Eastern Mediterranean University

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Project Title: Designing and Testing Different Types of Solar Air Heaters

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ABSTRACT

The future of our planet depends on the energy sources which is using economically. Exploitotion of energy sources increase our needs of energy. Energy sources such as fossil fuels are dangerous for environment and cannot be used for a long time. That's why we need a renewable energy source. In this context, solar energy is being seen as suitable source for saving the energy sources and development of countries which can receive rays from the sun. Carried out some experiments proves that solar air heater can provide high thermal performance in heating systems. According to different Solar Air Heater designs, efficiencies of solar collectors can be increased. In addition to these, new designs of Solar Air Heater are emerging in various aspects, in different materials which are used, in acceptable cost.

In this project, we decided to use conical type, double glazing type and square tube type absorbers for having a large area where air passes. A thin aluminum material was used for absorber plate. Heat losses were minimized by using glass wool material. We used solar selective coating to help us absorb the sun's energy. Then, incident angles were calculated for increasing the collector performance. After all these works, air inlet temperature, the glazing cover temperature, the absorber plate temperature and air exit temperature were calculated and efficiency differences were compared between different type of solar air heaters.

ACKNOWLEDGEMENT

We would like to express our deepest appreciation to all those who provided us the possibility to complete this Capstone Project. A special gratitude we give to our final year project supervisor, Assoc. Prof. Dr. Hasan HACIŞEVKİ, whose contribution in stimulating suggestions and encouragement, helped us to coordinate our project especially in completing this report.

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A heartfelt thanks to our project coordinator Assist. Prof. Dr. Mostafa RANJBAR for his advices and his teachings on the way to becoming a good enginneer.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

A_c	Area of collector,[m^2]
C_p	Specific heat of the fluid [kJ / kg.K]
I	Solar radiation [W / m^2]
$\acute{m}$	Mass flow rate [kg / s]
Q	Volumetric flow rate [m^3 / s]
V	Velocity of the outlet air [m / s]
T_{in}	Inlet temperature[˚C]
T_{out}	Outlet temperature[˚C]
ΔT	Temperature difference[˚C]
η	Thermal efficiency of solar collector
ρ	Density of air [kg / m^3]
$U_{overall}$	Overall heat transfer coefficient [W/m^2.K]
k	Thermal conductivity [W/ m. ˚C]
Q_{loss}	Total heat loss [W]

CHAPTER 1

INTRODUCTION

1.1 WHAT IS THE SOLAR ENERGY ?

Solar energy is an energy which is obtained from the sun and without its entity all life on earth would end. Solar energy has been looked onto as a grave source of energy for many years because of the endless amounts of energy that are made freely existing, if harnessed by modern technology.

1.2 THE IMPORTANCE OF THE SOLAR ENERGY

Solar energy has an important role for many things since it started be used. Increasingly, engineers are learning how to harness this significant resource and use it to change traditional energy sources.

1.2.1 Solar Energy is Important in Nature

Solar energy is an important part of a nearly every life process, if not, all life process. Plants and animals, similar, use solar energy to produce significant foods in their cells. Plants use the energy to produce the green chlorophyll that they need survive ,while people use the sun rays to produce vitamin D in their bodies. However, when man learned to actually convert solar energy in useable energy,it became even more important [1].

1.2.2 Solar Energy Is Important as Clean Energy

Since solar energy is fully natural, it is considered a clean energy source. It doesn't break the environment or create a threat to Eco-systems the way oil and some other energy sources might. It does not cause greenhouse gases, air or water pollution. The small quantity of effect it does have on the environment is usually from the chemicals and solvents that are used during the manufacture of the photovoltaic cells that are need to transform the sun's energy in electricity.

1.2.3 Why Solar Energy is Important for us?

The most important topic of all is likely why soalr energy is important to you, personally,

- Fossil fuels, like gas and oil, are not renewable energy. Once they finished they can not be replenished. Someday these fuels will gone and then human will either need to come up with a new way to provide power.
- Fossil fuels create massive pollution in the environment. This pollution influences waterways, the air you take a breath, and even the meat and fruit and vegetable that you eat.
- These fuels are very expensive to take back from the earth and they are expensive to use. Other, more Eco-friendly energy sources like wind and solar energies are relatively not expensive and easy to produce.

1.2.4 Advantages

1. Solar energy is free although there is a cost in the building of “collectors” and other equipment necessary to convert solar energy into electricity or hot water.

2. Solar energy doesn’t cause pollution. However, solar collectors and other associated equipment / machines are manufactured in factories that in turn cause some pollution.

3. Solar energy can be used in distant areas where it is too expensive to extend the electricity power grid.

4. Many everyday items such as calculators and other low power consuming devices can be powered by solar energy effectively.

5. It is predicted that the world’s oil reserves will last for 30 to 40 years. However , solar energy is infinite (forever) [2].

1.2.5 Disadvantages

1. Solar energy can only be hamessed when it is daytime and there is no cloud .

2. Solar collectors, Panels and cells are relatively expensive to manufacture although prices are falling rapidly.

3. Solar power stations can be built but they don’t match the power output of similar sized conventional power stations. They are also very expensive.

4. Large areas of land are required to capture the suns energy. Collectors are usually arranged together especially when electricity is to be produced and used in the same location.

5. Solar power is used to charge batteries so that solar powered devices can be used at night. Also, the batteries are large and heavy and need storage space. They also need replacing from time to time [2].

1.3 SOLAR AIR HEATING

The solar air heater (SAH) is one of the most important applications of solar energy, it is a device that comprises mainly of a collector, glazing material and an absorber. The absorber is usually a metallic material with good conuctivity such as Aluminum or sheet steel. The metallic material absorbs energy from the sunlight and get heated in the process, thereby heating surrounding air.

Solar air heaters operate on some of the most fundamental and simple thermodynamics principles:

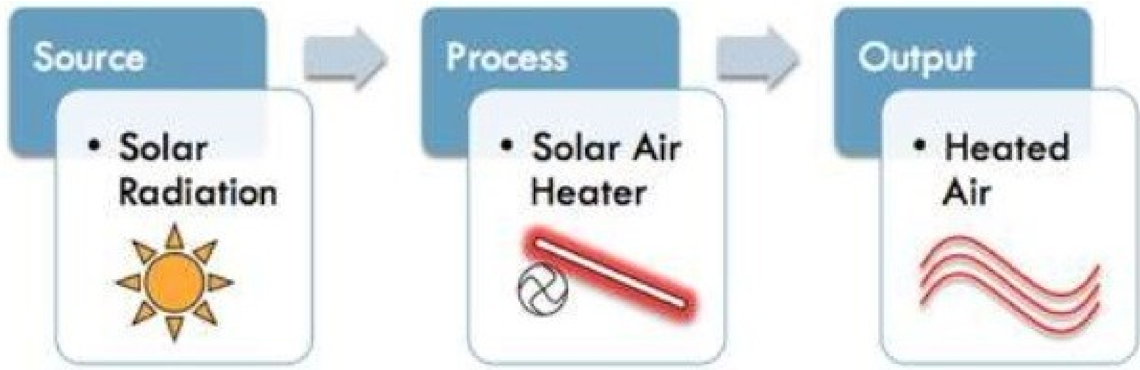


Figure 1.1: Basic of Solar Air Heater[33]

Absorbtion of the solar radiation by a solid body results in the body heating up. In large terms this solid body is known as the "collector". Some bodies are better at absorption than others, such as those with black non-reflective surfaces.

Convection of heat from the heated solid body to air as it pass over the surface.Typically a fan is used to force the air across the heated body, the fan can be solar powered or mains powered.

Different types of solar air heater technology obtain this process using the same basic priciples but through the use of different solid bodies moving as the collector. The fan that transfers the air opposite the heated surface is also used as part of a ducting system to direct heated air in the dwelling space. Besides to heating the air inside of that space, the heat can also be absorbed by thermal mass such as walls, flooring, furniture and other contents. Such heat is effectively “stocked” and slowly spent beyod sunlight hours.

1.4 APPLICATION AREAS OF SOLAR AIR HEATER

A variety of applications can use the technology of solar air heating to reduce the impact of using traditional heat sources, such as fossil fuels, to create sustainable resources for the production of thermal energy. Aplications such as heating, the season extends greenhouse trick ventilation preheating or process heat can be resolved with the devices of air solar heater.

Solar air heat can also be used in process applications such as drying laundry,crops (i.e. tea,corn,coffee,figs,grapes,apricots) and other drying applications. Air heated through a solar collector and then passed over a medium to be dried can supply an efficiency means by which to decrease the humudity content of the material.

1.5 SAVING WITH SOLAR AIR HEATER

Case studies and University investigations shows us that some climatical systems may be caused the decrease the confidence on convectional heating and cooling systems by over 50%. Naturally results do vary depending on the local climate, size and type of system installed, size and type of existing heating/cooling, size of dwelling and the thermal properties of the house (insulation, draft protection).

1.6 THE AIM OF PROJECT

The main purpose of this project is to design and testing a solar air heater (SAH) device to absorb solar energy by collector and transfer energy to the air for heating. Basicly, the cold air passing through the device and heating the spaces by sunrise. Solar air heater collectors were installed on the roof of the EMU Mechanical Engineering Departmant. An important point of this project is that testings will perform in winter conditions. Generally, solar air heater datas are given in summer time, we wonder that which differences will occur between summer and winter conditions such as temperature differences and efficiencies. For this reason, we will use 3 different type collectors which has different absorber shapes.

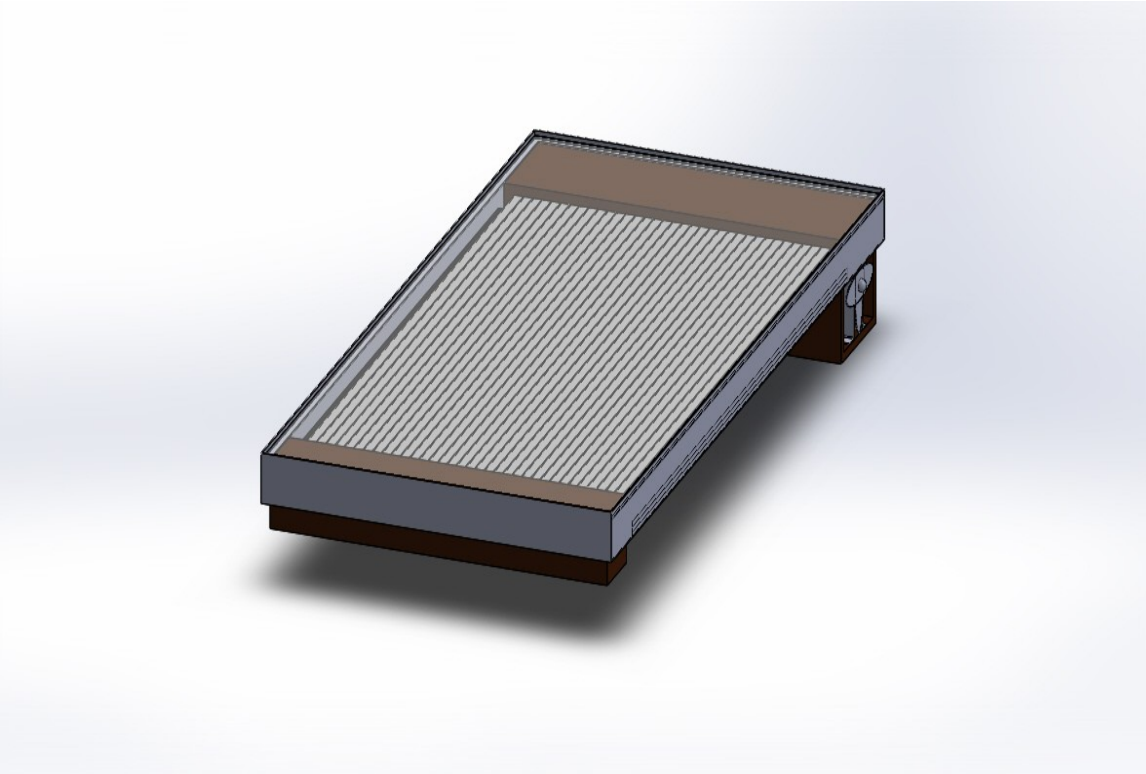


Figure 1.2 : Aliminum Tube Type

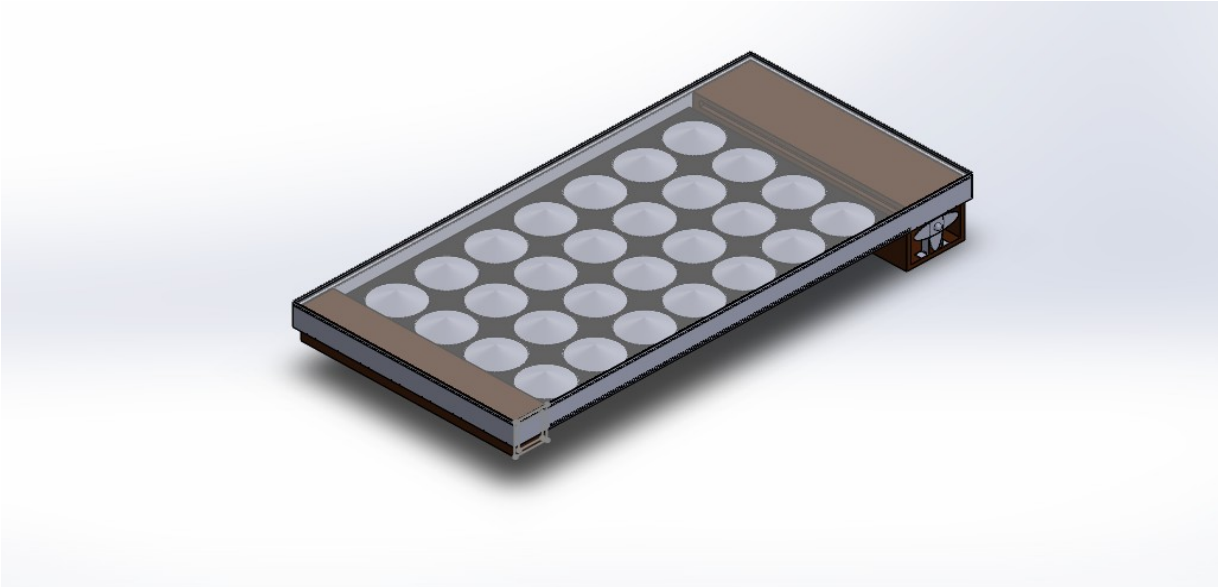


Figure 1.3 : Conical Type

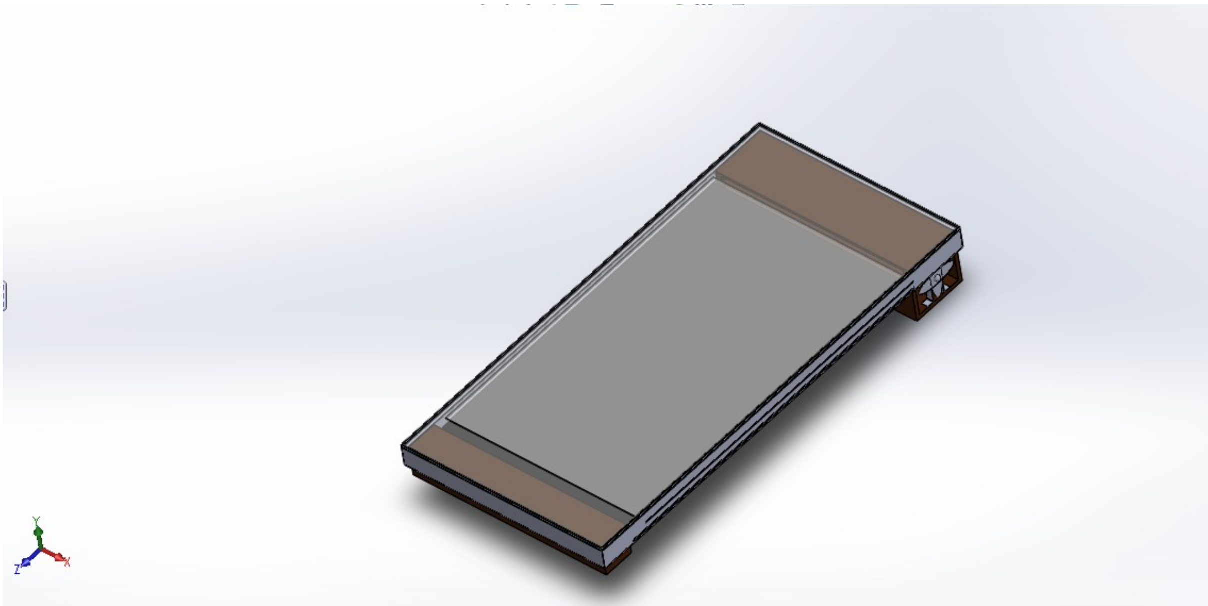


Figure 1.4 : Double Glazing Type

CHAPTER 2

LITERATURE REVIEW

2.1 OVERVIEW OF SOLAR AIR HEATERS

Air is mostly used as heat transfer in different types of energy conversion systems. Heating process covers industrial heat processes and for heating of buildings. Flat plate collector is one of the best options for heating air, but the applications of solar air heaters have not been developed than water air heaters. Using air particles as a working fluid in a flat plate collector provides us that eliminates the need for a heat exchanger which is transfering the heat from liquid to air in a water heating collector. Different designs of a solar air collectors can be used to increase the efficiency of used collectors.

2.2 RESEARCHES AND DEVELOPMENTS

Solar air heating researches and developments started in the 1940s, with studies by Miller [3], Lof [4] and Telkes[5]. These works included the construction and testing of complete solar air heating systems by Lof in 1944 and Telkes in 1947, in houses located in Colorado and Massachusetts, respectively. The overlapped glass solar air heater invented by Lof has been tested by his collaborators [6,7]. Selcuk[8] conducted a quasi-steady state analysis of the overlapped glass plate air heater and tested the model experimentally. In 1950s, Bliss[9] designed, built, and tested a solar air heating system in an Arizona house. Studied on simple flat plate collectors were conducted by Whillier [10], Close [11], and Gupta and Garg [12]. Charters [13] theoretically investigated the performance of single glazed collector designs having the flow above and below the absorber plate. Cope-Appel and

Haberstroh [14] theoretically examined the flow paths for single flat plate employing two glass covers.

Solar air heaters have been made in many variables such as glazing types, absorber surfaces have included overlapped, spaced, clear and black glass plates, single smooth metal sheets, flow-through stacked screens or mesh, corrugated metal plates, finned metal sheets, etc. In some collector types air passing beneath the plate or underlying air gaps reduces downward heat loss. Sheven et al. [15] classified various air heating collector designs under six categories according to the type of absorbing surface. Different parameters may be defined by the performance improvement techniques.

Theoretical and experimental studies on the flat plate of solar air collectors started by Buelow [16]. The purpose of a V-groove type in the absorber plate is increasing the solar absorptance and the turbulance in the air was given by Hollands [17].

Close[11] tested the effect of triangular cross sectional grooves with a selective surface for the various flow paths. Charters and MacDonald [18] also examined the V-grooved absorbing surface for the various flow arrangements. Gupta and Garg [12] examined the absorber composed of two sheets of round corrugated material, transversely placed above each other and welded along the length. Cole-Appel and Haberstroh [14] used a simple linear model to compare the thermal performance of five flat plate solar air heater designs, two of them were of the straight finned type. Bevill and Brandt [19] studied the effects of specularly reflecting fins on a single glazed collector with the air flow and fins located above the absorber plate.

Solar air heaters for different applications are seperate according to its cost. The cost of air heating by a solar collector is dominated by the collector material cost and air pumping cost. Charters [20] examined the optimization of the aspect ratio of the rectangular flow passage from the view point of minimizing the cost for a fixed pumping power. Hollands and Scheven [21] examined the effect of the dimensions of the rectangular and triangular air flow passages on the coefficient of forced convective heat transfer from absorber to flowing air in plate type air heating collectors.

Selcuk[22] suggested the use of broken glass pieces for matrix air heaters. Broken pieces almost without cost, glass being transparent to solar radiation can be used in three ways for absorbing the solar radiation. First of these, the top surface is blackened so that the radiation is absorbed at the top. Secondly, the radiation is allowed to be absorbed gradually throughtout the volume of the matrix. Finally, the bottom of the matrix is blackened so that the unabsorbed radiation is collected at the bottom, which is insulated from the environment.

Charters [13] also examined the heat transfer events in symmetrically heated ducts representing the flat plate solar collector. Karmare and Tikekar [23] experimentally investigated heat transfer to the airflow in the rectangular duct of an aspect ratio 10:1.

Efficiency of solar air heaters relation with different types of geometry of roughness elements on the absorber plate was studied by Mittal et al [24]. The effective efficiency has been computed by using the correlations for heat transfer and friction factor developed by various investigators within the investigated range of operating and system parameters. Sahu and Bhagoria [25] studied heat transfer coefficient by using 90° broken transverse ribs on absorber plate of a solar air heater; the roughened wall has heated while the remaining three walls are insulated. The roughened wall has roughness with pitch (P), ranging from 10-30 mm, height of the rib of 1.5 mm and duct aspect ratio of 8. The air flow rate corresponds to Reynolds number between 3000-12,000. The heat transfer results have been compared with those for smooth ducts under similar flow and thermal boundary condition to determine the thermal efficiency of solar air heater.

2.3 WORKING PRINCIPLES OF SOLAR AIR HEATER

Most solar air heating systems are same. The concept is that, sun rays absorbed from the sun and coverted to heat into collectors which are covered with glass or plastic.

Solar radiations can not absorbed with a high efficiency without a integrated system so an unique design is required to make this energy transfer possible and deliver the heated air into a building. The technologies designed are known as Solar Air Heaters.

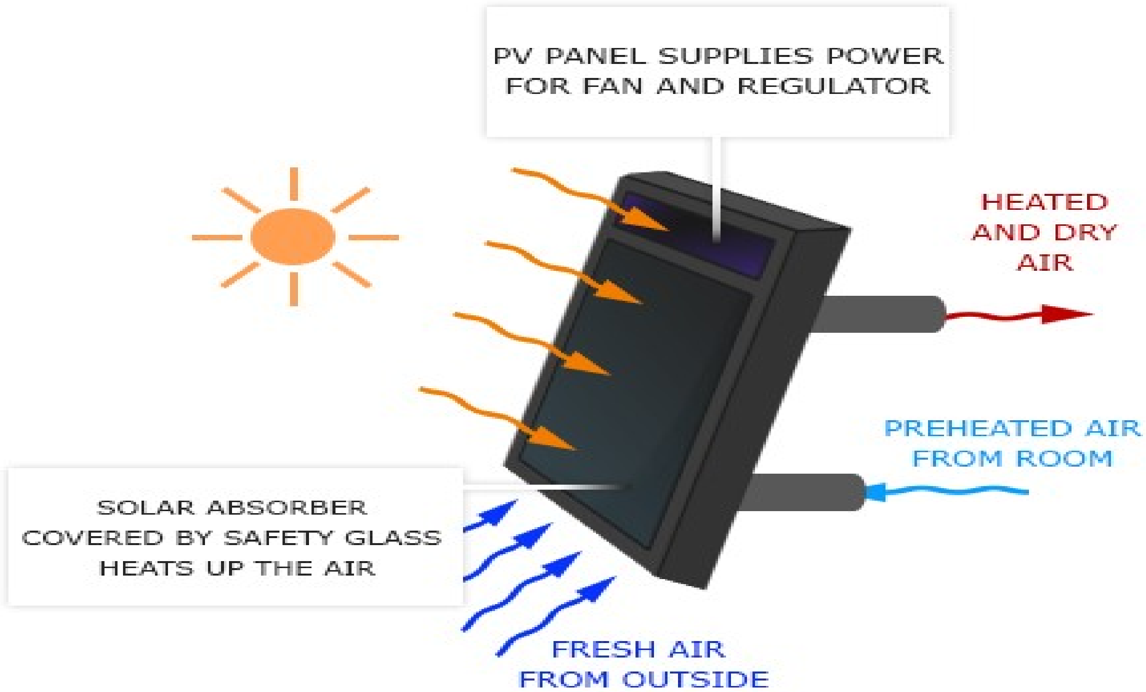


Figure 2.1 : Working principle of solar air heater [26]

Solar Air Heating systems and principles can be explained with some thermodynamic rules which are ;

1. Absorption of the solar radiation by a solid body results in the body heating up. In broad terms this solid body is known as the 'collector'. Some bodies are

better at absorption than others, such as those with black non-refletive surfaces.

2. Convection of heat from the heated solid body to the air as it passes over the surface. Typically a fan is used to force the air across the heated body, the fan can be solar powered or mains powered.

Most of Solar Air Heater manufacturers use these basic principles but different solid bodies or other components are added on collectors. The fan that transfers the air across the heated surface is also used as part of a ducting system to direct the heated air into the dwelling space. In addition to heating the air within that space, the heat can further be absorbed by thermal mass such as walls, flooring, furniture and other contents. Such heat is effectively ‘ stored’ and slowly dissipates beyond sunligt hours [27].

In winter conditions, people can control the mechanisms automatically or manually easily according to system type. For example; when outside temperature is warmer than the inside temperature, you can turn on the fan and blow the warm air directly into your living areas or through the home’s thermal mass. In the contarary case, so, when the outside temperature decreases just turn the fan off. The fan can be coupled with an adjacent damper and this type funs are more useful because the direction of the heat flows does not reverse at nights and in this situations, owners can manually control the system with these fan types which has a valve flap.

In an automated systems, the fan can controlled by an electronic differention thermostat, with one sensor located within the outlet duct and the other within the space of the home to be heated or within the ducting of the thermal mass itself. When the temperature at the collector extends the predetermined amount above that of the room or the air in the duct of the thermal mass, the fan is operational and then turns off when it falls below the predetermined amount. These thermostats generally come with an on/off switch that overrides the system if required.

If the home did not overheat during the day but you wish to cool it down in preparation for the following hot day you can ‘purge’ the accumulated warm air by simply opening a ceiling vent that is connected to inlet duct of the collector. By natural convection the hot air will rise unassisted and dissipate through both the coller surface of the collector and the collectors roof vent to work effectively open low level windows preferably on the southern side of the home where the cooler denser air will enter to displace the vented air until equilibrium is maintained.

Further, some Solar Air Heating Systems also having cooling capabilities. Working principles of these systems like that, heat is obtained through the use of different type collectors, and cooling process are applied and the cold is delivered to the application a heat transfer which is chilled water or dry cool air. These systems consists of some main components such as the air conditioning subsytems, auxiliary subsystems etc.

2.4 SOLAR AIR HEATING SYSTEM APPLICATION

2.4.1 Commercial and residential buildings

Most commercial an residential buildings need for ventilation air. Solar Ventilation Preheating systems preheat this air before bringing it into the building. An air-handling unit sucks ventilation air through the solar collector and delivers it throughout the building with conventional ductwork. On cold days, the solar collectors preheat the air and heater in the air-handling unit provides the necessary remaining heat. On cold sunny days, the solar system can likely provides all the necessary air heating. In the summer, a bypass damper is opened, avoiding an unnecessary load on the air-conditioning system.

An additional advantage of making the solar collector a part the building is that the collector can recapture building wall heat loss. As the heat conducts out the building wall, it reaches the collector air channel. At this point the ventilation air blowing through the channel pick up this heat and blows it back into the building. Typically the ventilation air recaptures half of the wall heat loss.

Most commercial, multi-unit residential and institutional buildings have existing air handling systems. In some cases (apartment buildings, schools), the air handling system is a dedicated ventilation system. In other buildings (offices), the air handling system provides space heating, cooling and ventilation with ventilation air making up between 10 and 20% of the total airflow. In either case, the solar air heating system is connected to the outdoor air intake and the air is distributed through conventional ductwork. The solar air heating system supplies a constant flow of outdoor air preheating the ventilation air.

2.4.2 Industrial Buildings

Industrial ventilation air heating applies to buildings requiring large volumes of outdoor air to replace air exhaustedd from painting, welding, automotive fabrication, or other manufacturing operations. Because of the wide-open plant areas and high ceilings, it is possible to design a Solar Heating System that can replace conventional make-up air heaters. Instead of using a conventional heater to provide the additional heat required, solar make-up air heaters combine solar preheated air with warm building ceiling air and deliver this air to the building. The solar air-handling unit is designed to vary the amount of outdoor air and recirculated air to achieve a flow of constant temperature air (typically 15 to 18 °C). As depicted in **Figure 2.2,** in industrial buildings where there is no existing air distribution sysstem, the Solar Air Heating System interior components consist of a constant-speed fan, a recirculation damper system and a fabric distribution-duct. Perforated fabric ducting is low-cost method of delivering make-up air throughout the building. A recirculation damper system incorporated into the fan compratment mixes warm indoor air with cooler solar collector air to maintain the constant delivered air temperature. The ratio of indoor air to solar air heating system air varies continuosly with changes in the solar collector outlet air teperature, while a duct thermostat the damper system.

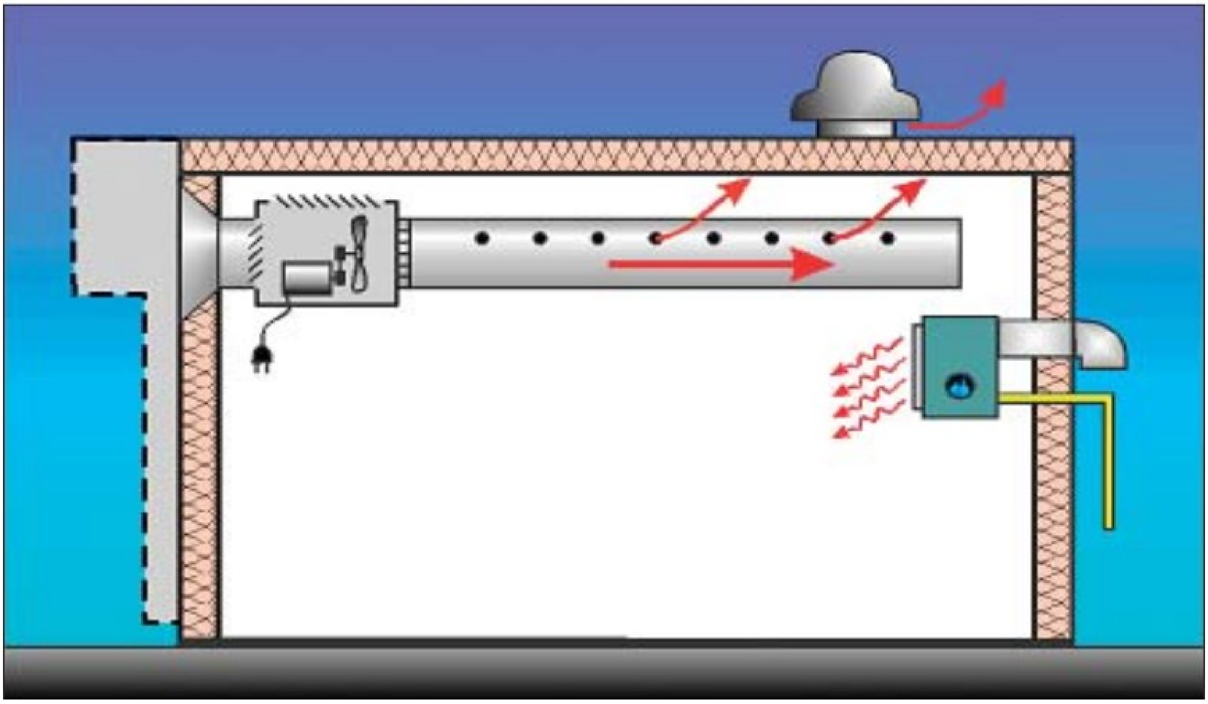


Figure 2.2 :Industiral Building [34]

The mixture of ventilation air and recirculated is distributed to the plant through perforated fabric ducts, which are located at ceiling level. Because the air from the ducting is cooler than air at the ceiling, the ventilation air will cool the ceiling reducing heat loss through the roof at the temperature of exhaust airr an the air will naturally fall, mixing destratifying the building air.

Another advantage of the system is that it can recapture building wall heat loos if the collectors are mounted on the building wall.

2.4.3 Process Air

Large quantities of outdoor air are used for process air heating applications. Drying of agricultural products is a good application for solar energy, as the required temperature rise must be kept relatively low to prevent damaging the crops. Those crops that are harvested continuously over the year are well suited because all the available solar radiation can be used. Solar systems can also serve as a preheater to (high temperature) industrial drying systems.

Solar process air heating systems are similar to ventilation air preheating system. The perforated plate absorber is located in any convenient location that has good exposure to the sun. Sloped roofs as well as walls are suitable mounting structures. A constant flow of air is taken through the collectors and is ducted into the air intake of the process. If necessary, additional heat can be added from auxiliary sources to deliver the desired air temperature and some or all of the process air can bypass the collectors if the air is above the desired temperature [28].

2.5 TYPES OF SOLAR AIR HEATER APPLICATIONS

2.5.1 Type 1

In this type, ambient air passes from a glazed or unglazed collector directly, provides ventilation and heating in the room. It is mostly used in cottage buildings and large industrial buildings.

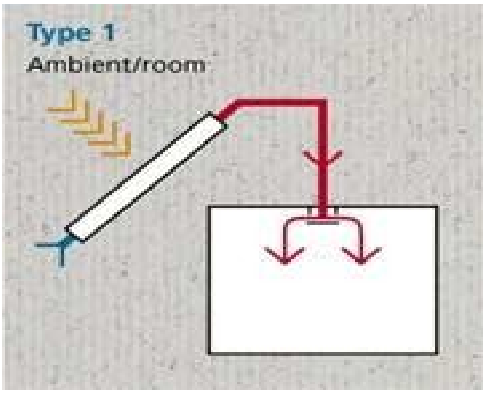


Figure 2.3.1 : Type 1 SAH [35]

2.5.2 Type 2

In second type room air is circulateted to the collector. The heated air rises to a thermal storage ceiling from which it is conveyed back into the room. This system uses natural convection and it is a good chooice for apartment buildings.

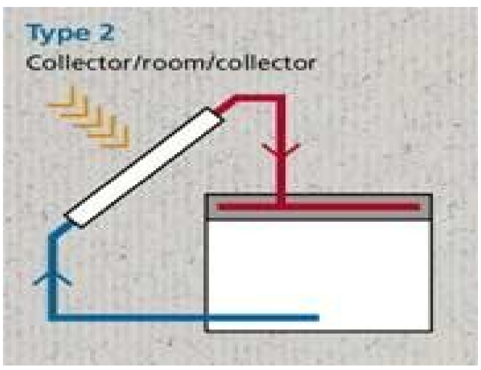


Figure 2.3.2 : Type 2 SAH [35]

2.5.3 Type 3

It is particularly suited for retrofitting poorly insulated buildings. Collector heated air passes through a cavity between an outer, insulated wall and an inner faced. This creates a buffer which considerably reduces heat loss via the facede of building.

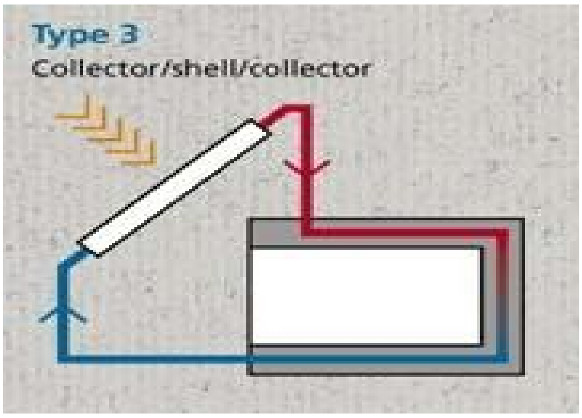


Figure 2.3.3 : Type 3 SAH [35]

2.5.4 Type 4

It is commonly used air heating system. Heated air is circulated through channels in the floor or in the wall. Heat is radiated into the room with a time delay of four to six hours. This system consists large radiating surfaces, which provide for a comfortable climate. Used forced fans provide us the best efficiency and thermal output.

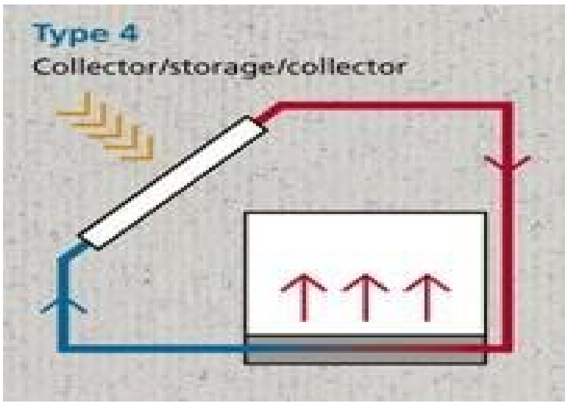


Figure 2.3.4 : Type 4 SAH [35]

2.5.5 Type 5

It is one step forward version of type 4 ; room air is circulated through separate channels of the storage. Heat can be stored and used for a long time and released when it is needed but investment costs are more than the other types.

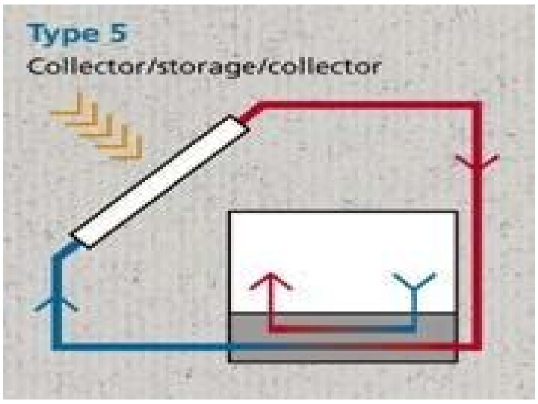


Figure 2.3.5 : Type 5 SAH [35]

2.5.6 Type 6

It is combination of a solar air collector, a heat exchanger and a conventional heating system. Thus , common radiators or wall heating components may be used. This system can also provide domestic hot water and they may be used in buildings in which heat has to be transported over long distances [29].

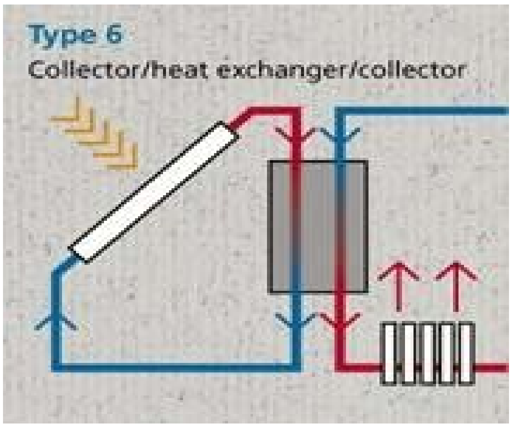


Figure 2.3.6 : Type 6 SAH [35]

CHAPTER 3

3.1 DESIGN AND MANUFACTURING

Some of background informations were covered about the importance of solar air heating , its history and developments and opportunities of sun energy for buildings, for saving energy and environment. Building a solar air collector is simple and helpful project for both beginner engineers and students.

In this project, 3 different collector types was used but having same collector dimensions which are 1930 mm in length, 960 mm in width and 120 mm in depth.

Solar collectors can be designed according to their absorber plate. Manufacturers are using different types absorbers such as copper, stainless steel, mild steel, aluminium. Also, absorber types provide different efficiencies and increase the surface area of collector. For first type, 25x25 mm aluminum tubes were used with in length 1561 mm. Secondly, conical type aluminum absorber was used which diameter is 200 mm and height is 40mm. For last one, double glazing collector type was used. Especially, panels and tubes should painted with a black color because dark colors tend to absorb more heat than light colors. Selective black type color was choosed which is more suitable. Panel has been insulated with tiled wood which has 1540 mm length, 910 mm width and 10 mm thickness. Also, with a 10 mm thickness expanded polstyrene for conical type collector and 20 mm for the other collectors were placed at bottom part but a factor should be considered which is polystyrene has a tendancy to melt at high temperatures. In addition to these, for against the heat loss from the sides and inner-outer surfaces were insulated by expanded polystyrene. Main aim of insulation is that reduces unwanted heat loss and saving the energy in heating systems. Thermal conductivity is the property of material's ability to conduct heat and the thermal conductivity of gases increases according to increasing temperature and also velocity of the air molecules can be more with increasing temperature. The temperature limits of polystyrene is between -50°C and 75°C as seen **table 3.1**. With using different techniques, thermal conductivities can be decreased around 10 %.

For pulling to air, we added a electric fan at the upper box of collectors. It pulls air from the atmosphere and pass it through the collector then blow it out. We can control the air mass flow rate with this device. Also a plastic pipe was connected to the fan which has 800 mm length and 160 mm diameter.

Panels were covered with smooth glasses. Glass is used to allow sunlight in. In double glazing type, collector was covered with two same size glasses for have 2 time air circulations. The aim of double glazing type collector is that reducing to heat loss minimum. This consists of two sheets of glass with space in between and this space filled with air. Double glazing is more expensive than single glazing but it prevents to heat loss.

Table 3.1 : Temperature Limits of Some Common Insulation Materials [40]

Insulation Material	Temperature Range			
	Low		High	
	(^oC)	(^oF)	(^oC)	(^oF)
Calcium Silicate	-18	0	650	1200
Cellular Glass	-260	-450	480	900
Elastomeric foam	-55	-70	120	250
Fiberglass	-30	-20	540	1000
Mineral Wool, Ceramic fiber			1200	2200
Mineral Wool, Glass	0	32	250	480
Mineral Wool, Stone	0	32	760	1400
Phenolic foam			150	300
Polyisocyanurate or polyiso	-180	-290	150	300
Polystyrene	-50	-60	75	165
Polyurethane	-210	-350	120	250
Vermiculite	-272	-459	760	1400

Table 3.2 : Table of Insulation Commonly Used in Solar Collectors [41]

Material	R-value per inch (US)	R-value per thickness	Working temperature	Notes
polyisocyanurate rigid board (foil faced)	6.8 - 7.7		200F (93C)	
polyurethane rigid board (foil faced)	6.8		200F (93C)	
extruded polystyrene rigid board	5.0		165F (74C)	
expanded polystyrene rigid board	3.6-4.4		165F (74C)	Combustable. Not a good choice for a solar collector. This is the white one. Also in the form of "peanuts".
fiber glass batts	3.0 - 4.3		180F (82C)	Good fire resistance.
mineral/rock wool batts	3.0 - 4.0		> 500F (> 260C)	Excellent fire resistance.
straw bale	1.45			
wood (general)	0.75 - 1.41			
wood (oak)	0.75			
wood (pine)	0.91 - 1.32			
wood (cedar)	1.09 - 1.41			
plywood	1.25			
glass - single pane		0.91		
glass with 1/4" air gap		1.69		
glass with 1/2" air gap		2.04		
glass with 3/4" air gap		2.38		
low-E glass (0.20) with 1/2" air gap		3.13		
Suntuf polycarbonate sheet (Palram)		0.68		
6mm Twin Wall polycarbonate sheet (Macrolux)		1.58		
8mm Twin Wall polycarbonate sheet (Macrolux)		1.72		
10mm Twin Wall polycarbonate sheet 1700 g/m^2 (Macrolux)		1.77		
10mm Twin Wall polycarbonate sheet 2000 g/m^2 (Macrolux)		1.89		

3.2 MEASUREMENT EQUIPMENTS

3.2.1 Digital Anemometer

Turbulance has a important role in air flows and transport of heat and mass. In spite of other velocity measurements types, it is most used developed the new technology and to increased interest in detailed description of turbulent flow fields. The digital anemometer consists of a sensor, a small electrically heated wire exposed to the fluid flow. The simple working principle of the system is the heat transfer from the heated wire to the cold surrounding fluid, heat transfer which is function of the fluid velocity so it is relation between the fluid velocity and the electrical output. For all measurements, direct calibration of the anemometer is neccessary and outlet air velocities need to be measured to prevent effect of the ambient air velocity. You can see a picture of hot wire anemometer in **Figure 3.1**.

The volumetric flow rate can be calculated by the equation 3.1:

Q = A x V ……………………………………………………………..……(eqn. 3.1)

Where ;

Q is volumetric flow rate [m^3/s¿

A is the outlet area [m^2¿

V is outlet velocity [m/s]

Figure 3.1 : Digital Anemometer [36]

Table 3.3 : HYELEC MS6252A Digital Anemometer Parameters [36]

AIR VELOCYTY	RANGE	ACCURACY	MS6252A
m/s(meter per second)	0.40−30.0	±(2.0% reading + 50)	√
ft/m (feet per minute)	80−5900	±(2.0% reading + 50)	√
km/h (kilometer per hour)	1.4−108.0	±(2.0% reading + 50)	√
mile/h(mile per hour)	0.9−67.0	±(2.0% reading + 50)	√
Knots(nautical miles pe r hour)	0.8−58.0	±(2.0% reading + 50)	√
AIR FLOW	**RANGE**	**AREA**	**MS6252A**
CFM	0 t o 9 9 9 9 9 0	0 to 9.999ft^2	√
CMM	0 t o 9 9 9 9 9 0	0 to 9.999ft^2	√
CMS	0 t o 9 9 9 9	0 to 9.999 m⊐2;	√
Flow Area Setting			√
MAX/MIN Function			√
Display Back light			√
Auto Power Off			√
Low Battery indication			√
GENERAL			
Power Supply	l x 9 V 6 F 22Battery(not Included this order)		
Product Size	165mm x 85mm x 38mm(6.5" x 3.3" x1.5")		
Product Weight	2 0 0 g (0 .41b)		
Category	CE RoHS		

3.2.2 Pyranometer

A pyranometer is a type of actinometer that can measure solar irradiance in the desired location and solar radiation flux density. LPPYRA10 – Secundary class Pyranometer was used for measuring solar irradiance which is shown in **Figure 3.2**. The solar radiation spectrum extends approximately between 300 and 2800 nm. The pyranometer only requires a flat spectral sensitivity to help cover the spectrum. The main components of pyranometers are thermopile, glass dome and occulating disc [30].

A pyranometer is operated based on the measurement of temperature difference between surfaces. The black coating on the thermopile sensor absorbs the solar radiation, while the clear surface reflects it, hence less heat is absorbed. The thermopile is used for this temperature differences. The potential difference created in the thermopile owing to the temperature gradient between the two surfaces is used for measuring the amount of solar radiation. The tilt angle of the panel was set as 36° to get the highest exposure to solar irradiance.

Figure 3.2 : LPPYRA10 – Secundary class Pyranometer [39]

3.2.3 Electric Motor Fan

We choosed an electric motor centrifugal fan which model is shown in **Figure 3.3**. The reason of choosing this fan is that against the overheating due to the high temperature of the air coming out from the collector.On the other hand, it provides to controlling demand velocities of the air. You can check properties of this device in **Table 3.4**

Figure 3.3 : Electric Motor Fan [37]

Table 3.4 : Properties of electric motor fan [37]

Voltage Type (AC/DC)	AC
Voltage [(V)]	230
Phase [(~)]	Single Phase
Frequency [(Hz)]	50
Power [(W)]	600
Capacitor [(µf)]	8
Speed [(rpm)]	2700
Air Flow [(m^3/h)]	1800
Weight [(Kg)]	9,2

3.2.4 Thermometer

To measure temperatures in a flow fluid, usually thermometer are used. Thermometer is available for different temperature ranges. A thermometer consists two different thermocouples which made from different materials and connected each other by means of two junction forming an electrical circuit. If one junction is related with temperature 1 , the other is related with temperature 2 so if one junction is heated and the other cooled and voltage is produced with a ratio between temperature difference of this junction. There are different thermometer according to their combinations of metals or calibrations. The most common calibrations are J, K, T and E. In this project, we used K type thermometer which is shown in **figure 3.4** for measuring the plate temperature and it gives us a good accuracy and wide measuring range.

Figure 3.4 : Thermometer [38]

3.3 STRUCTURAL ARRANGEMENT

A solar heater collector consists four main parts which are frame, absorber materials, glazing materials and insulation materials. All collector designs are shown in between **figure 3.5.1 – 3.5.3**

3.3.1 Conical Type of Solar Air Heater

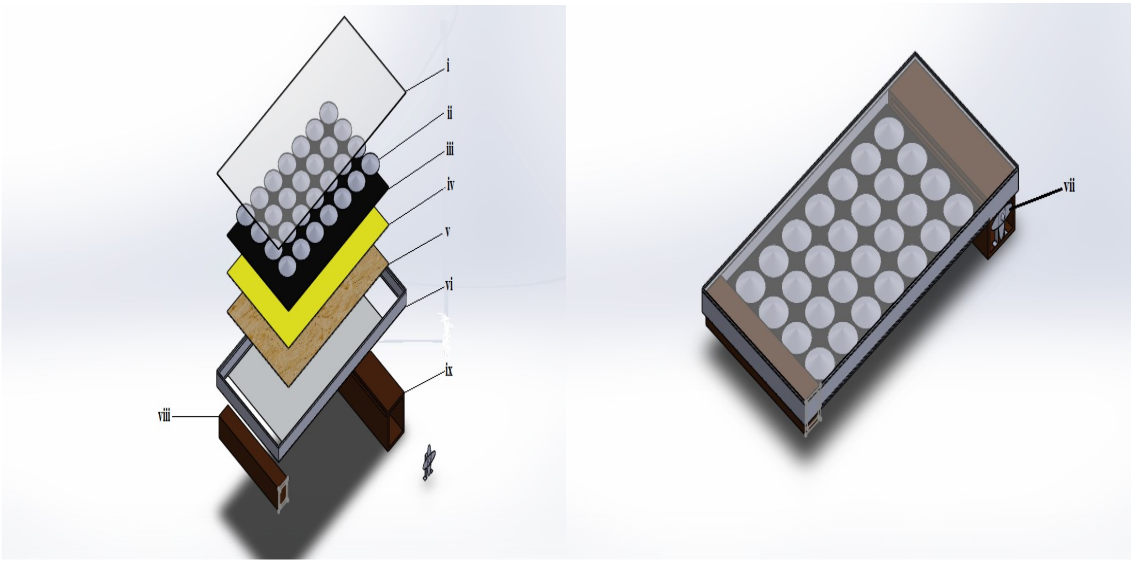


Figure 3.5.1 : Conical Type Solar Air Heater

i. Glass (t:5mm , width: 935mm , h:1935mm)
ii. Conical aluminum materials (d: 200mm h:40mm)
iii. Aluminum Absorber Plate (t:10mm , width: 935mm , h:1525.5mm)
iv. Glass Wool Insulation Material (t:10 mm , width: 935mm , h: 1525.5mm)
v. Osb (t:10mm , width: 935mm , h: 1525.5mm)
vi. Frame
vii. Fan
viii. Collector box
ix. Fan box

3.3.2 Square Tube Type of Solar Air Heater

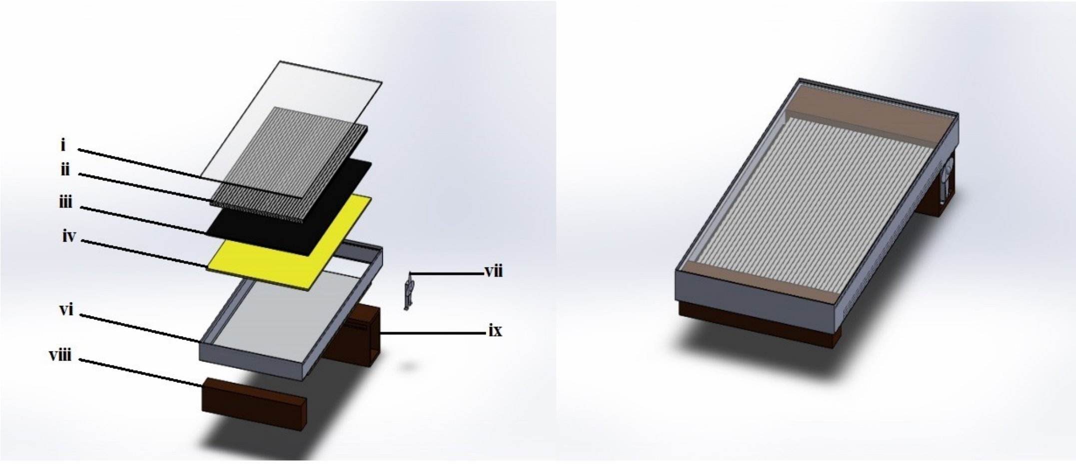


Figure 3.5.2 : Square Tube Type Solar Air Heater

i. Glass (t:5mm , width: 935mm , h:1935mm)
ii. Square Tubes (25x25mm, h: 1561mm)
iii. Aluminum Absorber Plate (t:10mm , width: 935mm , h:1525.5mm)
iv. Glass Wool Insulation Material (t:10 mm , width: 935mm , h: 1525.5mm)
v. Osb (t:10mm , width: 935mm , h: 1525.5mm)
vi. Frame
vii. Fan
viii. Collector box
ix. Fan box

3.3.3 Double Glazing Type of Solar Air Heater

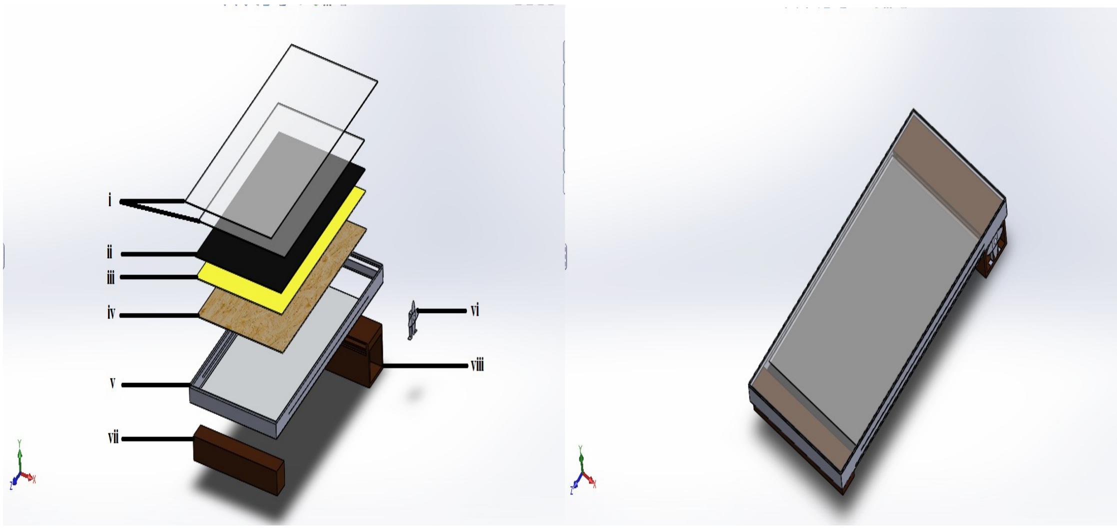


Figure 3.5.3 : Double Glazing Type (SAH)

i. Glasses (t:5mm , width: 935mm , h:1935mm)
ii. Aluminum Absorber Plate (t:10mm , width: 935mm , h:1525.5mm)
iii. Glass Wool Insulation Material (t:10 mm , width: 935mm , h: 1525.5mm)
iv. Osb (t:10mm , width: 935mm , h: 1525.5mm)
v. Frame
vi. Fan
vii. Collector box
viii. Fan box

3.4 THERMAL ANALYSIS

Energy analysis is necessary part of all systems to obseve real performance. The energy analysis is related with thermodynamics and heat transfer laws and the thermal efficiency has been calculated based on the recorded data. The energy analysis present us limits of efficiencies with different types collector applications. By using the following formulas, we examined mass flow rate and thermal efficiencies of different types of solar air heating collectors.

The efficiency of a solar collector is the ratio of the amount of useful heat collected to the total amount of solar radiation striking the collector surface during any period of time. [31]

Efficiency of solar collector can be expressed as:

$$\eta = \frac{Q_u}{I \, x \, A_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(eqn. 3.2)}$$

where:

A_c is the collector area, [m^2]

I is solar intensity, [W / m^2]

Q_u is useful heat collected, [W]

Useful heat collected for an air-type solar collector can be expressed as:

$$Q_u = \dot{m} C_{p(T_{out} - T_{¿})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(eqn. 3.3)}$$

where:

$\dot{m}$ is the mass flow rate, [kg / s]

Cp is the specific heat of fluid, [J / kg. ℃]

$T_{¿}$ is the air temperature of the fluid at the environment, [℃¿

T_{out} is the air temperature of the fluid at the exit, [$°C$¿

Mass flow rate can be expressed as:

$\dot{m}$ = ρ x $\dot{V}$ ……………………………………………………………..……(eqn. 3.4)

where:

ρ is the density of the fluid, [kg / m^3]

$\dot{V}$ is the volume flow rate, [m^3 / s]

Volume flow rate can be expressed as:

$\dot{V}$ = v x A ……………………………………………………………..……(eqn. 3.5)

v is the flow velocity of the mass elements, [m / s]

A is the cross-sectional vector area/surface, [m^2]

Heat loss can be determined as :

$Q_{loss} = U_{overall} A_{surface} \Delta T$ ……………………….…….…..…………………(eqn. 3.6)

Where ;

Q_{loss} is the heat loss, [W]

$A_{surface}$ is the surface area for each collector, [m^2]

$U_{overall}$ is the overall heat transfer coefficient, [$W/m^2.K$]

ΔT is the temperature difference between inlet and outlet, [˚C]

and $U_{overall}$ can be determined as :

$$U_{overall} = U_{Top} + U_{edge} + U_{bottom} \quad \text{……………………………………..…(eqn. 3.7)}$$

Where:

$U_{overall}$ is the overall heat-loss coefficient, [$W/m^2.K$]

U_{Top} is the heat-loss coefficient for top surface of the collector, [$W/m^2.K$]

U_{bottom} is the heat-loss coefficient for bottom surface of the collector, [$W/m^2.K$]

U_{edge} is the heat-loss coefficient for edge surface of the collector, [$W/m^2.K$]

U_{Top} , $U_{edge} \wedge U_{bottom}$ can be determined as :

$$U_{Top}, U_{edge}, U_{bottom} = \frac{1}{Ros + \sum \frac{lmaterials}{k\,materials} + Ris} \quad \text{…(eqn. 3.8)}$$

Where ;

$k_{material}$ is the thermal conductivity of using material, [W/ $m℃¿$

$l_{material}$ is the thickness of using material, [m]

Ros is the outside surface resistance, [m^2 $℃/W$]

Ris is the inside surface resistance, [m^2 $℃/W$]

Assumptions ;

Ros = 0.05 m^2 $℃/W$, Ris = 0.1 m^2 $℃/W$ [43]

Using materials are stated in following **table 3.5** ;

Table 3.5 : Thermal Properties of Materials [42]

Insulation Material	**THERMAL CONDUCTIVITY** (k)	**THICKNESS(** l **)**
Soft wooden fan box	0.12 W/ $m℃$	18 mm
Aluminum Conics	205 W/ $m℃$	0.4 mm
Soft Wooden collector box	0.12 W/ $m℃$	15 mm
Thin aluminum sheet	205 W/ $m℃$	0.5 mm
Glass at the mid point	1.05 W/ $m℃$	4 mm
OSB	0.13 W/ $m℃$	10 mm
Glass wool	0.04 W/ $m℃$	10 mm
Outside glass	1.05 W/ $m℃$	4 mm

Aluminum Collector panel	205 W/ $m℃$	2.5 mm
Aluminum Square tube	205 W/ $m℃$	2.5 mm

CHAPTER 4

MANUFACTURING, ASSEMBLY and TESTING

4.1 MANUFACTURING AND ASSEMBLY

Collectors which are designed in this project was used in the last semesters. Before the starting manufacturing processes, old design of collector components were disassembled each other and it provided us the better starting. First of all, We determined which parts are using in our collectors and we completed our technical drawings and according to their dimensions, components were produced. We had 3 type design and they had different parts. Although, some parts were constant which are collector boxes, fan boxes, glasses, polystyrenes,motors, absorber plates and osb. Osbs were bought from a carpenter and they fasten to inner surface of the collector with screwing. Then, glass wool material glued on the osbs with silicon. At the same time, we prevent to heat loss from the collector with silicon material. Later, aluminum absorber plates were placed smoothly and painted to black colour. We needed to 3 collector boxes and 3 fan boxes for our built and we produced these in technical workshop. Firstly, woods were cut in square shape according to dimensions and we created our boxes with these woods. Just collector box of double glazing design was completely closed because at this desing, air would come from the upper fan box. The other collector boxes had a space for allow the entry of air into the collector. Fan boxes of collectors which are placed on top side of collectors have a gap from fan side for allow the air flow from the collector to fan. All collector boxes were assembled with screwing and silicon. After all of these works, we started to produce our different absorber parts which are square tube type, conical type and double glazing. In square tube type, we used 34 piece square tube and we assembled these tubes vertically to base of collector. We compress these tubes from collector box to fan box because air would pass through into these tubes. In conical absorber part, we bought 2 pieces aluminum sheet metal and we created 28 piece of conical part with cutting and bending processes. We assembled these parts one by one on the absorber plate with screwing again. We had 7 horizontal part lines and 4 vertically part lines. In double glazing design, we used 2 piece glasses. One of them is placed inside the collector which has 35mm height from the absorber plate and the other one was placed top of collector zone. We used a ray system which name is tracking for placing of inside glasses and used silicon for sticking. Air flow would happen between these 2 glasses. In addition to these, we used 2 glasses for closing to other collectors. By the way, during these processes, 4 pieces thermocouple were placed with band for measure different temperatures. One of them was on absorber plate, one thermocouple was on glasses, one thermocouple was inside the fan and one thermocouple was free for measure the ambient temperature.

4.2 TESTING AND IMPORTANT PARAMETERS

The designed collectors which have different absorber plates were tested and datas were taken at roof of the Eastern Mediternean University in Famagusta during the fall semester in between 4.01.2016 and 11.01.2016. Generally, weather was clear, although, some datas are taken in windy and rainy weather. Windy weather has caused some data deviations. All collectors were placed at same tilt angle which was 36 degree. This angle was selected because latitude angle of North Cyprus is around 35 degree. During testing stages, we measured the inlet temperatures, glass temperatures, outlet temperatures and absorber plate temperatures with k-type thermometer. We measured solar irradiances with a pyronometer and we measured velocity of the air which exit the fan pipe with a digital anemometer for settings of the mass flow rates of the air. Then, we calculated the thermal efficiencies of the square type, conical type and double glazing type of collectors one by one with different mass flow rates. Finally, we compared these efficiencies each other. All informations are available with several figures in chapter 5.

4.2.1 Role of the Solar Irradiance

Solar irradiance is defined as the amount of radiant energy emitted by the Sun over all wavelengths that fall each second on one meter square outside the earth's atmosphere. By way of further definition, irradiance is defined as the amount of electromagnetic energy incident on a surface per unit time per unit area. Solar refers to electromagnetic radiation in the spectral range of approximately 1-9 ft (0.30-3 m), where the shortest wavelengths are in the ultraviolet region of the spectrum, the intermediate wavelengths in the visible region, and the longer wavelengths are in the near infrared. Total means that the solar flux has been integrated over all wavelengths to include the contributions from ultraviolet, visible, and infrared radiation and solar radiation strongly dependant on location and local weather. For this projects, datas are taken at E.M.U Mechanical Engineering Department in 09-14/01/2016. The figure 4.1 which is given above shows us the daily average of the solar intensity for our experiment location. The result show that the maximum daily average of the solar intensity was obtained as 970 W/m^2 in 09.01.2016. Also, we changes all radiation values according to our tilt angle which is 36 degree.

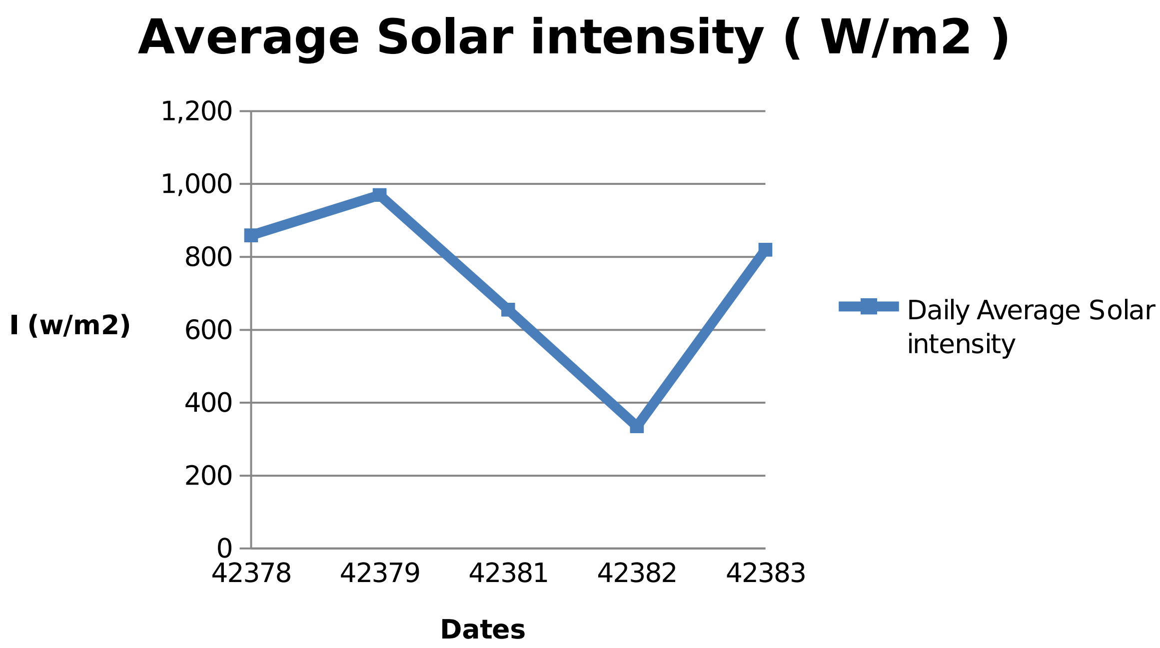


Figure 4.1: Average of solar intensity during the study (09-14/01/2016)

4.2.2 Role of the Different Mass Flow Rate

In this Project, our aim is that designing 3 different collector type and analyzing its thermal efficiencies. The received energy rates of the solar air heaters were evaluated for various air flow rates (0.02, 0.04, 0.07, 0.09, 0.11 kg.s-1) are investigated. Optimum values of air mass flow rates are suggested to maximize the performance of the solar collector. inlet and exit temperatures of the collectors were measured three times for each mass flow rate and then an average temperature data was obtained. The maximum temperature difference measured as 28 °C for conical type collector at 0.02 kg/s mass flow rate as shown in **figure 5.2**. For 25x25 mm square tube type collector, the maximum temperature difference was 26 °C at 0.02 kg/s mass flow rate as shown in **figure 5.1**. Last of all, for double glazing type collector, the maximum temperature difference was obtained as 23 °C at 0.02 kg/s mass flow rate, as shown in **figure 5.3**. All maximum temperature differences were observed at 13:00 in 13.01.2016 and at the slowest mass flow rate which is 0.02 kg/s.

4.2.3 Role of the different absorber shapes

Many SAHs are available at present to give better thermal aspects, but it is not enough to satisfy the need of user. The improvement of efficiency and reducing of heat loss of the collectors can be changed depends on surface area of absorber plates so it is relation with its design. Also, flowing rate of the fluid can effect on efficiency of the collectors and it is again relation with absorber shape. In this project, we have selected three solar air heater collector of the same overall dimensions 920 mm (W) x 1920 mm (L) but with different absorber shapes which are square tube type, conical type and double glazing type. The other design parameters were same such as thickness of glass cover, aluminum absorber material, angle of the collectors. Also, all plates were painted with black colour. For each absorber shape, different temperature differences and efficiencies were determined and they are available in chapter 5.

4.2.4 Role of the variable environmental conditions

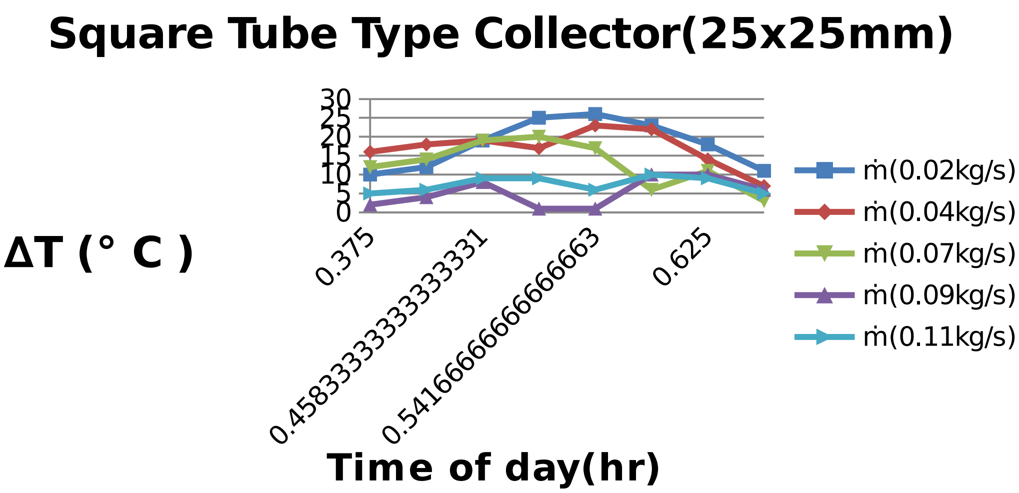
During the experiments, all collectors were located at the same location and they had same tilt angle which was 36°. Although, all collectors affected because of winter conditions. Winter conditions were cause to decreasing temperature differences between inlet and outlet temperature and it involved to low efficiency values. On the other hand, wind is cause of some turbulance inside the fan and it affected out temperature values when we read the mass flow rate values and temperature values. In addition these, naturally, solar intensity values were different for each experiment day.

CHAPTER 5

RESULTS AND DISCUSSION

After all stages of the project, some results were observed and presented in between **figure 5.1.1 – 5.6.5**. These figures contain temperature difference values between outlet and inlet air against time at different mass flow rates for each collector type, the temperature difference between outlet and inlet air against time at each mass flow rate separately for each collector type and efficiency performance at different and same mass flow rates against time for each collector type. After observing all these figures, we present some discussion to decide which collector type has high efficiency at certain mass flow rates.

5.1 THE TEMPERATURE DIFFERENCE BETWEEN OUTLET AND INLET AIR AGAINST TIME AT DIFFERENT MASS FLOW RATES FOR EACH COLLECTOR.



In this section, for each one collector type, temperature difference values shown in between **figure 5.1.1 – 5.1.3** which are below at different mass flow rates. Also, all datas are stated in appendix tables.

Figure 5.1.1: The outlet and inlet air temperature differences against time at different mass flow rates during the period of the study (09-14/01/2016) in square tube type collector.

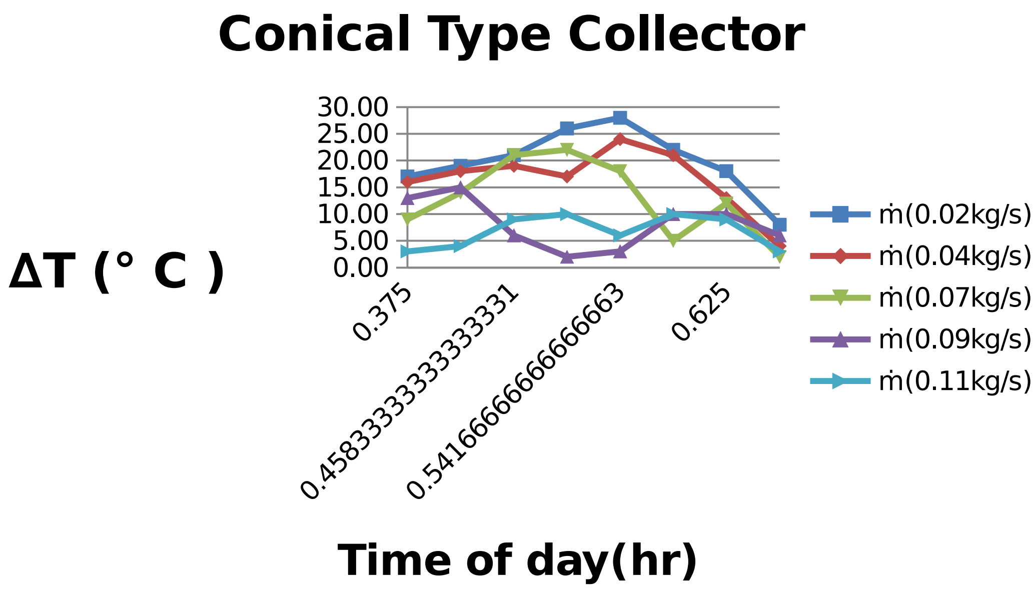


Figure 5.1.2: The outlet and inlet air temperature differences against time at different mass flow rates during the period of the study (09-14/01/2016) in conical type collector.

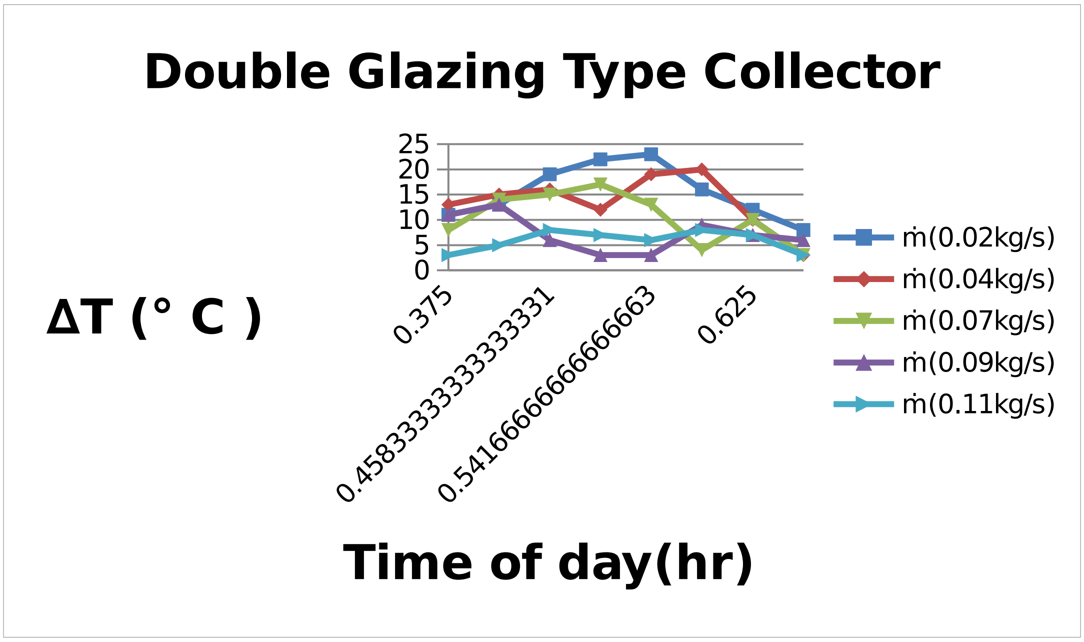


Figure 5.1.3: The outlet and inlet air temperature differences against time at different mass flow rates during the period of the study (09-14/01/2016) in double glazing type collector.

5.2 THE TEMPERATURE DIFFERENCE BETWEEN OUTLET AND INLET AIR AGAINST TIME AT SAME MASS FLOW RATES FOR EACH COLLECTOR.

In this section, for all collector types, temperature difference values shown in between **figure 5.2.1- 5.2.5** which are below at same mass flow rate. Also, all datas are stated in appendix tables.

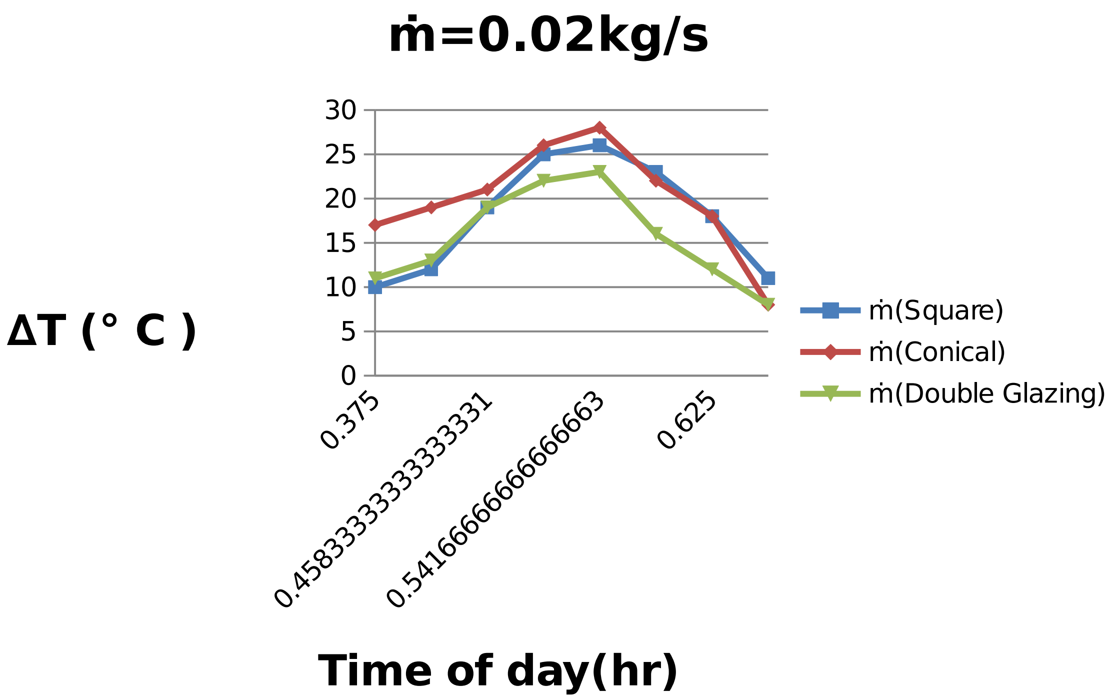


Figure 5.2.1: The outlet and inlet air temperature differences at 0.02 kg/s against time in a day (13/01/2016)

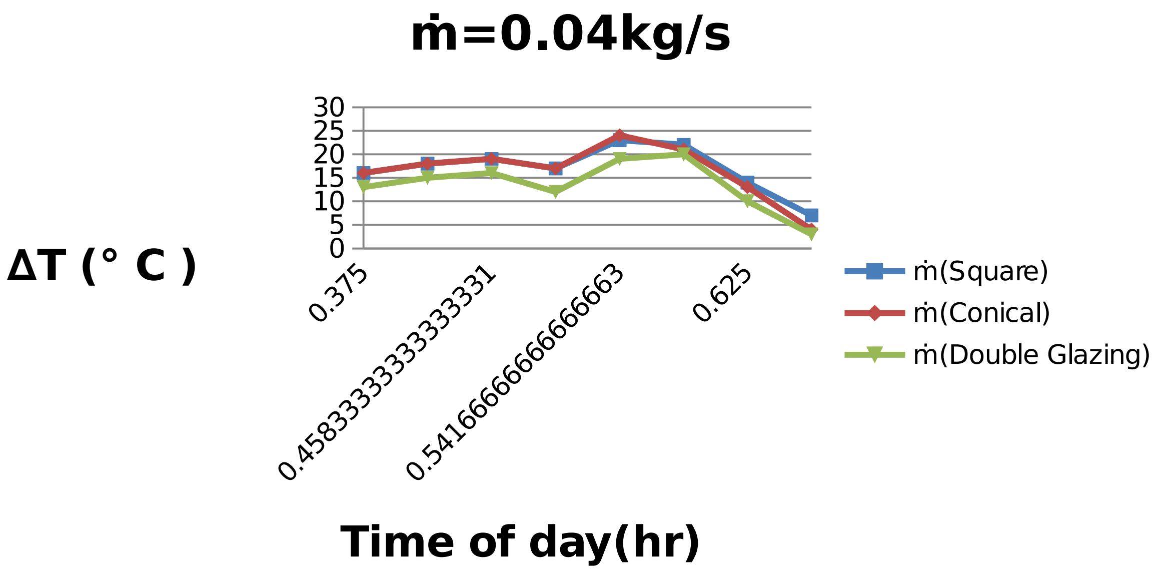


Figure 5.2.2: The outlet and inlet air temperature differences at 0.04 kg/s against time in a day (09/01/2016)

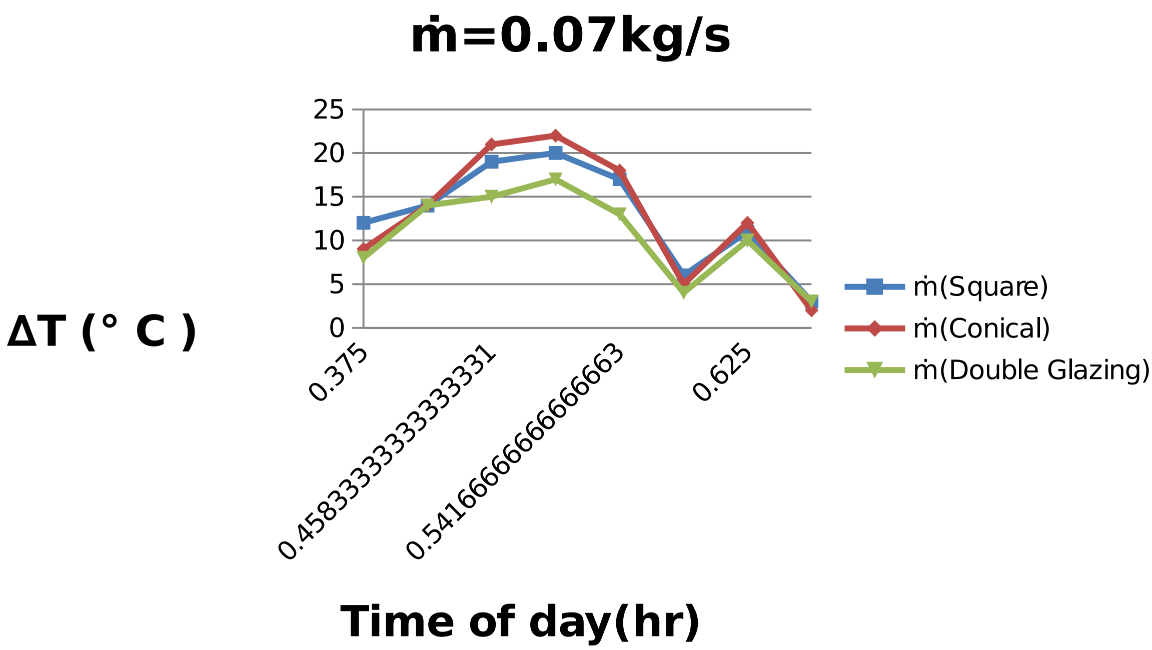


Figure 5.2.3: The outlet and inlet air temperature differences at 0.07 kg/s against time in a day (10/01/2016)

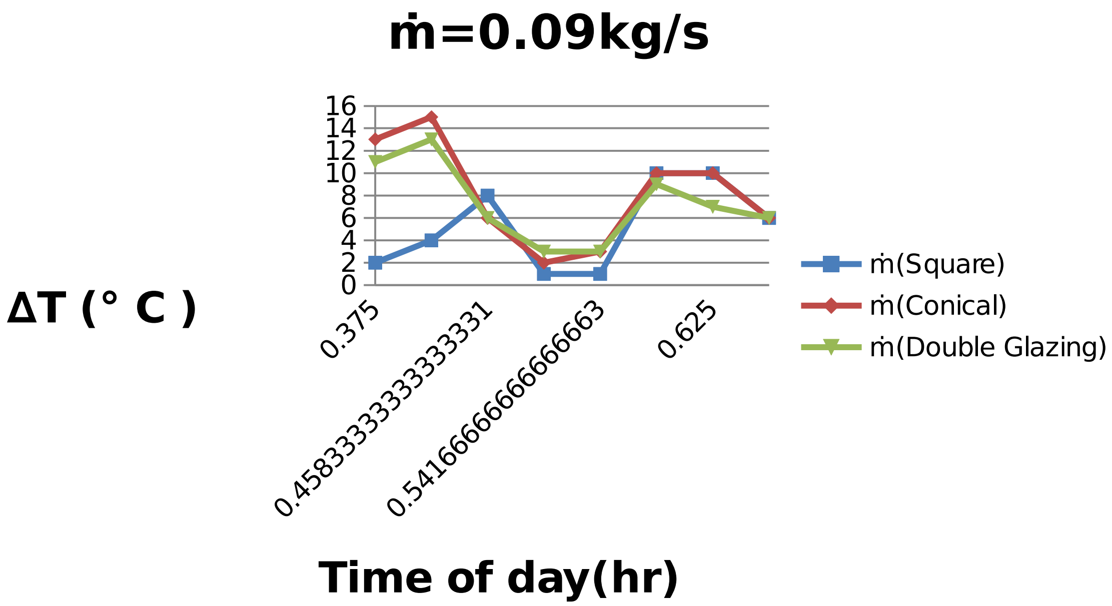


Figure 5.2.4: The outlet and inlet air temperature differences at 0.09 kg/s against time in a day (14/01/2016)

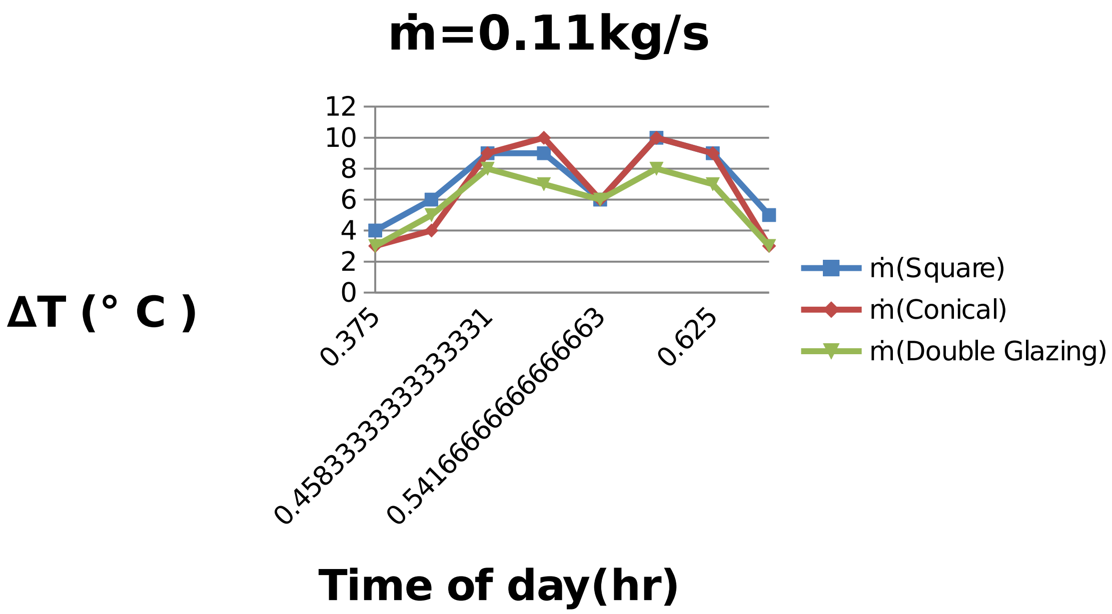


Figure 5.2.5: The outlet and inlet air temperature differences at 0.11 kg/s against time in a day (12/01/2016)

5.3 THE THERMAL EFFICIENCY OF THE COLLECTORS

This section presents us that an experimental thermal efficiency analysis for each designed collectors with different mass flow rates. The measured parameters were the solar intensity factor, the absorbing plate temperature, the ambient temperature and the temperature difference between outlet and inlet air. Thermal efficiencies allow us for understanding to design effects and effect of different mass flow rates on collectors. After the analysis of the results, the optimal efficiency was obtained as 94 % at 0.11 kg/s mass flow rate (at 12:00 and 14:00 hour) for conical collector type. The maximum efficiency for square tube type collector was calculated again as 94 % at 0.11 kg/s mass flow rate (at 14:00 hour). Last of all, the maximum efficiency for double glazing type collector was calculated as 79 % at 0.09 kg/s mass flow rate (at 10:00 hour). We can not compare results according to mass flow rate changes because mass flow rates was not changed in an one experiment day. We can compare the results like that which collector type has high efficiency values at same mass flow rate, depends on this explanation, conical type collector had high efficiencies at 0.02 kg/s and 0.09 kg/s mass flow rates which were % 66 and % 49 as average. Square tube and conical type collectors had so close high efficiencies at 0.04 kg/s and 0.07 kg/s mass flow rates which were

% 44 and % 52 as average. Last of all, square tube type collector had high efficiency at 0.11 kg/s mass flow rate which was % 68 as average. To compare these result, we took averages by one by for all efficiency values in an one experiment day and results proof that conical type collector can give high efficiency for different mass flow rates. After that, square tube type collector has more efficiency than double glazing type collector at different mass flow rates. Also, we know that, sometimes, datas can show some deviations because of winter conditions because each experiment day was done at different mass flow rates and different ambient temperatures. All datas are aveliable in **figure between 5.3.1 - 5.5** and all datas are stated in appendix tables.

5.3.1. The thermal efficiencies at the different mass flow rates for each collector type.

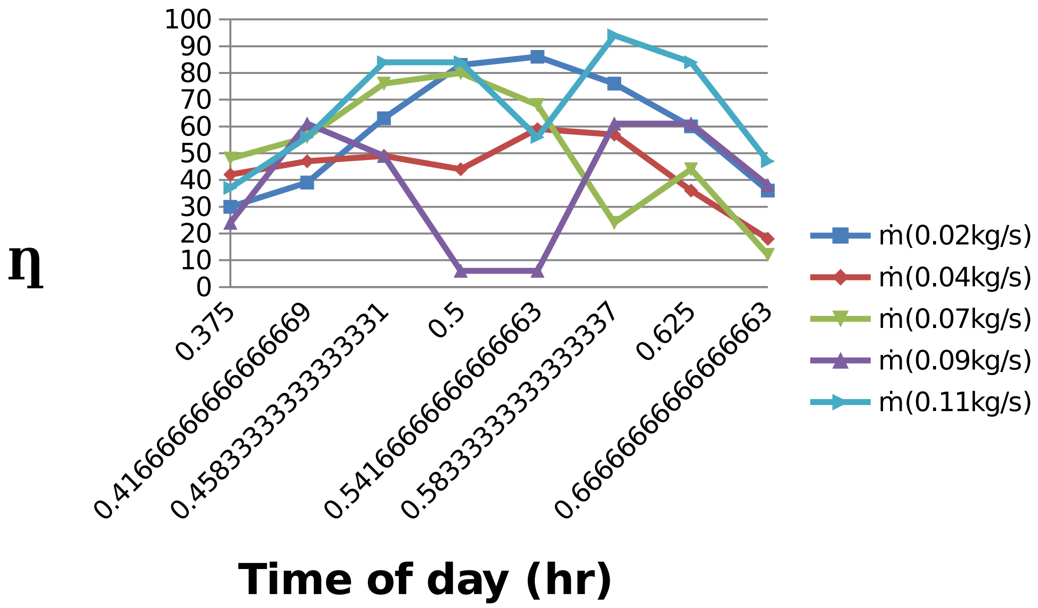


Figure 5.3.1: Efficiency performance at different mass flow rates against time for the square tube type SAH collector

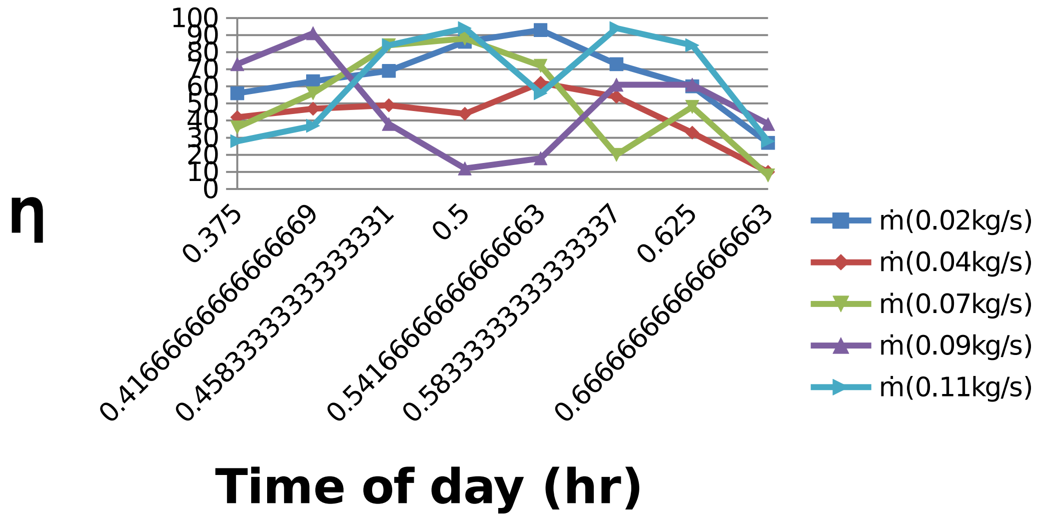


Figure 5.3.2: Efficiency performance at different mass flow rates against time for the conical type SAH collector

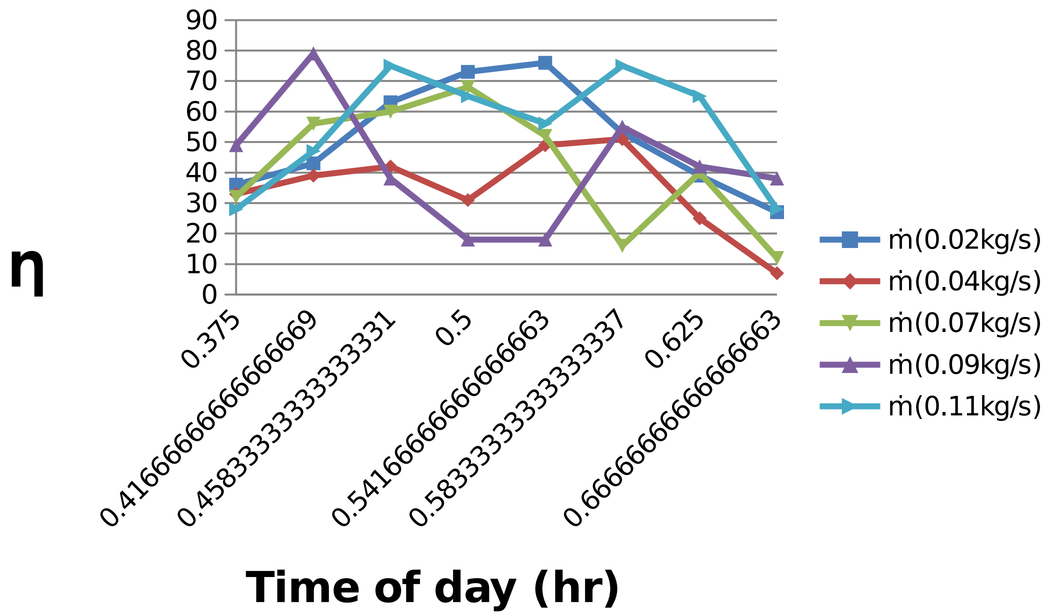


Figure 5.3.3: Efficiency performance at different mass flow rates against time for the double glazing type SAH collector

5.3.2. The thermal efficiencies at the same mass flow rate for each collector type

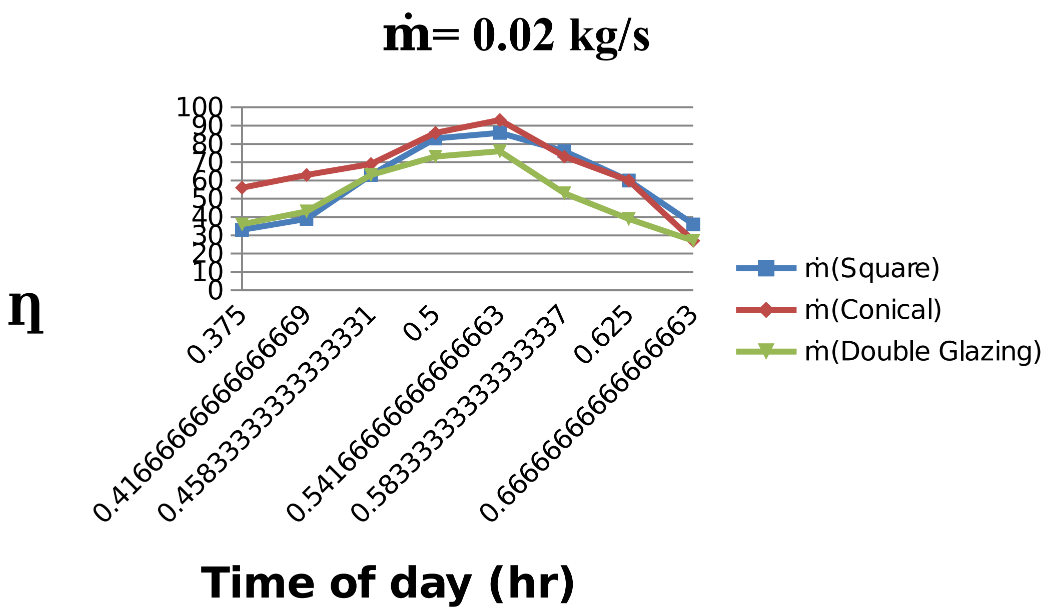


Figure 5.4.1: Efficiency of the collectors at 0.02 (kg/s)

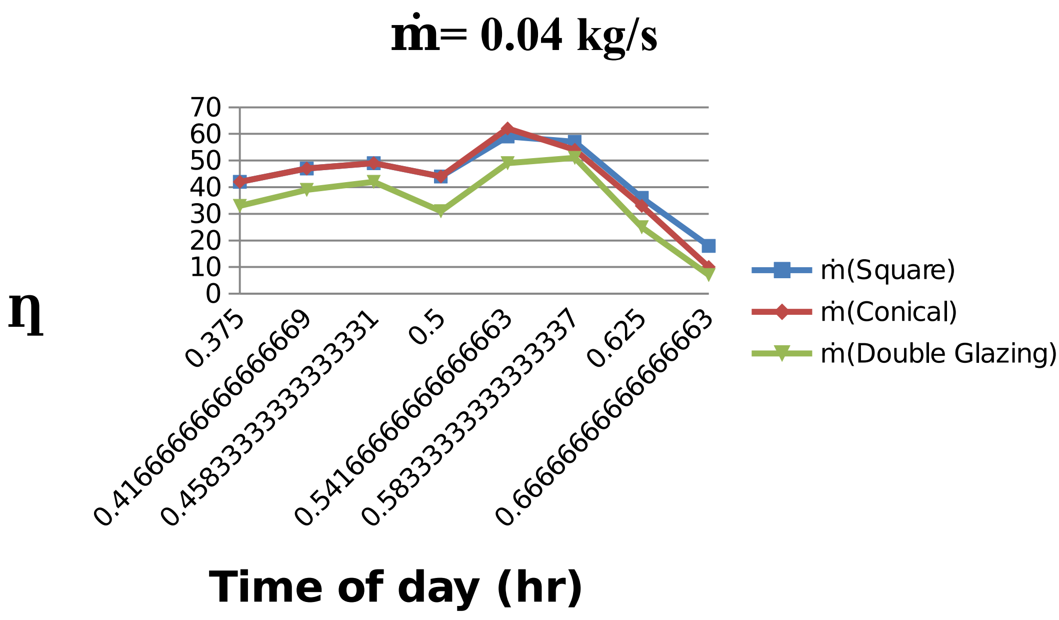


Figure 5.4.2: Efficiency of the collectors at 0.04 (kg/s)

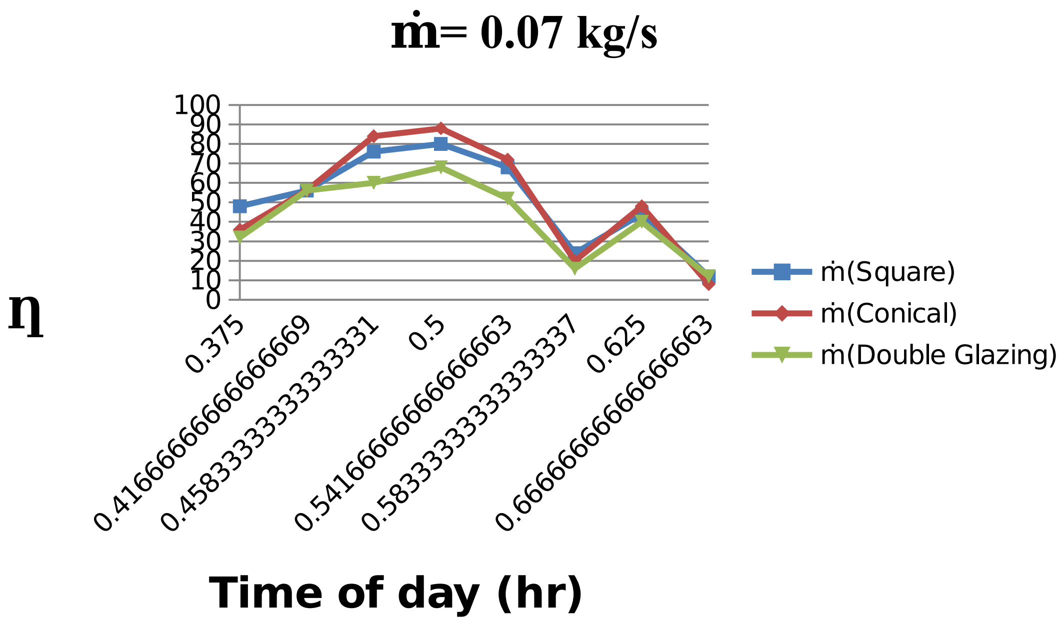


Figure 5.4.3: Efficiency of the collectors at 0.07 (kg/s)

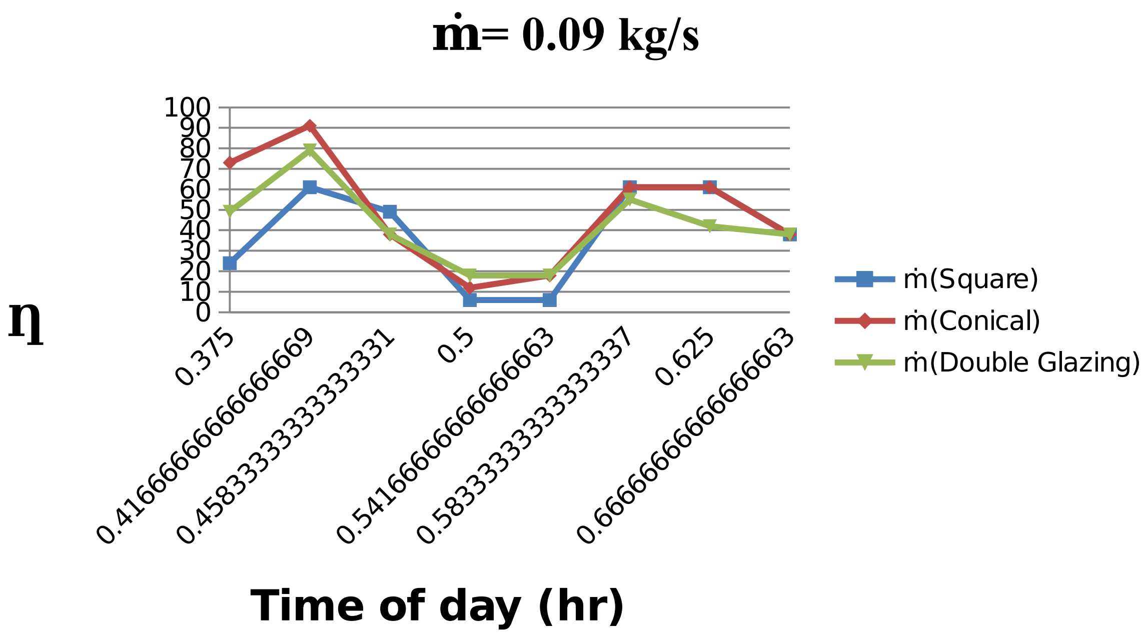


Figure 5.4.4: Efficiency of the collectors at 0.09 (kg/s)

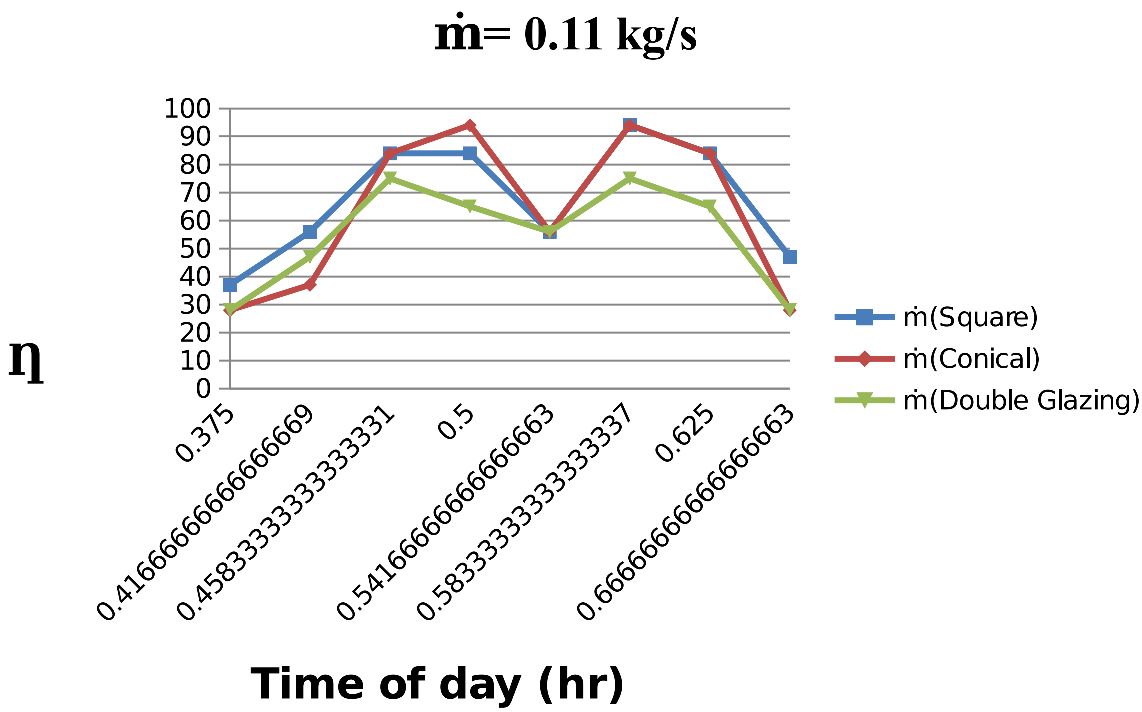


Figure 5.4.5: Efficiency of the collectors at 0.11 (kg/s)

5.3.3 Comparison of Thermal Efficiency Between 3 different collector types

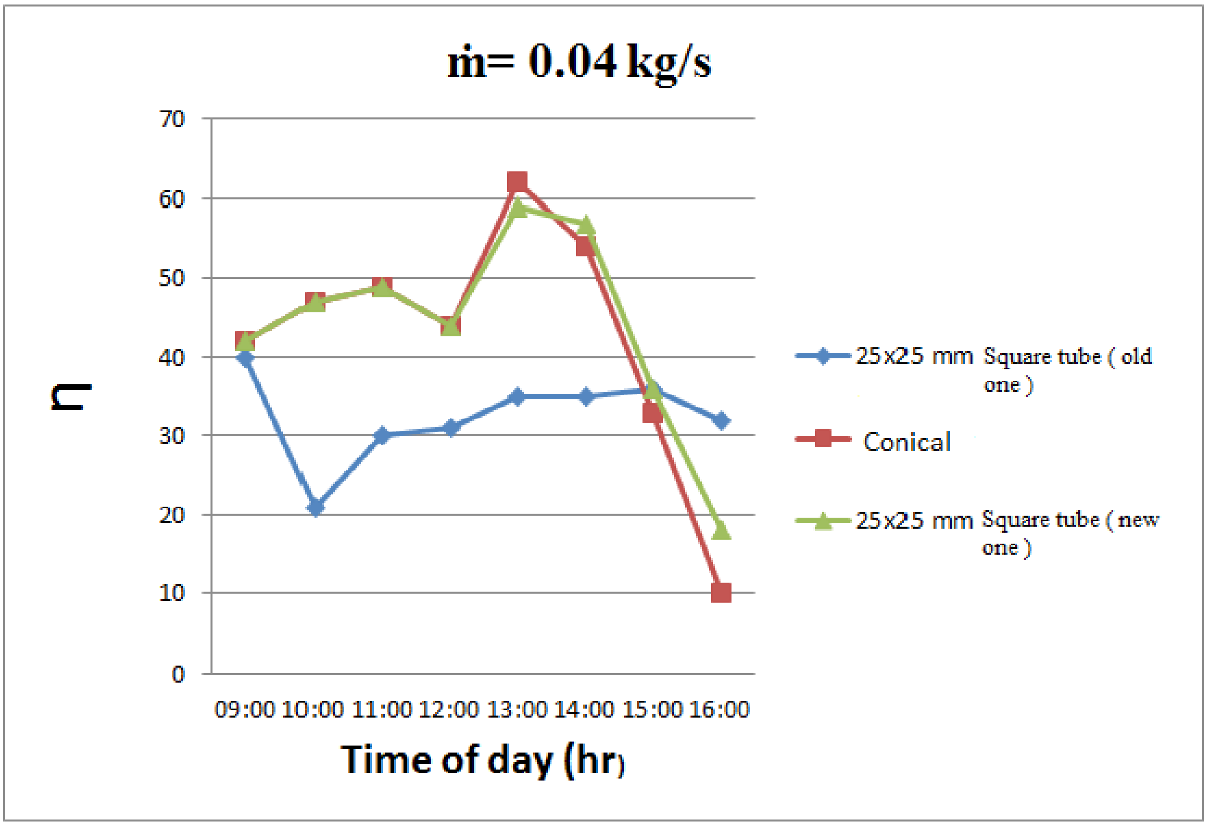


Figure 5.5: Comparison of Thermal Efficiency Between Conical type and 2 square tube type collector (25x25) which was designed in 23.12.2013 and newest one at 0.04 kg/s mass flow rate

5.4 HEAT LOSS OF COLLECTOR TYPES

For getting best efficiency results, we need some insulation materials such as foam, glass wool, aluminum plates, osb plate, aluminum foil, glass. Different insulation materials can be used for different designs, although, we used same materials for determining the absorber shape effect on each collector type. Despite all these insulation materials, we can not prevent all heat loss. Material thickness, thermal conductivity values and heat loss formulas are required for heat loss calculations and they are aveliable in chapter 3. Heat loss coefficient for top surface was calculated as 0.78 W/m^2K, for edges surface was calculated as 1.57 W/m^2K and for bottom surface were calculated as 1.55 W/m^2K. Then, the overall heat transfer coefficient was founded as 3.7 W/m^2K and it was same approximately for each collector type. Therefore, effective parameter was temperature difference for calculating the heat losses. It means that we had high heat loss values when we had high temperature differences. Also, surface areas were calculated for each collector type. Highest heat losses values were calculated (319.3 W for square tube type, 355.6 W for conical type and 187.2 W for double glazing type) at 13:00 hour in 13.01.2016 (at 0.02 kg/m^3). After completed calculations, some figures were plotted in **figure 5.6.1- 5.6.5** which are below show us the heat losses values.

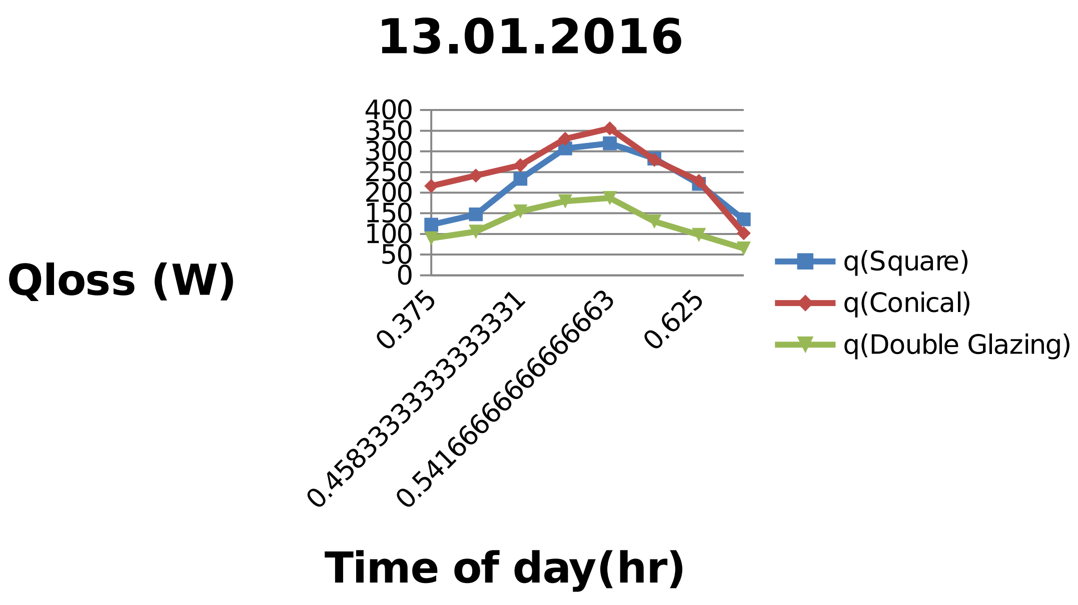


Figure 5.6.1: Heat losses values against time for each collector type in 13.01.2016

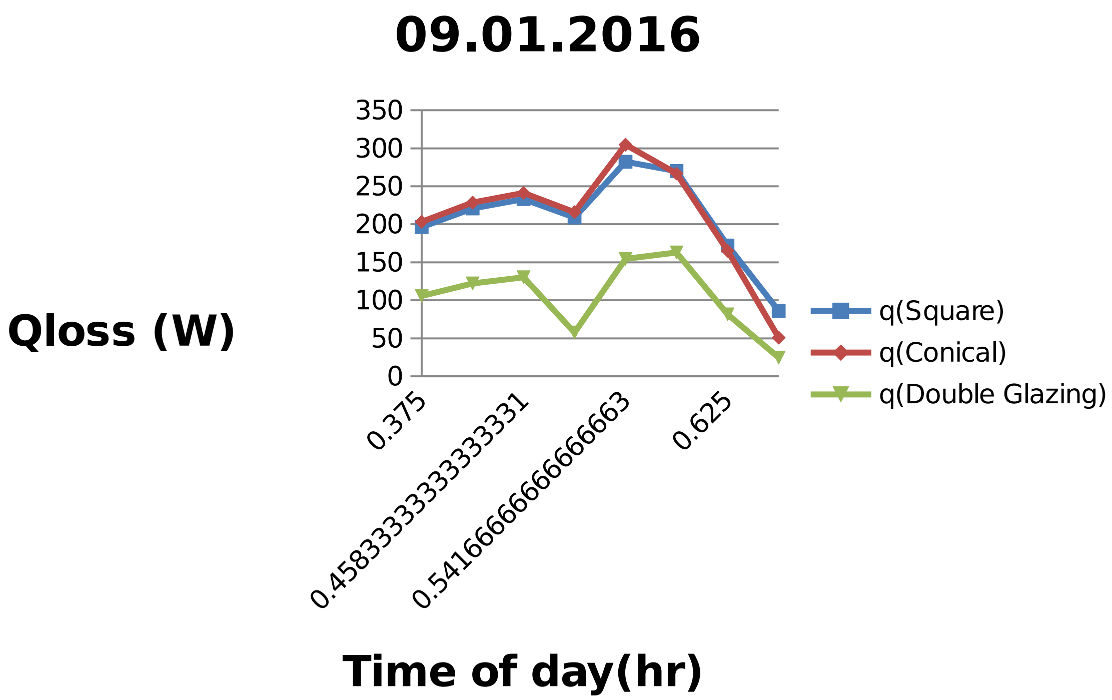


Figure 5.6.2: Heat losses values against time for each collector type in 09.01.2016

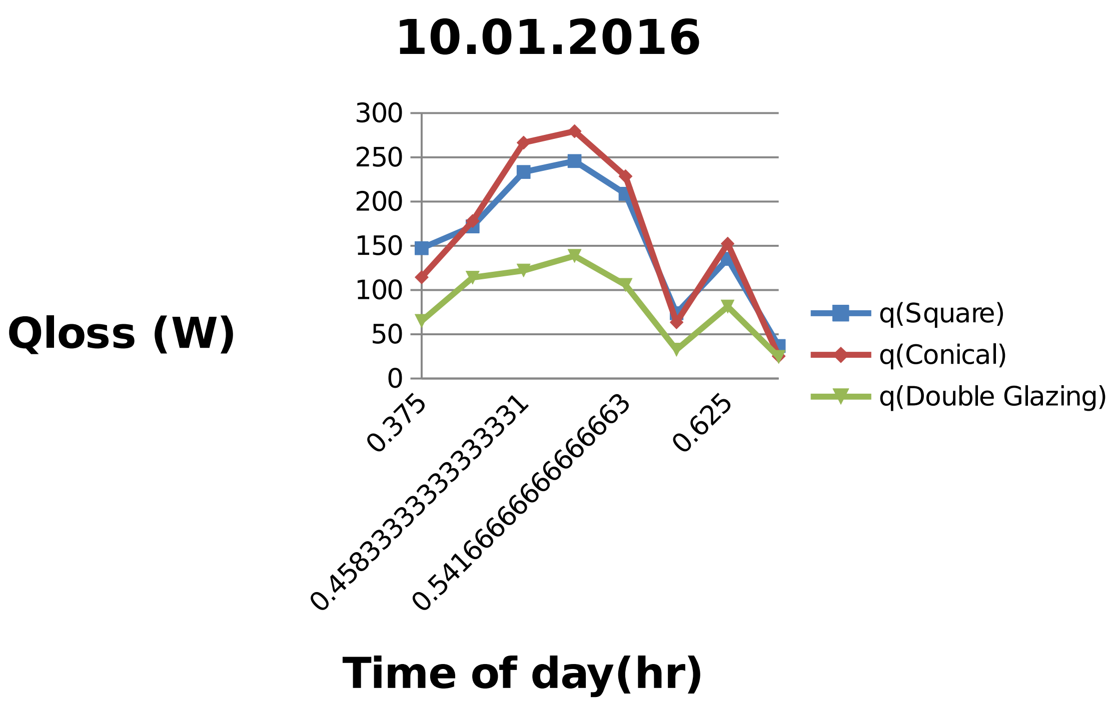


Figure 5.6.3: Heat losses values against time for each collector type in 10.01.2016

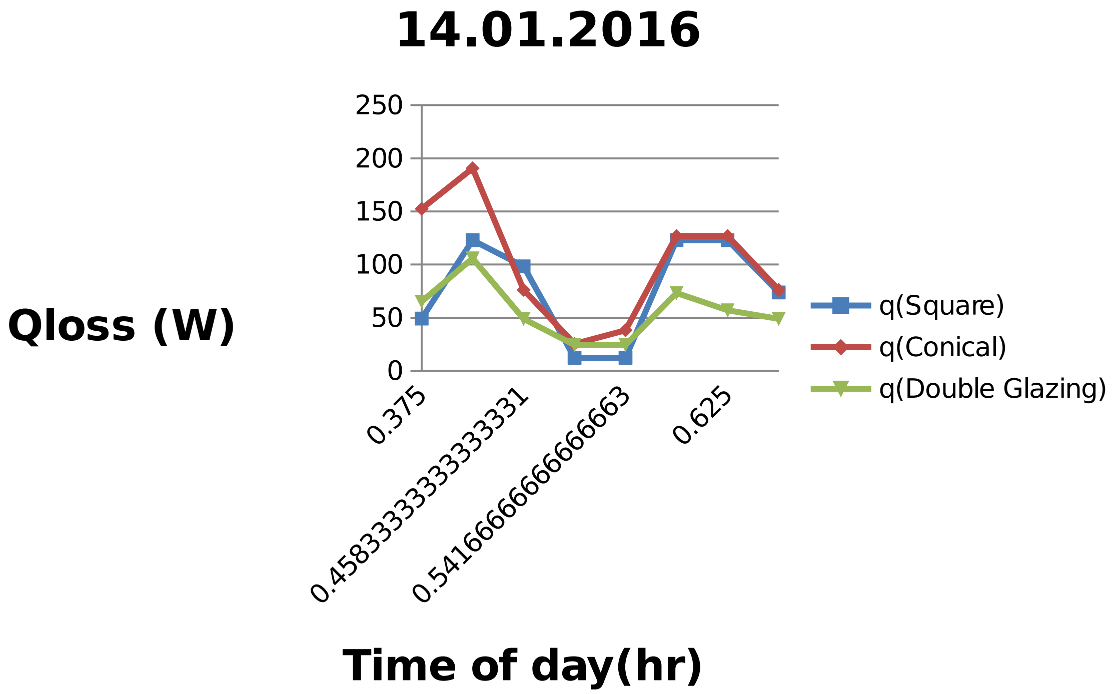


Figure 5.6.4: Heat losses values against time for each collector type in 14.01.2016

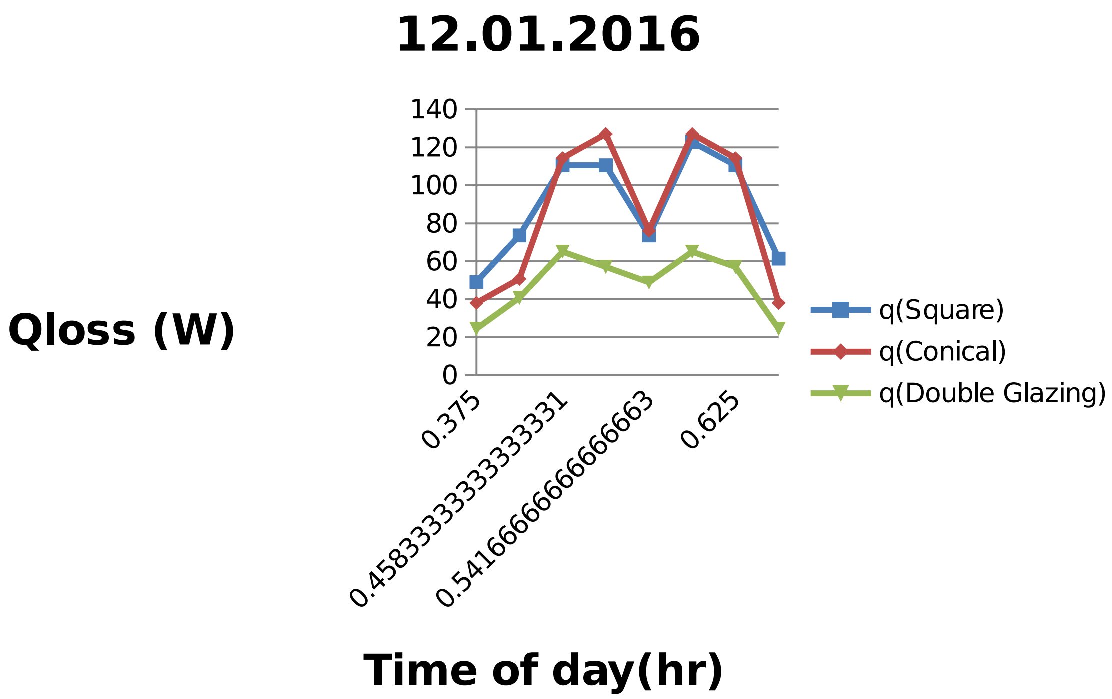


Figure 5.6.5: Heat losses values against time for each collector type in 12.01.2016

CHAPTER 6

CONCLUSION AND FUTURE WORKS

In conclusion, different types of solar air heater collectors has been designed and manufactured according to their different absorber plate shapes which were square type, conical type and double glazing type. The main aim of this project was to compare the thermal performance of these three type solar air collectors in winter conditions at the roof of the Mechanical Engineering Department of Eastern Mediterranean University in the city of Famagusta in January, 2016.

According to results, the performance of the SAHs was significant. The efficiencies were carrying some differences because of variable environmental conditions and their different design. Experiments were performed at different mass flow rates and each mass flow rate value was used for a different day. Conical type collector reached the maximum temperature difference as ΔT= 28 ℃ at 0.02 kg/s, and the maximum thermal efficiency was calculated as 94% at 0,11 kg/s. The maximum temperature difference for square type collector was measured as ΔT= 26 ℃ at 0.02 kg/s and the highest efficiency was estimated as 93% at 0,11 kg/s. For the double glazing collector, the maximum temperature difference was observed as ΔT= 23 ℃ at 0,02 kg/s and the thermal efficiency was measured as 79% at 0,09 kg/s. On the other hand, heat loss analysis proof that heat loss values were directly proportional with temperature differences between inlet and outlet air, surface area of collectors and overall heat coefficient value. Highest heat loss value was calculated as 355.6 W for conical type collector. All observed datas verified that conical type collector can show high efficiency performance at all different mass flow rate values, after conical type, square tube type collector had better efficiency performance and double glazing type collector was worst in these 3 type collector at all taken different mass flow rate values. To sum up, solar air collectors can be used in many different areas for energy saving and they can present us a lot of benefits such as economical incomes. Therefore, if we have the facilities to install these systems, we should decide the best collector type for us according to its efficiency or its cost and start to use it.

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APPENDICES

APPENDIX A

DATES	COMMENTS
12.10.2015	Disassembling of old Designed collectors
20.10.2015	Material and Equipment Collection
02.11.2015	Manufacturing of Collector Parts
24.11.2015	Assemblying of Collector Parts
04.01.2016	Data Collection
03.01.2016	Rapor Writings
28.01.2016	Presentation

TEAM LOOKBOOK

FigureA1 : Double glazing type of SAH

FigureA2 : Square pipe type of SAH

FigureA3 : Conical Type of SAH

FigureA4 : Assemblying of middle glass material

FigureA5 : Fitting glass wool in collector

FigureA6: Cutting of osb part

FigureA7: Painting of absorber plates

APPENDIX B

GANNT CHART

	SOURCE	AMOUNT	PRICE(TL)	TOTAL(TL)
MOTOR	M.E Department of EMU	3	-	-
GLASS(900*1470mm)	Ilkay construction market	1	30	30
GLASS(935*1935mm)	Ilkay construction market	3	50	150
ALUMINIUM ABSORBER PLATES	Ilkay construction market	3	38	114
ALUMINIUM PIPE(25*25*1560mm)	M.E Department of EMU	34	-	-
CONICAL PARTS	Ilkay construction market	28	4	112
COLLECTOR PANEL	M.E Department of EMU	3	-	-
COLLECTOR BOX	Katkın Carpenter Shop	3	30	90
COLLECTOR FAN BOX	Katkın Carpenter Shop	3	30	90
OSB	Ilkay construction market	3	20	60
SCREW	Ilkay construction market	1 (BOX)	7	7
SILICONE	Deniz Plaza	8	10	80
THERMOMETER	E-bay website	1	100	100
THERMOCOUPLE	E-bay website	10	10	100
POLYSTYRENE (900*1560*10mm)	Deniz Plaza	3	27	81

TOTAL				**1,014 TL**

Table B.1 : Material Cost

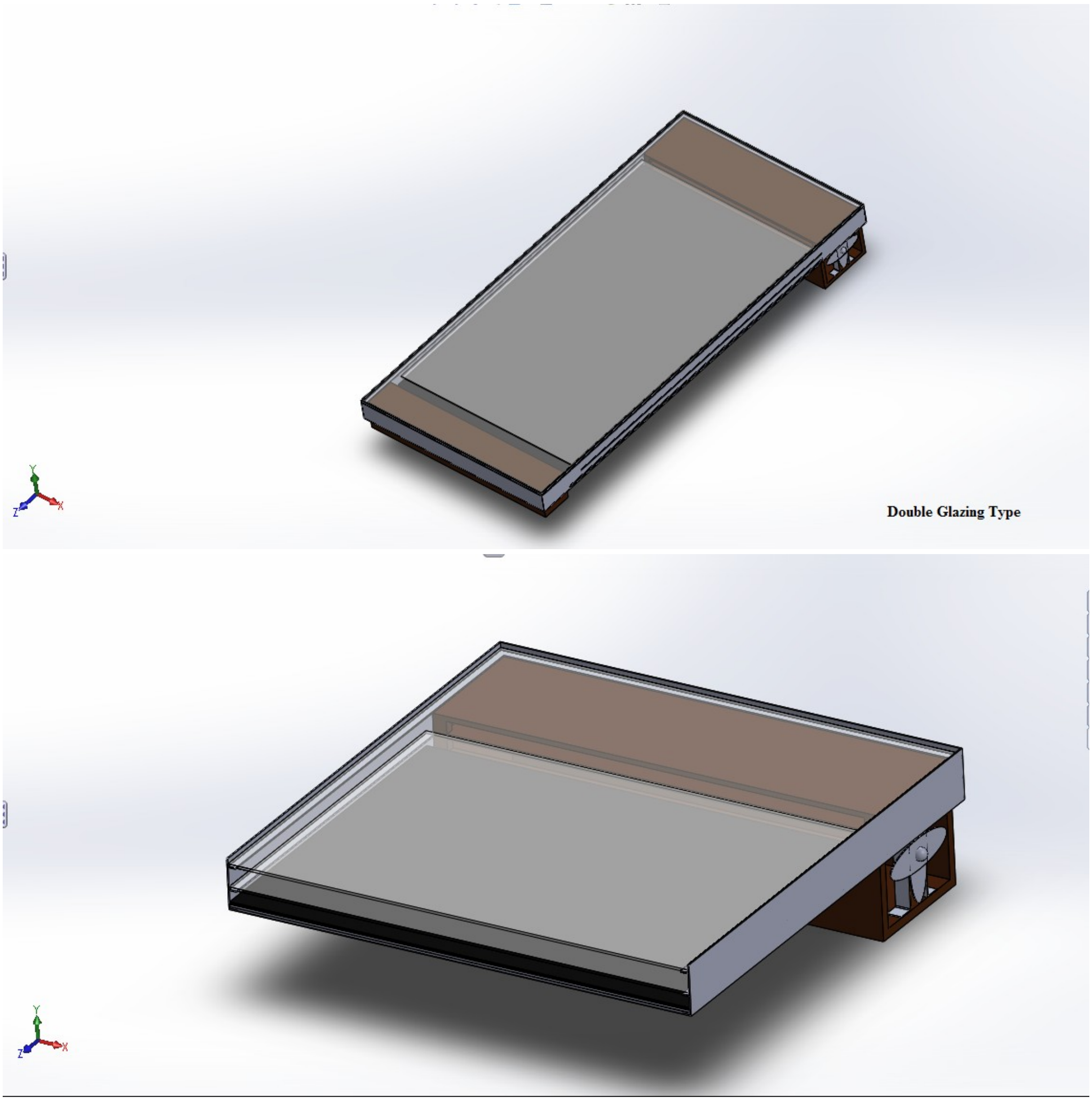
APPENDIX C

TECHNICAL DRAWINGS

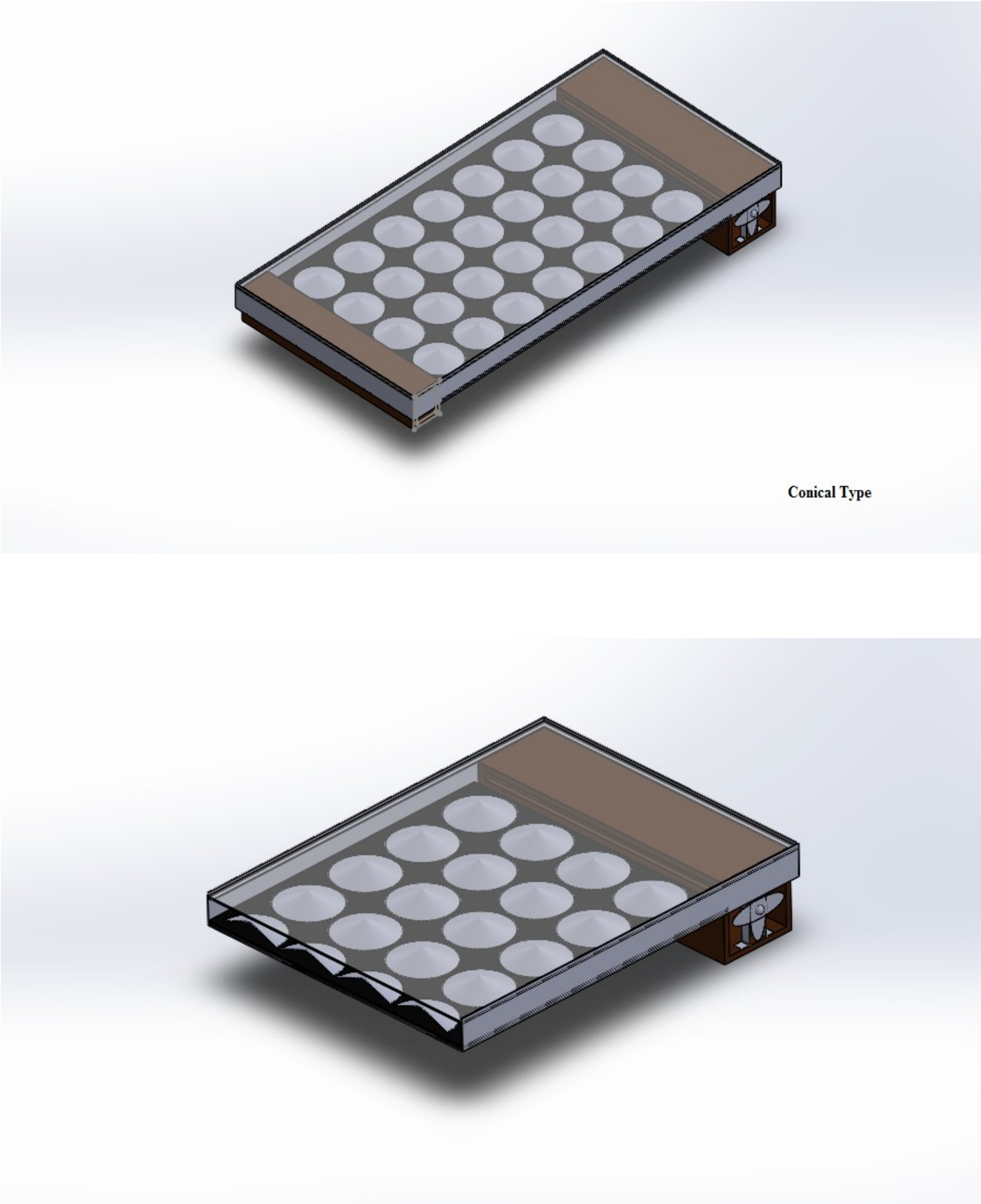
A) Assembly and Detail Drawings of Square Tube Type Collector (A later shows us that part numbers of this type collector in technical drawings.)

B) Assembly and Detail Drawings of Conical Type Collector (B later shows us that part numbers of this type collector in technical drawings.)

C) Assembly and Detail Drawings of Double Glazing Type Collector (C later shows us that part numbers of this type collector in technical drawings.)



FigureC1 : Isometric view of double glazing



FigureC2 : Isometric view of conical type

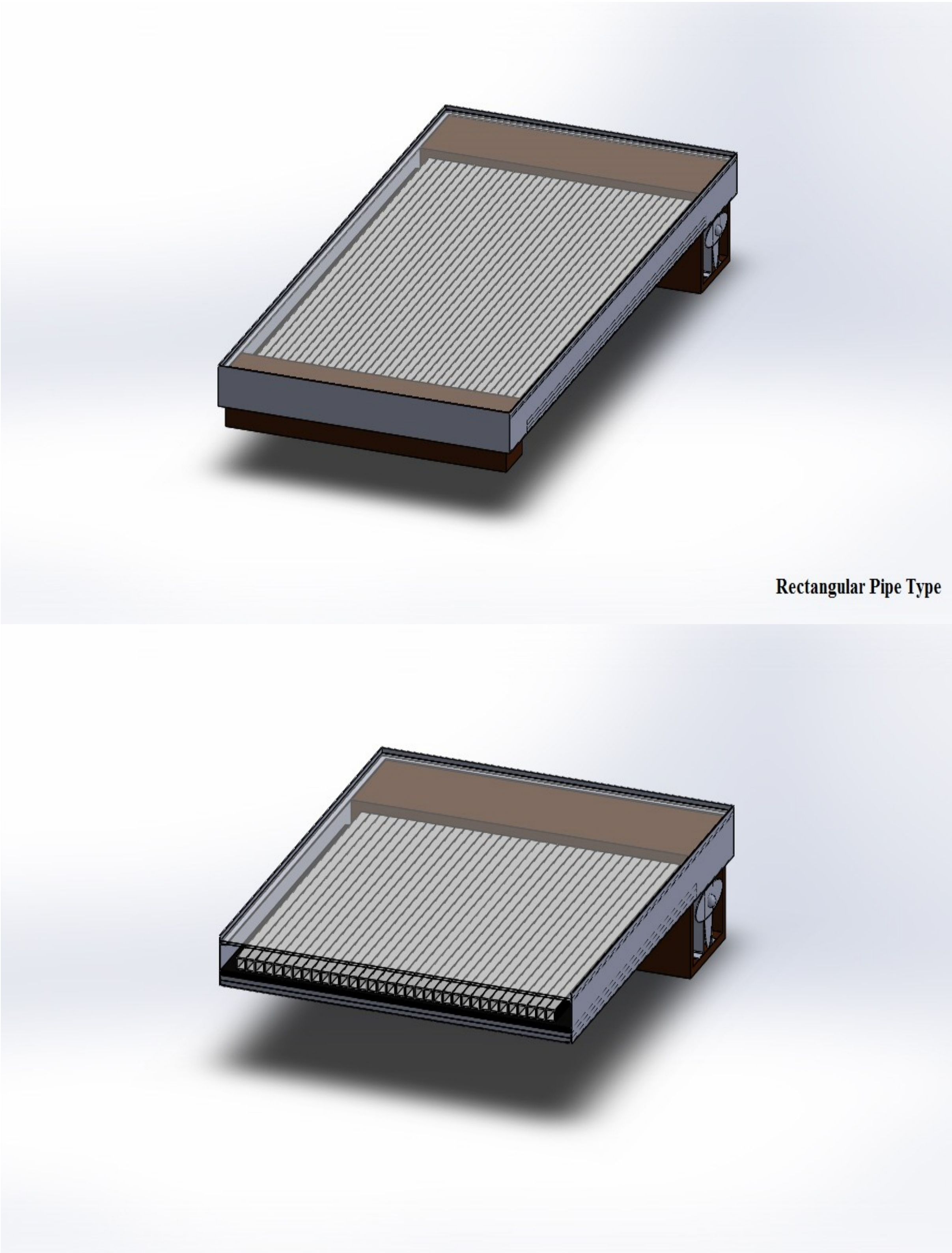


Figure C3 : Isometric view of square square pipe type

APPENDIX D

Website of Our Capstone Team Project

students.emu.edu.tr/100092

TABLES

Air mass flow rate: $\acute{m}$ = 0.02 kg/s					
Time	**Temperature(°C)**	**Square Type**	**Conical Type**	**Double Glazing Type**	**Overall Radiation**
	$T_{absorber}$	43	68	64	
09:00	$T_{¿}$	24	24	24	
	T_{out}	34	41	35	
	$T_{absorber}$	45	70	66	
10:00	$T_{¿}$	26	26	26	
	T_{out}	38	45	39	
	$T_{absorber}$	53	77	75	
11:00	$T_{¿}$	23	23	23	
	T_{out}	42	44	42	
	$T_{absorber}$	66	84	81	
12:00	$T_{¿}$	25	25	25	
	T_{out}	50	51	47	335.2w/ m^2
	$T_{absorber}$	68	85	85	
13:00	$T_{¿}$	25	25	25	
	T_{out}	51	53	48	
	$T_{absorber}$	61	77	75	
14:00	$T_{¿}$	25	25	25	
	T_{out}	48	47	41	
	$T_{absorber}$	54	67	68	
15:00	$T_{¿}$	25	25	25	
	T_{out}	43	43	37	
	$T_{absorber}$	39	38	38	
16:00	$T_{¿}$	22	22	22	
	T_{out}	33	30	30	

Table 1: Obtained data at 0.02 kg/s air mass flow rate

Air mass flow rate: $\dot{m}$ = 0.04 kg/s					
Time	**Temperature(°C)**	**Square Type**	**Conical Type**	**Double Glazing Type**	**Overall Radiation**
09:00	$T_{absorber}$	43	64	59	859.621w/ m^2
	$T_{¿}$	20	20	20	
	T_{out}	36	36	33	
10:00	$T_{absorber}$	45	66	61	
	$T_{¿}$	20	20	20	
	T_{out}	38	38	35	
11:00	$T_{absorber}$	49	69	62	
	$T_{¿}$	20	20	20	
	T_{out}	39	39	36	
12:00	$T_{absorber}$	50	75	64	
	$T_{¿}$	23	23	23	
	T_{out}	40	40	35	
13:00	$T_{absorber}$	59	79	76	
	$T_{¿}$	25	25	25	
	T_{out}	48	49	44	
14:00	$T_{absorber}$	57	74	70	

	$T_{¿}$	25	25	25	
	T_{out}	47	46	45	
15:00	$T_{absorber}$	42	54	51	
	$T_{¿}$	22	22	22	
	T_{out}	36	35	32	
16:00	$T_{absorber}$	27	26	27	
	$T_{¿}$	19	19	19	
	T_{out}	26	23	22	

Table 2: Obtained data at 0.04 kg/s air mass flow rate

Air mass flow rate: $\acute{m}$ = 0.07 kg/s					
Time	**Temperature(°C)**	**Square Type**	**Conical Type**	**Double Glazing Type**	**Overall Radiation**
09:00	$T_{absorber}$	28	40	44	970w/ m^2
	$T_{¿}$	14	14	14	
	T_{out}	26	23	22	
10:00	$T_{absorber}$	40	59	55	
	$T_{¿}$	18	18	18	
	T_{out}	32	32	32	
11:00	$T_{absorber}$	44	70	60	
	$T_{¿}$	20	20	20	

	T_{out}	39	41	35
12:00	$T_{absorber}$	45	73	63
	$T_{¿}$	20	20	20
	T_{out}	40	42	37
13:00	$T_{absorber}$	47	63	56
	$T_{¿}$	22	22	22
	T_{out}	39	40	35
14:00	$T_{absorber}$	26	30	29
	$T_{¿}$	19	19	19
	T_{out}	25	24	23
15:00	$T_{absorber}$	33	51	44
	$T_{¿}$	18	18	18
	T_{out}	29	30	28
16:00	$T_{absorber}$	23	22	23
	$T_{¿}$	18	18	18
	T_{out}	21	20	21

Table 3: Obtained data at 0.07 kg/s air mass flow rate

Air mass flow rate: $\acute{m}$ = 0.09 kg/s					
Time	**Temperature(°C)**	**Square Type**	**Conical Type**	**Double Glazing Type**	**Overall Radiation**

09:00	$T_{absorber}$	40	61	52	
	$T_{¿}$	21	21	21	
	T_{out}	25	33	29	
10:00	$T_{absorber}$	42	63	52	
	$T_{¿}$	23	23	23	
	T_{out}	33	38	36	
11:00	$T_{absorber}$	34	38	33	
	$T_{¿}$	22	22	22	
	T_{out}	30	28	28	
12:00	$T_{absorber}$	26	28	27	
	$T_{¿}$	21	21	21	
	T_{out}	22	23	24	820w/m^2
13:00	$T_{absorber}$	26	27	25	
	$T_{¿}$	20	20	20	
	T_{out}	21	23	23	
14:00	$T_{absorber}$	37	56	43	
	$T_{¿}$	22	22	22	
	T_{out}	32	32	31	
15:00	$T_{absorber}$	31	45	35	
	$T_{¿}$	19	19	19	
	T_{out}	29	29	26	
16:00	$T_{absorber}$	28	35	32	
	$T_{¿}$	19	19	19	
	T_{out}	25	25	25	

Table 4: Obtained data at 0.09 kg/s air mass flow rate

Air mass flow rate: $\acute{m}$ = 0.11 kg/s						
Time	**Temperature(°C)**	**Square Type**	**Conical Type**	**Double Glazing Type**	**Overall Radiation**
09:00	$T_{absorber}$	25	27	28	655.2w/ m^2
	$T_{¿}$	18	18	18	
	T_{out}	22	21	21	
10:00	$T_{absorber}$	27	29	30	
	$T_{¿}$	20	20	20	
	T_{out}	26	24	25	
11:00	$T_{absorber}$	35	51	47	
	$T_{¿}$	22	22	22	
	T_{out}	31	31	30	
12:00	$T_{absorber}$	31	41	33	
	$T_{¿}$	20	20	20	
	T_{out}	29	30	27	
13:00	$T_{absorber}$	27	33	29	
	$T_{¿}$	19	19	19	
	T_{out}	25	25	24	
14:00	$T_{absorber}$	33	46	38	
	$T_{¿}$	20	20	20	
	T_{out}	30	31	28	
15:00	$T_{absorber}$	31	45	36	
	$T_{¿}$	20	20	20	

	T_{out}	29	29	27
16:00	$T_{absorber}$	24	26	24
	$T_{¿}$	19	19	19
	T_{out}	24	22	22

Table 5: Obtained data at 0,11 kg/s air mass flow rate

DATE: 13.01.2016	**Air mass flow rate: $\acute{m}$ = 0.02kg/s**		
TIME	**SQUARE TYPE (25X25)**	**CONICAL TYPE**	**DOUBLE GLAZING TYPE**
09:00	10	17	11
10:00	12	19	13
11:00	19	21	19
12:00	25	26	22
13:00	26	28	23
14:00	23	22	16
15:00	18	18	12
16:00	11	8	8

Table 6:Temperature differences at 0.02kg/s air mass flow rate

DATE: 09.01.2016	Air mass flow rate: $\dot{m}$ = 0.04kg/s		
TIME	SQUARE TYPE (25X25)	CONICAL TYPE	DOUBLE GLAZING TYPE
09:00	16	16	13
10:00	18	18	15
11:00	19	19	16
12:00	17	17	12
13:00	23	24	19
14:00	22	21	20
15:00	14	13	10
16:00	7	4	3

Table 7 :Temperature differences at 0.04kg/s air mass flow rate

Table 8:Temperature differences at 0.07kg/s air mass flow rate

DATE: 10.01.2016	Air mass flow rate: $\acute{m}$ = 0.07kg/s		
TIME	**SQUARE TYPE (25X25)**	**CONICAL TYPE**	**DOUBLE GLAZING TYPE**
09:00	12	9	8
10:00	14	14	14
11:00	19	21	15
12:00	20	22	17
13:00	17	18	13
14:00	6	5	5
15:00	11	12	10
16:00	3	2	3

Table 9:Temperature differences at 0.09kg/s air mass flow rate

DATE: 14.01.2016	**Air mass flow rate: $\dot{m}$ = 0.09kg/s**		
TIME	**SQUARE TYPE (25X25)**	**CONICAL TYPE**	**DOUBLE GLAZING TYPE**
09:00	4	12	8
10:00	10	15	13
11:00	8	6	6
12:00	1	2	3
13:00	1	3	3
14:00	10	10	9
15:00	10	10	7
16:00	6	6	6

Table 10:Temperature differences at 0.11kg/s air mass flow rate

DATE: 12.01.2016	**Air mass flow rate: $\acute{m}$ = 0.11kg/s**		
TIME	**SQUARE TYPE (25X25)**	**CONICAL TYPE**	**DOUBLE GLAZING TYPE**
09:00	4	3	3
10:00	6	4	5
11:00	9	9	8
12:00	9	10	7
13:00	6	6	6
14:00	10	10	8
15:00	9	9	7
16:00	5	3	3

Table 11: Efficiencies of panels at 0.02kg/s air mass flow rate

DATE: 13.01.2016	**Air mass flow rate: $\dot{m}$ = 0.02kg/s**		
TIME	**SQUARE TYPE (25X25)**	**CONICAL TYPE**	**DOUBLE GLAZING TYPE**
09:00	33%	56%	36%
10:00	39%	63%	43%
11:00	63%	69%	63%
12:00	83%	86%	73%
13:00	86%	93%	76%
14:00	76%	73%	53%
15:00	60%	60%	39%
16:00	36%	27%	27%

Table 12: Efficiencies of panels at 0.04kg/s air mass flow rate

DATE: 09.01.2016	Air mass flow rate: $\dot{m}$ = 0.04kg/s		
TIME	**SQUARE TYPE (25X25)**	**CONICAL TYPE**	**DOUBLE GLAZING TYPE**
09:00	42%	42%	33%
10:00	47%	47%	39%
11:00	49%	49%	42%
12:00	44%	44%	31%
13:00	59%	62%	49%
14:00	57%	54%	51%
15:00	36%	33%	25%
16:00	18%	10%	7%

Table 13: Efficiencies of panels at 0.07kg/s air mass flow rate

DATE: 10.01.2016	**Air mass flow rate: $\acute{m}$ = 0.07kg/s**		
TIME	**SQUARE TYPE (25X25)**	**CONICAL TYPE**	**DOUBLE GLAZING TYPE**
09:00	48%	36%	32%
10:00	56%	56%	56%
11:00	76%	84%	60%
12:00	80%	88%	68%
13:00	68%	72%	52%
14:00	24%	20%	16%
15:00	44%	48%	40%
16:00	12%	8%	12%

Table 14: Efficiencies of panels at 0.09kg/s air mass flow rate

DATE: 14.01.2016	Air mass flow rate: $\dot{m}$ = 0.09kg/s		
TIME	**SQUARE TYPE (25X25)**	**CONICAL TYPE**	**DOUBLE GLAZING TYPE**
09:00	24%	73%	49%
10:00	61%	91%	79%
11:00	49%	38%	38%
12:00	6%	12%	18%
13:00	6%	18%	18%
14:00	61%	61%	55%
15:00	61%	61%	42%
16:00	38%	38%	38%

Table 15: Efficiencies of panels at 0.11kg/s air mass flow rate

DATE: 12.01.2016	**Air mass flow rate: $\acute{m}$ = 0.11kg/s**		
TIME	**SQUARE TYPE (25X25)**	**CONICAL TYPE**	**DOUBLE GLAZING TYPE**
09:00	37%	28%	28%
10:00	56%	37%	47%
11:00	84%	84%	75%
12:00	84%	94%	65%
13:00	56%	56%	56%
14:00	94%	94%	75%
15:00	84%	84%	65%
16:00	47%	28%	28%