ENERGY-SAVING SOLAR POWERED COOLING SYSTEM

by

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

JUNE 2006

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(ELECTRICAL & ELECTRONICS ENGINEERING)

Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

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June 2006

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NIK FAZLIENA BT NIK IBRAHIM @ NIK FAUZI

ABSTRACT

The main objective of this project is to design an energy-saving solar powered cooling system for the residential sector. The focus is on the new energy-saving design where one of the relatively new designs is the evaporative cooler. Malaysia is seen as a fertile market for renewable energy as it grapples with growing demand for power to feed rapid economic expansion at the same time as global oil are rising. Since Malaysia is blessed with enough amount of solar energy during daytime, it would a waste if it is not utilized for cooling purposes. It is during daytime that air-conditioners are normally used and the electricity consumption of the air-conditioning unit is normally high, making of unaffordable for lower income group. The development of a solar powered evaporative cooling system is probably a reasonably good solution to provide comfortable living especially for the rural folks. The environment is no longer conducive with unusually daily high temperatures. The evaporative cooler is powered by the photovoltaic cells to operate the cooling system. The cooled air that flows out is dry air and the humidity is low. It can lower about 5 °C to 8 °C of the room temperature. The major components of this evaporative cooler are solar panel, battery storage, plastic plates heat-exchanger, water spray, re-circulating water pump, outdoor air intake with air filter, supply fans and exhaust fans. Through this project work, it is shown that the evaporative cooler uses a fraction of the energy of air conditioners and photovoltaic cells can provide enough electricity to run the system effectively. Solar energy can be converted to electricity by using photovoltaic cells. The solar electricity generated will charge the battery when cooling system is inactive and the battery work as a back up when solar energy is not sufficient. The construction of the evaporative cooler prototype has been successfully developed to the real application based on the research and analysis that was conducted.

ACKNOWLEDGEMENTS

I would like to thank to ALLAH SWT for giving me an opportunity to do this final year project and because of His mercies, I am successfully completing this project. I would like to express my appreciation to the university, Universiti Teknologi PETRONAS for giving the facilities in implementing the project.

My appreciation is extended to my beloved supervisor, Dr Balbir Singh Mahinder Singh for the numerous hour of spending his time for giving me motivation and encouragement to assist my project successfully. He has guided, supervised and gave a lots of opinions that helped me in completing my project for the pre-EDX, EDX and final presentation. Constructive criticism and suggestions have pushed and raised me to improve my project.

I would especially like to thank the electrical lab technicians, Miss Siti Hawa Hj Tahir, Miss Faizah M.Isa and Mr Rosli Mohd for giving me their hands in constructing my prototype and for spending their time to help me to run this project effectively.

I also would like to acknowledge the contribution of all my friends and other lecturers for their contributions and supports to this project. Without their supports this volume may not have come to fruition.

Finally, I would thank my family. They always encourage me to carry on and they supported me the all the way. I have had the comfort of my family to cheer me on during my hard times in developing and completed the project.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Malaysia is fortunate to be blessed with generous and diverse energy resources ranging from fossil fuels to renewable energy resources such as biomass and solar energy. Among these sources, gas and hydro resources are particularly pertinent to the economic development and with the construction of major pipelines in the peninsular, utilization of significant levels of natural gas in the domestic energy economy has begun, (Yokobori, 2000).

Besides the energy resource supply and development aspects, there are several related issues emerging in Malaysia's energy scene, such as the increase in the price of oil. The 1973 Oil Embargo was not the result of a real energy shortage, but should have made us aware of the energy limitations that might prevail. The oil crisis in the 1970s was a blessing in disguise for the developed countries to seek for alternative energy resources. Today they are well established in utilizing their renewable energy options. Whereas in Malaysia, only recently renewable energy and energy efficiency were brought on the mainstream of the national economic agenda under the development of the energy sector, (Lim, 2004).

Malaysia is seen as an especially fertile market for renewable energy as it grapples with growing demand for power to feed rapid economic expansion at the same time as global oil are rising. As a major producer of agricultural commodities, and with intense solar radiation, Malaysia also has great interest in new and renewable energy sources, particularly in the use of agricultural wastes as well as solar drying in rural communities, despite the four-fuel strategy. Rural electrification programmed will comprise grid extensions as well as the provision of stand alone generators such as solar installations or hybrid systems. With the inclusion of Renewable Energies as the fifth fuel in its energy plan under the 9th Malaysia Development Plan, more government support is to be expected for Renewable Energy Projects in general. On the other hand overall prospects for PV in nation with a relatively high electrification rate will remain limited until PV generated electricity competes with the grid kWh-costs.

Solar power can be classified as direct or indirect. Direct solar power involves only one transformation into a usable form. For example, the sunlight hits photovoltaic cell creating electricity with no moving parts. Indirect solar power involves more than one transformation to reach a usable form. The demands for solar power are increasing and still continue.

Most solar energy used today is harnessed as heat or electricity. Deployment of solar power depends largely upon local conditions and requirements. But as all industrialised nations share a need for electricity, it is clear that solar power will increasingly be used to supply a cheap, reliable electricity supply. Of the new energy sources, solar power has become the most widely used by households. With the expected increase in energy prices, energy efficiency through energy conservation and improved technology will be important issues of the future. More effective measures to ensure efficient utilization of energy will be introduced.

Due to changes in lifestyle and increasing urbanization as well as rural-urban migration, the average number of persons per dwelling is expected to decrease from 4.91 in 1990 to 4.8 in 2000. The electrification rate, on other hand, is projected to reach 95% in 2000 compared to 82% in 1990. This implies that more houses will be built with the majority electrified, thereby increasing residential demand for electricity. However, most uses of renewable power focus on electricity generation.

Usually the evaporative coolers work best in places where the humidity is relatively low. Although the humidity in Malaysia is relatively high, that does not necessarily mean that evaporative cooler would be total failure if it were to be used here. It the scope of certainly be worthwhile the project is to investigate the effectiveness of this system in Malaysia. Since Malaysia is blessed with enough amount of solar energy during daytime, it would a waste if it is not utilized for cooling purposes. It is during daytime that air-conditioners are normally used and the electricity consumption of the air-conditioning unit is normally high, making of unaffordable for lower income group. The development of a solar powered evaporative cooling system is probably a reasonably good solution to provide comfortable living especially for the rural folks. The environment is no longer conducive with unusually daily high temperatures.

1.2 Problem Statement

Issues of global warming have been in the news for a long time. The global temperature of our world is rising because of the bad effect from human activities. Due to this, the sea level is increasing from year to year as the effect from the increased temperature. In Malaysia, the average temperature is more than 30°C, which is considered very hot and realized that our country has the potential to make full use of solar energy which will produce electricity.

Many uptown people are using cooling system to overcome this effect. On the other hand, people of rural communities find it difficult to afford a cooling system as the maintenance cost is high. According to the research, the standard of living in Malaysia shows that there is a big gap between the rich and the poor.

The development of a solar powered evaporative cooling system is probably a reasonably good solution to provide comfortable living and to allow the rural folks to enjoy proper facilities, such as air conditioning systems. The main aims of this project are to produce an energy saving cooler which is economical and consumes less power. This would provide a comfortable environment for rural communities as the one-off cost related to solar powered air cooler would definitely benefit them in the long run.

1.3 Objectives

The objectives of this project are:

i. To identify the heat transfer mechanism in a typical house and carry out CLTD.
ii. To identify a suitable solar evaporative cooling system design.
iii. To design and build a cost effective energy-saving solar powered evaporative cooler prototype.

1.4 Scope of Study

The scope of this project is to design an energy-saving evaporative cooling system that uses solar energy as its power source. Since Malaysia is blessed with enough daily sunshine, therefore it can be safely assumed that devices that are designed to utilize solar energy can be practical and there should not be any problem in implementing solar powered technologies.

CHAPTER 2

LITERATURE AND THEORETICAL REVIEW

In Malaysia towards development of energy efficient systems would certainly pushed the R & D efforts. As mentioned earlier, the work on this project is aligned to the current energy scenes and will be beneficial to the people. The development of the evaporative cooling system would allow the lower income groups to have a comfortable life. It is vital that a suitable cost effective energy-saving cooling system to be defined.

2.1 Fundamentals of Air Conditioning Systems

Air conditioning means the full mechanical control of the internal environment to maintain specified conditions for a certain purpose. The objective may be to provide a thermally comfortable temperature, humidity, air cleanliness and freshness for the users of the building or it may be to satisfy operational conditions for machinery or processes. The tern air conditioning may be used to describe an air-cooling system that reduces excessive temperatures but does not guarantee precise conditions, to minimize capital and operational costs. This is better described as comfort cooling.

Low-cost air conditioning may only cool inside the building by a specific number of degrees Celsius below the outside air temperature or limit the internal percentage saturation to 70%. The power consumed of conventional air-conditioning system is very high. 1 hp air-conditioner consumes as much as 746 watts of electricity power.

Most air-conditioning units operate by ducting air across the colder, heat-absorbing side of a refrigeration apparatus and directing it back into the air-conditioned space. The refrigeration apparatus is controlled by some form of thermostat. In water-cooled air-conditioning units, the waste heat is carried away by a flow of water. For recirculation in water-cooled units, a cooling tower is used. This apparatus maintains a constant level of water in the system and replaces water lost by evaporation. The development of small self-contained systems has greatly expanded the use of air conditioning in homes. A portable or window-mounted air conditioner is usually adequate for one room.

2.1.1 The Basic Concepts of a Split Air Conditioning System

a. A split air conditioning system consists of an indoor unit and an outdoor unit connected together by refrigerant pipes. The refrigerant circulates between these 2 units [i.e. 2 parts of the system] to take heat from indoor to outdoor, by firstly having heat of the room air absorbed into the refrigerant via an air-refrigerant heat exchanger which is the indoor unit, then conveying the heat to the outdoor unit for disposal.

b. The indoor unit comprises a finned coil and a fan which is driven by an electric motor. Refrigerant is circulated inside the finned coil to the outside unit and then back to the indoor unit. The fan pulls or pushes air around the outer surfaces of the coil inside the indoor unit, taking warm air from the room and injecting cooled air into the room in summer. The refrigerant has no direct contact with air. So the heat of the room air is transferred into the refrigerant in the indoor unit. Inside the coil, refrigerant evaporates, and the indoor unit is therefore commonly called an evaporator. The indoor unit is wall-mount or ceiling mount unit.

c. The outdoor unit

The refrigerant then takes the heat from the indoor unit to the outdoor unit, which is commonly called a condensing unit. In an air-cooled outdoor unit, heat exchange occurs in the same way as the indoor unit. However, the outdoor unit contains a refrigerant compressor, in addition to having a finned coil and motor-driven fan. The refrigerant does not have direct contact with air. Refrigerant going through this outdoor coil is losing its energy across the metal surface of the coil to the atmosphere, as outside air is drawn pass the surface of the finned coil by the fan. By passing through this finned coil, the outside air is heated up, by normally about 5 ^{o}C rise in temperature. The outside air passing through the outdoor unit is an open circuit. That is, air path is not recirculated.

2.2 Evaporative Cooling Principles

Evaporative cooling occurs when moisture is added to air that has a relative humidity of less than 100%. The lower the relative humidity, which is dependent on the air's dry and wet bulb temperatures, the greater the potential for evaporative cooling. Evaporative cooling is one way to reduce temperatures inside buildings. As water evaporates, it absorbs energy from the surrounding environment. A well-maintained ventilation system with evaporative cooling can reduce incoming air -12 to -6°C. Evaporative cooling systems lower air temperature using mists, sprays, or wetted pads. Introducing water into ventilation air increases relative humidity while lowering the air temperature. Evaporative coolers are sized based on cubic feet per minute (CFM) of airflow. Airflow for evaporative coolers is typically higher than conventional air conditioning systems. Two to three CFM per square foot or three to four CFM per square foot in hot desert climates is typical. Improperly sized evaporative coolers will waste water and energy and may cause excess humidity or other comfort problems. The typical evaporative pad cooling system draws outside air into the building through wet vertical pads. The major components of this system are: pad media, water supply, water pump, distribution pipe, gutter, sump, and bleed-off line. As air flows past the moist pad surfaces, some of the moisture evaporates into the air stream. Heat is withdrawn from the air during this process and the air leaves the pad at a lower temperature with higher moisture content.

Water is continuously circulated over and through the pad cells during operation. A pump transports water from a sump through a filter and to a distribution pipe along the top of each pad. A gutter collects unevaporated water that drains from the bottom of each pad. Water can be recycled as long as salt or minerals do not collect noticeably on the pads.

Only part of the water flowing over the pad material is evaporated. Water temperature does not have a great effect on the cooling achieved. Recommended minimum water flow rates through vertically-mounted pads and sump capacities. The excess water that is collected from the pad should be screened to remove pad fibers and other debris before the water is returned to the sump.

Once the cooling requirements are determined, it is possible to size an evaporative cooling system. The following factors must be considered:

a) The size of the cooling load of the equipment (including power equipment)

b) The size of the cooling load of the building

c) Oversizing to account for humidification effects

d) Oversizing to create redundancy

e) Oversizing for future requirements

The Watt loads of each of these factors can be summed to determine the total thermal load.

2.3 Basic Principles of Building Energy Simulation

Air-conditioning load calculation is the fundamental of building energy simulation and it is also the first step to be considered in building energy consumption. Air-conditioning load calculation is the design load estimation for an air-conditioning system. Based on design criteria and thermal properties of the building, the cooling, heating, latent and fresh air loads of the building will be estimated to determine the design flow rate and capacity of the air-conditioning system and its equipment. In its simplest term air-conditioning load can be divided into "heating load" and "cooling load". The calculation of heating load is usually more straightforward because the heat transfer in a room in winter is relatively stable. In the coldest weather period the room may not receive sunshine, therefore, the heat gains from the sun, occupancies, lighting and equipment are usually not considered in the estimation of peak heating load. Thus, a steady-state calculation method is usually enough for computing heating load. However, for cooling load calculation, the complex effect of heat transfer, solar radiation and heat storage has to be considered and this make the calculation complicated. To understand the basic principle of cooling load calculation, one must distinguish the difference between "heat gain" and "cooling load", (Hui, 1998). Figure 2.1 shows the relationship between instantaneous heat gain and cooling load.

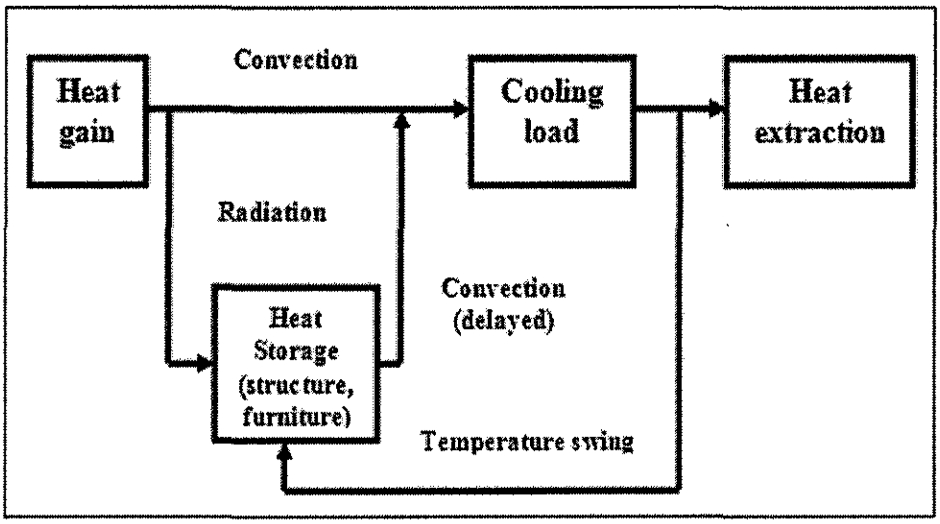


Figure 2.1 : Relationship between instantaneous heat gain and cooling load [14]

The cooling load of an air-conditioning system should be determined based on simultaneously usage of the rooms it serves, the type of air-conditioning system and the type of control method. The cooling load should be calculated using the block load which combines the hourly cooling loads of all the rooms, and with the addition of the fresh air load and the load due to temperature rise at the air handling unit, air duct, water pump, chilled water pipe and water tank. Because some of the loads may vary during the 24 hours period in a day, it is necessary to calculate for each hour and see which one will give the largest block load. The amount of the load will also be affected by the running period of the air-conditioning installation. For intermittently operated air-conditioning systems, load calculation should consider the effect between pre-cooling/pre-heating and the storage of heat.

The building cooling load components are direct solar radiation, transmission load, ventilation/infiltration load and internal load. Calculating all these loads individually and adding them up gives the estimate of total cooling load. The load, thus calculated, constitutes total sensible load. Normal practice is that, depending on the building type, certain percent of it is added to take care of latent load applying the laws of heat transfer and solar radiation makes load estimations. Step by step calculation procedure has been adequately reported in the literature. It is a scientific and exact approach, but time consuming and lengthy. Overall heat transfer coefficients for all the components of building envelope are computed with help of thermal properties of the building materials. For the design conditions and the building materials used, cooling load temperature difference, solar heat gain factors and cooling load factors are calculated. Principles of solar energy calculation are applied to determine the direct and indirect solar heating component of the building. The requisite data of building material properties, climate conditions and ventilation standard are also established and reported. First principle is applied to yields the rates of heat transfer through different building components. All these components, when added up, give the total cooling (or heating) load of a building, (Ansari F.A, 2005).

2.4 Heat Sources and Heat Losses Mechanism

Heating and air-conditioning systems control the temperature, humidity and the total air quality in residential, commercial and other buildings. Heating, air-conditioning and refrigeration systems consists of many mechanical, electrical and electronic components, such as motors, compressors, pumps, fans, ducts, pipes, thermostats and switches.

The heat sources to be described basically are those which comprise the summer cooling load. Some heat sources, such as people, lights and small domestic appliances are so variable that they usually are not considered when determining the load. The solar heat entering a structure directly and by conduction through the building materials. The heat entering by conduction through the walls and roof is not immediately absorbed in the room. Depending on the construction material used, the effect of conducted solar heat may be felt for several hours. Heat conduction through materials is the result of differences between the indoor and outdoor air temperatures. The greater the temperature difference, the faster is the flow of heat. The quality of heat conducted in this manner depends on the size of the wall or roof area and on the resistance offered by the material to the heat flow. The position of the building with relation to the sun is a factor that does not change the total heat load, but which can be put to practical use. Heat from the sun enters a building through the walls and roof at a much slower rate than it does through glass. As the solar heat penetrates the surface skin of the building, some of the heat enters the building material and some is reflected to the atmosphere. The heat absorption process is continuous and the amount of solar heat entering the building material penetrates deeper until it reaches the inside surface. If the sun were stationary so that it could shine continuously in one location with the same intensity, approximately seven hours would be required for the heat to reach the interior surface of a 12 inch thick brick wall.

Another source of heat that must be considered when making a cooling load estimate is infiltration. The heat due to this source is in the air entering the building through cracks around doors and windows and through open doors. This heat load is directly related to the quality of the building construction and to the presence or absence of weather stripping. If good construction practices were followed, there is less total crack area. Therefore, the cooling load estimate is smaller. The degree of infiltration is also affected by wind velocity, that is, the stringer the wind, the greater is the amount of infiltration. The final important source of outside heat is from moisture. Moisture enters the building by infiltration and is called the latent load. The moisture enters through cracks and becomes part of the room load or it is carried with the ventilation air and becomes part of the outdoor supply air load.

When estimating the heat load, indoor heat sources must be considered also. These sources include people, lights, appliances and motors. People are a source of both sensible heat and latent heat. The heat produced by a person depends upon the energy that is being exerted. A person at rest causes less heat than a person being very active. All lights give off heat. The emitted by incandescent bulbs is directly related to the wattage of the bulbs. The heat produced by fluorescent lamps is approximately 25% greater than that expected from the rated wattage. This heat increase is due to the additional electricity required by the ballast. The heat load from all types of lights varies according to the usage. Motor heat generally is based on the horsepower rating, but varies according to usage and to the starting and stopping characteristics of the motor.

Heat is also lost through floors on ground level (slab construction) and through floors and walls below the ground level. There is usually a greater heat loss from the outer areas of slab floors on ground level than through basement floors and walls that are below the ground level. This difference in heat loss due to the difference in temperature between surface ground and the ground below the surface. The surface ground temperature varies with the air temperature. This temperature variation decreases almost uniformly as the depth below the ground surface increases.

Heat loss also occurs because heat is required to increase the temperature of the air used for ventilation. A better term for this heat is perhaps the source of the heat load, rather than heat loss. The heat used to increase the ventilation air temperature is not actually lost since it enters the heated space. However, this heat is an additional requirement (heat load) since the cold ventilation air must be heated.

2.4.1 Rate of Heat Transfer

The rate at which heat is conducted through any material depends on three factors:

i. The temperature difference across which the heat flows
ii. The area of the surface through which heat is flowing
iii. The *thermal resistance (R)* of the material to heat transfer

This can be expressed by the following equation:

$$Q = \frac{1}{R} \times A \times TD \tag{2.1}$$

where:

Q = heat transfer rate, BTU/hr

R = thermal resistance of material, hr-ft^2-F/BTU

A = surface area through which heat flows, ft^2

TD = t_H-t_L = temperature difference across which heat flows, from higher temperature t_H to lower temperature t_L, F

2.5 Cooling Load Temperature Difference (CLTD)

Cooling load temperature difference (CLTD) and cooling load factor (CLF) are used to convert the space sensible heat gain to space sensible cooling load, (Pita,2002).

The space sensible cooling load Q_{rs} is calculated as:

$$Q_{rs} = A \times U \times CLTD \tag{2.2}$$

where;

A = area of external wall or roof

U = overall heat transfer coefficient of the external wall or roof.

2.5.1 Cooling Load Factor (CLF)

The cooling load factor is defined as:

$$CLF = \frac{SensibleCoolingLoad}{SensibleHeatGain} = \frac{Q_{rs}}{Q_{es}} \tag{2.3}$$

CLF is used to determine solar loads or internal loads.

2.5.2 Cooling Load from Heat Gain through Exterior Structure

The cooling loads caused by conduction heat gains through the exterior roof, walls, ceiling, and glass are each calculated by use of the following equation:

$$Q = U \times A \times CLTD \tag{2.4}$$

where:

Q = cooling load for roof, wall, or glass BTU/hr

U = overall heat transfer coefficient for roof, wall, or glass, BTU/hr-ft^2-F , Table A.3 and A.4 (in Appendix)

A = area of roof, wall, or glass, ft^2

CLTD = cooling load temperature difference, F

The cooling load temperature difference (CLTD) is not the actual temperature difference between the outdoor and indoor air. It is modified value that accounts for the heat storage/time lag effects. The CLTD values are listed in Table A.1 and A.2 in the Appendix . The CLTD table is based on an indoor temperature of 75F. For other indoor temperatures, the CLTD should be corrected by 1F for each 1F temperature difference from 75F. The CLTD values should also be interpolated between the listed outdoor temperature values, (Pita,2002).

2.5.3 Conduction through Interior Structure

The building materials used in a structure have a large impact on the amount of heat that leaks into the building. The amount of heat transferred through a building material is known as the heat of transmission. Actually, this is heat transfer via conduction, (Pita,2002). The heat of transmission is calculated using a heat transfer coefficient called the *U factor* expressed in (Btuh/^{o}F/sq.ft.).

The heat that flows from interior unconditioned spaces to the conditioned space through partitions, floors and ceiling can be determined from equation :

$$Q = A \times U \times TD \tag{2.5}$$

where:

Q = heat gain (cooling load) through partition, floor and ceiling, BTU/hr

A = area of partition, floor or ceiling, ft^2

U = overall heat transfer coefficient, BTU/hr-ft^2-F

TD = temperature difference from one side to other,^{o}F

2.5.4 Cooling Load from Heat Gain through Windows

The sensible cooling load due to heat gains through glass (windows and doors) are found by using glass load factors (GLF). These are listed in Table A.16 in the Appendix. The GLF values account for both solar radiation and conduction through glass. Values should be interpolated between listed outdoor temperatures, (Pita,2002). The glass sensible cooling load is determined from equation:

$$Q = A \times GLF \tag{2.6}$$

where:

Q = sensible cooling load due to heat gain through glass, BTU/hr

A = area of glass, ft^2

GLF = glass load factor, BTU/hr- ft^2

2.5.5 Solar Radiation through Glass

Radiant energy from the sun passes through transparent materials such as glass and becomes a heat gain to the room. Its value varies with time, orientation, shading, and storage effect. The solar cooling load can be found from the following equation:

$$Q = SHGF \times A \times SC \times CLF \tag{2.7}$$

where;

Q = solar radiation cooling load for glass, BTU/hr

SHGF = maximum solar heat gain factor, BTU/hr-ft^2

A = area of glass, ft^2

SC = shading coefficient

CLF = cooling load factor for glass

The maximum solar heat gain factor (SHGF) is the maximum solar heat gain through single clear glass at a given month, orientation, and latitude, (Pita,2002).

2.5.6 Infiltration and Ventilation Heat Loss

The heat loss due to infiltration and controlled natural ventilation is divided into sensible and latent losses, (Pita, 2002).

2.5.6.1 Sensible Heat Loss Effect of Infiltration Air

Infiltration occurs when outdoor air enters through building openings, due to wind pressure. The opening of most concern to us are cracks around window sashes and door edges, and open doors.

The amount of heat required to offset the sensible heat loss from infiltrating air can be determined by:

$$Q_s = 1.1 \times CFM \times TC \tag{2.8}$$

where;

Q_s = sensible heat loss from infiltration or ventilation air, BTU/hr

CFM = air infiltration (or ventilation) flow rate, ft^3/min

TC = temperature change between indoor and outdoor air, F

2.5.6.2 Latent Heat Loss Effect on Infiltration Air

Since infiltration air is often less humid than the room air, the room air humidity may fall to an unacceptable level for comfort. If the room air humidity is to be maintained, water vapor must be added. The addition of this moisture requires heat (latent heat of vaporization of water). This is expressed by the following equations:

The energy quantity associated with net loss of moisture from the space is latent heat loss which is given by:

$$Q_l = 0.68 \times CFM \times (W_i' - W_o') \tag{2.9}$$

where;

Q_l = latent heat required for infiltration or ventilation air, BTU/hr

CFM = air infiltration or ventilation rate, ft^3/min

W_i', W_o' = higher (indoor) and lower (outdoor) humidity ratio in grains water/lb dry air (gr w/lb d.a.)

2.5.6.3 Air Change Method

This procedure for finding the infiltration rate is based on the number of air changes per hour (ACH) in a room caused by the infiltration. Determination of the expected number of air changes is based on experience and testing. Suggested values range from 0.5 ACH to 1.5 ACH for buildings ranging from "tight" to "loose" construction.

Using the definition of an air change, Equation 2.10 can be used to find the air infiltration rate in CFM.

$$CFM = ACH \times \frac{V}{60} \tag{2.10}$$

where;

CFM = air infiltration rate to room, CFM

ACH = number of air changes per hour for room

V = room volume, ft^3

2.5.6.4 Ventilation (Outside Air) Load

Some outside air is usually brought into nonresidential buildings through the mechanical ventilation equipment (air handlings units) in order to maintain the indoor air quality. The outside ventilation air will be an additional part of the building heating load, since the entering air is at the outdoor temperature and humidity,(Pita, 2002).

Equation 2.8 and 2.9 are also used to find the ventilation heating load. However, the ventilation air is heated (and humidified, if required) in the air conditioning equipment, before it enters the room. Therefore, it is part of the total building heating load, but not part of the individual room heating loads.

2.6 The Photovoltaic (PV) Theory

A solar photovoltaic is the most benign method of power generation today. The photovoltaic cell is the device that uses the photovoltaic effect of semiconductors that collect the solar energy and convert it to electrical energy. The amount of conversion is depends on the intensity of sunlight. The PV reduces absolutely no emission and uses the unlimited resource of the free sunshine as its fuel. Since the sunshine is available everywhere whenever there is a sun, the PV applications have no boundary. The PV system also has no moving part. Thus the operation of a PV system is very quiet, clean and requires almost no maintenance. Today, most PV modules are guaranteed to last between 20 to 30 years.

Solar photovoltaic is made of semiconductor material, most commonly silicon. The PV panel works on the principle of the photovoltaic effect. The photovoltaic effect is the conversion of sunlight (photon) directly into electricity. This occurs when the PV cell is exposed to the light (photon) and struck by the sunlight (photon). The electrical charges are generated and this can be conducted away by electrical conductor as direct current (DC). The 'freeing' silicon electrons to travel from the PV cell, through electronic circuitry, to a load. Then they return to the PV cell, where the silicon recaptures the electron and the process is repeated.

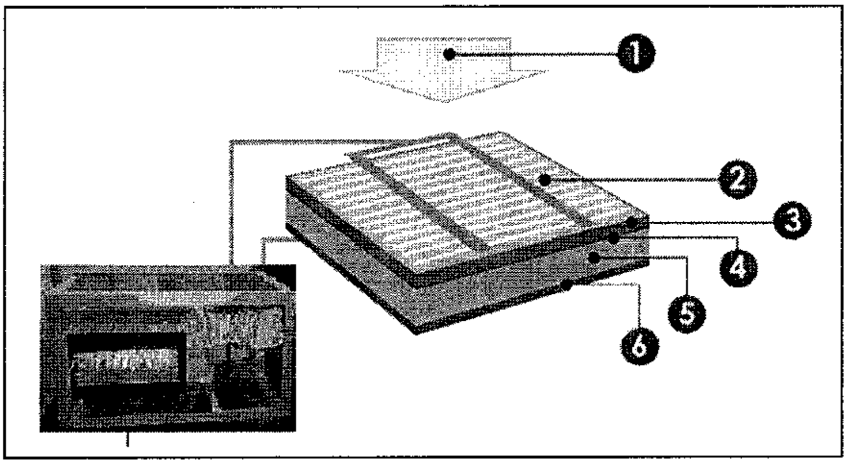


Figure 2.2 : The photovoltaic effect in a solar cell – (1) light (photons), (2) front contact, (3) negative layer, (4) diversion layer, (5) positive layer and (6) back contact

2.6.1 Types of Solar Cell

There are more than three types of solar cells that normally used today. The different types of solar cells are because of on how the silicones are made into cells. These are the general types of solar cells:

(a) Monocrystalline Silicon Cells

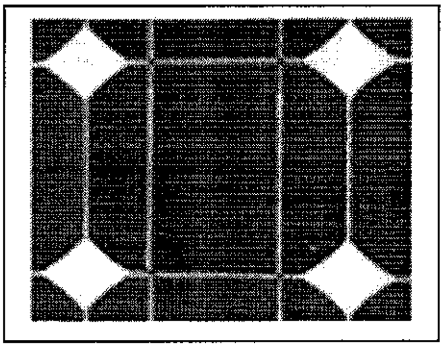


Figure 2.3 : Monocrystalline Silicon Cell

Made using cells saw-cut from a single cylindrical crystal of silicon, this is the most efficient of the photovoltaic (PV) technologies. The principle advantage of monocrystalline cells are their high efficiencies, typically around 15%,although the manufacturing process required to produce monocrystalline silicon is complicated, resulting in slightly higher costs than other technologies, (Zweibel, 1990).

(b) Multicrystalline Silicon Cells

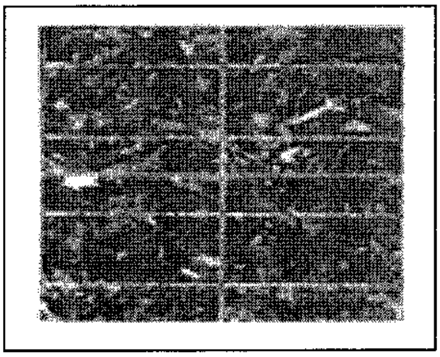


Figure 2.4 : Multicrystalline Silicon Cells

It is made from cells cut from an ingot of melted and recrystallised silicon. In the manufacturing process, molten silicon is cast into ingots of polycrystalline silicon, these ingots are then saw-cut into very thin wafers and assembled into complete cells. Multicrystalline cells are cheaper to produce than monocrystalline ones, due to the simpler manufacturing process. However, they tend to be slightly less efficient, with average efficiencies of around 12%, creating a granular texture, (Zweibel, 1990).

(c) Thick-film Silicon

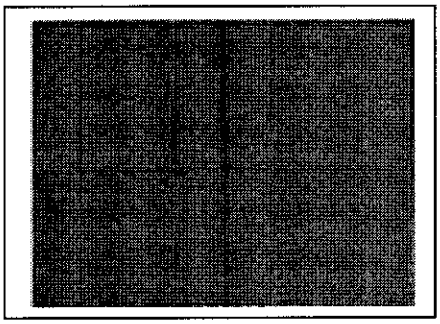


Figure 2.5 : Thick-film Silicon

Another multicrystalline technology where the silicon is deposited in a continuous process onto a base material giving a fine grained, sparkling appearance. Like all crystalline PV, this is encapsulated in a transparent insulating polymer with a tempered glass cover and usually bound into a strong aluminum frame, (Zweibel, 1990).

CHAPTER 3
METHODOLOGY / PROJECT WORK

3.1 Project Work

The project focused on prototype construction. The project continued with detailed analysis of the performance of solar power evaporative cooling system which will include the key elements of project.

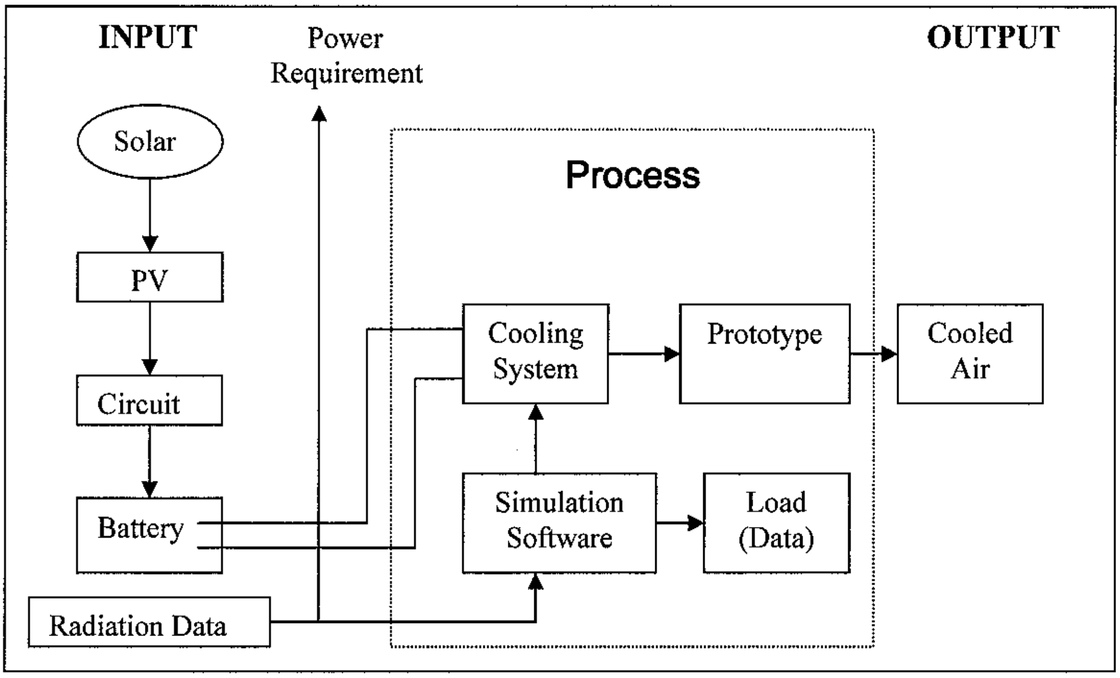


Figure 3.1 : The Flowchart of The Energy Savings Solar-Powered Cooling System

First semester : Literature Review -> Research -> Data Gathering -> Calculations

Second semester : Design -> Prototype -> Testing -> Installation -> Analysis

Figure 3.2 : Flowchart of the Main Tasks

3.2 Design Justification

From the conceptual design of the evaporative cooler in Figure 3.5, the operation of the system which is named as Suria Cooler II is stated below. Starting from the energy conversion of the solar panel to the air-cooling process, each part has its own task. The system will be explained according to the parts involved.

3.2.1 Solar Panel

This evaporative cooler is using the solar photovoltaic (PV) panel to collect the solar energy and convert it to electrical energy. The solar electricity generated is charges the battery when cooling system is inactive and the battery work as a back up when solar energy is not sufficient especially during night. The photovoltaic systems are chosen in harnessing the solar power because of the sunlight received in Malaysia throughout the year, which is 800W/m^2 (NSTP, 2005).

The features of the solar panel used:

i. Rated power = 180 watts
ii. Rated voltage = 35 V
iii. Rated current = 5.71 A
iv. Open-circuit voltage = 43 V
v. Short-circuit current = 6.2 A
vi. Dimensions (Length x Width x Thick) = 1.2 m x 0.525 m x 0.055 m
vii. Weight = 15kg

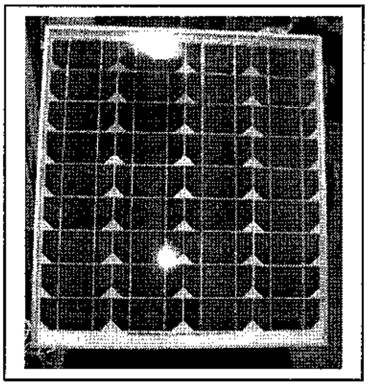


Figure 3.3 : Solar Panel

3.2.2 Battery Storage

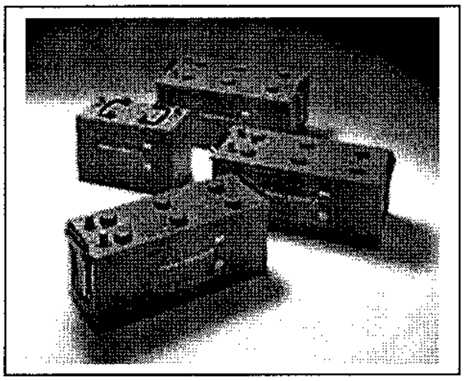


Figure 3.4 : Battery Storage

Battery storage is used as a back up when solar panel doesn't provide sufficient energy to the evaporative cooler. Batteries store the electrical energy generated by the solar panel during sunny periods and deliver it whenever the solar panel cannot supply power. Normally, batteries discharged during the night or cloudy weather. But if the load exceeds the array output during the day, the batteries can supplement the energy supplied by the solar panel. No single component in a photovoltaic system is more affected by the size and usage of the load than storage batteries. If a charge controller is not included in the system, oversized loads or excessive.

Batteries are available in many sorts and sizes. 12V batteries are used most. Provided that the batteries are new and of the same type and size, they can be connected to increase the capacity of the battery storage. Some solar electricity systems come with special solar batteries. Other systems use ordinary car batteries. Solar batteries are to be preferred as they are adapted for use in a solar electric system and will last considerably longer. The amount of electricity needed and the size of the battery storage determine the duration of the dark period that can be bridged.

3.2.3 Power Source

The temperature in the afternoon is high in Malaysia. Therefore, the solar source is not wasted because this cooling system using solar panels to convert the solar energy to electrical source that will generate a water pump and a fan that works together. Solar panels are used to transfer the energy into electricity, which supplies less power for the pump and the fan since it is based on a DC source. Less power means less electricity used, and thus less cost is consumed. The solar energy will always be available on a hot day and thus electricity can be provided to ensure the cooler works. Frank (2005) says global warming trends in the last 23 years are characterized by longer, more intense heat wave periods, as witnessed in extreme by the summer 2003. Overheating risks are illustrated in the following for climate scenario C with 8 heat days (maximum outdoor air temperature $\theta_{e,max} > 30$ °C) and climate scenario D with 29 heat days.

3.2.4 Water Pump

When the energy is transferred into direct current (DC), the pump will be generated. Pita (2002), says that a pump provides the pressure necessary to overcome the resistance to flow of a liquid in a piping system. Water will be pumped from a water tank and flows through a rubber pipe to the water spray. The pump then increases the pressure of the water by increasing its velocity first, and then converting the velocity energy to pressure energy.

According to Pita (2002), the items of major importance in the performance of a pump are the pressure (head) it will develop, the flow rate it will deliver, the horsepower required to drive the pump, and its efficiency. These are called the pump characteristics. The water tank provides water supply for the flowing process of the cooling system. The water supply is cold since it is taken from the lower part of the tank. In order to maintain its low temperature, the rubber pipe is used to provide insulation to the flow of water.

Based on Pita (2002), thermal insulation should be used on all cold or hot hydronic system piping. On both hot and chilled water systems, thermal insulation serves two purposes:

1. To reduce energy waste and possible increased size of heating or refrigerating equipment.
2. To reduce incorrect distribution of heat. Uninsulated piping may result in the water being at an unsatisfactory temperature when it reaches the conditioned spaces.

Rubber is a good insulator and can insulate the water flow from losing its initial temperature. Pita (2002) says a good insulation should have the following characteristics:

- Low thermal conductivity
- Noncombustible
- Not subject to deterioration or rot
- Adequate strength

Rubber is the closest material that fulfills the characteristics and therefore the pipe is insulated using rubber. The cold water can be used in the next stage where it is going to flow into another part of the system.

3.3 Conceptual Design of Evaporative Cooler

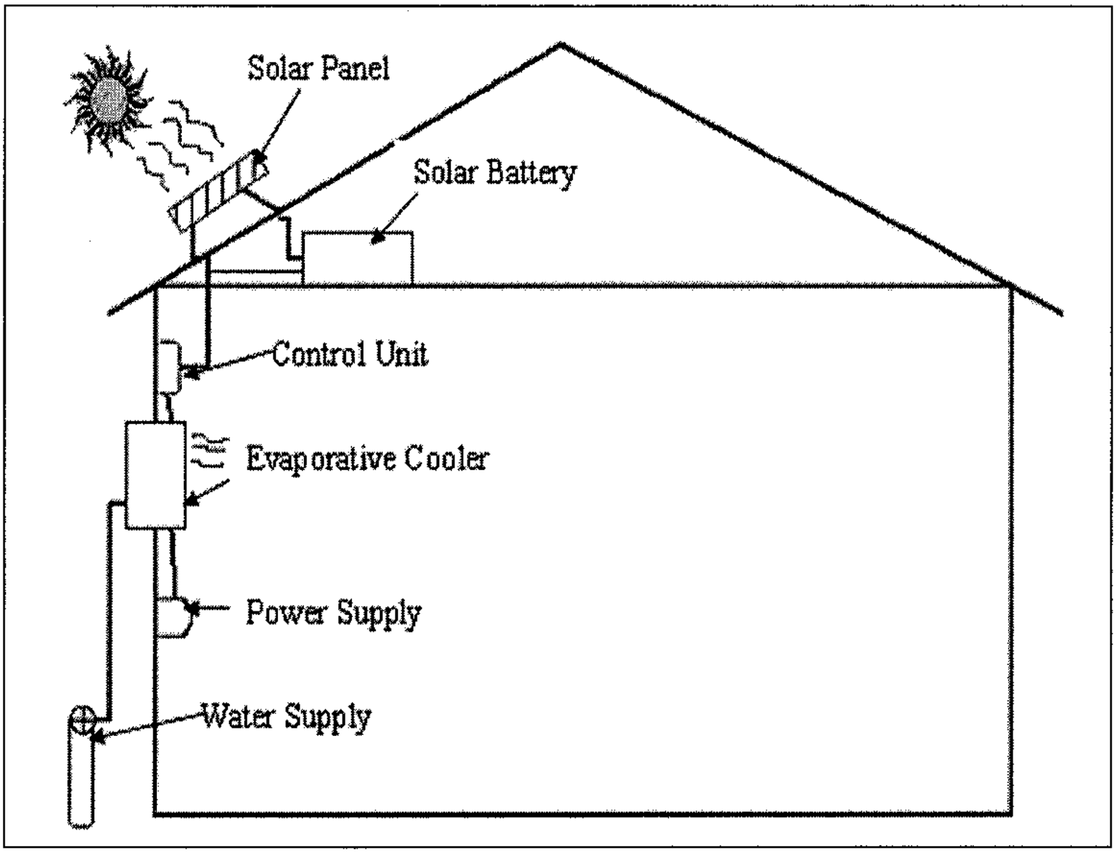


Figure 3.5 : Plan of the evaporative cooling system placing to the house

3.3.1 Evaporative Cooling Process

A typical indirect evaporative cooler shows in Figure 3.6. The main components of this cooler are a plastic plates heat exchanger, a water spray and recirculating system, an outdoor air intake with filters, a supply fan and exhaust fan connected by the same vertical shaft and a perspex casing to prevent corrosion.

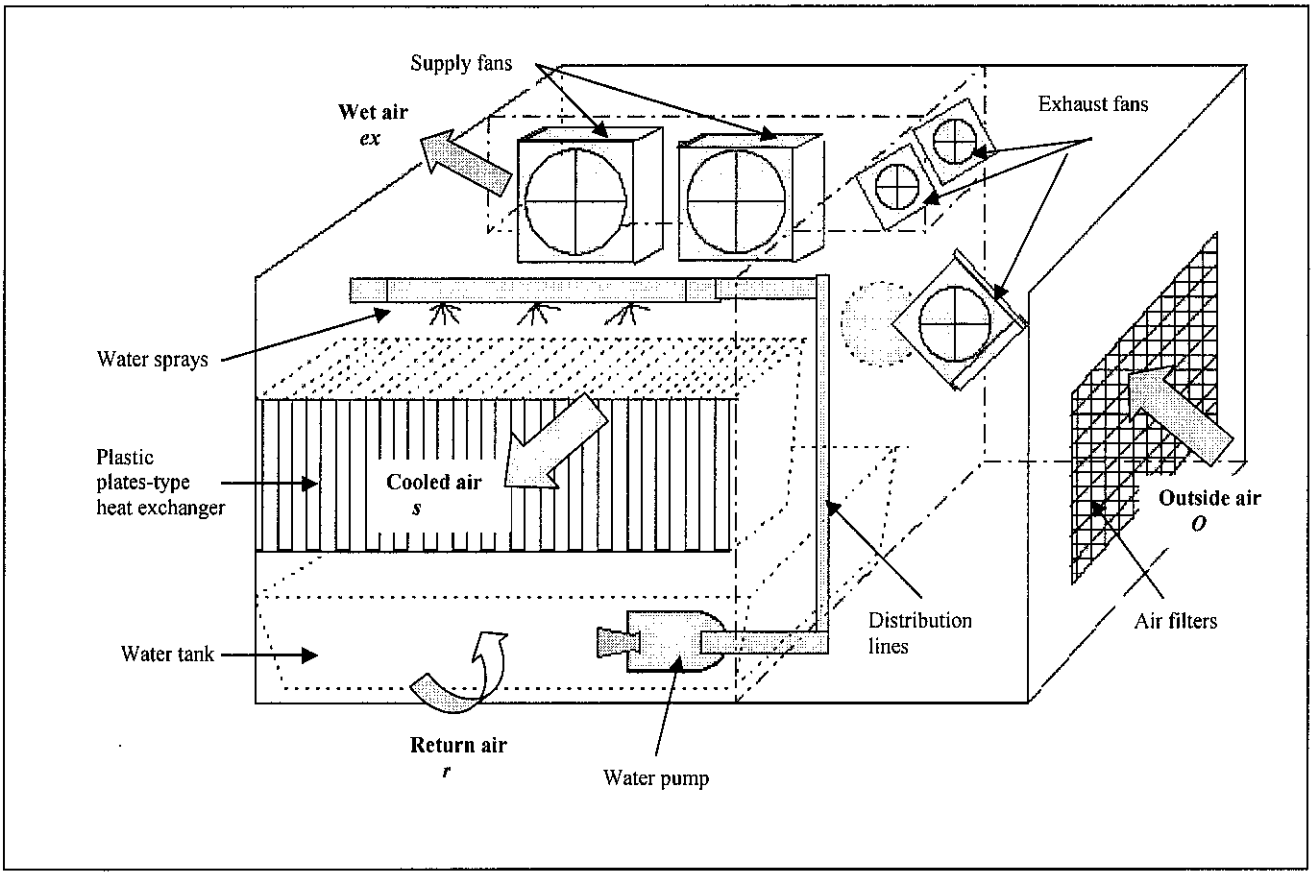


Figure 3.6 : A typical indirect evaporative cooler schematic diagram

The core part of this indirect evaporative cooler is the plastic plates heat exchanger as shows in Figure 3.8. The plastic plates are made from dimpled, thin polyvinyl chloride plastic. These plates are spaced from 0.08 to 0.12 in. (2 to 3 mm) apart and form alternate horizontal and vertical passages (i.e., the air to be cooled flows horizontally, and the air that is sprayed flows vertically). Because the plates are only about 0.01 in. (0.25 mm) thick, the thermal resistance of each plastic plate is very small, although the thermal conductivity of the plastic is low.

Hot, dry outdoor air at point *O* enters the intake and filters and is extracted by the supply fan. It then enters the back of the exchanger and is forced through the horizontal passages, in which it releases its heat through the plastic plates to the adjacent wetted surfaces of the vertical passages. The cooled air at point *s* flows out the front to the conditioned space, as shown in Figure 3.6.

Water sprays over the vertical passages at the top of the plate heat exchanger, and forms both wetted surfaces and water droplets. Evaporation from these wetted surfaces and droplets absorbs heat released from the air flowing horizontally through the plastic plates. Excess water drops to a sump, which recirculates it to spraying nozzles by means of a pump. Makeup water is supplied from the city water supply to account for the evaporation and carryover. Water is periodically bled off to prevent the buildup of solid matter.

Return air from the conditioned space at point *r* is drawn through the vertical passages between the plastic plates. It absorbs the evaporated water vapor, and its humidity ratio increases. The higher the velocity of the wet air, the greater the wet surface heat-transfer coefficient h_{wet}, the larger the enthalpy difference $\Delta h_{s,w}$ between the saturated air film at the wetted surface and the wet airstream, and the higher the pressure drop of the wet airstream. Wet air is then forced through the exhaust fan and discharged to the outdoor atmospheric at point *ex*.

Other types of indirect evaporative coolers may use absorbent-lined vertical passages to drip water from the top through distributing troughs instead of using water sprays. Propeller fans may be used instead of centrifugal fans for wet air exhaust. Dampers may be used to extract outdoor air from outdoors or return air from the conditioned space as the wet air depends on which of them has a lower entering wet-bulb temperature. Figure 3.7 shows the layout drawing of the indirect evaporative cooler.

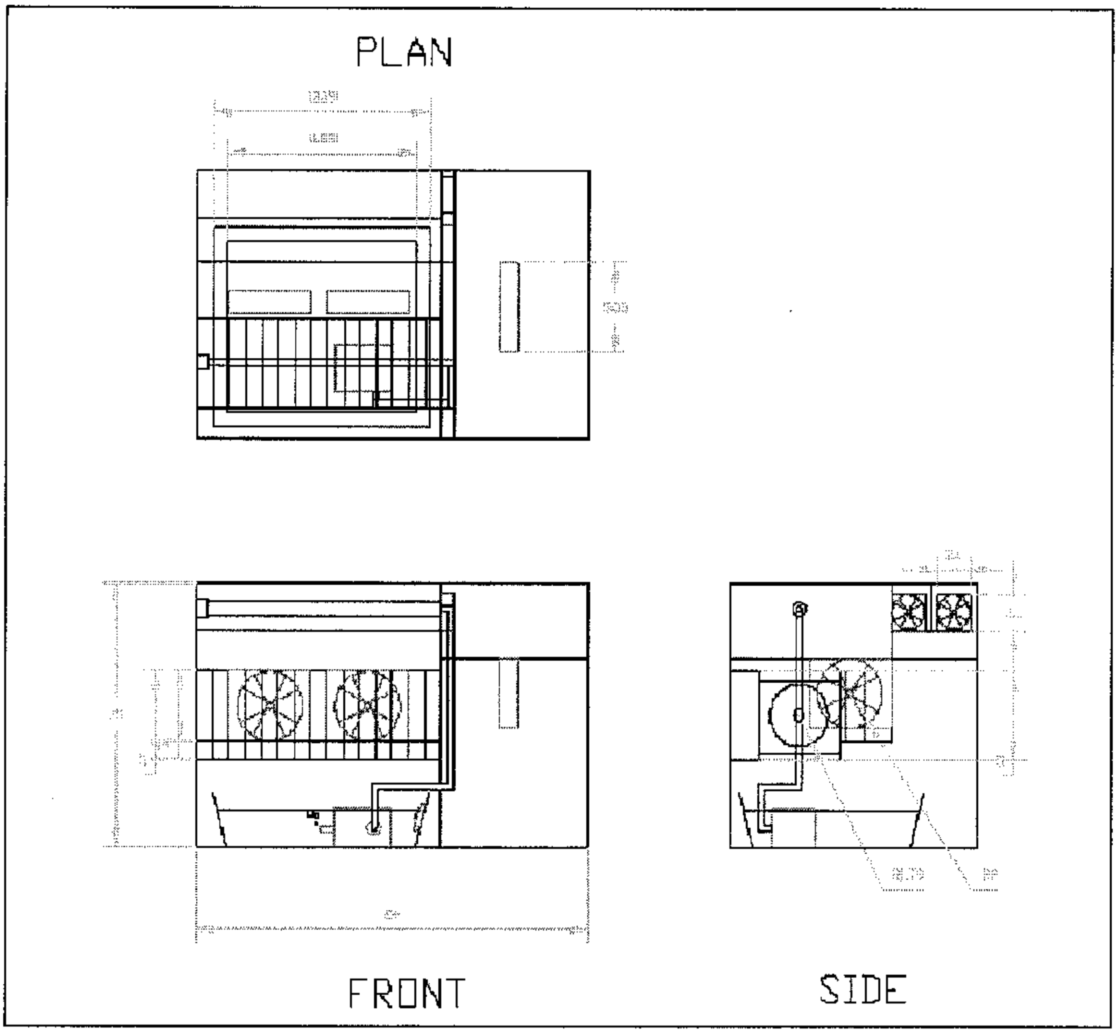


Figure 3.7 : The layout drawing of the indirect evaporative cooler

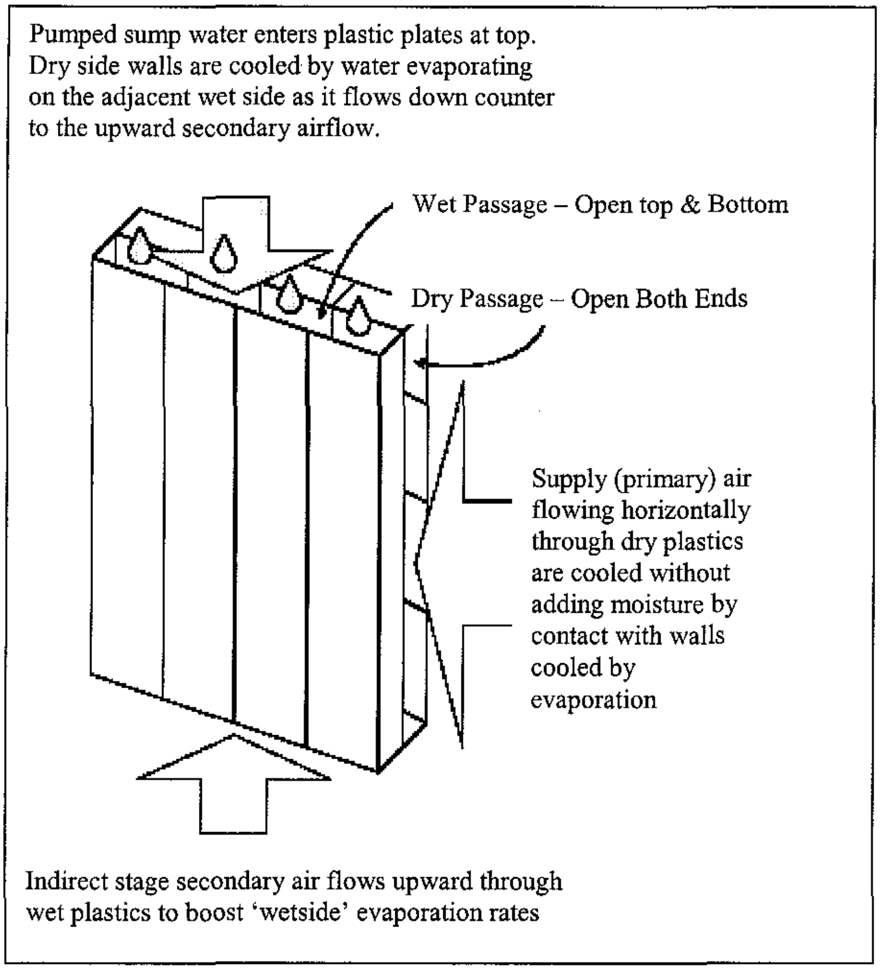


Figure 3.8 : An indirect evaporative plastic plates heat-exchanger

3.3.2 Evaporative Cooler Prototype

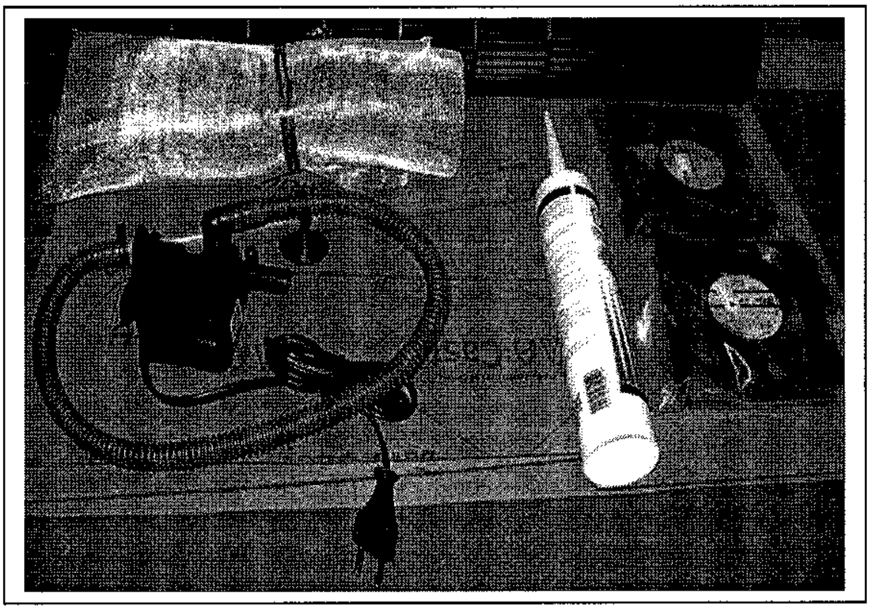


Figure 3.9 : Materials

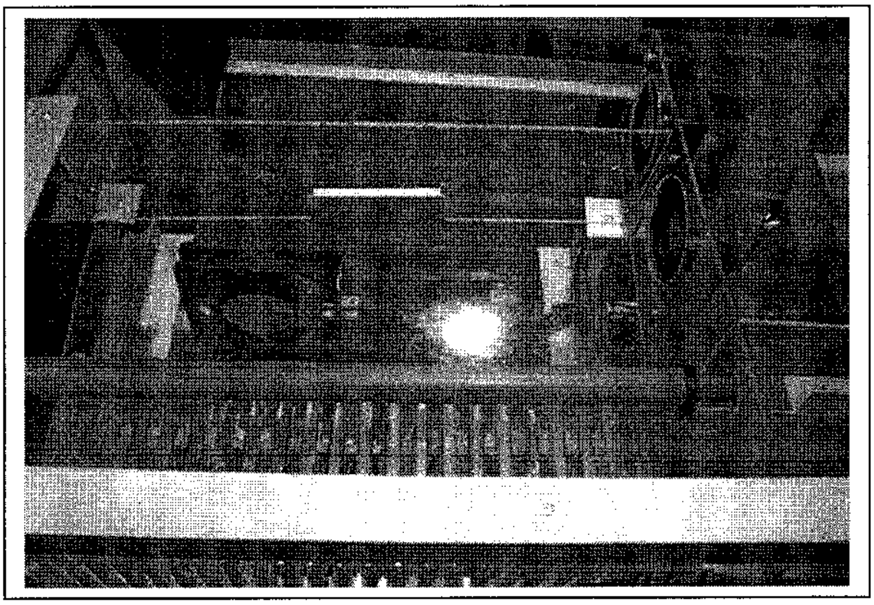


Figure 3.10: Top view of evaporative cooler prototype

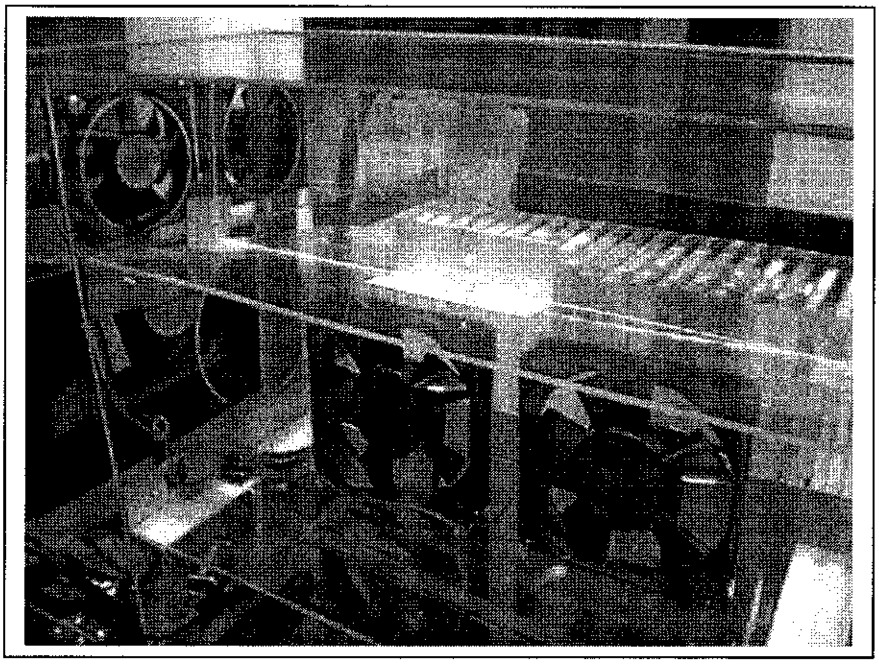


Figure 3.11 : Back view of evaporative cooler prototype

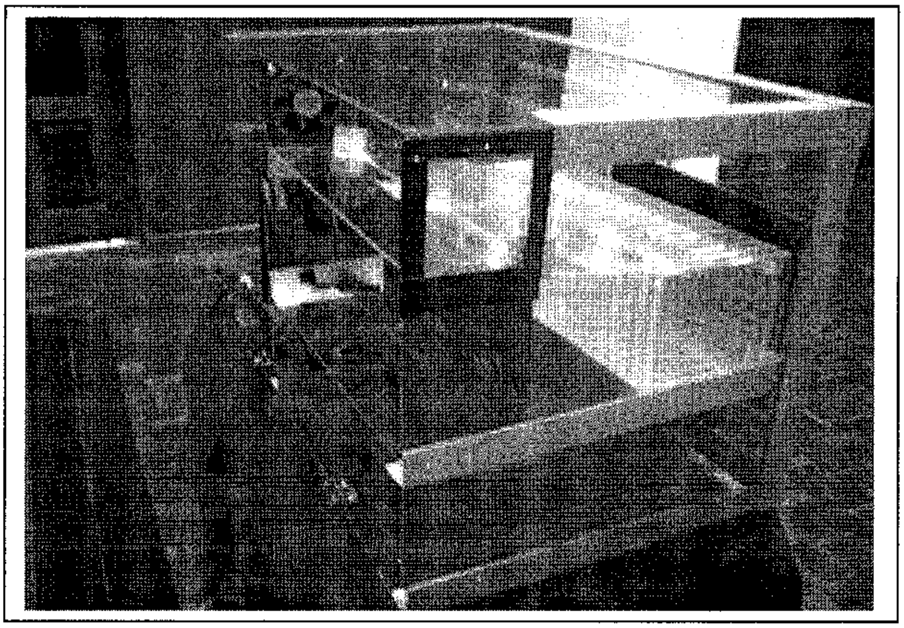


Figure 3.12 : Side view of evaporative cooler prototype

Figure 3.13 : Side view of evaporative cooler prototype

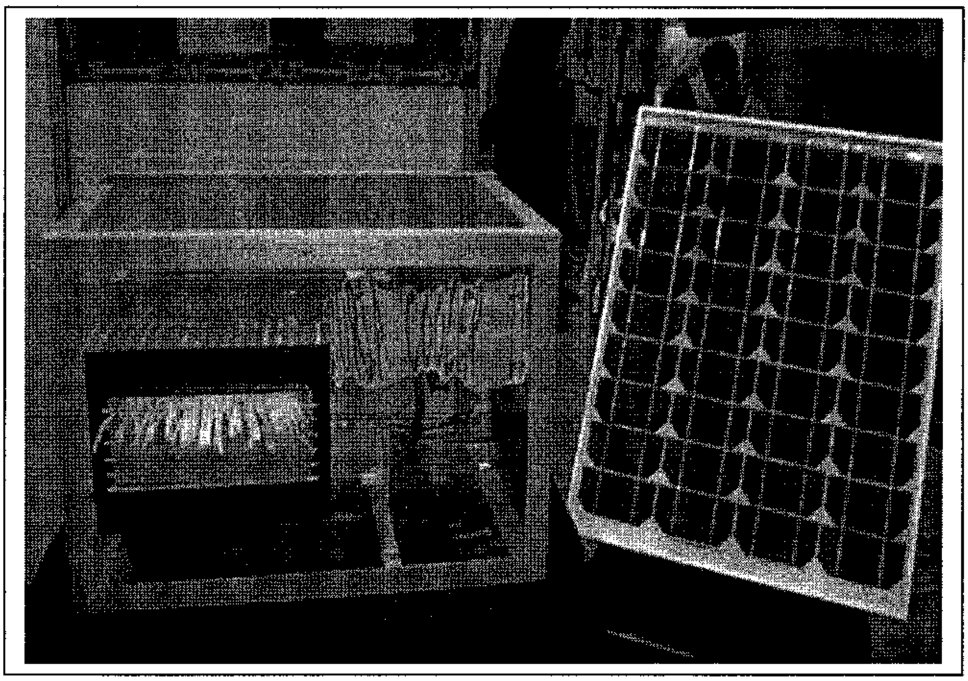


Figure 3.14 : Front view of evaporative cooler prototype with solar panel

CHAPTER 4

RESULTS AND DISCUSSION

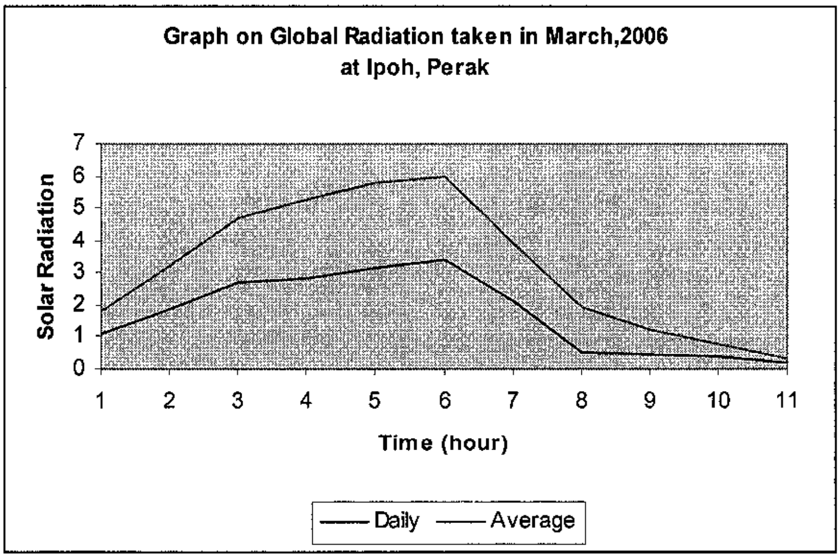
4.1 Solar Insolation and Radiation Data

With such wide percolation of solar PV applications, the insolation data collection becomes very crucial and critical to PV system design. The procurement of solar insolation data is either by conducting direct measurements of the solar radiation pattern at the location through-out the year and over several years or purchasing the data from meteorological department. Both these methods of insolation data procurement are time consuming and expensive and, therefore, will inhibit the design process of the PV system design for a given location. Therefore, there is need for developing a reasonably accurate mathematical model to estimate the solar insolation at any location for any given day of the year. Measured monthly average values of daily insolation provide a good starting point for developing the solar insolation model. The usefulness of long-term monthly averaged daily insolation can be understood from the fact that at a particular location, these averages are relatively constant so that past values can be used to estimate future ones. Under cloudless skies, solar insolation is essentially due to the direct beam radiation. The accurate prediction of direct radiation is important in most PV applications. This prediction can be performed in various ways depending on the time scale and availability of necessary data. The Table 4.1 shows the average solar radiation data at a various time. Graph 4.1 shows the solar radiation versus time.

Table 4.1 : The daily and average solar radiation data at a various time taken on March,2006 at Ipoh station.

Time (hour)	Daily (MJm^{-2})	Average (MJm^{-2})
8	1.08	0.72
9	1.88	1.33
10	2.67	2.03
11	2.82	2.42
12	3.15	2.62
13	3.43	2.53
14	2.09	1.83
15	0.53	1.38
16	0.46	0.76
17	0.36	0.43
18	0.2	0.13

Graph 4.1 : The graph on solar radiation versus time



4.2 Equipment Sizing

The size of a cooling system must be selected carefully in order to ensure occupants comfort and optimum efficiency. The temperature in structure must be maintained by removing heat as fast as it leaks in on the highest demand day, which is the hottest day. The greater the temperature differences between the inside and the outside of the structure, the faster the heat transfer. If a cooling system is undersized, it will fall behind and the temperature will begin to rise. If the system is grossly undersized, the temperature will become hot enough to cause occupant discomfort. Conversely, if a cooling system is oversized, it will be more expensive to purchase and operate and may not provide close control at part-load conditions.

For most residential applications, the inside design temperature is typically 75°F with 50% relative humidity. This temperature may vary somewhat from person to person, depending on age, weight, activity level and metabolism. Whenever possible, it is best to consult the occupants before selecting the inside design temperature.

4.3 Calculation for Solar Panel

The solar panel used has an output power rating of 180 watts, this solar panel (per cell) has a dimension of 1.2 m x 0.525 m x 0.055 m. It used 1 modules of solar panel. The area to be covered at the top of the roof according to the specification (dimensions);

Area = 1.2 m x 0.525 m

= $\underline{1.26\ m^2}$

The total area of the house rooftop is 200 m^2. Thus, the area that is going to be covered with the photovoltaic (PV) is 0.63 % of the rooftop area. The total rating for the solar panel is 180 watts. The data obtained from the meteorological station (Ipoh, Perak) stated that the amount daily average of radiation received is around of 506.25 W/m^2. The power generated by an area of 1.26 m^2 of PV is approximately 360 watts. It is clearly mentioned that the module is running at the maximum achievable rating.

As for the output it yields an approximation of 63 % from the total rating (180 watts), which in turn achieves about 11 watts.

4.4 Calculation on Load Analysis

Power *(P)* = Voltage *(V)* x Current *(I)*

Table 4.2 : Calculation for Load Analysis

Description	**Voltage *(V)***	**Current *(I)***	**Power *(P = VI)***
Water Pump	12V	0.42A	12V x 0.42A = 5 W
Fan	12V	0.36A	12V x 0.36A = 4.32 W

4.5 The Result of Experiment

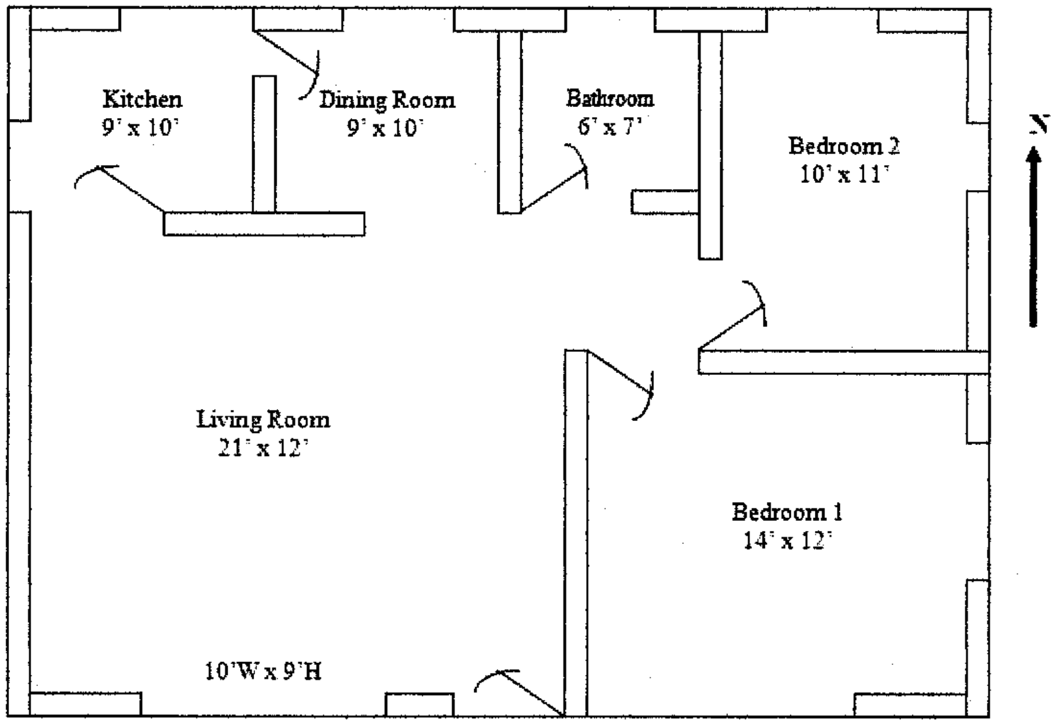
The research done on 28 August 2005 at Kampung Selboh, Parit was to analyze the reading in a rest room during hot time in the rural area residence. The experiment is taken around 1100 until 1300 using the PASCO device, data studio, temperature sensor and laptop set. The temperature sensor is placed at the different location in the room and the temperature reading is recorded every 10 minutes for 10 seconds. The temperature reading for temperature sensor 1 and 2 was recorded in Table 4.4. This experiment done to make sure that the solar powered air conditioning system is sufficient for rural communities.

From the experiment result obtained, the room's temperature is getting higher from 30 °C to 33 °C. This is because the data that collected was at the peak of the hot time, which was on an afternoon. Both temperature sensors 1 and 2 placed separately in the room because to make sure that the data recorded is more accurately. The focus is the rest room because the evaporative cooler is suitable set up in the rest room. The size of the room is 4.2m x 6.0m x 3.0m (width x length x height).

Table 4.3 : Temperature Reading for Temperature Sensor 1 and 2

Time (hours)	Temperature sensor (1)°C	Temperature sensor (2)°C
1110	30	30
1120	30	30
1130	30	30
1140	30	30
1150	31	32
1200	31	32
1210	31	32
1220	32	32
1230	32	33
1240	32	33
1250	32	33
1300	32	33

4.6 Residential Cooling Load Calculations



Ceiling height = 8'   Single clear glass, blinds
$U_w = 0.20$ $U_r = 0.10$ $U_d = 0.47$
Windows = 3.5' W x 4' H, except as noted
Doors = 3' x 7'

Figure 4.1 : Architectural house plan

The steps in determining residential cooling loads as follows:

1. Indoor design temperature = 75F (23.9°C)
   Outdoor design temperature = 96F (35.6°C)
2. The dimensions are taken from the building plans and the gross and net areas of each element are calculated and recorded in Table 4.4. Note that large closets in a room are included as part of the room. The hallway is included as part of the living room because there is no separating room.
3. Heat transfer coefficients for the materials listed are found from Tables A.21 and A.22 (in Appendix 7) and recorded.

4. Select the CLTD values from Table A.12 (in Appendix). Outdoor temperature range is 22F (-5.6 °C), in the M class. The wall heat gains in each room are then calculated using Equation 2.4, and recorded in Table 4.4. Other elements are calculated in the same way.
5. From Table A.16 (in Appendix) for the windows on the south side, the CLF for the type of glass and shading is 28 BTU/hr-ft^2 at 95F outdoors and 75F indoors. The heat gains are calculated and recorded for this and all other windows.
6. For a two-bedroom house, assume occupancy of four: two in the living room, two in the dining area at peak load times. Assume a 1200 BTU/hr kitchen appliance load.
7. Infiltration is found from Table A.18 (in Appendix) and Equation 2.10. (If air quality were poor from too little infiltration, some outside air would have to be mechanically introduced, adding to the load.)
8. The individual gains are added to find the RSCL for each room and building.

Table 4.4 : Summary of residential cooling load calculations

Room Name	**Living Room**					**Dining Room**				
Plan Size	21 x 12 + 21 x 4					9 x 10				
Wall	D.	*U*	*A*	CLTD	Btu/hr	D.	*U*	*A*	CLTD	Btu/hr
	S	0.2	104	16	333	N	0.2	58	13	151
	E	0.2	128	23	589	E	0.2	66	23	304
Roof/ceiling		0.1	336	47	1579		0.1	90	47	423
Floor										
Door	S	0.47	21	16	158					
Windows	D.			CLF		D			CLF	
	S		40	28	1120	N		14	23	322
						E		14	50	700
Infiltration					443					119
People	2 x 225				450	2 X 275				550
Appliances										
RSCL (BTU/hr)					4672					2569
RSCL (Watts)					1370.09					753.37

Room Name	Bedroom 1					Bedroom 2				
Plan Size	14 x 12 + 3 x 4					10 x 11 + 3 x 4				
Wall	D.	*U*	*A*	CLTD	Btu/hr	D.	*U*	*A*	CLTD	Btu/hr
	W	0.2	106	23	488	W	0.2	74	23	340
	S	0.2	82	16	262	N	0.2	74	13	192
Roof/ceiling		0.1	180	47	846		0.1	122	47	573
Floor										
Door										
Windows	D.			CLF		D			CLF	
	W		14	50	700	W		14	50	700
	S		14	28	392	N		14	23	322
Infiltration					238					161
People										
Appliances										
RSCL (BTU/hr)					2926					2288
RSCL (Watts)					858.06					670.97

Room Name	Kitchen					Bathroom				
	9 x 10					6 x 7				
Wall	D.	*U*	*A*	CLTD	Btu/hr	D.	*U*	*A*	CLTD	Btu/hr
	N	0.2	37	13	96	N	0.2	74	23	88
Roof/ceiling		0.1	90	47	423		0.1	42	47	197
Floor										
Door	N.	0.47	21	13	128					
Windows	D.			CLF		D.			CLF	
	N		14	23	322	N		14	23	322
Infiltration					119					55
People										
Appliances					1200					
RSCL (BTU/hr)					2288					662
RSCL (Watts)					670.97					194.13

4.7 Calculations for Heat Loss from a Person

Area, $A_s = 1.6\ m^2$

Surface Temperature, $T_s = 29°C$

$T_\alpha = 20\ °C$

Convection heat transfer coefficient = 6 W/ m^2

$\varepsilon = 0.95$

$\mathbf{Q_{conv} = h\ A_s (T_s - T_\alpha)}$

$= (6\ W/m^2\ .\ °C)(1.6\ m^2)(29\text{-}20)\ °C$

$= \underline{86.4\ W}$

$\mathbf{Q_{rad} = \varepsilon\ \sigma A_s (T_s^{\ 4} - T_{surr}^{\ 4})}$

$= (0.95)(5.67 \times 10^{-8}\ W/m^2.k^4)(1.6\ m^2) \times [(29+273)^4 - (20+273)^4]k^4$

$= \underline{81.7\ W}$

$\mathbf{Q_{total} = Q_{conv} + Q_{rad}}$

$= (86.4 + 81.7)\ W$

$= \underline{168.1\ W}$

Table 4.5 : Cooling Load Estimation for Occupancy

Number of people	**Sensible Cooling Load (watts)**	**Latent Cooling Load (watts)**	**Total Cooling Load (watts)**
0	1560	0	1560
1	1650	50	1700
2	1740	100	1840
3	1830	150	1980
4	1920	200	2120
5	2010	250	2260

CHAPTER 5
CONCLUSION AND RECOMMENDATION

All of the work is successfully done within the timeframe. The theory and concept of the cooling system of an evaporative cooler has been studied and implemented. The evaporative cooling system has been designed and the prototype is also constructed. The study on battery storage is also important so that it will provide a sufficient supply if the solar panel supply is not affordable.

This project is suitable for the rural area communities because it is practical and effective. This evaporative cooler consumes less electricity; therefore it can save the villagers' expenditure for electricity since it requires the low voltage. The system of this project utilizes the renewable energy source in order to produce energy without using natural resources. Malaysia has a high rate of sun radiation which results in the effectiveness and optimum usage of solar panels as energy generator.

From the calculation and research done, it is practical to apply 'Solar Powered Evaporative Cooling System' for rural folks. This is because it is a cost saving device for a long term usage. In addition, renewable energy source is the best available and economical alternative to replace depleting energy sources which is considered expensive. For instance, the price of the crude oil is increasing and it is very hard for us to predict when the price of crude oil will reduce. Hence, the objectives are fulfilled and the project successfully completed within the timeframe.

As for recommendations, it is recommended that this cooling system is applied to the real life application. This is because the system is applicable and beneficial. In order to make the system more efficient, a high quality of solar panel can be used to generate more electricity and energize other devices. Further research and study will contribute to the successfulness of this project.

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APPENDICES

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	■													
	-Propose Topic														
	-Topic assigned to students														
2	Preliminary Research/Design Work		■	■											
	-Introduction and objectives														
	-Project Planning														
	-List of references/literature														
	-Research on PV and solar radiation														
3	Submission of Preliminary Report (Initial Proposal)			●											
4	Project Work				■	■	■	■							
	-List of Reference/Literature														
	-Practical/Laboratory Work														
5	Submission of Progress Report								●						
6	Project work continue								■	■	■	■			
	-Practical/Laboratory Work														
7	Submission of Draft Report												●		
8	Submission of Interim Report													●	
9	Oral Presentation														●

● Suggested milestone

■ Process

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Work Continue		■	■											
	-Practical/Laboratory Work														
2	Submission of Progress Report 1			●											
3	Project Work Continue				■	■	■	■							
	-Radiation data collected - Research and experiment														
4	Submission of Progress Report 2								●						
5	Project work continue								■	■	■	■			
	-Implementation of the design -Build prototype -Testing and refinement -Pre-EDX exhibition -EDX exhibition														
6	Submission of Dissertation Final Draft												●		
7	-Oral Presentation -Submission of Technical Report													●	
8	Submission of Project Dissertation														●

● Suggested milestone

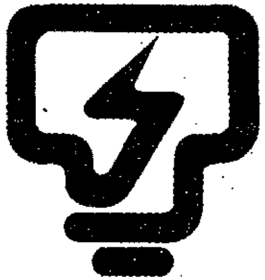
■ Process

Appendix 3

TNB may get Govt nod to up power prices by 10pc

mm 16/8/2005 - 36

PRECISE



TENAGA Nasional Bhd (TNB) may get Government approval by December to raise electricity prices by as much as 10 per cent, a Credit Suisse First Boston (CSFB) analyst said.

The company may receive a 2.35 sen per kilowatt-hour increase in gross rates because of a higher cost of natural gas, Tan Ting Min, a CSFB analyst, wrote in the daily note yesterday.

TNB has been seeking Government approval to increase power prices that were last raised in May 1997. The company said last month that power failures may occur if it doesn't get a rate increase within four years because the company would lack funds to upgrade and maintain its power lines.

The analyst left her "neutral" recommendation on TNB's shares unchanged. TNB buys natural gas from Petroliam Nasional Bhd (Petronas) at a subsidised rate.

TNB has to raise its power prices by 0.8 sen per kilowatt-hour, or 3.4 per cent, to cover every RM1, or 16 per cent, increase in per million British thermal units of gas, CSFB said. – Bloomberg

Appendix 4

Renewed interest in renewable energy

NST 23/8/2005 - 7 PRECISE

Power supply to industry buildings and thousands of homes

PORT DICKSON: Tenaga Nasional Berhad (TNB) reinforced the organisation's commitment to the Government's Five Fuel Strategy with the launch of the gas-fuelled PD1 power plant.

Introduced in the 1990's, the policy was aimed at the diversification of the nation's electricity generation mix through the development of indigenous energy resources.

TNB's current energy generation mix is approximately 35% coal, 34.7% natural gas and 18.2% hydro with the remaining 12.1% from oil, gas and diesel for a combined installed capacity of 10,481MW.

TNB has also driven the development of Renewable Energy (RE) resources into commercially viable ventures through Renewable Energy Power Purchase Agreements (REPPA).

Under the agreements, power generated from RE fuels is linked to the National Grid.

Five such agreements have been signed in Peninsular Malaysia to date, with a total generation capacity of 26.2MW fuelled by oil palm waste, landfill gas and municipal waste.

TNB is also negotiating REPPA with developers of small Government-backed renewable energy programmes utilising mini hydro, landfill gas and other biomass resources such as wood waste and rice husk.

Growing up in a green environment

Appendix 5

TNB in talks with firm to save fuel costs

S 5/5/05 - 3

PRECISE

TENAGA NASIONAL BERHAD

TENAGA Nasional Bhd (TNB) is said to be currently exploring the use of a technology that would enable coal-fired power plants to use high sulphur coal and save the power industry billions of ringgit in fuel cost.

The process, which involves applying a chemical to crushed coal, is said to lower emissions of pollutants created by the burning of coal and increases the efficiency of the burn. "This GTS technology works on all types of coal and hence offers a large profit margin for the end user. It is fundamentally a pre-combustion technique that offers flexibility in operations, and users do not have to retrofit existing plant facilities to use it," said Alpha Beyond Sdn Bhd director Adrian Ooi.

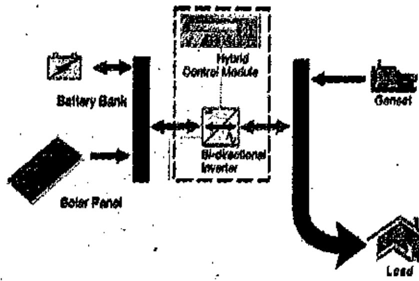
Alpha Beyond has been granted an exclusive licence to operate, develop and commercialise the technology. It calculates that based on coal consumption of 20 million tonnes per annum, power companies in Malaysia would be able to save RM1.9bil per annum in coal costs assuming the price of coal remains at current prices.

"The GTS technology will provide power generation companies such as TNB and other independent power producers an amazing economic advantage," Ooi said in a statement. "Together with YTS Engineerings Sdn Bhd, we are in final discussions with TNB for the long-term utilisation of coal treated with GTS technology in Malaysia. TNB has established a special task force to explore the beneficial technology for the major coal-fired power plants in Malaysia," he added. Alpha Beyond has formed a marketing alliance with YTS Engineerings to market the technology to all coal-fired power generation plants in Malaysia.

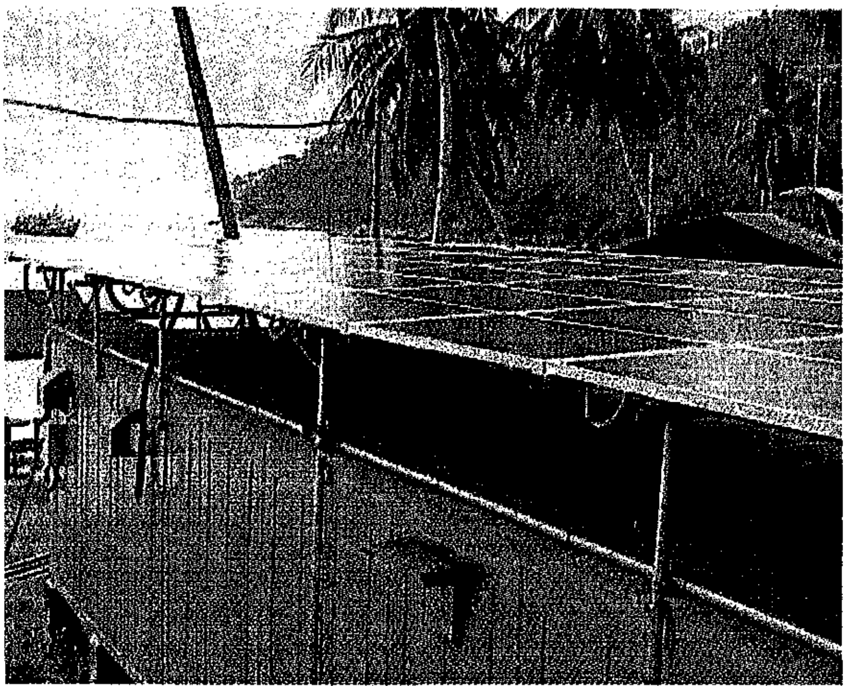
The statement said high sulphur coal had not been a viable option thus far as burning of such coal did not meet environmental and quality laws and guidelines and due to significant increase in demand for low sulphur coal for generation activity, the cost of low sulphur coal had doubled over the past two years.

NST 6/1/2005 - 5 PRECISE PRECISE

3 provides Solar Hybrid Power l economic power



Concept of Solar Hybrid System



ak Kaleh in Pulau Pemanggil

JOHOR BAHRU: Life has changed for the better for the inhabitants on remote islands off the coast of Mersing. In cooperation with the Government's Five Fuel Strategy, TNB is electrifying remote islands and villages throughout Malaysia by means of Solar Hybrid Systems (SHS).

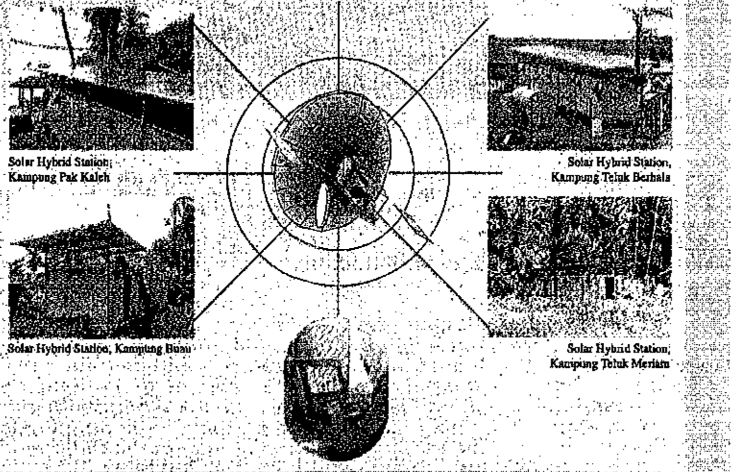
The reliable and constant energy supply means fishermen, from six of these islands, can now keep their daily catch fresh for market in deep freezers. Prior to SHS, fish had to be eaten or sold the same day. This is only one, but clearly beneficial, improvement to the islander's lives and the economies of the islands.

SHS are a combination of solar power panels and generator sets. Battery packs store solar power generated through the day to deliver a 24-hour power supply. Fuelled predominantly by solar power, the generator sets kick-in during overcast days.

Supplied and operated by TNB, SHS can positively impact the lives of thousands of Malaysians living on remote islands and within jungle interiors. Realising the human benefits the systems offer, TNB is looking into ways of further promoting solar and other renewable energy sources into the future.

, standalone solar panels were fitted to many homes in remote
ese offered only 4 to 5 hours of minimal power a day.
S to be installed in Malaysia was in Langkawi, Kedah in 2001. It provides
cilities at a tourist cable car attraction on Gunung Machinchang. SHS
so as the views from the cable car would not be spoilt by power lines.
nitored remotely and no permanent TNB staff are required on site.
ions were recently installed to islands near Pulau Tioman at a cost
llion, two villages on a nearby island will soon be enjoying the
les.
islands around Malaysia enjoy SHS and soon, 16 remote villages in five
lso benefit from the service.

RY:	Pulau Besar	Pulau Pemanggil	Pulau Sibu	Pulau Aur
	20	32	68	42
	0	1	1	1
	1	1	1	2
ty	1	1	1	1
y	8	4	13	10
	30	39	84	56



Remote Monitoring and SCADA features

/ a fisherman electricity and 1 eat for life

ıen they sat irst meal with on Pulau Aur, technicians sional Berhad veritable feast .

o much fish to a-ES (a wholly iary of TNB) Azhar Abdul ber of the team nd technicians the island to install Solar Hybrid Systems (SHS) on the island last year.

"I realised after the meal that without freezers to store their catch, the fishermen had to eat almost everything they caught each day.

Before SHS, electricity was provided by diesel-fuelled generators which cost as much as RM500 a month to supply electricity 12 hours a day to 6 homes.

Since the deployment of the SHS, the same households now enjoy uninterrupted power supply at a fraction of the cost – just RM60 per month.

So what of the "fish feasts" of last year?

"Well, now they have freezers, on our last visit the feast was definitely not as much as it was.

"But, the hospitality remained the same. They made us feel proud to work for TNB," said Mohd. Azhar, smiling.

Islanders' bountiful daily catch

Appendix 7

Table A.1 COOLING LOAD TEMPERATURE DIFFERENCES (CLTD) FOR CALCULATING COOLING LOAD FROM FLAT ROOFS, F

Roof No	Description of Construction	Weight, lb/ft²	U-value, BTU / h•ft²•°F	Solar Time 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Hour of Maximum CLTD	Minimum CLTD	Maximum CLTD	Difference CLTD
														Without Suspended Ceiling																	
1	Steel sheet with 1-in. (or 2-in.) insulation	7 (8)	0.213 (0.124)	1	−2	−3	−3	−5	−3	6	19	34	49	61	71	78	79	77	70	59	45	30	18	12	8	5	3	14	−5	79	84
2	1-in. wood with 1-in. insulation	8	0.170	6	3	0	−1	−3	−3	−2	4	14	27	39	52	62	70	74	74	70	62	51	38	28	20	14	9	16	−3	74	77
3	4-in. lightweight concrete	18	0.213	9	5	2	0	−2	−3	−3	1	9	20	32	44	55	64	70	73	71	66	57	45	34	25	18	13	16	−3	73	76
4	2-in. heavyweight concrete with 1-in. (or 2-in.) insulation	29 (0.122)	0.206	12	8	5	3	0	−1	−1	3	11	20	30	41	51	59	65	66	66	62	54	45	36	29	22	17	16	−1	67	68
5	1-in. wood with 2-in. insulation	9	0.109	3	0	−3	−4	−5	−7	−6	−3	5	16	27	39	49	57	63	64	62	57	48	37	26	18	11	7	16	−7	64	71
6	6-in. lightweight concrete	24	0.158	22	17	13	9	6	3	1	1	3	7	15	23	33	43	51	58	62	64	62	57	50	42	35	28	18	1	64	63
7	2.5-in. wood with 1-in. ins.	13	0.130	29	24	20	16	13	10	7	6	6	9	13	20	27	34	42	48	53	55	56	54	49	44	39	34	19	6	56	50
8	8-in. lightweight concrete	31	0.126	35	30	26	22	18	14	11	9	7	7	9	13	19	25	33	39	46	50	53	54	53	49	45	40	20	7	54	47
9	4-in. heavyweight concrete with 1-in. (or 2-in.) insulation	52 (52)	0.200 (0.120)	25	22	18	15	12	9	8	8	10	14	20	26	33	40	46	50	53	53	52	48	43	38	34	30	18	8	53	45
10	2.5-in. wood with 2-in. ins.	13	0.093	30	26	23	19	16	13	10	9	8	9	13	17	23	29	36	41	46	49	51	50	47	43	39	35	19	8	51	43
11	Roof terrace system	75	0.106	34	31	28	25	22	19	16	14	13	13	15	18	22	26	31	36	40	44	45	46	45	43	40	37	20	13	46	33
12	6-in. heavyweight concrete with 1-in. (or 2-in.) insulation	75 (75)	0.192 (0.117)	31	28	25	22	20	17	15	14	14	16	18	22	26	31	36	40	43	45	45	44	42	40	37	34	19	14	45	31
13	4-in. wood with 1-in. (or 2-in) insulation	17 (18)	0.106 (0.078)	38	36	33	30	28	25	22	20	18	17	16	17	18	21	24	28	32	36	39	41	43	43	42	40	22	16	43	27

COOLING LOAD TEMPERATURE DIFFERENCES (CLTD) FOR CALCULATING COOLING LOAD FROM FLAT ROOFS, F (Continued)

Roof No	Description of Construction	Weight, lb/ft²	*U*-value, BTU/h•ft²•°F	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Hour of Maximum CLTD	Minimum CLTD	Maximum CLTD	Difference CLTD
	With Suspended Ceiling																														
1	Steel Sheet with 1-in. (or 2-in.) insulation	9 (10)	0.134 (0.092)	2	0	−2	−3	−4	−4	−1	9	23	37	50	62	71	77	78	74	67	56	42	28	18	12	8	5	15	−4	78	82
2	1-in. wood with 1-in. ins.	10	0.115	20	15	11	8	5	3	2	3	7	13	21	30	40	48	55	60	62	61	58	51	44	37	30	25	17	2	62	60
3	4-in. lightweight concrete	20	0.134	19	14	10	7	4	2	0	0	4	10	19	29	39	48	56	62	65	64	61	54	46	38	30	24	17	0	65	65
4	2-in. heavyweight concrete with 1-in. insulation	30	0.131	28	25	23	20	17	15	13	13	14	16	20	25	30	35	39	43	46	47	46	44	41	38	35	32	18	13	47	34
5	1-in. wood with 2-in. ins	10	0.083	25	20	16	13	10	7	5	5	7	12	18	25	33	41	48	53	57	57	56	52	46	40	34	29	18	5	57	52
6	6-in. lightweight concrete	26	0.109	32	28	23	19	16	13	10	8	7	8	11	16	22	29	36	42	48	52	54	54	54	47	42	37	20	7	54	47
7	2.5-in. wood with 1-in. insulation	15	0.096	34	31	29	26	23	21	18	16	15	15	16	18	21	25	30	34	38	41	43	44	44	42	40	37	21	15	44	29
8	8-in. lightweight concrete	33	0.093	39	36	3	3	29	26	23	20	18	15	14	14	15	17	20	25	29	34	38	42	45	46	44	42	21	14	46	32
9	4-in. heavyweight concrete with 1-in. (or 2-in.) ins.	53 (54)	0.128 (0.090)	30	29	27	26	24	22	21	20	20	21	22	24	27	29	32	34	36	38	38	38	37	36	34	33	19	20	38	18
10	2.5-in. wood with. 2-in. ins	15	0.072	35	33	30	28	26	24	22	20	18	18	18	20	22	25	28	32	35	38	40	41	41	40	39	37	21	18	41	23
11	Roof terrace system	77	0.082	30	29	28	27	26	25	24	23	22	22	22	23	23	25	26	28	29	31	32	33	33	33	33	32	22	22	33	11
12	6-in. heavyweight concrete with 1-in. (or 2-in.) insulation	77 (77)	0.125 (0.088)	29	28	27	26	25	24	23	22	21	21	22	23	25	26	28	30	32	33	34	34	34	33	32	31	20	21	34	13
13	4-in. wood with 1-in. (or 2-in.) insulation	19 (20)	0.082 (0.064)	35	34	33	32	31	29	27	26	24	23	22	21	22	22	24	25	27	30	32	34	35	36	37	36	23	21	37	16

Table A.2 COOLING LOAD TEMPERATURE DIFFERENCES (CLTD) FOR CALCULATING COOLING LOAD FROM SUNLIT WALLS, F

North Latitude Wall Facing	Solar Time, h 0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	Hr of Maximum CLTD	Minimum CLTD	Maximum CLTD	Difference CLTD
Group A Walls																												
N	14	14	14	13	13	13	12	12	11	11	10	10	10	10	10	10	11	11	12	12	13	13	14	14	2	10	14	4
NE	19	19	19	18	17	17	16	15	15	15	15	15	16	16	17	18	18	18	19	19	20	20	20	20	22	15	20	5
E	24	24	23	23	22	21	20	19	19	18	19	19	20	21	22	23	24	24	25	25	25	25	25	25	22	18	25	7
SE	24	23	23	22	21	20	20	19	18	18	18	18	18	19	20	21	22	23	23	24	24	24	24	24	22	18	24	6
S	20	20	19	19	18	18	17	16	16	15	14	14	14	14	14	15	16	17	18	19	19	20	20	20	23	14	20	6
SW	25	25	25	24	24	23	22	21	20	19	19	18	17	17	17	17	18	19	20	22	23	24	25	25	24	17	25	8
W	27	27	26	26	25	24	24	23	22	21	20	19	19	18	18	18	18	19	20	22	23	25	26	26	1	18	27	9
NW	21	21	21	20	20	19	19	18	17	16	16	15	15	14	14	14	15	15	16	17	18	19	20	21	1	14	21	7
Group B Walls																												
N	15	14	14	13	12	11	11	10	9	9	9	8	9	9	9	10	11	12	13	14	14	15	15	15	24	8	15	7
NE	19	18	17	16	15	14	13	12	12	13	14	15	16	17	18	19	19	20	20	21	21	21	20	20	21	12	21	9
E	23	22	21	20	18	17	16	15	15	15	17	19	21	22	24	25	26	26	27	27	26	26	25	24	20	15	27	12
SE	23	22	21	20	18	17	16	15	14	14	15	16	18	20	21	23	24	25	26	26	26	26	25	24	21	14	26	12
S	21	20	19	18	17	15	14	13	12	11	11	11	11	12	14	15	17	19	20	21	22	22	22	21	23	11	22	11
SW	27	26	25	24	22	21	19	18	16	15	14	14	13	13	14	15	17	20	22	25	27	28	28	28	24	13	28	15
W	29	28	27	26	24	23	21	19	18	17	16	15	14	14	14	15	17	19	22	25	27	29	29	30	24	14	30	16
NW	23	22	21	20	19	18	17	15	14	13	12	12	12	11	12	12	13	15	17	19	21	22	23	23	24	11	23	9
Group C Walls																												
N	15	14	13	12	11	10	9	8	8	7	7	8	8	9	10	12	13	14	15	16	17	17	17	16	22	7	17	10
NE	19	17	16	14	13	11	10	10	11	13	15	17	19	20	21	22	22	23	23	23	23	22	21	20	20	10	23	13
E	22	21	19	17	15	14	12	12	14	16	19	22	25	27	29	29	30	30	30	29	28	27	26	24	18	12	30	18
SE	22	21	19	17	15	14	12	12	12	13	16	19	22	24	26	28	29	29	29	29	28	27	26	24	19	12	29	17
S	21	19	18	16	15	13	12	10	9	9	9	10	11	14	17	20	22	24	25	26	25	25	24	22	20	9	26	17
SW	29	27	25	22	20	18	16	15	13	12	11	11	11	13	15	18	22	26	29	32	33	33	32	31	22	11	33	22
W	31	29	27	25	22	20	18	16	14	13	12	12	12	13	14	16	20	24	29	32	35	35	35	33	22	12	35	23
NW	25	23	21	20	18	16	14	13	11	10	10	10	10	11	12	13	15	18	22	25	27	27	27	26	22	10	27	17
Group D Walls																												
N	15	13	12	10	9	7	6	6	6	6	6	7	8	10	12	13	15	17	18	19	19	19	18	16	21	6	19	13
NE	17	15	13	11	10	8	7	8	10	14	17	20	22	23	23	24	24	25	25	24	23	22	20	18	19	7	25	18
E	19	17	15	13	11	9	8	9	12	17	22	27	30	32	33	33	32	32	31	30	28	26	24	22	16	8	33	25
SE	20	17	15	13	11	10	8	8	10	13	17	22	26	29	31	32	32	32	31	30	28	26	24	22	17	8	32	24
S	19	17	15	13	11	9	8	7	6	6	7	9	12	16	20	24	27	29	29	29	27	26	24	22	19	6	29	23
SW	28	25	22	19	16	14	12	10	9	8	8	8	10	12	16	21	27	32	36	38	38	37	34	31	21	8	38	30
W	31	27	24	21	18	15	13	11	10	9	9	9	10	11	14	18	24	30	36	40	41	40	38	34	21	9	41	32
NW	25	22	19	17	14	12	10	9	8	7	7	8	9	10	12	14	18	22	27	31	32	32	30	27	22	7	32	25
Group E Walls																												
N	12	10	8	7	5	4	3	4	5	6	7	9	11	13	15	17	19	20	21	23	20	18	16	14	20	3	22	19
NE	13	11	9	7	6	4	5	9	15	20	24	25	25	26	26	26	26	26	25	24	22	19	17	15	16	4	26	22
E	14	12	10	8	6	5	6	11	18	26	33	36	38	37	36	34	33	32	30	28	25	22	20	17	13	5	38	33
SE	15	12	10	8	7	5	5	8	12	19	25	31	35	37	37	36	34	33	31	28	26	23	20	17	15	5	37	32
S	15	12	10	8	7	5	4	3	4	5	9	13	19	24	29	32	34	33	31	29	26	23	20	17	17	3	34	31
SW	22	18	15	12	10	8	6	5	5	6	7	9	12	18	24	32	38	43	45	44	40	35	30	26	19	5	45	40
W	25	21	17	14	11	9	7	6	6	6	7	9	11	14	20	27	36	43	49	49	45	40	34	29	20	6	49	43
NW	20	17	14	11	9	7	6	5	5	5	6	8	10	13	16	20	26	32	37	38	36	32	28	24	20	5	38	33
Group F Walls																												
N	8	6	5	3	2	1	2	4	6	7	9	11	14	17	19	21	22	23	24	23	20	16	13	11	19	1	23	23
NE	9	7	5	3	2	1	5	14	23	28	30	29	28	27	27	27	27	26	24	22	19	16	13	11	11	1	30	29
E	10	7	6	4	3	2	6	17	28	38	44	45	43	39	36	34	32	30	27	24	21	17	15	12	12	2	45	43
SE	10	7	6	4	3	2	4	10	19	28	36	41	43	42	39	36	34	31	28	25	21	18	15	12	13	2	43	41
S	10	8	6	4	3	2	1	1	3	7	13	20	27	34	38	39	38	35	31	26	22	18	15	12	16	1	39	38
SW	15	11	9	6	5	3	2	2	4	5	8	11	17	26	35	44	50	53	52	45	37	28	23	18	18	2	53	48
W	17	13	10	7	5	4	3	3	4	6	8	11	14	20	28	39	49	57	60	54	43	34	27	21	19	3	60	57
NW	14	10	8	6	4	3	2	2	3	5	8	10	13	15	21	27	35	42	46	43	35	28	22	18	19	2	46	44
Group G Walls																												
N	3	2	1	0	−1	2	7	8	9	12	15	18	21	23	24	24	25	26	22	15	11	9	7	5	18	−1	26	27
NE	3	2	1	0	−1	9	27	36	39	35	30	26	26	27	27	26	25	22	18	14	11	9	7	5	9	−1	39	40
E	4	2	1	0	−1	11	31	47	54	55	50	40	33	31	30	29	27	24	19	15	12	10	8	6	10	−1	55	56
SE	4	2	1	0	−1	5	18	32	42	49	51	48	42	36	32	30	27	24	19	15	12	10	8	6	11	−1	51	52
S	4	2	1	0	−1	0	1	5	12	22	31	39	45	46	43	37	31	25	20	15	12	10	8	5	14	−1	46	47
SW	5	4	3	1	0	0	2	5	8	12	16	26	38	50	59	63	61	52	37	24	17	13	10	8	16	0	63	63
W	6	5	3	2	1	1	2	5	8	11	15	19	27	41	56	67	72	67	48	29	20	15	11	8	17	1	72	71
NW	5	3	2	1	0	0	2	5	8	11	15	18	21	27	37	47	55	55	41	25	17	13	10	7	18	0	55	55

Table A.3 WALL CONSTRUCTION GROUP DESCRIPTION

Group No.	Description of Construction	Weight (lb/ft²)	*U*-Value (BTU/h•ft²•°F)
4-in. Face brick + (brick)			
C	Air space + 4-in. face brick	83	0.358
D	4-in. common brick	90	0.415
C	1-in. insulation or air space + 4-in. common brick	90	0.174–0.301
B	2-in. insulation + 4-in. common brick	88	0.111
B	8-in. common brick	130	0.302
A	Insulation or air space + 8-in. common brick	130	0.154–0.243
4-in. Face brick + (heavyweight concrete)			
C	Air space + 2-in. concrete	94	0.350
B	2-in. insulation + 4-in. concrete	97	0.116
A	Air space or insulation + 8-in. or more concrete	143–190	0.110–0.112
4-in. Face brick + (light or heavyweight concrete block)			
E	4-in. block	62	0.319
D	Air space or insulation + 4-in. block	62	0.153–0.246
D	8-in. block	70	0.274
C	Air space or 1-in. insulation + 6-in. or 8-in. block	73–89	0.221–0.275
B	2-in. insulation + 8-in. block	89	0.096–0.107
4-in. Face brick + (clay tile)			
D	4-in. tile	71	0.381
D	Air space + 4-in. tile	71	0.281
C	Insulation + 4-in. tile	71	0.169
C	8-in. tile	96	0.275
B	Air space or 1-in. insulation + 8-in. tile	96	0.142–0.221
A	2-in. insulation + 8-in. tile	97	0.097
Heavyweight concrete wall + (finish)			
E	4-in. concrete	63	0.585
D	4-in. concrete + 1-in. or 2-in. insulation	63	0.119–0.200
C	2-in. insulation + 4-in. concrete	63	0.119
C	8-in. concrete	109	0.490
B	8-in. concrete + 1-in. or 2-in. insulation	110	0.115–0.187
A	2-in. insulation + 8-in. concrete	110	0.115
B	12-in. concrete	156	0.421
A	12-in. concrete + insulation	156	0.113
Light and heavyweight concrete block + (finish)			
F	4-in. block + air space/insulation	29	0.161–0.263
E	2-in. insulation + 4-in. block	29–37	0.105–0.114
E	8-in. block	47–51	0.294–0.402
D	8-in. block + air space/insulation	41–57	0.149–0.173
Clay tile + (finish)			
F	4-in. tile	39	0.419
F	4-in. tile + air space	39	0.303
E	4-in. tile + 1-in. insulation	39	0.175
D	2-in. insulation + 4-in. tile	40	0.110
D	8-in. tile	63	0.296
C	8-in. tile + air space/1-in. insulation	63	0.151–0.231
B	2-in. insulation + 8-in. tile	63	0.099
Metal curtain wall			
G	With/without air space + 1- to 3-in. insulation	5–6	0.091–0.230
Frame wall			
G	1-in. to 3-in. insulation	16	0.081–0.178

Table A.4 CLTD CORRECTION FOR LATITUDE AND MONTH APPLIED TO WALLS AND ROOFS, NORTH LATITUDES, F

Lat.	Month	N	NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S	HOR
0	Dec	−3	−5	−5	−5	−2	0	3	6	9	−1
	Jan/Nov	−3	−5	−4	−4	−1	0	2	4	7	−1
	Feb/Oct	−3	−2	−2	−2	−1	−1	0	−1	0	0
	Mar/Sept	−3	0	1	−1	−1	−3	−3	−5	−8	0
	Apr/Aug	5	4	3	0	−2	−5	−6	−8	−8	−2
	May/Jul	10	7	5	0	−3	−7	−8	−9	−8	−4
	Jun	12	9	5	0	−3	−7	−9	−10	−8	−5
8	Dec	−4	−6	−6	−6	−3	0	4	8	12	−5
	Jan/Nov	−3	−5	−6	−5	−2	0	3	6	10	−4
	Feb/Oct	−3	−4	−3	−3	−1	−1	1	2	4	−1
	Mar/Sept	−3	−2	−1	−1	−1	−2	−2	−3	−4	0
	Apr/Aug	2	2	2	0	−1	−4	−5	−7	−7	−1
	May/Jul	7	5	4	0	−2	−5	−7	−9	−7	−2
	Jun	9	6	4	0	−2	−6	−8	−9	−7	−2
16	Dec	−4	−6	−8	−8	−4	−1	4	9	13	−9
	Jan/Nov	−4	−6	−7	−7	−4	−1	4	8	12	−7
	Feb/Oct	−3	−5	−5	−4	−2	0	2	5	7	−4
	Mar/Sept	−3	−3	−2	−2	−1	−1	0	0	0	−1
	Apr/Aug	−1	0	−1	−1	−1	−3	−3	−5	−6	0
	May/Jul	4	3	3	0	−1	−4	−5	−7	−7	0
	Jun	6	4	4	1	−1	−4	−6	−8	0	−7
24	Dec	−5	−7	−9	−10	−7	−3	3	9	13	−13
	Jan/Nov	−4	−6	−8	−9	−6	−3	9	3	13	−11
	Feb/Oct	−4	−5	−6	−6	−3	−1	3	7	10	−7
	Mar/Sept	−3	−4	−3	−3	−1	−1	1	2	4	−3
	Apr/Aug	−2	−1	0	−1	−1	−2	−1	−2	−3	0
	May/Jul	1	2	2	0	0	−3	−3	−5	−6	1
	Jun	3	3	3	1	0	−3	−4	−6	−6	1
32	Dec	−5	−7	−10	−11	−8	−5	2	9	12	−17
	Jan/Nov	−5	−7	−9	−11	−8	−15	−4	2	9	12
	Feb/Oct	−4	−6	−7	−8	−4	−2	4	8	11	−10
	Mar/Sept	−3	−4	−4	−4	−2	−1	3	5	7	−5
	Apr/Aug	−2	−2	−1	−2	0	−1	0	1	1	−1
	May/Jul	1	1	1	0	0	−1	−1	−3	−3	1
	Jun	1	2	2	1	0	−2	−2	−4	−4	2
40	Dec	−6	−8	−10	−13	−10	−7	0	7	10	−21
	Jan/Nov	−5	−7	−10	−12	−9	−6	1	8	11	−19
	Feb/Oct	−5	−7	−8	−9	−6	−3	3	8	12	−14
	Mar/Sept	−4	−5	−5	−6	−3	−1	4	7	10	−8
	Apr/Aug	−2	−3	−2	−2	0	0	2	3	4	−3
	May/Jul	0	0	0	0	0	0	0	0	1	1
	Jun	1	1	1	0	1	0	0	−1	−1	2
48	Dec	−6	−8	−11	−14	−13	−10	−3	2	6	−25
	Jan/Nov	−6	−8	−11	−13	−11	−8	−1	5	8	−24
	Feb/Oct	−5	−7	−10	−11	−8	−5	1	8	11	−18
	Mar/Sept	−4	−6	−6	−7	−4	−1	4	8	11	−11
	Apr/Aug	−3	−3	−3	−3	−1	0	4	6	7	−5
	May/Jul	0	−1	0	0	1	1	3	3	4	0
	Jun	1	1	2	1	2	1	2	2	3	2

Table A.5 COOLING LOAD TEMPERATURE DIFFERENCES (CLTD) FOR CONDUCTION THROUGH GLASS

Solar time, h	CLTD °F	Solar time, h	CLTD °F
0100	1	1300	12
0200	0	1400	13
0300	−1	1500	14
0400	−2	1600	14
0500	−2	1700	13
0600	−2	1800	12
0700	−2	1900	10
0800	0	2000	8
0900	2	2100	6
1000	4	2200	4
1100	7	2300	3
1200	9	2400	2

SHADING COEFFICIENTS FOR GLASS WITHOUT OR WITH INTERIOR SHADING DEVICES

	Nominal Thickness, in. (Each light)	Without Shading	With Interior Shading				
			Venetian Blinds		Roller Shades		
					Opaque		Translucent
Type of Glazing			Medium	Light	Dark	Light	Light
Single glass							
Clear	¼	0.94	0.74	0.67	0.81	0.39	0.44
Heat absorbing	¼	0.69	0.57	0.53	0.45	0.30	0.36
Double glass							
Clear	¼	0.81	0.62	0.58	0.71	0.35	0.40
Heat absorbing	¼	0.55	0.39	0.36	0.40	0.22	0.30

Table A.6 MAXIMUM SOLAR HEAT GAIN FACTOR (SHGF) BTU/HR • FT² FOR SUNLIT GLASS, NORTH LATITUDES

20° N. Lat

	N	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	29	29	48	138	201	243	253	233	214	232
Feb.	31	31	88	173	226	244	238	201	174	263
Mar.	34	49	132	200	237	236	206	152	115	284
Apr.	38	92	166	213	228	208	158	91	58	287
May	47	123	184	217	217	184	124	54	42	283
June	59	135	189	216	210	173	108	45	42	279
July	48	124	182	213	212	179	119	53	43	278
Aug.	40	91	162	206	220	200	152	88	57	280
Sep.	36	46	127	191	225	225	199	148	114	275
Oct.	32	32	87	167	217	236	231	196	170	258
Nov.	29	29	48	136	197	239	249	229	211	230
Dec.	27	27	35	122	187	238	254	241	226	217

24° N. Lat

	N	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	27	27	41	128	190	240	253	241	227	214
Feb.	30	30	80	165	220	244	243	213	192	249
Mar.	34	45	124	195	234	237	214	168	137	275
Apr.	37	88	159	209	228	212	169	107	75	283
May	43	117	178	214	218	190	132	67	46	282
June	55	127	184	214	212	179	117	55	43	279
July	45	116	176	210	213	185	129	65	46	278
Aug.	38	87	156	203	220	204	162	103	72	277
Sep.	35	42	119	185	222	225	206	163	134	266
Oct.	31	31	79	159	211	237	235	207	187	244
Nov.	27	27	42	126	187	236	249	237	224	213
Dec.	26	26	29	112	180	234	247	247	237	199

28° N. Lat

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	25	25	35	117	183	235	251	247	238	196
Feb.	29	29	72	157	213	244	246	224	207	234
Mar.	33	41	116	189	231	237	221	182	157	265
Apr.	36	84	151	205	228	216	178	124	94	278
May	40	115	172	211	219	195	144	83	58	280
June	51	125	178	211	213	184	128	68	49	278
July	41	114	170	208	215	190	140	80	57	276
Aug.	38	83	149	199	220	207	172	120	91	272
Sep.	34	38	111	179	219	226	213	177	154	256
Oct.	30	30	71	151	204	236	238	217	202	229
Nov.	26	26	35	115	181	232	247	243	235	195
Dec.	24	24	24	99	172	227	248	251	246	179

32° N. Lat

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	24	24	29	105	175	229	249	250	246	176
Feb.	27	27	65	149	205	242	248	232	221	217
Mar.	32	37	107	183	227	237	227	195	176	252
Apr.	36	80	146	200	227	219	187	141	115	271
May	38	111	170	208	220	199	155	99	74	277
June	44	122	176	208	214	189	139	83	60	276
July	40	111	167	204	215	194	150	96	72	273
Aug.	37	79	141	195	219	210	181	136	111	265
Sep.	33	35	103	173	215	227	218	189	171	244
Oct.	28	28	63	143	195	234	239	225	215	213
Nov.	24	24	29	103	173	225	245	246	243	175
Dec.	22	22	22	84	162	218	246	252	252	158

36° N. Lat

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	22	22	24	90	166	219	247	252	252	155
Feb.	26	26	57	139	195	239	248	239	232	199
Mar.	30	33	99	176	223	238	232	206	192	238
Apr.	35	76	144	196	225	221	196	156	135	262
May	38	107	168	204	220	204	165	116	93	272
June	47	118	175	205	215	194	150	99	77	273
July	39	107	165	201	216	199	161	113	90	268
Aug.	36	75	138	190	218	212	189	151	131	257
Sep.	31	31	95	167	210	228	223	200	187	230
Oct.	27	27	56	133	187	230	239	231	225	195
Nov.	22	22	24	87	163	215	243	248	248	154
Dec.	20	20	20	69	151	204	241	253	254	136

40° N. Lat

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	20	20	20	74	154	205	241	252	254	133
Feb.	24	24	50	129	186	234	246	244	241	180
Mar.	29	29	93	169	218	238	236	216	206	223
Apr.	34	71	140	190	224	223	203	170	154	252
May	37	102	165	202	220	208	175	133	113	265
June	48	113	172	205	216	199	161	116	95	267
July	38	102	163	198	216	203	170	129	109	262
Aug.	35	71	135	185	216	214	196	165	149	247
Sep.	30	30	87	160	203	227	226	209	200	215
Oct.	25	25	49	123	180	225	238	236	234	177
Nov.	20	20	20	73	151	201	237	248	250	132
Dec.	18	18	18	60	135	188	232	249	253	113

44° N. Lat

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	17	17	17	64	138	189	232	248	252	109
Feb.	22	22	43	117	178	227	246	248	247	160
Mar.	27	27	87	162	211	236	238	224	218	206
Apr.	33	66	136	185	221	224	210	183	171	240
May	36	96	162	201	219	211	183	148	132	257
June	47	108	169	205	215	203	171	132	115	261
July	37	96	159	198	215	206	179	144	128	254
Aug.	34	66	132	180	214	215	202	177	165	236
Sep.	28	28	80	152	198	226	227	216	211	199
Oct.	23	23	42	111	171	217	237	240	239	157
Nov.	18	18	18	64	135	186	227	244	248	109
Dec.	15	15	15	49	115	175	217	240	246	89

48° N. Lat

	N (Shade)	NNE/ NNW	NE/ NW	ENE/ WNW	E/ W	ESE/ WSW	SE/ SW	SSE/ SSW	S	HOR
Jan.	15	15	15	53	118	175	216	239	245	85
Feb.	20	20	36	103	168	216	242	249	250	138
Mar.	26	26	80	154	204	234	239	232	228	188
Apr.	31	61	132	180	219	225	215	194	186	226
May	35	97	158	200	218	214	192	163	150	247
June	46	110	165	204	215	206	180	148	134	252
July	37	96	156	196	214	209	187	158	146	244
Aug.	33	61	128	174	211	216	208	188	180	223
Sep.	27	27	72	144	191	223	228	223	220	182
Oct.	21	21	35	96	161	207	233	241	242	136
Nov.	15	15	15	52	115	172	212	234	240	85
Dec.	13	13	13	36	91	156	195	225	233	65

Table A.7 COOLING LOAD FACTORS (CLF) FOR GLASS WITHOUT INTERIOR SHADING, IN NORTH LATITUDE SPACES HAVING CARPETED FLOORS

		Solar Time																							
Dir.	Room Mass	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
	L	.00	.00	.00	.00	.01	.64	.73	.74	.81	.88	.95	.98	.98	.94	.88	.79	.79	.55	.31	.12	.04	.02	.01	.00
N	M	.03	.02	.02	.02	.02	.64	.69	.69	.77	.84	.91	.94	.95	.91	.86	.79	.79	.56	.32	.16	.10	.07	.05	.04
	H	.10	.09	.08	.07	.07	.62	.64	.64	.71	.77	.83	.87	.88	.85	.81	.75	.76	.55	.34	.22	.17	.15	.13	.11
	L	.00	.00	.00	.00	.01	.51	.83	.88	.72	.47	.33	.27	.24	.23	.20	.18	.14	.09	.03	.01	.00	.00	.00	.00
NE	M	.01	.01	.00	.00	.01	.50	.78	.82	.67	.44	.32	.28	.26	.24	.22	.19	.15	.11	.05	.03	.02	.02	.01	.01
	H	.03	.03	.03	.02	.03	.47	.71	.72	.59	.40	.30	.27	.26	.25	.23	.20	.17	.13	.08	.06	.05	.05	.04	.04
	L	.00	.00	.00	.00	.00	.42	.76	.91	.90	.75	.51	.30	.22	.18	.16	.13	.11	.07	.02	.01	.00	.00	.00	.00
E	M	.01	.01	.00	.00	.01	.41	.72	.86	.84	.71	.48	.30	.24	.21	.18	.16	.13	.09	.04	.03	.02	.01	.01	.01
	H	.03	.03	.03	.02	.02	.39	.66	.76	.74	.63	.43	.29	.24	.22	.20	.18	.15	.12	.08	.06	.05	.05	.04	.04
	L	.00	.00	.00	.00	.00	.27	.58	.81	.93	.93	.81	.59	.37	.27	.21	.18	.14	.09	.03	.01	.00	.00	.00	.00
SE	M	.01	.01	.01	.00	.01	.26	.55	.77	.88	.87	.76	.56	.37	.29	.24	.20	.16	.11	.05	.04	.03	.02	.02	.01
	H	.04	.04	.03	.03	.03	.26	.51	.69	.78	.78	.68	.51	.35	.29	.25	.22	.19	.15	.09	.08	.07	.06	.05	.05
	L	.00	.00	.00	.00	.00	.07	.15	.23	.39	.62	.82	.94	.93	.80	.59	.38	.26	.16	.06	.02	.01	.00	.00	.00
S	M	.01	.01	.01	.01	.01	.07	.14	.22	.38	.59	.78	.88	.88	.76	.57	.38	.28	.18	.09	.06	.04	.03	.02	.02
	H	.05	.05	.04	.04	.03	.09	.15	.21	.35	.54	.70	.79	.79	.69	.52	.37	.29	.21	.13	.10	.09	.08	.07	.06
	L	.00	.00	.00	.00	.00	.04	.09	.13	.16	.19	.23	.39	.62	.82	.94	.94	.81	.54	.19	.07	.03	.01	.00	.00
SW	M	.02	.02	.01	.01	.01	.05	.09	.13	.16	.19	.22	.38	.60	.78	.89	.89	.77	.52	.20	.10	.07	.05	.04	.03
	H	.07	.06	.05	.05	.04	.07	.11	.14	.16	.18	.21	.35	.55	.71	.80	.79	.69	.48	.20	.14	.11	.10	.08	.07
	L	.00	.00	.00	.00	.00	.03	.07	.10	.13	.15	.16	.18	.31	.55	.78	.92	.93	.73	.25	.10	.04	.01	.01	.00
W	M	.02	.02	.01	.01	.01	.04	.07	.10	.13	.14	.16	.17	.30	.53	.74	.87	.88	.69	.24	.12	.07	.05	.04	.03
	H	.06	.06	.05	.04	.04	.06	.09	.11	.13	.15	.16	.17	.28	.49	.67	.78	.79	.62	.23	.14	.11	.09	.08	.07
	L	.00	.00	.00	.00	.00	.04	.09	.14	.17	.20	.22	.23	.24	.31	.53	.78	.92	.81	.28	.10	.04	.02	.01	.00
NW	M	.02	.02	.01	.01	.01	.05	.10	.13	.17	.19	.21	.22	.23	.30	.52	.75	.88	.77	.26	.12	.07	.05	.04	.03
	H	.06	.05	.05	.04	.04	.07	.11	.14	.17	.19	.20	.21	.22	.28	.48	.68	.79	.69	.23	.14	.10	.09	.08	.07
	L	.00	.00	.00	.00	.00	.08	.25	.45	.64	.80	.91	.97	.97	.91	.80	.64	.44	.23	.08	.03	.01	.00	.00	.00
Hor.	M	.02	.02	.01	.01	.01	.08	.24	.43	.60	.75	.86	.92	.92	.87	.77	.63	.45	.26	.12	.07	.05	.04	.03	.02
	H	.07	.06	.05	.05	.04	.11	.25	.41	.56	.68	.77	.83	.83	.80	.71	.59	.44	.28	.17	.13	.11	.10	.09	.08

Values for nominal 15 ft by 15 ft by 10 ft high space, with ceiling, and 50% or less glass in exposed surface at listed orientation.

L = Lightweight construction, such as 1 in. wood floor, Group G wall.

M = Mediumweight construction, such as 2 to 4 in. concrete floor, Group E wall.

H = Heavyweight construction, such as 6 to 8 in. concrete floor, Group C wall.

Table A.8 COOLING LOAD FACTORS (CLF) FOR GLASS WITHOUT INTERIOR SHADING, IN NORTH LATITUDE SPACES HAVING UNCARPETED FLOORS

		Solar Time																							
Dir.	Room Mass	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
	L	.00	.00	.00	.00	.01	.64	.73	.74	.81	.88	.95	.98	.98	.94	.88	.79	.79	.55	.31	.12	.04	.02	.01	.00
N	M	.12	.09	.07	.06	.05	.33	.45	.53	.61	.69	.76	.82	.85	.86	.85	.81	.80	.70	.60	.43	.32	.24	.19	.15
	H	.24	.21	.19	.18	.16	.43	.48	.51	.56	.61	.66	.71	.73	.74	.73	.71	.71	.62	.52	.42	.36	.32	.29	.26
	L	.00	.00	.00	.00	.01	.51	.83	.88	.72	.47	.33	.27	.24	.23	.20	.18	.14	.09	.03	.01	.00	.00	.00	.00
NE	M	.03	.02	.02	.02	.02	.24	.45	.57	.58	.49	.41	.36	.32	.29	.27	.24	.21	.17	.13	.10	.07	.06	.05	.04
	H	.08	.07	.07	.06	.06	.27	.43	.49	.45	.37	.32	.29	.28	.27	.26	.24	.22	.19	.16	.14	.12	.11	.10	.09
	L	.00	.00	.00	.00	.00	.42	.76	.91	.90	.75	.51	.30	.22	.18	.16	.13	.11	.07	.02	.01	.00	.00	.00	.00
E	M	.03	.02	.02	.02	.01	.20	.41	.57	.65	.64	.55	.44	.36	.31	.26	.23	.19	.16	.12	.09	.07	.06	.04	.04
	H	.08	.08	.07	.06	.06	.24	.40	.50	.53	.50	.41	.33	.30	.28	.26	.24	.22	.19	.16	.14	.13	.11	.10	.09
	L	.00	.00	.00	.00	.00	.27	.58	.81	.93	.93	.81	.59	.37	.27	.21	.18	.14	.09	.03	.01	.00	.00	.00	.00
SE	M	.04	.03	.02	.02	.02	.13	.31	.48	.62	.69	.69	.61	.50	.41	.35	.30	.25	.20	.15	.12	.09	.07	.06	.05
	H	.10	.09	.08	.08	.07	.18	.32	.45	.53	.56	.54	.47	.39	.35	.32	.29	.26	.23	.19	.17	.15	.14	.12	.11
	L	.00	.00	.00	.00	.00	.07	.15	.23	.39	.62	.82	.94	.93	.80	.59	.38	.26	.16	.06	.02	.01	.00	.00	.00
S	M	.05	.04	.04	.03	.02	.05	.09	.14	.24	.38	.53	.65	.72	.71	.63	.52	.42	.33	.24	.18	.14	.11	.09	.07
	H	.13	.12	.10	.09	.09	.11	.14	.17	.25	.36	.47	.55	.58	.56	.49	.41	.36	.30	.25	.21	.19	.17	.16	.14
	L	.00	.00	.00	.00	.00	.04	.09	.13	.16	.19	.23	.39	.62	.82	.94	.94	.81	.54	.19	.07	.03	.01	.00	.00
SW	M	.08	.07	.05	.04	.03	.05	.07	.09	.12	.15	.17	.26	.40	.54	.66	.73	.72	.61	.43	.31	.23	.17	.13	.10
	H	.15	.14	.12	.11	.10	.11	.12	.14	.15	.17	.18	.26	.37	.48	.56	.59	.57	.47	.33	.27	.23	.21	.19	.17
	L	.00	.00	.00	.00	.00	.03	.07	.10	.13	.15	.16	.18	.31	.55	.78	.92	.93	.73	.25	.10	.04	.01	.01	.00
W	M	.08	.07	.05	.04	.04	.04	.06	.08	.10	.12	.13	.15	.21	.35	.50	.63	.71	.67	.46	.33	.24	.18	.14	.11
	H	.14	.13	.12	.11	.10	.10	.11	.12	.13	.14	.15	.16	.21	.33	.45	.54	.58	.52	.33	.26	.22	.19	.18	.16
	L	.00	.00	.00	.00	.00	.04	.09	.14	.17	.20	.22	.23	.24	.31	.53	.78	.92	.81	.28	.10	.04	.02	.01	.00
NW	M	.08	.06	.05	.04	.03	.05	.07	.10	.13	.15	.17	.19	.20	.24	.36	.51	.64	.66	.46	.32	.23	.17	.13	.10
	H	.13	.12	.11	.10	.09	.10	.12	.13	.15	.16	.17	.18	.19	.23	.33	.46	.55	.53	.33	.25	.21	.18	.16	.15
	L	.00	.00	.00	.00	.00	.08	.25	.45	.64	.80	.91	.97	.97	.91	.80	.64	.44	.23	.08	.03	.01	.00	.00	.00
Hor.	M	.07	.06	.05	.04	.03	.06	.14	.26	.40	.53	.64	.73	.78	.80	.77	.70	.59	.45	.33	.24	.19	.14	.11	.09
	H	.16	.15	.13	.12	.11	.13	.20	.29	.39	.48	.56	.61	.65	.65	.63	.57	.49	.40	.32	.28	.25	.22	.20	.18

Values for nominal 15 ft by 15 ft by 10 ft high space, with ceiling, and 50% or less glass in exposed surface at listed orientation.
L = Lightweight construction, such as 1 in. wood floor, Group G wall.
M = Mediumweight construction, such as 2 to 4 in. concrete floor, Group E wall.
H = Heavyweight construction, such as 6 to 8 in. concrete floor, Group C wall.

Table A.9 COOLING LOAD FACTORS (CLF) FOR GLASS WITH INTERIOR SHADING, NORTH LATITUDES (ALL ROOM CONSTRUCTIONS)

Fenestration Facing	Solar Time, h																							
	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
N	0.08	0.07	0.06	0.06	0.07	0.73	0.66	0.65	0.73	0.80	0.86	0.89	0.89	0.86	0.82	0.75	0.78	0.91	0.24	0.18	0.15	0.13	0.11	0.10
NNE	0.03	0.03	0.02	0.02	0.03	0.64	0.77	0.62	0.42	0.37	0.37	0.37	0.36	0.35	0.32	0.28	0.23	0.17	0.08	0.07	0.06	0.05	0.04	0.04
NE	0.03	0.02	0.02	0.02	0.02	0.56	0.76	0.74	0.58	0.37	0.29	0.27	0.26	0.24	0.22	0.20	0.16	0.12	0.06	0.05	0.04	0.04	0.03	0.03
ENE	0.03	0.02	0.02	0.02	0.02	0.52	0.76	0.80	0.71	0.52	0.31	0.26	0.24	0.22	0.20	0.18	0.15	0.11	0.06	0.05	0.04	0.04	0.03	0.03
E	0.03	0.02	0.02	0.02	0.02	0.47	0.72	0.80	0.76	0.62	0.41	0.27	0.24	0.22	0.20	0.17	0.14	0.11	0.06	0.05	0.05	0.04	0.03	0.03
ESE	0.03	0.03	0.02	0.02	0.02	0.41	0.67	0.79	0.80	0.72	0.54	0.34	0.27	0.24	0.21	0.19	0.15	0.12	0.07	0.06	0.05	0.04	0.04	0.03
SE	0.03	0.03	0.02	0.02	0.02	0.30	0.57	0.74	0.81	0.79	0.68	0.49	0.33	0.28	0.25	0.22	0.18	0.13	0.08	0.07	0.06	0.05	0.04	0.04
SSE	0.04	0.03	0.03	0.03	0.02	0.12	0.31	0.54	0.72	0.81	0.81	0.71	0.54	0.38	0.32	0.27	0.22	0.16	0.09	0.08	0.07	0.06	0.05	0.04
S	0.04	0.04	0.03	0.03	0.03	0.09	0.16	0.23	0.38	0.58	0.75	0.83	0.80	0.68	0.50	0.35	0.27	0.19	0.11	0.09	0.08	0.07	0.06	0.05
SSW	0.05	0.04	0.04	0.03	0.03	0.09	0.14	0.18	0.22	0.27	0.43	0.63	0.78	0.84	0.80	0.66	0.46	0.25	0.13	0.11	0.09	0.08	0.07	0.06
SW	0.05	0.05	0.04	0.04	0.03	0.07	0.11	0.14	0.16	0.19	0.22	0.38	0.59	0.75	0.83	0.81	0.69	0.45	0.16	0.12	0.10	0.09	0.07	0.06
WSW	0.05	0.05	0.04	0.04	0.03	0.07	0.10	0.12	0.14	0.16	0.17	0.23	0.44	0.64	0.78	0.84	0.78	0.55	0.16	0.12	0.10	0.09	0.07	0.06
W	0.05	0.05	0.04	0.04	0.03	0.06	0.09	0.11	0.13	0.15	0.16	0.17	0.31	0.53	0.72	0.82	0.81	0.61	0.16	0.12	0.10	0.08	0.07	0.06
WNW	0.05	0.05	0.04	0.03	0.03	0.07	0.10	0.12	0.14	0.16	0.17	0.18	0.22	0.43	0.65	0.80	0.84	0.66	0.16	0.12	0.10	0.08	0.07	0.06
NW	0.05	0.04	0.04	0.03	0.03	0.07	0.11	0.14	0.17	0.19	0.20	0.21	0.22	0.30	0.52	0.73	0.82	0.69	0.16	0.12	0.10	0.08	0.07	0.06
NNW	0.05	0.05	0.04	0.03	0.03	0.11	0.17	0.22	0.26	0.30	0.32	0.33	0.34	0.34	0.39	0.61	0.82	0.76	0.17	0.12	0.10	0.08	0.07	0.06
HOR.	0.06	0.05	0.04	0.04	0.03	0.12	0.27	0.44	0.59	0.72	0.81	0.85	0.85	0.81	0.71	0.58	0.42	0.25	0.14	0.12	0.10	0.08	0.07	0.06

Table A.10 RATES OF HEAT GAIN FROM OCCUPANTS

Degree of Activity	Typical Applications	Total Heat Adults, Male, Btu/h	Total Heat Adjusted,[d] Btu/h	Sensible Heat, Btu/h	Latent Heat, Btu/h
Seated at theater	Theater—Matinee	390	330	225	105
Seated at theater	Theater—Evening	390	350	245	105
Seated, very light work	Offices, hotels, apartments	450	400	245	155
Moderately active office work	Offices, hotels, apartments	475	450	250	200
Standing, light work; walking	Department store, retail store	550	450	250	200
Walking; standing	Drug store, bank	550	500	250	250
Sedentary work	Restaurant[e]	490	550	275	275
Light bench work	Factory	800	750	275	475
Moderate dancing	Dance hall	900	850	305	545
Walking 3 mph; light machine work	Factory	1000	1000	375	625
Bowling[f]	Bowling alley	1500	1450	580	870
Heavy work	Factory	1500	1450	580	870
Heavy machine work; lifting	Factory	1600	1600	635	965
Athletics	Gymnasium	2000	1800	710	1090

[a] Tabulated values are based on 75°F room dry-bulb temperature. For 80°F room dry-bulb, the total heat remains the same, but the sensible heat values should be decreased by approximately 20%, and the latent heat values increased accordingly.

[c] All values are rounded to nearest 5 Btu/h.

[d] *Adjusted heat gain* is based on normal percentage of men, women, and children for the application listed, with the postulate that the gain from an adult female is 85% of that for an adult male, and that the gain from a child is 75% of that for an adult male.

[e] Adjusted total heat gain for *Sedentary work, Restaurant,* includes 60 Btu/h for food per individual (30 Btu/h sensible and 30 Btu/h latent.)

[f] For *Bowling,* figure one person per alley actually bowling, and all others at sitting (400 Btu/h) or standing and walking slowly (550 Btu/h).

Table A.12 CLTD VALUES FOR SINGLE-FAMILY DETACHED RESIDENCES[a]

	Design Temperature, °F											
	85		90			95			100		105	110
Daily Temp. Range[b]	L	M	L	M	H	L	M	H	M	H	M	H
All walls and doors												
North	8	3	13	8	3	18	13	8	18	13	18	23
NE and NW	14	9	19	14	9	24	19	14	24	19	24	29
East and West	18	13	23	18	13	28	23	18	28	23	28	33
SE and SW	16	11	21	16	11	26	21	16	26	21	26	31
South	11	6	16	11	6	21	16	11	21	16	21	26
Roofs and ceilings												
Attic or flat built-up	42	37	47	42	37	51	47	42	51	47	51	56
Floors and ceilings												
Under conditioned space, over unconditioned room, over crawl space	9	4	12	9	4	14	12	9	14	12	14	19
Partitions												
Inside or shaded	9	4	12	9	4	14	12	9	14	12	14	19

[a]Cooling load temperature differences (CLTDs) for single-family detached houses, duplexes, or multifamily, with both east and west exposed walls or only north and south exposed walls, °F.

[b]L denotes low daily range, less than 16 °F; M denotes medium daily range, 16 to 25 °F; and H denotes high daily range, greater than 25 °F.

Table A.11 SHADE LINE FACTORS (SLF)

Direction Window Faces	Latitude, Degrees N						
	24	32	36	40	44	48	52
East	0.8	0.8	0.8	0.8	0.8	0.8	0.8
SE	1.8	1.6	1.4	1.3	1.1	1.0	0.9
South	9.2	5.0	3.4	2.6	2.1	1.8	1.5
SW	1.8	1.6	1.4	1.3	1.1	1.0	0.9
West	0.8	0.8	0.8	0.8	0.8	0.8	0.8

Shadow length below the overhang equals the shade line factor times the overhang width. Values are averages for the 5 h of greatest solar intensity on August 1..

Table A.13 HEAT GAIN FROM EQUIPMENT

		Recommended Rate of Heat Gain, BTU/hr			
		Without Hood			With H
Appliance	**Size**	**Sens.**	**Latent**	**Total**	**Sensi**
Restaurant, electric blender, per quart of capacity	1 to 4 qt	1000	520	1520	48
Coffee brewer	12 cups/2 brnrs	3750	1910	5660	181
Coffee heater, per warming burner	1 to 2 brnrs	230	110	340	11
Display case (refrigerated), per ft^3 of interior	6 to 67 ft^3	62	0	62	
Hot plate (high-speed double burner)		7810	5430	13,240	624
Ice maker (large)	220 lb/day	9320	0	9320	
Microwave oven (heavy-duty commercial)	0.7 ft^3	8970	0	8970	
Toaster (large pop-up)	10 slice	9590	8500	18,080	580

Appliance	**Size**		**Recommended Rate of Heat Gain, BTU/hr**
Computer Devices			
Communication/transmission			5600–9600
Disk drives/mass storage			3400–22,400
Microcomputer/word processor	16–640 kbytes		300–1800
Minicomputer			7500–15,000
Printer (laser)	8 pages/min		1000
Printer (line, high-speed)	5000 or more pages/min		2500–13,000
Tape drives			3500–15,000
Terminal			270–600
Copiers/Typesetters			
Blue print			3900–42,700
Copiers (large)	30–67 copies/min		1700–6600
Copiers	6–30 copies/min		460–1700
Miscellaneous			
Cash register			160
Cold food/beverage			1960–3280
Coffee maker	10 cup	sensible	3580
		latent	1540
Microwave oven	1 ft^3		1360
Paper shredder			680–8250
Water cooler	8 gal/hr		6000

Table A.14 HEAT GAIN FROM TYPICAL ELECTRIC MOTORS

				Location of Motor and Driven Equipment with Respect to Conditioned Space or Airstream		
				A	B	C
Motor Name-plate or Rated Horse-power	Motor Type	Nom-inal rpm	Full Load Motor Effici-ency in Percent	Motor in, Driven Equip-ment in Btu/h	Motor out, Driven Equip-ment in Btu/h	Motor in, Driven Equip-ment out Btu/h
0.05	Shaded Pole	1500	35	360	130	240
0.08	Shaded Pole	1500	35	580	200	380
0.125	Shaded Pole	1500	35	900	320	590
0.16	Shaded Pole	1500	35	1160	400	760
0.25	Split Phase	1750	54	1180	640	540
0.33	Split Phase	1750	56	1500	840	660
0.50	Split Phase	1750	60	2120	1270	850
0.75	3-Phase	1750	72	2650	1900	740
1	3-Phase	1750	75	3390	2550	850
1	3-Phase	1750	77	4960	3820	1140
2	3-Phase	1750	79	6440	5090	1350
3	3-Phase	1750	81	9430	7640	1790
5	3-Phase	1750	82	15,500	12,700	2790
7.5	3-Phase	1750	84	22,700	19,100	3640
10	3-Phase	1750	85	29,900	24,500	4490
15	3-Phase	1750	86	44,400	38,200	6210
20	3-Phase	1750	87	58,500	50,900	7610
25	3-Phase	1750	88	72,300	63,600	8680
30	3-Phase	1750	89	85,700	76,300	9440
40	3-Phase	1750	89	114,000	102,000	12,600
50	3-Phase	1750	89	143,000	127,000	15,700
60	3-Phase	1750	89	172,000	153,000	18,900
75	3-Phase	1750	90	212,000	191,000	21,200
100	3-Phase	1750	90	283,000	255,000	28,300
125	3-Phase	1750	90	353,000	318,000	35,300
150	3-Phase	1750	91	420,000	382,000	37,800
200	3-Phase	1750	91	569,000	509,000	50,300
250	3-Phase	1750	91	699,000	636,000	62,900

Table A.15 SENSIBLE HEAT COOLING LOAD FACTORS FOR PEOPLE

	Hours After Each Entry Into Space																							
Total hours in space	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2	0.49	0.58	0.17	0.13	0.10	0.08	0.07	0.06	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
4	0.49	0.59	0.66	0.71	0.27	0.21	0.16	0.14	0.11	0.10	0.08	0.07	0.06	0.06	0.05	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.01
6	0.50	0.60	0.67	0.72	0.76	0.79	0.34	0.26	0.21	0.18	0.15	0.13	0.11	0.10	0.08	0.07	0.06	0.06	0.05	0.04	0.04	0.03	0.03	0.03
8	0.51	0.61	0.67	0.72	0.76	0.80	0.82	0.84	0.38	0.30	0.25	0.21	0.18	0.15	0.13	0.12	0.10	0.09	0.08	0.07	0.06	0.05	0.03	0.04
10	0.53	0.62	0.69	0.74	0.77	0.80	0.83	0.85	0.87	0.89	0.42	0.34	0.28	0.23	0.20	0.17	0.15	0.13	0.11	0.10	0.09	0.08	0.07	0.06
12	0.55	0.64	0.70	0.75	0.79	0.81	0.84	0.86	0.88	0.89	0.91	0.92	0.45	0.36	0.30	0.25	0.21	0.19	0.16	0.14	0.12	0.11	0.09	0.08
14	0.58	0.66	0.72	0.77	0.80	0.83	0.85	0.87	0.89	0.90	0.91	0.92	0.93	0.94	0.47	0.38	0.31	0.26	0.23	0.20	0.17	0.15	0.13	0.11
16	0.62	0.70	0.75	0.79	0.82	0.85	0.87	0.88	0.90	0.91	0.92	0.93	0.94	0.95	0.95	0.96	0.49	0.39	0.33	0.28	0.24	0.20	0.18	0.16
18	0.66	0.74	0.79	0.82	0.85	0.87	0.89	0.90	0.92	0.93	0.94	0.94	0.95	0.96	0.96	0.97	0.97	0.97	0.50	0.40	0.33	0.28	0.24	0.21

CLF = 1.0 for systems shut down at night and for high occupant densities such as in theaters and auditoriums

Table A.16 WINDOW GLASS LOAD FACTORS (GLF) FOR SINGLE-FAMILY DETACHED RESIDENCES

Design Temperature, °F	Regular Single Glass						Regular Double Glass						Heat-Absorbing Double Glass						Clear Triple Glass		
	85	90	95	100	105	110	85	90	95	100	105	110	85	90	95	100	105	110	85	90	95
No inside shading																					
North	34	36	41	47	48	50	30	30	34	37	38	41	20	20	23	25	26	28	27	27	30
NE and NW	63	65	70	75	77	83	55	56	59	62	63	66	36	37	39	42	44	44	50	50	53
E and W	88	90	95	100	102	107	77	78	81	84	85	88	51	51	54	56	59	59	70	70	73
SE and SW[b]	79	81	86	91	92	98	69	70	73	76	77	80	45	46	49	51	54	54	62	63	65
South[b]	53	55	60	65	67	72	46	47	50	53	54	57	31	31	34	36	39	39	42	42	45
Horizontal skylight	156	156	161	166	167	171	137	138	140	143	144	147	90	91	93	95	96	98	124	125	127
Draperies, venetian blinds, translucent roller shades fully drawn																					
North	18	19	23	27	29	33	16	16	19	22	23	26	13	14	16	18	19	21	15	16	18
NE and NW	32	33	38	42	43	47	29	30	32	35	36	39	24	24	27	29	29	32	28	28	30
E and W	45	46	50	54	55	59	40	41	44	46	47	50	33	33	36	38	38	41	39	39	41
SE and SW[b]	40	41	46	49	51	55	36	37	39	42	43	46	29	30	32	34	35	37	35	36	38
South[b]	27	28	33	37	38	42	24	25	28	31	31	34	20	21	23	25	26	28	23	24	26
Horizontal skylight	78	79	83	86	87	90	71	71	74	76	77	79	58	59	61	63	63	65	69	69	71
Opaque roller shades fully drawn																					
North	14	15	20	23	25	29	13	14	17	19	20	23	12	12	15	17	17	20	13	13	15
NE and NW	25	26	31	34	36	40	23	24	27	30	30	33	21	22	24	26	27	29	23	23	26
E and W	34	36	40	44	45	49	32	33	36	38	39	42	29	30	32	34	35	37	32	32	35
SE and SW[b]	31	32	36	40	42	46	29	30	33	35	36	39	26	27	29	31	32	34	29	29	31
South[b]	21	22	27	30	32	36	20	20	23	26	27	30	18	19	21	23	24	26	19	20	22
Horizontal skylight	60	61	64	68	69	72	57	57	60	62	63	65	52	52	55	57	57	59	56	57	59

[a]Glass load factors (GLFs) for single-family detached houses, duplexes, or multi-family, with both east and west exposed walls or only north and south exposed walls, Btu/h • ft².

[b]Correct by +30% for latitude of 48° and by −30% for latitude of 32°. Use linear interpolation for latitude from 40 to 48° and from 40 to 32°.

To obtain GLF for other combinations of glass and/or inside shading: $GLF_a = (SC_a/SC_t)(GLF_t - U_tD_t) + U_aD_t$, where the subscripts a and t refer to the alternate and table values, respectively. SC_t and U_t are given in Table 5. $D_t = (t_a - 75)$, where $t_a = t_o - (DR/2)$; t_o is the outdoor design temperature and DR is the daily range.

Table A.17 THERMAL RESISTANCE *R* OF BUILDING AND INSULATING MATERIALS ($hr \cdot ft^2$-F/BTU)

Description		Density lb/ft³	Resistance (*R*) Per Inch	Per Listed Thickness
BUILDING BOARD				
Boards, Panels, Subflooring, Sheathing				
Woodboard Panel Products				
Asbestos-cement board		120	0.25	--
Asbestos-cement board	0.125 in.	120	--	0.03
Asbestos-cement board	0.25 in.	120	--	0.06
Gypsum or plaster board	0.375 in.	50	--	0.32
Gypsum or plaster board	0.5 in.	50	--	0.45
Gypsum or plaster board	0.625 in.	50	--	0.56
Plywood (Douglas Fir)		34	1.25	--
Plywood (Douglas Fir)	0.25 in.	34	--	0.31
Plywood (Douglas Fir)	0.375 in.	34	--	0.47
Plywood (Douglas Fir)	0.5 in.	34	--	0.62
Plywood (Douglas Fir)	0.625 in.	34	--	0.77
Plywood or wood panels	0.75 in.	34	--	0.93
Vegetable fiber board				
Sheathing, regular density	0.5 in.	18	--	1.32
	0.78125 in.	18	--	2.06
Sheathing, intermediate density	0.5 in.	22	--	1.22
Nail-base sheathing	0.5 in.	25	--	1.14
Shingle backer	0.375 in.	18	--	0.94
Shingle backer	0.3125 in.	18	--	0.78
Sound deadening board	0.5 in.	15	--	1.35
Tile and lay-in panels, plain or acoustic		18	2.50	--
	0.5 in.	18	--	1.25
	0.75 in.	18	--	1.89
Laminated paperboard		30	2.00	--
Homogeneous board from repulped paper		30	2.00	--
Hardboard				
Medium density		50	1.37	--
High density, service temp. service underlay		55	1.22	--
High density, std. tempered		63	1.00	--
Particleboard				
Low density		37	1.85	--
Medium density		50	1.06	--
High density		62.5	0.85	--
Underlayment	0.625 in.	40	--	0.82
Wood subfloor	0.75 in.		--	0.94
BUILDING MEMBRANE				
Vapor—permeable felt		--	--	0.06
Vapor—seal, 2 layers of mopped 15-lb felt		--	--	0.12
Vapor—seal, plastic film		--	--	Negl.
FINISH FLOORING MATERIALS				
Carpet and fibrous pad		--	--	2.08
Carpet and rubber pad		--	--	1.23
Cork tile	0.125 in.	--	---	0.28
Terrazzo	1 in.	--	--	0.08
Tile—asphalt, linoleum, vinyl, rubber		--	--	0.05
vinyl asbestos				
ceramic				
Wood, hardwood finish	0.75 in.			0.68
INSULATING MATERIALS				
Blanket and Batt				
Mineral fiber, fibrous form processed				
from rock, slag, or glass				
approx. 2–2.75 in.		0.3–2.0	--	7
approx. 3–3.5 in.		0.3–2.0	--	11
approx. 3.50–6.5 in.		0.3–2.0	--	19
approx. 6–7 in.		0.3–2.0		22
approx. 8.5 in.		0.3–2.0		30

(Continued)

Description	Density lb/ft³	Resistance (*R*) Per Inch	Per Listed Thickness
MASONRY UNITS			
Brick, common	120	0.20	--
Brick, face	130	0.11	--
Clay tile, hollow:			
1 cell deep 3 in.	--	--	0.80
1 cell deep 4 in.	--	--	1.11
2 cells deep 6 in.	--	--	1.52
2 cells deep 8 in.	--	--	1.85
2 cells deep 10 in.	--	--	2.22
3 cells deep 12 in.	--	--	2.50
Concrete blocks, three oval core:			
Sand and gravel aggregate 4 in.	--	--	0.71
8 in.	--	--	1.11
12 in.	--	--	1.28
Cinder aggregate 3 in.	--	--	0.86
4 in.	--	--	1.11
8 in.	--	--	1.72
12 in.	--	--	1.89
Lightweight aggregate 3 in.	--	--	1.27
(expanded shale, clay, slate, 4 in.	--	--	1.50
or slag; pumice) 8 in.	--	--	2.00
12 in.	--	--	2.27
Concrete blocks, rectangular core:			
Sand and gravel aggregate			
2 core, 8 in. 36 lb	--	--	1.04
Same with filled cores	--	--	1.93
Lightweight aggregate (expanded shale, clay, slate, or slag; pumice):			
3 core, 6 in. 19 lb	--	--	1.65
Same with filled cores	--	--	2.99
2 core, 8 in. 24 lb	--	--	2.18
Same with filled cores	--	--	5.03
3 core, 12 in. 38 lb	--	--	2.48
Same with filled cores	--	--	5.82
Stone, lime or sand	--	0.08	--
Gypsum partition tile:			
3 × 12 × 30 in. solid	--	--	1.26
3 × 12 × 30 in. 4-cell	--	--	1.35
4 × 12 × 30 in. 3-cell	--	--	1.67
PLASTERING MATERIALS			
Cement plaster, sand aggregate	116	0.20	--
Sand aggregate 0.375 in.	--	--	0.08
Sand aggregate 0.75 in.	--	--	0.15
Gypsum plaster:			
Lightweight aggregate 0.5 in.	45	--	0.32
Lightweight aggregate 0.625 in.	45	--	0.39
Lightweight aggregate on metal lath 0.75 in.	--	--	0.47
Perlite aggregate	45	0.67	--
Sand aggregate	105	0.18	--
Sand aggregate 0.5 in.	105	--	0.09
Sand aggregate 0.625 in.	105	--	0.11
Sand aggregate on metal lath 0.75 in.	--	--	0.13
Vermiculite aggregate	45	0.59	--
ROOFING			
Asbestos-cement shingles	120	--	0.21
Asphalt roll roofing	70	--	0.15
Asphalt shingles	70	--	0.44
Built-up roofing 0.375 in.	70	--	0.33
Slate 0.5 in.	--	--	0.05
Wood shingles, plain and plastic film faced	--	--	0.94

(Continued)

Description	Density lb/ft³	Resistance (R) Per Inch	Per Listed Thickness
Board and Slabs			
Cellular glass	8.5	2.63	--
Glass fiber, organic bonded	4–9	4.00	--
Expanded rubber (rigid)	4.5	4.55	--
Expanded polystyrene extruded			
Cut cell surface	1.8	4.00	--
Expanded polystyrene extruded			
Smooth skin surface	2.2	5.00	--
Expanded polystyrene extruded			
Smooth skin surface	3.5	5.26	--
Expanded polystyrene, molded beads	1.0	3.57	--
Expanded polyurethane (R-11 exp.)	1.5	6.25	--
(Thickness 1 in. or greater)	2.5		
Mineral fiber with resin binder	15	3.45	--
Mineral fiberboard, wet felted			
Core or roof insulation	16–17	2.94	--
Acoustical tile	18	2.86	--
Acoustical tile	21	2.70	--
Mineral fiberboard, wet molded			
Acoustical tile	23	2.38	--
Wood or cane fiberboard			
Acoustical tile 0.5 in.	--	--	1.25
Acoustical tile 0.75 in.	--	--	1.89
Interior finish (plank, tile)	15	2.86	--
Wood shredded (cemented in preformed slabs)	22	1.67	--
LOOSE FILL			
Cellulosic insulation (milled paper or wood pulp)	2.3–3.2	3.13–3.70	--
Sawdust or shavings	8.0–15.0	2.22	--
Wood fiber, softwoods	2.0–3.5	3.33	--
Perlite, expanded	5.0–8.0	2.70	--
Mineral fiber (rock, slag, or glass)			
approx. 3.75–5 in	0.6–2.0		11
approx. 6.5–8.75 in	0.6–2.0		19
approx. 7.5–10 in	0.6–2.0		22
approx. 10.25–13.75 in.	0.6–2.0		30
Vermiculite, exfoliated	7.0–8.2	2.13	--
	4.0–6.0	2.27	--
Roof Insulation			
Preformed, for use above deck			1.39
Different roof insulations are available in different			
thicknesses to provide the design C values listed.			to
Consult individual manufacturers for actual			
thickness of their material			8.33
MASONRY MATERIALS			
Concretes			
Cement mortar	116	0.20	--
Gypsum-fiber concrete 87.5% gypsum,			
12.5% wood chips	51	0.60	--
Lightweight aggregates including expanded	120	0.19	--
shale, clay, or slate; expanded slags;	100	0.28	--
cirders; pumice; vermiculite; also	80	0.40	--
cellular concretes	60	0.59	--
	40	0.86	--
	30	1.11	--
	20	1.43	
Perlite, expanded	40	1.08	
	30	1.41	
	20	2.00	
Sand and gravel or stone aggregate (oven dried)	140	0.11	
Sand and gravel or stone aggregate (not dried)	140	0.08	
Stucco	116	0.20	

(Continued)

Description	Density lb/ft³	Resistance (*R*)	
		Per Inch	Per Listed Thickness
SIDING MATERIALS (on flat surface)			
Shingles			
Asbestos-cement	120	--	0.21
Wood, 16 in., 7.5 exposure	--	--	0.87
Wood, double, 16 in., 12 in. exposure	--	--	1.19
Wood, plus insul. backer board, 0.3125 in	--	--	1.40
Siding			
Asbestos-cement, 0.25 in., lapped	--	--	0.21
Asphalt roll siding	--	--	0.15
Asphalt insulting siding (0.5 in. bed.)	--	--	1.46
Wood drop, 1 x 8 in	--	--	0.79
Wood, bevel, 0.5 x 8 in., lapped	--	--	0.81
Wood, bevel, 0.75 x 10 in., lapped	--	--	1.05
Wood, plywood, 0.375 in., lapped	--	--	0.59
Wood, medium density siding, 0.4375 in	40	0.67	
Aluminum or steel, over sheathing			
Hollow-backed	--	--	0.61
Insulating-board backed nominal 0.375 in.	--	--	1.82
Insulating-board backed nominal 0.375 in., foil backed			2.96
Architectural glass	--	--	0.10
WOODS			
Maple, oak, and similar hardwoods	45	0.91	--
Fir, pine, and similar softwoods	32	1.25	--
Fir, pine, and similar softwoods 0.75 in.	32	--	0.94
1.5 in.		--	1.89
2.5 in.		--	3.12
3.5 in.		--	4.35

Table A.18 AIR CHANGE RATES AS A FUNCTION OF OUTDOOR DESIGN TEMPERATURES

	Outdoor Design Temperature, °F					
Class	**85**	**90**	**95**	**100**	**105**	**110**
Tight	0.33	0.34	0.35	0.36	0.37	0.38
Medium	0.46	0.48	0.50	0.52	0.54	0.56
Loose	0.68	0.70	0.72	0.74	0.76	0.78

Values for 7.5 mph wind and indoor temperature of 75°F.

Table A.19
THERMAL RESISTANCE *R* OF SURFACE AIR FILMS AND AIR SPACES (hr · ft^2-F/BTU)

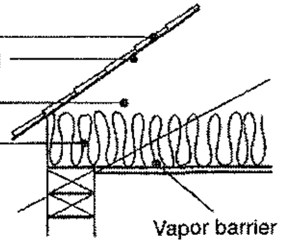
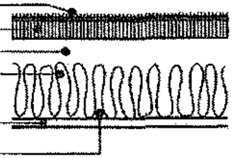
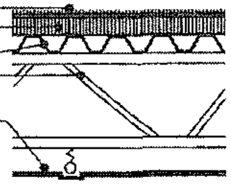
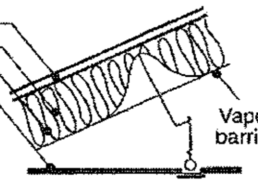
SURFACE AIR FILMS

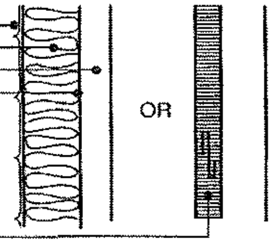
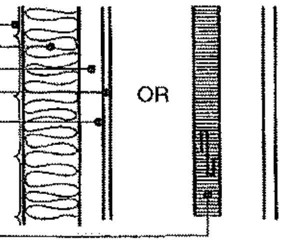
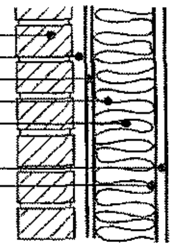
	Direction of Heat Flow	*R*-Value
STILL AIR (interior surfaces)		
Horizontal	Upward	0.61
Sloping–45 degree	Upward	0.62
Vertical	Horizontal	0.68
Sloping–45 degree	Downward	0.76
Horizontal	Downward	0.92
MOVING AIR (exterior surfaces)		
15 mph Wind (Winter)	Any	0.17
7.5 mph Wind (Summer)	Any	0.25

AIR SPACES

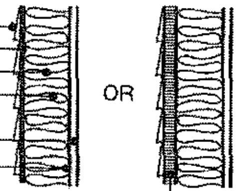
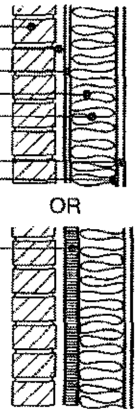
Position of Air Space	Direction of Heat Flow	Thickness of Air Space			
		½″	¾″	1½″	3½″
		R-Value			
Horizontal	Up	0.84	0.87	0.89	0.93
45° Slope	Up	0.90	0.94	0.91	0.96
Vertical	Horizontal	0.91	1.01	1.02	1.01
Horizontal	Down	0.92	1.02	1.14	1.21
45° Slope	Down	0.92	1.02	1.09	1.05

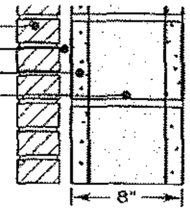
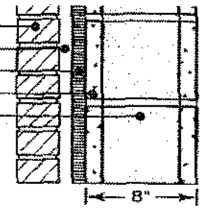
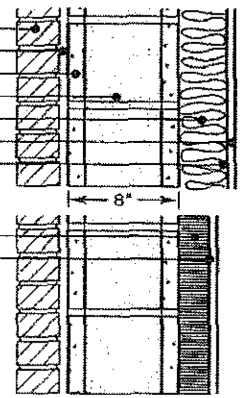
Table A.20 TYPICAL BUILDING ROOF AND WALL CONSTRUCTION CROSS-SECTIONS AND OVERALL HEAT TRANSFER COEFFICIENTS, BTU/HR-FT²-F

ROOF SECTIONS	R_i	U_w
 Asphaltic shingles 1/2" plywood sheathing 2 × trusses @ 16"- 24" o.c. Batt or loose fill insulation Vapor barrier	11 19 22 30	0.08 0.05 0.04 0.03
 Built-up roof 1/2" Plywood deck 2 × rafters @ 16"- 24" o.c. Batt or loose fill insulation 1/2" Drywall ceiling Vapor barrier	11 19 22 30	0.07 0.05 0.04 0.03
 Built-up roof Rigid insulation Metal deck Bar joists @ 16"- 24" o.c. Lay-in ceiling	No ceiling 5.5 8 11 15 Ceiling 5.5 8 11 15	 0.14 0.11 0.08 0.06 0.10 0.08 0.06 0.05
 Metal roof Steel purlins Batt insulation Lay-in ceiling Vapor barrier	No ceiling 3.5 8 11 19 Ceiling 3.5 8 11 19	 0.23 0.11 0.08 0.05 0.13 0.08 0.07 0.04

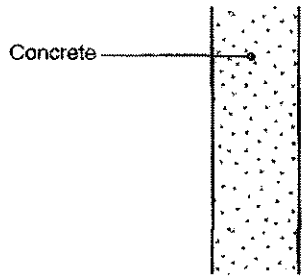
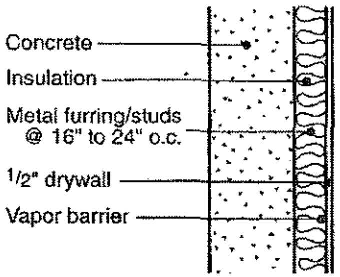
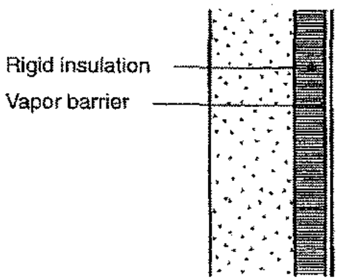
WALL SECTIONS	R_i	U_w
 Metal siding Insulation Metal studs or girts Vapor barrier OR Insulated metal sandwich panel	3.5 8 11 19	0.23 0.11 0.08 0.05
 Metal siding Insulation Metal studs or girts 1/2" drywall Vapor barrier OR Insulation metal sandwich panel	3.5 8 11 19	0.17 0.10 0.07 0.05
 Brick veneer Air space Sheathing Insulation Metal studs @ 16"-24" o.c. 1/2" drywall Vapor barrier	8 11 19	0.09 0.07 0.05

(Continued)

WALL SECTIONS	R_i	U_w
Wood or metal siding Sheathing Insulation 2 × 4 studs @ 16"-24" o.c. 1/2" drywall Vapor barrier Rigid insulation  	8 11 14	0.09 0.08 0.07
2 × 6 studs, same construction as above	8 11 19	0.09 0.07 0.05
Face brick Air space Sheathing Insulation 2 × 4 studs @ 16"-24" o.c. 1/2" drywall Vapor barrier OR Rigid insulation 	8 11 19	0.09 0.07 0.06
2 × 6 studs, same construction as above	8 11 19	0.08 0.07 0.05

WALL SECTIONS	DENSITY	R_i	U_w
Face brick Air space 8" Conc. block Core insulation  	Conc. Block 80#/cu ft	no insulation core insulation	0.23 0.12
	Conc. Block 120#/cu ft	no insulation core insulation	0.27 0.16
Face brick Air space Rigid insulation 8" Conc. block Core insulation  	Conc. Block 80#/cu ft	Core insulation and R_i 3 5.5 8 11	0.09 0.07 0.06 0.05
	Conc. Block 120#/cu ft	Core insulation and R_i 3 5.5 8 11	0.11 0.09 0.07 0.06
Face brick Air space 8" Conc. block Core insulation Insulation 1/2" drywall Vapor barrier Rigid insulation Vapor barrier  	Conc. Block 80#/cu ft	Core insulation and R_i 3.5 (1 × 2 @ 16" o.c.) 5.5 8 (2 × 3 @ 16" o.c.)	0.08 0.07 0.06
	Conc. Block 120#/cu ft	Core insulation and R_i 3.5 (1 × 2 @ 16" o.c.) 5.5 8 (2 × 3 @ 16" o.c.)	0.10 0.08 0.07

(Continued)

WALL SECTIONS	DENSITY	W	R_i	U_w
	80#/cu ft	6" 8" 12"	— — —	0.31 0.25 0.18
	120#/cu ft	6" 8" 12"	— — —	0.50 0.42 0.32
 OR 	80#/cu ft	6"	3 5.5 8 11	0.15 0.11 0.09 0.07
		8"	3 5.5 8 11	0.13 0.10 0.08 0.06
		12"	3 5.5 8 11	0.11 0.09 0.07 0.06
	120#/cu ft	6"	3 5.5 8 11	0.18 0.13 0.10 0.07
		8"	3 5.5 8 11	0.17 0.12 0.09 0.07
		12"	3 5.5 8 11	0.15 0.11 0.09 0.07

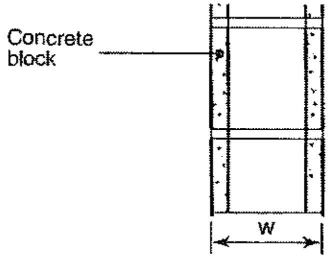
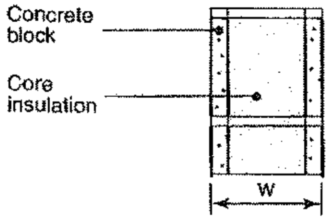
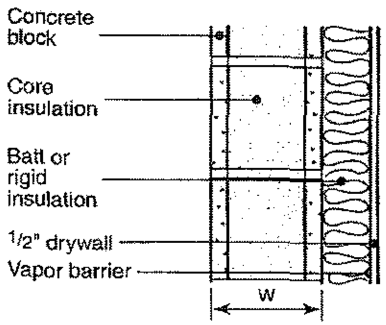
WALL SECTIONS	DENSITY	W	R_i	U_w
	Conc. Block 80#/cu ft	6" 8" 12"	— — —	.37 .34 .29
	Conc. Block 120#/cu ft	6" 8" 12"	— — —	.47 .43 .38
	Conc. Block 80#/cu ft	6" 8" 12"	— — —	.18 .14 .10
	Conc. Block 120#/cu ft	6" 8" 12"	— — —	.26 .22 .17
	Conc. Block 80#/cu ft	6"	3.5 5.5 8	.11 .09 .07
		8"	3.5 5.5 8	.09 .08 .05
		12"	3.5 5.5 8	.07 .06 .05
	Conc. Block 120#/cu ft	6"	3.5 5.5 8	.13 .10 .08
		8"	3.5 5.5 8	.12 .09 .06
		12"	3.5 5.5 8	.10 .08 .06

Table A.21 OVERALL HEAT TRANSFER COEFFICIENT *U* FOR BUILDING CONSTRUCTION COMPONENTS, BTU/HR-FT^2-F

Construction	*U*-Value in BTU/hr-ft^2-F	
	Summer	Winter
WALLS		
Frame with wood siding, sheathing, and inside finish:		
No insulation	.22	.23
R-7 insulation (2 in.–2½ in.)	.09	.09
R-11 insulation (3 in.–3½ in.)	.07	.07
Frame with 4 in. brick or stone veneer, sheathing, and inside finish:		
No insulation	.24	.24
R-7 insulation	.09	.09
R-11 insulation	.07	.07
Frame with 1 in. stucco, sheathing, and inside finish:		
No insulation	.29	.29
R-7 insulation	.10	.10
R-11 insulation	.07	.07
Masonry:		
8 in. concrete block, no finish	.49	.51
12 in. concrete block, no finish	.45	.47
Masonry (8 in. concrete block):		
Inside finish:		
furred gypsum wallboard (½ in.); no insulation	.29	.30
furred, foil-backed gypsum wallboard (½ in.); no insulation	.29	.30
1 in. polystyrene insulation board (*R*-5), and ½ in. gypsum wallboard	.13	.13
Masonry (8 in. cinder block or hollow clay tile):		
Inside finish:		
furred gypsum wallboard (½ in.); no insulation	.25	.25
furred, foil-backed gypsum wallboard (½ in.); no insulation	.17	.17
1 in. polystyrene insulation board (*R*-5), and ½ in. gypsum wallboard	.12	.12
Masonry (4 in. face brick and 8 in. cinder block or 8 in. hollow clay tile):		
Inside finish:		
furred gypsum wallboard (½ in.); no insulation	.22	.22
furred, foil-backed gypsum wallboard (½ in.); no insulation	.15	.16
1 in. polystyrene insulation board (*R*-5), and ½ in. gypsum wallboard	.12	.12
Masonry (12 in. hollow clay tile or 12 in. cinder block):		
Inside finish:		
furred gypsum wallboard (½ in.); no insulation	.24	.24
furred, foil-backed gypsum wallboard (½ in.); no insulation	.16	.17
1 in. polystyrene insulation board (*R*-5), and ½ in. gypsum wallboard	.12	.12
Masonry (4 in. face brick, 4 in. common brick):		
Inside finish:		
furred gypsum wallboard (½ in.); no insulation	.28	.28
furred, foil-backed gypsum wallboard (½ in.); no insulation	.18	.19
1 in. polystyrene insulation board (*R*-5), and ½ in. gypsum wallboard	.13	.13
Masonry (8 in. concrete or 8 in. stone):		
Inside finish:		
furred gypsum wallboard (½ in.); no insulation	.33	.34
furred, foil-backed gypsum wallboard (½ in.); no insulation	.21	.21
1 in. polystyrene insulation board (*R*-5), and ½ in. gypsum wallboard	.14	.14
Metal with vinyl inside finish, *R*-7 (3 in. glass fiber batt)	.14	.14
PARTITIONS		
Frame (½ in. gypsum wallboard one side only): No insulation	.55	.55
Frame (½ in. gypsum wallboard each side):		
No insulation	.31	.31
R-11 insulation	.08	.08
Masonry (4 in. cinder block):		
No insulation, no finish	.40	.40
No insulation, one side furred gypsum wallboard (½ in.)	.26	.26
No insulation, both sides furred gypsum wallboard (½ in.)	.19	.19
One side 1 in. polystyrene insulation board (*R*-5), and ½ in. gypsum wallboard	.13	.13

(Continued)

Construction	*U*-Value in BTU/hr-ft^2-F	
	Summer	Winter
CEILING–FLOOR		
Frame (asphalt tile floor, $\frac{5}{8}$ in. plywood, $\frac{25}{32}$ in. wood subfloor, finished ceiling):		
Heat flow up	.23	.23
Heat flow down	.20	.19
Concrete (asphalt tile floor, 4 in. concrete deck, air space, finished ceiling):		
Heat flow up	.34	.33
Heat flow down	.26	.25
ROOF (flat roof, no finished ceiling)		
Steel deck:		
No insulation	.64	.86
1 in. insulation (*R*-2.78)	.23	.25
2 in. insulation (*R*-5.56)	.15	.16
1 in. Wood deck:		
No insulation	.40	.48
1 in. insulation (*R*-2.78)	.19	.21
2 in. insulation (*R*-5.56)	.12	.13
2.5 in. Wood deck:		
No insulation	.25	.26
1 in. insulation (*R*-2.78)	.15	.16
2 in. insulation (*R*-5.56)	.10	.11
4 in. Wood deck:		
No insulation	.17	.18
1 in. insulation (*R*-2.78)	.12	.12
2 in. insulation (*R*-5.56)	.09	.09
ROOF–CEILING (flat roof, finished ceiling)		
Steel deck:		
No insulation	.33	.40
1 in. insulation (*R*-2.78)	.17	.19
2 in. insulation (*R*-5.56)	.12	.13
1 in. Wood deck:		
No insulation	.26	.29
1 in. insulation (*R*-2.78)	.15	.16
2 in. insulation (*R*-5.56)	.11	.11
2.5 in. Wood deck:		
No insulation	.18	.20
1 in. insulation (*R*-2.78)	.12	.13
2 in. insulation (*R*-5.56)	.09	.10
4 in. Wood deck:		
No insulation	.14	.15
1 in. insulation (*R*-2.78)	.10	.10
2 in. insulation (*R*-5.56)	.08	.08
4 in. Lightweight concrete deck:		
No insulation	.14	.15
6 in. Lightweight concrete deck:		
No insulation	.10	.11
8 in. Lightweight concrete deck:		
No insulation	.08	.09
2 in. Heavyweight concrete deck:		
No insulation	.32	.38
1 in. insulation (*R*-2.78)	.17	.19
2 in. insulation (*R*-5.56)	.11	.12
4 in. Heavyweight concrete deck:		
No insulation	.30	.36
1 in. insulation (*R*-2.78)	.16	.18
2 in. insulation (*R*-5.56)	.11	.12
6 in. Heavyweight concrete deck:		
No insulation	.28	.33
1 in. insulation (*R*-2.78)	.16	.17
2 in. insulation (*R*-5.56)	.11	.12

(Continued)

Construction	*U*-Value in BTU/hr-ft²-F	
	Summer	Winter
ROOF–CEILING (wood frame pitched roof, finished ceiling on rafters)		
No insulation	.28	.29
R-19 insulation (5½ in.–6½ in.)	.05	.05
ROOF–ATTIC–CEILING (attic with natural ventilation)		
No insulation	.15	.29
R-19 insulation (5½ in.–6½ in.)	.04	.05
FLOORS		
Floor over unconditioned space, no ceiling:		
Wood frame:		
No insulation	.33	.27
R-7 insulation (2 in.–2½ in.)	.09	.08
Concrete deck:		
No insulation	.59	.43
R-7 insulation	.10	.09
DOORS		
Solid wood:		
1 in. thick	.61	.64
1½ in. thick	.47	.49
2 in. thick	.42	.43
Steel:		
1½ in. thick, mineral fiber core	.58	.59
1½ in. thick, polystyrene core	.46	.47
1½ in. thick, urethane foam core	.39	.40

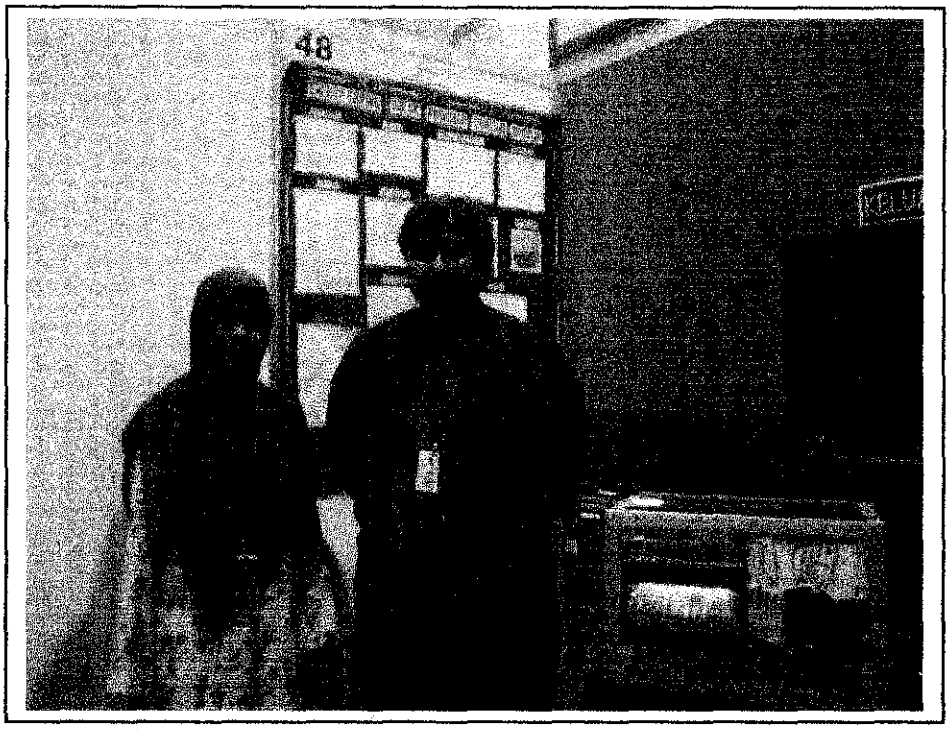
Table A.22 OVERALL HEAT TRANSFER COEFFICIENT *U* FOR GLASS (BTU/HR-FT²-F) (For glass installed vertically)

Type of Glazing	Type of Frame (Sash)			
	Aluminum (with thermal break)		Wood or Vinyl	
	Winter	Summer	Winter	Summer
Single glass	1.10	1.01	0.98	0.90
Double glass				
⅜ in. air space	0.60	0.56	0.51	0.47
⅜ in. air space E-film	0.48	0.45	0.39	0.37
Triple Glass				
⅜ in. air space	0.46	0.43	0.38	0.36
⅜ in. argon space	0.34	0.33	0.25	0.24

Note: E-film is a reflective coating (E = 0.15).

APPENDIX 8

Invention and Design Exhibition 17 (EDX 17) For Final Year Project, Universiti Teknologi PETRONAS



With my supervisor, Dr. Balbir Singh