CHAPTER 1

INTRODUCTION

1.1 Background of Study

Radiant light and heat from the sun has abundant energy potential. This solar energy has potential to be used more intensively in the present and future. This applies to solar power generation, solar heating as well as solar cooling. The solar heat leads to increase in surrounding temperature. When temperature rises, people tend to look to cooling comfort including air conditioning system. It is shown in Figure 1 that the demand of electricity for cooling purposes increase with the increasing the amount of the solar radiation. This implies that the more solar radiation at certain time of a day, the more cooling demand required for people's thermal comfort. The sun, which heat up the earth also delivers energy which can cool the earth. Using this advantage, evaporative solar cooler system is designed. This cooler will use solar electricity as main power resources.

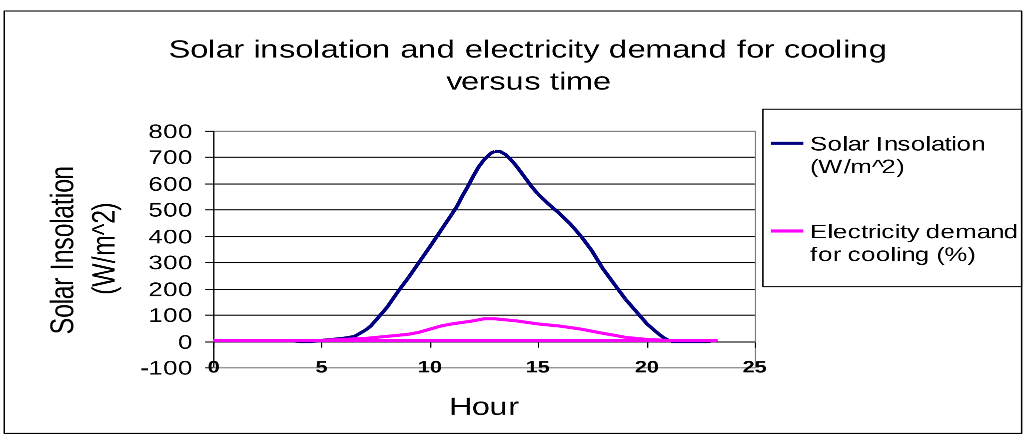


Figure 1: Graph of solar insolation and electricity demand for cooling versus time

1.2 Problem Statement

1.2.1 Problem Identification

Conventional air conditioning system has high power requirement, approximately 3-5 horsepower (HP). The high electricity demand for cooling purpose increase the electricity bills, which will lead to increase in living cost. In order to utilize the electricity efficiently, the need to design an alternative cooling system is inevitable. The development of Evaporative Solar Cooler System is a reasonably good solution to provide low power and low cost cooling system for domestic sector.

1.2.2 Significance of The Project

The significance of this project is that in the future, renewable energy, which is solar energy, can be utilized for generating electricity to power up applications. The evaporative solar cooler system is one of the low cost and low power cooling applications that can be developed using the solar electricity. This evaporative solar cooler system has many advantages such as:

- Provide low power and low cost alternative air-conditioning system for domestic sector.
- Reduce electricity bills because evaporative solar cooler system use less electricity compared to conventional air-conditioning system, which will lead to reducing in living cost.
- Reduce the environmental effect due to emission of chlorofluorocarbons (CFC) of conventional air-conditioning system.

1.3 Objectives

The objectives of this project are:

- To carry out feasibility study on the possibility of utilizing solar energy for cooling purposes.
- To do cooling load analysis and develop Cooling Load Calculator.
- To design and build prototype for Evaporative Solar Cooler System that is powered by solar energy for domestic sector

1.4 Scope of Study

The scopes of study for this project are:

- Study on solar geometry which includes the sun's characteristic.
- Research on how solar energy generating electricity
- Study on cooling load analysis
- Research and design of evaporative solar cooler system for domestic sector

1.5 Relevancy And Feasibility Of The Project

This project is relevant to the study of alternative renewable energy where people are paying attention to develop applications that utilize the renewable energy. The project is feasible as it utilizes renewable solar energy to generate electricity for cooling application. This project is low in cost for analysis and brings huge benefits for the future.

CHAPTER 2

LITERATURE REVIEW

2.1 Solar Energy

Sun's heat and light provide source of energy that can be utilized in various ways. There are varieties of solar technologies that have been developed including solar heating, solar cooling, and solar photovoltaic (PV) systems. The main concentration in this project is PV technology. The design of PV system depends on assessment of solar radiation from the sun. The sun acts as emitter of solar radiation, with average of $1000W/m^2$ at standard test condition. It is shown in Figure 2 that when the solar radiation enter the earth's atmosphere, a part of the incident energy being removed by scattering and absorption by particles in the earth. There are two types of solar radiation, which is beam radiation and diffuse radiation. The radiation that reaches the surface directly without being scattered is beam radiation. The radiation that have been scattered before reaching the ground is known as diffuse radiation. Reflection that is received by the receiver after being reflected by the ground is known as albedo.

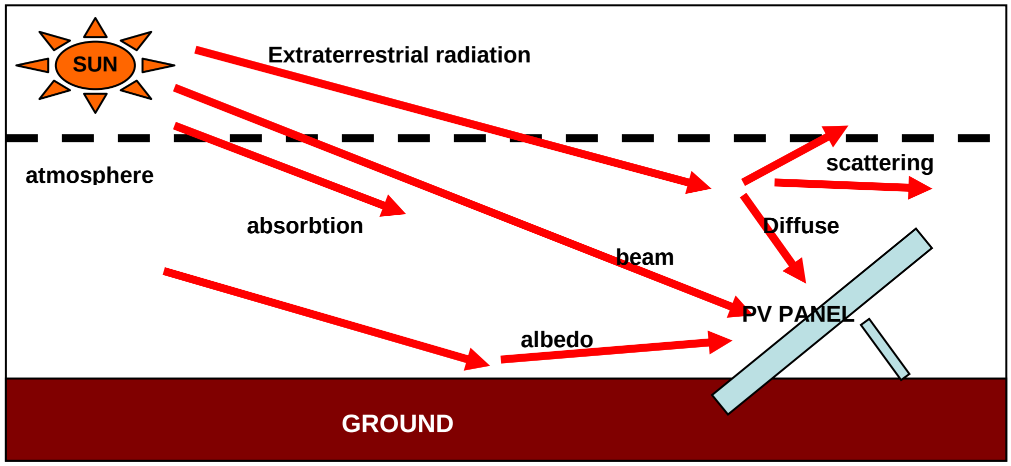


Figure 2: Solar radiation

Due to the apparent motion of the sun, climatic condition (cloud), the amount of radiation that reaches the ground is not a constant value. Figure 3 shows the apparent motion of the sun. The earth revolves around the sun in elliptical orbit. The sphere in figure 3 represents the relative position of the sun and the earth. The motion of the earth around the sun is represented by the apparent motion of the sun in elliptic which is tilted at 23.45^{o} to the equator. The angle between the line joining the centers of the earth and the sun is known as solar declination and denoted by δ.[4]

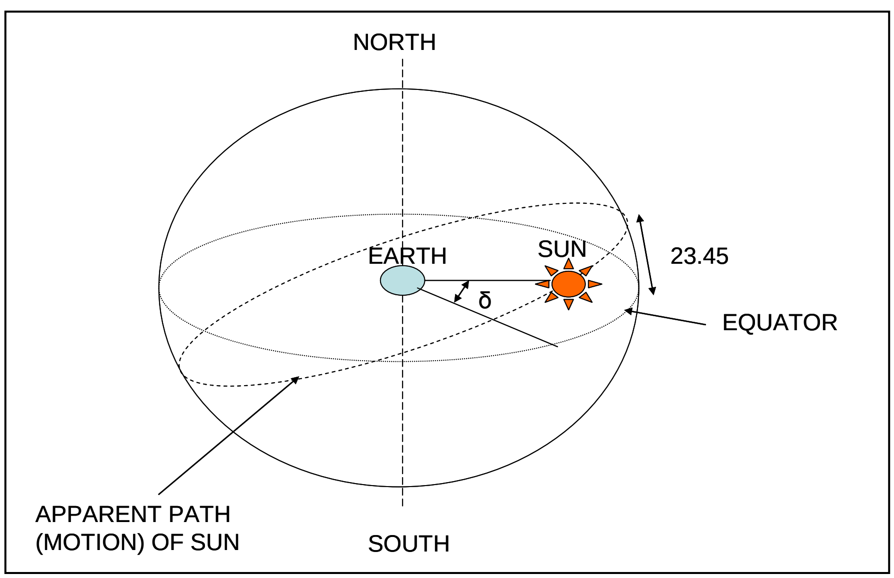


Figure 3: The apparent yearly motion of the sun

2.2 Solar Photovoltaic (PV) system

In PV system, solar cells are the fundamental power conversion unit from solar energy to solar electricity. Solar cells which is made of semiconductor, is used to capture the sun radiation and convert the radiation into solar electricity. The solar cell operation is based on the ability of semiconductors to convert sun radiation into electricity by photovoltaic effect. In the process, the solar insolation, which contain photons are reflected and absorbed by solar cells. This generates electron-hole pairs on both side of the junction of the cell. This generate minority carrier (mobile charged particles in the semiconductor) that diffuse to the junction and are swept away by the electric field which produce electric current across the solar cells. [4]

Solar cells are not the only component for generating solar electricity in photovoltaic system. Other parts are required to provide the electricity supply. The solar photovoltaic system consists of number of subsystems such as photovoltaic generator system, storage subsystem (battery), measurement and monitoring system (power conditioning) and backup generator system as shown in figure 4.

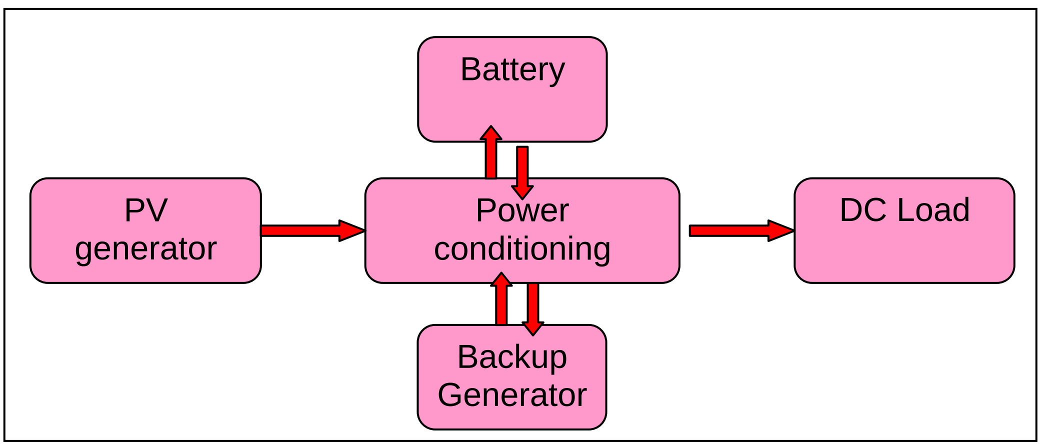


Figure 4: Solar Photovoltaic system

Photovoltaic generator system consists of the photovoltaic modules. The photovoltaic modules are interconnected to form a DC panel. A collection of panel produce photovoltaic array as shown in Figure 5.

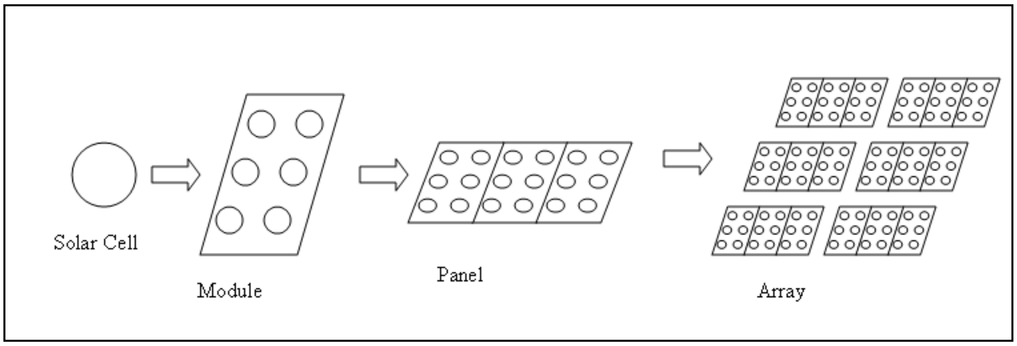


Figure 5: The photovoltaic hierarchy

Due to transient meteorological condition, power generated is either utilized directly or can be stored in battery. A lead-acid battery is the most common means of energy storage in PV system today. The fluctuating solar insolation intensity requires power conditioning system which is the charge controller. The function of a charge controller is to protect the battery bank from overcharging. When the bank is fully charged, the controller interrupts the flow of electricity from the PV panels. The backup generator serves as an auxiliary system to enhance stability and sustainability of the whole system.

2.3 Air Conditioning System

Air conditioning is a combined process that conditions the area for thermal comfort. It controls and maintains the temperature of conditioned area. An air conditioning system can be classified according to their construction and operating characteristic. The widely used air conditioning system is the individual room air conditioning system. This type of air conditioning system has a separated indoor-outdoor split unit and a heat pump. The heat pump extracts heat from the heat sources (indoor) and rejects the heat to air (outdoor). Freon is commonly used refrigerant or heat exchanger in this conventional air conditioning system. The usage of this refrigerant brought negative impact to the environment.

For cooling big buildings such as office, the commonly used air conditioner is central air conditioning system. This air conditioning have high compressor that have large capacity which can produce hundred tons of air conditioning.

For wide area of conditioned space such as airport and various building, the suitable type of air conditioning system is gas district cooling system. This system generates chilled water for air conditioning system as well as electricity for the building. This system is environmental friendly system because the main fuel used in the gas district cooling is natural gas while the chillers use non-CFC type of refrigerant.

Other type of air conditioning system is evaporative cooling air conditioning system. An evaporative cooling air conditioning system uses evaporation of water process to cool the designated area. This type of air conditioning system is designed in this project. Further details on this air conditioning system are discussed in the next section.

2.4 Evaporative Solar Cooler System

Evaporative solar cooler system is an air cooler system that uses solar power as sources of electricity. The solar electricity is generated from the sun by using photovoltaic cells technology by converting solar energy into solar electricity. The evaporative solar cooler uses evaporative cooling process to cool designated area. Evaporative cooling is a physical phenomenon in which evaporation of liquid (water) into the air will cool the surrounding and object in contact with it [1]. This cooler produces cooling effect by combining water evaporation process and reliable air moving system. The water evaporates due to the difference in temperature and vapor pressure between the water and the surrounding. The water and the air tend to equalize its temperature and vapor pressure. Thus, the water molecules evaporate and become gas molecule in the surrounding air. The amount of energy required to evaporate the air is known as latent heat. By heat conduction principle, the heat will move from the higher temperature in the air to the lower temperature of the water. So, the air becomes cooler.

There are three types of evaporative cooler which are direct evaporative cooler, indirect evaporative cooler, or two stage evaporative cooler. In direct evaporative cooler, the evaporated water cools the object in contact with it. The operation of this evaporative cooler is based on forced convection principle as shown in Figure 6. Water distribution system is located on the top of the cooler to supply water to the evaporative pad. Water soaks the evaporative pad (also known as cooling pad) and trickles through the pad. Water pump send back the excessive water from the pad to the top of the pad. A blower fan blows air through the evaporative pad which blows the cooled air into the house. The humidity of the cooled air is high.

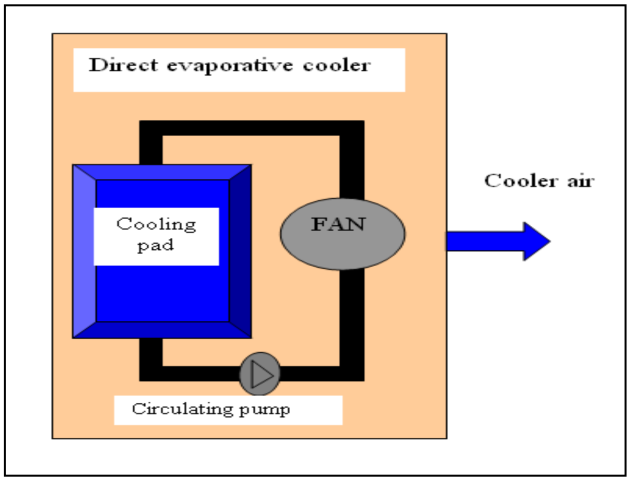


Figure 6: Direct Evaporative Cooler

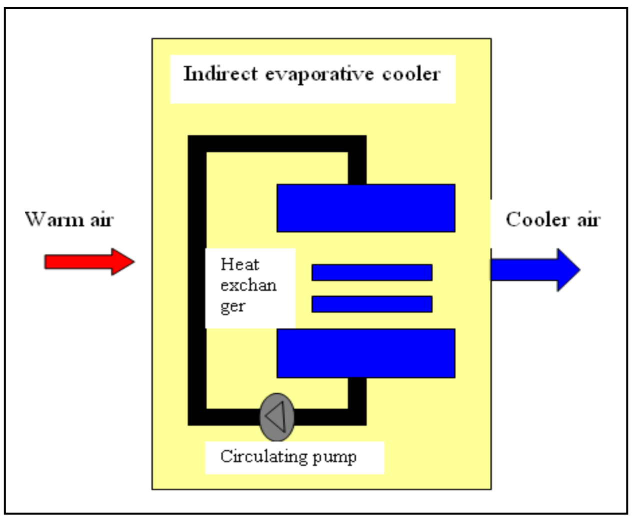


Figure 7: Indirect Evaporative Cooler

In indirect evaporative cooler, heat exchanger is used to cool the air, as shown in figure 7. The cooled air does not in direct contact with the conditioned object. The two-stage evaporative cooler is a combination of direct and indirect evaporative cooler. Two-stage evaporative coolers produce less humidity levels as compared with direct evaporative coolers. The humidity of two-stage evaporative coolers is between 50 and 70 percent, depending on the climate, compared to a traditional system that produces about 80 percent relative humidity air.

2.5 Heat Transfer

Heat transfer principal has to be considered in designing evaporative solar cooler system in order to minimize sources of heat. Heat transfer is the transition of thermal energy from a heated item to a cooler item. When an object or fluid is at a different temperature than its surroundings or another object heat transfer occurs so that the body and the surroundings reach thermal equilibrium. Heat transfer always occurs from a hot particle to a cold particle. The heat transfer required temperature difference between two medium. [1] Heat can be transferred in three different ways which in conduction, convection and radiation.

Conduction is the transfer of energy from a region of higher temperature to the region of low temperature in solids, liquids or gases. In gases or liquids, conduction is due to collisions and diffusion of the molecules during their random motion. In solids, it is due to the combination of vibrations of the molecules in a attice and the energy transported by free electron.[1] In designing the cooler factors that has to be considered is heat that conducted by object in the designated area. For example if the designated area is a house, heat conduction from human’s body, walls, roofs, windows and objects in the house should be considered. The rate of heat conduction through a medium depends on the thermal conductivity of the material, its thickness, areas and temperature differences across the medium. Rate of heat conduction is given in equation below [2]:

$$Qcond = \frac{kA\Delta T}{\Delta x} \tag{2.1}$$

Where, $Qcond$ = rate of heat conduction

k= thermal conductivity of the material

A = Area

ΔT = Temperature difference

Δx = Thickness

Convection is energy transfer between a surface and the adjacent liquid or gas that is in motion. Convection involves the combined effects of conduction and fluid motion. The faster the fluid motion, the greater the convection heat transfers [2]. Convection is divided into two categories, which are forced convection and natural convection. Natural convection is not generated by any external source such as fan but only by density differences in the fluid due to temperature difference. For example, when surrounding air receives heat, the air becomes less dense and rises. The surrounding, cooler air then moves to replace it. This cooler air is then heated and the process continued and repeated, forming convection current. Forced convection is generated by an external source such as fan. The concept of forced convection is used in the evaporative solar cooler system where the evaporated water is forced to circulate in the designated area by the fan blower in order to enhance the fluid motion for the designated area. So, the cooler should be placed on top of the designated area. This is due of the convection process occur where the warm air (which have low density than cold air) tend to stay in the top of cold air.

Radiation is the transfer of heat through empty space. Radiation does not require the presence of a material medium to take place. Example of energy transfer by radiation is the energy of the solar insolation from the sun to the earth. Radiation is sources of heat that should be minimized in designing cooling system.

2.6 Cooling Load Calculation

Cooling load calculations for air conditioning system design are used to determine the heat that must be removed from the area to maintain constant air temperature. The purpose of determining the heat is to determine the sizing of the system and equipment capacity for optimum design.

Cooling loads are usually classified into two categories: external and internal cooling loads. Internal cooling load are formed by the release of sensible heat and latent heat from the heat sources inside the conditioned space. For example, people, electric lights, equipment and appliances inside the conditioned space. External cooling load are formed because of heat gains in the conditioned area from external sources through the building. Examples of external cooling loads are:

- Heat gain from exterior wall or roofs
- Solar heat gain and conductive heat gain transmitted through the fenestrations, especially from window

There are various cooling load calculation method can be used to determine the total of heat. The methods are:

- Heat balance equations
- Transfer function and time function
- Cooling load temperature difference (CLTD) / Cooling load factor (CLF) method
- Total equivalent temperature difference (TETD) / time-averaging (TA) method

In this project, CLTD/CLF method is used for the total cooling load calculation. The coefficients are attached in Appendix II.

2.6.1 Cooling Load from Heat Gain through Structure (Walls and Roofs)

$$Q = A \times U \times CLTD \qquad (2.2)$$

Where;

Q= Cooling Load due to walls or roof (BTU-hr)

A = area for external walls or roofs (ft^2)

U = overall heat transfer coefficient for walls or roof (BTU/hr-ft^2)

CLTD = Cooling Load Temperature Difference, F

The CLTD values are listed in Table C in Appendix II. The CLTD values are interpolated between the listed outdoor temperatures. The heat transfer coefficients, U are listed in Table A in Appendix II.

2.6.2 Cooling Load from Heat Gain through Windows

$$Q = A \times GLF \qquad (2.3)$$

Where;

Q = Cooling Load due to heat gain through glass (BTU-hr)

A = Area of window glass (ft^2)

GLF = Glass Load Factor (BTU/hr-ft^2)

The Glass Load Factor are listed in Table D Appendix II

2.6.3 Cooling Load from People

$$Q = n \times (SHG \times LHG) \qquad (2.4)$$

Where;

Q = Cooling Load due people (BTU-hr)

n = number of people in the conditioned space

SHG = sensible heat gain per person

LHG = latent heat gain per person

Sensible heat gain per person and latent heat gain per person can be found in Table F Appendix II.

2.6.4 Cooling Load from Electrical Equipment and Appliances

$$Q = 3.4 \times W \tag{2.5}$$

Where;

Q = Cooling Load from electrical equipments / appliances (BTU/hr)

W = Equipment Capacity, watts

2.6.5 Cooling Load due to the infiltrating air

$$Q = 1.1 \times CFM \times TC \tag{2.6}$$

Where;

Q = sensible cooling load due to infiltrating air

CFM = air infiltration rate into room

TC = temperature change between inside and outdoor air

CFM can be found by; $$CFM = ACH \times \frac{V}{60} \tag{2.7}$$

Where

CFM= air infiltration rate into room, CFM

ACH= number of air changes per hour

V= Volume of room, ft^3

Air changes per hour are listed in Table E in Appendix II.

Three categories of construction tightness are described as follows:

- Tight: Well-fitted windows and doors, weather-striping, no fireplace
- Medium: Average fit windows and doors, fireplace that can be closed off
- Loose: Poorly fitted windows and doors, fireplace without shut-off

CHAPTER 3

METHODOLOGY AND PROJECT WORK

3.1 Procedure Identification

Flow chart below summarizes the methodology:

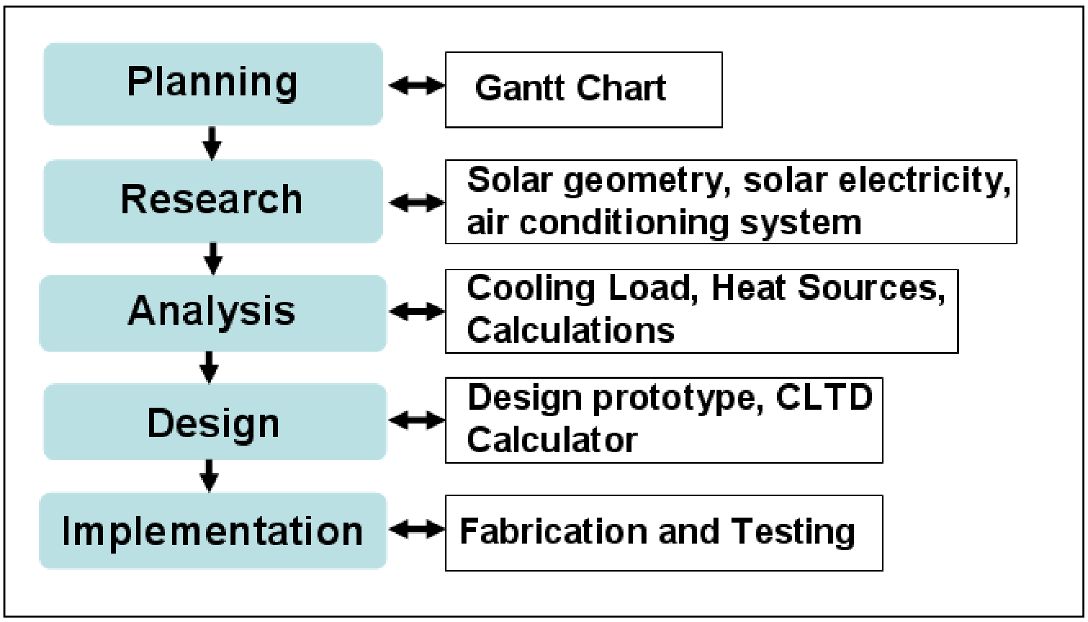


Figure 8: Flow Chart of Methodology

The methodology is divided into five phases: planning, research, analysis, design and implementation phase. The planning phase is the fundamental process of understanding why the system should be built and determining where to go about building it. This phase will ensure all activities will be done along the development of the system will be on time. The outcome for this phase is Gantt chart of activities. The Gantt chart for this project is included in the Appendix I.

The research phase is where all related information for this project is to be collected. The research include the feasibility study on solar geometry, solar electricity, possibility of utilizing solar energy for cooling, evaporative cooler system, heat sources and cooling load. The analysis is where many factors/consideration being analyzed before the implement the system. This phase include defining input and output process, cooling load analysis, equipment sizing analysis and equipment location analysis. The design phase decides how the system will operate. All the components required for the evaporative solar cooler system have to be specified. Design has to be analyzed for optimum efficiency with low cost and low power. The outputs of this phase are the design for the evaporative cooler and the design for cooling load calculator.

The final phase is the implementation phase which includes fabrication, testing and improvement. In this phase, the prototypes which represent the evaporative solar cooler system have to be constructed. This phase is the most critical phase for the project. The evaporative solar cooler system has to be constructed and tested to ensure it performs as designed. Testing is one of the most critical steps in implementation. If the evaporative solar cooler system passes the testing, the implementation phase proceeded to improvement phase. In the improvement phase, modifications are made to increase the quality of the model. However, if the model fails the testing, the model will be analyzed again to identify the changes needed for the model.

3.2 Project Work

The project work is divided into three phase: input, process and output. The input for this project is the entire component required which include solar panel, charge controller and battery. Other input is the data needed which include the radiation and load data. Next, in the process phase the input being used to provide solar electricity to the evaporative solar cooler system prototype. The prototype of evaporative solar cooler system is designed and fabricated. The output is the cooled air from the e evaporative solar cooler system.

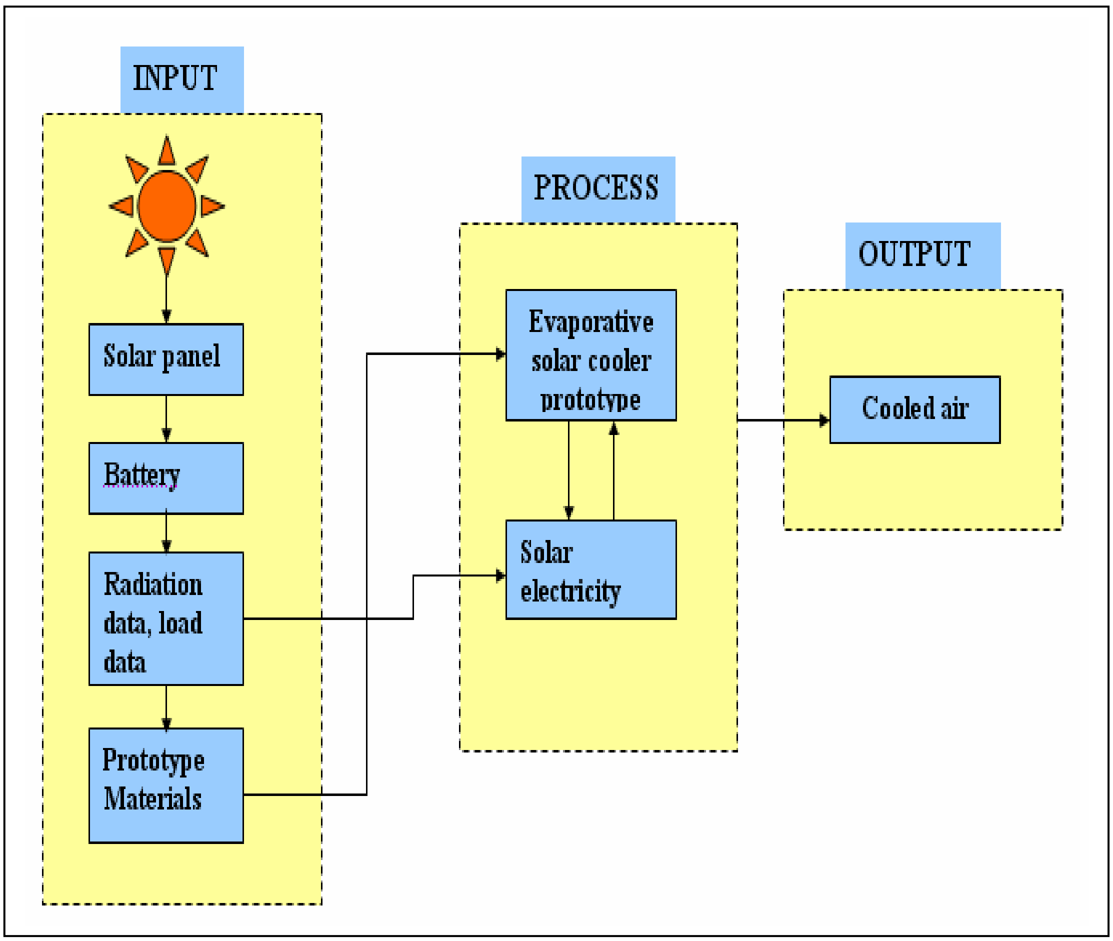


Figure 9: Project Work

3.3 Tools/Equipment Required

The tools and equipment which are required in this project are divided into two parts which is software and prototype parts. For software part, the simulation is done to develop Cooling Load Calculator by using Visual Basic which is compatible with Windows operating system.

Prototype part is further divided into two parts which is the evaporative cooler system part and solar electricity part. For the evaporative cooler system, the equipment required are fan blower, water pump, cooling pad, water distribution system, heat exchanger which is made of aluminium and cooler casing which is made of Perspex. Tools used to build the system include machine tool in the laboratory. For the solar electricity part, equipments needed are solar panels, charge controllers, and batteries.

3.4 Design justification

System requirement for designing the evaporative solar cooler system is divided into two parts; evaporative cooler parts and power source parts. The function of the evaporative cooler part is to cool the designated area. This evaporative cooler is supplied with electricity from the power source part. The electricity supply power to the fan blower and water pump of the cooler. Source of electricity is from the solar radiation which is then converted to solar electricity in the power source part. The system are discussed and explained according to each parts involved.

3.4.1 Solar Panel

PV panels are required for the evaporative cooler to produce direct current (DC) electricity from the solar insolation. The electricity produced depend on efficiency of the cell used, array area, location and array orientation.

Figure 10: Solar Panel

3.4.2 Battery Storage

Battery storage is used as an auxiliary system when solar panel is unable to provide the sufficient energy to the evaporative cooler such as at night or cloudy day. The batteries are available in many type and sizes. The specifications of battery used are:

- Type: Seal Lead Acid
- Rated voltage = 12V
- Rated ampere-hour = 7Ah

Figure 11: Battery Storage

3.4.3 Charge Controller

Charge controller is required to protect the battery bank from overcharging. It does this by monitoring the battery bank. When the bank is fully charged, the controller interrupts the flow of electricity from the PV panels.

3.4.4 Water Pump

The water pump provides sufficient pressure to overcome the resistance to flow of a liquid in piping system. Water pump is required to send back the water trickle from the bottom to the top of the evaporative pad and heat exchanger. Figure 12 below show the water pump used in this project. The specifications of water pump used are:

- Rated voltage = 12V
- Rated current = 0.9A

. Figure 12: Water pump

3.4.5 Water Distribution System

Water distribution system is required to distribute the water into the evaporative cooling pad. The amount of water distributed into the evaporative/cooling pad is controlled by the water distribution system. PVC pipe is used for the water distribution system because of the low thermal conductivity and adequate strength of PVC.

3.4.6 Fan Blower

The function of blower fan is to draw air through the heat exchanger and evaporative pad which then will blow the cooled air into the designated area. There are few types of fan blower can be used for the evaporative solar cooler system. Figure 13 below show the fan blower used in this project. The specifications of battery used are:

- Rated voltage = 12V
- Rated current = 0.2A
- CFM = 80

Figure 13: Fan Blower

3.4.7 Evaporative pad

The evaporative cooling pad is required to absorb water from water distribution system to allow the water to be evaporated using the fan blower. The thickness of the cooling pad is important for cooling efficiency. Thicker cooling pad will be more efficient as the thickness allow longer air contact.

3.5 Evaporative Solar Cooler System Prototype

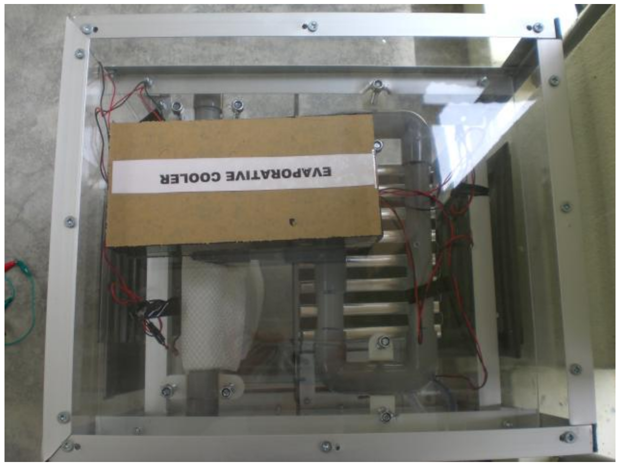


Figure 14: Top view of evaporative cooler prototype

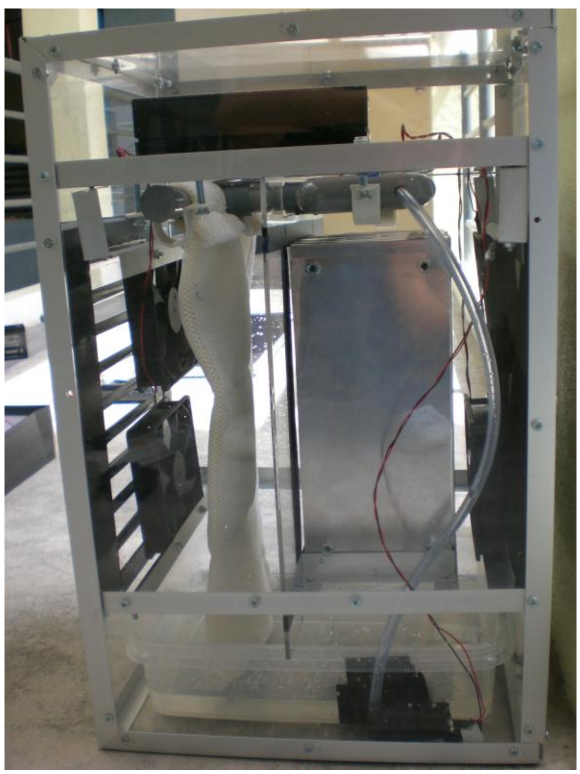


Figure 15: Side view of evaporative cooler prototype

Figure 16: Front view of evaporative cooler prototype

Figure 17: Aluminium Plat Type Heat Exchanger

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Evaporative Solar Cooler System Design

4.1.1 Two – stage evaporative cooler (Indirect –direct)

In this project, a two stage solar evaporative cooler is designed. For two-stage evaporative cooler, the cooling process is divided into 2 stages. In the first stage, warm air is cooled indirectly by passing through a cross-flow plat type heat exchanger that cools without adding moisture. In the second (direct) stage, air passes through an evaporative pad where the temperature drops more and the air picks up water, which increases the humidity. Because the air supply to the second stage evaporator is pre-cooled, less humidity is added to the air because cooler air is unable to hold as much moisture compared to warmer air. The result is cool air with a relative humidity between 50 and 70%. Figure 18 show the schematic for the two stage evaporative cooler that is designed.

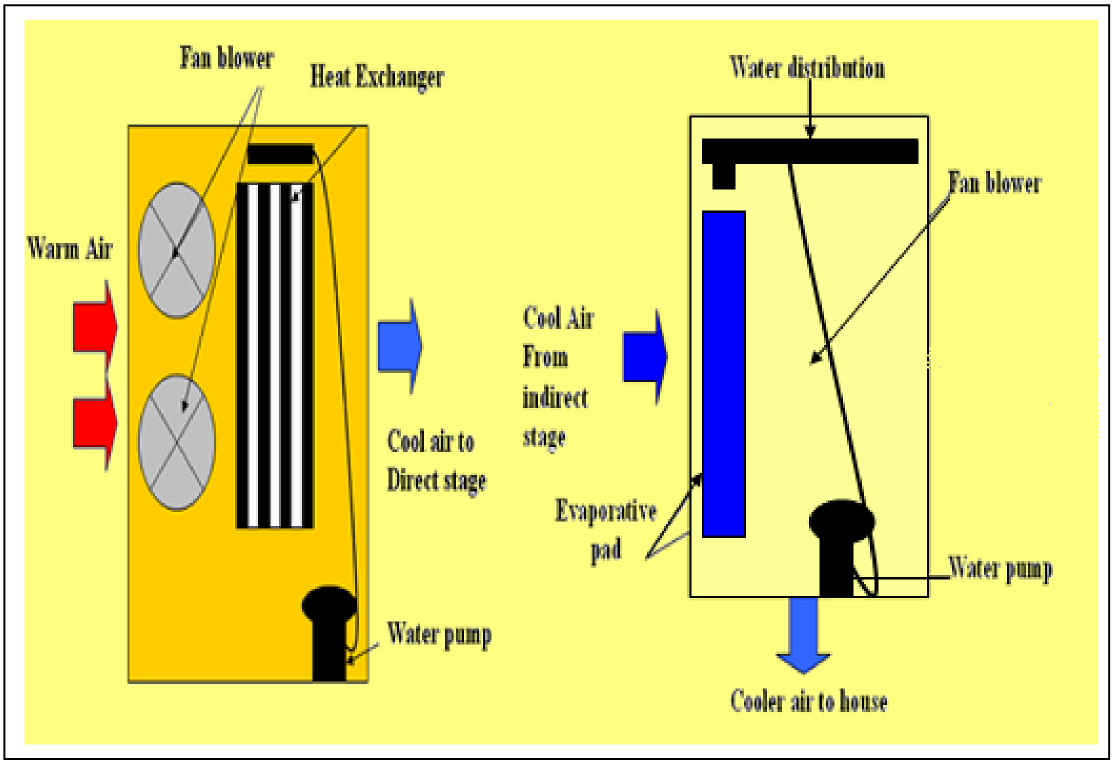


Figure 18: Schematic of two-stage evaporative cooler

4.1.2 Plate type heat exchanger

In indirect stage, one of the important components is the heat exchanger. The most efficient type of heat exchanger that is used is the plat type heat exchanger. A plat type heat exchanger uses metal (aluminium) plates to transfer heat between two fluids. The advantages of this plat type heat exchanger compared to conventional heat exchanger is in that the fluids are exposed to a much larger surface area because the fluids spread out over the plates. This improves the transfer of heat and increases the speed of the temperature change. Besides that, the plat type heat exchanger can operate with any combination of gas or liquid. Figure 19 show the design of plat type heat exchanger. A plate type heat exchanger is comprised of layers flat aluminium plates. In between each plate, there is a spacer to separate the layers of aluminium plates. In a plate-fin heat exchanger, the plats are easily able to be rearranged.

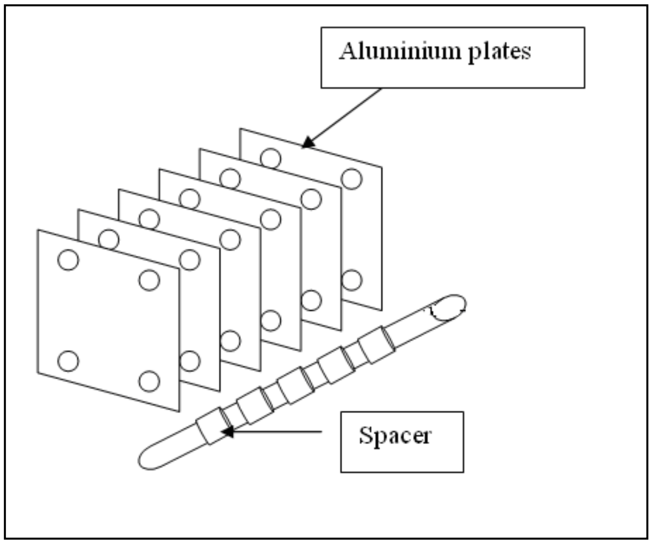


Figure 19: Design of plat type heat exchanger

4.1.3 Cross flow Arrangement

Cross flow arrangement is used for the heat exchanger as shown in figure 20. Cross flow arrangement exist when one fluids flows perpendicular to the second fluid. This means that one fluid flows through the tube (horizontal) while the other fluid flows at 90^o angle difference with respect to the first fluid. There are three fluids streams in plate type heat exchanger which are the cooled air, dry air and water along the vertical passage as shown in figure 21. The cooled air and the water are in cross flow arrangement. Warm and dry outdoor air at point A extracted by the supply fan, enters the back of the heat exchanger. The air is forced through the horizontal passage in which it releases its heat through the plates to the adjacent wetted surface of the vertical passages. The cooled air at point B flows out the front of to the direct part of the evaporative cooler.

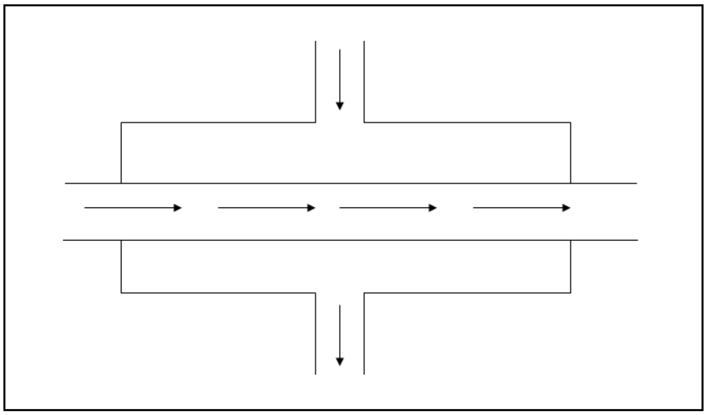


Figure 20: Cross flow arrangement

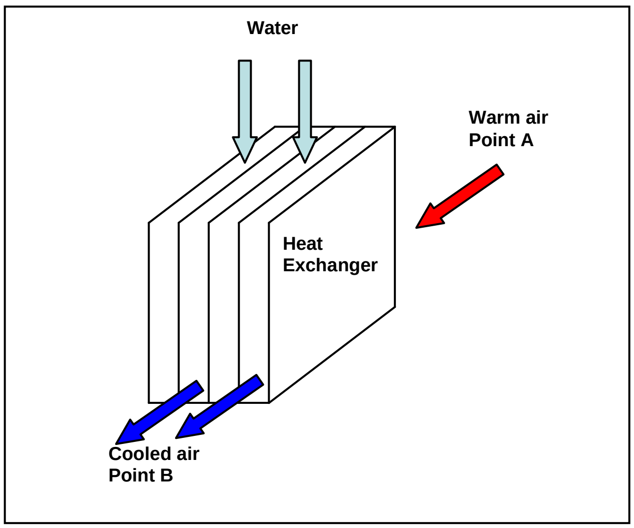


Figure 21: Cross flow heat exchanger

4.1.4 Layout Drawing

Figure below shows the layout drawing of the evaporative solar cooler system. The layouts include top view, side view and front view of the evaporative solar cooler system.

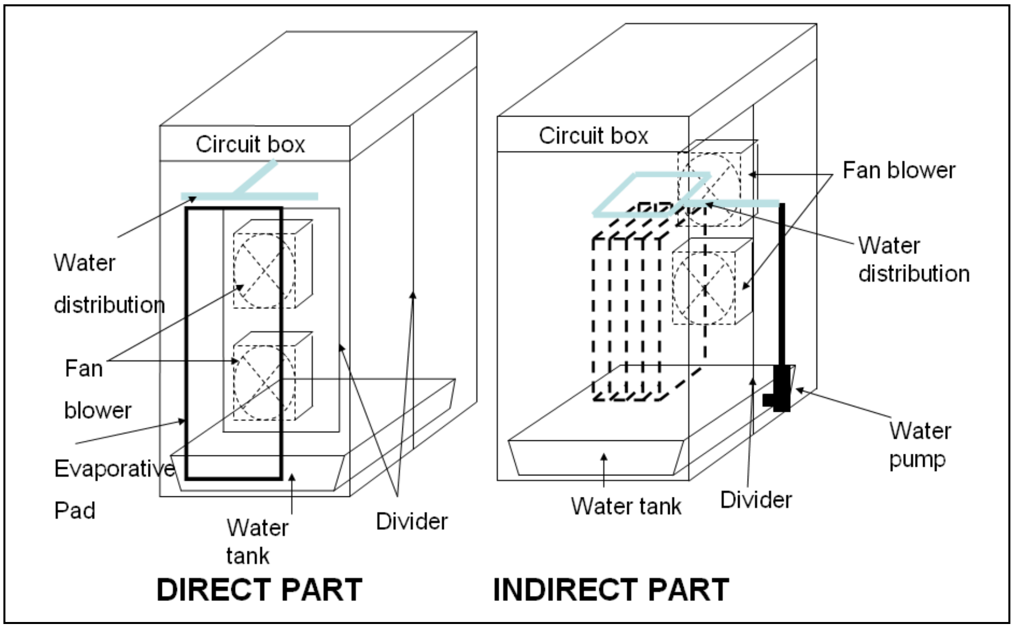


Figure 22: Layout drawing of evaporative solar cooler system

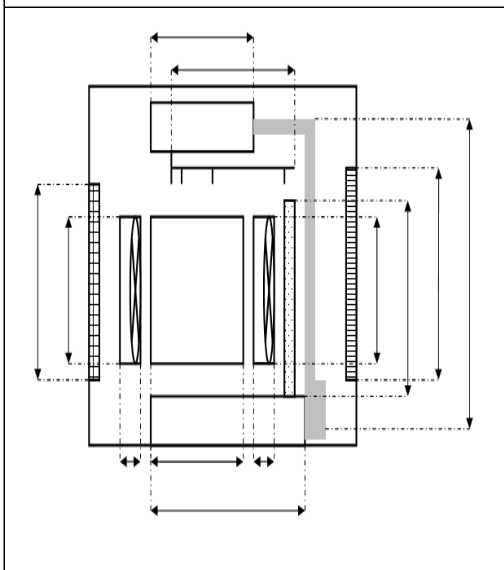
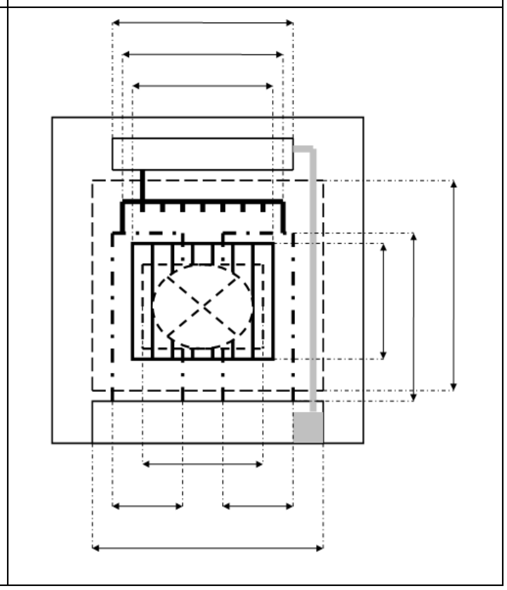
Side view	Front view
	

Figure 23: Layout drawing of evaporative solar cooler system

4.2 Calculation on Load Analysis

Load analysis is calculation for the load used for the evaporative solar cooler system which includes the fan and water pump. In this calculation, it is assumed that the average usage of air cooling system is 35 hour per week. The power requirement for the load is calculated by using equation:

$$\text{Power} = \text{Voltage (V)} \times \text{Current (I)} \quad (4.1)$$

Table 1: Load analysis

Items	Voltage (V)	Current (I)	Power (P)	Quantities	Total Watt	Hours/Week	Watt-Hour/Week
Fan	12V	0.2A	2.4W	4	9.6W	35	336
Water Pump	12V	0.9A	10.8W	1	10.8W	35	378
Total							714

Both load have DC System voltage = 12 V. So, total amp-hours per week used by DC loads:

$$= \frac{714Watt - hour / Week}{12V}$$

= 59.5 A-h/Week

Total average ampere hour per day

$$= \frac{59.5A - h / Week}{7days}$$

= 8.5 A-h/day

4.3 Equipment Sizing

The equipment sizing must be selected carefully in order to obtain optimum efficiency. The equipment sizing is divided into four parts which include evaporative cooler sizing, battery sizing and PV panel sizing.

4.3.1 PV Array Sizing

Harnessing device such as PV panel is rather expensive. Thus, proper sizing of the solar panel should be done. From the load analysis calculation, total average ampere-hour per day = 8.5 A-h. It is assumed that the average sun hour per day in Malaysia is 5 hours. From the solar panel specification, peak amp of solar module or current at maximum power = 2 A

Total ampere-hour per day with compensation for loss of battery charge/discharge

$= 1.2 \times \text{Ampere-hour per day}$

$= 1.2 \times 8.5 \text{ A-h/day}$

$= 10.2 \text{ A-h/day}$

Total solar array amp required for the system

$$= \frac{\text{Ampere-hour per day}}{\text{Sun hour per day}}$$

$$= \frac{10.2 \text{ A-h/day}}{5 \text{ hour/day}}$$

$= 2.04 \text{ A}$

So, total modules of solar modules in parallel required

$$= \frac{\text{Total solar array amp required}}{\text{Current at maximum power}}$$

$$= \frac{2.04}{2}$$

= 1 module

4.3.2 Battery sizing

From the load analysis calculation, daily amp-hour requirement = 8.5 Ah-hr. Maximum number of consecutive cloudy weather days expected in Malaysia or number of days of autonomy the system can support is taken to be 2 days

Amount of amp-hour need to store in the battery

= Daily amp-hour requirement x days of autonomy

= 10.2 A-h/day × 2 days

= 20.4 Ah

Given that the depth of discharge of battery or safety factor to avoid over-draining of battery= 0.5 (50%)

Total battery capacity

$$= \frac{\text{Amount of amp-hour need to store in the battery}}{\text{Depth of discharge of battery}}$$

$$= \frac{20.4Ah}{0.5}$$

= 40.8 Ah

From the specification of the battery, total amp-hour rating of battery = 12Ah. So, number of batteries wired in parallel required

$$= \frac{\text{Total battery capacity}}{\text{Total amp-hour rating of battery}}$$

$$= \frac{40.8Ah}{12Ah}$$

= 4

Number of batteries wired in series required

$$= \frac{\text{Nominal system voltage}}{\text{Battery Voltage}}$$

$$= \frac{12V}{12V}$$

= 1

Number of battery required for the system

= Number of batteries wired in series x Number of batteries wired in parallel

= 4×1

= 4 batteries

4.4 Evaporative Cooler Sizing

The proper size of evaporative cooler must be designed in order for the cooler to cool efficiently. The sizing is essential to ensure that the evaporative cooler will not be undersized or oversized. If the evaporative cooler is undersized, the cooling system will unable to provide thermal comfort for the occupants. Conversely, if the evaporative cooler is oversized, the system will be wasteful in energy used and non cost effective.

Evaporative cooler size is rated by the volume of air it can deliver to the designated area. The size of an evaporative cooler is measured in cubic feet per minute (CFM), or the number of cubic feet of air a cooler can move in a minute:

$$\text{CFM required for ventilation} = \frac{\text{Length(ft)} \times \text{Width(ft)} \times \text{Height(ft)}}{\text{Minutes per air change}}$$

Minutes per air change is based on table 2 below:

Table 2: Recommended air changes

RECOMMENDED AIR CHANGES	
Area to be Ventilated	Minutes Per Air Change
Dry Cleaners, Kitchens, Theaters, Toilets, Cafeterias	3-5
Bakeries, Boiler Room, Laundries	1-3
Attic Ventilation (entire home)	2-2 ½
Attic only (air-conditioned home)	4-6

The number of evaporative coolers required is determined by dividing the total CFM needed for the area by the output of the air output of the evaporative cooler. The output of cooler is based on specification of the evaporative cooler.

$$\text{Number of evaporative coolers required} = \frac{\text{Total CFM needed}}{\text{Output of cooler in CFM}} \qquad (4.1)$$

For evaporative solar cooling system, the sizing is determined using the sizing formula. For room dimensions with length = 10 ft, width = 8 ft and height = 8 ft, the sizing is shown below. Given that minutes per air change is 2 for house.

$$\text{CFM} = \frac{10 \times 8 \times 8}{2}$$

$$= 640 \text{ CFM}$$

$$\text{Output of cooler} = 4 \text{ fans} \times 80 \text{ CFM per fan}$$

$$= 320 \text{ CFM}$$

$$\text{Number of evaporative cooler required} = \frac{640}{320}$$

$$= 2$$

4.5 Evaporative Cooler Location

The location of the evaporative cooler must be selected for optimum utilization of the cooling system. For small room, the most suitable and low cost cooling system placement is window mounting system. The best position for the cooler is near an open window or external door with an opening on opposite side of room

Evaporative cooler are best located in shade and on sides of building that are windward. All heat sun striking coolers or their water supply lines evaporate the water without cooling air. That increases the washed-air humidity and reduces resulting comfort. Cooler placed in windward receive fresh dry air and ease flow through room. Side near sources of steam, smoke, vapor, odors, dusts and used washed air should be avoided.

Evaporative coolers are more suitable and efficient for areas where humidity is low. If the outside air is already humid, the cooling effect of the unit is limited. Figure 24 below show the recommended placement for the evaporative cooler

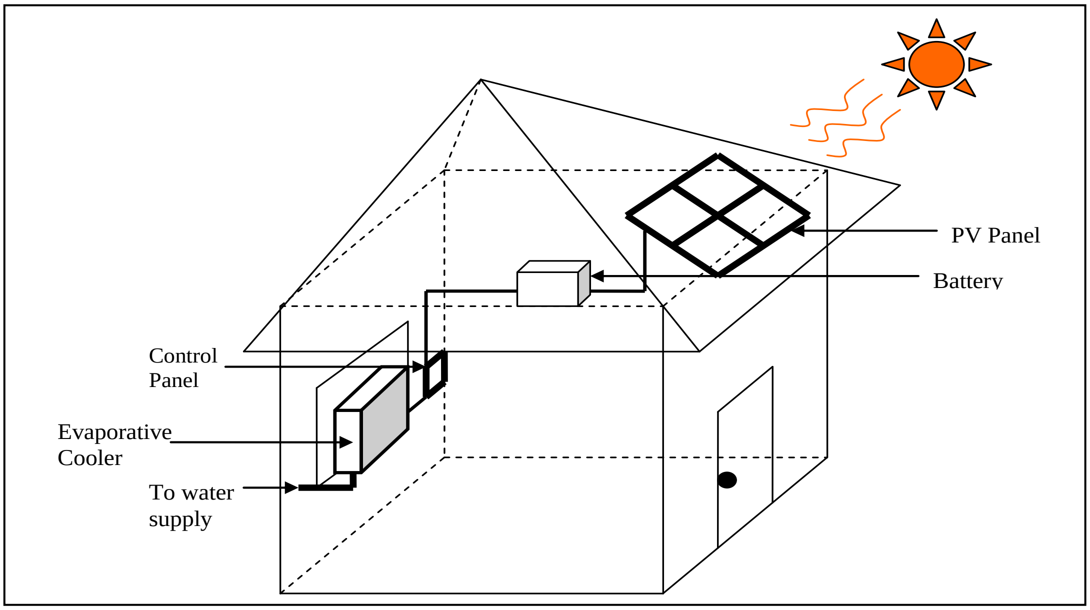


Figure 24: Evaporative cooler location

4.6 Residential Cooling Load Calculation Procedures

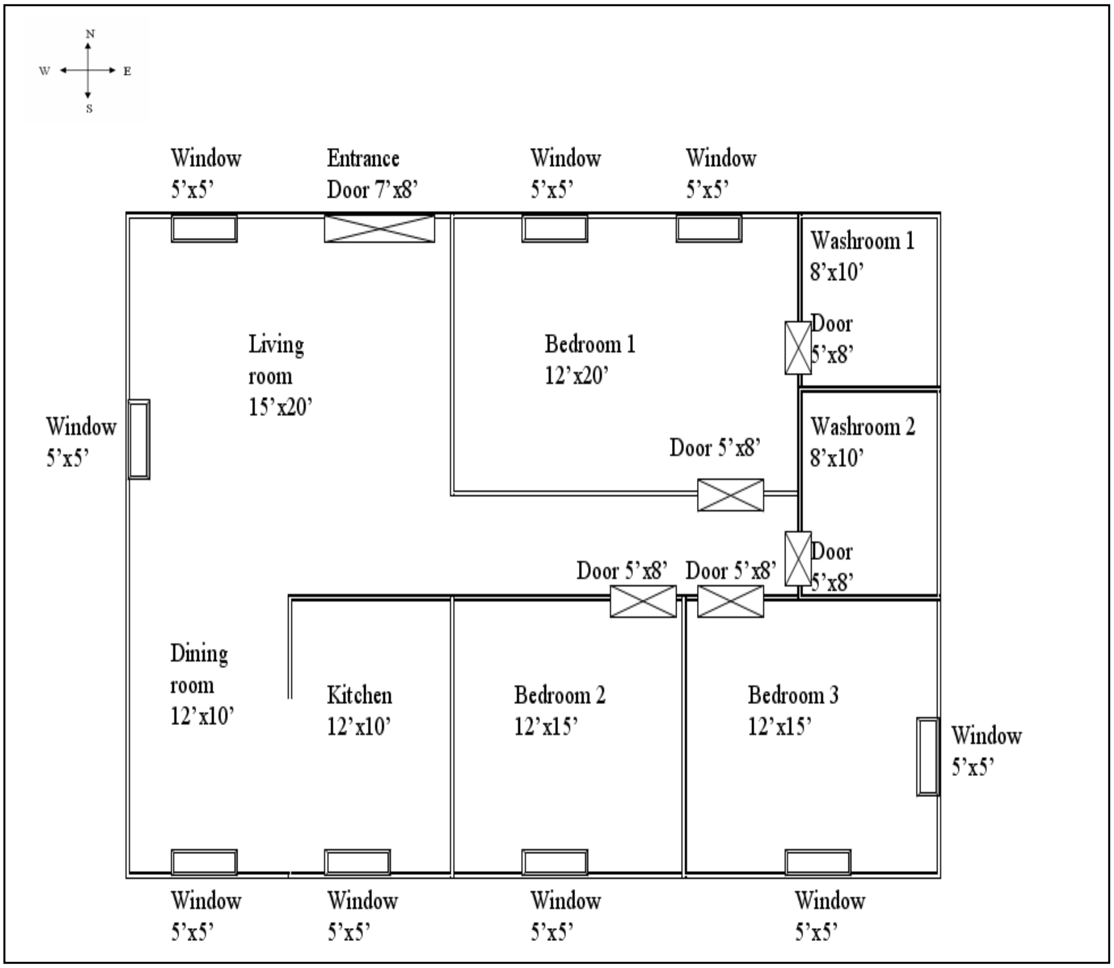


Figure 25: Architectural plan of a house and dimension

The steps in determining residential cooling loads can be summarized as follows:

1. The indoor and outdoor design temperature is 80 F and 90 F
2. The architectural plan of a house and dimension of each area are shown in figure 25 above. Ceiling height is 10 ft.
3. The heat transfer coefficients, U for each element (wall, roof and window) are selected in Table A and Table B in Appendix II. For this architectural plan, the coefficient are given as follows:

   U wall = 0.24 ; U roof = 0.08 ; U window = 0.56

4. The wall, window and roof heat gain are calculated using CLTD value from Table C in Appendix II.
5. Occupancy and appliance load (lighting and equipment) are determined.
6. The result is the air conditioning equipment total cooling load as shown in table 3 to table 10.

Table 3: Cooling Load calculation for dining room

Source	Direction	U		Unit		Unit	Btu/hr
Wall	W	0.24	120	ft^2	18	CLTD	518.4
	S	0.24	100	ft^2	11	CLTD	264
Window	S	0.56	25	ft^2	24	SCL	336
Roof	-	0.08	120	ft^2	42	CLTD	403.2
Occupants	-	-	-	Persons	-	Watt	-
Lighting	-	-	80	Watt	3.41	Btu-hr/watt	272.8
Equipment	-			Watt	3.41	Btu-hr/watt	-
Total							1794.14
Power requirement: 526.14 Watt = 0.705hp							

Table 4: Cooling Load calculation for kitchen

Source	Direction	U		Unit		Unit	Btu/hr
Wall	S	0.24	100	ft^2	11	CLTD	264
Window	S	0.56	25	ft^2	24	SCL	360
Roof	-	0.08	120	ft^2	42	CLTD	403.2
Occupants	-	-	1 Eating	Persons	150	Watt	511.5
Lighting	-	-	80	Watt	3.41	Btu-hr/watt	272.8
Equipment	-	-	-	Watt	3.41	Btu-hr/watt	-
Total							1787.5
Power requirement: 524.19Watt = 0.703hp							

Table 5: Cooling Load calculation for living room

Source	Direction	U		Unit		Unit	Btu/hr
Wall	N	0.24	200	ft^2	8	CLTD	384
	W	0.24	150	ft^2	18	CLTD	648
Window	N	0.56	25	ft^2	16	SCL	224
	W	0.56	25	ft^2	40	SCL	560
Roof	-	0.08	300	ft^2	42	CLTD	1008
Occupants	-	-	3 seated/rest	Persons	115	Watt	1176.45
Lighting	-	-	100	Watt	3.41	Btu-hr/watt	341
Equipment	-	-	-	Watt	3.41	Btu-hr/watt	-
Total							4341.45
Power requirement: 1273.15 Watt = 1.706hp							

Table 6: Cooling Load calculation for bedroom 1

Source	Direction	U		Unit		Unit	Btu/hr
Wall	N	0.24	200	ft^2	8	CLTD	384
Window	N	0.56	25	ft^2	16	SCL	224
	N	0.56	25	ft^2	16	SCL	224
Roof	-	0.08	240	ft^2	42	CLTD	806.4
Occupants	-	-	0	Persons	-	Watt	-
Lighting	-	-	40	Watt	3.41	Btu-hr/watt	136.4
Equipment	-	-	-	Watt	3.41	Btu-hr/watt	-
Total							1774.8
Power requirement: 520.47 Watt = 0.698hp							

Table 7: Cooling Load calculation for bedroom 2

Source	Direction	U		Unit		Unit	Btu/hr
Wall	S	0.24	150	ft^2	11	CLTD	396
Window	S	0.56	25	ft^2	24	SCL	336
Roof	-	0.08	180	ft^2	42	CLTD	604.8
Occupants	-	-	0	Persons	-	Watt	-
Lighting	-	-	40	Watt	3.41	Btu-hr/watt	136.4
Equipment	-	-	-	Watt	3.41	Btu-hr/watt	-
Total							1473.2
Power requirement: 432.02 Watt = 0.579hp							

Table 8: Cooling Load calculation for bedroom 3

Source	Direction	U		Unit		Unit	Btu/hr
Wall	S	0.24	150	ft^2	11	CLTD	396
	E	0.24	120	ft^2	18	CLTD	518.4
Window	S	0.56	25	ft^2	24	SCL	336
	E	0.56	25	ft^2	40	SCL	560
Roof	-	0.08	180	ft^2	42	CLTD	604.8
Occupants	-	-	0	Persons	-	Watt	-
Lighting	-	-	40	Watt	3.41	Btu-hr/watt	136.4
Equipment	-	-	-	Watt	3.41	Btu-hr/watt	-
Total							2551.6
Power requirement: 748.27 Watt = 1.003hp							

Table 9: Cooling Load calculation for wash room 1

Source	Direction	U		Unit		Unit	Btu/hr
Wall	N	0.24	100	ft^2	8	CLTD	192
	E	0.24	80	ft^2	18	CLTD	345.6
Roof	-	0.08	80	ft^2	42	CLTD	268.8
Occupants	-	-	0	Persons	-	Watt	-
Lighting	-	-	30	Watt	3.41	Btu-hr/watt	102.3
Equipment	-	-	-	Watt	3.41	Btu-hr/watt	-
Total							908.7
Power requirement: 266.48 Watt = 0.357hp							

Table 10: Cooling Load calculation for wash room 2

Source	Direction	U		Unit		Unit	Btu/hr
Wall	E	0.24	100	ft^2	18	CLTD	432
Roof	-	0.08	80	ft^2	42	CLTD	268.8
Occupants	-	0	-	Persons	-	Watt	
Lighting	-	-	30	Watt	3.41	Btu-hr/watt	102.3
Equipment	-			Watt	3.41	Btu-hr/watt	
Total							803.1
Power requirement: 235.5 Watt = 0.315hp							

4.7 Cooling Load Calculation Software

Cooling load calculator software developed in order to calculate the cooling load for residential. Visual basic is used to develop this software. This software can be easily used by anyone compared to the calculation methodology. The output of this software is how much power requirement for the designated area in horsepower unit. This software is very important so that user can determine the cooling load of their designated area and choose suitable evaporative cooler system.

Figure 26 show the screenshot of the welcoming page of the cooling load calculator. In the calculator, user has to input the data step by step for the software to complete the calculation. The calculation is divided into six parts:

- Environments – Includes outdoor and indoor design temperature. The temperature is used to determine the CLTD values for walls, roofs and windows.
- Roofs – Includes size and types of the roof constructions.
- Walls - Includes size and types of the wall constructions.
- Windows - Includes size and types of the window constructions.
- Occupancy – Includes number of peoples and their activities which is used to calculate the cooling load.
- Appliances – Includes lighting and electrical equipments (in watt).

To calculate the total cooling load required, user can input the data and click on the 'calculate' button as shown in figure 27. The 'cancel' button is used to terminate the application. To reset the input value the user can click on the 'clear' button. The result of the calculation is shown as in figure 28.

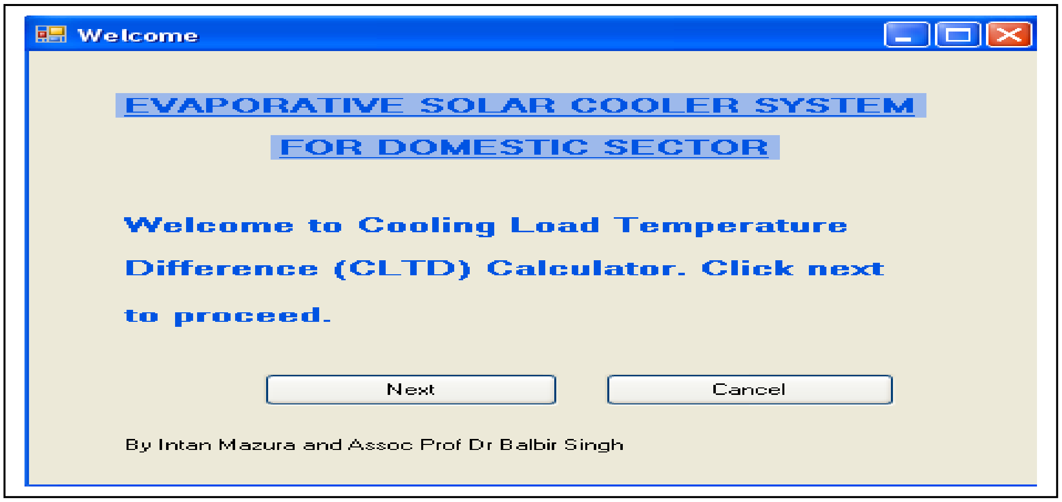


Figure 26: Screenshot of welcoming page of the Cooling Load Calculator

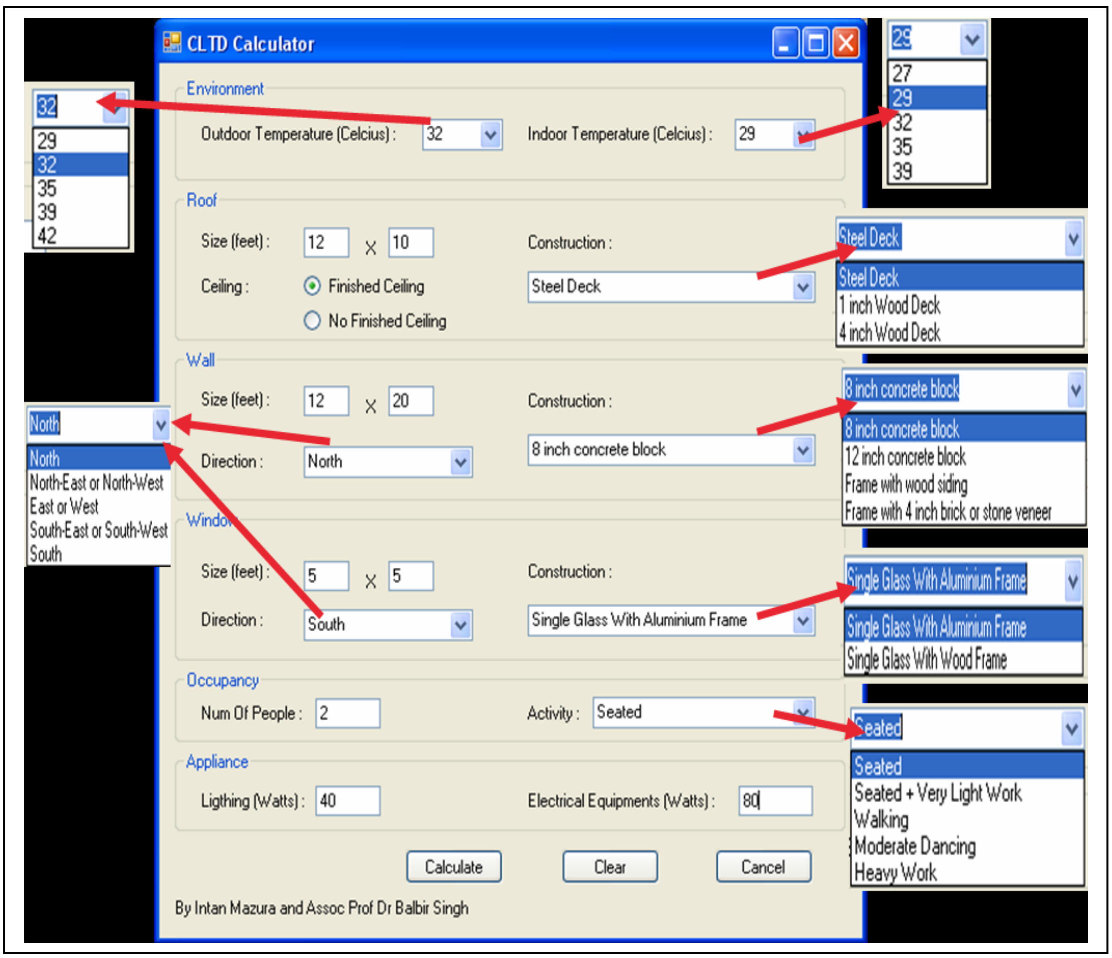


Figure 27: Screenshot of the Cooling Load Calculator

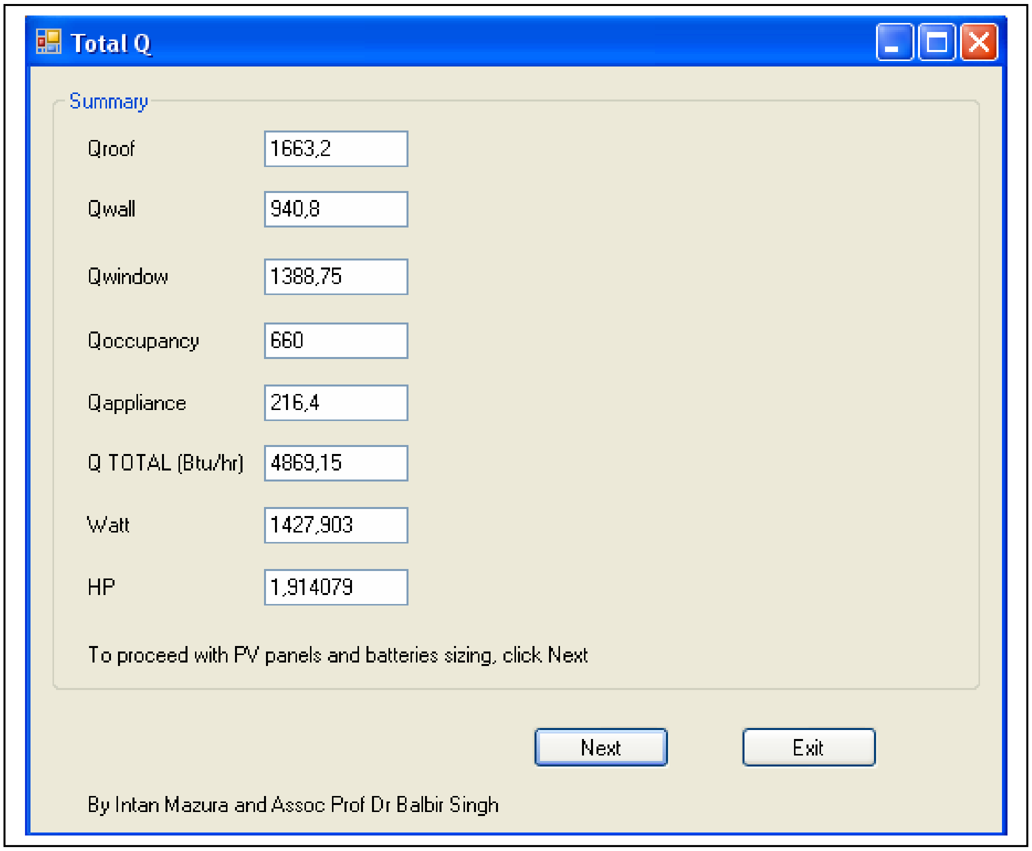


Figure 28: Screenshot of the result of total cooling load

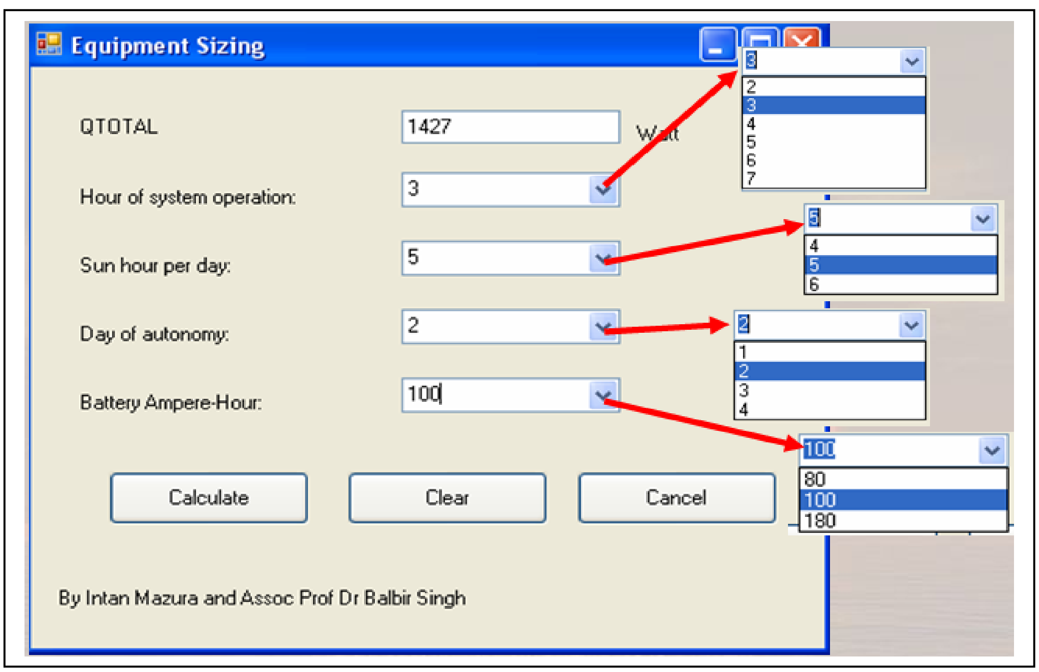


Figure 29: Screenshot of the equipment sizing

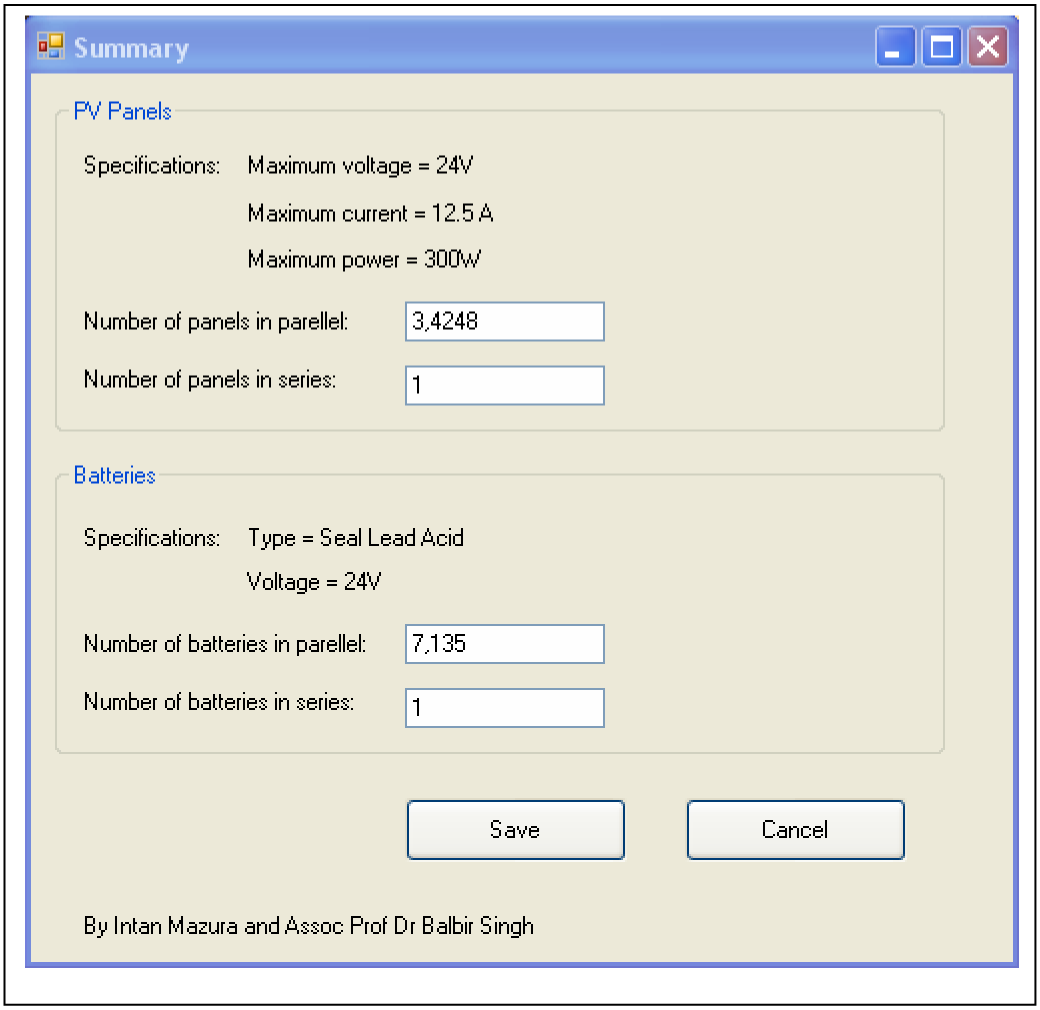


Figure 30: Screenshot of the result of equipment sizing

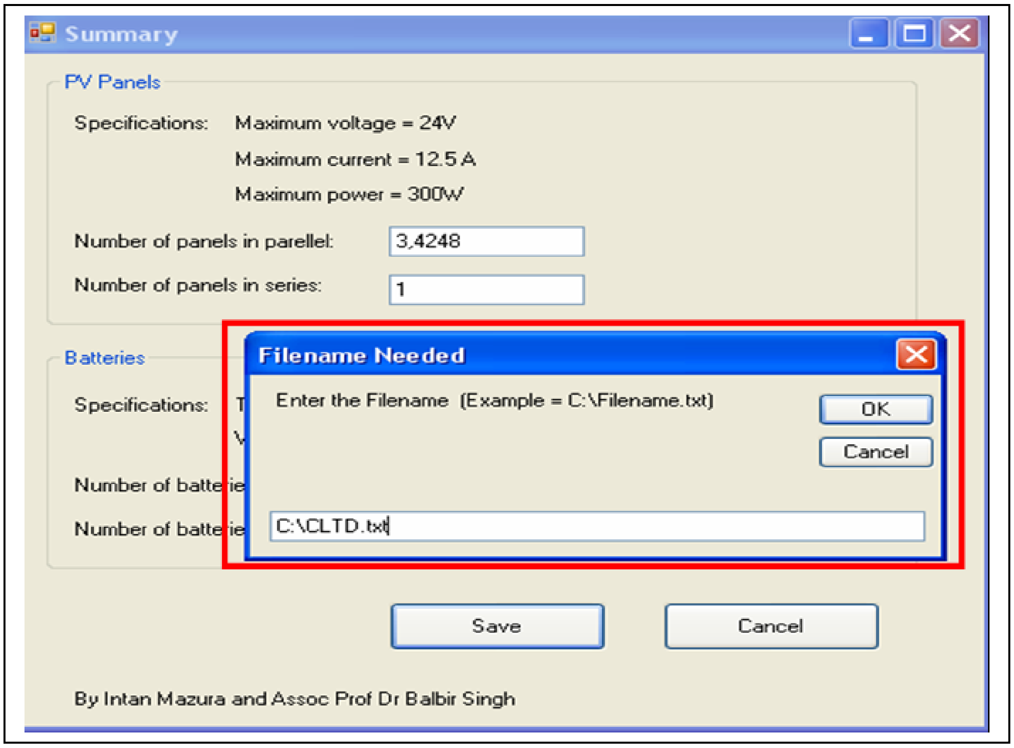


Figure 31: Screenshot of the location for saved result of equipment sizing

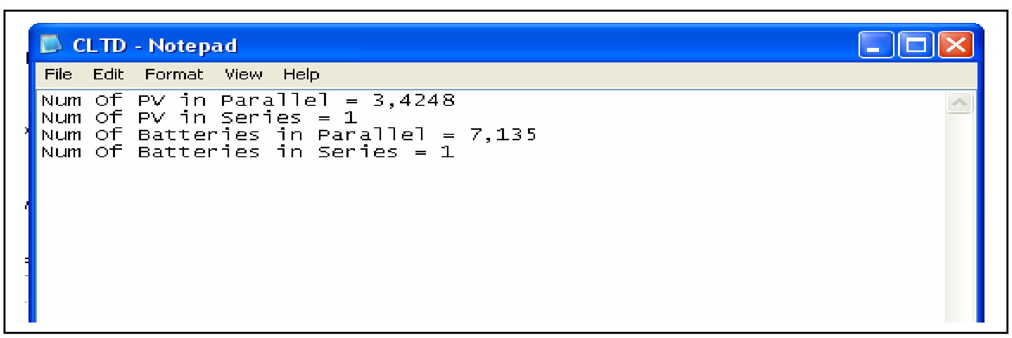


Figure 32: Screenshot of the saved result of equipment sizing

CHAPTER 5

CONCLUSION AND RECOMENDATION

5.1 Conclusion

All for the work planned is successfully completed within the expected time. The feasibility study on the possibility of utilizing solar energy for cooling purposes has been completed. The analysis of cooling load has been done and cooling load calculator has been developed. The evaporative solar cooler system prototype has been designed, fabricated and tested. Thus, the objectives of this project have been met.

This evaporative solar cooler system is suitable for domestic sector because it is effective for thermal comfort at low power. This evaporative solar cooler system consumes low power and utilizes free and clean solar energy. Since Malaysia is blessed with abundant amount of solar radiation this cooler system can be used at optimized efficiency.

5.2 Recommendation

It is recommended that this solar evaporative cooler system is being applied in real life domestic sector. This is because this evaporative solar cooler system provides an alternative for low cost and environmental friendly cooling system. Integrating this system in the domestic sector will be energy-saving and cost-effective.

The system also can be integrated with direct current (DC) compressor to increase efficiency of the evaporative solar cooler system. The compressor is used to cool the water in the evaporative cooler which will result in more cooling effect for the output of the system.

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