COMPUTATION OF SOLAR RADIATION HEAT GAIN IN ANALYSING ENERGY EFFICIENT OPERATION OF AN AIR-CONDITIONING SYSTEM

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Report submitted in partial fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

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UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled *"Computation of Solar Radiation Heat Gain in Analysing Energy Efficient Operation of An Air-Conditioning System"* is written by *Syahrul Ramadhan Bin Ahmad Kamal Ariffin*. I have examined the final copy of this report and in my opinion, it is fully adequate in terms of language standard, and report formatting requirement for the award of the degree of Bachelor Engineering. I here with recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor Mechanical Engineering.

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I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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بسم الله الرحمن الرحيم

In the Name of Allah, the Most Gracious and the Most Merciful

Specially dedicated to

My beloved mother Sharifah Binti Ismail, sisters and those who have

Encouraged and always be with me during hard times,

Inspired me throughout my journey of learning

And instilled my passion for energy sustainability

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ABSTRACT

In any building, air-conditioning system is essential to maintain thermal comfort of the occupants as well as ensuring their optimum productivity. However, the electricity consumption by air-conditioning alone is more than 50% from the total electricity consumption. Hence it must be designed carefully to optimize electrical energy supplied and avoid energy wastage. The operation of an air-conditioning system are depend largely on the heat gain absorbed by the building. Heat gain may come from internal heat gain as well as external heat gain but the main contribution of heat gain is the solar radiation heat gain.Solar radiation heat gain values varies every day with respect to the different position of the sun.In order to solve energy wastage problem in air-conditioning system, the computation of the solar radiation heat gain is done. In this study the equations used are the ‘Clear-sky Solar Radiation’ as suggested by ASHRAE in book of fundamentals 2009. The equations are then being made acomputer model of C++ computer programming by using Code::Blocks version 8.02 to calculate the solar radiation heat gain.The heat gain of every months are represented by the heat gain on their 21st day. The results are then being plotted into graphs to show the relationship between Irradiance, E and Total Solar Radiation Heat Gain, Q to a building. Lastly, the total solar radiation heat gain curves for twelve months are being plotted in another graphs for ease of analysis on how the sun position can actually affect the solar radiation heat gain.

ABSTRAK

Dalam setiap bangunan, sistem penghawa dingin merupakan salah satu keperluan asas untuk menjamin keselesaan penghuninya serta memastikan produktiviti kerja berada pada tahap tertinggi. Namun begitu, sistem penghawa dingin menggunakan tenaga elektrik lebih daripada 50% daripada jumlah keseluruhan penggunaan tenaga elektrik. Oleh sebab itu, sistem penghawa dingin perlu direka bentuk secara teliti untuk mengelakkan pembaziran tenaga di samping menggunakannya secara optimum. Operasi setiap sistem penghawa dingin bergantung besar kepada kedapatan haba yang diserap oleh bangunan tersebut. Kedapatan haba adalah terdiri daripada kedapatan haba dalaman dan kedapatan haba luaran akan tetapi kedapatan haba radiasi solar merupakan penyebab utama. Kedapatan haba radiasi solar adalah berbeza-beza pada setiap hari malah berbeza juga pada setiap jam kesan daripada posisi matahari yang berbeza. Untuk menyelesaikan masalah kebaziran tenaga elektrik dalam penggunaan penghawa dingin, kedapatan haba solar radiasi perlu dikira secara teliti. Dalam pengkajian ini, persamaan-persamaan yang digunakan merupakan 'Kaedah Solar Radiasi Langit Cerah' seperti mana yang telah disarankan oleh ASHRAE di dalam Buku Asas 2009.Kemudiannya, persamaan-persamaan itu telah diprogramkan di dalam sebuah program komputer menggunakan perisian 'Code::Blocks' versi 8.02 untuk memudahkan pengiraan. Kedapatan haba pada setiap bulan diwakilkan oleh kedapatan haba oleh hari yang ke 21 pada setiap bulan. Keputusan dapatan haba telah dijadikan dalam bentuk graf untuk menunjukkan hubungkait antara sinaran matahari dan kedapatan haba solar radiasi oleh sesuatu bangunan. Akhir skali, keluk setiap jumlah kedapatan haba solar radiasi untuk jangka masa 12 bulan telah dijadikan sekali lagi dalam graf yang berlainan untuk memudahkan analisis tentang bagaimana posisi matahari boleh memberi kesan kepada kedapatan haba solar radiasi.

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LIST OF SYMBOLS

A	Area
ab	Air mass component
ad	Air mass component
β	Solar altitude angle
CO_2	Carbon dioxide
E_0	Extraterrestrial radiant flux
E_{SC}	Solar constant
E_b	Beam normal irradiance
E_d	Diffuse horizontal irradiance
E_t	Clear-sky irradiance
$E_{t,b}$	Beam/direct irradiance component
$E_{t,d}$	Diffuse irradiance component
$E_{t,r}$	Ground reflected irradiance component
H	Hour angle
I_t	Hourly global solar radiation
m	Air mass
n	Number of day
ϕ	Solar azimuth angle
θ	Angle of incidence
Q	Total fenestration solar radiation heat gain
q_b	Beam solar radiation heat gain
q_d	Diffuse solar radiation heat gain
δ	Solar inclination
τ_b	Beam solar optical depth
τ_d	Diffuse solar optical depth
Ψ	Surface azimuth
γ	Surface solar azimuth angle

LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
AST	Apparent solar time
BLAST	Building load analysis and system thermodynamics
CL	Cooling load
ET	Equation of time
HVAC	Heating, ventilation and air-conditioning
IAC (θ,Ω)	Direct indoor solar attenuation coefficient
IAC_D	Diffuse indoor solar attenuation coefficient
LON	Longitude of site
LSM	Longitude of local standard time meridian
LST	Local standard time
SHG	Solar heat gain
SHGC (θ)	Direct solar heat gain coefficient
$(SHGC)_D$	Diffuse solar heat gain coefficient
UMP	Universiti Malaysia Pahang
UTC	Universal time coordinated

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Nowadays, due to economic and environmental reasons many organizations around the globe are constantly under pressure to reduce the energy consumption in their building operation. Energy cost is one of the main cost drivers in any businesses and the reduction in energy consumption will lead to reduction of operating costs and thereby helps to increase the organization's profit.

Besides the depletion of natural resources, the main environmental issue which relates to the energy consumption is the increase of emission of carbon dioxide (CO_2) that contributes to global warming. As a result, the idea of green technology and efficient energy usage has been introduced and improved to minimize the problem from arising.

In any building, air-conditioning system is regarded as essential equipment for ensuring the comfort of the building's occupants so that they can carry out their activities in a comfortable environment. In addition, air-conditioning is among appliances that consume most electricity, hence it must be carefully designed to optimize the electrical energy supplied.

To initiate the proper energy usage for air-conditioning, the Malaysian government has introduced several steps in order to educate the community regarding energy efficiency in daily life. One such initiative done since 2011 is by implementing an order to all government offices to set the air-conditioning temperature no lower than

24 °C and this order will be extended to the private sector by 2013. Furthermore, a rebate of RM 200 and RM 100 are given to people who buy 5-Star Energy Rating refrigerators and air- conditioning equipment respectively. These initiatives are among the initiatives for Malaysia to achieve its vision to reduce carbon emission by 40% in 2020.

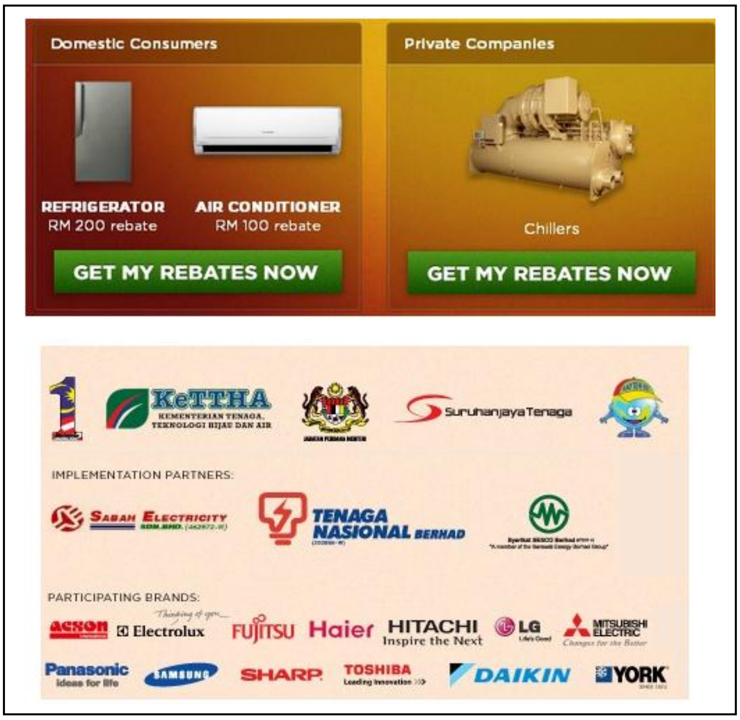

Figure 1.1: Rebate promotions for refrigerator and air-conditioning

Source: www.saveenergy.gov.my (2011)

Figure 1.2:5-Starenergy efficient tag logo

Source: www.tnb.com.my (2013)

As part of the engineer's responsibility to help achieve this vision, the installation of an air-conditioning system must properly take into count the heat gains into the building which comes from external and internal means. The major heat gains for external means comes from the radiation of sunlight through the windows .To ensure an air- conditioning energy efficient building, the heat gain need to be calculated properly.

1.2 PROBLEM STATEMENT

The air-conditioning system is one of major appliances in any building nowadays. In most modern air-conditioned office and commercial buildings in Malaysia, air conditioning systems take up to 60 to 70% of the total electricity consumption every month and often the cooling load actually required is less compared to the cooling load supplied by the air- conditioning system. This will therefore cool the room more than what it is required and result in electrical energy wastage. Furthermore, the current method of heat gains of solar radiation calculation which has big contribution for the total heat gain is not thorough and detailed.

This project will cover the computation of variable heat gain into a building. The heat gain computation will cover only the external source especially the solar radiation through the windows. On the other hand, the internal heat gains such as heat from occupants, appliances and lighting are not being calculated because these values do not vary with time in a day.

1.3 PROJECT OBJECTIVES

The objectives of this project are determined. There are three objectives that have been defined to be focused on as stated below:

i. To understand the knowledge of solar radiation that varies with the sun position

ii. To compute heat gain into hypothetical building by means of solar radiation

iii. To establish a computer model to compute variable heat gain for assessing the real- time loads for air-conditioning.

1.4 SCOPE OF STUDY

The project objectives are narrowed down to reduce the complexity of the study. Firstly, a comprehensive literature review has been conducted properly to determine suitable formulas for the heat load calculations for solar radiation which varies with the sun position.

Secondly, the office of Faculty of Mechanical Engineering is proposed as the hypothetical building to be used in this project. The hypothetical building here is that the analysis does not take the office information as a whole together with the number of occupants, appliances and lighting but will take only the building envelope information especially window specifications. This is to synchronize with the objectives of the study in which it is only covers the solar radiation through windows.

CHAPTER 2

LITERATURE REVIEW

2.1 POTENTIAL OF SOLAR ENERGY IN MALAYSIA

Mohd Zainal et al (2010) has stated that energy has become a fundamental part of people's daily lives as well as being vital to the social and economic progress of every country. They also explained that the energy that are being using today can be divided into two groups called the renewable and non-renewable energy. As the name goes, renewable energy is derived from natural processes that are replenished constantly. One of the various forms of renewable energy is the solar energy which is derived directly from the sun. Moreover, they also stating some statistics back from 2005 which shown that the worldwide electricity generation was 17450 TWh out of which 40% originated from coal, 20% from gas, 16% from nuclear, 16% hydro, 7% from oil and the remaining of nearly 2% that makes up electricity from renewable sources. For the same year in Malaysia, the percentage of energy profile in Malaysia is mainly comes from natural gas for both national commercial primary and national power sector categories.

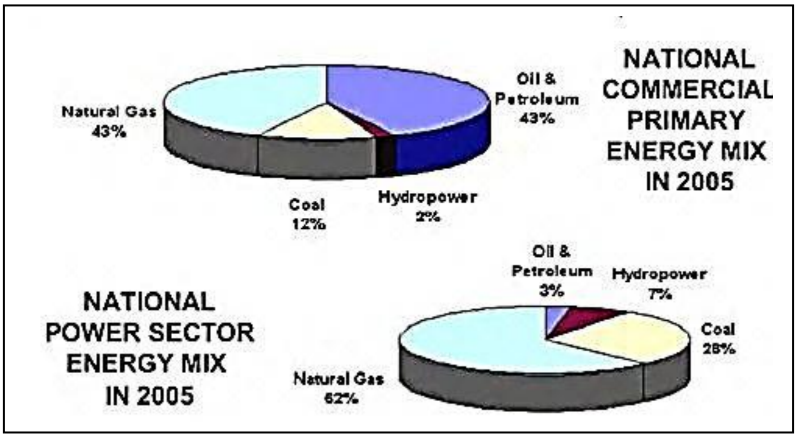

Figure 2.1: Energy profile in Malaysia

Source: TNB Research (2005)

Later, they also elaborated on the impact of the increasing usage of the energy. According to them, they major issues of the world nowadays are none other than energy problem and global warming. Global warming is a phenomenon that occurs due to the increase in the average temperature of the earth resulting from the toxic gases produced by factories and burning of fossil fuel around the world. In order to reduce this effect, alternative energy source must be used. They ended their explanation by stating that renewable energy sources such as solar and wind energy have been used for quite some time but there are still many reasons why they have not emerged as primary energy sources.

Kamaruzzaman et al (1992) as cited in a journal entitled 'Monthly mean hourly global solar radiation estimation' has stressed that for the studies of solar energy, the data on solar radiation and its component values at a given specific location are very crucial and important. This is to gather accurate knowledge of the availability of solar resource at any place. Furthermore, they also mentioned that the average values of hourly, daily and monthly global irradiations on horizontal surfaces are needed in many applications of solar energy design.

2.2 MALAYSIA SOLAR IRRADIANCE

As cited in the same journal, Muzathik et al (2010) has relates the solar energy with Malaysia perspective and he has come up with a view by stating that Malaysia is a country which is blessed by having abundant of solar energy. The annual average solar irradiations for Malaysia has a magnitude of 4.21- 5.56 kW h m^{-2} and the sunshine duration is more than 2200 h per year. But as for many developing countries like Malaysia, solar radiation measurements are not easily been achieved due to high equipment costs, maintenance and calibration of the measuring devices. So, the alternative solution for this problem is to estimate solar radiation by using modeling approach such as the prediction of hourly global solar radiation, I_t for any day.

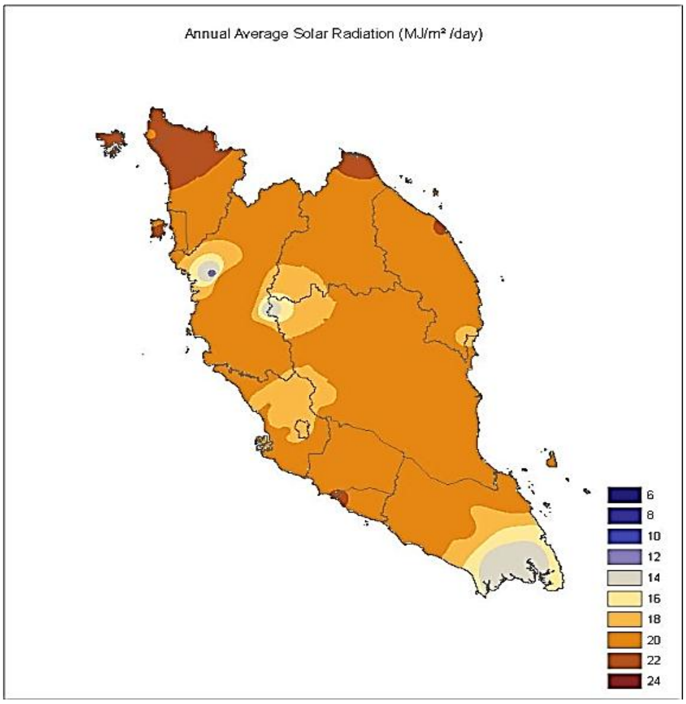

Figure 2.2: Annual average solar radiation in Malaysia

Source: TNB Research (2005)

2.3 AIR-CONDITIONING ENERGY CONSUMPTION

Nina et al (2012) has stated that tropical climates countries such as Malaysia, Singapore, Thailand and Indonesia are very concern about cooling in building for the occupant's comfort. Although thermal comfort is a major concern but the energy consumption in building especially for air-conditioning system must be taken into count. They have also mentioned that most of all commercial offices in Malaysia which are being occupied by air conditioning system consume averagely 70 percent of the total energy consumption in a year. Thus, a precise and accurate cooling load calculation should be applied for the essential decisions regarding the required capacity of the air conditioning system.

In an another study done by Al-Rabghi et al (2004), they has mentioned that the percentage of energy consumed by air-conditioning systems in buildings in city of Jeddah, Saudi Arabia during summer is over 50 percent of the total electric consumption. According to them, energy is utilized in sizeable quantities to provide air-conditioning in offices, commercial buildings, educational institutions and homes. Resulted from that, they has suggested a need to study alternative means of air-conditioning and to identify and implement strategies to save energy and at the same time maintaining good thermal comfort environment in the buildings.

2.4 HEAT GAIN AND COOLING LOAD CALCULATION PRINCIPLES

According to ASHRAE (2011), heating and cooling load calculations are the primary design basis for most heating and air-conditioning systems and components. Cooling and heating load calculations can significantly affect first cost of building construction, comfort and productivity of occupants and operating cost of energy consumption. In general, heating and cooling loads are the rates of energy input(heating) or removal (cooling) required maintaining an indoor environment at a desired temperature and humidity condition.

Heating and air conditioning systems are designed, sized, and controlled to accomplish that energy transfer. The amount of heating or cooling required at any particular time varies widely and depending on external and internal factors. Peak design of heating and cooling load calculations are used to determine the maximum rate of heating and cooling energy transfer needed at any point in time.

In an air-conditioning design, the following heat flow rates, each of which varies with time must be differentiated.

- Space Heat Gain which is an instantaneous rate of heat gain is the rate at which heat enters into and/or is generated within a space. Heat gain is classified by its mode of entry into the space and whether it is sensible or latent.
- Entry modes include
  i. Solar radiation through transparent surfaces
  ii. Heat conduction through exterior walls and roofs

2.5 EXTERNAL HEAT GAINS

2.5.1 SOLAR RADIATION HEAT GAINS

Thevenard et al (2009) believed that solar heat gains (SHG) and the cooling load (CL) play a great part in the comfort conditions. They elaborated the idea by mentioning that cooling loads comprise both sensible and latent components and depending on the heat transfer by means of conduction, convection and long-wave radiation through the building envelope. Furthermore, a significant fraction of the cooling load is also being contributed by solar heat gains through fenestration and indirectly by the absorption of solar radiation through the envelope.

Apart from that, they also suggested that the design conditions data should take count for all 12 months of the year instead of on an annual basis. This is because the peak cooling design conditions happen not necessary during the hottest month but it may occur during the shoulder season when the sun is lower on the horizon and imposes larger solar heat gains through vertical fenestration. So, it is advisable by them to calculate the loads on a monthly basis and take the yearly maximum as the design value.

From another study done by Wu et al (2007), he suggested that the best solar radiation data at any place of interest should be measured continuously and accurately at that site for long term. However, it cannot be done because of certain problems such as the financial of the maintenance, instrument calibration and other limitations.

2.5.2 CLEAR-SKY SOLAR RADIATION

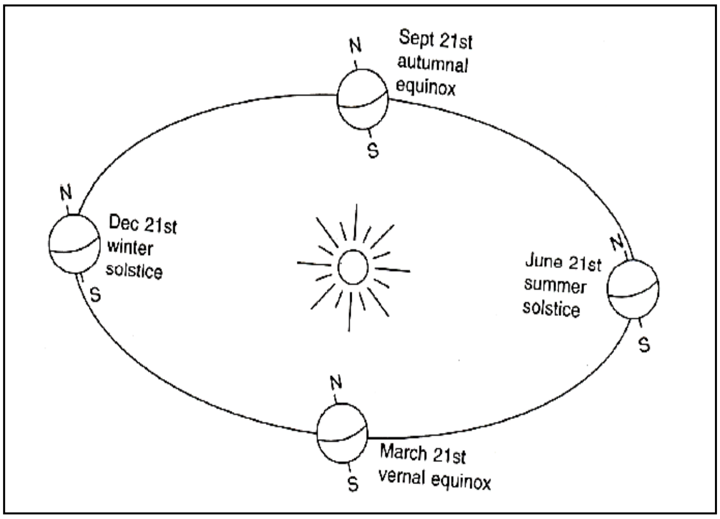

Figure 2.3: Motion of earth around the sun

Source: ASHRAE Book of Fundamentals (2009)

ASHRAE (2009) gives an overview regarding the clear-sky solar irradiance. According to it, clear-sky solar irradiance parameters are useful in calculating solar related air conditioning loads for any time of any day in a year. The parameters are provided for the 21st day of each month. This is because the 21st day of the month is usually a convenient day for solar calculations because June 21 and December 21 represent the solstices which is the longest and shortest days. Apart from that, March 21 and September 21 are close to equinox in which the days and nights have the same length of time.

From another study done by Al-Sanea et al (2004), they had stressed the importance of solar radiation by mentioning that the accurate estimation of solar radiation on the earth's surface is needed in many applications. The calculations include the air conditioning loads in buildings, design and performance evaluation of passive building heating system as well as solar energy collection and conversion system.

In addition, from their exhaustive study, they found that ASHRAE clear- sky model appears to be a general method for them to calculate the temporal and spatial variations of solar radiations. Furthermore, they also stressed the users who wish to use this model for their calculations by reminding that as the name of 'clear-sky' implies this model only applicable to basic atmosphere only.

In addition, the statement is further explained by Thevenard et al (2009) by stressing that the calculation of solar heat gain by using ASHRAE solar radiation model should only concerned with solar radiation under clear skies because this will normally result in the maximum solar heat gains through fenestration.

2.6 INFLUENCE OF DIFFERENT OUTDOOR DESIGN CONDITIONS

According to Bulut et al (2008), outdoor design conditions such as local climatic conditions are important parameters for energy efficiency of buildings. This is because the energy consumption in a building depends on climatic conditions and the performance of heating, ventilating and air conditioning (HVAC) systems changes with them. In addition, a better design of a building HVAC application that takes amount of right climatic conditions will result in a better comfort and more energy efficient buildings. They added that outdoor design conditions are weather data information for design purposes showing the characteristic features of the climate at a particular location which will affect building loads and economical design. The result of incorrect selection of outdoor conditions can be dramatic in view of energy and comfort.

This theory is being supported by Schiavon et al (2008) which also suggested that the heating energy need is not affected by the air velocity increase but it depends on the outdoor conditions (climate zone).

2.7 ENERGY EFFICIENT BUILDING

2.7.1 STRATEGIES THAT REQUIRE NO EXPENDITURES

Al-Rabghi et al (2004) had explained on air-conditioning controller function which act as the brain of air-conditioning system. This controller will be fed with information such as indoor control parameters such as air temperature and relative humidity. Later, these value will be compared with set point values and if there is sufficient different, the controller will send signals to other components to act accordingly. They also stressed that if the controller does not function properly then the required indoor environment will not be achieved and may result in either or both of energy wastage and dissatisfaction of thermal comfort of occupants.

They also further elaborated their explanation by mentioning that large portion of energy would be wasted if the building is kept at low temperature during unoccupied periods. In order to solve this problem, they suggested that the air-conditioning controller must be frequently re-programmed to save energy during unoccupied periods. Furthermore, they also promoted regarding the sensors that are sensitive to the presence of occupants which already available in the market. These sensors can turn the air-conditioning off when the space is unoccupied.

2.7.2 STRATEGIES THAT REQUIRE FURTHER INVESTMENT

According to Al-Rabghi et al (2004), the best method for reducing the external loads of a building is to insulate the building thermally. They later explained that when a building is thermally insulated especially the external walls and the roof, the total load will reduce. Today, there are lot of insulation materials such as blocks, bricks and layers that available in the market for home builders. They also recommended that imposing effective rules and regulations is needed as to make sure that all new buildings are thermally well insulated. This suggestion can be a reality through good support from city municipality.

Besides, they also suggested that one way to minimize external solar radiation loads is by using double or triple glazing for windows. This is because among the external loads for a building is the infiltration load which is unwanted external air that enters into the building through small holes and openings. In order to minimize this load, they building should be air tight. Their arguments continue by mentioning that the cost of the insulation layers or the insulated construction materials for home owners can be paid back in a very short period of time as the electricity bill will be lower.

Besides, in the same journal they also suggested that energy simulation programs can be effectively used to study the energy consumption by a building even it is not being built yet. Different alternative cases and parameters can be considered and being studied in order to determine which is the most economical and energy efficient. They also elaborated on the energy simulations programs by giving out several programs that are already available in the market. Based on them, simulation programs are mainly two types which the first one is the commercial type.

This commercial type is developed by the air-conditioning companies such as TRACE which is developed by TRANE. On the other hand, the other type is the government supported programs such as BLAST and DOE 2. In these programs, building information together with the weather file for the city under study can be supplied to the program. Then the program will does it works by calculating the building loads, air-conditioning loads, plant loads and the energy demands and these calculations are performed on hourly basis. They ended their explanation by stating that although these programs are best used during the designing stages of buildings but one can still get benefit from these programs for studying and also modifying the existing buildings.

Thermal cool storage is a method of energy saving in a building (Al-Rabghi et al, 2004). It is known that the outdoor temperature changes from hour to hour and from month to month. This will later result in the different cooling load and air conditioning demand which varies during the day and throughout the year.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will be discussed on the methods of how this research should be conducted. In this study, there are few process stages that have been through. The processes will be described in the following flow chart together with their explanations. The methodology flow chart is constructed to show the process of tasks throughout the project and is it constructed based on the scope of the project so that all the objectives will be achieved at the end of the project. Besides, the flow chart also acts as a guideline to make sure that the project is on the right track.

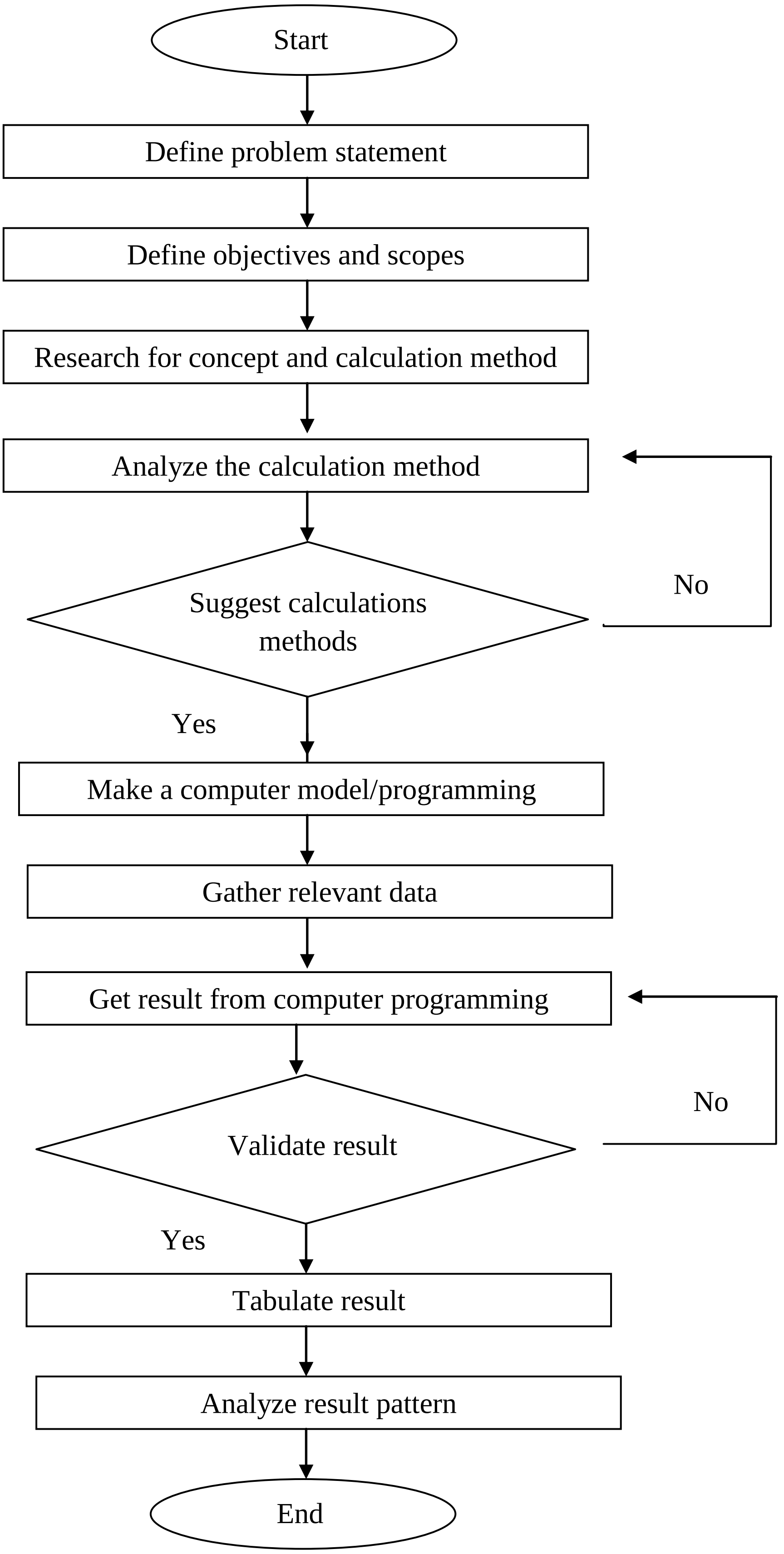

Figure 3.1: Project overall flow chart

3.2 HYPOTHETICAL BUILDING INFORMATION

The hypothetical building to be used in this project is the office of the Faculty of Mechanical Engineering which is located at the administration block. It is being noted that only the windows information is counted for the calculations of solar radiation heat gain.

Figure 3.2: Faculty of Mechanical Engineering Administration Block

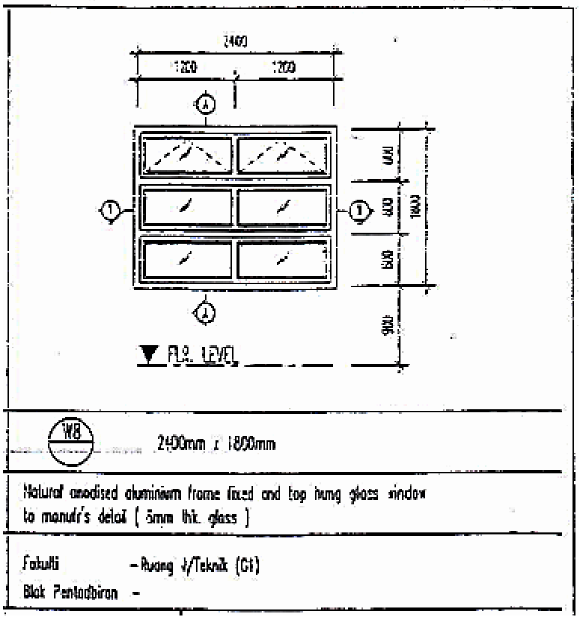

Figure 3.3: Hypothetical building window specifications

Source: Department of Development and Property Management, UMP

All data regarding the building information are gained from the Department of Property Management and Development of Universiti Malaysia Pahang. According to the data provided, the window type and specifications that being used at the building is as below:

- Code : W8
- Type : Natural Anodised Aluminium frame fixed and top hung glass window
- Dimension : 2400mm x 1800mm
- Thickness : 6mm

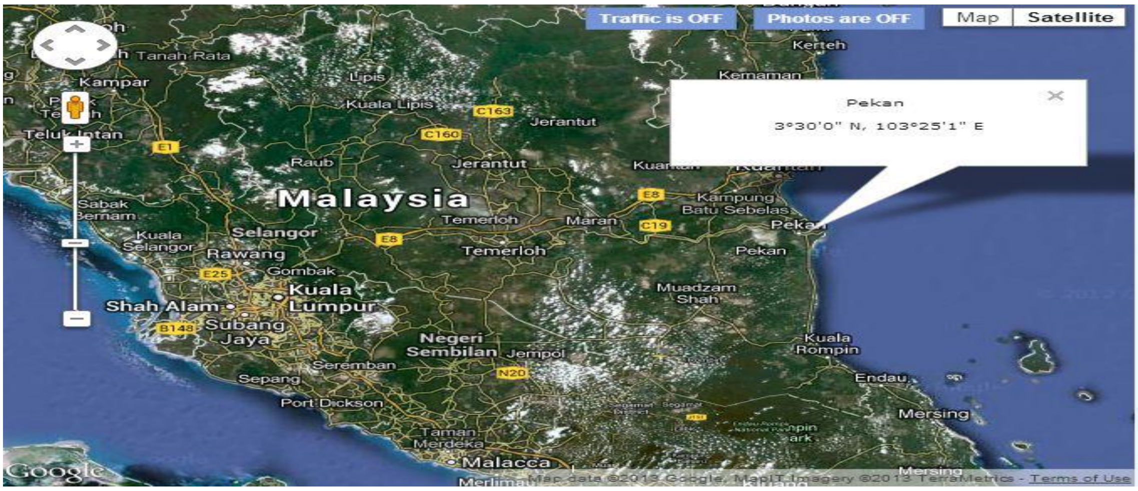

Figure 3.4: Pekan district latitude and longitude

Source: www.maps.google.com.my (2013)

The location data of this building are as below:

- The latitude and longitude are:
  3^{O} 30' 0'' N and 103^{O} 25' 1" E in DMS (Degree Minute Second)
  or 3.5^{O} N and 103.42^{O} E in (Decimal degree)
- Local standard Meridian Longitude: +120 E^{O}
- Malaysia Universal Time Coordinated (UTC) : +8

3.3 SELECTING THE FORMULA AND EQUATION

The equations to be used in the calculations are all based on ASHRAE Book of Fundamental 2009. The calculations are using the 'clear-sky solar radiation' method. This method is chose to synchronize with the scope of the project and to reduce the complexity of the calculations but achieve the objectives accordingly.

3.3.1 SOLAR CONSTANT, E_{SC} AND EXTRATERRESTRIAL SOLAR RADIATION

Solar constant is the intensity of solar radiation on a surface normal to the sun's rays beyond the earth's atmosphere at the average earth-sun distance. The value that is proposed by the World Meteorological Organization in 1981, E_{SC}= 1367 W/m^2

It is known that the earth's orbit is slightly elliptical, so the extraterrestrial radiant flux, E_o varies throughout the year and reaching the maximum value of 1412 W/m^{2}beginning of January when the earth is closest to the sun (aphelion) and minimum value of 1322 W/m^{2}near the beginning of July when the earth is farthest from the sun (perihelion)

$$E_o = E_{SC}\left\{1 + 0.033\ \cos\left[360°\frac{(n-3)}{365}\right]\right\} \qquad \text{n; day of the year} \qquad (3.1)$$

In the calculations, the solar radiation of 21st day of every month is taken to represent the solar radiation heat gain for those particular months. This is because all the four distinct seasons happens on 21st day of months March, June, September and December. From this four month, it can easily see of how the position of the sun give effect to the solar radiation heat gain and in order to show the continuity between all the months, the other months solar radiation heat gain are also represented by their respective 21st day.

3.3.2 EQUATION OF TIME AND SOLAR TIME

The earth's orbital velocity is varies throughout the year so apparent solar time (AST) also varies from the mean time kept by a clock running at a uniform rate. The variation is called the equation of time (ET) and approximately by the following formula.

With ET is in minutes and

$$\Gamma = 360^{\circ}\frac{n-1}{365} \qquad (3.2)$$

$$ET = 2.2918\,(0.0075 + 0.1868\cos(\Gamma) - 3.2077\sin(\Gamma) - 1.4615\cos(2\Gamma) - 4.089\sin(2\Gamma) \qquad (3.3)$$

AST = LST + ET/60 + (LON –LSM)/15 (3.4)

where;

LST = local standard time, decimal hour

ET = equation of time in minutes

LSM = longitude of local standard time meridian, ⁰ E of Greenwich

LON = longitude of site, ⁰ E of Greenwich

3.3.3 DECLINATION

The earth's equatorial plane is tilted at an angle of 23.45⁰ to the orbital plane, so the solar inclination, δ is the angle between the earth-sun line and the equatorial plane and the value varies throughout the year. This variation causes the changing seasons with their unequal of daylight and darkness.

$$\delta = 23.45\sin\left(360^{\circ}\frac{n+284}{365}\right) \qquad (3.5)$$

3.3.4 SUN POSITION

The sun's position in the sky is conveniently expressed in terms of the solar altitude above the horizontal and the solar azimuth measured from the south.

H = 15 (AST -12) (3.6)

Where;

H is the angular displacement of the sun east or west of the local meridian due to the rotation of the earth. H value is zero at solar noon, positive in the afternoon and negative in the morning.

3.3.5 SOLAR ALTITUDE ANGLE

Solar altitude angle, β can be defined as the angle between the horizontal plane and a line emanating from the sun. The value ranges from 0^{o} when sun is on the horizon and to 90^{o} if the sun is directly overhead and negative values correspond to night times.

$$\sin\beta = \cos L \cos\delta \cos H + \sin L \sin\delta \quad (3.7)$$

$$\beta = sin^{-1}(\cos L\, cos\,\delta \cos H + \sin L \sin\delta) \quad (3.8)$$

3.3.6 SOLAR AZIMUTH ANGLE

Solar azimuth angle, ϕ is the angular displacement from south of the projection on the horizontal plane of the earth-sun line. It is noted that it is counted positive for afternoon hours and negative for morning hours.

$$\sin\phi = \sin H \cos\delta / \cos\beta \quad (3.9)$$

3.3.7 AIR MASS

Air mass is the ration of the mass of atmosphere in the actual earth/sun path to the mass that would exist if the sun were directly overhead.

$$m = \frac{1}{[\sin\beta + 0.50572\ (6.07995 + \beta)]^{-1.6364}} \quad (3.10)$$

3.3.8 CLEAR SKY SOLAR RADIATION

The solar radiation on a clear day is can be defined by its direct and diffuse components. The direct is represented the part of the radiation which emanating directly from the solar disc while the diffuse components is the radiation emanating from the rest of the sky. In order to calculate the clear sky solar radiation, the air mass components *ab* and *ad* should be determined first.

The air mass components *ab* and *ad* can be determined by the following;

$$ab = 1.219 - 0.043\tau_b - 0.151\tau_d - 0.204\tau_b\tau_d \quad (3.11)$$

$$ad = 0.202 - 0.852\tau_b - 0.007\tau_d - 0.357\tau_b\tau_d \quad (3.12)$$

Beam normal irradiance and diffuse horizontal irradiance;

$$E_b = E_o \exp[-\tau_b m^{ab}] \quad (3.13)$$

$$E_d = E_o \exp[-\tau_d m^{ad}] \quad (3.14)$$

Where;

E_b	: Beam normal irradiance
E_d	: Diffuse horizontal irradiance
E_o	: Extraterrestrial normal irradiance
m	: Air mass
τ_b and τ_d	: Beam and diffuse optical depth and their value are location- specific and value varies throughout the year (Assumption values τ_b : 0.3 and τ_d : 2.3)
ab and *ad*	: Beam and diffuse air mass components

3.3.9 TRANSPOSITION TO RECEIVING SURFACES OF VARIOUS ORIENTATIONS

The surface solar azimuth angle, γ is defined as the angular difference between the solar azimuth, ϕ and the surface azimuth, Ψ

$$\gamma = \phi - \Psi \tag{3.15}$$

Surface azimuth could be defined as the displacement from south of the projection on the horizontal plane and normal to the surface and surface that face west (solar noon to sunset) have positive value while surface that face east (sunrise until solar noon) have negative value. It is measured that the value for surface azimuth is 60^{o} and the sign is based on the time whether in the morning or evening as explained above.

3.3.10 ANGLE OF INCIDENCE

The angle of incidence, θ is the angle between the line normal to the irradiated surface and the earth sun line. This parameter is important in fenestration; load calculations and solar technology because it affects the intensity of the direct component of solar radiation striking the surface and the surface's ability to absorb, transmit or reflects the sun's rays.

$$\cos\theta = \cos\beta \cos\gamma \tag{3.16}$$

(only applicable for vertical surface when tilt angle = 90^{o})

3.3.11 CLEAR SKY SOLAR IRRADIANCE INCIDENT ON RECEIVING SURFACES

The clear-sky irradiance E_t which reach the surface is the total sum of three components which are;

i. the beam/direct component, $E_{t,b}$ from the solar disc
ii. the diffuse components, $E_{t,d}$ from the sky dome
iii. the ground reflected component, $E_{t,r}$ from the ground in front of receiving surface

The beam component;

$$E_{t,b} = E_b \cos\theta \quad ; \text{only valid when } \cos\theta > 0 \tag{3.17}$$

The diffuse component;

$$Y = \max(0.45, 0.55 + 0.437\cos\theta + 0.313\cos^2\theta) \tag{3.18}$$

$E_{t,d} = E_d Y$ (only applicable to vertical surface with tilt angle 90°) (3.19)

The ground reflected component;

$E_{t,r} = (E_b \sin\beta + E_d)\, \rho_g (1 - \cos\Sigma)/ 2$ (3.20)

where; ρ_g is the ground reflectance

Total solar irradiance;

$E_t = E_{t,b} + E_{t,d} + E_{t,r}$ (3.21)

3.3.12 FENESTRATION SOLAR RADIATION HEAT GAINS

The total fenestration solar radiation heat gains can be determined by the following equation;

i. Direct solar heat gain, q_b

$q_b = AE_{t,b}\, SHGC\,(\theta)\, IAC\,(\theta,\Omega)$ (3.22)

ii. Diffuse solar heat gain, q_d

$q_d = A\,(E_{t,d} + E_{t,r})\,(SHGC)_D IAC_D$ (3.23)

Total fenestration solar radiation heat gain:

$Q = q_b + q_d$ (3.24)

3.4 COMPUTER PROGRAMMING

The calculations for the 'clear-sky' solar radiation are programmed by using C++ Programming. This programming is done through Code::Blocks version 8.02. The coding of the programming can be view at Appendix A. The programming is made universal in which the user can determine the solar radiation heat gain at any place in the world as long as the correct data are being key in into it.

Before using this programming the users must first determine several values beforehand. Such values are the Solar Heat Gain Coefficients (SHGC) and Indoor attenuation Coefficients (IAC). These both values could be obtained from manufacturers but in case of not provided; users may also get the values from ASHRAE Book of Fundamentals 2009.

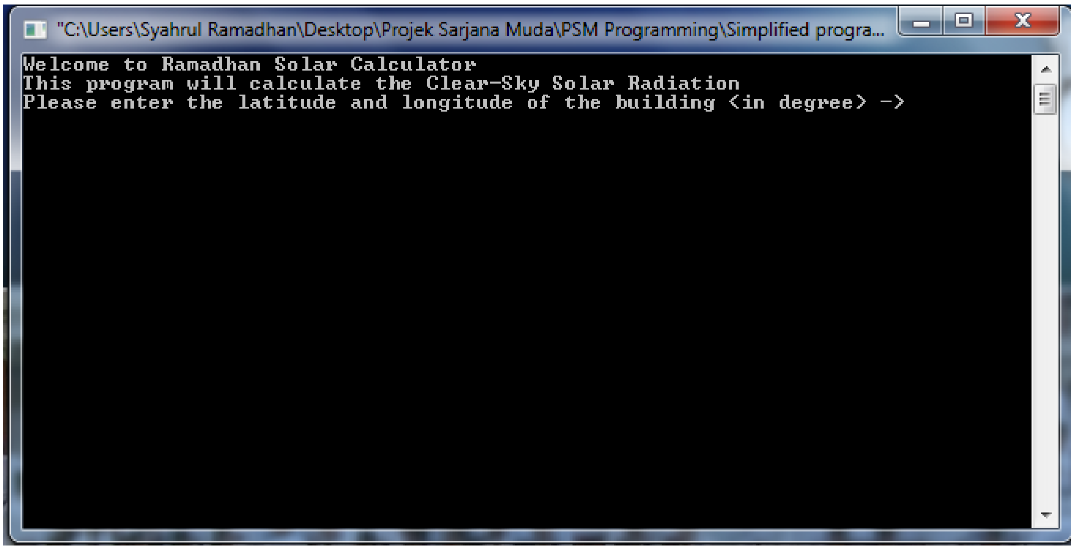

Figure 3.5: First interface of the programming

The programming will first introduced its purpose to the users so that the users know this programming is only applicable to solar radiation heat gain calculation only. In this programming, the data that need to be inserted have to use the proper units that are suggested in the programming itself to avoid the user from getting wrong result.

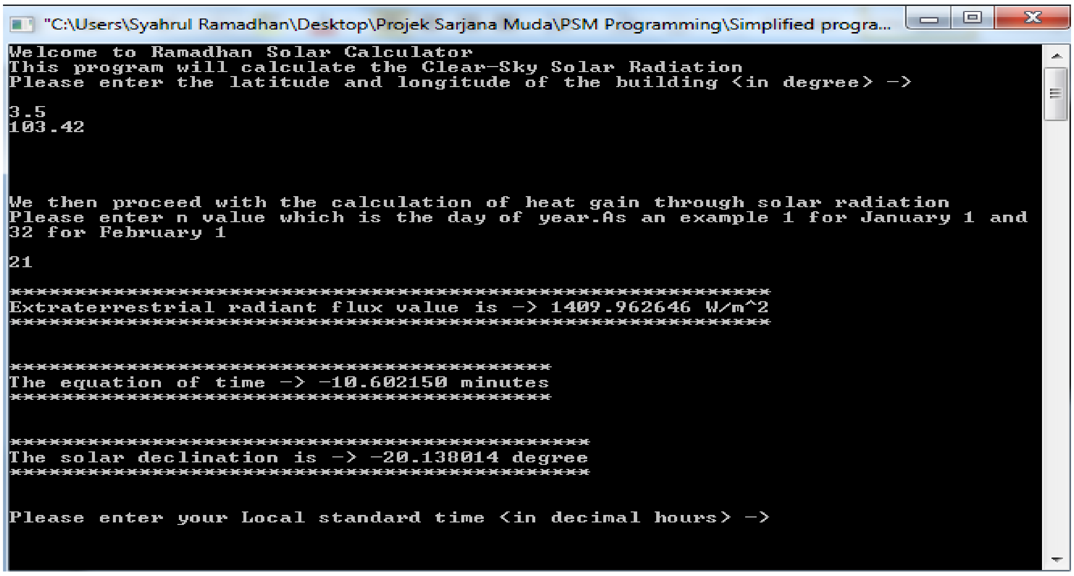

Figure 3.6: Interface of the programming when values are inserted

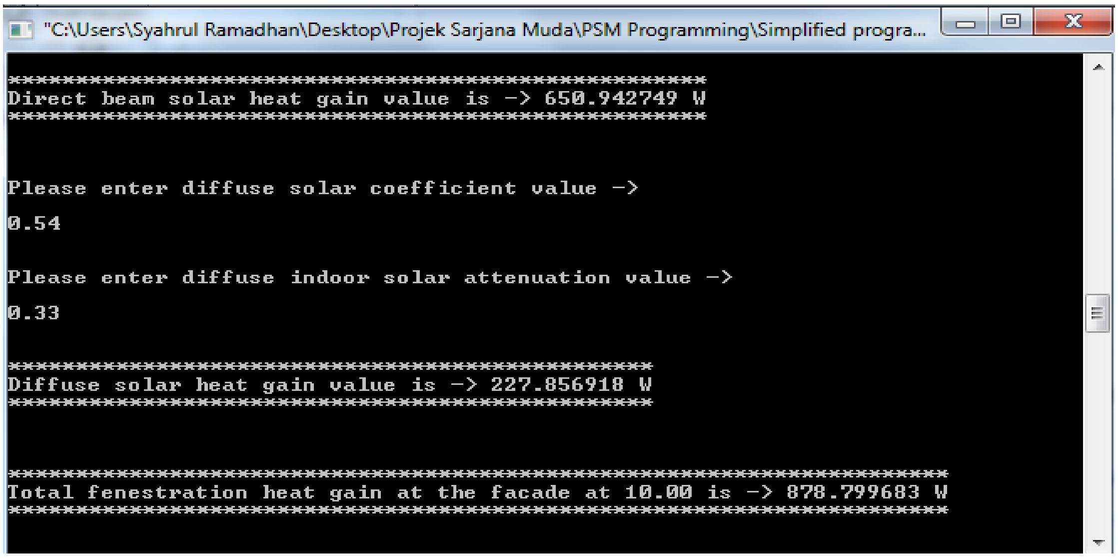

Figure 3.7: Final interface of the programming

The data and values that are being inserted into this programming must be done carefully. This is because this computer programming is being programmed by using looping which mean that the value that is calculated before will be used again for the next calculations if needed. If one of the values wrongly entered, it is afraid that it will affect the end result.

The final interface of the programming will show the results of the solar radiation heat gain. The result shown are consists of three different parts namely the Direct Beam Solar Heat Gain, Diffuse Solar Heat Gain and Total Fenestration Heat Gain. These three results will ease the user to see how daily sun movement affects the direct and diffuse solar heat gain values in that particular day.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter will discuss about the results and discussion of the project. The result of the solar radiation heat gain for every month are recorded and tabulated in table and graph. Furthermore, the total solar heat gains of every month are presented again in other graphs for comparison.

4.2 SOLAR RADIATION HEAT GAIN FOR EVERY MONTH

The solar radiation results for every month are being tabulated into monthly tables to show the continuity and ease of understanding of how the position of sun could affect the solar radiation heat gain into the building. The tables can be viewed at Appendix B. Moreover, from the table four parameters which are the irradiance, direct heat gain, diffuse heat gain and total solar radiation heat gain are selected to be plotted in a graph and a total of twelve graphs are plotted to represent twelve months in a year. This is to know how the position of the sun gives effect to solar irradiance value and solar radiation heat gain in the buildings.

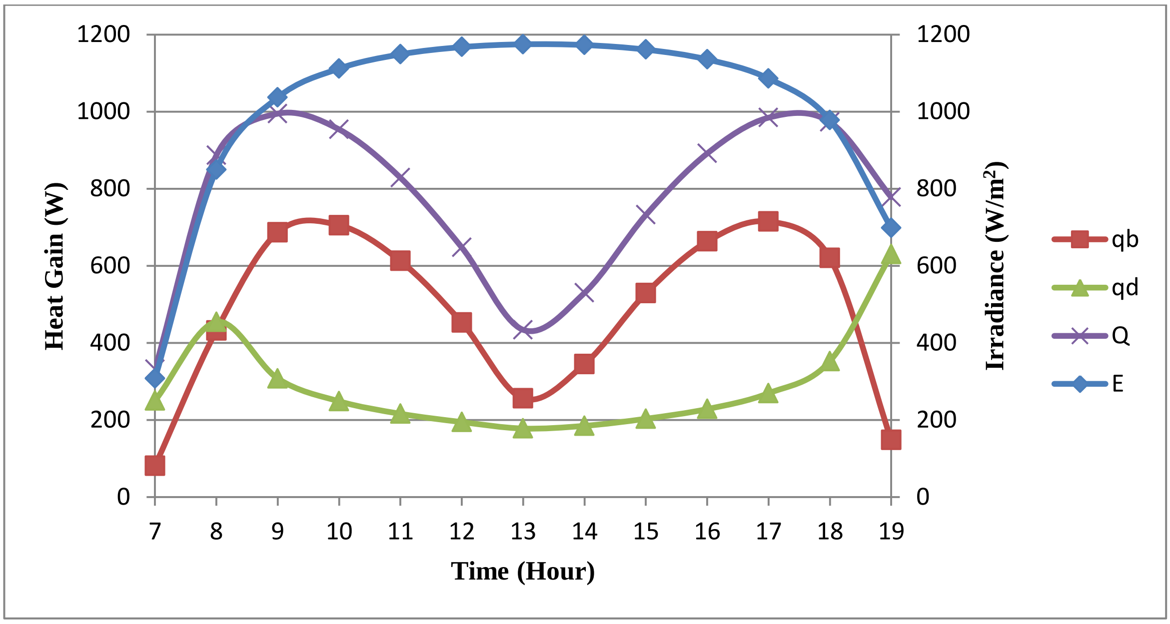

Figure 4.1: Solar Irradiance and Heat Gain for January

Figure 4.1 shows the solar irradiance and solar radiation heat gain at the hypothetical building in January. From the graph, it can be clearly seen that the month of January provides the highest solar irradiance, E with the intensity of 1174.60 W/m^2 at 1300 hours.

Besides, the highest total solar radiation, Q of the building for this month is 994.62 W which occurs at 0900 hours. Meanwhile the lowest total solar radiation is 331.44 W at 0700 hours. In the morning, the diffuse heat gain, q_d is higher compared to direct heat gain, q_b. This is because of the high value of air mass ratio in the morning which is up to of 18.99. But starting at 0800 hours, the direct heat gain will be higher than the diffuse heat gain because low number of air mass ratio with the range of 1.09 until 6.24.

The lowest value of total solar radiation is at 1300 hours although the solar irradiance is the highest at this hour. This is because at solar noon the sun lies on the north-south plane and the radiation to the windows mainly comes from the diffuse heat gain rather than direct heat gain. In the evening starting from 1700 hours, the direct heat gain value starts decreasing while the diffuse heat gain is increasing. This is because of the increase in value of air mass and also the heat that is absorbed in the wall since morning and re-radiating back to the environment.

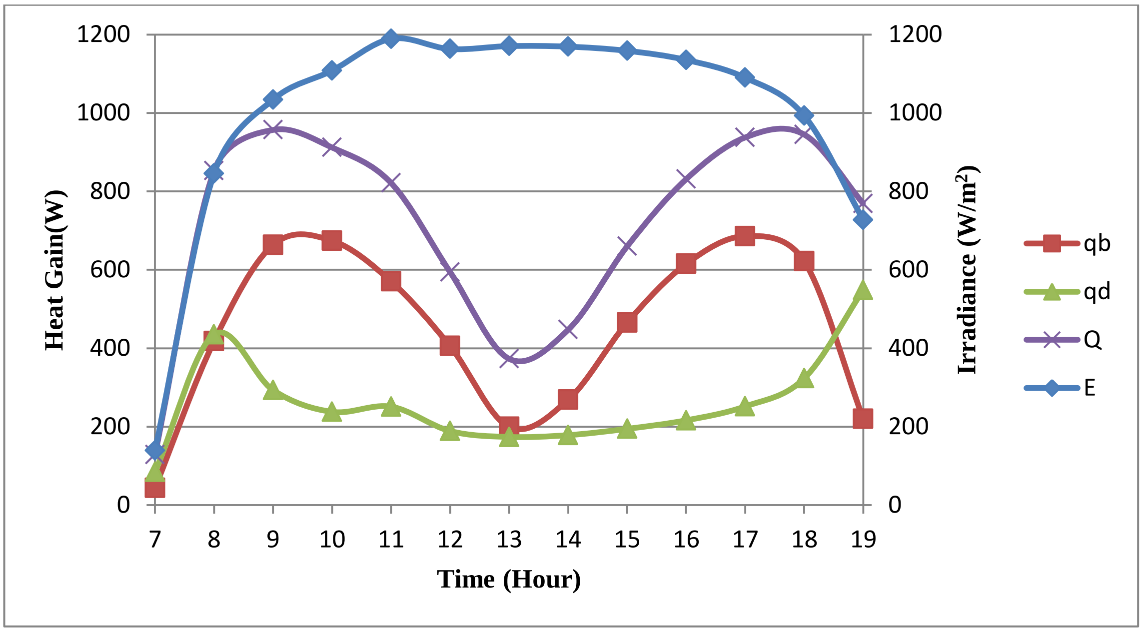

Figure 4.2: Solar Irradiance and Heat Gain for February

Figure 4.2 shows the solar irradiance and solar radiation heat gain at the hypothetical building in February. From the graph, it can be clearly seen that the month of February provides the highest solar irradiance with the intensity of 1188.97 W/m^2 at 1100 hours.

Besides, the highest total solar radiation, Q of the building for this month is 956.70 W which occurs at 0900 hours. Meanwhile the lowest total solar radiation is 128.52 W at 0700 hours. In the morning, the diffuse heat gain, q_d is higher compared to direct heat gain, q_b. This is because of the high value of air mass ratio in the morning which is up to of 20.53. But starting at 0800 hours, the direct heat gain will be higher than the diffuse heat gain because low number of air mass ratio with the range of 1.05 until 6.14.

The lowest value of total solar radiation is at 1300 hours although the solar irradiance is the second highest at this hour. This is because at solar noon the sun lies on the north-south plane and the radiation to the windows mainly comes from the diffuse heat gain rather than direct heat gain. In the evening starting from 1700 hours, the direct heat gain value starts decreasing while diffuse heat gain is increasing. This is because of the increase in value of air mass and also the heat that is absorb in the wall since morning re-radiate back to the environment.

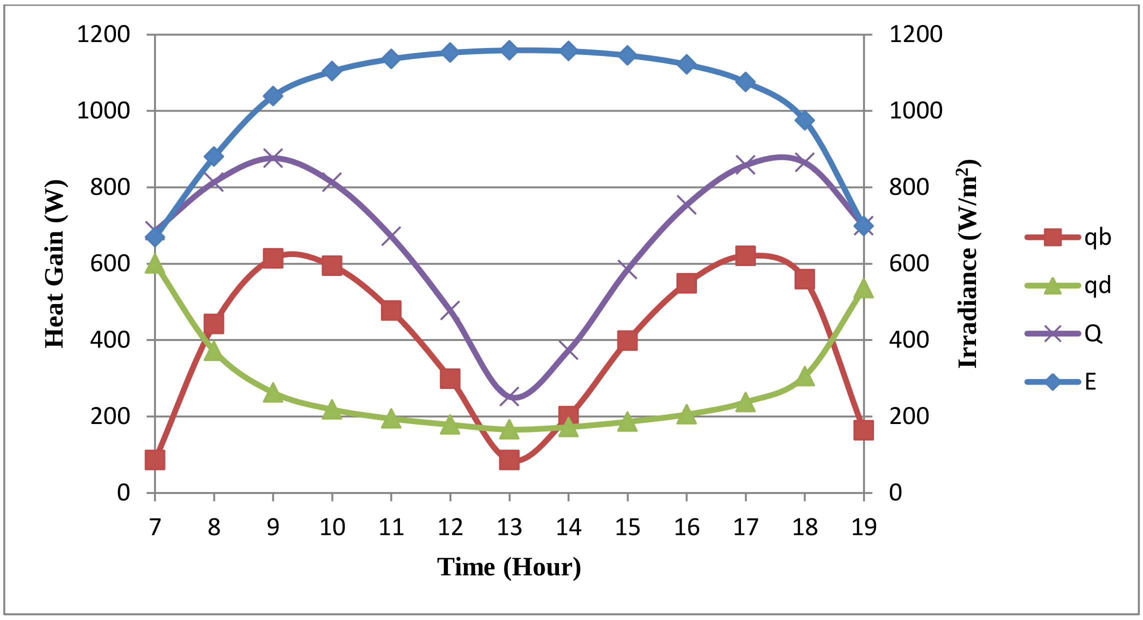

Figure 4.3: Solar Irradiance and Heat Gain in March

Figure 4.3 shows the solar irradiance and solar radiation heat gain at the hypothetical building in March. From the graph, it can be clearly seen that the month of March provides the highest solar irradiance, E with the intensity of 1158.50 W/m^2 at 1300 hours.

Besides, the highest total solar radiation, Q of the building for this month is 876.11 W which occurs at 0900 hours. Meanwhile the lowest total solar radiation is 251.39 W at 1300 hours. In the morning, the diffuse heat gain, q_d is higher compared to direct heat gain, q_b. This is because of the high value of air mass ratio in the morning which is up to of 20.53. But starting at 0800 hours, the direct heat gain will be higher than the diffuse heat gain because low number of air mass ratio with the range of 1.00 until 4.94.

The lowest value of total solar radiation occurred at 1300 hours although the solar irradiance is the highest at this hour. This is because at solar noon the sun is directly overhead and the radiation to the windows mainly comes from the diffuse heat gain rather than direct heat gain. In the evening starting from 1700 hours, the direct heat gain value starts decreasing while the diffuse heat gain is increasing. This is because of the increase in value of air mass and also the heat that is absorbed in the wall since morning and re-radiating back to the environment.

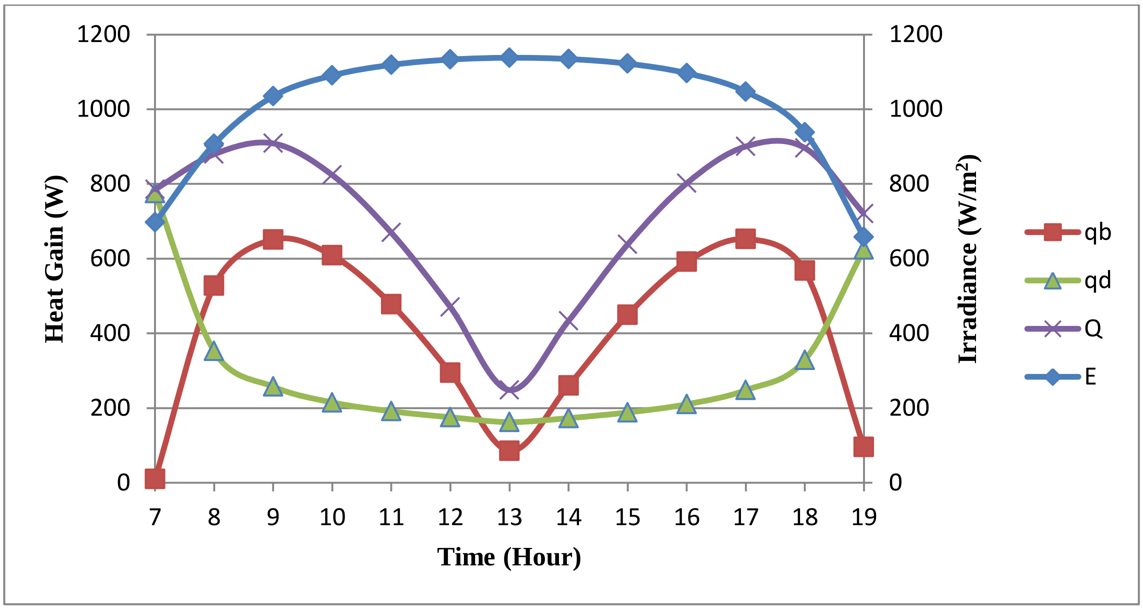

Figure 4.4: Solar Irradiance and Heat Gain in April

Figure 4.4 shows the solar irradiance and solar radiation heat gain at the hypothetical building in April. From the graph, it can be clearly seen that the month of April provides the highest solar irradiance, E with the intensity of 1137.80 W/m^2 at 1300 hours.

Besides, the highest total solar radiation, Q of the building for this month is 908.53 W which occurs at 0900 hours. Meanwhile the lowest total solar radiation is 248.32 W at 1300 hours. In the morning, the diffuse heat gain, q_d is higher compared to direct heat gain, q_b. This is because of the high value of air mass ratio in the morning which is up to of 47.06. But starting at 0800 hours, the direct heat gain will be higher than the diffuse heat gain because low number of air mass ratio with the range of 1.01 until 4.03.

The lowest value of total solar radiation occurred at 1300 hours although the solar irradiance is the highest at this hour. This is because at solar noon the sun lies on the north-south plane and the radiation to the windows mainly comes from the diffuse heat gain rather than direct heat gain. In the evening starting from 1700 hours, direct heat gain value starts decreasing while diffuse heat gain is increasing. This is because of the increase in value of air mass and also the heat that is absorbed in the wall since morning and re-radiating back to the environment.

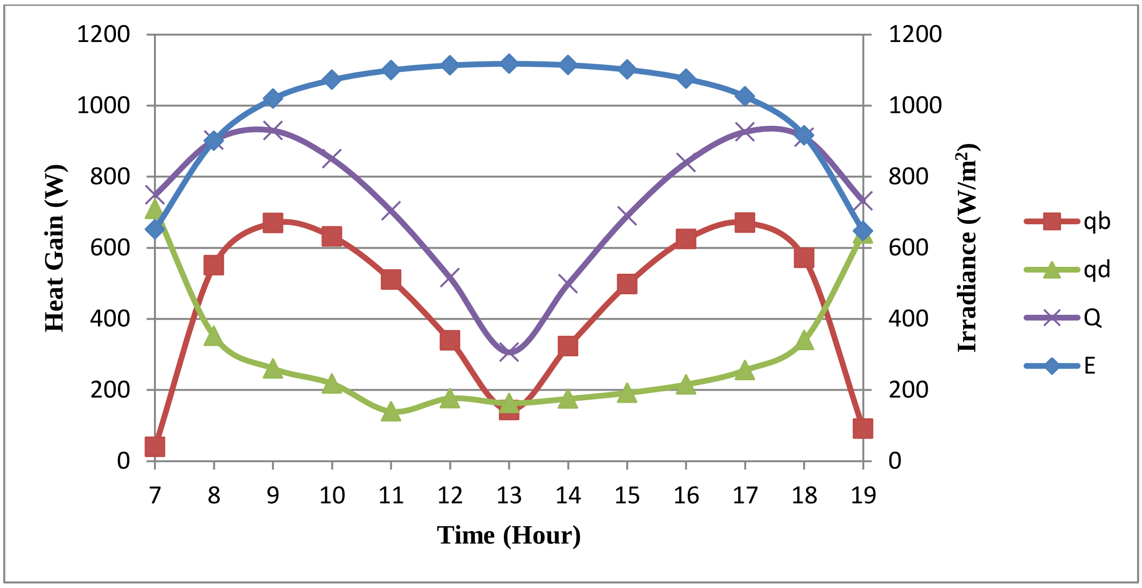

Figure 4.5: Solar Irradiance and Heat Gain in May

Figure 4.5 shows the solar irradiance and solar radiation heat gain at the hypothetical building in May. From the graph, it can be clearly seen that the month of May provides the highest solar irradiance, E with the intensity of 1117.44 W/m^2 at 1300 hours.

Besides, the highest total solar radiation, Q of the building for this month is 929.48 W which occurs at 0900 hours. Meanwhile the lowest total solar radiation is 305.93 W at 1300 hours. In the morning, the diffuse heat gain, q_d is higher compared to direct heat gain, q_b. This is because of the high value of air mass ratio in the morning which is up to of 30.22. But starting at nearly 0800 hours, the direct heat gain will be higher than the diffuse heat gain because low number of air mass ratio with the range of 1.04 until 3.89.

The lowest value of total solar radiation occurred at 1300 hours although the solar irradiance is the highest at this hour. This is because at solar noon the sun lies on the north-south plane and the radiation to the windows mainly comes from the diffuse heat gain rather than direct heat gain. In the evening starting from 1700 hours, the direct heat gain value starts decreasing while the diffuse heat gain is increasing. This is because of the increase in value of air mass and also the heat that is absorbed in the wall since morning and re-radiating back to the environment.

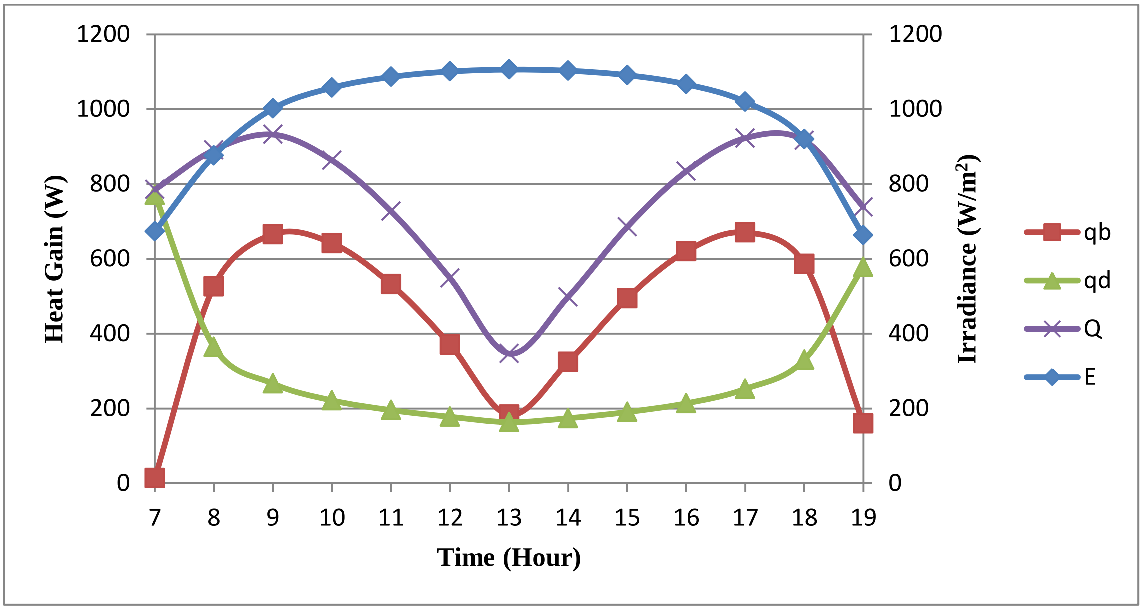

Figure 4.6: Solar Irradiance and Heat Gain in June

Figure 4.6 shows the solar irradiance and solar radiation heat gain at the hypothetical building in June. From the graph, it can be clearly seen that the month of June provides the highest solar irradiance, E with the intensity of 1105.59 W/m^2 at 1300 hours.

Besides, the highest total solar radiation, Q of the building for this month is 931.89 W which occurs at 0900 hours. Meanwhile the lowest total solar radiation is 346.48 W at 1300 hours. In the morning, the diffuse heat gain, q_d is higher compared to direct heat gain, q_b. This is because of the high value of air mass ratio in the morning which is up to of 43.71. But starting at 0800 hours, the direct heat gain will be higher than the diffuse heat gain because low number of air mass ratio with the range of 1.06 until 4.24.

The lowest value of total solar radiation occurred at 1300 hours although the solar irradiance is the highest at this hour. This is because at solar noon the sun lies on the north-south plane and the radiation to the windows mainly comes from the diffuse heat gain rather than direct heat gain. In the evening starting from 1700 hours, the direct heat gain value starts decreasing while the diffuse heat gain is increasing. This is because of the increase in value of air mass and also the heat that is absorbed in the wall since morning and re-radiating back to the environment.

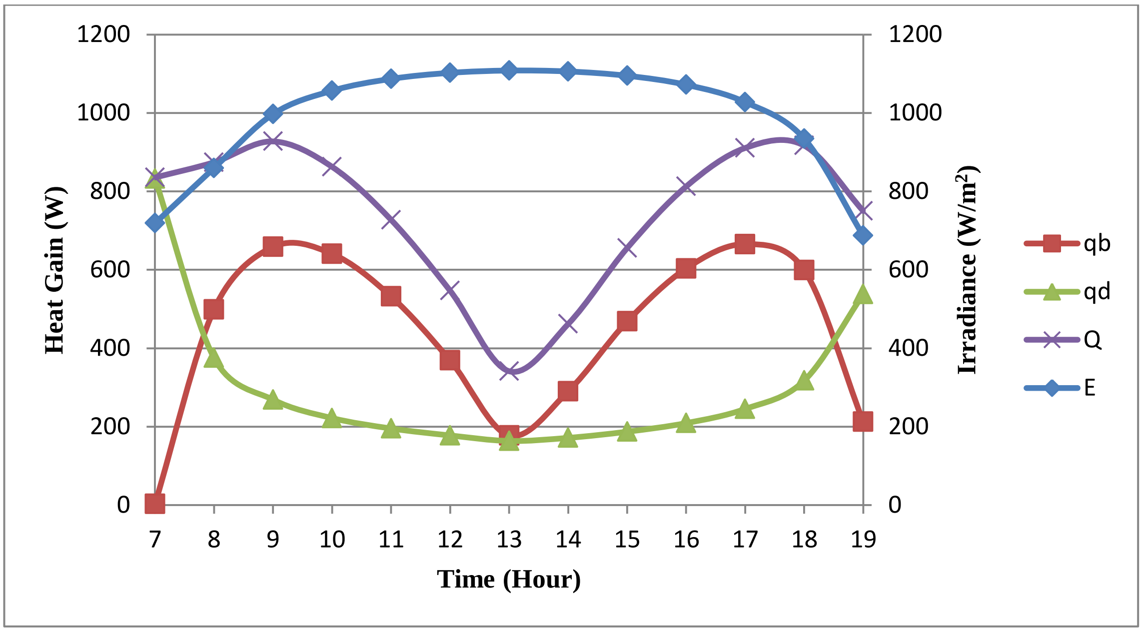

Figure 4.7: Solar Irradiance and Heat Gain in July

Figure 4.7 shows the solar irradiance and solar radiation heat gain at the hypothetical building in July. From the graph, it can be clearly seen that the month of July provides the highest solar irradiance, E with the intensity of 1108.05 W/m^2 at 1300 hours.

Besides, the highest total solar radiation, Q of the building for this month is 927.35 W which occurs at 0900 hours. Meanwhile the lowest total solar radiation is 341.35 W at 1300 hours. In the morning, the diffuse heat gain, q_d is higher compared to direct heat gain, q_b. This is because of the high value of air mass ratio in the morning which is up to of 64.84. But starting at 0800 hours, the direct heat gain will be higher than the diffuse heat gain because low number of air mass ratio with the range of 1.05 until 4.60.

The lowest value of total solar radiation occurred at 1300 hours although the solar irradiance is the highest at this hour. This is because at solar noon the sun lies on the north-south plane and the radiation to the windows mainly comes from the diffuse heat gain rather than direct heat gain. In the evening starting from 1700 hours, the direct heat gain value is decreasing while the diffuse heat gain is increasing. This is because of the increase in value of air mass and also the heat that is absorbed in the wall since morning and re-radiating back to the environment.

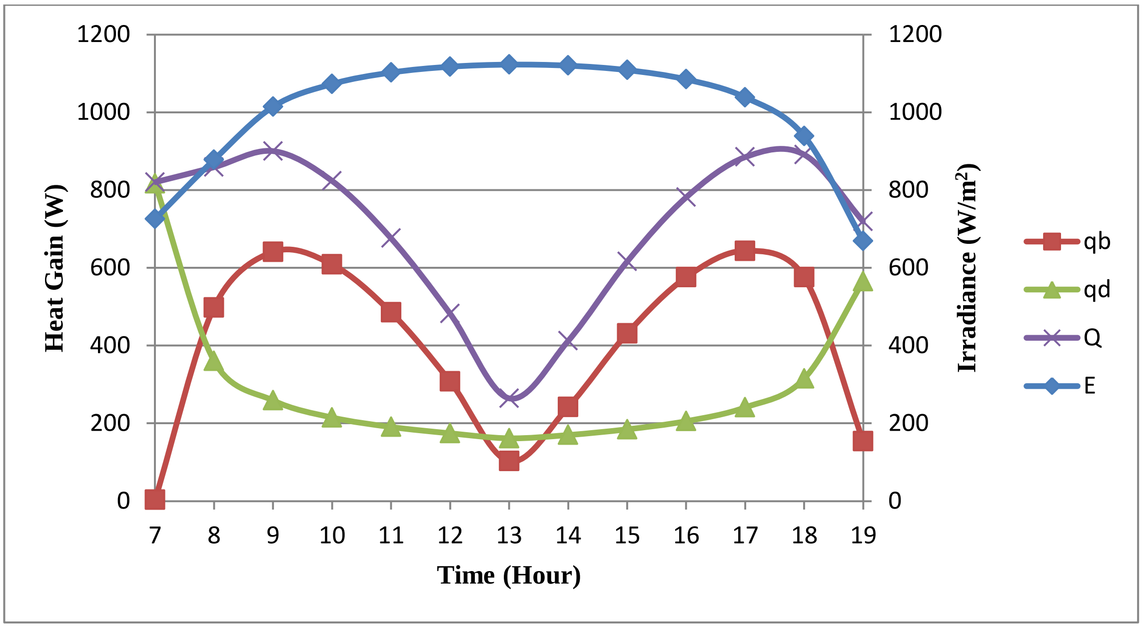

Figure 4.8: Solar Irradiance and Heat Gain in August

Figure 4.8 shows the solar irradiance and solar radiation heat gain at the hypothetical building in August. From the graph, it can be clearly seen that the month of August provides the highest solar irradiance with the intensity of 1122.53 W/m^2 at 1300 hours.

Besides, the highest total solar radiation, Q of the building for this month is 900.09 W which occurs at 0900 hours. Meanwhile the lowest total solar radiation is 264.30 W at 1300 hours. In the morning, the diffuse heat gain, q_d is higher compared to direct heat gain, q_b. This is because of the high value of air mass ratio in the morning which is up to of 64.79. But starting at 0800 hours, the direct heat gain will be higher than the diffuse heat gain because low number of air mass ratio with the range of 1.01 until 4.38.

The lowest value of total solar radiation occurred at 1300 hours although the solar irradiance is the highest at this hour. This is because at solar noon the sun lies on the north-south plane and the radiation to the windows mainly comes from the diffuse heat gain rather than direct heat gain. In the evening starting from 1700 hours, the direct heat gain value starts decreasing while the diffuse heat gain is increasing. This is because of the increase in value of air mass and also the heat that is absorbed in the wall since morning and re-radiating back to the environment.

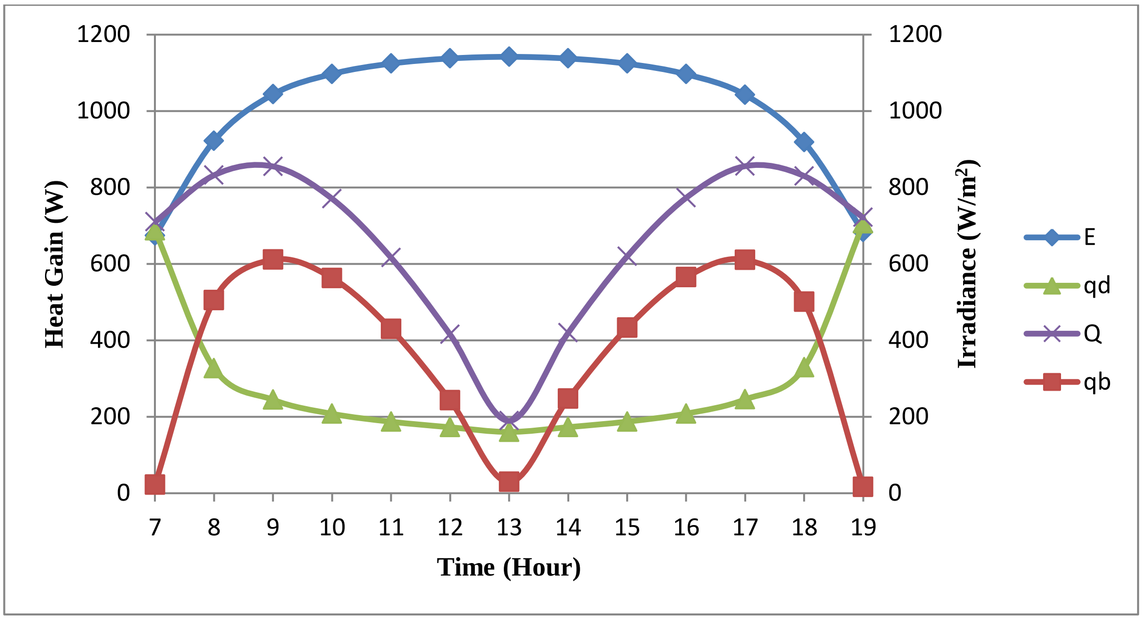

Figure 4.9: Solar Irradiance and Heat Gain in September

Figure 4.9 shows the solar irradiance and solar radiation heat gain at the hypothetical building in September. From the graph, it can be clearly seen that the month of September provides the highest solar irradiance, E with the intensity of 1141.28 W/m^2 at 1300 hours.

Besides, the highest total solar radiation, Q of the building for this month is 855.52 W which occurs at 1700 hours. Meanwhile the lowest total solar radiation is 189.19 W at 1300 hours. In the morning, the diffuse heat gain, q_d is higher compared to direct heat gain, q_b. This is because of the high value of air mass ratio in the morning which is up to of 36.02. But starting at 0800 hours, the direct heat gain will be higher than the diffuse heat gain because low number of air mass ratio with the range of 1.00 until 3.86.

The lowest value of total solar radiation occurred at 1300 hours although the solar irradiance is the highest at this hour. This is because at solar noon the sun is directly overhead and the radiation to the windows mainly comes from the diffuse heat gain rather than direct heat gain. In the evening starting from 1700 hours, the direct heat gain value starts decreasing while the diffuse heat gain is increasing. This is because of the increase in value of air mass and also the heat that is absorbed in the wall since morning and re-radiating back to the environment.

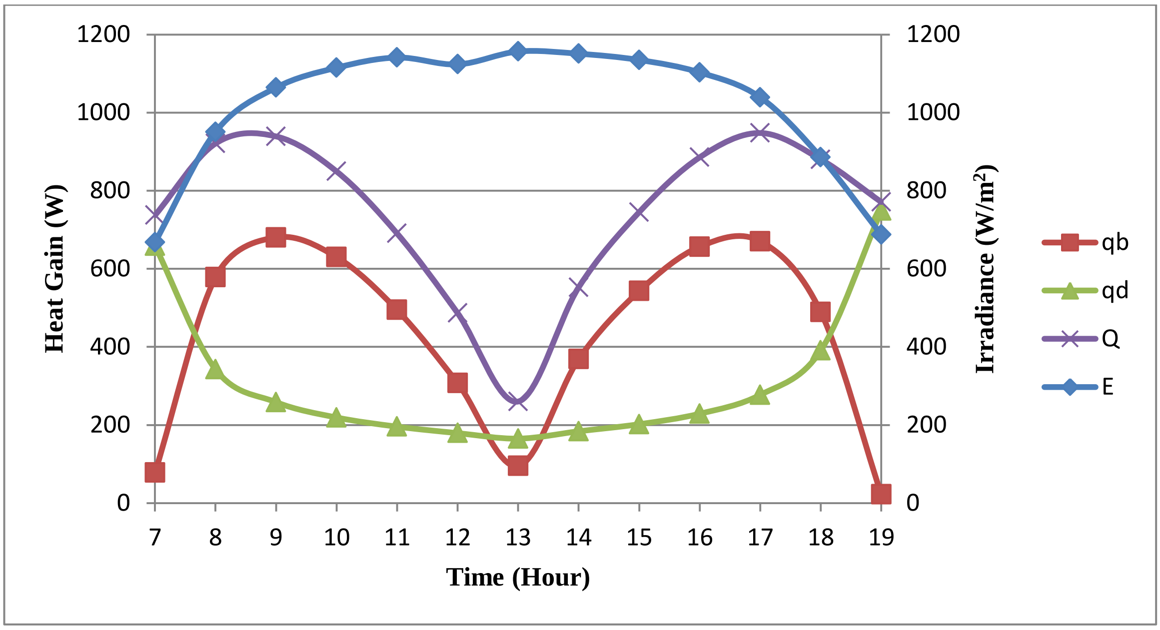

Figure 4.10: Solar Irradiance and Heat Gain in October

Figure 4.10 shows the solar irradiance and solar radiation heat gain at the hypothetical building in October. From the graph, it can be clearly seen that the month of October provides the highest solar irradiance, E with the intensity of 1156.47 W/m^2 at 1300 hours.

Besides, the highest total solar radiation, Q of the building for this month is 947.70 W which occurs at 1700 hours. Meanwhile the lowest total solar radiation is 260.11 W at 1300 hours. In the morning, the diffuse heat gain, q_d is higher compared to direct heat gain, q_b. This is because of the high value of air mass ratio in the morning which is up to of 22.22. But starting at 0800 hours, the direct heat gain will be higher than the diffuse heat gain because low number of air mass ratio with the range of 1.04 until 4.83.

The lowest value of total solar radiation occurred at 1300 hours although the solar irradiance is the highest at this hour. This is because at solar noon the sun lies on the north-south plane and the radiation to the windows mainly comes from the diffuse heat gain rather than direct heat gain. In the evening starting from 1700 hours, the direct heat gain value starts decreasing while the diffuse heat gain is increasing. This is because of the increase in value of air mass and also the heat that is absorbed in the wall since morning and re-radiating back to the environment.

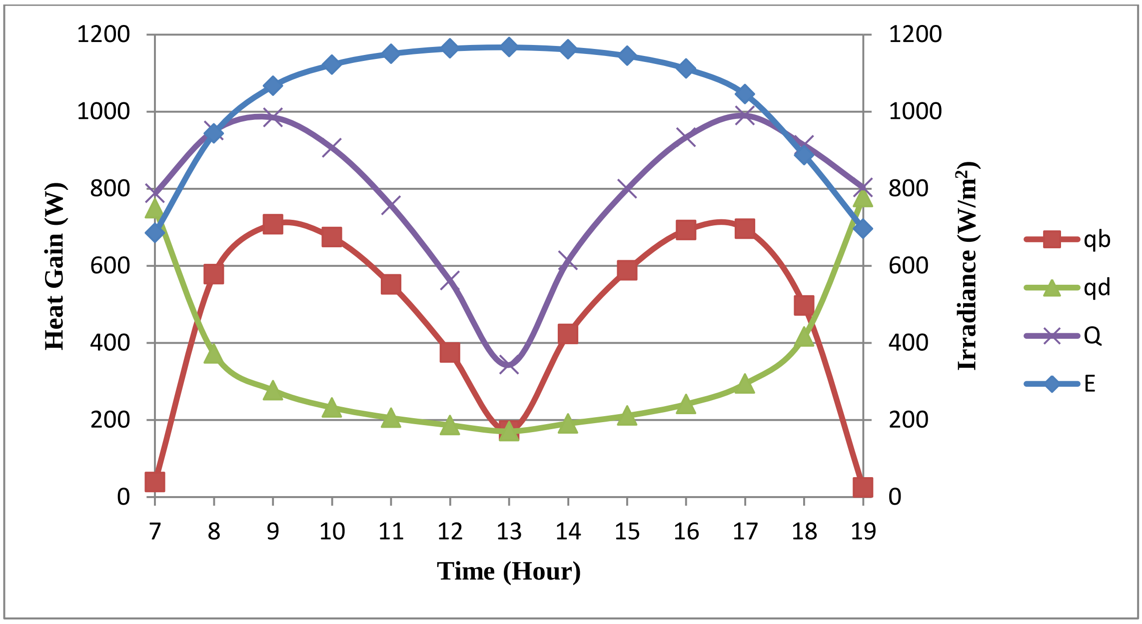

Figure 4.11: Solar Irradiance and Heat Gain in November

Figure 4.11 shows the solar irradiance and solar radiation heat gain at the hypothetical building in November. From the graph, it can be clearly seen that the month of November provides the highest solar irradiance, E with the intensity of 1166.55 W/m^2 at 1300 hours.

Besides, the highest total solar radiation, Q of the building for this month is 989.28 W which occurs at 1700 hours. Meanwhile the lowest total solar radiation is 342.80 W at 1300 hours. In the morning, the diffuse heat gain, q_d is higher compared to direct heat gain, q_b. This is because of the high value of air mass ratio in the morning which is up to of 30.95. But starting at 0800 hours, the direct heat gain will be higher than the diffuse heat gain because low number of air mass ratio with the range of 1.09 until 5.11.

The lowest value of total solar radiation occurred at 1300 hours although the solar irradiance is the highest at this hour. This is because at solar noon the sun lies on the north-south plane and the radiation to the windows mainly comes from the diffuse heat gain rather than direct heat gain. In the evening starting from 1700 hours, the direct heat gain value starts decreasing while the diffuse heat gain is increasing. This is because of the increase in value of air mass and also the heat that is absorbed in the wall since and morning re-radiating back to the environment.

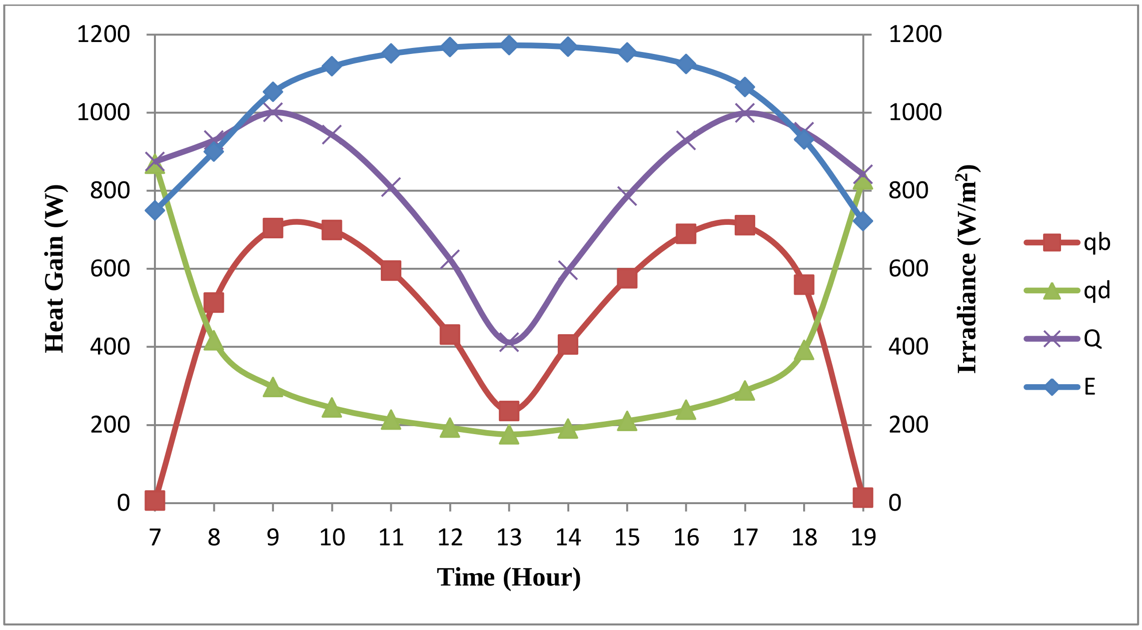

Figure 4.12: Solar Irradiance and Heat Gain in December

Figure 4.12 shows the solar irradiance and solar radiation heat gain at the hypothetical building in December. From the graph, it can be clearly seen that the month of December provides the highest solar irradiance, E with the intensity of 1172.26 W/m^2 at 1300 hours.

Besides, the highest total solar radiation, Q of the building for this month is 1000.41 W which occurs at 0900 hours. Meanwhile the lowest total solar radiation is 411.72 W at 1300 hours. In the morning, the diffuse heat gain, q_d is higher compared to direct heat gain, q_b. This is because of the high value of air mass ratio in the morning which is up to of 56.84. But starting at 0800 hours, the direct heat gain will be higher than the diffuse heat gain because low number of air mass ratio with the range of 1.12 until 4.97.

The lowest value of total solar radiation occurred at 1300 hours although the solar irradiance is the highest at this hour. This is because at solar noon the sun lies on the north-south plane and the radiation to the windows mainly comes from the diffuse heat gain rather than direct heat gain. In the evening starting from 1700 hours, the direct heat gain value starts decreasing while the diffuse heat gain is increasing. This is because of the increase in value of air mass and also the heat that is absorbed in the wall since morning and re-radiating back to the environment.

4.3 ANALYSIS OF TOTAL SOLAR RADIATION HEAT GAIN IN A YEAR

In this part, the total solar radiation heat gain value for every month are being plotted again in a graph to show how these values vary throughout the year. The values of total solar heat gain are being plotted into three different graphs rather than plotting all twelve months values in one graph. This is to reduce the complexity of the graph itself.

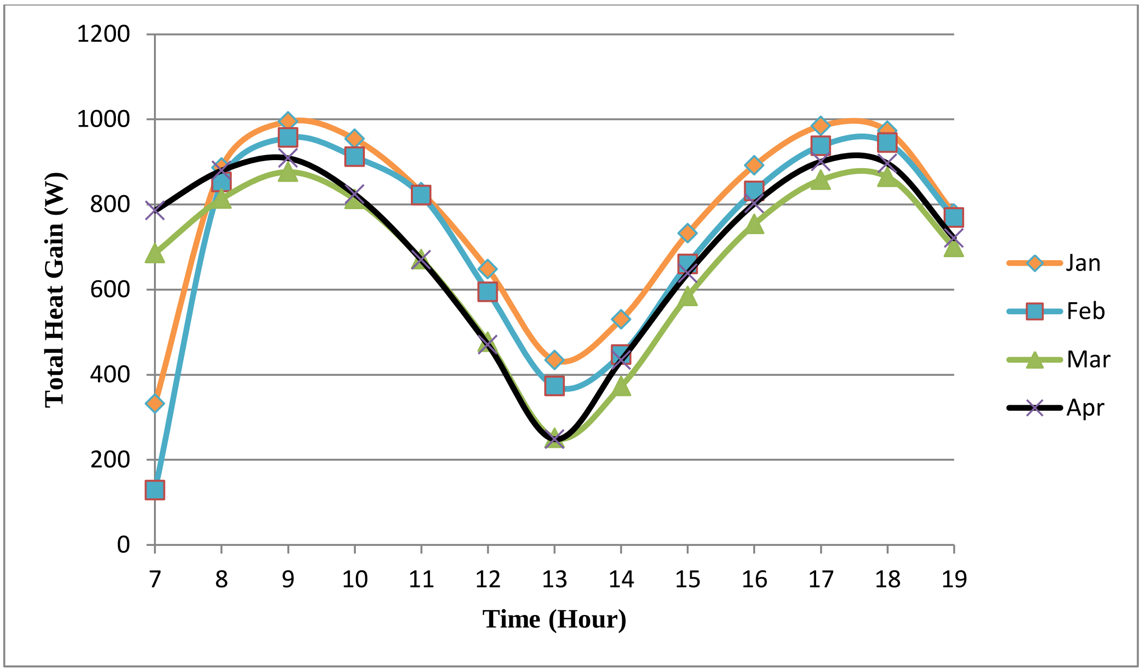

Figure 4.13: Total heat gain for the first quarter of the year

Figure 4.13 which show the comparison of the total heat gain for the first quarter of the year that consists four months from January until April. In these curves, it can be clearly seen that the highest total heat gain happens in the month of January of which the value is up to 994.62 W at 0900 hours. Meanwhile the lowest total heat gain happens in the month of March with the highest value at 876.11 W and at 0900 hours.

On the other hand, Figure 4.14 which consists of another four months from May until August has shown quite a stable value of total solar heat gain for these four consecutive months with the highest value of solar radiation heat gain at 929.48 W, 931.89 W, 927.35 W and 900.09 W, respectively.

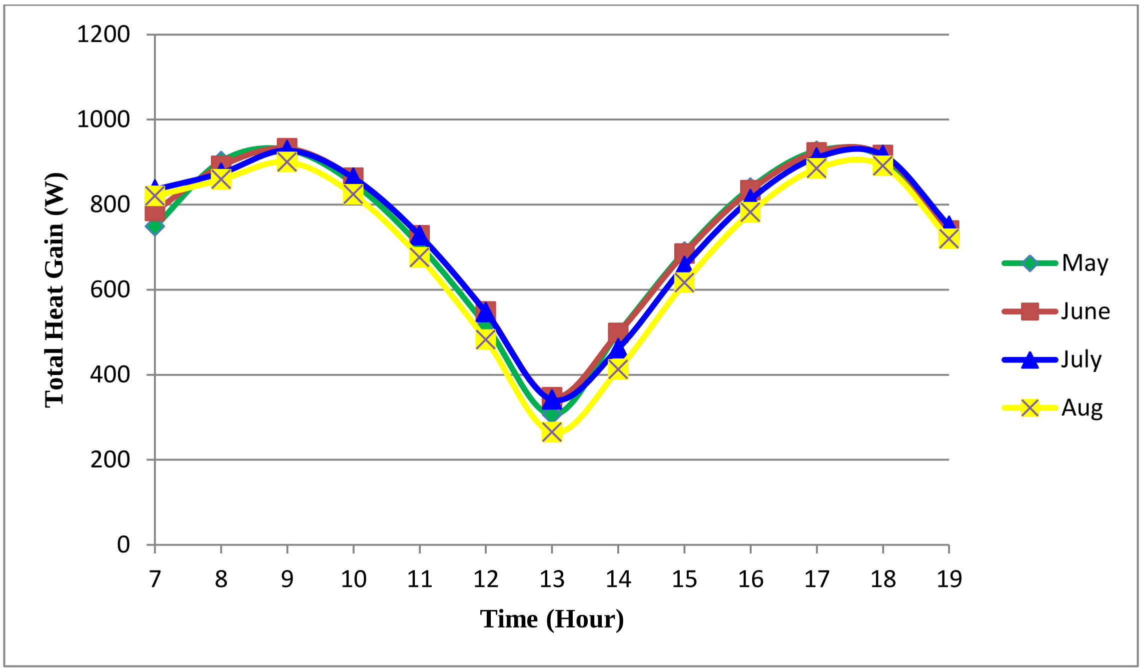

Figure 4.14: Total solar heat gain for second quarter of the year

As for the analysis part, it can be said that the values obtained are a bit off from the theory. According to Haberlin H. (2012), the highest solar radiation heat gain should be obtained in the month of June since in that month, the northern hemisphere experiences the summer solstice while on the other hand the lowest solar radiation heat gain occurs in the month of December because of Winter Solstice at the northern hemisphere.

This theory is being supported by Noor et al (2011) when they mentioned that East Coast of Malaysia experienced high solar radiation especially between May until November. Furthermore, they also came out with a figure by stating that the average solar radiation in the location is 982 W/m^2 and the highest solar radiation could be reached up to 1200 W/m^2 in the month of June as June is mid- summer for the Northern Hemisphere.

On the other hand, from another study done by Al-Sanea et al (2004) they provided some arguments of how the result could be different from the theory. According to them, the ASHRAE model implemented utilizes the standard values of the coefficients proposed in the original model and the calculations are also made with a different set of coefficients proposed in the literature.

They later added that the result show that the ASHRAE model calculations generally over-predict the measured data particularly for the months of October until May. So, in order to overcome this they had proposed a parameter so called the daily total flux for every month to adjust the calculated clear sky flux in order to account for the effects of local weather conditions.

They also explained that when ASHRAE model calculations are multiplied with this factor, the results agree well with the measured monthly-averaged hourly variation of the total solar flux. Lastly, they had recommended that these adjustment factors be employed when the ASHRAE clear-sky model is used for solar radiation calculations.

Another reason is because of the assumptions of τ_b and τ_d values that have been made earlier in the calculations and the assumptions values made were fixed throughout the whole year instead of varying them. According to ASHRAE Book of Fundamental 2009, the value of τ_b and τ_d are location- specific and they vary during the year. The variables embody the dependence of the clear-sky solar radiation upon local conditions such as elevation, precipitable water content and aerosols. The average values were determined through ASHRAE Research Project RP-1453 by Thevenard (2009).

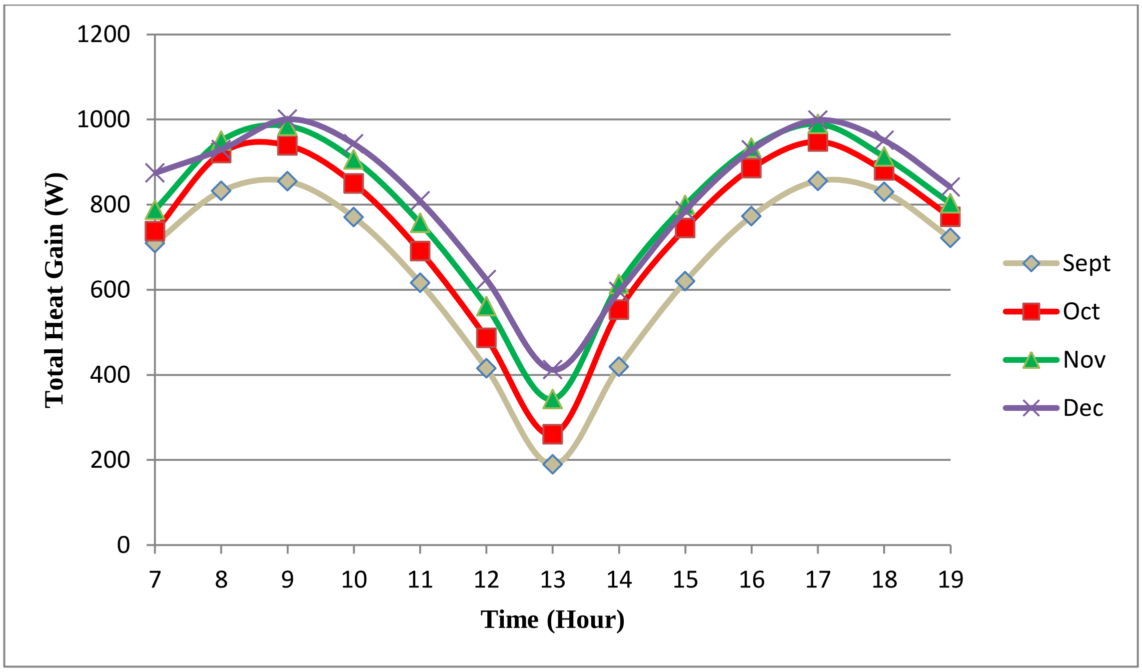

Figure 4.15: Total solar heat gain for third quarter of the year

Referring to Figure 4.15, it is seen that the highest total solar radiation heat gain occurs in the month of December in which the value is not very accurate according to the theory and the reasons explained earlier.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter reviews the overall conclusions which are made based on the results and analysis shown in previous chapter. In the sections 5.2 discusses regarding the conclusions of the study while chapter 5.3 discusses about the recommendations for future works.

5.2 CONCLUSION

As the conclusion, a C++ computer programming to calculate the solar radiation heat gain has been developed by using Code::Blocks version 8.02. The equations and method used are solely based on 'Clear-sky Solar Radiation' method as suggested by ASHRAE Book of Fundamentals 2009. Besides, some of the equations also checked and compared with other journal to prove its validity.

From this computer programming, the computation of solar radiation heat gain of the Faculty of Mechanical Engineering administration block has been obtained. The result are taken monthly for a duration of twelve months in a year. The solar radiation heat gain for 21st day of each month represents the solar radiation heat gain for that particular month for ease of analysis.

For the analysis part, the result is plotted into monthly graphs and four parameters have been identified to be studied from the graph. Those parameters are the irradiance, direct solar heat gain, diffuse solar heat gain and the total solar radiation heat gain. The discussion of monthly graphs has been done. Furthermore, the total solar radiation heat gain results are being combined together in another graph to see the different of the curves throughout the year. Then the analysis and the arguments for the combined graphs are also being done and discussed.

5.3 RECOMMENDATIONS

There are some recommendations that can be made for further work of this study. Such recommendations are the usage of correct value of optical depth, τ_b and τ_d. According to ASHRAE Book of Fundamental (2009), the values of τ_b and τ_d are location-specific and vary during the year. These values embody the dependence of clear-sky solar radiation upon local conditions which also take count the elevation, precipitable water content and aerosols. The average values of τ_b and τ_d can be determined through ASHRAE Research Project, RP-1452 by Thevenard (2009). It is important to use these values for further work in this study as to obtain more precise results.

Furthermore, this study could also be expanded its scope from computation of solar radiation heat gain to computation of external heat gain. Computation of external heat gain mainly consists of solar radiation, conduction through the wall, door and windows, infiltration through windows and air changes into the building per unit hour. For the purpose of computation of external heat gain, one needs to get data regarding the building envelope information such as the U-factor of the wall and windows, daily bulb and dry temperature, wind speed and humidity.

Besides, the result from this study could be more accurate by also taking count of the internal heat gain from the building itself. Although internal heat gain values are not vary with time and are constant throughout the day but their contribution to the heat gain cannot be neglected. Internal heat gain may consist of the heat from lights, people, appliances and electrical equipments.

In this study the values of solar heat gain coefficient (SHGC) for windows are obtained through ASHRAE Book of Fundamental (2009) and the values selection are based on the windows data information provided by the manufacturer. Moreover, one may also obtain the real values of SHGC from its manufacturer. This will make the result of heat gain to be more accurate and precise.

REFERENCES

Actacir, M. A., Büyükalaca O., Bulut, H., Yllmaz, T., 2008. Influence of different outdoor design conditions on design cooling load and design capacities of air-conditioning equipments. *Journal of Energy Conversion and Management*.49: 1766-1773.

Al-Sanea, S.A., Zedan, M.F., Al-Ajlan, S.A., 2004. Adjustment factors for the ASHRAE Clear-Sky Model based on solar radiation measurement in Riyadh. *Journal of Applied Energy*. 79: 215-237.

Al-Raghbi, O.M., Akyurt, M.M., 2004.A survey of energy efficient strategies for effective air-conditioning. *Journal of Energy Conversion and Management*.45:1643-1654.

ASHRAE, 2009 ASHRAE *Handbook - Fundamentals (SI)*, Atlanta, Ga. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2009.

ASHRAE, 2011 ASHRAE *Handbook- HVAC Applications (SI)*, Atlanta, Ga. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2011

Arora, C.P., 2009. *Refrigeration and Air Conditioning*.International Edition. Tata McGraw-Hill Publishing Company Limited.

Haberlin, H., 2012. *Photovoltaics System Design and Practice*. United Kingdom, UK. A John Wiley & Sons, Ltd., Publications

Jayamaha, L.,2006. *Energy- Efficient Building Systems*. New York, NY. Tata McGraw-Hill Publishing Company Limited.

Nina, S.N., Yusof, T.M., Basirul, A.A.S.,2012. Analysis of Heat Gain in Computer Laboratory and Excellent Centre by using CLTD/CLF/SCL Method.*Journal of Malaysian Technical Universities Conference on Engineering & Technology (MUCET)*, ISBN: 978-967-5415-49-4, 323-329.

Noor, M.M., Amirrudin, A.K., Kadirgama, K., Sharma, K.V.,2011. The Potential of Wind and Solar Energy in Malaysia East Coast: Preliminary Study at Universiti Malaysia Pahang (UMP). *Transactions of the Wessex Institute*. Paper ID: 22994. DOI: 10.2495/RAV110431.

Schiavan, S., Melikov, A. K., 2008.Energy saving and improved comfort by increased air movement.*Journal of Energy and Buildings*.40: 1954-1960

Thevenard, D. and Gueymard, C.A., 2009.Monthly average clear-sky broadband irradiance database for worldwide solar heat gain and building cooling load calculations.*Journal of Solar Energy*.83: 1998-2018

APPENDIX A

(PROJECT GANTT CHART)

FINAL YEAR PROJECT 1

PROJECT ACTIVITIES	WEEK													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Briefing of project title, objective and scope of study														
Research on Journals and Articles														
Calculations Method Research														
Gather relevant data														
Report submission														
Proposal presentation														

FINAL YEAR PROJECT 2

PROJECT ACTIVITIES	WEEK														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Explore computer programming															
Working on computer programming for calculations															
Get result															
Result verification															
Report writing															
Project presentation															

APPENDIX B

(COMPUTER PROGRAMMING CODING)

```
#include <stdio.h>
#include <math.h>

const float Pi = 3.141592654;
constintSolar_constant = 1367;

int main()

{

    /*This equation will calculate the heat transfer by conduction*/

   float
Latitude,Longitude,Area,Extraterrestrial_radiant_flux,Day_of_year,First,Equation_of_time,Solar_declination,Local_standard_time,Local_standard_meridian,Apparent_solar_time,Hour_angle,Beta,Beta_value,Sinphi,Phi_value,Air_mass,ab,ad,Beam_optical_depth,Diffuse_optical_depth,Beam_normal_irradiance,Diffuse_horizontal_irradiance,Tilt_angle,Surface_azimuth_angle,Surface_solar_azimuth_angle,Angle_of_incidence,Thetha,Beam_component,Diffuse_component,Ground_reflected_component,Ground_reflectance,Y_value,Big_number1,Big_number2,Area_window,Beam_solar_coefficient,Beam_solar_attenuation,Direct_heat_gain,Diffuse_heat_gain,Diffuse_solar_coefficient,Diffuse_solar_attenuation,Total;


printf("Welcome to Ramadhan Solar Calculator\n");
printf("This program will calculate the Clear-Sky Solar Radiation\n");

printf("Please enter the latitude and longitude of the building <in degree> ->\n\n");
scanf("%f%f",&Latitude,&Longitude);

    /*This program will calculate the heat transfer by radiation using the ASHRAE Clear-Sky Solar Radiation Model*/

printf("\n\n\n\nWe then proceed with the calculation of heat gain through solar radiation\n");
printf("Please enter n value which is the day of year.As an example 1 for January 1 and 32 for February 1\n\n");
scanf("%f",&Day_of_year);
```

```
    /*Extraterrestrial radiant flux on a surface normal to the sun's ray*/

Extraterrestrial_radiant_flux = Solar_constant*(1+(0.033*cos(360*(Pi/180)*((Day_of_year-3)/365))));

printf("\n********************************************************\n");
printf("Extraterrestrial radiant flux value is -> %f W/m^2\n",Extraterrestrial_radiant_flux);
printf("********************************************************\n");

    First = 360*((Day_of_year-1)/365);


    /*Equation of time and solar time*/

Equation_of_time = 2.2918*(0.0075+(0.1868*cos(First*(Pi/180)) - 3.2077*sin(First*(Pi/180)) - 1.4615*cos(2*First*(Pi/180)) - 4.089*sin(2*First*(Pi/180))));
printf("\n\n***************************************\n");
printf("The equation of time -> %f minutes\n",Equation_of_time);
printf("***************************************\n");


    /*This equation will calculate Solar declination angle as the earth equatorial plane is tilted at an angle of 234.5 degree*/

Solar_declination = 23.45*sin(360*(Pi/180)*((Day_of_year +284)/365));

printf("\n\n******************************************\n");
printf("The solar declination is -> %f degree\n",Solar_declination);
printf("******************************************\n\n");


    /*This equation will calculate the Apparent solar time*/

printf("\nPlease enter your Local standard time <in decimal hours> ->\n\n");
```

```
scanf("%f",&Local_standard_time);


printf("\n\nPlease enter your Local standard time meridian of Greenwich\n");
printf("<negative in western hemisphere><in degree>\n\n");
scanf("%f",&Local_standard_meridian);

Apparent_solar_time = Local_standard_time + (Equation_of_time/60) + ((Longitude -
Local_standard_meridian)/15);
printf("\n\n************************************************************\n");
printf("The Apparent solar time value-> %f decimal hours\n",Apparent_solar_time);
printf("************************************************************\n");



   /*This equation will calculate the Hour Angle*/

Hour_angle = 15*(Apparent_solar_time - 12);
printf("\n\n************************************\n");
printf("The hour angle -> %f degree\n",Hour_angle);
printf("************************************\n");


   /*This equation will calculate the Solar Altitude Angle*/

   Beta = (cos(Latitude*(Pi/180))*cos(Solar_declination*(Pi/180))*cos(Hour_angle*(Pi/180)))
+ (sin(Latitude*(Pi/180))*sin(Solar_declination*(Pi/180)));
Beta_value = (asin(Beta))*(180/Pi);
printf("\n\n***************************************************\n");
printf("Solar altitude angle value is -> %f degree\n",Beta_value);
printf("***************************************************\n");


   /*This equation will calculate the Solar Azimuth Angle*/

Sinphi = sin(Hour_angle*(Pi/180))*cos(Solar_declination*(Pi/180))/cos(Beta_value*(Pi/180));
```

```
Phi_value = (asin(Sinphi))*(180/Pi);
printf("\n\n***********************************************\n");
printf("The Solar Azimuth angle is -> %f degree\n",Phi_value);
printf("***********************************************\n");


    /*This equation will calculate Relative Air Mass*/

Air_mass = 1/((sin(Beta_value*(Pi/180)))+(0.50572*pow((6.07995+Beta_value),-1.6364)));
printf("\n\n**********************************\n");
printf("The Air Mass value is -> %f\n",Air_mass);
printf("**********************************\n\n");


    /*This equation will calculate air mass exponents ab and ad*/

printf("\nPlease enter the value of Beam and Diffuse Optical Depth\n\n");
scanf("%f%f",&Beam_optical_depth,&Diffuse_optical_depth);

ab = (1.219)-(0.043*Beam_optical_depth)-(0.151*Diffuse_optical_depth)-(0.204*Beam_optical_depth*Diffuse_optical_depth);
printf("\nab value is %f\n\n",ab);

ad = (0.202)-(0.852*Beam_optical_depth)-(0.007*Diffuse_optical_depth)-(0.357*Beam_optical_depth*Diffuse_optical_depth);
printf("ad value is %f\n\n",ad);


    /*This equation will calculate the Beam Normal Irradiance and Diffuse Horizontal Irradiance*/

Beam_normal_irradiance = Extraterrestrial_radiant_flux*exp((-Beam_optical_depth)*pow(Air_mass,ab));
printf("\n\n*************************************\n");
printf("Beam normal irradiance -> %f\n",Beam_normal_irradiance);
printf("*************************************\n");
```

```
Diffuse_horizontal_irradiance = Extraterrestrial_radiant_flux*exp((-
Diffuse_optical_depth)*pow(Air_mass,ad));
printf("\n\n*******************************************\n");
printf("Diffuse horizontal irradiance -> %f\n",Diffuse_horizontal_irradiance);
printf("*******************************************\n");

printf("\n\nPlease enter the value of tilt/slope angle\n");
printf("between the surface and horizontal plane <in degree> ->\n\n");
scanf("%f",&Tilt_angle);

printf("\n\nPlease enter the value of surface azimuth angle\n");
printf("<in degree>\n\n");
scanf("%f",&Surface_azimuth_angle);

Surface_solar_azimuth_angle = Phi_value - Surface_azimuth_angle;

Angle_of_incidence = cos(Beta_value*(Pi/180))*cos(Surface_solar_azimuth_angle*(Pi/180));
Thetha = (acos(Angle_of_incidence))*(180/Pi);

printf("\n*****************************************\n");
printf("Angle of incidence is -> %f degree\n",Thetha);
printf("*****************************************\n\n");

Beam_component = Beam_normal_irradiance*cos(Thetha*(Pi/180));
printf("\n*******************************************\n");
printf("Beam component value is -> %f W/m^2\n",Beam_component);
printf("*******************************************\n\n");

printf("Please enter ground reflectance value ->\n\n");
scanf("%f",&Ground_reflectance);

Ground_reflected_component =
((Beam_normal_irradiance*sin(Beta_value*(Pi/180)))+Diffuse_horizontal_irradiance)*Ground
_reflectance*((1-(cos(Tilt_angle*(Pi/180))))/2);
printf("\n\n*******************************************************\n");
```

```
printf("Ground reflected component value is -> %f W/m^2\n",Ground_reflected_component);
printf("*****************************************************\n\n");

    Big_number1 = (cos(Thetha*(Pi/180)));
    Big_number2 = pow(Big_number1,2);
Y_value = (0.55)+(0.437*cos(Thetha*(Pi/180)))+(0.313*Big_number2);


if(Y_value> 0.45)
    {
Diffuse_component = Diffuse_horizontal_irradiance*Y_value;
printf("\n\n*********************************************\n");
printf("Diffuse component value is -> %f W/m^2\n",Diffuse_component);
printf("*********************************************\n\n");

    }

else
    {
Diffuse_component = Diffuse_horizontal_irradiance*0.45;
printf("\n\n******************************************\n");
printf("Diffuse component value is -> %f W/m^2\n",Diffuse_component);
printf("*************************************************\n\n");

    }


printf("\nThe calculation is then will calculate the fenestration heat gain\n");
printf("by the building through Direct solar and diffuse solar\n\n");

printf("\nPlease enter facade window area value <in m^2> ->\n\n");
scanf("%f",&Area_window);
printf("\n\nPlease enter beam solar coefficient value ->\n\n");
scanf("%f",&Beam_solar_coefficient);
printf("\n\nPlease enter beam indoor solar attenuation value ->\n\n");
scanf("%f",&Beam_solar_attenuation);
```

```
Direct_heat_gain = Area_window*Beam_component*Beam_solar_coefficient*Beam_solar_attenuation;
printf("\n\n******************************************************\n");
printf("Direct beam solar heat gain value is -> %f W\n",Direct_heat_gain);
printf("******************************************************\n\n");

printf("\n\nPlease enter diffuse solar coefficient value ->\n\n");
scanf("%f",&Diffuse_solar_coefficient);
printf("\n\nPlease enter diffuse indoor solar attenuation value ->\n\n");
scanf("%f",&Diffuse_solar_attenuation);

Diffuse_heat_gain = Area_window*(Diffuse_component+Ground_reflected_component)*Diffuse_solar_coefficient*Diffuse_solar_attenuation;
printf("\n\n**************************************************\n");
printf("Diffuse solar heat gain value is -> %f W\n",Diffuse_heat_gain);
printf("**************************************************\n\n");

    Total = Direct_heat_gain + Diffuse_heat_gain;

printf("\n\n************************************************************************\n");
printf("Total fenestration heat gain at the facade at %.2f is -> %f W\n",Local_standard_time,Total);
printf("************************************************************************\n\n");


return(0);

}
```

APPENDIX C

(RESULT OBTAINED FROM COMPUTER PROGRAMMING)

Month	: January	No of days	: 21
Extraterrestrial radiant flux, E_o (W/m^2)	: 1409.96	Equation of time, ET (minutes)	: -10.60
Solar declination, δ (^{O})	: - 20.14		

				Beam Solar Heat Gain					Diffuse Solar Heat Gain				
Local Standard Hour, LST	Apparent Solar Time, AST	Hour Angle, H (^{O})	Solar Altitude Angle, β (^{O})	Solar Azimuth Angle, Φ (^{O})	Beam Normal Irradiance E_b (W/m^2)	Angle of Incident, θ (^{O})	Beam Component $E_{t,b}$ (W/m^2)	Beam Solar Heat Gain, q_b (W/m^2)	Diffuse Horizontal Irradiance, E_d (W/m^2)	Diffuse Component, $E_{t,d}$ (W/m^2)	Ground Reflected Component, $E_{t,r}$ (W/m^2)	Diffuse Solar Heat Gain, q_d (W/m^2)	Total Window Heat Gain, Q (W)
7.00	4.72	-94.23	-5.17	-70.07	862.18	11.31	845.43	811.90	221.64	283.59	14.39	250.25	331.44
8.00	5.72	-79.23	8.86	-68.98	461.11	12.59	450.02	432.17	388.42	495.08	45.95	454.36	886.53
9.00	7.72	-64.23	22.73	-66.45	780.38	23.58	715.22	686.85	256.07	310.72	55.76	307.77	994.62
10.00	8.72	-49.23	36.22	-61.81	910.70	36.26	734.31	705.19	200.83	222.09	73.90	248.57	953.76
11.00	9.72	-34.23	48.92	-53.48	976.58	49.24	637.60	612.31	171.96	166.58	90.81	216.16	828.47
12.00	10.72	-19.23	59.75	-37.86	1010.51	62.18	471.59	452.88	156.79	128.90	102.97	194.72	647.60
13.00	11.72	-4.23	66.00	-9.80	1023.83	74.91	266.59	256.01	150.77	103.28	108.61	177.94	433.96
14.00	12.72	10.77	64.10	23.68	1020.21	69.40	359.01	344.78	152.41	113.17	107.02	184.92	529.69
15.00	13.72	25.77	55.38	45.92	998.68	56.56	550.38	528.56	162.10	143.61	98.39	203.23	731.79
16.00	14.72	40.77	43.53	57.74	952.93	43.57	690.38	663.00	182.41	188.04	83.87	228.35	891.35
17.00	15.72	55.77	30.41	64.16	865.33	30.66	744.34	714.82	220.31	255.00	65.83	269.44	984.25
18.00	16.72	70.77	16.72	67.76	680.51	18.38	645.78	620.17	297.32	370.64	49.31	352.67	972.84
19.00	17.72	85.77	2.76	69.62	156.43	10.00	154.05	147.94	541.39	695.09	54.89	629.84	777.79

Month : February

No of days : 52

Extraterrestrial radiant flux, E_o (W/m^2) : 1396.99

Equation of time, ET (minutes) : -13.96

Solar declination, δ (°) : - 11.23

				Beam Solar Heat Gain					Diffuse Solar Heat Gain				
Local Standard Hour, LST	Apparent Solar Time, AST	Hour Angle, H (°)	Solar Altitude Angle, β (°)	Solar Azimuth Angle, Φ (°)	Beam Normal Irradiance E_b (W/m^2)	Angle of Incident, θ (°)	Beam Component $E_{t,b}$ (W/m^2)	Beam Solar Heat Gain, q_b (W/m^2)	Diffuse Horizontal Irradiance, E_d (W/m^2)	Diffuse Component, $E_{t,d}$ (W/m^2)	Ground Reflected Component, $E_{t,r}$ (W/m^2)	Diffuse Solar Heat Gain, q_d (W/m^2)	Total Window Heat Gain, Q (W)
7.00	5.66	-95.07	-5.65	-79.05	1155.76	19.84	87.16	44.03	83.69	103.61	-3.00	84.49	128.52
8.00	6.66	-80.07	9.03	-78.08	463.11	20.11	434.88	417.63	382.17	472.53	45.49	435.03	852.66
9.00	7.66	-65.07	23.63	-76.13	785.00	28.35	690.87	663.47	248.79	292.83	56.34	293.24	956.70
10.00	8.66	-50.07	38.06	-72.81	914.16	39.85	701.86	674.03	193.84	207.42	75.74	237.80	911.83
11.00	9.66	-35.07	52.13	-66.65	973.99	52.43	593.88	570.33	214.99	200.55	98.39	251.04	821.37
12.00	10.66	-20.07	65.19	-53.34	1012.92	65.37	422.17	405.43	150.06	118.02	106.95	188.93	594.36
13.00	11.66	-5.07	74.43	-18.85	1026.60	78.34	207.43	199.20	143.85	93.66	113.28	173.79	372.99
14.00	12.66	9.93	72.27	33.73	1024.92	74.15	279.70	268.60	145.02	100.46	112.04	178.46	447.06
15.00	13.66	24.93	61.16	58.98	1004.53	61.16	484.55	465.33	153.85	128.25	103.37	194.52	659.85
16.00	14.66	39.93	47.64	69.11	962.50	48.29	640.39	614.99	172.64	169.07	88.38	216.21	831.19
17.00	15.66	54.93	33.41	74.10	882.15	35.94	714.19	685.87	207.68	230.30	69.34	251.65	937.51
18.00	16.66	69.93	18.91	76.87	714.96	25.14	647.25	621.58	277.84	334.00	50.95	323.29	944.87
19.00	17.66	84.93	4.28	78.45	242.38	18.93	229.28	220.19	485.00	603.07	50.31	548.71	768.90

Month : March

No of days : 80

Extraterrestrial radiant flux, E_o (W/m^2) : 1377.96

Equation of time, ET (minutes) : -7.86

Solar declination, δ (°) : - 0.40

				Beam Solar Heat Gain					Diffuse Solar Heat Gain				
Local Standard Hour, LST	Apparent Solar Time, AST	Hour Angle, H (°)	Solar Altitude Angle, β (°)	Solar Azimuth Angle, Φ (°)	Beam Normal Irradiance E_b (W/m^2)	Angle of Incident, θ (°)	Beam Component $E_{t,b}$ (W/m^2)	Beam Solar Heat Gain, q_b (W/m^2)	Diffuse Horizontal Irradiance, E_d (W/m^2)	Diffuse Component $E_{t,d}$ (W/m^2)	Ground Reflected Component $E_{t,r}$ (W/m^2)	Diffuse Solar Heat Gain, q_d (W/m^2)	Total Window Heat Gain, Q (W)
7.00	5.76	-93.55	-3.56	-89.81	102.84	30.01	89.06	85.53	565.96	658.30	55.96	599.84	685.36
8.00	6.76	-78.55	11.41	-88.88	535.87	30.87	459.95	441.71	343.77	397.29	44.98	371.41	813.12
9.00	7.76	-63.55	26.37	-87.81	806.41	37.59	639.03	613.68	231.94	253.47	59.02	262.43	876.11
10.00	8.76	-48.55	41.33	-86.38	920.22	47.72	619.11	594.55	183.13	180.50	79.08	218.00	812.55
11.00	9.76	-33.55	56.25	-84.02	978.49	59.50	496.59	476.89	157.31	134.09	97.09	194.14	671.04
12.00	10.76	-18.55	71.06	-78.47	1008.50	72.07	310.51	298.19	143.76	102.68	109.77	178.41	476.61
13.00	11.76	-3.55	84.73	-42.30	1019.95	84.98	89.28	85.74	138.55	81.83	115.42	165.65	251.39
14.00	12.76	11.45	77.90	71.39	1015.93	78.15	208.68	200.41	140.38	91.66	113.38	172.19	372.60
15.00	13.76	26.45	63.27	82.12	995.39	65.38	414.72	398.27	149.70	117.73	103.87	186.10	584.37
16.00	14.76	41.45	48.39	85.44	952.36	53.15	571.14	548.49	168.96	156.23	88.10	205.19	753.68
17.00	15.76	56.45	33.44	87.20	870.38	42.08	645.95	620.33	204.74	214.31	68.44	237.46	857.79
18.00	16.76	71.45	18.48	88.40	697.86	33.46	582.19	559.10	277.08	313.77	49.83	305.36	864.46
19.00	17.76	86.45	3.51	89.38	196.15	29.57	170.60	163.83	502.26	586.07	51.43	535.37	699.21

Month : April

Extraterrestrial radiant flux, E_o (W/m^2) : 1354.17

Solar declination, δ (°) : 11.58

No of days : 111

Equation of time, ET (minutes) : 1.22

				Beam Solar Heat Gain					Diffuse Solar Heat Gain				
Local Standard Hour, LST	Apparent Solar Time, AST	Hour Angle, H (°)	Solar Altitude Angle, β (°)	Solar Azimuth Angle, Φ (°)	Beam Normal Irradiance E_b (W/m^2)	Angle of Incident, θ (°)	Beam Component $E_{t,b}$ (W/m^2)	Beam Solar Heat Gain, q_b (W/m^2)	Diffuse Horizontal Irradiance, E_d (W/m^2)	Diffuse Component $E_{t,d}$ (W/m^2)	Ground Reflected Component $E_{t,r}$ (W/m^2)	Diffuse Solar Heat Gain, q_d (W/m^2)	Total Window Heat Gain, Q (W)
7.00	5.92	-91.27	-0.54	-78.36	11.53	18.37	10.94	10.51	685.38	854.42	68.53	775.10	785.61
8.00	6.92	-76.27	14.14	-78.93	598.48	23.47	548.96	527.18	308.19	374.19	45.44	352.41	879.59
9.00	7.92	-61.27	28.83	-78.70	816.96	33.92	677.91	651.02	217.59	245.48	61.15	257.51	908.53
10.00	8.92	-46.27	43.48	-77.34	915.01	46.16	633.74	608.61	175.28	175.78	80.49	215.22	823.82
11.00	9.92	-31.27	57.99	-73.65	966.23	59.00	497.65	477.92	152.52	130.88	97.19	191.53	669.44
12.00	10.92	-16.27	71.97	-62.50	992.27	71.99	306.83	294.66	140.75	100.64	108.43	175.58	470.24
13.00	11.92	-1.27	81.82	-8.81	1001.05	84.89	89.24	85.70	136.74	80.88	112.76	162.62	248.32
14.00	12.92	13.73	74.19	58.54	994.86	74.19	271.03	260.28	139.57	96.62	109.68	173.25	433.53
15.00	13.92	28.73	60.43	72.56	972.11	61.20	468.27	449.70	149.87	124.86	99.53	188.45	638.15
16.00	14.92	43.73	45.96	76.94	926.13	48.32	615.86	591.43	170.38	166.81	83.62	210.31	801.74
17.00	15.92	58.73	31.32	78.57	838.80	35.93	679.24	652.30	208.30	231.03	64.44	248.13	900.43
18.00	16.92	73.73	16.64	78.95	651.99	25.01	590.83	567.40	286.21	344.33	47.29	328.88	896.28
19.00	17.92	88.73	1.95	78.51	105.59	18.61	100.06	96.09	552.49	687.99	55.61	624.48	720.57

Month : May

No of days : 141

Extraterrestrial radiant flux, E_o (W/m^2) : 1334.90

Equation of time, ET (minutes) : 3.74

Solar declination, δ (°) : 20.14

Local Standard Hour, LST	Apparent Solar Time, AST	Hour Angle, H (°)	Solar Altitude Angle, β (°)	Solar Azimuth Angle, Φ (°)	Beam Solar Heat Gain: Beam Normal Irradiance E_b (W/m^2)	Beam Solar Heat Gain: Angle of Incident, θ (°)	Beam Solar Heat Gain: Beam Component $E_{t,b}$ (W/m^2)	Beam Solar Heat Gain: Beam Solar Heat Gain, q_b (W/m^2)	Diffuse Solar Heat Gain: Diffuse Horizontal Irradiance, E_d (W/m^2)	Diffuse Solar Heat Gain: Diffuse Component $E_{t,d}$ (W/m^2)	Diffuse Solar Heat Gain: Ground Reflected Component $E_{t,r}$ (W/m^2)	Diffuse Solar Heat Gain: Diffuse Solar Heat Gain, q_d (W/m^2)	Total Window Heat Gain, Q (W)
7.00	5.96	-90.64	0.60	-69.86	41.62	9.88	41.01	39.38	609.74	783.10	61.02	708.90	784.28
8.00	6.96	-75.64	14.68	-70.09	602.02	17.75	573.37	550.62	298.68	373.39	45.12	351.47	902.09
9.00	7.96	-60.64	28.71	-68.91	804.01	29.95	696.63	669.00	214.89	250.05	60.12	260.48	929.48
10.00	8.96	-45.64	42.55	-65.67	897.26	42.85	657.82	631.73	174.69	181.44	78.14	217.99	849.73
11.00	9.96	-30.64	55.82	-58.41	946.45	55.83	531.52	510.44	152.87	136.69	93.58	139.38	703.82
12.00	10.96	-15.64	67.43	-41.27	971.41	68.69	353.09	339.08	141.62	106.24	103.86	176.45	515.53
13.00	11.96	-0.64	73.35	-2.11	979.48	81.24	149.18	143.26	137.96	86.06	107.64	162.67	305.93
14.00	12.96	14.36	68.26	38.94	972.71	69.78	336.23	322.89	141.03	104.14	104.46	175.18	498.08
15.00	13.96	29.36	56.91	57.46	949.39	56.94	517.84	497.30	151.55	133.59	94.70	191.72	689.02
16.00	14.96	44.36	43.71	65.25	902.79	43.96	649.80	624.02	172.26	176.86	79.61	215.39	839.41
17.00	15.96	59.36	29.91	68.73	814.76	31.05	698.05	670.36	210.32	242.74	61.66	255.64	926.00
18.00	16.96	74.36	15.89	70.05	627.70	18.73	549.47	570.89	288.14	358.61	45.99	339.79	910.68
19.00	17.96	89.36	1.81	69.93	96.71	10.09	95.21	91.43	550.53	706.68	55.36	639.96	731.40

Month	: June	No of days	: 172
Extraterrestrial radiant flux, E_o (W/m^2)	: 1323.10	Equation of time, ET (minutes)	: -1.32
Solar declination, δ (°)	: 23.45		

				Beam Solar Heat Gain					Diffuse Solar Heat Gain				
Local Standard Hour, LST	Apparent Solar Time, AST	Hour Angle, H (°)	Solar Altitude Angle, β (°)	Solar Azimuth Angle, Φ (°)	Beam Normal Irradiance E_b (W/m^2)	Angle of Incident, θ (°)	Beam Component $E_{t,b}$ (W/m^2)	Beam Solar Heat Gain, q_b (W/m^2)	Diffuse Horizontal Irradiance, E_d (W/m^2)	Diffuse Component $E_{t,d}$ (W/m^2)	Ground Reflected Component $E_{t,r}$ (W/m^2)	Diffuse Solar Heat Gain, q_d (W/m^2)	Total Window Heat Gain, Q (W)
7.00	5.87	-91.91	-0.36	-66.48	14.41	6.48	14.32	13.75	658.98	852.19	65.89	771.01	784.76
8.00	6.87	-76.91	13.40	-66.72	567.15	14.96	547.94	526.20	308.35	389.86	43.97	364.34	890.54
9.00	7.87	-61.91	27.09	-65.38	781.65	27.58	692.80	665.33	219.61	259.85	57.56	266.56	931.89
10.00	8.87	-46.91	40.53	-61.82	879.48	40.56	660.14	641.64	177.63	188.76	74.92	221.43	863.07
11.00	9.87	-31.91	53.28	-54.21	931.04	53.50	553.79	531.82	154.85	142.56	90.12	195.41	727.23
12.00	10.87	-16.91	64.21	-37.83	957.56	66.24	385.82	370.51	142.93	111.04	100.51	177.66	548.18
13.00	11.87	-1.91	69.96	-5.12	966.89	78.63	190.58	183.02	138.70	89.92	104.71	163.45	346.48
14.00	12.87	13.09	66.38	31.23	961.40	69.44	337.69	324.30	141.19	104.78	102.20	173.83	498.12
15.00	13.87	28.09	56.32	51.16	939.73	56.77	514.95	494.53	150.96	133.37	93.29	190.35	684.88
16.00	14.87	43.09	43.87	60.38	895.79	43.87	645.78	620.16	170.48	175.20	79.13	213.59	833.75
17.00	15.87	58.09	30.55	64.73	813.25	30.88	697.95	670.26	206.21	238.30	61.96	252.16	922.42
18.00	16.87	73.09	16.90	66.54	641.99	18.08	610.27	586.07	277.61	346.52	46.42	330.00	916.07
19.00	17.87	88.09	3.14	66.68	168.00	7.38	166.61	160.00	494.47	638.48	50.37	578.50	738.50

Month : July

No of days : 202

Extraterrestrial radiant flux, E_o (W/m^2) : 1323.70

Equation of time, ET (minutes) : -6.35

Solar declination, δ (°) : 20.44

				Beam Solar Heat Gain					Diffuse Solar Heat Gain				
Local Standard Hour, LST	Apparent Solar Time, AST	Hour Angle, H (°)	Solar Altitude Angle, β (°)	Solar Azimuth Angle, Φ (°)	Beam Normal Irradiance E_b (W/m^2)	Angle of Incident, θ (°)	Beam Component $E_{t,b}$ (W/m^2)	Beam Solar Heat Gain, q_b (W/m^2)	Diffuse Horizontal Irradiance, E_d (W/m^2)	Diffuse Component $E_{t,d}$ (W/m^2)	Ground Reflected Component $E_{t,r}$ (W/m^2)	Diffuse Solar Heat Gain, q_d (W/m^2)	Total Window Heat Gain, Q (W)
7.00	5.78	-93.17	-1.74	-69.40	3.28	9.55	3.24	3.11	715.39	919.51	71.53	832.28	835.39
8.00	6.78	-78.17	12.30	-69.83	539.57	15.70	519.43	498.83	319.96	403.40	43.49	375.30	874.13
9.00	7.78	-63.17	26.33	-68.89	774.17	27.69	685.54	658.35	223.01	263.69	56.63	269.01	927.35
10.00	8.78	-48.17	40.17	-66.03	878.00	40.55	667.17	640.70	178.54	189.75	74.49	221.91	862.61
11.00	9.78	-33.17	53.53	-59.60	932.22	53.54	554.05	532.07	154.58	142.26	90.43	195.41	727.48
12.00	10.78	-18.17	65.50	-44.80	960.33	66.41	384.28	369.04	141.94	110.00	101.58	177.69	546.73
13.00	11.78	-3.17	72.78	-10.08	970.91	79.01	185.05	177.71	137.14	88.41	106.45	163.64	341.35
14.00	12.78	11.83	69.51	33.29	966.68	71.78	302.27	290.28	139.06	99.74	104.46	171.49	461.77
15.00	13.78	26.83	58.86	54.87	946.60	59.00	487.56	468.22	148.13	127.11	95.83	187.23	655.45
16.00	14.78	41.83	45.91	63.91	905.06	46.04	628.30	603.37	166.65	167.35	81.67	209.13	812.50
17.00	15.78	56.83	32.21	67.97	826.89	33.08	692.87	665.39	200.63	227.91	64.14	245.26	910.65
18.00	16.78	71.83	18.24	69.62	666.22	20.54	623.86	599.11	267.88	330.48	47.64	317.55	916.66
19.00	17.78	86.83	4.19	69.74	224.73	10.59	220.90	212.14	462.19	592.52	47.86	537.80	749.94

Month	: August	No of days : 233
Extraterrestrial radiant flux, E_o (W/m^2)	: 1336.15	Equation of time, ET (minutes) : -3.57
Solar declination, δ (^{O})	: 11.75	

				Beam Solar Heat Gain					Diffuse Solar Heat Gain				
Local Standard Hour, LST	Apparent Solar Time, AST	Hour Angle, H (^{O})	Solar Altitude Angle, β (^{O})	Solar Azimuth Angle, Φ (^{O})	Beam Normal Irradiance E_b (W/m^2)	Angle of Incident, θ (^{O})	Beam Component $E_{t,b}$ (W/m^2)	Beam Solar Heat Gain, q_b (W/m^2)	Diffuse Horizontal Irradiance, E_d (W/m^2)	Diffuse Component $E_{t,d}$ (W/m^2)	Ground Reflected Component $E_{t,r}$ (W/m^2)	Diffuse Solar Heat Gain, q_d (W/m^2)	Total Window Heat Gain, Q (W)
7.00	5.84	-92.47	-1.70	-78.11	3.33	18.19	3.16	3.03	722.00	900.82	72.19	817.14	820.17
8.00	6.84	-77.47	12.97	-78.73	562.01	22.65	518.66	498.09	315.81	385.24	44.19	360.64	858.73
9.00	7.84	-62.47	27.65	-78.56	794.88	32.89	667.49	641.02	219.44	249.66	58.83	259.07	900.09
10.00	8.84	-47.47	42.30	-77.27	897.16	45.06	633.68	608.54	175.44	178.04	77.92	214.96	823.50
11.00	9.84	-32.47	56.81	-73.78	950.31	57.88	505.26	485.22	151.86	132.24	94.71	190.60	675.82
12.00	10.84	-17.47	70.83	-63.54	977.60	70.87	320.40	307.69	139.54	101.42	106.29	174.44	482.13
13.00	11.84	-2.47	81.39	-16.39	987.49	83.77	107.05	102.80	135.03	81.16	111.14	161.50	264.30
14.00	12.84	12.53	75.10	55.68	982.57	75.14	251.92	241.93	137.28	93.71	108.68	169.97	411.89
15.00	13.84	27.53	61.52	71.62	961.58	62.16	449.07	431.26	146.79	120.71	99.20	184.69	615.95
16.00	14.84	42.53	47.10	76.47	918.48	49.25	599.53	575.75	166.05	160.83	83.89	205.52	781.27
17.00	15.84	57.53	32.49	78.29	836.80	36.78	670.21	643.63	201.60	221.92	65.11	241.05	884.67
18.00	16.84	72.53	17.81	78.77	665.02	25.65	599.47	575.69	273.48	327.70	47.69	315.25	890.95
19.00	17.84	87.53	3.13	78.40	168.94	18.66	160.07	153.72	499.79	622.24	50.90	565.31	719.03

Month	: September	No of days	:264
Extraterrestrial radiant flux, E_o (W/m^2)	: 1357.18	Equation of time, ET (minutes)	: 6.90
Solar declination, δ (°)	: -0.20		

				Beam Solar Heat Gain					Diffuse Solar Heat Gain				
Local Standard Hour, LST	Apparent Solar Time, AST	Hour Angle, H (°)	Solar Altitude Angle, β (°)	Solar Azimuth Angle, Φ (°)	Beam Normal Irradiance E_b (W/m^2)	Angle of Incident, θ (°)	Beam Component $E_{t,b}$ (W/m^2)	Beam Solar Heat Gain, q_b (W/m^2)	Diffuse Horizontal Irradiance, E_d (W/m^2)	Diffuse Component $E_{t,d}$ (W/m^2)	Ground Reflected Component $E_{t,r}$ (W/m^2)	Diffuse Solar Heat Gain, q_d (W/m^2)	Total Window Heat Gain, Q (W)
7.00	6.01	-89.86	0.13	-89.79	26.56	29.79	23.05	22.14	646.89	753.62	64.70	687.23	709.37
8.00	7.01	-74.86	15.10	-88.84	621.72	32.26	525.77	504.92	299.87	342.88	46.19	326.74	831.66
9.00	8.01	-59.86	30.07	-87.74	829.99	40.00	635.76	610.54	213.31	227.90	62.92	244.23	854.78
10.00	9.01	-44.86	45.02	-86.20	924.09	50.64	586.07	562.83	172.57	164.47	82.62	207.51	770.34
11.00	10.01	-29.86	59.93	-83.53	973.12	62.65	447.00	429.27	150.72	123.10	99.29	186.77	616.04
12.00	11.01	-14.86	74.62	-76.29	997.62	75.33	252.69	242.67	139.63	110.19	95.05	172.36	415.04
13.00	12.01	0.14	86.30	2.23	1005.04	88.28	30.25	29.05	136.25	76.77	113.92	160.14	189.19
14.00	13.01	15.14	74.42	76.56	997.32	75.08	256.78	246.60	139.76	95.49	110.04	172.61	419.21
15.00	14.01	30.14	59.65	83.60	972.45	62.42	450.29	432.43	151.02	123.76	99.02	187.09	619.52
16.00	15.01	45.14	44.73	86.24	922.80	50.42	588.01	564.68	173.14	165.44	82.26	208.02	772.70
17.00	16.01	60.14	29.78	87.76	827.44	39.82	635.51	610.30	214.40	229.46	62.54	245.22	855.52
18.00	17.01	75.14	14.81	88.86	615.34	32.15	520.98	500.32	302.49	346.16	45.98	329.32	829.64
19.00	18.01	90.14	-0.16	89.81	19.04	29.81	16.52	15.87	663.95	773.40	66.39	705.26	721.13

Month	: October	No of days	: 294
Extraterrestrial radiant flux, E_o (W/m^2)	: 1380.20	Equation of time, ET (minutes)	: 15.51
Solar declination, δ (°)	: -11.75		

				Beam Solar Heat Gain					Diffuse Solar Heat Gain				
Local Standard Hour, LST	Apparent Solar Time, AST	Hour Angle, H (°)	Solar Altitude Angle, β (°)	Solar Azimuth Angle, Φ (°)	Beam Normal Irradiance E_b (W/m^2)	Angle of Incident, θ (°)	Beam Component $E_{t,b}$ (W/m^2)	Beam Solar Heat Gain, q_b (W/m^2)	Diffuse Horizontal Irradiance, E_d (W/m^2)	Diffuse Component $E_{t,d}$ (W/m^2)	Ground Reflected Component $E_{t,r}$ (W/m^2)	Diffuse Solar Heat Gain, q_d (W/m^2)	Total Window Heat Gain, Q (W)
7.00	6.15	-87.30	1.53	-78.12	85.59	18.19	81.31	78.09	582.16	726.35	58.45	659.08	737.17
8.00	7.15	-72.70	16.15	-76.69	654.68	23.06	602.35	578.46	295.76	359.94	47.78	342.41	920.87
9.00	8.15	-57.70	30.64	-74.13	849.14	33.46	708.45	680.35	214.77	243.22	64.76	258.65	938.99
10.00	9.15	-42.70	44.89	-69.57	939.16	45.68	656.13	630.10	175.76	83.85	177.18	219.22	849.32
11.00	10.15	-27.70	58.51	-60.62	986.13	58.52	515.03	494.60	154.85	99.58	133.73	195.93	690.53
12.00	11.15	-12.70	70.20	-39.45	1008.94	71.50	320.08	307.38	114.54	104.09	109.38	179.27	486.65
13.00	12.15	2.30	74.58	8.49	1014.41	84.40	98.93	95.00	142.05	84.61	111.99	165.11	260.11
14.00	13.15	17.30	67.01	48.19	1003.98	67.52	383.83	368.61	146.79	111.98	107.10	183.98	552.59
15.00	14.15	32.30	54.45	64.11	974.83	54.55	565.37	542.95	159.92	145.32	95.30	202.08	745.02
16.00	15.15	47.30	40.56	71.28	917.62	41.84	683.65	656.54	185.22	194.35	78.19	228.89	885.42
17.00	16.15	62.30	26.22	75.07	806.07	29.98	698.25	670.56	233.01	271.09	58.92	277.14	947.70
18.00	17.15	77.30	11.68	77.23	544.77	20.71	509.56	489.35	340.99	420.30	45.13	390.87	880.22
19.00	18.15	92.30	-2.96	78.39	24.75	18.62	23.45	22.52	662.58	825.05	66.13	748.42	770.95

Month : November

No of days : 325

Extraterrestrial radiant flux, E_o (W/m^2) : 1400.31

Equation of time, ET (minutes) : 13.83

Solar declination, δ (^{O}) : -20.44

				Beam Solar Heat Gain					Diffuse Solar Heat Gain				
Local Standard Hour, LST	Apparent Solar Time, AST	Hour Angle, H (^{O})	Solar Altitude Angle, β (^{O})	Solar Azimuth Angle, Φ (^{O})	Beam Normal Irradiance E_b (W/m^2)	Angle of Incident, θ (^{O})	Beam Component $E_{t,b}$ (W/m^2)	Beam Solar Heat Gain, q_b (W/m^2)	Diffuse Horizontal Irradiance, E_d (W/m^2)	Diffuse Component $E_{t,d}$ (W/m^2)	Ground Reflected Component $E_{t,r}$ (W/m^2)	Diffuse Solar Heat Gain, q_d (W/m^2)	Total Window Heat Gain, Q (W)
7.00	6.13	-88.12	0.53	-69.48	41.12	9.50	40.56	38.95	643.61	827.35	64.40	748.90	787.85
8.00	7.13	-73.12	14.49	-67.84	627.33	16.44	601.70	577.83	315.21	396.25	47.22	372.43	950.26
9.00	8.13	-58.12	28.20	-64.54	838.66	28.54	736.76	707.54	227.61	267.54	62.40	277.09	984.63
10.00	9.13	-43.12	41.40	-58.64	935.56	41.42	701.55	673.72	185.92	195.90	80.46	232.09	905.82
11.00	10.13	-28.12	53.47	-47.90	985.97	54.41	573.86	551.09	163.62	148.95	95.59	205.37	756.46
12.00	11.13	-13.12	62.82	-27.75	1010.57	67.27	390.47	374.98	152.56	116.80	105.15	186.40	561.37
13.00	12.13	1.88	65.99	4.33	1016.80	79.85	179.25	172.14	149.75	95.35	107.86	170.66	342.80
14.00	13.13	16.88	60.89	34.00	1006.30	64.07	440.03	422.58	154.49	123.74	103.37	190.72	613.30
15.00	14.13	31.88	50.61	51.25	976.25	51.16	612.25	587.97	167.95	159.08	92.25	211.07	799.04
16.00	15.13	46.88	38.17	60.45	917.00	38.17	720.91	692.32	194.01	210.89	76.07	241.00	933.31
17.00	16.13	61.88	24.80	65.56	801.47	25.38	724.11	695.39	243.27	292.00	57.95	293.89	989.28
18.00	17.13	76.88	11.01	68.39	532.31	13.81	516.93	496.43	354.43	449.96	45.61	416.19	912.61
19.00	18.13	91.88	-2.88	69.68	26.42	10.13	26.00	24.97	669.48	859.29	66.81	777.74	802.72

Month : December

Extraterrestrial radiant flux, E_o (W/m^2) : 1410.99

Solar declination, δ (°) : -23.45

No of days : 355

Equation of time, ET (minutes) : 2.17

				Beam Solar Heat Gain					Diffuse Solar Heat Gain				
Local Standard Hour, LST	Apparent Solar Time, AST	Hour Angle, H (°)	Solar Altitude Angle, β (°)	Solar Azimuth Angle, Φ (°)	Beam Normal Irradiance E_b (W/m^2)	Angle of Incident, θ (°)	Beam Component $E_{t,b}$ (W/m^2)	Beam Solar Heat Gain, q_b (W/m^2)	Diffuse Horizontal Irradiance, E_d (W/m^2)	Diffuse Component $E_{t,d}$ (W/m^2)	Ground Reflected Component $E_{t,r}$ (W/m^2)	Diffuse Solar Heat Gain, q_d (W/m^2)	Total Window Heat Gain, Q (W)
7.00	5.93	-91.04	-2.34	-66.64	6.01	7.04	5.97	5.73	742.89	959.82	74.26	868.43	874.16
8.00	6.93	-76.04	11.34	-65.23	546.70	12.48	533.79	512.62	352.84	449.89	46.04	416.48	929.10
9.00	7.93	-61.04	24.78	-62.14	807.29	24.87	732.45	703.40	245.25	295.31	58.36	297.02	1000.42
10.00	8.93	-46.04	37.69	-56.56	920.98	37.82	727.49	698.64	196.80	214.61	75.99	244.05	942.68
11.00	9.93	-31.04	49.49	-46.73	979.51	50.79	619.27	594.71	171.10	162.78	91.58	213.62	808.32
12.00	10.93	-16.04	58.85	-29.33	1008.98	63.58	448.99	431.18	157.92	127.35	102.14	192.73	623.91
13.00	11.93	-1.04	63.03	-2.09	1018.74	76.06	245.49	235.75	153.52	103.39	106.15	175.97	411.72
14.00	12.93	13.96	59.81	26.12	1011.39	65.32	422.25	405.50	156.83	123.43	103.10	190.24	595.74
15.00	13.93	28.96	50.98	44.87	985.00	52.57	598.72	574.97	168.65	157.06	93.39	210.33	785.30
16.00	14.93	43.96	39.41	55.51	931.46	39.62	717.50	689.05	192.24	206.15	78.35	238.93	927.97
17.00	15.93	58.96	26.60	61.54	828.29	26.65	740.32	710.96	236.42	281.50	60.74	287.41	998.37
18.00	16.93	73.96	13.22	64.92	600.20	14.09	582.15	559.06	330.73	419.47	46.80	391.58	950.63
19.00	17.93	88.96	-0.44	66.53	13.75	6.55	13.66	13.12	707.99	915.49	70.79	828.28	841.40