparison of Heat Flux between TRF Method and CTF from ASHRAE Book

k (hour)	T(˚C)	A Heat Flux (ASHRAE) (W/m^2)	B Heat Flux (TRF) (W/m^2)	100 (B-A) / A (%)
1	32.2	9.65	12.47	22.61
2	35.1	12.52	20.95	40.24
3	37.8	16.31	28.72	43.21
4	40.1	20.69	35.87	42.32
5	41.8	25.42	42.42	40.08
6	43.0	30.12	48.24	37.56
7	43.3	34.50	53.30	35.27
8	43.0	38.29	57.49	33.40
9	41.8	41.19	60.76	32.20
10	40.1	43.02	62.96	31.67
11	37.8	43.65	64.19	32.00
12	35.1	43.02	64.39	33.19
13	32.2	41.19	63.67	35.31
14	29.3	38.32	62.09	38.28
15	26.7	34.54	59.89	42.32
16	24.4	30.15	44.61	47.32
17	22.6	25.42	43.54	41.62
18	21.5	20.72	43.34	52.19
19	21.1	16.34	42.42	61.48
20	21.5	12.55	35.87	65.01
21	22.6	9.65	33.87	71.51
22	24.4	7.83	29.67	73.61

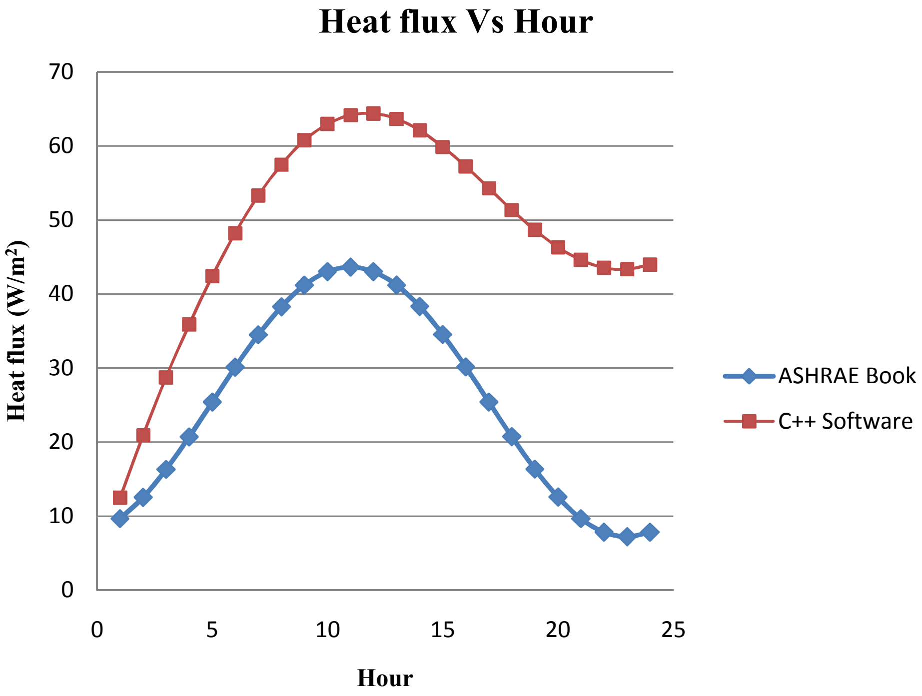

Figure 4.1: Graph Heat Flux Vs Hour for TRF method and CTF from ASHRAE Book

From the comparison between result from ASHRAE Book and computer programming using Visual C++ Software, the both graph shows the sinusoidal graph and the percentage error is about 36.98%.That means, the Thermal Response Factor method using Microsoft Visual C++ software can be used to determine the heat transfer rate through a wall building which is has the differences of thermal physical properties.

4.4 WALL THICKNESS

The thickness use in this project has maximum 400mm.There are three differences thickness which is 200mm, 300mm, and 400mm are use in the analysis with same the thermal conductivity, k = 0.727 W/m.K, density of material, p = 1922 kg/m^3 and specific heat capacity, C_p = 840 kJ/kg.K

4.4.1 Result for difference thickness

Table 4.2: Result Values for Difference Thickness

k (hour)	T(˚C)	Heat Gain (200mm) (W/m^2)	Heat Gain (300mm) (W/m^2)	Heat Gain (400mm) (W/m^2)
1	26.0	32.71	21.81	16.36
2	25.8	34.90	22.44	16.63
3	25.7	37.30	23.19	16.94
4	25.5	39.91	24.04	17.30
5	25.4	42.67	24.94	17.70
6	25.2	45.44	25.88	18.12
7	25.6	48.16	26.85	18.56
8	27.1	50.71	27.80	18.99
9	28.5	53.00	28.69	19.41
10	29.3	54.96	29.52	19.79
11	29.8	56.49	30.22	20.14
12	30.1	57.54	30.80	20.43
13	30.3	58.12	31.24	20.68
14	30.2	58.23	31.55	20.86
15	29.8	57.91	31.72	20.99
16	29.4	57.21	31.75	21.06
17	28.8	56.23	31.70	21.10
18	28.0	55.07	31.58	21.08
19	27.3	53.87	31.38	21.06
20	27.0	52.67	31.19	21.05
21	26.8	51.65	31.04	21.01
22	26.6	50.85	30.92	21.01
23	26.4	50.42	30.90	21.05
24	26.2	50.34	30.97	21.12

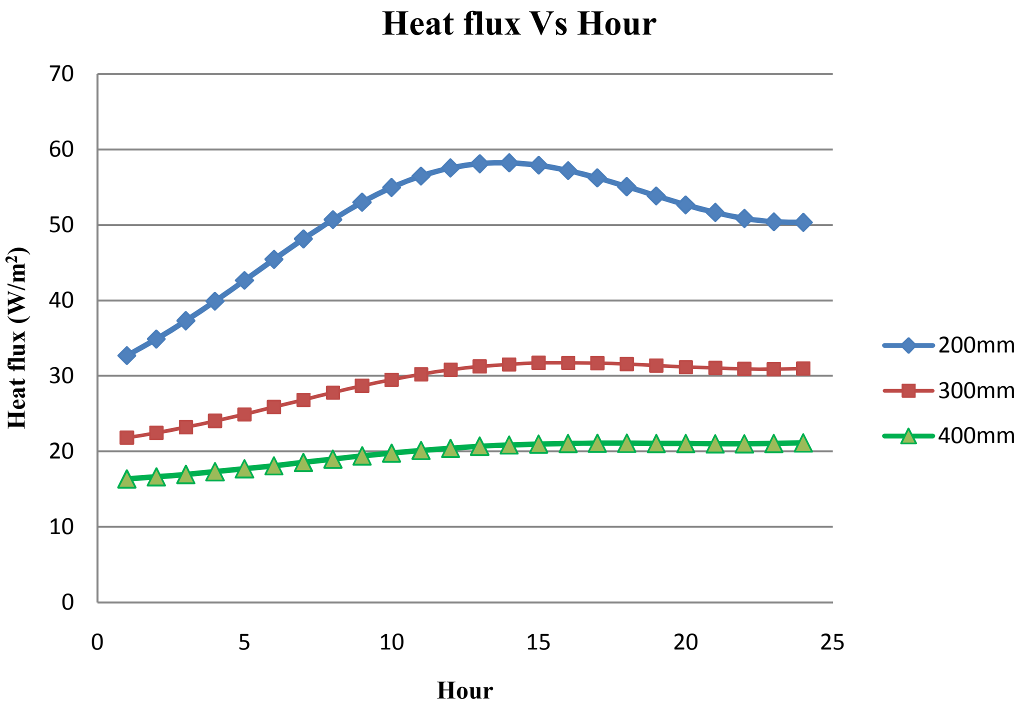

Figure 4.2: Graph Heat Flux Vs Hour for Differences Thickness

From the graph in Figure 4.2, the graph shown that the value of heat flux through a wall building at 200mm is higher (58.23 W/m^2) than the other thickness because the wall has the small heat resistance and the heat transfer rate is faster. This is happened because the heat flows from outside to inside take in short time.

Different with the wall building has 400mm thickness; the value of heat transfer rate through a wall building is smaller (21.10 W/m^2) because the wall has the high resistance and the heat flow moving is slow. This is happened because the heat flows from outside to inside take a long time before reach.

Thus the rate of heat transfer through a wall building is proportional to the temperature difference across the wall and the heat transfer area, but is inversely proportional to the thickness of the wall.

4.5 DENSITY OF MATERIAL

The three common density of material use in this project including common brick, face brick and fire clay brick. The analysis of heat transfer rate into wall building use the different density of material which is 1922 kg/m^3, 2082 kg/m^3 and 2400 kg/m^3.The material still have the same values of thermal conductivity, k = 0.727 W/m.K and specific heat, C_p = 840 kJ/kg.K. The thickness of material use in this analysis considered as 200mm.

4.5.1 Result for difference densities

Table 4.3: Result Values for Difference Densities

k (hour)	T(˚C)	Heat Gain (Brick, common) (W/m^2)	Heat Gain (Brick, face) (W/m^2)	Heat Gain (Brick, fire clay) (W/m^2)
1	26.0	32.71	32.71	32.71
2	25.8	34.90	34.71	34.46
3	25.7	37.30	36.97	36.42
4	25.5	39.91	39.40	38.57
5	25.4	42.67	41.98	40.86
6	25.2	45.44	44.60	43.18
7	25.6	48.16	47.18	45.51
8	27.1	50.71	49.58	47.73
9	28.5	53.00	51.80	49.76
10	29.3	54.96	53.69	51.54
11	29.8	56.49	55.18	52.96
12	30.1	57.54	56.27	54.05
13	30.3	58.12	56.89	54.74
14	30.2	58.23	57.07	55.03
15	29.8	57.91	56.85	55.00
16	29.4	57.21	56.31	54.63
17	28.8	56.23	55.47	54.02
18	28.0	55.07	54.49	53.25
19	27.3	53.87	53.40	52.38
20	27.0	52.67	52.34	51.54
21	26.8	51.65	51.40	50.78
22	26.6	50.85	50.71	50.20
23	26.4	50.42	50.31	49.87
24	26.2	50.34	50.24	49.87

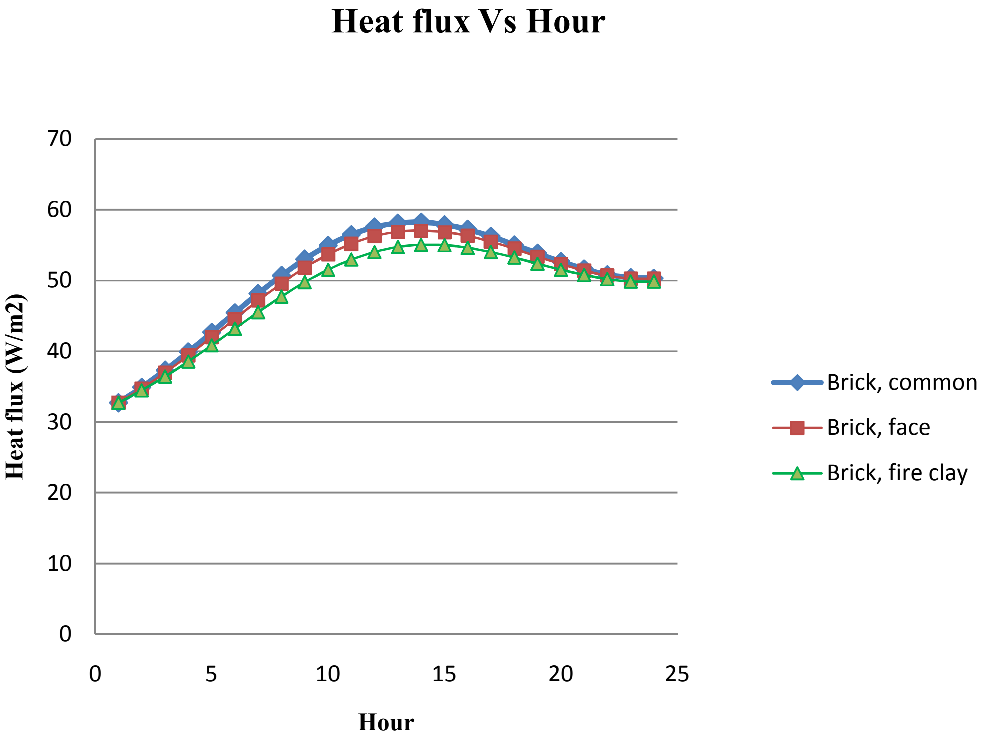

Figure 4.3: Graph Heat Flux Vs Hour for Difference Densities

Based on graph in Figure 4.3, the graph shows that the Brick, common shows the higher value of heat flux (58.23 W/m^2) than the Brick, face and Brick, fire clay. This is because the value of thermal conductivity in Brick, common is higher than Brick, face and Brick, fire clay.

Also, when the mass of material increases, the density of material also increases. Therefore, the density of material is proportional to mass of material. So it not surprising that the value for density of Brick, common is higher than Brick, face and Brick, fire clay.

The thermal conductivity of a solid such as Brick is obtained by adding the lattice and electronic components. The relatively high thermal conductivities of pure metals are primary due to the electronic component. The lattice component of thermal conductivity strongly depends on the way molecules are arranged.

4.6 WALL INSULATION

In this analysis, there are three types of wall will analyze. Assuming the first wall considered not have insulator. The other walls have the insulator placed at the outside of wall and the insulator placed at the both side of wall. The analysis of heat transfer rate into wall building use the different of density, 1922 kg/m^3 and 1602 kg/m^3, same the values of thermal conductivity, k = 0.727 W/m.K and specific heat, C_p = 840 kJ/kg.K. The thickness of wall insulation use in this project is 25mm.

4.6.1 Result for difference wall insulations

Table 4.4: Result Values for difference insulations

k (hour)	T(˚C)	Heat Gain (none) (W/m^2)	Heat Gain (outside of wall) (W/m^2)	Heat Gain (both side of wall) (W/m^2)
1	26.0	32.71	19.39	17.45
2	25.8	34.90	25.43	33.94
3	25.7	37.30	31.28	46.47
4	25.5	39.91	36.87	56.18
5	25.4	42.67	42.20	63.86
6	25.2	45.44	47.21	69.82
7	25.6	48.16	51.83	74.42
8	27.1	50.71	55.96	77.67
9	28.5	53.00	59.58	79.74
10	29.3	54.96	62.62	80.55
11	29.8	56.49	65.01	80.32
12	30.1	57.54	66.75	79.07
13	30.3	58.12	67.89	76.95
14	30.2	58.23	68.40	74.15
15	29.8	57.91	68.40	70.90
16	29.4	57.21	67.98	67.47
17	28.8	56.23	67.21	64.06
18	28.0	55.07	66.27	60.92
19	27.3	53.87	65.24	58.28
20	27.0	52.67	64.27	56.30
21	26.8	51.65	63.46	55.16
22	26.6	50.85	62.94	54.90
23	26.4	50.42	62.78	55.57
24	26.2	50.34	62.97	57.11

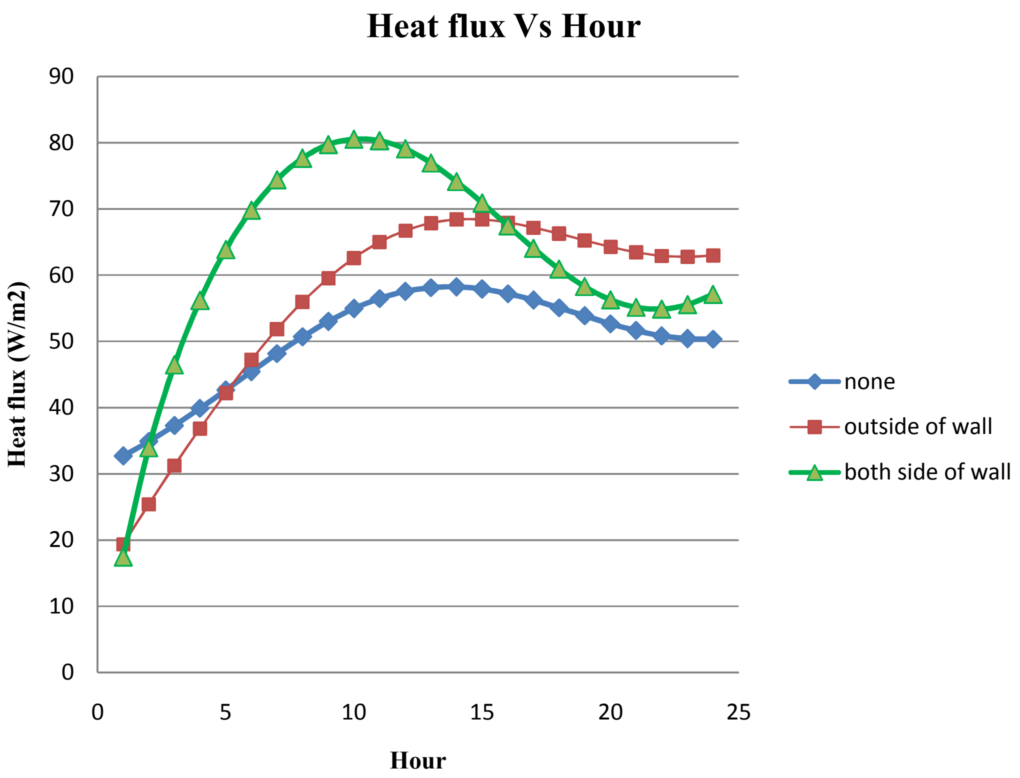

Figure 4.4: Graph Heat Flux Vs Hour for difference insulations

Based on graph in Figure 4.4, the graph shows that the insulators placed at the both side of wall shows the higher value of heat flux (80.55 W/m^2). The thermal conductivity of a material is a measure of the ability of the material to conduct heat. A High value for thermal conductivity indicates that the material is a good heat conductor, and low value for thermal conductivity indicates that the material is a poor heat conductor or call as insulator.

Materials such as rubber, wood, and Styrofoam are poor conductors of heat and have low conductivity values, these materials suitable as insulator for wall building. Note that material such as copper and silver not suitable to wear as insulator because that are good electric conductors are also good heat conductors, and have high values of thermal conductivity.

Note that, adding more insulation to a wall building always decreases heat transfer. The thicker of the wall insulation, the lower value of heat transfer rate. This is expected, since the heat transfer area is constant, an adding the insulation always increases the thermal resistance of the wall building without increasing the convection resistance. The additional insulation increases the conduction resistance of the insulation layer but decreases the convection resistance of the surface because of the increase in the outer surface area for convection.

4.7 WIND VELOCITY

The wind velocity also affects the heat transfer rate through a wall because of the value of convection heat transfer coefficients, where the value of convection heat transfer coefficients depends on the Reynolds number. There are five types of convection such as free convection of gases, free convection of liquids, forced convection of gases, forced convection of liquids and the lastly is boiling and condensation. In this analysis, only three different value of wind velocity will be used, those are 0 km/j, 12 km/j, and 24 km/j. The analysis of heat transfer rate into wall building use the same density of material, p = 1922 kg/m^3 same values of thermal conductivity, k = 0.727 W/m.K and specific heat, C_p = 840 kJ/kg.K. The thickness of material use in this analysis considered as 200mm.

Table 4.5: Wind velocity (ASHRAE book, 1993)

Wind Velocity, u, km/j	h_o (W/m^{2}K)
0	17.0
12	22.7
24	34.0

4.6.1 Result for difference wind velocities

Table 4.6: Result Values for difference Wind Velocity

k (hour)	T(˚C)	Heat Gain (0 km/j) (W/m^2)	Heat Gain (12 km/j) (W/m^2)	Heat Gain (24 km/j) (W/m^2)
1	26.0	21.81	21.81	21.81
2	25.8	31.08	33.08	36.97
3	25.7	39.48	43.07	49.98
4	25.5	47.04	51.98	61.21
5	25.4	53.87	59.94	70.88
6	25.2	59.90	66.88	79.10
7	25.6	65.25	72.88	85.97
8	27.1	69.72	77.83	91.42
9	28.5	73.39	81.79	95.46
10	29.3	76.19	84.62	98.04
11	29.8	78.12	86.40	99.24
12	30.1	79.21	87.17	99.16
13	30.3	79.50	86.95	97.85
14	30.2	79.10	85.93	95.56
15	29.8	78.12	84.22	92.51
16	29.4	76.70	82.08	88.95
17	28.8	75.03	79.61	85.20
18	28.0	73.21	77.10	81.50
19	27.3	71.46	74.70	78.15
20	27.0	69.90	72.66	75.39
21	26.8	68.70	71.10	73.43
22	26.6	67.97	70.19	72.45
23	26.4	67.76	69.97	72.48
24	26.2	68.08	70.48	73.54

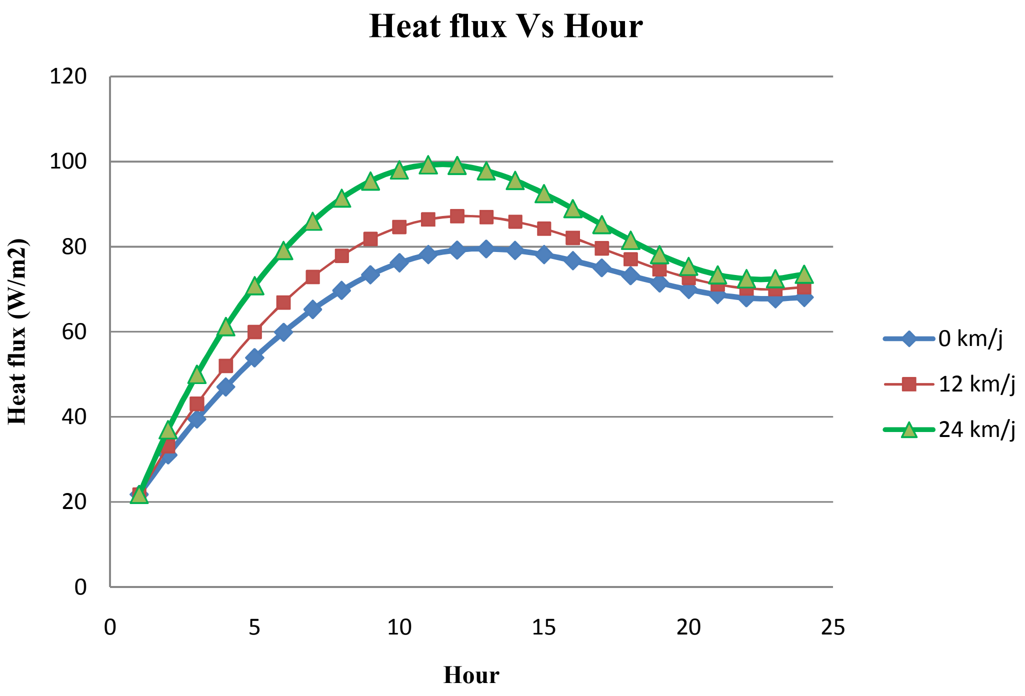

Figure 4.5: Graph Heat Flux Vs Hour for difference Wind Velocity

Based on graph in Figure 4.5, there are not much different about the graph and the higher value of heat flux is 99.24 W/m^2 at 24 km/j .This is happened because the value of convection heat transfers coefficients of material. That means the value of convection heat transfer coefficients depends on wind velocity moving.

Despite the complexity of convection, the rate of convection heat transfer is observed to be proportional to the temperature difference, and is conveniently expressed by Newton's Law of cooling, $\quad = h \quad \Delta$, where h is the convection heat transfer coefficients.

The convection heat transfer coefficient is not property of the fluid. It is an experimentally determined parameter whose value depends on all the variables influencing convection such as the surface geometry, the nature of fluid motion, the properties of fluid, and the bulk fluid velocity.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The science that deals with the determination of the rates of such energy transfer actually is heat transfer. Heat can be transfer in three different modes such as by conduction, convection or radiation. The transfer of energy as heat is always from the higher temperature medium to the lower temperature medium, and heat transfer rate stops when the two medium reach the same temperature or in equilibrium state.

The first analysis of heat transfer rate through a wall building was wall thickness. Three different thicknesses were used such as 200mm 300mm and 400mm.From the results, the 200mm thickness show the higher value for the heat flux (58.23 W/m^2). Here, the rate of heat transfer through a wall building is proportional to the temperature difference across the wall and the heat transfer area, but is inversely proportional to the thickness of the wall.

The second analysis was about the density of material. The three common density of material was used in this project such as Brick, common, Brick, face and Brick, fire clay. From the results, the Brick, common shows the higher value of heat flux (58.23 W/m^2). Here, when the mass of material increases, the density of material also increases. Therefore, the density of material is proportional to mass of material.

The third analysis was about the wall insulation. In this analysis, there are three types of wall will analyze. Assuming the first wall considered no insulator, the others wall has the insulator placed at the outside of wall and the insulator placed at the both side of wall. From the results, the wall that has considered the insulator placed at the both side of wall shows the higher heat flux (80.55 W/m^2).The wall has no insulator shows the lowest value of heat flux was (58.23 W/m^2).So, adding more insulation to a wall building always increasing the value of heat transfer rate. The thicker the insulation, the lower value of heat transfer rate.

The fourth analysis was about wind velocity. In this analysis, three types of wind velocity were used such as 0 km/j, 12 km/j, and 24 km/j. From the results, the wall were has the wind velocity 24 km/j shows the higher value of heat flux was 99.24 W/m^2 and the lowest value at the wind velocity 0 km/j was 79.50 W/m^2. The convection heat transfer coefficient is not property of the fluid. It is an experimentally determined parameter whose value depends on all the variables influencing convection such as the surface geometry, the nature of fluid motion, the properties of fluid, and the bulk fluid velocity. So, the rate of convection heat transfer is observed to be proportional to the temperature difference, and is conveniently expressed by Newton's Law of cooling, $= h \quad \Delta$.

In this project, from the comparison between result from ASHRAE Book and computer programming using Visual C++ Software, the both graph shows the sinusoidal graph and the percentage error is about 36.98%.That means, the Thermal Response Factor method using Visual C++ software can be used to determine the heat transfer rate through a wall building which is has the differences of thermal physical properties.

5.2 RECOMMENDATION FOR FUTURE WORK

Several future works are expected could be done; hopefully the analysis of heat transfer rate through a wall building not using the constant room temperature. This is because the room temperature will affected with the surrounding environment such as heat loss from the lamp and human. Besides that, use the different material when doing the analysis, in this project the material used is only Brick. So that, the result shows not much different to each other because the value of density of material almost same. Lastly, find the sol-air temperature before doing the analysis, sol-air temperature actually is outside air temperature of wall building without change with the radiation.

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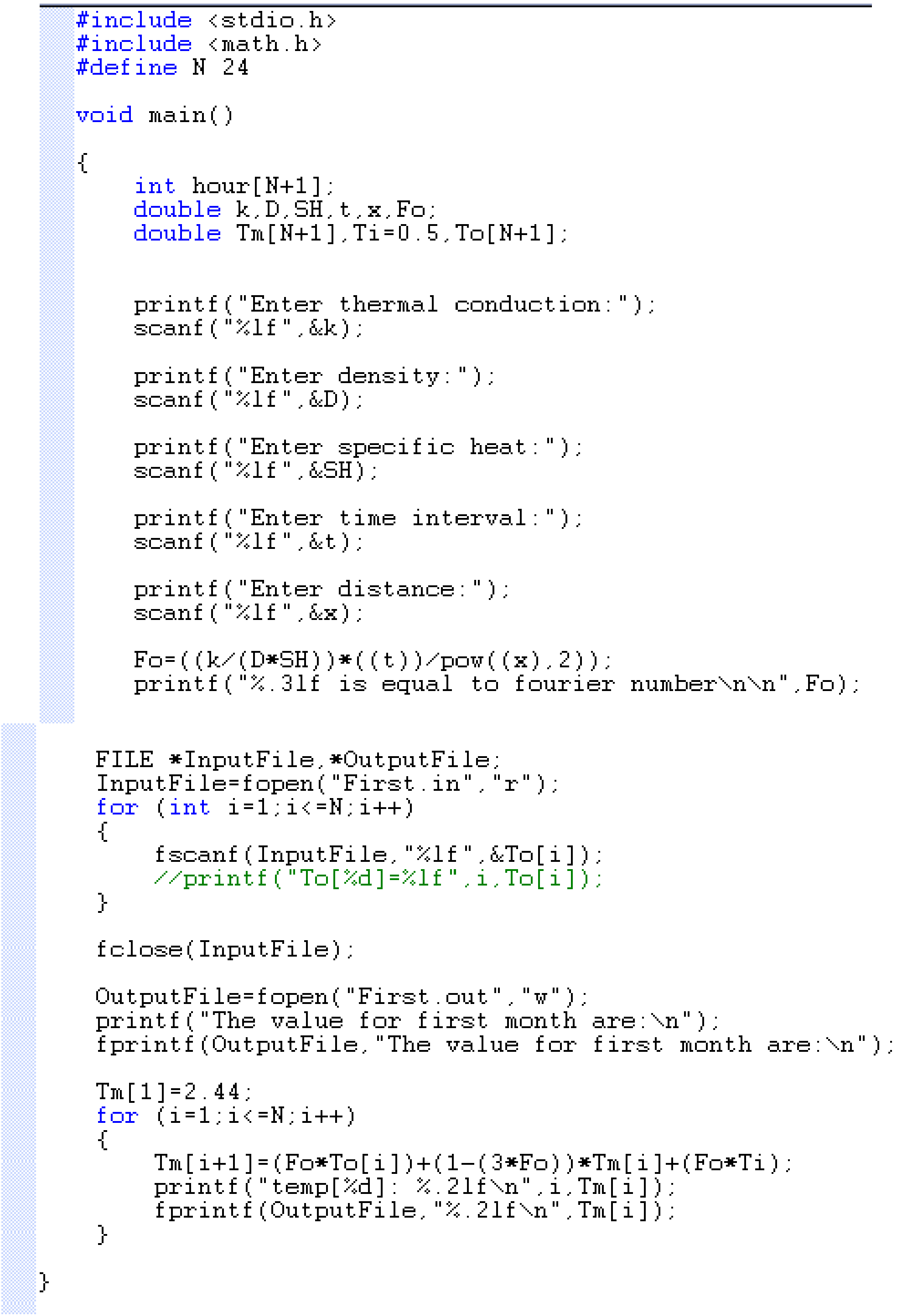
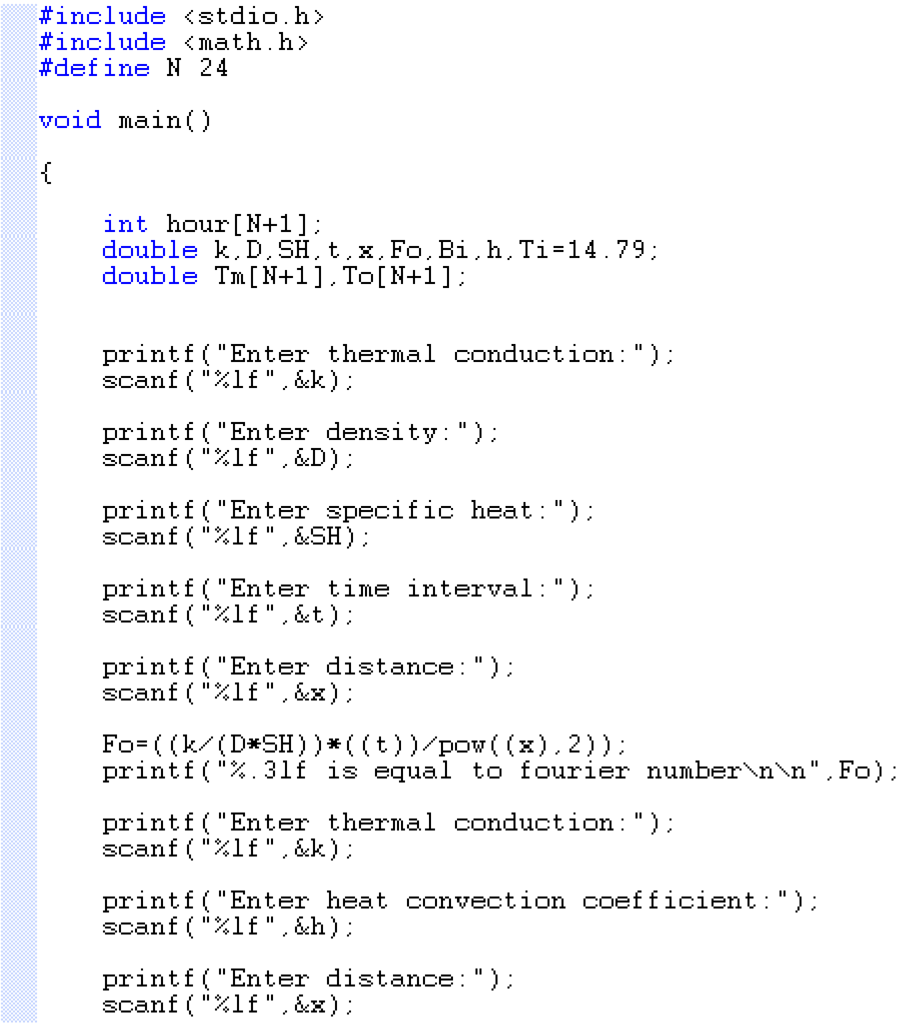
APPENDIX A

Hour\Typical temperature	1 (˚C)	2 (˚C)	3 (˚C)	4 (˚C)	5 (˚C)	6 (˚C)
1	24.4	25.6	26.0	25.9	25.5	24.6
2	24.2	25.4	25.8	25.7	25.3	24.5
3	24.1	25.2	25.7	25.6	25.1	24.3
4	24.0	25.1	25.5	25.5	24.8	24.3
5	23.9	24.9	25.4	25.4	24.8	24.2
6	23.8	24.8	25.2	25.3	24.7	24.1
7	24.1	25.1	25.6	25.5	25.2	24.5
8	25.3	26.4	27.1	26.9	26.6	25.6
9	26.6	27.9	28.5	27.9	27.9	26.9
10	27.8	28.9	29.3	28.6	28.7	27.7
11	28.6	29.5	29.8	29.1	29.2	28.4
12	29.2	30.0	30.1	29.4	29.5	28.7
13	29.4	30.1	30.3	29.5	29.6	28.7
14	29.2	29.9	30.2	29.4	29.3	28.4
15	28.9	29.5	29.8	29.4	29.1	28.0
16	28.3	29.0	29.4	29.1	28.8	27.5
17	27.6	28.4	28.8	28.7	28.2	26.9
18	26.6	27.5	28.0	27.9	27.4	26.1
19	25.8	26.8	27.3	27.2	26.8	25.6
20	25.4	26.4	27.0	26.8	26.5	25.4
21	25.1	26.3	26.8	26.6	26.3	25.2
22	24.9	26.2	26.6	26.4	26.1	25.1
23	24.7	26.0	26.4	26.2	25.9	25.0
24	24.6	25.8	26.2	26.1	25.7	24.8

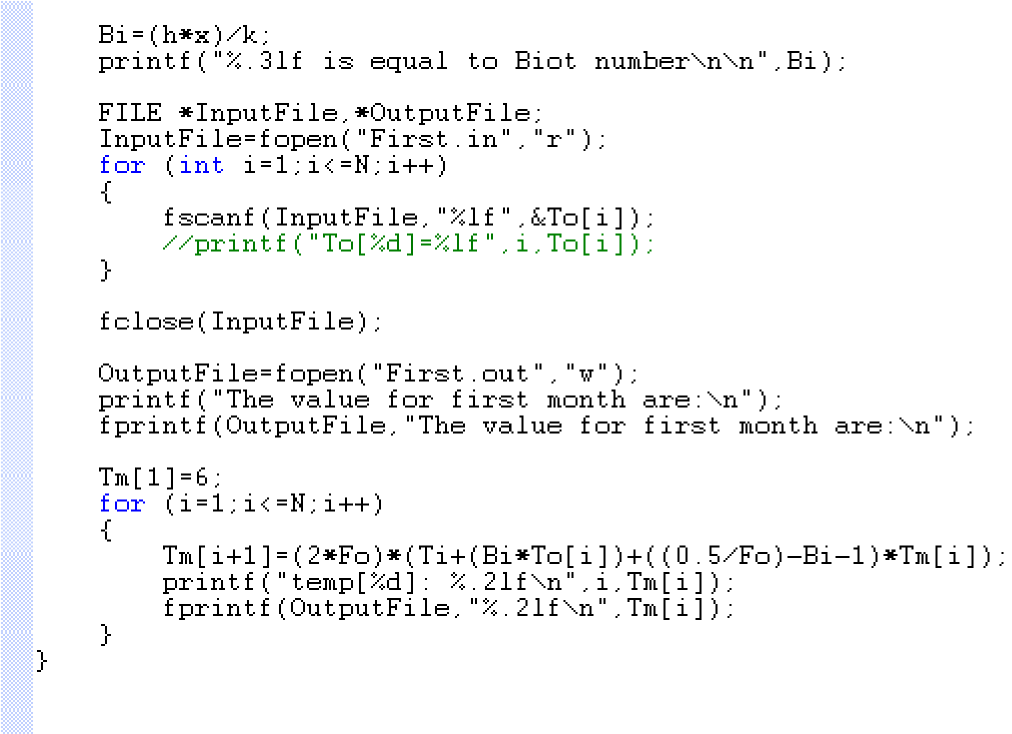
APPENDIX B



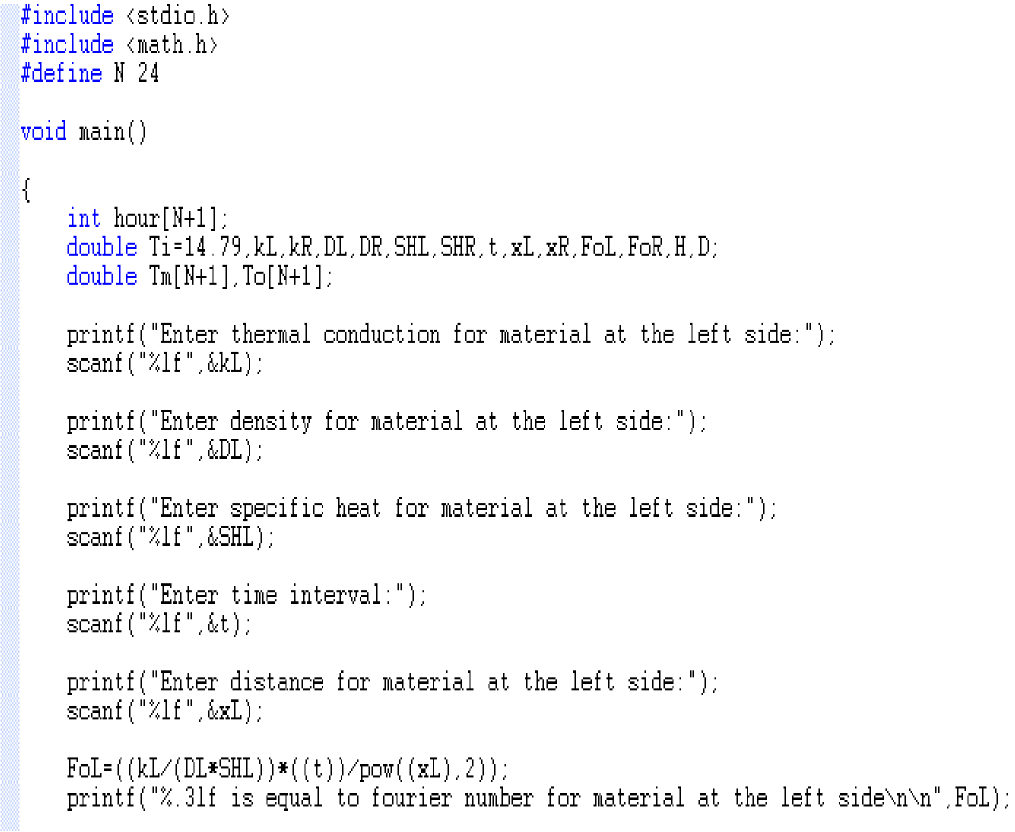
```
#include <stdio.h>
#include <math.h>
#define N 24

void main()

{
    int hour[N+1];
    double k,D,SH,t,x,Fo;
    double Tm[N+1],Ti=0.5,To[N+1];


    printf("Enter thermal conduction:");
    scanf("%lf",&k);

    printf("Enter density:");
    scanf("%lf",&D);

    printf("Enter specific heat:");
    scanf("%lf",&SH);

    printf("Enter time interval:");
    scanf("%lf",&t);

    printf("Enter distance:");
    scanf("%lf",&x);

    Fo=((k/(D*SH))*((t))/pow((x),2));
    printf("%.3lf is equal to fourier number\n\n",Fo);


    FILE *InputFile,*OutputFile;
    InputFile=fopen("First.in","r");
    for (int i=1;i<=N;i++)
    {
        fscanf(InputFile,"%lf",&To[i]);
        //printf("To[%d]=%lf",i,To[i]);
    }

    fclose(InputFile);

    OutputFile=fopen("First.out","w");
    printf("The value for first month are:\n");
    fprintf(OutputFile,"The value for first month are:\n");

    Tm[1]=2.44;
    for (i=1;i<=N;i++)
    {
        Tm[i+1]=(Fo*To[i])+(1-(3*Fo))*Tm[i]+(Fo*Ti);
        printf("temp[%d]: %.2lf\n",i,Tm[i]);
        fprintf(OutputFile,"%.2lf\n",Tm[i]);
    }

}
```



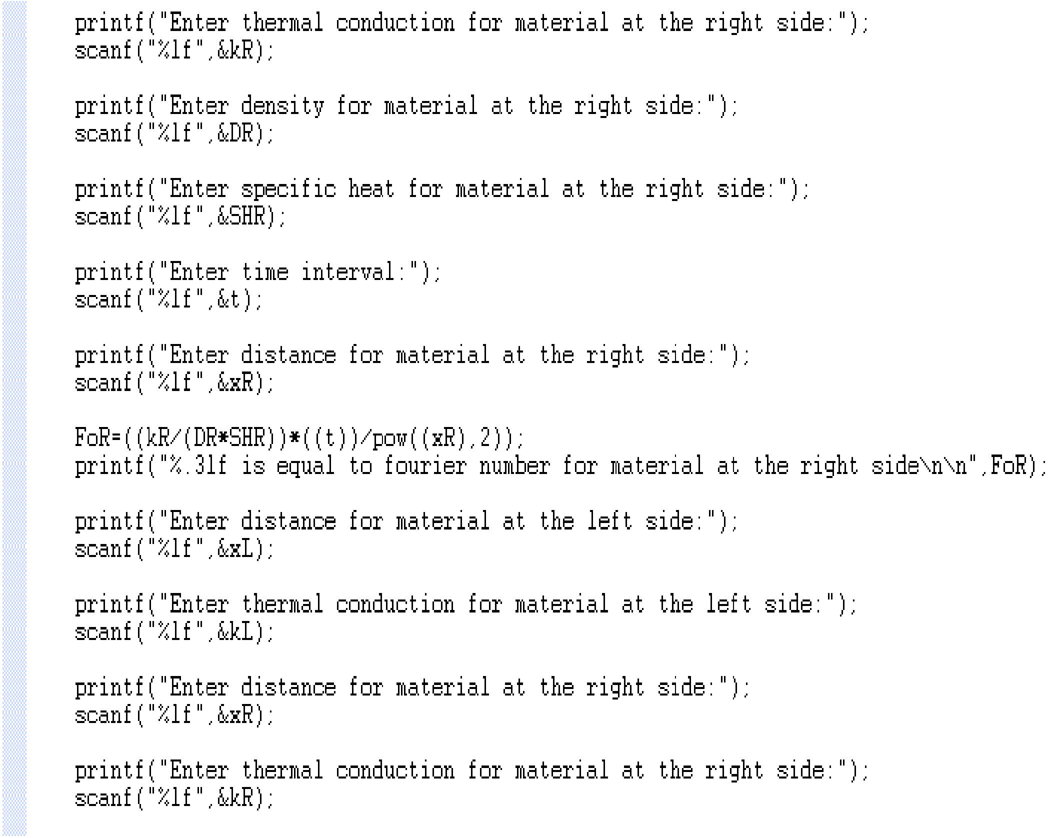
```
#include <stdio.h>
#include <math.h>
#define N 24

void main()

{

    int hour[N+1];
    double k,D,SH,t,x,Fo,Bi,h,Ti=14.79;
    double Tm[N+1],To[N+1];


    printf("Enter thermal conduction:");
    scanf("%lf",&k);

    printf("Enter density:");
    scanf("%lf",&D);

    printf("Enter specific heat:");
    scanf("%lf",&SH);

    printf("Enter time interval:");
    scanf("%lf",&t);

    printf("Enter distance:");
    scanf("%lf",&x);

    Fo=((k/(D*SH))*((t))/pow((x),2));
    printf("%.3lf is equal to fourier number\n\n",Fo);

    printf("Enter thermal conduction:");
    scanf("%lf",&k);

    printf("Enter heat convection coefficient:");
    scanf("%lf",&h);

    printf("Enter distance:");
    scanf("%lf",&x);
```



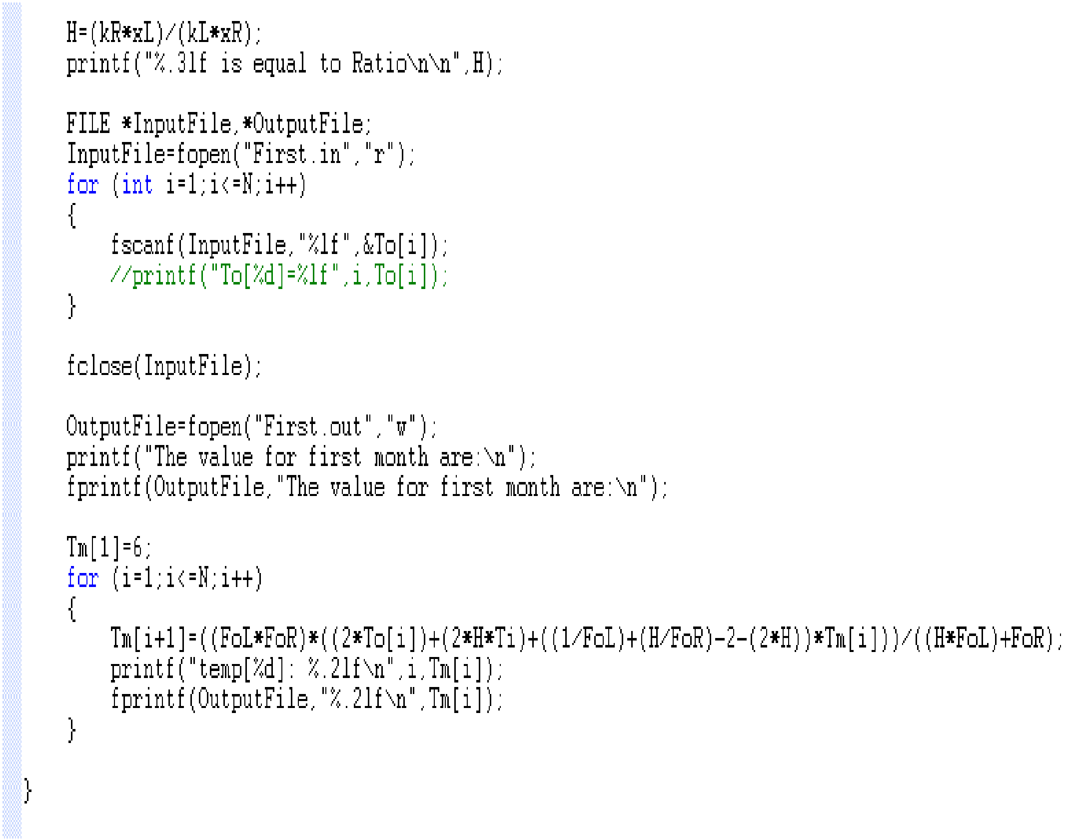
```
    Bi=(h*x)/k;
    printf("%.3lf is equal to Biot number\n\n",Bi);

    FILE *InputFile,*OutputFile;
    InputFile=fopen("First.in","r");
    for (int i=1;i<=N;i++)
    {
        fscanf(InputFile,"%lf",&To[i]);
        //printf("To[%d]=%lf",i,To[i]);
    }

    fclose(InputFile);

    OutputFile=fopen("First.out","w");
    printf("The value for first month are:\n");
    fprintf(OutputFile,"The value for first month are:\n");

    Tm[1]=6;
    for (i=1;i<=N;i++)
    {
        Tm[i+1]=(2*Fo)*(Ti+(Bi*To[i])+((0.5/Fo)-Bi-1)*Tm[i]);
        printf("temp[%d]: %.2lf\n",i,Tm[i]);
        fprintf(OutputFile,"%.2lf\n",Tm[i]);
    }
}
```



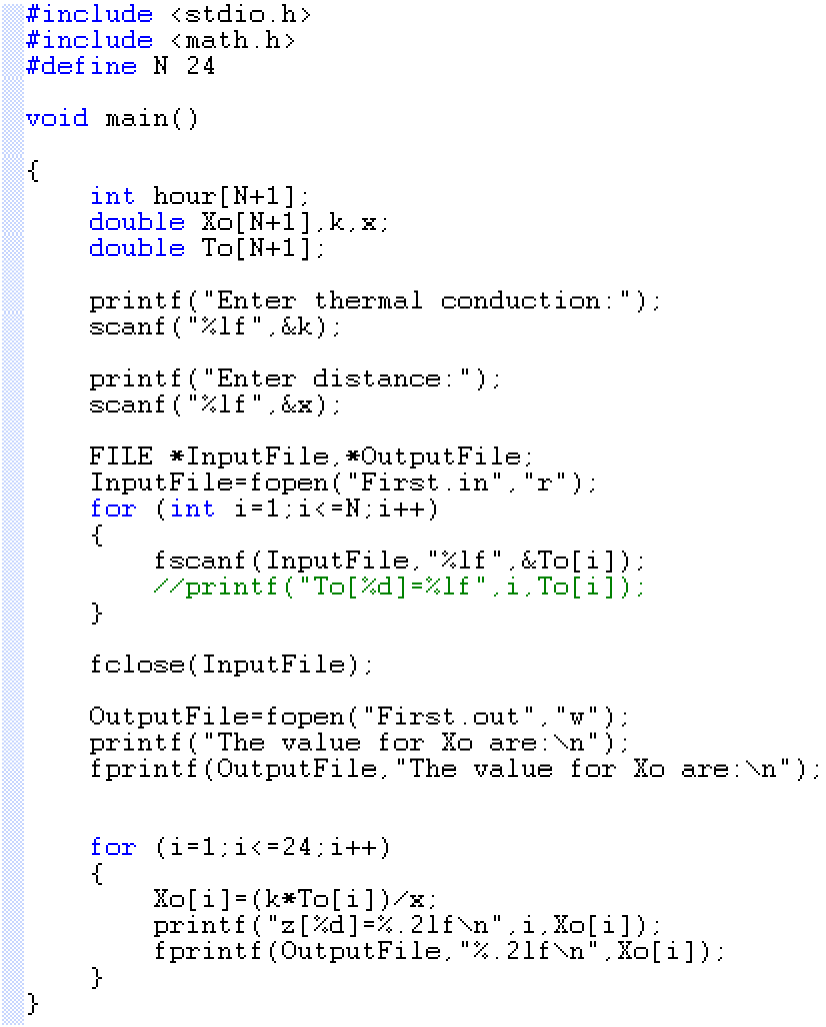
```
#include <stdio.h>
#include <math.h>
#define N 24

void main()

{
    int hour[N+1];
    double Ti=14.79,kL,kR,DL,DR,SHL,SHR,t,xL,xR,FoL,FoR,H,D;
    double Tm[N+1],To[N+1];

    printf("Enter thermal conduction for material at the left side:");
    scanf("%lf",&kL);

    printf("Enter density for material at the left side:");
    scanf("%lf",&DL);

    printf("Enter specific heat for material at the left side:");
    scanf("%lf",&SHL);

    printf("Enter time interval:");
    scanf("%lf",&t);

    printf("Enter distance for material at the left side:");
    scanf("%lf",&xL);

    FoL=((kL/(DL*SHL))*((t))/pow((xL),2));
    printf("%.3lf is equal to fourier number for material at the left side\n\n",FoL);
```



```
printf("Enter thermal conduction for material at the right side:");
scanf("%lf",&kR);

printf("Enter density for material at the right side:");
scanf("%lf",&DR);

printf("Enter specific heat for material at the right side:");
scanf("%lf",&SHR);

printf("Enter time interval:");
scanf("%lf",&t);

printf("Enter distance for material at the right side:");
scanf("%lf",&xR);

FoR=((kR/(DR*SHR))*((t))/pow((xR),2));
printf("%.3lf is equal to fourier number for material at the right side\n\n",FoR);

printf("Enter distance for material at the left side:");
scanf("%lf",&xL);

printf("Enter thermal conduction for material at the left side:");
scanf("%lf",&kL);

printf("Enter distance for material at the right side:");
scanf("%lf",&xR);

printf("Enter thermal conduction for material at the right side:");
scanf("%lf",&kR);
```



```
    H=(kR*xL)/(kL*xR);
    printf("%.3lf is equal to Ratio\n\n",H);

    FILE *InputFile,*OutputFile;
    InputFile=fopen("First.in","r");
    for (int i=1;i<=N;i++)
    {
        fscanf(InputFile,"%lf",&To[i]);
        //printf("To[%d]=%lf",i,To[i]);
    }

    fclose(InputFile);

    OutputFile=fopen("First.out","w");
    printf("The value for first month are:\n");
    fprintf(OutputFile,"The value for first month are:\n");

    Tm[1]=6;
    for (i=1;i<=N;i++)
    {
        Tm[i+1]=((FoL*FoR)*((2*To[i])+(2*H*Ti)+((1/FoL)+(H/FoR)-2-(2*H))*Tm[i]))/((H*FoL)+FoR);
        printf("temp[%d]: %.2lf\n",i,Tm[i]);
        fprintf(OutputFile,"%.2lf\n",Tm[i]);
    }

}
```



```
#include <stdio.h>
#include <math.h>
#define N 24

void main()

{
    int hour[N+1];
    double Xo[N+1],k,x;
    double To[N+1];

    printf("Enter thermal conduction:");
    scanf("%lf",&k);

    printf("Enter distance:");
    scanf("%lf",&x);

    FILE *InputFile,*OutputFile;
    InputFile=fopen("First.in","r");
    for (int i=1;i<=N;i++)
    {
        fscanf(InputFile,"%lf",&To[i]);
        //printf("To[%d]=%lf",i,To[i]);
    }

    fclose(InputFile);

    OutputFile=fopen("First.out","w");
    printf("The value for Xo are:\n");
    fprintf(OutputFile,"The value for Xo are:\n");


    for (i=1;i<=24;i++)
    {
        Xo[i]=(k*To[i])/x;
        printf("z[%d]=%.2lf\n",i,Xo[i]);
        fprintf(OutputFile,"%.2lf\n",Xo[i]);
    }
}
```