Improving heat pump performance during cold weather using solar-air heat collector

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ملخص

المشروع يهدف الى دراسة امكانيه تحسين كفائه نظام التكيف بالغاز في المباني الخاصة والعامة , وذلك في الحالات التي تكون فيها درجات الحرارة منخفضة في الخارج وتتوفر الطاقة الشمسية .

تتركز الفكرة الاساسية على تسخين الهواء الداخل الى الوحدة الخارجية في نظام التكيف بواسطه الجامع الحراري للطاقة الشمسية , حيث أن كفاءة انظمه التكيف تقل مع انخفاض درجات الحرارة الخارجية , وفي نفس الوقت ان استخدام التدفئة من خلال الجامع للطاقة الشمسية مباشرة يتطلب تمرير قنوات هوائية كبيره في الاغلب غير مناسبه للمساكن والمباني الصغيرة .

فالمشروع يجمع بين الجوانب الإيجابية للنظامين , حيث ان رفع درجه حراره الهواء الداخل الى الوحدة الخارجية يرفع من كفائه نظام التكيف , وبالإضافة الى ذلك انه في حاله عدم تشغيل نظام التكيف نستطيع الحصول على التدفئة من الجامع الحراري وتمريرها الى اقرب مكان في المنزل بشكل مباشر والتي لا تحتاج قنوات هوائية .

Abstract

This project aims to study the possibility of enhancing the efficiency of gas air-conditioning system in private and public buildings, that is during the temperature is cold outside the building and the solar energy is available. The main idea of the project is to heat the air that enters the external unit of the air conditioning unit by using solar air heating collector system, this because the conditioning air system generally lose its COP when the external temperature decreases. In the same time, using the heating by solar air heat collector directly requires passing a complex air ducts inside the building which is usually inappropriate for small buildings. So this project combines the advantages of the both systems, because increasing the temperature of air which enters the collector unit, increases the COP of the conditioning system. In addition, when the conditioning system is not operating, the heated air can be passed directly to the near zoon of the house which does not require ducts.

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Chapter One

Introduction and motivations

1.1 Introduction of heating

The heating is preparing the environment inside the places to overcome the heat loss which results from the decrease the outdoor temperature. Heating is essential for human comfort in the places where the temperature is low during the winter. Human used many methods and sources for heating such as:

- Fire: the first heating system was a fire in the caves and when the human discovered the way of making a hole in the wall or ceiling, that was the development of the first fireplace.
- Coal, fossil fuels, and gases: produce heat and pollutes the air; used in making fires which produces heat.
- Electricity: provides us with an easy and comfort heating. It is relatively safe, clean and low maintenance costs, but it's operation costs high.
- Solar energy: Used in heating through solar air heat collector, and this is what will be used in this project

In this research oriented project, it is expecting to improve the performance of heat pump during cold weather by heating the cold air using sun rays which improves the efficiency of air conditioning system, the heat pump, during winter .

For the purpose of this project, Solidworks® software program will be used to analyze the system "heat collectors".

1.2 The problem

Palestine has an ongoing difficulties regarding the traditional energy supply such   as petrol, gas and electricity, In addition to that high cost, which is comparable to the most expensive countries in the world.

Moreover, the Israeli occupation controls the amounts and prices of energy products, and also controls it's availability in the markets. In winter, warming is considered as a basic need for human comfort in places where temperature is low. Heating is required for resident and for some industries and agricultural products as well.

Given most of the available energy resources are limited and delivered at high cost, it became necessary to improve performance of system and to integrate renewable sources such as solar energy which is available in Palestine.

This project objectives are completely in line with this trend when it comes to performance improvement and renewable energy inter action in Palestine. People are increasingly relay on air-conditioning systems for heating their homes. Most of these systems are based on compressible fluids. Greatly, the gas heat pump system performance decline when the outside temperature decreases to very low temperature during winters. This problem is very obvious and common which raises the question of possible improvement of the performance during such bad weather when the heating is needed. Though, heating the outside component of heat pump using solar energy could improve the performance, which means also integration of renewable energy.

Such idea needs investigation to determine its effectiveness and possible modifications. The project main idea is to make this investigation.

1.3 Research hypothesis

- Increasing the temperature of heat exchanger "evaporator " of the heat pump leads to increase the efficiency of air conditioner system.
- Reduce the cost of heating process.

1.4 Goal and objectives

1- The main goal of this project is to increase the performance of air conditioning system during winter.

2- The project will be flexible; the system is easy to expand or shrink according to future requirements.

3- The project will provide a model for integrating solar energy in heating application.

1.5 Project scope

The solar air heat collector system aims to improve the efficiency of air conditioner and reduce its electrical consumption in winter through heat collector in many cases:

1. The heat collector system is used to increase the efficiency of the heat pump during the cold weather and the sun is shining "sunny and cold days". When the conditioner is turned on, the heat collector works to increase the temperature of the air that enters the conditioner, reducing its dependence on electricity and increase its efficiency.

2. In case the heat pump is turned off and the weather is cold and sunny, the amount of heat that produced by heat collector directly enters the house without passing though the heat exchanger of the heat pump, for example: when there is nobody at home, the heat pump is turned off, and in this case the hot air directly enters the house. So when people come back to home, they will find that the house temperature is elevated and they don't have to heat the house from the beginning. This method reduces the amount of heat required to heat the house and as a result reduce the monthly heating costs.
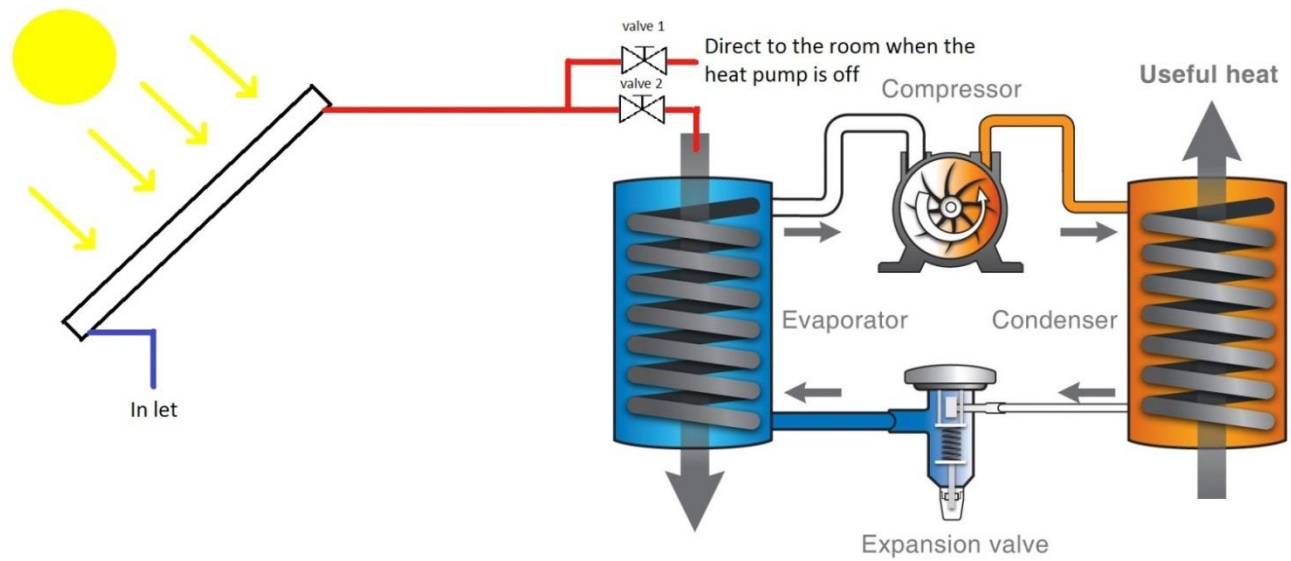
Fig. 1.1: Project description

1.6 Disadvantages of our project

1- The system is ineffective in many cases, such as: the cloudy weather, the sun is not shining or at night.

2- The dust that accumulates on the solar panels reduces the system efficiency.

1.7 Time table

The time for the first semester is illustrated in table (1.1).

Table (1.1): The time table for the first semester.

Task	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Wk7	Wk8	Wk9	Wk10	Wk11	Wk12
Identification of Project Idea	█	█	█									
Drafting a Preliminary Project Proposal				█	█	█						
Literature Review					█	█	█	█				
Documentation of Literature Review							█	█	█			
Suggestion a Setup Project Design										█	█	█
Writing a First Draft Report												█
Presentation of First Semester												

1.8 Budget

Table 1.2: Budget of the project.

	Component name	Number of component we needed	Price (NIS)	Total cost
1	Centrifugal fan	1	100	100
2	RTD temperature sensor	3	30	90
3	Flexible air ducts	5(m)	20	100
4	Solar air heat collector	2	250	500
5	Stepper motor	2	25	50
6	Microcontroller (PIC)	1	50	50
7	Wire connection	20(m)	3	60
			Total price	**950**

Chapter Two

Gas heat pump

2.1 General principles

One of the most fundamental laws of nature is the **conservation of energy.** It simply states that during an interaction energy can change from one form to another. But the total amount of energy remains constant. This mean that energy cannot be created or destroyed.

So the heat pump takes the energy from the outside and concentrates the heat in the room or house or the volume that we need to increase the temperature in it. So the change in the energy content of a body or any other system is equal to the difference between the energy input and the energy output. So the energy balance is expressed as:

$$E_{in} - E_{out} = E \tag{2.1}$$

The **first law of thermodynamics** is simply an expression of the conservation of energy principle, and it asserts that *energy* is a thermodynamic property. The **second law of thermodynamics** asserts that energy has *quality* as well as *quantity,* and actual processes occur in the direction of decreasing quality of energy.[1]

2.1.1 System and control volumes

A system is defined as a quantity of matter or a region in space chosen for study. The mass or region outside the system is called the surroundings. The real or imaginary surface that separates the system from its surroundings is called the boundary. These terms are illustrated in Fig. 1.2. The boundary of a system can be fixed or movable. Note that the boundary is the contact surface shared by both the system and the surroundings. Mathematically speaking, the boundary has zero thickness, and thus it can neither contain any mass nor occupy any volume in space.

Systems may be considered to be closed or open depending on whether a fixed mass or a fixed volume in space is chosen for study. A closed system(also known as a control mass) consists of a fixed amount of mass and no mass can cross its boundary. That is, no mass can enter or leave a closed system. But energy, in the form of heat or work, can cross the boundary and the volume of a closed system does not have to be fixed. If, as a special case, even energy is not allowed to cross the boundary, that system is called an isolated system.[1]
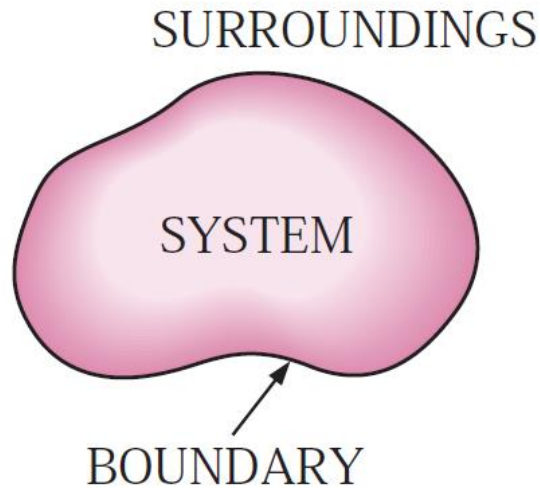
Fig. 2.1: System, surroundings, and boundary.

2.1.2 The steady-flow process

The terms steady and uniform are used frequently in engineering, and thus it is important to have a clear understanding of their meanings. The term steady implies no change with time.

The steady-flow process, which can be defined as a process during which a fluid flows through a control volume steadily (Fig. 2.2). That is, the fluid properties can be changed from point to point within the control volume, but at any fixed point remain the same during the entire process. Therefore, the volume V, the mass m, and the total energy content E of the control volume remain constant during a steady flow process.[1]

Steady-flow conditions can be closely approximated by devices that are intended for continuous operation such as turbines, pumps, boilers, condensers, and heat exchangers or power plants or refrigeration systems. Some cyclic devices, such as reciprocating engines or compressors do not satisfy any of the conditions stated above since the flow at the inlets and the exit swill be pulsating and not steady.[1]
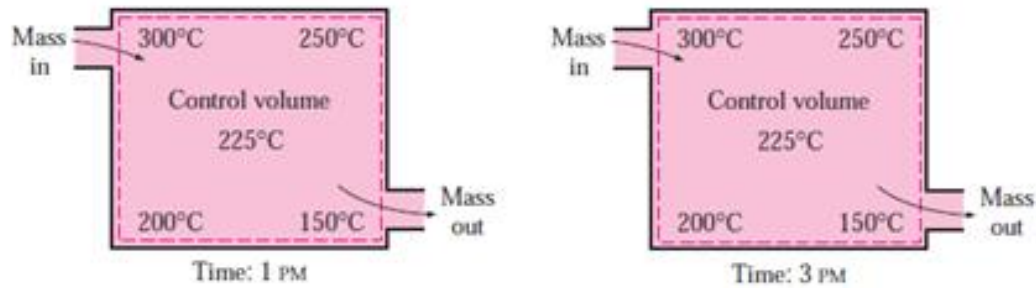
Fig. 2.2: During a steady-flow process, fluid properties within the control volume may change with position but not with time.

2.1.3 Temperature and the zeroth law of thermodynamics

It is a common experience that a cup of hot coffee left on the table eventually cools off and a cold drink eventually warms up. That is, when a body is brought into contact with another body that is at a different temperature, heat is transferred from the body at higher temperature to the one at lower temperature until both bodies attain the same temperature. At that point, the heat transfer stops and the two bodies are to have reached thermal equilibrium. The equality of temperature is the only requirement for thermal equilibrium.[1]

The zeroth law of thermodynamics states that if two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other. It may seem silly that such an obvious fact is called one of the basic laws of thermodynamics. However, it cannot be concluded from the other laws of thermodynamics, and it serves as a basis for the validity of temperature measurement. By replacing the third body with a thermometer, the zeroth law can be restated as two bodies are in thermal equilibrium if both have the same temperature reading even if they are not in contact.[1]

In thermodynamic analysis, it is often helpful to consider the various forms of energy that make up the total energy of a system in two groups: macroscopic and microscopic. The macroscopic forms of energy are those a system possesses as a whole with respect to some outside reference frame, such as kinetic and potential energies. The microscopic forms of energy are those related to the molecular structure of a system and the degree of the molecular activity, and they are independent of outside reference frames. The sum of all the microscopic forms of energy is called the internal energy of a system and is denoted by U.[1]

2.1.4 Heat is transferred by three mechanisms

- **Conduction** is the transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a result of interaction between particles.
- **Convection** is the transfer of energy between a solid surface and the adjacent fluid that is in motion, and it involves the combined effects of conduction and fluid motion.
- **Radiation** is the transfer of energy due to the emission of electromagnetic waves (or photons).[1]

2.1.5 Enthalpy-a combination property

A person looking at the tables of thermodynamics will notice two new properties: enthalpy h and entropy s. Entropy is a property associated with the second law of thermodynamics, and we will not use it until it is properly defined. However, it is appropriate to introduce enthalpy at this point.[1]

In the analysis of certain types of processes, particularly in power generation and refrigeration (Fig. 2.3),we frequently encounter the combination of properties u+Pv. For the sake of simplicity and convenience, this combination is defined as a new property, enthalpy, and given the symbol h:

$$h = u + pv \quad \text{(kj/kg)} \tag{2.2}$$
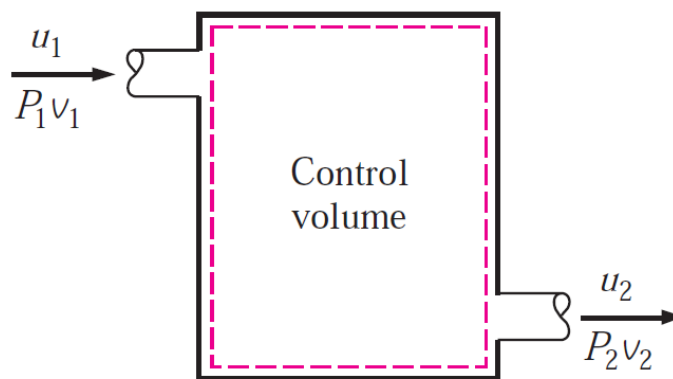
Fig. 2.3: The combination u +Pv is frequently encountered in the analysis of control volumes

2.2 Components of the Heat Pump

There are four important components of the heat pump: compressor, condenser, expansion valve and the evaporator.
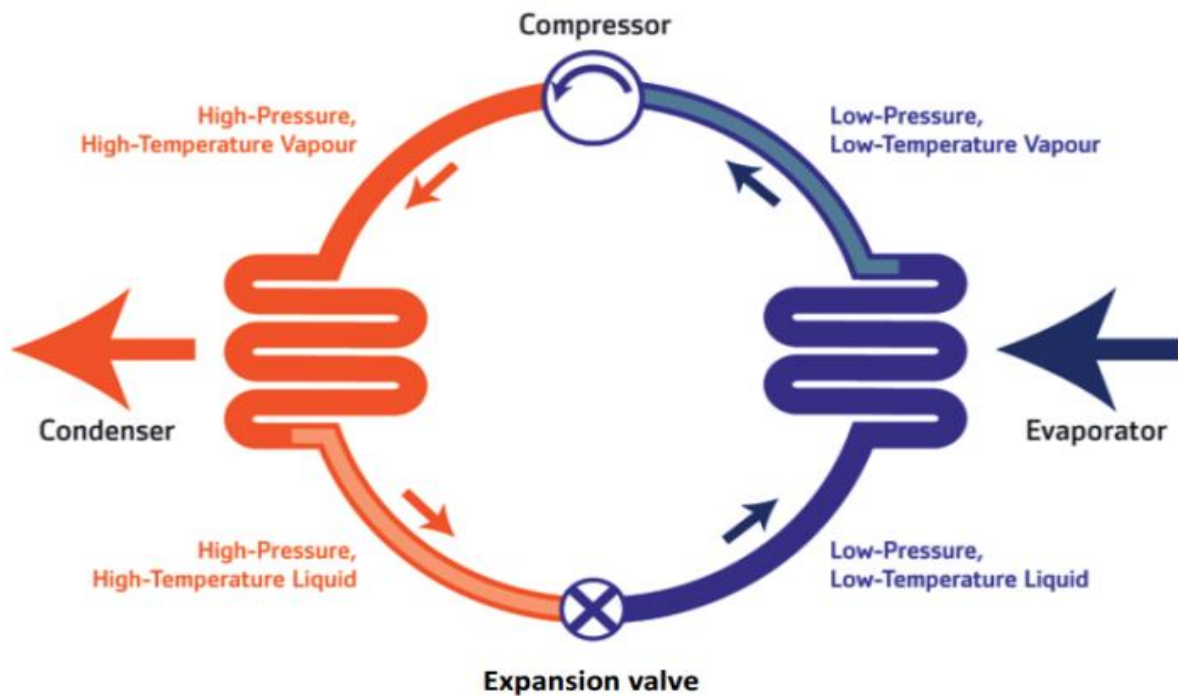
Fig. 2.4: Heat pump concept.

2.2.1 Compressor

Compressor is the one of the most important parts of the heat pump. Inside the compressor the refrigerant is compressed to extremely high pressures, where its temperature is also increased. The refrigerant enters the compressor at low pressure and low temperature in gaseous state and leaves the compressor at high pressure and high temperature in gaseous state.[2]

Types of compressors

There are two types of compressors: reciprocating compressors and rotary compressors. The reciprocating compressors have piston and cylinder arrangement similar to the reciprocating engine. While the reciprocating engine produces power by consuming fuel, the reciprocating compressor produces compression by consuming power. In fact the compressor can also be driven directly by the engine.

The reciprocating action of the piston inside the cylinder helps in compressing the refrigerant. The rotary compressors have a rotor which rotates inside the closed chamber and compresses the incoming refrigerant.[2]

2.2.2 Condenser

The next important part of the heat pump is condenser. The function of the heat pump is to heat the room and it is the condenser that produces the heating effect inside the room. The main purpose of the refrigerator is to cool the substance or materials and this effect is produced by the evaporator. Thus, while the evaporator acts as the main component in refrigerators producing the cooling effect, the condenser acts as the main component of the heat pump producing the heating effect. In the air conditioner the condenser is placed outside the room which is to be cooled, but in the heat pump the condenser is placed inside the room which is to be heated.

The refrigerant leaving the compressor is at very high pressure and high temperature. This refrigerant then enters the condense which is usually made up of copper coil. Due to high temperature of the refrigerant, the condenser coil also becomes very hot and it becomes the source of heat which can be delivered inside the room.

There is a fan or the blower behind the condenser coil that absorbs the room air or atmospheric air and blows it over the hot condenser coil. As the air is passed over the condenser coil, it gets heated and the heated air flows to the room making the room hot. The air is absorbed continuously by the fan and the hot air is thrown into the room keeping it at temperature much higher than the atmospheric temperature. There are two types of fans that can be used with the condenser coil: forced fan and induced fan.[2]

2.2.3 Expansion valve

The expansion valve is the pressure reducing device. When the high pressure and medium temperature refrigerant enters the expansion valve, its pressure reduces suddenly and along with it its temperature also becomes very low suddenly. The expansion valve most commonly used in the heat pumps is copper capillary tube. The refrigerant leaves the expansion valve at extremely low pressure and low temperature in partially liquid state and partially gaseous state.

2.2.4 Evaporator

While in the air conditioners the evaporator is located inside the room, in heat pumps the evaporator is located outside the room and exposed to the atmosphere which is at very low temperature. Just like condenser the evaporator is also made up of copper coil. The low pressure and low temperature refrigerant enters the evaporator coil, due to this the temperature of the coil also reduces drastically and it becomes even lower than the atmospheric temperature.

Since the temperature of the refrigerant inside the evaporator is less than the atmospheric temperature, it tends to absorb the heat from the atmosphere. The fan or the blower blows atmospheric air over the evaporator giving up the heat to the refrigerant and heating it. Since the refrigerant absorbs the heat from atmospheric air, its temperature increases, while its pressure remains constant and it get converted entirely into the gaseous state.[2]

2.3 Advantages and disadvantages of the heat pump

Advantages of Heat Pumps:

Homeowners with a heat pump system may have more comfortable winters than others. While many people experience dry skin because of a lack of relative humidity in their heated homes, those with heat pumps may notice moister skin.

Heat pumps are clean, quiet and odorless. Heat pumps are safer than systems relying on combustion. Heat pumps are powered by electricity and require no combustible materials.[7]

Disadvantages of Heat Pumps:

It is expensive to install a heat pump. Heat pumps have very high startup costs. While a heat pump will probably save money in the long run. The installation costs may prevent many homeowners from choosing one. Secondly, heat pumps have trouble operating in cold areas.

Prolonged exposure to subfreezing temperatures will damage the system and prevent it from operating at full efficiency. Many homeowners find that the heat generated by a heat pump created in their home during the winter months feel "cold." However, this problem can usually be fixed by changing the air direction.[7]

2.4 Heat Exchanger

As the name implies, heat exchangers are devices where two moving fluid streams exchange heat without mixing. Heat exchangers are widely used in various industries, and they come in various designs.

The conservation of mass principle for a heat exchanger in steady operation requires that the sum of the inbound mass flow rates equal the sum of the outbound mass flow rates. This principle can also be expressed as follows: Under steady operation, the mass flow rate of each fluid stream flowing through a heat exchanger remains constant.[1]

Heat exchangers typically involve no work interactions (w = 0) and negligible kinetic and potential energy changes (Δke = 0, Δpe = 0) for each fluid stream. The heat transfer rate associated with heat exchangers depends on how the control volume is selected. Heat exchangers are intended for heat transfer between two fluids within the device, and the outer shell is usually well insulated to prevent any heat loss to the surrounding medium.[1] When the entire heat exchanger is selected as the control volume. Basic Equations for Heat Exchanger:

$$\dot{Q}_{w,in} = \dot{Q}_{R,out}$$

R-134a

Control volume boundary
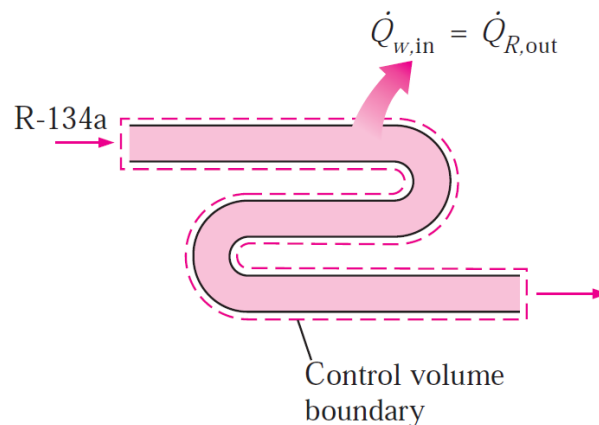
Fig. 2.5: Concept of heat exchanger

2.5 Coefficient of performance

The coefficient of performance " COP " is a measure of the amount of power input to a system compared to the amount of power output by that system:

$$COP = \frac{power\ output}{power\ input} \tag{2.3}$$

The COP is therefore a measurement of efficiency; the higher the number, the more efficient the system is. The COP is dimensionless because the input power and output power are measured in Watt. The COP is also an instantaneous measurement in that the units are power which can be measured at one point in time.

Consider a simple electric heater. All of the electricity that is input to the unit is converted to heat. There is no waste and the power output (in heat) equals the power input (in electricity), so the COP is one. The COP can be used to describe any system, not just heating and cooling.[12]

An air conditioning system uses power to move heat from one place to another place. When cooling, the air conditioning system is moving heat from the space being cooled (usually a room), to somewhere it is unwanted (usually outside). A heat pump uses the same principles, but it is moving heat from outside (the cold side) to the space being heated inside (the living space).

The maximum theoretical COP for an air conditioning system is expressed by Carnot's theorem, reduced to the following equation:

$$COP_{max} = \frac{T_C}{T_H - T_C} \tag{2.4}$$

Where T_C is the cold temperature and T_H is the hot temperature. For space cooling, the cold temperature is inside the space; for space heating, the cold temperature is outside. All temperatures

are expressed in Kelvin. To convert from °C to Kelvin, add 273.15. To convert from °F to °C, subtract 32, multiply by 5 and divide by 9.

As you can see from equation, as the difference between the hot temperature and the cold temperature increases, the COP becomes lower, and vice versa. This means that an air conditioning system is more efficient when the room temperature is closer to the outside temperature and will use more power when there is a larger difference in these temperatures.

Typical COP values for air conditioning and heat pump systems are in the range 2 to 4, or about a tenth of the theoretical maximum. However, this helps to explain where the power is used in such a system. [12]
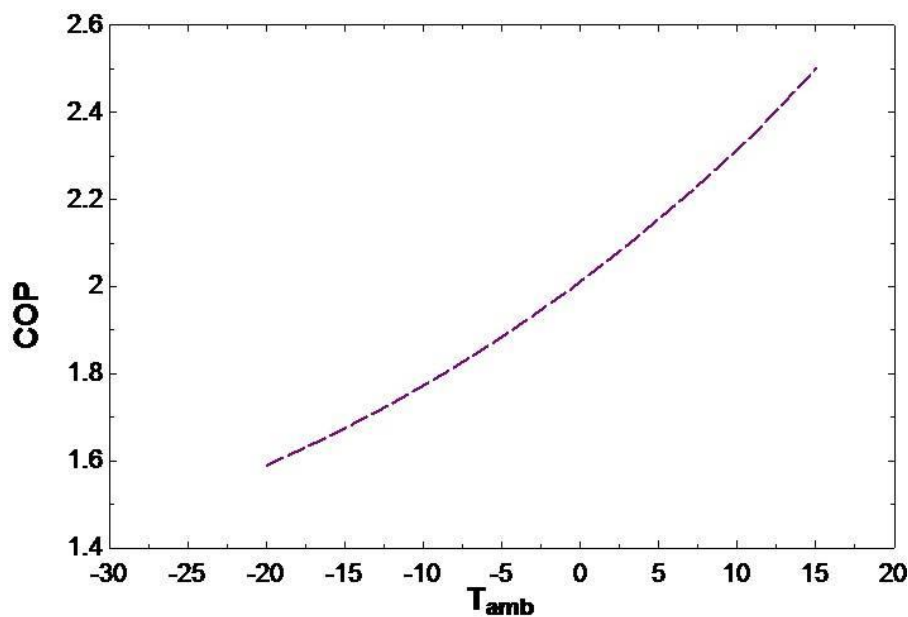
Fig. 2.6: Relation between COP and T outdoor

Chapter Three

Solar air heat collector

3.1 Solar heating systems in Palestine

3.2 Heat transfer fundamentals

3.3 Thermal radiant properties

3.4 Heat collection rate

3.5 Solar radiation and heat collection

3.6 Wind speed and heat collection

3.7 Incident angle and heat collection

3.8 Inlet temperature and heat collection

3.1 Solar heating systems in Palestine

For thermal-solar collectors two collection and transport media are common: water and air. In water-media collectors, water circulates through copper tubing attached to an absorptive surface. The circulating water takes the heat that is being captured by the blacken surface and transfers the heat to the storage tank. The air-media collector is less expensive and less efficient in terms of carrying heat.

However, it is easier to install and is nearly a maintenance-free system. Without water, the collector does not have rust and freezing problems. By using the air-media collector, the water-to-air heat exchange can be eliminated because the heated air can be directly used in the house. Since the 70's, solar heating systems both using air and water have been used. In general, the solar heating system can provide at least 50 percent of the heating demand, and the flowing tables illustrate the air temperature and the sun duration in Palestine.

Table (3.1): Mean of air temperature in the West Bank by month and station location, 2010 (C^0)

Month	Station Location							
	Jenin	Gaza	Tulkarm	Nablus	Ramallah	Jericho	Bethlehem	Hebron
January	14.3	16.0	16.4	12.7	11.8	16.8	12.7	11.7
February	14.7	16.8	16.9	17.3	11.8	18.1	12.8	12.0
March	17.2	19.5	18.6	21.0	14.6	21.0	15.5	14.3
April	19.8	22.1	19.9	23.5	16.4	24.1	17.6	16.7
May	23.1	25.2	22.5	27.1	19.8	27.8	20.8	19.7
June	26.1	29.0	26.0	29.9	22.4	31.1	24.2	22.0
July	27.7	30.1	27.1	30.8	22.8	32.3	24.6	23.2
August	29.9	32.5	29.1	33.5	25.7	34.5	27.7	26.2
September	27.9	30.0	27.4	30.6	23.0	31.8	24.2	22.7
October	25.1	28.0	25.8	29.2	21.9	29.0	23.1	21.6
November	21.1	24.1	22.5	26.7	19.7	23.5	19.5	19.2
December	15.2	17.9	18.2	14.1	13.0	17.7	13.4	12.3
Annual Mean	**21.8**	**24.3**	**22.5**	**24.7**	**18.6**	**25.6**	**19.7**	**18.5**

[13]

Table (3.2): Mean sunshine duration in Palestine by month and station location, 2010(hour\day)

Station Location				Month
Hebron	Jericho	Ramallah	Jenin	
5.8	5.9	6.8	5.8	January
5.9	6.3	6.7	5.1	February
6.7	7.1	7.3	7.6	March
9.0	9.1	9.4	9.4	April
10.3	9.8	10.3	10.1	May
11.6	11.1	11.6	11.6	June
11.8	11.3	11.8	11.6	July
11.4	10.8	11.2	10.8	August
8.5	9.1	9.7	9.5	September
7.2	8.2	8.7	8.3	October
6.5	8.2	9.0	7.4	November
4.7	6.0	6.6	5.8	December
8.3	**8.6**	**9.1**	**8.6**	**Annual Mean**

[13]

3.2 Heat transfer fundamentals

In order to better understand the operation of the system, several fundamental heat transfer concepts must also be understood. The amount of heat collected in a solar collector will depend on conduction, convection and radiation. Conduction is the heat transfer from solid to solid. Generally for a solar collector the goal is to minimize the conductive losses out of the upper and lower surfaces of the collector. The conductivity of the corrugated sheet metal is 0.029w/m.k. The insulation layer (the extruded polystyrene panel) under the corrugated sheet metal slows down the conductive heat loss through the collector.

Convection is the transfer of heat to and from a fluid to a solid or within a fluid. For the Solar system, heat is transferred to the transport fluid (air) at the inside surface of the metal panel to the air.

Heat flow is caused by temperature difference. That is, wherever there is temperature difference within a conductive media, there is heat flow. Heated air tends to flow from areas of high density to

areas of low density, high temperature. With a fan installed as a pressure driving force, the outdoor air at the inlet of the collector .Then the heated air is either sent to the heat exchanger to preheat the hot water or sent vertically down under the raised floor for occupancy heating. For the purpose of capturing solar radiation, the corrugated sheet metal is painted with black acrylic latex paint, with emissivity value ranges from 0.84 to 0.90 and absorption rate ranges from 0.92 to 0.97.

3.3 Thermal radiant properties

Thermal radiation happens whenever there is temperature difference between two regions in view of each other. The transfer of heat in this way does not depend on any intermediate material. In the Solar Collector, the heated corrugated sheet metal will radiate its heat to its surroundings, including the air cavity above it.

Emissivity is a property of the surface characterizing how effectively the surface radiates when compared to a "blackbody". It is the ratio of the emission of thermal radiant flux from the surface to the flux that would be emitted by a blackbody at the same temperature. The value is always between 0 and 1.

The blackbody is an ideal surface that emits the maximum possible thermal radiation at a given temperature. Solar radiation incident on a glazing system is partly transmitted and partly reflected, and partly absorbed by the system.

Reflectance is the fraction of the reflected part of the incident flux. It means that the less the amount of solar radiation is reflected, the more the amount of solar radiation is being absorbed or transmitted by the surface. Absorptance is the ratio between the amount of radiation absorbed by a surface to the total incident flux on the surface. In the case of Solar Collector, the less reflectance the corrugated sheet metal has, the better.

After the solar radiation strikes an opaque surface, which in this case is the corrugated sheet metal , some radiation is reflected off the surface. The amount of reflection is determined by both the incident angle and the reflectance of the surface. Assuming little absorption happens in the air, the rest of the incident solar radiation is absorbed by the surface. How much of the heat being absorbed by the surface depends on the absorptance of the surface. In this case, high absorptance and low

reflectance will make the system reach its optimal performance. The heat being absorbed will be stored and conducted through surface materials. When the temperature of the surface material is higher than its surroundings, it will emit heat to the surroundings.

The higher the emissivity of the material, the more heat it will give off. The net rate of radiation heat exchange between a surface and its surroundings can be expressed as equation1:

$$q = \varepsilon \, A\sigma \, (T_{s4} - T_{sur4}) \tag{3.1}$$

- q = heat exchange (W)
- ε = the emissivity of the surface
- A = surface area (m2)
- σ = Stefan-Boltzmann constant ($\sigma = 5.67 \times 10\text{-}8$ W/m2.K4)
- T_s = the absolute temperature of the surface (K)
- T_{sur} = the temperature of the surroundings (K)

The use of a corrugated sheet metal collector plate has its advantage. The corrugated shape helps the solar heat absorption because direct solar radiation strikes the surface and is reflected several times on the surface, and therefore increases the amount of absorption.

When the air is heated by solar radiation, it becomes less dense and rises toward the outlet. During the process, it continues to be heated through the collector. The result is heated air at the outlet and a temperature difference between the inlet and outlet.

3.4 Heat collection rate

To determine the amount of heat collected within the system, two variables must be known:

1) The temperature difference between the inlet and outlet

2) The air flow rate through the collector

When these are known, the energy collected can be calculated according to the sensible heat gain is calculated as following:

$$Qv = 1.08 * T_{diff} * V \; E \tag{3.2}$$

- Qv = sensible heat collected (Btu or 1.06 kj)
- Tdiff = temperature difference between outlet and inlet (C°)
- V = air flow rate through the collector, in cubic feet per minute (m^3/h)
- 1.08 = a constant, whose units are kj.m^3/h.c°. The air density is 1.225 kg/m^3 under

Normal temperature and pressure, which is 25 C° and 1atm.

The specific heat of air is 1.006 kJ/kg.C. 1.08 equals air density multiplied by air specific heat, and then multiplied by60min/h. (Note: this value may vary slightly and be lower for low density conditions)(Benjamin Stein and John S. Reynolds, 1999)

3.5 Solar radiation and heat collection

The amount of heat collected will depend on the intensity of incident solar radiation. Thus solar radiation is included as a parameter to observe its relationship with the heat that can be collected from the system. In the ideal case, solar radiation and heat collected from the system should have a directly proportional relationship. But in real case situations, clouds and particles in the sky, the wind speed, and other factors may affect the solar radiation. The relationship may turn out to be less than proportional.

Global Horizontal Radiation: Total amount of direct and diffuse solar radiation in Wh/m^2 received on a horizontal surface during the 60 minutes preceding the hour indicated. (NREL, 2004).

The solar energy flux is composed of two parts: that due to incident beam radiation (b) and that due to incident diffuse radiation (d). The diffuse radiation includes both diffuse sky radiation and radiation reflected from the ground. Their relationship can be expressed by Equation3:

$$Q_s = Q_b + Q_d \tag{3.3}$$

- Q_s= Total amount of solar energy flux, Wh/m^2
- Q_b= Incident beam radiation, Wh/m^2
- Q_d= Incident diffuse radiation, Wh/m^2

(ASHREA, 1999)

3.6 Wind speed and heat collection

Wind speed will affect both the airflow rate through the collection cavity and the collector' exteriors surface heat loss by convection. Under conditions of high solar radiation and low ambient temperature, high wind speeds will adversely affect the performance of the solar collector. Wind can increase the airflow rate over the corrugated sheet metal roofing therefore accelerating the convective heat loss of the collector's exterior surface. The more convective heat loss on the sheet metal surface, the more convective heat loss happens from the warmed air to the underside surface of the sheet metal. At the same time, high wind speeds can change the airflow value in Equation2,and compromise the assumption of constant heat flow. It contributes to the overall error of the heat collecting prediction.

3.7 Incident angle and heat collection

Part of the solar radiation incident on a solar collector surface is absorbed by the surface and part is reflected. For many materials, glass in particular, the proportion of the amount being reflected and being absorbed depends on the angle of incidence between the surface and the sun. The incident angle is defined as the angle between the incoming solar rays and a line normal to that surface. When the incident angle is 0 degree, the solar radiation absorption is maximal.

When the incident angle value increases, the amount of reflection is greater accordingly and the absorption is gradually reduced. For typical clear glass, for incident angles over 60 degrees, the absorption rate drops while the reflectance rises dramatically. Figure shows the relationship between the incident angle and the reflection and the absorption forc a typical transparent surface.

Fig. 3.1: Relationship between the incident angle and the reflection and the absorption for a typical transparent surface.

3.8 Inlet temperature and heat collection

The inlet temperature is the temperature of the air entering the collector. The relationship between the inlet temperature and the heat collection is twofold: in a certain range, when the inlet temperature rises, it is possible that the outlet temperature may not rise at the same rate. The reform, the temperature difference (T_{diff}) between the inlet and the outlet may actually go down. The heat collected at the outlet can be reduced because of the lower T_{diff} value. From observation, this situation happens normally in the morning when the ambient temperature begins to rise. The solar angle is still low and thus a large proportion of the solar radiation is reflected off the surface, while the ambient temperature is heated by the sun faster than the air flowing through the cavity of the collector.

Chapter Four

System components

4.1 Centrifugal fan

4.2 Thermistor

4.3 Flexible air ducts

4.4 Solar air heat collectors

4.5 Stepper motor

4.6 Display screen (20*40 LCD Display)

Through the full and accurate study for the project, the best performance for the system embodying in the selection of the following components:

4.1 Centrifugal fan

Centrifugal fans "squirrel cage fan" is a mechanical device for moving air, These fans increase the speed of air stream with the rotating impellers, it is use the kinetic energy of the impellers or the rotating blade to increase the pressure of the air stream which in turn moves them against the resistance caused by ducts, dampers and other components. Centrifugal fans accelerate air radially, changing the direction (typically by 90o) of the airflow. They are sturdy, quiet, reliable, and capable of operating over a wide range of conditions.[6]

Centrifugal fans are constant volume devices, meaning that, at a constant fan speed, a centrifugal fan will pump a constant volume of air rather than a constant mass. This means that the air velocity in a system is fixed even though mass flow rate through the fan is not.
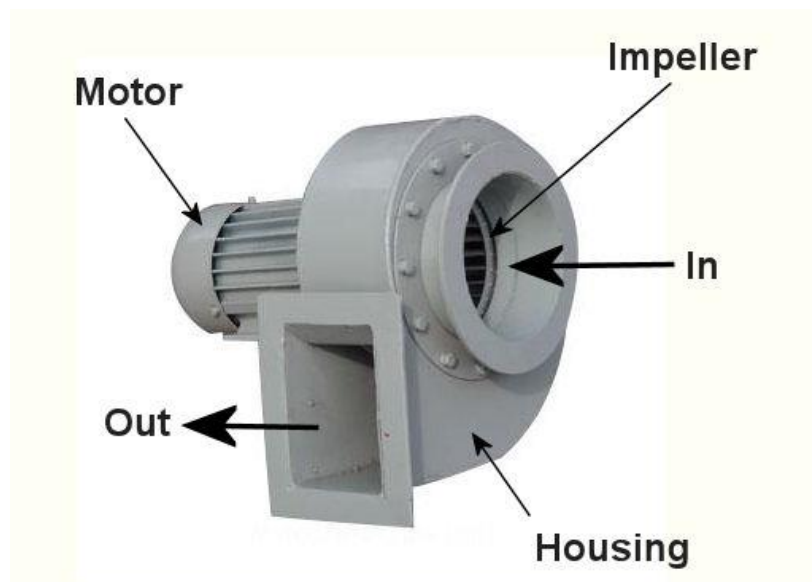
Fig. 4.1: Centrifugal fan

The centrifugal fan is one of the most widely used fans. Centrifugal fans are by far the most prevalent type of fan used in the heating, ventilating, and air conditioning industry today. They are

usually cheaper than axial fans and simpler in construction. It is used in transporting gas or materials and in ventilation system for buildings. They are also used commonly in central heating/cooling systems.

It has a fan wheel composed of a number of fan blades, or ribs, mounted around a hub. As shown in Figure 1, the hub turns on a driveshaft that passes through the fan housing. The gas enters from the side of the fan wheel, turns 90 degrees and accelerates due to centrifugal force as it flows over the fan blades and exits the fan housing

The fan wheel can be linked directly to the shaft of an electric motor. This means that the fan wheel speed is identical to the motor's rotational speed. With this type of fan drive mechanism, the fan speed cannot be varied unless the motor speed is adjustable. Air conditioning will then automatically provide faster speed because colder air is more dense.[6]

4.2 Thermistor

We need a temperature sensors to measure the temperature of air inside the solar air heat collector, and inside the house, to compare the difference of temperature and to determine how the control will be. So we need sensor to measure that temperature which is thermocouple.

A thermocouple as shown in figure (4.2), it's a sensor for measuring temperature. It consists of two dissimilar metals, joined together at one end, which produce a small unique voltage at a given temperature. This voltage is measured and interpreted by a thermocouple thermometer.

Fig. 4.2: Thermistor.

4.3 Flexible air ducts

Tubes consisting of three layers as shown in the image, the first layer is of aluminum plate, the second layer is a wool isolator, and the third layer is aluminum plate and a spiral metallic wire, to make it flexible. These layers together forms the thermal isolation tubes, these tubes are flexible, as it is easy to bend and have a very good or excellent isolation properties, and bears a relatively high temperatures up to 300° C.

Fig. 4.3: Flexible air ducts

4.4 Solar air heat collector :

Solar collectors, energy from solar thermal energy systems or concentrated solar thermal energy. When the sun shines on to a solar collector, the solar energy is converted into heat. Both light and heat from the sun accumulates in the collector so that the temperature increases and high temperatures can be transmitted as energy that you can utilize. Solar radiation includes both light and heat. Unlike solar cells that use sunlight to produce a voltage and electricity, solar collectors use an absorbent surface that can absorb as much solar energy as possible. A portion of the visible sunlight is heat. That is, approx. 52% of the visible sunlight is radiation in the form of heat that a solar collector can utilize..[11]
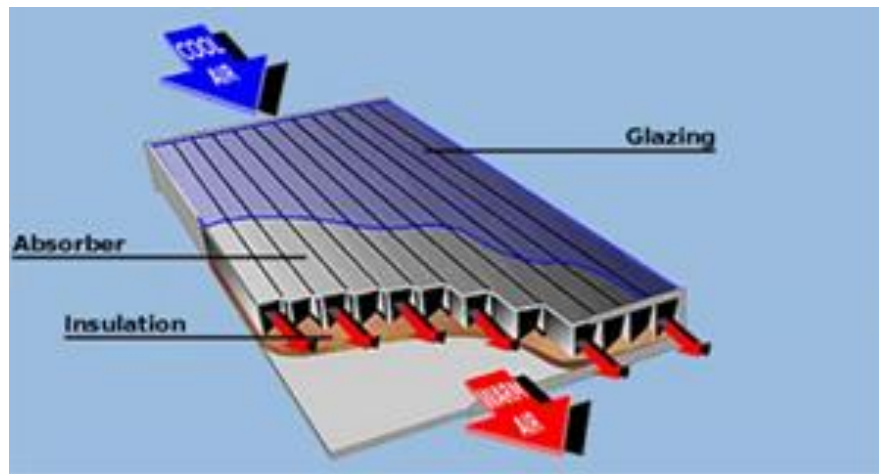
Fig. 4.4: Solar air heat collector

4.5 Stepper motor

The function of stepper motor is to open and close the duct that connect between the solar air heat collector and the air conditioner, and to connect between solar air heat collector and the house, like a vale . The stepper opening and closing by receiving a signal from the microcontroller.

Fig. 4.5: Stepper motor.

4.6 Display screen (20x4 LCD Display)

A display device is an output device for presentation of information in visual.
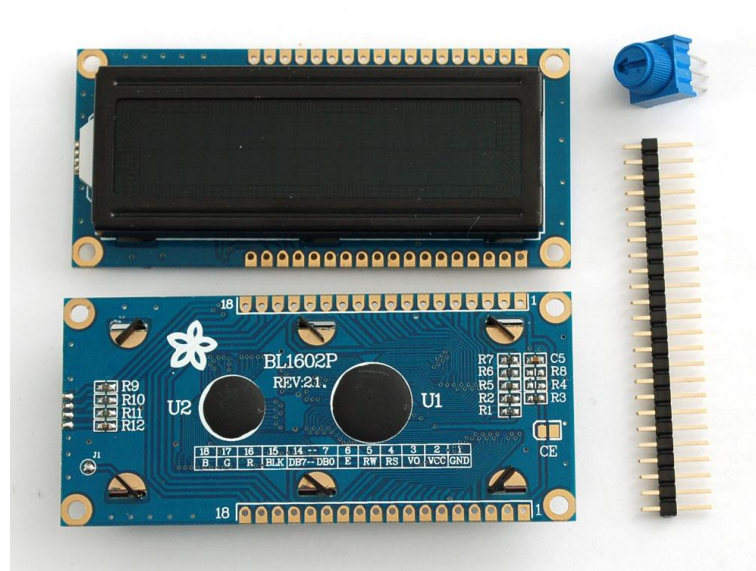
Fig. 4.6: Display screen (20x4 LCD Display).

This is an industry standard HD44780 based controlled 4 lines x 20 characters LCD display with WHITE characters on BLUE background and backlight. It is a parallel interface so you will need 7 General-purpose input/output (GPIO) pins for 4-bit mode or 11 GPIO pins for 8-bit mode to interface to this LCD screen.

Chapter Five

Control system

5.1 Introduction

5.2 Control system

        5.2.1 Introduction to control system

        5.2.2 Microcontroller

        5.2.3 Block diagram of the system

        5.2.4 Temperature sensors

        5.2.5 Stepper motor

        5.2.6 16x4 LCD Display

        5.2.7 Centrifugal fan

        5.2.8 Software Design

        5.2.9 Pin mapping

        5.2.10 Microcontroller program

        5.2.11 Design of Electronic Circuits

5.3 Connect and disconnect the systems

5.1 Introduction

To get the best performance for the system, we must determine all the possibilities that the system may pass through. There must be a smart and modern mechatronic control system, to give the best performance with the least possible energy consumption, and giving the best integration between the solar system and the heat pump system or the air conditioner. A microcontroller system " (PIC 18F4550) as shown in fig " will be used, that is because of its:

- Low power consumption
- Cheap costs of control
- Easy to program
- Rapid response.

Making comparison between the outdoor temperature and the air exiting through the solar air heat collector, when comparing the difference between the two temperatures, and when the difference is very low, it disconnects the air collector from the evaporator of the air conditioner, and make the conditioner takes the heat from the outdoor directly without passing through the solar air collector, because the energy that is required to run the system will be more than the energy that produced by the solar air heat collector, in night or in cloudy weather.

In summer days, the control system will take a signal from the conditioner, and read it's operation mode, so, if the conditioner is running in the heating mode, the solar air heat collector system will run, whereas if the conditioner is running in the cooling mode, the control system will disconnects the solar air heat collector system from the conditioner.

In this project, there will be no change to any part of the heat pump parts, or any of its proprieties, but the solar air heat collector system will accompany the air conditioner system.

The operation mode possibilities of the overall system "heat pump and solar collector systems" are shown in the flowchart:

1- The conditioner is running and the temperature of the collector is higher than the outdoor temperature, in this case the hot air will be pushed to the evaporator of the heat pump.

2- The conditioner is running and the temperature of the outdoor equals the temperature inside the solar air collector, in this case the solar air heat collector system will turn off, and will be disconnected from the air conditioner.

3- The conditioner is not running and the temperature of the collector is higher than the indoor temperature, in this case the hot air will directly enter the house.

4- The conditioner is not running and the temperature of the collector is lower than the indoor temperature, in this case nothing will be done.
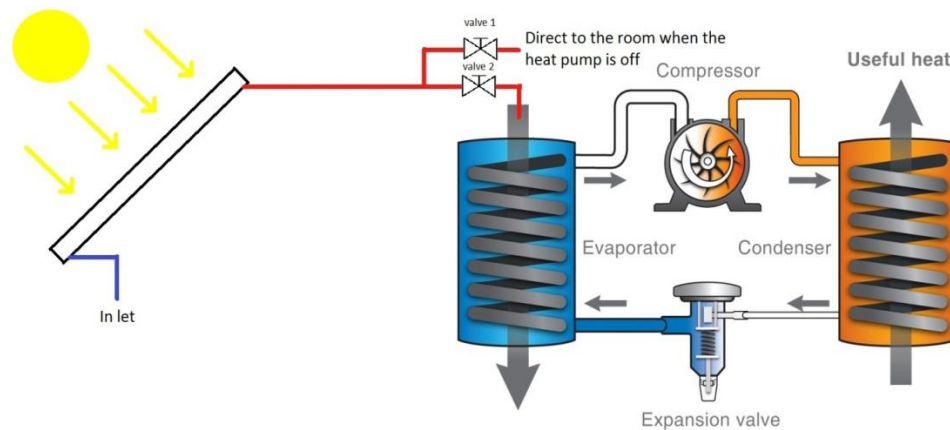
Fig. 5.1: Project description

5.2 Control system

5.2.1 Introduction to control system.

The controller will take electrical signal from the air-conditioner, so the solar air heat collector system will identify the status of the air-conditioner, whether it is running or not, and if the operation mode is heating or cooling. In case the conditioner is working, and connected to the solar air heat collector, the air pump of the conditioner system will work for the solar air heat collector at the same time "so, the air pump works for the both systems".

In case the conditioner is disconnected from the solar air heat collector and the temperature inside the collector is higher than the indoor temperature, the air will be pushed to the house by an air pump belongs to the solar air heat collector which works in this situation only.

What will disconnect the conditioner system from the solar air heat collector is an electrical motor connected to the worm gear, and connected to the worm gear from the both sides is rack and pinion, as shown in the figure, and this is how the both systems connect and disconnect from each other. The electrical valve1 will open the hot air way to the house directly in case the temperature of the solar air heat collector is higher than the outdoor temperature, and the air conditioner is turned off. The electrical valve2 will open the hot air way to the air conditioner in case the temperature of the solar air heat collector is higher than the outdoor temperature, and the air conditioner is turned on.
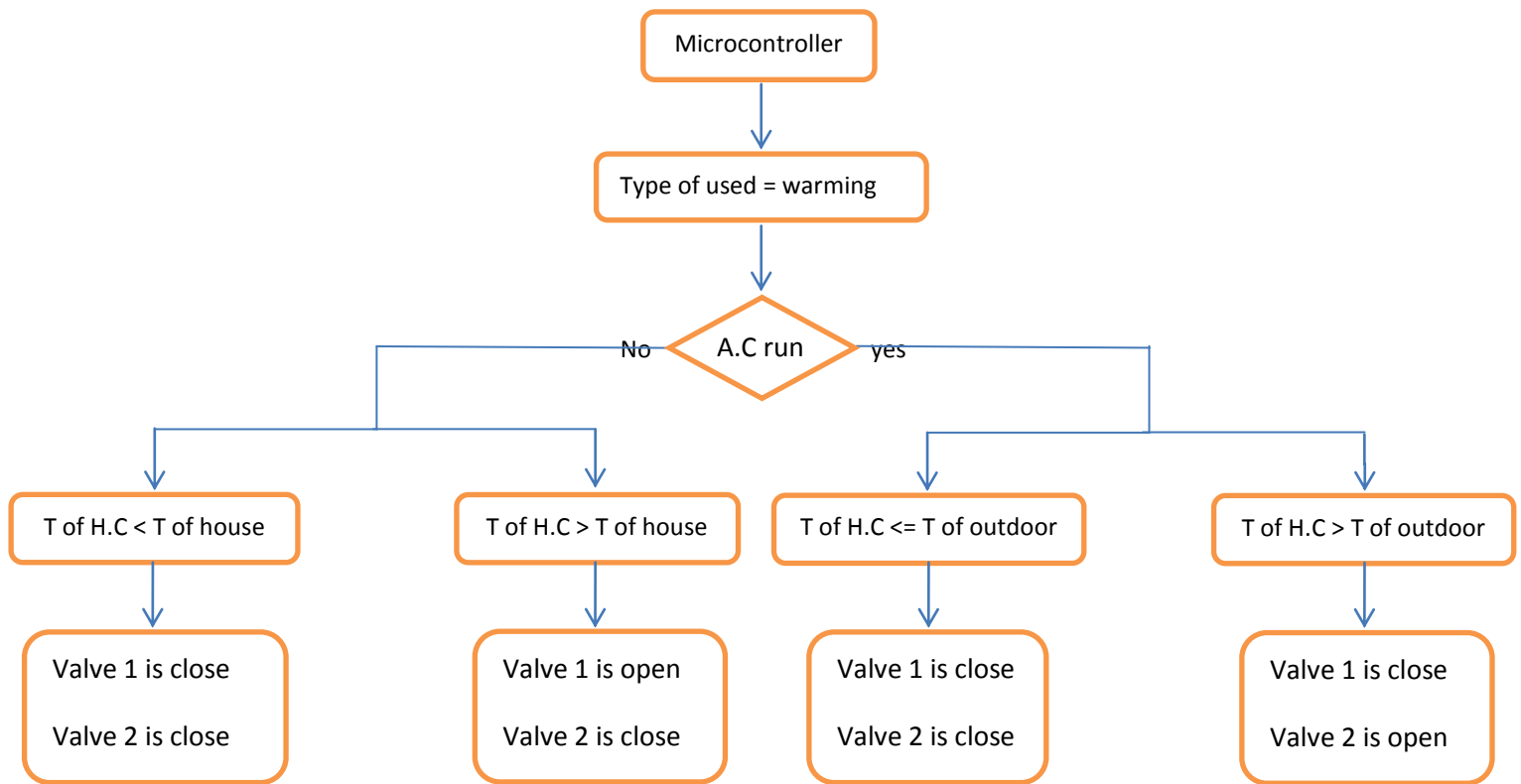
Fig. 5.2: Project flowchart

A.C= Air Conditioner
T= Temperature
H.C= Solar Air Heat Collector System
Valve 1: direct to the room
Valve 2: to the heat pump exchanger

5.2.2 Microcontroller

Microcontrollers are used to control and monitor each part of the system, in this project, the microcontroller used to monitor and compare if the air temperature in the solar air heat collector is higher than or less than of the room temperature , and to monitor the air conditioner if it operate or not, or if it in heating or cooling.
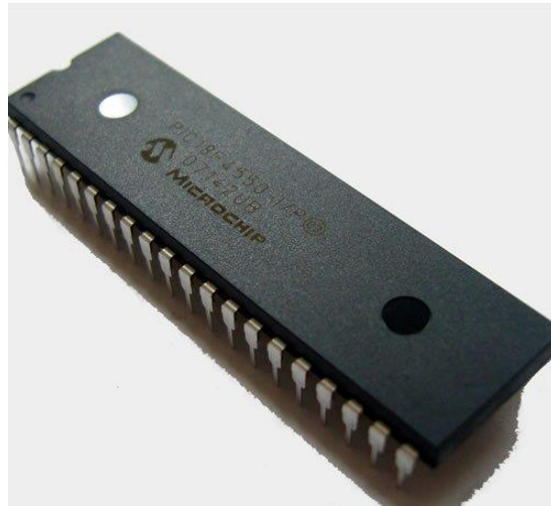
Fig. 5.3: PIC18F4550 microcontroller.
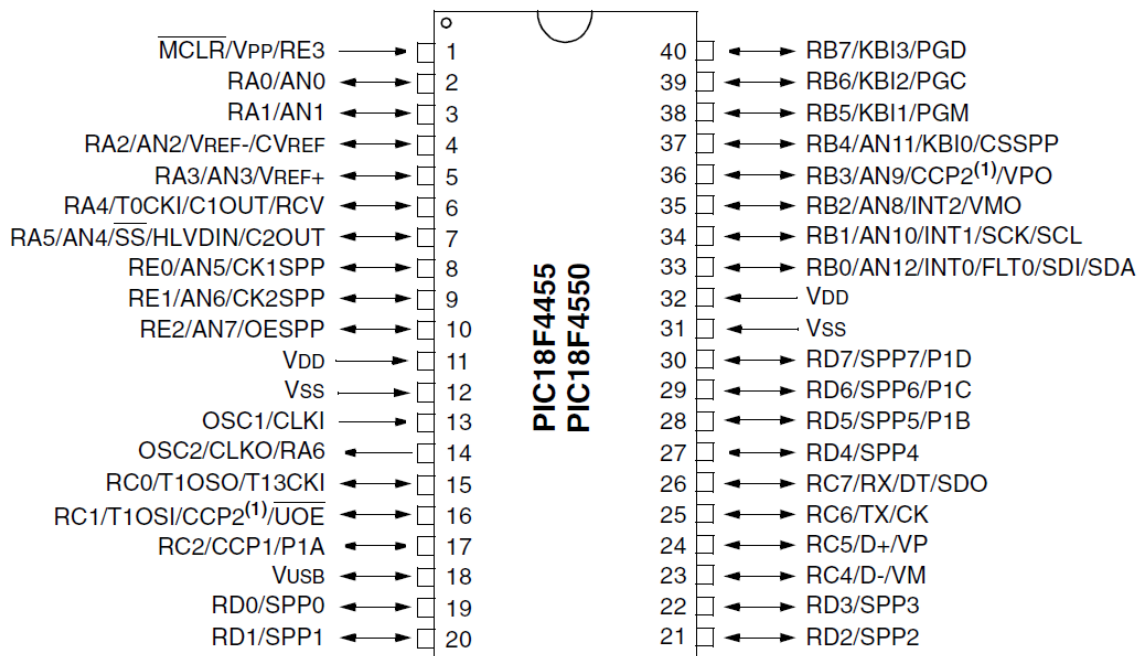
Fig. 5.4: PIC18F4550 pin diagram.

The PIC18F4550 has relatively low price compared to other microcontrollers, but still one of the best controllers used for small application in Mechatronics field. A microcontroller has a CPU (a microprocessor) in addition to a fixed amount of RAM, ROM, I/O ports, and a timer all on a single chip. In other words, the processor, RAM, ROM, I/O ports, and timers are all embedded together on one chip; therefore, the designer cannot add any external memory, I/O, or timers to it. The fixed amount of on-chip ROM, RAM, and number of I/O ports in microcontrollers makes them ideal for many applications in which cost and space are critical. That shown in figure 3.7.

Table 5.1: Specification of PIC18F4550.

Parameter Name	Value
Program Memory Type	Flash
Program Memory (KB)	32
CPU Speed (MIPS)	12
RAM Bytes	2,048
Data EEPROM (bytes)	256
Digital Communication Peripherals	1-UART, 1-A/E/USART, 1-SPI, 1-I2C1-MSSP(SPI/I2C)
Capture/Compare/PWM Peripherals	1 CCP, 1 ECCP
Timers	1 x 8-bit, 3 x 16-bit
ADC	13 ch, 10-bit
Comparators	2
USB (ch, speed, compliance)	1, Full Speed, USB 2.0
Temperature Range (C)	-40 to 85
Operating Voltage Range (V)	2 to 5.5
Pin Count	40

MikroC PRO for PIC is a software used for programming the PIC microcontroller, with C language. The mikroC PRO for PIC includes the USB HID bootloader application for PIC18 family of MCUs that feature internal USB HID module. Microcontrollers has the ability to write to their own

program memory. This feature allows a small bootloader program to receive and write new firmware into memory. In its most simple form, the bootloader starts the user code running, unless it finds that new firmware should be downloaded. If there is new firmware to be downloaded, it gets the data and writes it into program memory.

Fig 5.5: MikroC PRO for PIC.

5.2.3 Block diagram of the system.
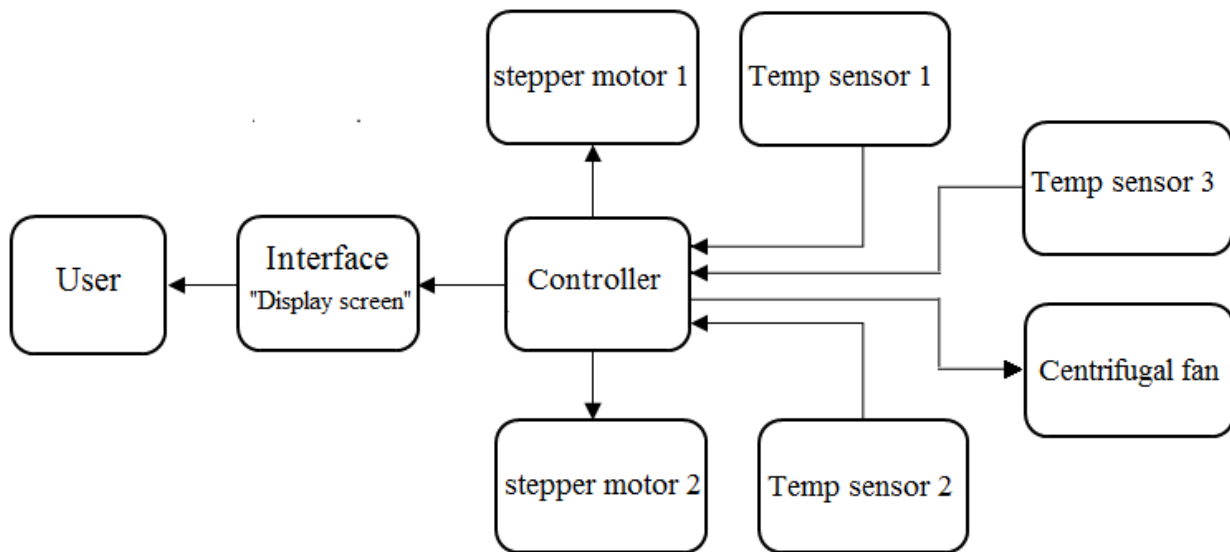
Fig. 5.6: Block diagram of the system.

As mentioned in the block diagram in figure 5.4, the user will have the ability to monitor the temperature in the solar air heat collector in outdoor and indoor directly by the display screen, this system is an embedded system, where the controller control the system without human intervention.

41

The controller must give signals to activate the stepper motor and centrifugal fan. The controller will receive signals from the temperature sensors.

5.2.4 Temperature sensors.

Thermistor (NTC)

A negative temperature coefficient (NTC) thermistors are temperature-sensing elements made of two terminal solid state electronic component that has been sintered in order to display large changes in resistance in proportion to small changes in temperature. This resistance can be measured by using a small and measured direct current, or dc, passed through the thermistor in order to measure the voltage drop produced. Thermistors are an incredibly accurate category of temperature sensors. This apparatus has three NTC 103 thermistors, in this apparatus the first one is in the solar air heat collector, the second is in the outdoor, and the third is in the indoor.

Fig 5.7: NTC 103 Thermistor.

Temperature Coefficient of Resistance (α)

One way to describe the curve of an NTC thermistor is to measure the slope of the resistance versus temperature (R/T) curve at one temperature. By definition, the coefficient of resistance is given by:

$$\propto = \frac{1}{R} * \frac{dR}{dT}$$
3.1

Where: T = Temperature in ˚C or K.

R = Resistance at Temperature T.
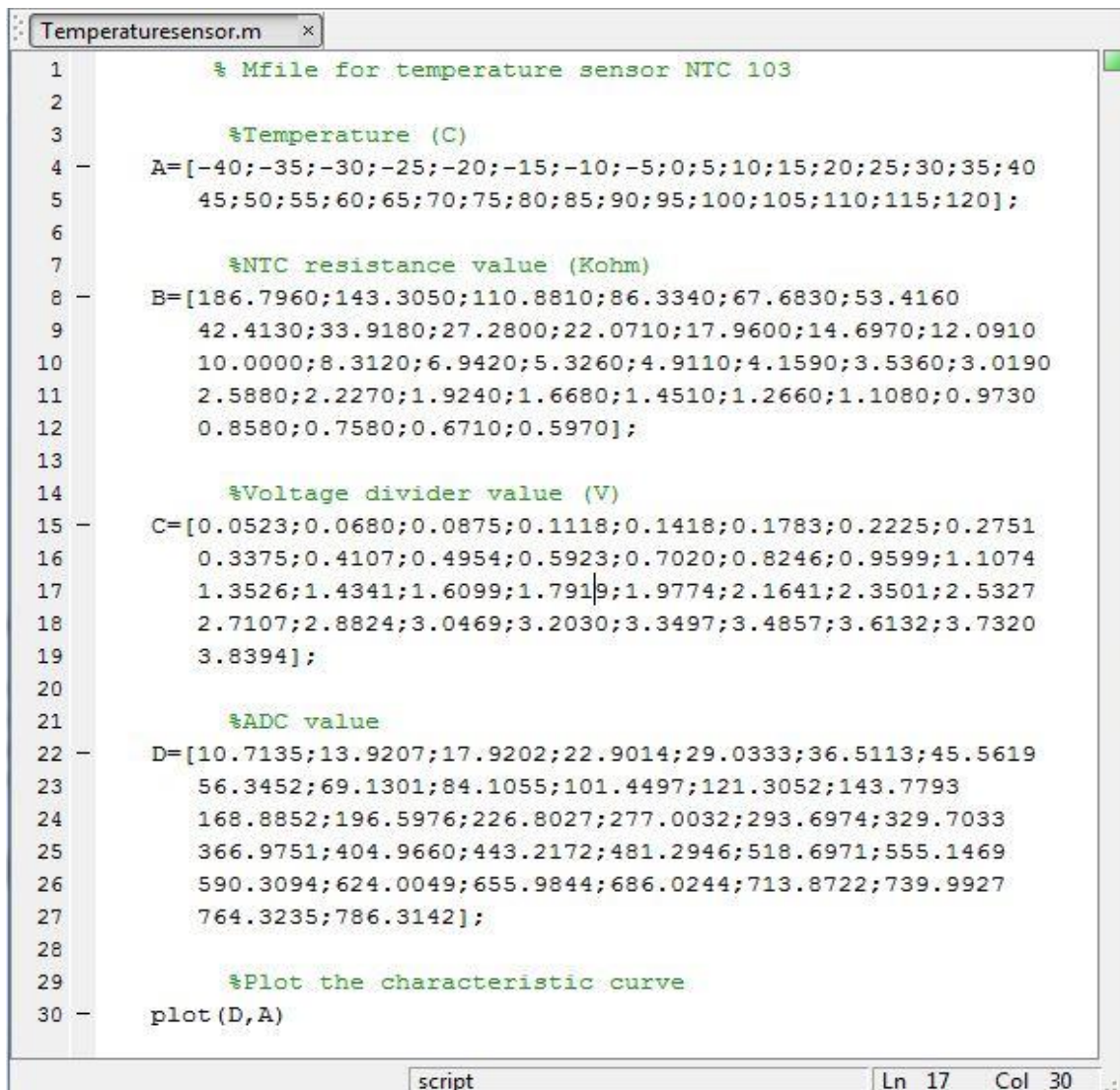
Table 5.2 Specification of NTC 103.

	NTC 103 F 343 F			
		RESISTANCE		
TEMP.		(kΩ)		TEMP.
(˚c)	min.	center	max.	(˚c)
-40	179.593	186.796	194.269	-40
-35	138.240	143.405	148.748	-35
-30	107.162	110.881	114.717	-30
-25	83.648	86.334	89.098	-25
-20	65.737	67.683	69.680	-20
-15	52.003	53.416	54.862	-15
-10	41.403	42.431	43.479	-10
-5	33.171	33.918	34.678	-5
0	26.737	27.280	27.830	0
5	21.678	22.071	22.469	5
10	17.677	17.960	18.246	10
15	14.494	14.697	14.901	15
20	11.947	12.091	12.235	20
25	9.900	10.000	10.100	25
30	8.213	8.312	8.410	30
35	6.848	6.942	7.037	35
40	5.737	5.326	5.916	40
45	4.828	4.911	4.996	45
50	4.081	4.159	4.237	50
55	3.465	3.536	3.609	55
60	2.954	3.019	3.086	60
65	2.528	2.588	2.650	65
70	2.172	2.227	2.284	70
75	1.873	1.924	1.975	75
80	1.622	1.668	1.715	80
85	1.409	1.451	1.494	85
90	1.228	1.266	1.305	90
95	1.073	1.108	1.144	95
100	0.942	0.973	1.006	100
105	0.828	0.858	0.888	105
110	0.731	0.758	0.785	110
115	0.647	0.671	0.697	115
120	0.574	0.597	0.620	120

As described in previous chapter this sensors (NTC 103) placed in three region, and this sensor will read the air temperatures in the three region. The first thee analog input pin in port A will be an input for temperature sensors (PORTA.RA0), (PORTA.RA1) and (PORTA.RA2).

By using MATLAB software we can get the characteristic equation for NTC 103 from Specification data as shown in table 5. And the Electronic Circuit for NTC 103 will discuss in fig . 5.16, NTC 103 will use as a voltage divider element with 2KΩ resistance. Fig 5.11 shows the connection circuit of the NTC.

First step it's save workspace variables and their values in MATLAB

```
Temperaturesensor.m    ×

1              % Mfile for temperature sensor NTC 103

2

3              %Temperature (C)
4 -     A=[-40;-35;-30;-25;-20;-15;-10;-5;0;5;10;15;20;25;30;35;40
5          45;50;55;60;65;70;75;80;85;90;95;100;105;110;115;120];

6

7              %NTC resistance value (Kohm)
8 -     B=[186.7960;143.3050;110.8810;86.3340;67.6830;53.4160
9          42.4130;33.9180;27.2800;22.0710;17.9600;14.6970;12.0910
10         10.0000;8.3120;6.9420;5.3260;4.9110;4.1590;3.5360;3.0190
11         2.5880;2.2270;1.9240;1.6680;1.4510;1.2660;1.1080;0.9730
12         0.8580;0.7580;0.6710;0.5970];

13

14             %Voltage divider value (V)
15 -    C=[0.0523;0.0680;0.0875;0.1118;0.1418;0.1783;0.2225;0.2751
16         0.3375;0.4107;0.4954;0.5923;0.7020;0.8246;0.9599;1.1074
17         1.3526;1.4341;1.6099;1.7919;1.9774;2.1641;2.3501;2.5327
18         2.7107;2.8824;3.0469;3.2030;3.3497;3.4857;3.6132;3.7320
19         3.8394];

20

21             %ADC value
22 -    D=[10.7135;13.9207;17.9202;22.9014;29.0333;36.5113;45.5619
23         56.3452;69.1301;84.1055;101.4497;121.3052;143.7793
24         168.8852;196.5976;226.8027;277.0032;293.6974;329.7033
25         366.9751;404.9660;443.2172;481.2946;518.6971;555.1469
26         590.3094;624.0049;655.9844;686.0244;713.8722;739.9927
27         764.3235;786.3142];

28

29             %Plot the characteristic curve
30 -    plot(D,A)

                       script                    Ln  17    Col  30
```

Fig 5.8: Temperature sensor Mfile in MATLAB.

Where

$$voltage\ divider\ value = \frac{2K\Omega\ resistance*source\ voltage}{2K\Omega\ resistance+NTC\ resistance} \qquad 4.1$$

$$ADC\ value = \frac{voltage\ divider\ value*1024}{5} \qquad 4.2$$

Now by using plot command between matrix A and matrix D we can get the characteristic curve for NTC 103.
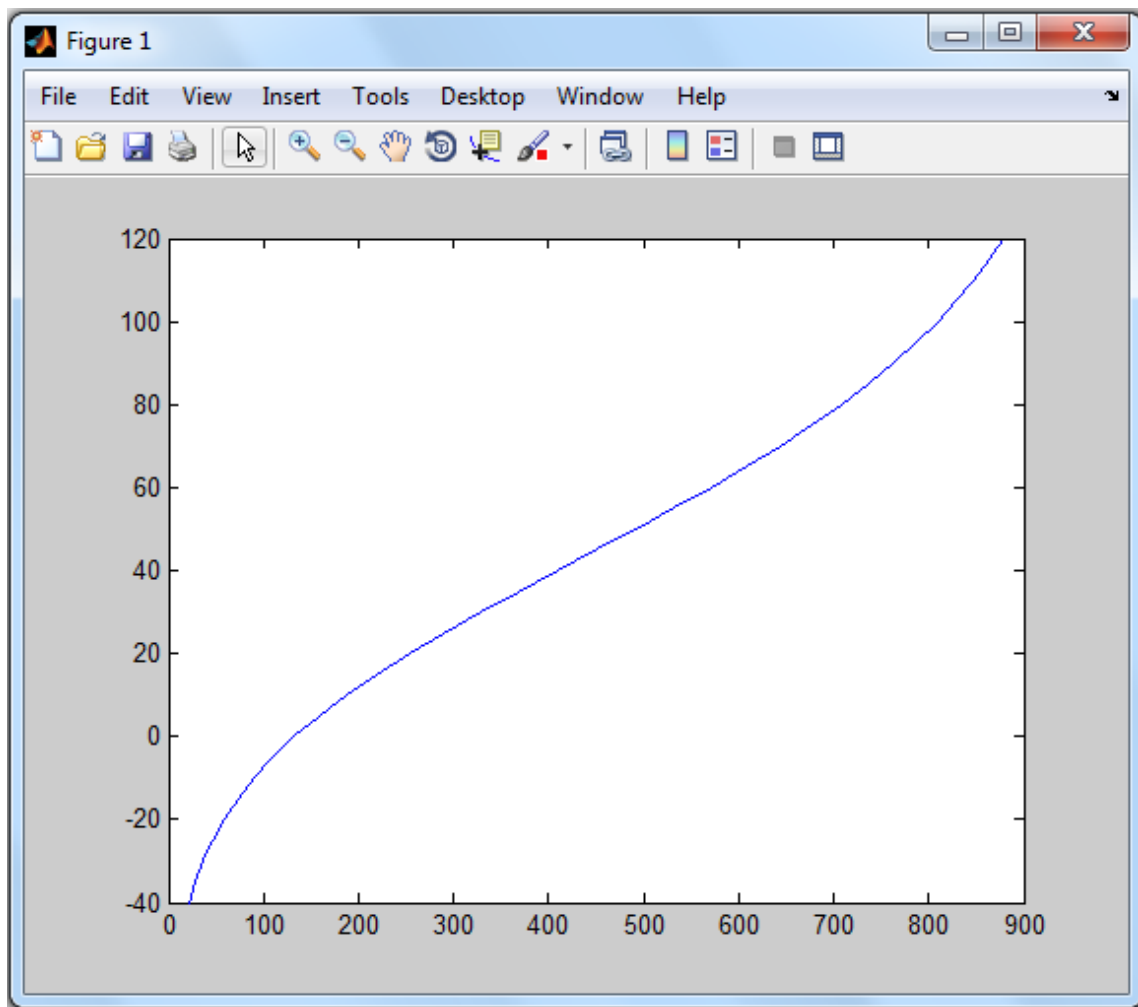
Fig 5.9: Characteristic curve for NTC 103.

The final step it's to get the characteristic equation for NTC 103 to put it in the mikroC program, by using basic fitting tool and select fifth order polynomial equation.
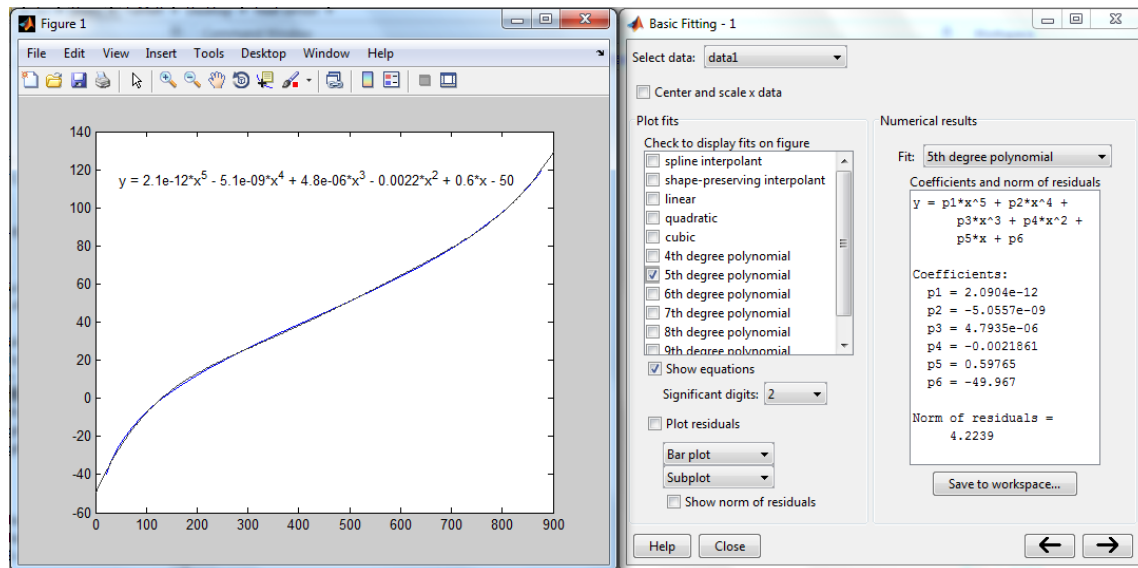
Fig 5.10: Characteristic equation for NTC 103.

5.2.5 Stepper motor

A stepper motor (or step motor) is a brushless DC electric motor that divides a full rotation into a number of equal steps. The motor's position can then be commanded to move and hold at one of these steps without any feedback sensor (an open-loop controller)

To open and close the streams we must use a mechanism that gives exactly position to close and open tube, so the best mechanism for opening and closing the streams is the rack and pinion mechanism which driven by stepper motor.

The first four output pins in port D will be using for controlling the stepper motor1 driver, and the last four output pins in port D will be using for controlling the stepper motor2, and by using pulses on and off with delay for speed control of stepper motor (PORTD.RD0, PORTD.RD1, PORTD.RD2, and PORTD.RD3) for the first motor and(PORTD.RD4, PORTD.RD5, PORTD.RD6, and PORTD.RD7) for the second motor.

Stepper motor connection with microcontroller.

The stepper motor operate under a 12v DC voltage, and the output voltage of the PIC is 5v DC which is not enough to power up the stepper motor; the figure 5.6 shown the connection circuit for stepper motor.
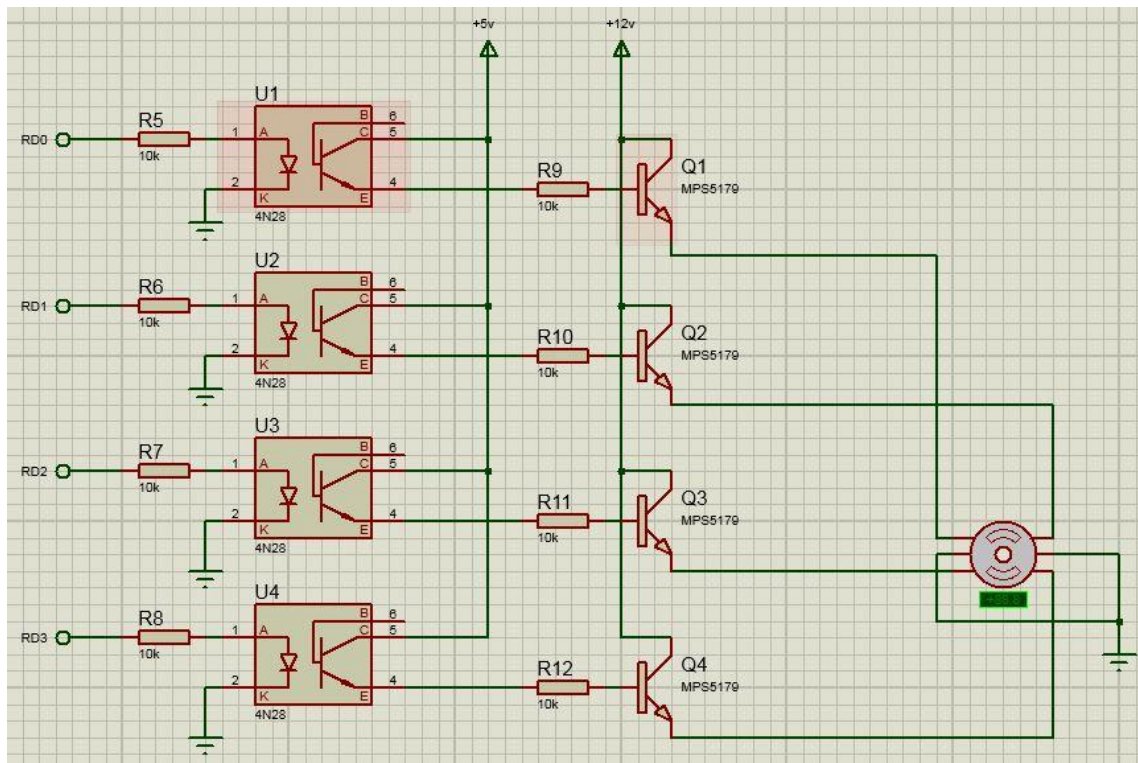
Fig 5.11: Stepper motor connection.

As shown in the previous figure the output taken from the PIC is connected to a optocoupler to a transistor and then to the stepper motor, the transistor used as a switch to turn on the stepper motor.

5.2.6 16x4 LCD Display

Table 5.3: Pin out Connections for 16x4 LCD Display.

Pin No	Symbol	Level	Description
1	VSS	0V	Ground
2	VDD	5V	Supply Voltage for logic
3	VO	(Variable)	Operating voltage for LCD
4	RS	H/L	H: DATA, L: Instruction code
5	R/W	H/L	H: Read(MPU?Module) L: Write(MPU?Module)
6	E	H,H->L	Chip enable signal
7	DB0	H/L	Data bus line
8	DB1	H/L	Data bus line
9	DB2	H/L	Data bus line
10	DB3	H/L	Data bus line
11	DB4	H/L	Data bus line
12	DB5	H/L	Data bus line
13	DB6	H/L	Data bus line
14	DB7	H/L	Data bus line
15	A	5V	LED +
16	K	0V	LED-

The following variables (LCD module connections) must be defined:

DB0 – Unused.

DB1 – Unused.

DB2 – Unused.

DB3 – Unused.

DB4 – PORTB.RB0.

DB5 – PORTB.RB1.

DB6 – PORTB.RB2.

DB7 – PORTB.RB3.

RS   – PORTB.RB4.

R/W – PORTB.RB5.

5.2.7 Centrifugal fan

Model	Impeller Type	Outlet	Phase	Pole	Power	Rated Voltage	Current	Frequency	Speed	Max. Pressure			Max. Air Flow			Net Weight
		mm	Ø	P	HP	V	A	Hz	r.p.m.	mmAq	inchAq	Pa	CMM	m3/h	CFM	KG
CYH1	Turbo	50	3	2	1/8	220/380	0.5/0.3	50	2900	40	1.58	392	2.2	132	78	4.3
								60	3400	60	2.37	588	2.6	156	92	
CYH2	Turbo	75	3	2	1/4	220/380	0.8/0.5	50	2900	70	2.77	686	5.5	330	194	8
								60	3400	90	3.56	882	6.5	390	229	
CYH3	Multi-blade	100	3	2	1/2	220/380	1.6/1	50	2900	51	2.02	500	13	780	459	12.8
								60	3450	74	2.92	725	15	900	530	
	Turbo					220/380	0.92/0.51	50	2900	80	3.16	784	11	660	388	
							1.2/1.2	60	3400	110	4.35	1078	13	780	459	
CYH4	Multi-blade	125	3	2	1/2	220/380	1.5/1.1	50	2900	65	2.57	637	14	840	494	18
								60	3310	93	3.68	911	17	1020	600	
	Turbo					220/380	2/1.3	50	2970	72	2.85	706	14	840	494	
								60	3450	100	3.95	980	17	1020	600	
	Multi-blade	125	3	2	1	220/380	3.1/1.9	50	2860	102	4.03	1000	21	1260	741	20
								60	3400	141	5.57	1382	24	1440	847	
CYH5	Turbo	75	3	2	1/2	220/380	1 /0.6	50	2900	150	5.93	1470	5	300	177	15
							1.3/0.75	60	3350	180	7.11	1764	7.5	450	265	
CYH6	Turbo	100	3	2	1	220/380	3/2	50	2850	210	8.30	2058	16	960	565	26
								60	3250	278	10.99	2724	19	1140	671	
						415	1.33	50	2850	210	8.30	2058	16	960	565	
							1.95	60	3250	275	10.87	2695	19	1140	671	

Fig 5.12: Centrifugal fan specification

Fig 5.13: Centrifugal fan on the inlet that we used

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It's used to push the hot air from solar air heat collector to the indoor when the air conditioner is off and the temperature of solar air heat collector is higher than the indoor temperature.

The centrifugal fan operate under a 220v AC voltage and 60 Hz with flow rate Q = 156 m^3/h, and the output voltage of the PIC is 5v DC which is not enough to power up the centrifugal fan, so we need relay to feeds electricity to the centrifugal fan and the relay controlled by the PIC as shown in fig 5.14.
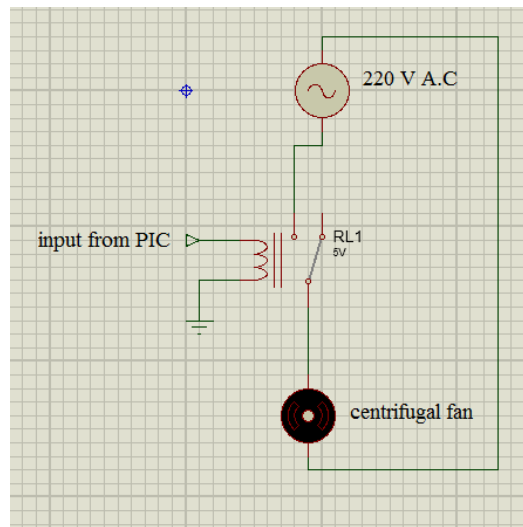
Fig 5.14: Centrifugal fan connection with microcontroller

5.2.8 Software Design

Introduction

To complete the desired procedures of the apparatus, rules must be done to lead the operation; these rules can be implemented using a microcontroller, and to make it work according to the rules; the rules must be translated to a language that can be understood by the used controller which is in this case PIC18F4550, the PIC18F4550 is programmed in C language with the mikroC PRO for PIC software.

In any system there must be outputs and inputs to interface with the mechanical Structure, in the project the outputs and inputs are illustrated in fig 5.15 .
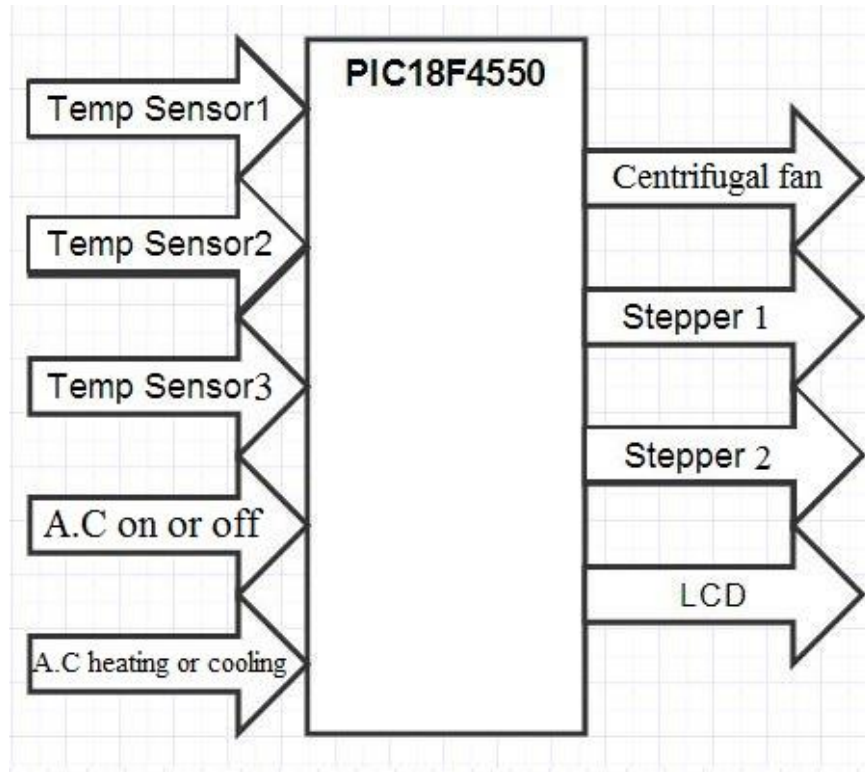
Fig 5.15: Input and outputs of the system.

A.C : air conditioner

According to the figure above these are the inputs and outputs of the system:

- **Inputs**

    - Temperature sensor 1: Detects the temperature of the solar air heat collector.
    - Temperature sensor 2: Detects the temperature of the outdoor.
    - Temperature sensor 3: Detects the temperature of the indoor.
    - Air conditioner is on or off .
    - Air conditioner is heating or cooling.

- **Outputs**

  - Centrifugal fan: Used to push the hot air from the solar air heat collector to the indoor when the air conditioner is off.

  - Stepper motor1: Used to open and close the stream between solar air heat collector and the air conditioner.

  - Stepper motor2: Use to open and close the stream between solar air heat collector and indoor.

  - LCD: Is the display screen.

5.2.9 Pin mapping

To interface with the outputs as denoted the address of each part must be known and named in the software, the following figure 4.2 shows the wiring of the peripherals and their pin number.
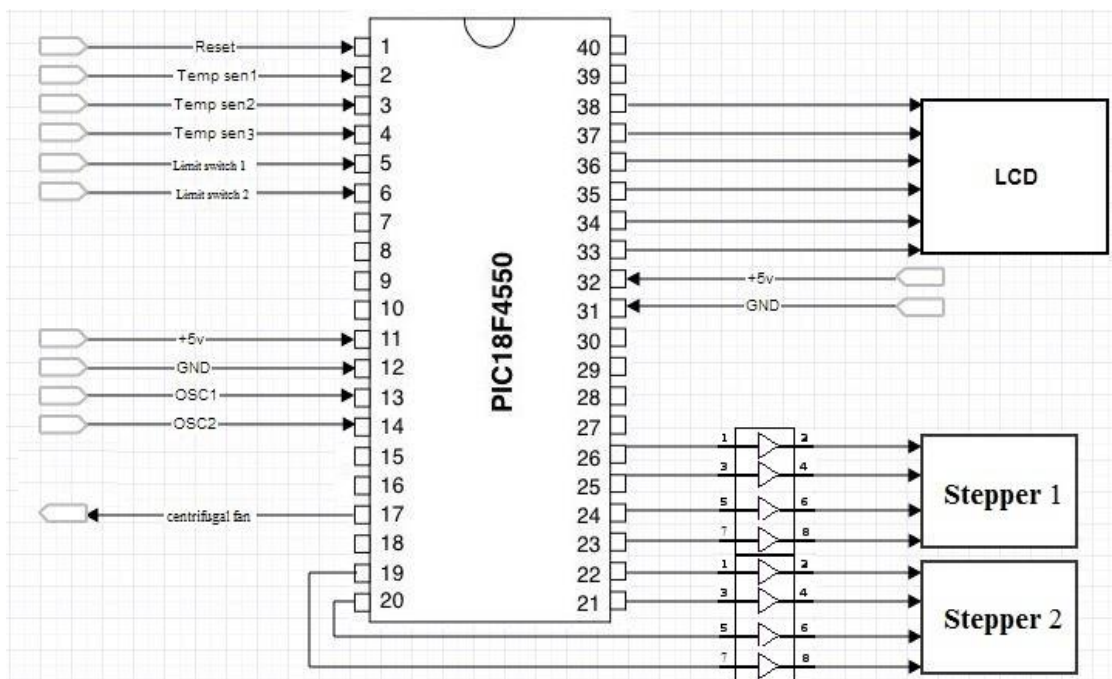
Fig 5.16: Pin mapping of peripherals to the PIC18F4550.

5.2.10 Microcontroller program

```
/* Program start */
sbit LCD_RS at LATB4_bit;                          // LCD module connections
sbit LCD_EN at LATB5_bit;
sbit LCD_D4 at LATB0_bit;
sbit LCD_D5 at LATB1_bit;
sbit LCD_D6 at LATB2_bit;
sbit LCD_D7 at LATB3_bit;


sbit LCD_RS_Direction at TRISB4_bit;
sbit LCD_EN_Direction at TRISB5_bit;
sbit LCD_D4_Direction at TRISB0_bit;
sbit LCD_D5_Direction at TRISB1_bit;
sbit LCD_D6_Direction at TRISB2_bit;
sbit LCD_D7_Direction at TRISB3_bit;               // End LCD module connections


void main() {
int TempA1=0, TempA2=0, TempA3=0, Con=0, Li1=0, Li2=0;
double NTCequation1=0,NTCequation2=0, NTCequation3=0;   //NTC 103 equation variables
char txt1[2], txt2[2], txt3[2] ;
Con=PORTA.RA3;
Li1=PORTA.RA4;
Li2= PORTA.RA5;
OSCCON=01110011;                        //8MHz Internal oscillator
ADCON1=00001101;                        //Configure RA0&RA1&RA3 pins as analog
TRISA=0xFF;                             //Configure PORTA as input
TRISC=0x00;
TRISD=0x00;                             //Configure PORTA as output
ADC_Init();                             //Initialize ADC module
Lcd_Init();                             //Initialize LCD
Lcd_Cmd(_LCD_CLEAR);                    //Clear display
```

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```
Lcd_Cmd(_LCD_CURSOR_OFF);              //Cursor off

while(1) {

PORTA=0x00;                            //Reset all ports
PORTD=0x00;
PORTC=0x00;
Lcd_Cmd(_LCD_CLEAR);                   //LCD start display
Lcd_Out(1,1,"Solar air heat");
Lcd_Out(2,4,"collector");
Delay_ms(2000);
Lcd_Cmd(_LCD_CLEAR);
Lcd_Out(2,4,"Project team");
Delay_ms(1000);
Lcd_Cmd(_LCD_CLEAR);
Lcd_Out(1,1,"Eng.Ibrahim");
Lcd_Out(2,1,"Eng. Bahaa");
Delay_ms(3000);
Lcd_Cmd(_LCD_CLEAR);
Lcd_Out(1,1,"Project Supervisors");
Lcd_Out(2,1," Dr.Momen Sughayyer");


Lcd_Cmd(_LCD_CLEAR);
Lcd_Out(1,1,"T1=");
TempA1=ADC_Read(0);                    // Read analog value from temp sensor 1
NTCequation1=0.0000000000020904*TempA1*TempA1*TempA1*TempA1*TempA1-
0.000000050557*TempA1*TempA1*TempA1*TempA1
+0.0000047935*TempA1*TempA1*TempA1-0.0021861*TempA1*TempA1+0.59765*TempA1-
49.967;      //NTC 103 equation
IntToStr(NTCequation1,txt1);                            // temp indoor
Lcd_Out(1,4,txt1);
```

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```c
Lcd_Out(1,8,"T2=");
TempA2=ADC_Read(1);                        // Read analog value from temp sensor 2
NTCequation2=0.0000000000020904*TempA2*TempA2*TempA2*TempA2*TempA2-
0.000000050557*TempA2*TempA2*TempA2*TempA2
+0.0000047935*TempA2*TempA2*TempA2-0.0021861*TempA2*TempA2+0.59765*TempA2-
49.967;      //NTC 103 equation
IntToStr(NTCequation2,txt2);                                //temp in solar collector
Lcd_Out(1,11,txt2);


Lcd_Out(2,4,"T3=");
TempA3=ADC_Read(2);                        // Read analog value from temp sensor 3
NTCequation3=0.0000000000020904*TempA3*TempA3*TempA3*TempA3*TempA3-
0.000000050557*TempA3*TempA3*TempA3*TempA3
+0.0000047935*TempA3*TempA3*TempA3-0.0021861*TempA3*TempA3+0.59765*TempA3-
49.967;      //NTC 103 equation
IntToStr(NTCequation3,txt3);                                //temp outdoor
Lcd_Out(2,8,txt3);


If((TempA2 > TempA1) && Con==0)

        If(Li1==1){
PORTC.RC2=1;
 PORTD.RD0=1;                               //Open valve to indoor
    PORTD.RD1=0;
    Delay_ms(200);
    PORTD.RD0=0;
    PORTD.RD1=1;
    Delay_ms(200);
    PORTD.RD0=1;
    PORTD.RD1=0;
        Delay_ms(200);
```

```
    PORTD.RD0=0;
    PORTD.RD1=1;
    Delay_ms(200);
    PORTD.RD0=1;
    PORTD.RD1=0;
    Delay_ms(200);
    PORTD.RD0=0;
    PORTD.RD1=0;


PORTC.RC4=1;                        // close valve to air conditioner
    PORTC.RC5=0;
  Delay_ms(200);
PORTC.RC4=0;
    PORTC.RC5=1;
  Delay_ms(200);
PORTC.RC4=1;
    PORTC.RC5=0;
  Delay_ms(200);
PORTC.RC4=0;
    PORTC.RC5=1;
  Delay_ms(200);
PORTC.RC4=1;
    PORTC.RC5=0;
Delay_ms(200);
PORTC.RC4=0;
    PORTC.RC5=0;
    }

If(Con==1&&Li2==1)
{
PORTD.RD2=1;                        // Open valve to air conditioner
```

```
    PORTD.RD3=0;
    Delay_ms(200);
    PORTD.RD2=0;
    PORTD.RD3=1;
    Delay_ms(200);
    PORTD.RD2=1;
    PORTD.RD3=0;
        Delay_ms(200);
    PORTD.RD2=0;
    PORTD.RD3=1;
    Delay_ms(200);
    PORTD.RD2=1;
    PORTD.RD3=0;
    Delay_ms(200);
    PORTD.RD2=0;
    PORTD.RD3=0;



PORTC.RC6=1;                                    // close valve to indoor
    PORTC.RC7=0;
    Delay_ms(200);
PORTC.RC6=0;
    PORTC.RC7=1;
    Delay_ms(200);
PORTC.RC6=1;
    PORTC.RC7=0;
    Delay_ms(200);
PORTC.RC6=0;
    PORTC.RC7=1;
    Delay_ms(200);
PORTC.RC6=1;
```

```
    PORTC.RC7=0;
Delay_ms(200);
PORTC.RC6=0;
    PORTC.RC7=0;
    }

If(TempA2<= TempA1)
       { if(Li1==1&&Li2==0)
{ PORTC.RC4=1;                                    // close valve to indoor
    PORTC.RC5=0;
   Delay_ms(200);
PORTC.RC4=0;
    PORTC.RC5=1;
   Delay_ms(200);
PORTC.RC4=1;
    PORTC.RC5=0;
   Delay_ms(200);
PORTC.RC4=0;
    PORTC.RC5=1;
   Delay_ms(200);
PORTC.RC4=1;
    PORTC.RC5=0;
Delay_ms(200);
PORTC.RC4=0;
    PORTC.RC5=0;
}
If(Li1==0&&Li2==1)
{
PORTD.RD2=1;                              // close valve to air conditioner
    PORTD.RD3=0;
    Delay_ms(200);
```

```
    PORTD.RD2=0;
    PORTD.RD3=1;
    Delay_ms(200);
    PORTD.RD2=1;
    PORTD.RD3=0;
        Delay_ms(200);
    PORTD.RD2=0;
    PORTD.RD3=1;
    Delay_ms(200);
    PORTD.RD2=1;
    PORTD.RD3=0;
    Delay_ms(200);
    PORTD.RD2=0;
    PORTD.RD3=0;
}
}
}
```

5.2.11 Design of Electronic Circuits

Introduction

An electronic circuit is composed of individual electronic components, such as resistors, transistors, capacitors, inductors and diodes, connected by conductive wires or traces through which electric current can flow. The combination of components and wires allows various simple and complex operations to be performed: signals can be amplified, computations can be performed, and data can be moved from one place to another. Circuits in the project are constructed of discrete components connected by individual pieces of wire. In this chapter the electrical parts and circuits are discussed, to explain the necessary resistance needed for the circuit protection and explaining the circuits of

each function such as temperature sensors, stepper driver, and power supply, these functions are divided into two groups the inputs and outputs as discussed in the previous chapter.

Power Supply

A power supply is a device that supplies electric power to an electrical load, a regulated power supply is one that controls the output voltage or current to a specific value; the controlled value is held nearly constant despite variations in either load current or the voltage supplied by the power supply's energy source. Three types of power sources are needed to power up the apparatus, 220v AC to power up the centrifugal fan, 12v DC to power up the stepper, and 5v DC to power up the control circuits such as the microcontroller.

Outputs

The control and activation of the outputs of the system are discussed in this section, which are the centrifugal fan, and two electrical stepper motors.

5.3 connect and disconnect the two systems

To connect the solar air heat collector system with the air conditioner system, an easy and appropriate method will be applied to do so, by using flexible connection, and this method will be done by using four pulleys, two for above the external unit and two for below it, and all these four pulleys to be fixed on the right and left sides of the external unit of the conditioner, and an electrical motor to provide motion power for two pulleys, and the motor pulls the flexible connection to the left by two bands connects the four pulleys when we need to connect the two systems together. And when we need to disconnect the both systems from each other, the motor rotates in the opposite direction, so bringing back the flexible connection to the left, so disconnecting both systems, and the two bands will be fixed or tied to the edge of the flexible connection, so when the motor wraps the bands, the two bands will pull the flexible connection to the right or left according to the motor

rotation direction. And the diagram below illustrates the procedure.
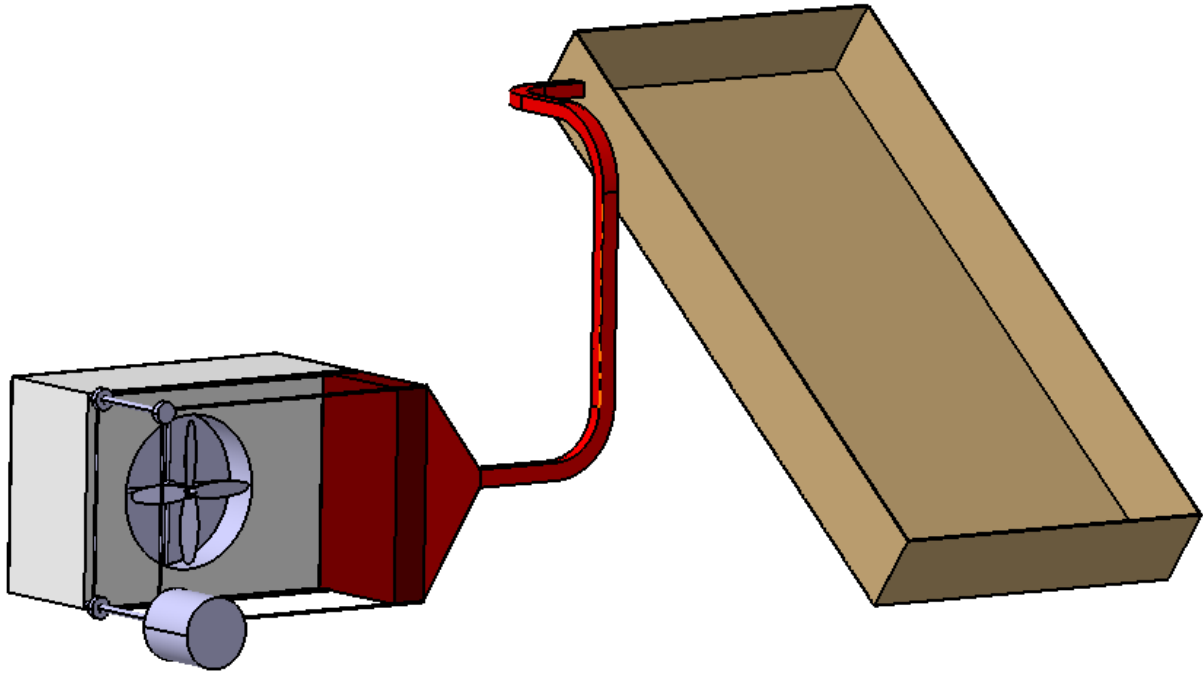

Fig. 5.17: flexible connection between the systems

Chapter six

Calculation and design

6.1 Gas heat pump

6.2 Solar air heat collector

      6.2.1 Fins specifications

      6.2.2 Inlet and outlet specifications

6.3 Heat load calculation of the studied house

6.1 Gas heat pump
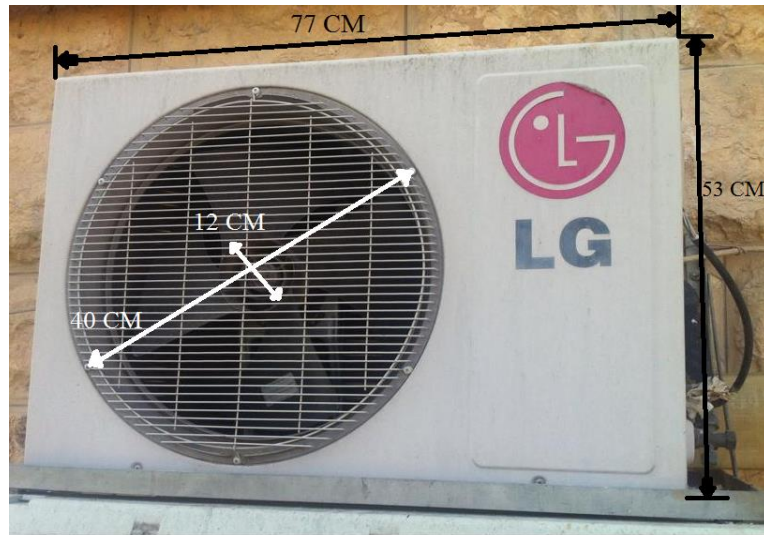
Fig. 6.1: Dimensions of outdoor unit.

Table 6.1: The dimensions of outdoor unit.

Width (cm)	Height (cm)	Outer diameter (cm)	Inner diameter (cm)
77	53	40	12

$$A = \pi r^2 \tag{6.1}$$

$$\text{Area of A. C} = \mathbf{\pi} * (\mathbf{0.20^2 - 0.06^2}) = \ \mathbf{0.1144}$$

$$\text{flow rate of A. C} = 0.28 \ ^{m^3}\!/_{s} \qquad [\,13\,]$$

So we need the same flow rate of Air conditioner (A.C) from solar air heat collector (S.C) to keep the system stable.

6.2 Solar air heat collector

Fig. 6.2: Solar air heat collector by catia.

Table 6.2: Components specification and characteristics of the solar air heat collector system parameters.

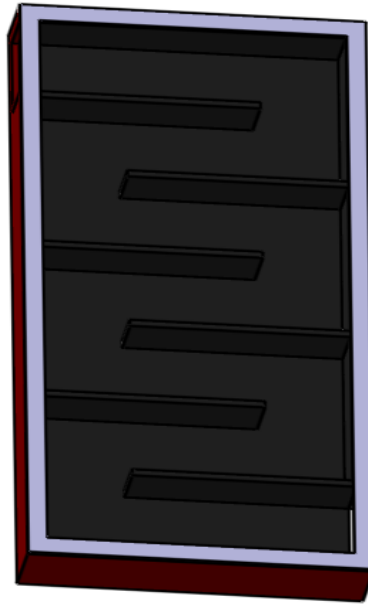|		
a.	Width	90 (cm)
b.	Height	180 (cm)
c.	No . of fins	10
d.	Length of fin	65 (cm)
e.	Area	16200 (cm^2)
f.	Effective area	13496 (cm^2)
g.	Absorber plate	1.0 mm aluminum (air collector)
h.	Surface treatment	Black paint coating
i.	Glazing	Normal window glass of thickness 4 mm
j.	No. of glazing	One
k.	Back insulation	Made of Thermocol sheets of thickness 20 mm
l.	Side insulation	Made of Thermocol sheets of thickness 20 mm
m.	Casing	Made of wood of thickness 16 mm
n.	Collector tilt	35°
o.	Air flow area	0.014 m^2

P.S: 1- To increase the effective area, we added Aluminum sheets on sides and fins.

2- The values of the table (6.2) are taken from Annex 1.
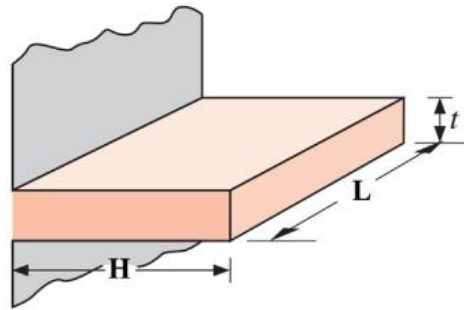
6.2.1 Fins specifications :

Fig. 6.3: The shapes of rectangular fin.
H=10 (cm).
L=65 (cm).
t=1.6 (cm).

6.2.2 Inlet and outlet specifications :

1. Inlet

Fig. 6.4: The inlet air flow with centrifugal fan.

Table 6.3: Specification of centrifugal fan.

a.	Name	CYH1
b.	Flow rate	156 (m^3 / h) = 0.0433 (m^3 / s)
c.	Speed	3400 r.p.m
d.	Frequency	60 Hz
e.	Power	1/8 HP = 93.25 watt/h
f.	Voltage	220 V
g.	Net weight	4.3 Kg

2. Outlet

Fig.6.5: The outlet air flow.

Now

Flow rate of centrifugal fan = 0.0433 m^3 / s

Air flow area of solar air heat collector = 0.014

Flow = area * velocity

The velocity of air in solar air heat collector is = 0.0433/0.014 = 3.0929 m/s

Flow rate of air in air conditioner in winter = 0.28 (m^3/s)

Air flow area for solar air heat collector = A*V = 0.014*3.1 = 0.0434 (m^3/s)

No . of solar air heat collector $= \dfrac{\text{flow rate of air in air conditioner}}{\text{air flow area for single solar air heat collector}} = \dfrac{0.28}{0.0434} = 6.4516$

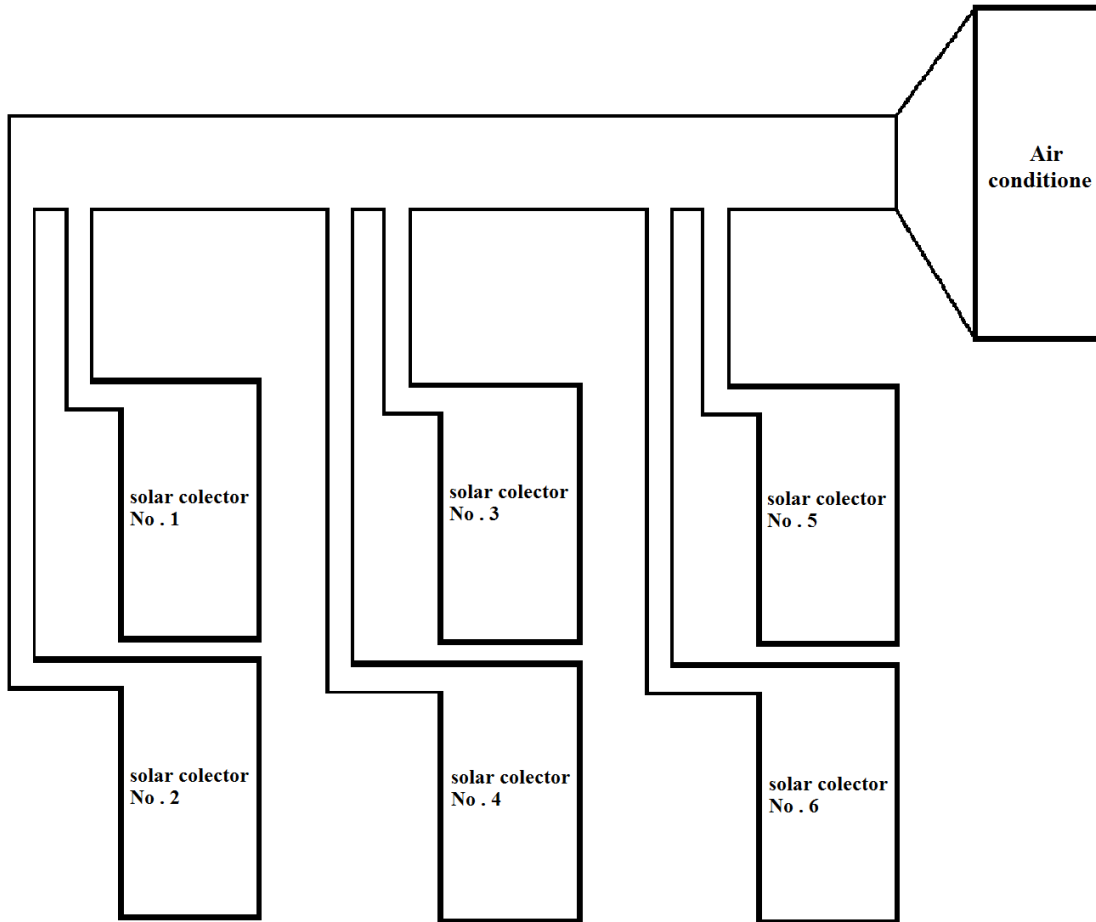No . of solar air heat collector ≈ 6 solar collector as in fig.

Fig. 6.6: Gathering of six solar air heat collectors in parallel.
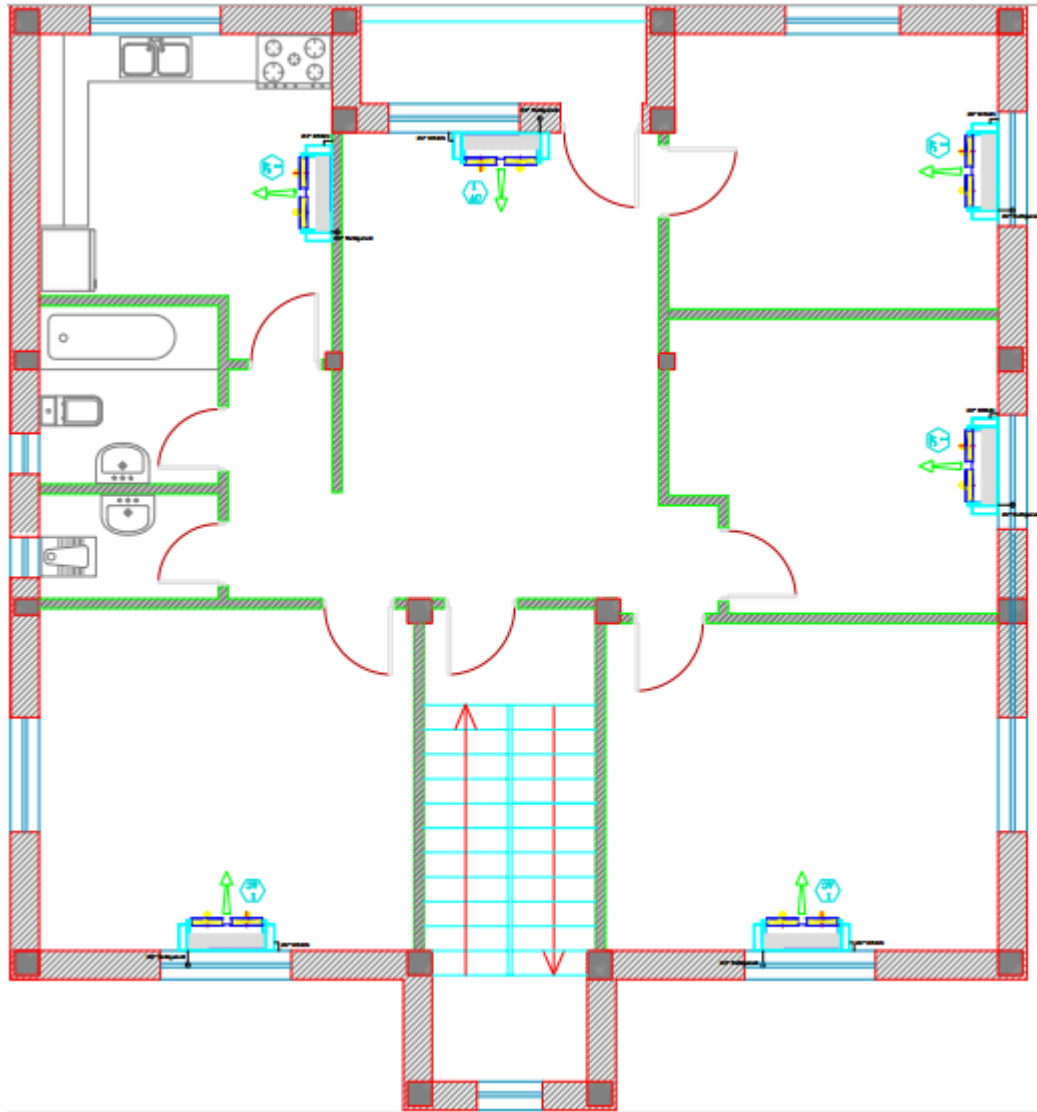
6.3 Heat load calculation of the studied house

Fig. 6.7: The house design.

Table 6.4: The dimensions of outdoor unit.

Heating Load Summary Sheet				
Room :		**M. Bed Room**		
	U	**A**	**ΔT**	**Q˙**
Wall	0.8212	21.09	16	277.1057
Un. From Stairs	2.111	11.495	8	194.1276
Un. From Toilet	1.916	6.0225	8	92.31288
Windows	3.5	3	16	168
Ceiling	**U1*A1**	**U2*A2**	**ΔT**	**Q˙**
	12.90026	3.184479	16	257.3559
Infiltration		**L**		**Q˙**
		12		926.4
Miscellaneous				10%
Q˙ [kW]				**2.1068**

Table 6.5: The dimensions of outdoor unit.

Heating Load Summary Sheet				
Room :		**Living Room**		
	U	**A**	**ΔT**	**Q˙**
Wall	0.8212	7.1825	16	94.3723
Un. From Stairs	2.111	4.115	8	69.49412
Un. From T, B.R & K	1.916	12.385	8	189.8373
Windows	3.5	1.6	16	89.6
Doors	5.8	1.86	16	172.608
Ceiling	**U1*A1**	**U2*A2**	**ΔT**	**Q˙**
	18.0606	4.458328	16	360.3028
Infiltration		**L**		**Q˙**
		6.2		478.64
Miscellaneous				10%
Q˙ [kW]				**1.6003**

P.S: The air conditioner is one ton and the this calculation is for the house in the figure 6.7.

Chapter seven

Results and conclusion

7.1 Experimental results

7.2 Conclusion

7.1: Experimental results

Fig. 7.1: The solar air heat collector.

Table 7.1: Experimental data

Time and date of read	T_{in} (c^o)	T_{out} (c^o)	Q (watt)
4/5/2015 at 11 AM	20	38	937.8
4/5/2015 at 6 PM	22	34	625.2
5/5/2015 at 11 AM	21	37	885.7
5/5/2015 at 6 PM	23	35	625.2

$$\dot{m} = \rho * A * V \qquad\qquad (7.1)$$

$\dot{m}$ = mass flow rate in solar collector (kg/s)
ρ = density of air = 1.2 (kg/m^3)
A = air flow area in solar air collector = 0.014 (m^2)
V = speed of air in solar air collector = 3.1 (m/s)

$$\dot{m} = 1.2 * 0.014 * 3.1 = 0.0521 \text{ kg/s}$$

$$Q_n = \dot{m} * Cp * (T_{out} - T_{in}) \qquad\qquad (7.2)$$

Q_n = collector useful energy (watt)
$\dot{m}$ = mass flow rate in solar collector (kg/s)
Cp = specific heat of air = 1000 (J/kg.K)
T_{out} = temperature of air at outlet of solar air heat collecter = 38 (C^o)
T_{in} = temperature of air at inlet of solar air heat collecter = 21 (C^o)

$$\eta = \frac{Q_n}{I * A_c} * 100\% \qquad\qquad (7.3)$$

η = efficiency of solar air heat collector
Q_n = collector useful energy (watt)
I = solar radiation (w/m^2) = 1100 watt/m^2
A_c = effective area = 1.3496 m^2

Case 1

$$Q_n = 0.0521 * 1000 * (20\text{-}38) = 937.8 \text{ watt}$$

$$\eta = \frac{937.8}{1.3496 * 1100} * 100\% = 63.17\%$$

Case 2

$$Q_n = 0.0521 * 1000 * (34\text{-}22) = 625.2 \text{ watt}$$

$$\eta = \frac{625.2}{1.3496*850} * 100\% = 54.5\ \%$$

Case 3

$$Q_n = 0.0521 * 1000 * (38\text{-}21) = 885.7 \text{ watt}$$

$$\eta = \frac{885.7}{1.3496*1100} * 100\% = 59.66\%$$

Case 4

$$Q_n = 0.0521 * 1000 * (35\text{-}23) = 625.2 \text{ watt}$$

$$\eta = \frac{625.2}{1.3496*850} * 100\% = 54.5\%$$

$$\text{Average efficiency} = \frac{0.6317+0.545+0.5966+0.545}{4} = 0.5796 = 57.96\%$$

7.2: Conclusion :

1. The system needs 6 solar air heat collectors to preserve the air flow to the air conditioner system.

2. The system needs to a surface area of $3*3*3.6 \text{ m}^3 = 32.4 \text{ m}^3$.

3. It is expected that the efficiency of the solar air heat collector system to decrease in the winter because of the strong winds, low temperature, low intensity of sunlight, and other factors which causes a decrease in the efficiency of the solar air heat collector system.

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13- Elsayed, Amr O., Hariri, Abdulrahman S. "Effect of Condenser Air Flow on Performance of Split Air Conditioner", World Renewable Energy Congress, 8-13 May 2011; Sweden. P: 2134.

14- Palestinian National Authority-Palestinian Central Bureau of Statistics. "Climatic conditions in the Palestinian territories". The annual report 2007, Ramallah; July 2008.

15- www.arabgeographers.net/vb/attachments/attachments/arab1281/. Accessed on 6th may 2015 at 01:40 AM.

16- Source: Metrological General Directorate

Annex 1: Reference of specification of solar air heat collector.

a.	Width air gap	http://www.builditsolar.com/projects/spaceheating/gregaircol/aircol.htm
b.	Height air gap	http://agronomy.emu.ee/vol08spec1/p08s101.pdf
c.	Speed of air in solar collector	http://www.academia.edu/8161134/a_comparative_experimental_investigation_of_thermal_performance_of_three_different_solar_air_heaters
f.	Centrifugal fan	http://www.blower.com.tw/en_pdc05_cyh.htm
g.	Absorber plate	http://www.hindawi.com/journals/isrn/2012/282538/
h.	Surface treatment	http://www.academia.edu/8161134/a_comparative_experimental_investigation_of_thermal_performance_of_three_different_solar_air_heaters
i.	Glazing	http://www.academia.edu/8161134/a_comparative_experimental_investigation_of_thermal_performance_of_three_different_solar_air_heaters
j.	No. of glazing	http://www.academia.edu/8161134/a_comparative_experimental_investigation_of_thermal_performance_of_three_different_solar_air_heaters
k.	Back insulation	http://www.academia.edu/8161134/a_comparative_experimental_investigation_of_thermal_performance_of_three_different_solar_air_heaters
l.	Side insulation	http://www.academia.edu/8161134/a_comparative_experimental_investigation_of_thermal_performance_of_three_different_solar_air_heaters
m.	Casing	http://www.academia.edu/8161134/a_comparative_experimental_investigation_of_thermal_performance_of_three_different_solar_air_heaters
n.	Collector tilt	www.arabgeographers.net/vb/attachments/attachments/arab1281/
o.	Flow rate of air in air conditioner	http://www.ep.liu.se/ecp/057/vol8/051/ecp57vol8_051.pdf