Arab Academy for Science, Technology and Maritime Transport

College of Engineering and Technology

<Mechanical engineering department>

B. Sc. Final Year Project

<Integrated parabolic concentrators with evacuated tubes solar collectors for high temperature air heaters>

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Integrated parabolic concentrators with evacuated tubes solar collectors for high temperature air.

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1	Introduction	Ahmed Basem Samir Ahmed Ashraf Abdelmohsen Mohamed Reda Ibrahim Mohamed Khaled Khamis
2	Theoretical Analysis	Ahmed Basem Samir Ahmed Ashraf Abdelmohsen
3	Components and results	Mohamed Khaled Khamis Mohamed Reda Ibrahim
4	Conclusion and Recommendation	Ahmed Basem Samir Ahmed Ashraf Abdelmohsen Mohamed Reda Ibrahim Mohamed Khaled Khamis

DEDICATION

We wholeheartedly dedicate this book and project to the Arab Academy for Science, Technology, and Maritime Transport, a beacon of knowledge and innovation. We express our deepest gratitude to the esteemed Head of mechanical engineering department Prof. Ali Ismail, the esteemed and valued supervisors, Prof. Ayman Bakry and Ass. Prof. Rola Afify, who tirelessly supervised and guided us, sharing their wisdom and expertise throughout this effort. We are forever indebted to the countless doctors we encountered along our journey, who generously imparted their knowledge, shaping us into the individuals we are today. Additionally, our heartfelt appreciation extends to our remarkable colleagues, whose unwavering support and collaboration proved invaluable to the successful completion of this project.

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First and foremost, we express our sincere gratitude to Allah for providing us with the guidance and strength to successfully complete this final year project.

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We would also like to extend our heartfelt thanks and greatest respect to all the dedicated staff members who have imparted their knowledge and expertise during the ten semesters of our pursuit towards our Bachelor of Science in Mechanical Engineering.

Lastly, we would like to express our profound appreciation to our parents for their endless efforts and unwavering support throughout every phase of our lives, particularly in our educational journey, which has brought us to this significant milestone in our education.

ABSTRACT

This project provides an introductory overview of the topic, encompassing various types of solar energies with a particular focus on solar energy for air heating purposes. It includes a comprehensive examination of solar air heaters, their definition, historical context, and different types. The project delves into the theoretical analysis and design of a parabolic trough, exploring the components employed in our project. Additionally, it investigates the impact of solar energy on air through the utilization of various additives and methods. Finally, the project concludes by presenting potential future recommendations and suggestions.

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Chapter one

1.INTRODUCTION

Renewable energy is energy that derived from natural sources that are refilled at a higher rate than they are consumed. Such as sunlight (solar energy, our energy dependent in our project), wind, the movement of water and geothermal heat. Generating renewable energy creates far lower emissions than burning fossil fuels. Transitioning from fossil fuels, which currently account for the lion's share of emissions, to renewable energy is key to addressing the climate crisis. Renewables are now cheaper in most countries, and generate three times more jobs than fossil fuels [1] .

1.1 Renewable energy sources

- Wind energy
- Hydro power
- Geothermal
- Solar Energy

1.1.1 Wind Energy

Wind energy harnesses the kinetic energy of moving air by using large wind turbines located on land (onshore) or in sea- or freshwater (offshore). Wind energy has been used for millennia, but onshore and offshore wind energy technologies have evolved over the last few years to maximize the electricity produced - with taller turbines and larger rotor diameters. [1]

Figure 1. 1 Wind turbine

1.1.2 Hydro power

Hydropower harnesses the energy of water moving from higher to lower elevations. It can be generated from reservoirs and rivers. Reservoir hydropower plants rely on stored water in a reservoir, while run-of-river hydropower plants harness energy from the available flow of the river. Hydropower currently is the largest source of renewable energy in the electricity sector. It relies on generally stable rainfall patterns, and can be negatively impacted by climate-induced droughts or changes to ecosystems which impact rainfall patterns [1].

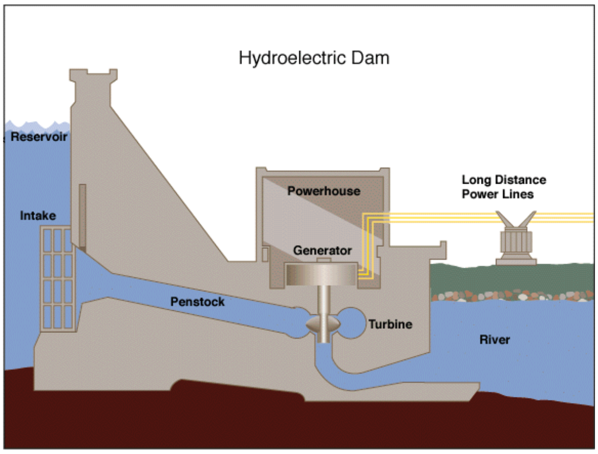

Figure 1. 2 Hydro power

1.1.3 Geothermal Energy

Geothermal energy utilizes the accessible thermal energy from the Earth's interior. Heat is extracted from geothermal reservoirs using wells or other means. Reservoirs that are naturally sufficiently hot and permeable are called hydrothermal reservoirs, whereas reservoirs that are sufficiently hot but that are improved with hydraulic stimulation are called enhanced geothermal systems. Once at the surface, fluids of various temperatures can be used to generate electricity. The technology for electricity generation from hydrothermal reservoirs is mature and reliable, and has been operating for more than 100 years [1].

1.1.4 Solar Energy

Solar energy is the most abundant of all energy resources and can even be harnessed in cloudy weather. The rate at which solar energy is intercepted by the Earth is about 10,000 times greater than the rate at which humankind consumes energy. Although not all countries are equally endowed with solar energy, a significant contribution to the energy mix from direct solar energy is possible for every country. Solar energy will be our concern relying on it as heat energy source for **Evacuated tubes** which will be mentioned lately in this report.[2]

Figure 1. 3 Solar panels

1.2 Solar air heater definition

Energy in various forms has played an increasingly important role in global economy. solar energy is considered as a necessary energy source to meet the increased demand of energy for development and to control the global climate change. the availability of solar radiation is infinite and non-polluting. Among different types of solar thermal systems, solar air heaters are widely used systems due to lower cost and simplicity in design. Solar air heating is a solar thermal technology in which the energy from the sun is captured by an absorbing medium and used to heat air. it is a clean source of energy and renewed that provides solar heating, ventilation heating or a type of heat application [2].

Solar air heater consists of three basic components

- Absorber

- transparent
- The enclosure [3].

1.2.1 The absorber

The absorber needs to be of dark color to soak up most of the radiation it receives. You can use matt black spray paint for this purpose. The layer of paint needs to be thin otherwise it will become a barrier for heat to flow into the absorber section. The absorber pipe is usually metallic which allows it to transfer heat effectively to the air on the inside of the pipe. Shown in **figure1.4** [3]

1.2.2 The transparent cover

The ideal choice for the transparent cover is the low iron glass. This type of glass allows most of the radiation through and is everlasting (unless broken). One can also use transparent plastic sheet or plexiglass. The transparent cover serves two purposes, it allows most solar radiation inside and also blocks heat from getting away through greenhouse effect. Thus, it acts as a blanket for the absorber pipes which can get really hot. Shown in **figure 1.4** [3]

1.2.3 The enclosure

Around the absorber pipes provides structural stability and it provides thermal insulation and blocks the heat from escaping through the backside. Shown in **figure 1.4**.[4]

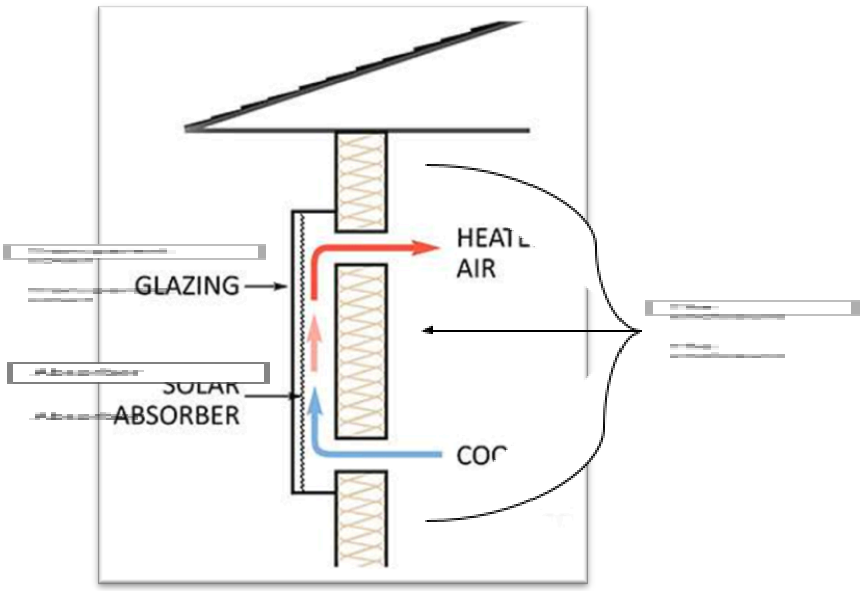

Figure 1. 4 Solar air heater component

1.3 History of solar air heaters

The sun has served as a source of heat since the beginning of time, but the earliest documented use of human-constructed solar collection system dates back to 1767 when Swiss scientist Horace de Saussure developed a rudimentary collector commonly referred to as a “hot box”. Astronomer sir john Herschel used hot boxes to cook food during an expedition to Africa in the 1830s, and the use of solar thermal energy for cooking and water distillation purposes subsequently become common in certain parts of Africa [4].

Early American pioneers of the late 1800s used black pots and pans to heat up water as they traveled during the day, thus popularizing the use of solar energy to heat water. The idea was put into widespread use in areas of the country which otherwise had to import fuel for water heating. For example, in 1897 nearly 30% of the houses in Pasadena, California, utilized solar water heaters [4].

Solar energy continued to be used moderately throughout the next century, but leapt in popularity during the energy and oil crisis of the 1970s. Use of solar energy tapered off as the energy crisis waned, but has risen again in popularity in the 1990s as populations become increasingly aware of the environmental and public health hazards caused by the burning of fossil fuels and the use of nuclear power [4]

1767: Swiss physicist creates first thermal solar collector.
2015: The Age of Solar Power

The solar power industry in Australia undergoes rapid growth during this period. As the cost of fossil fuels continues to rise, solar energy drops to record lows, as does the cost of rooftop installation. Almost every gizmo, gadget and environment are capable of harnessing the power of the sun’s unlimited resources, from luxury cars, to aeroplanes and, in some cases, entire states and countries. In 2015, solar power’s future is brighter than ever. And while it’s clear that so much has already been achieved, we know that Solar’s greatest achievements are still yet to come. [6]

1.4 Types of solar air heaters

- Non-concentrating collectors
- Concentrating collectors [5]

1.4.1 non-concentrating collectors

Non-concentrating collectors are able to use direct (beam) solar radiation under various angles as well as diffuse radiation scattered by atmospheric influences. They do not need to track the sun's position and can be installed in a fixed orientation. Non-concentrating solar thermal collectors can reach temperatures of up to 250°C/482°F, but since the efficiency decreases with increasing operating temperature, they usually operate and deliver heat at acceptable efficiencies at temperatures up to 100°C/212°F, with special high-efficiency non-concentrating collectors delivering heat up to 150°C/302°F. [5]

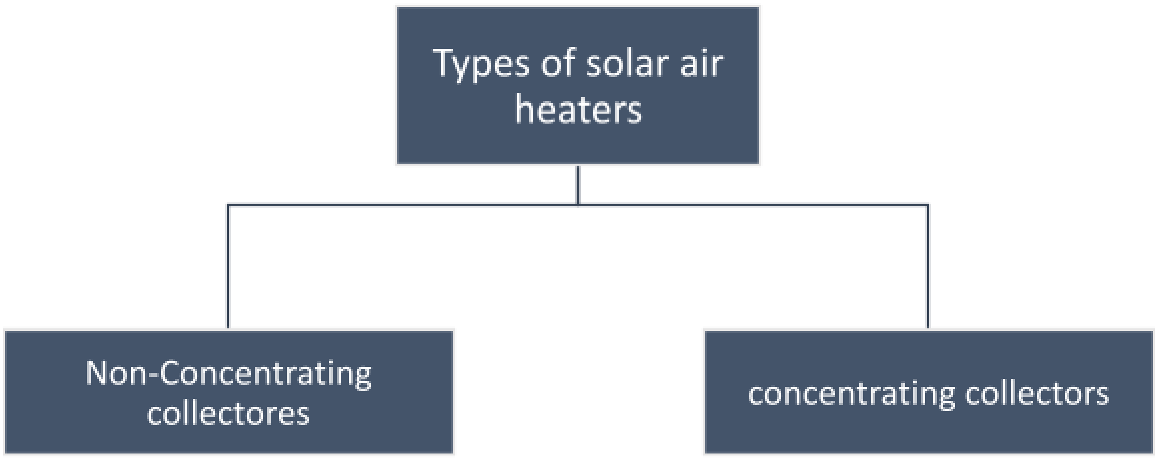

Figure 1. 5 Types of solar air heaters

Non-concentrating collectors Types

1.4.1.1 Flat plate Collector

It is the most common solar collector types which is commonly used in solar water heating system in homes and in solar space heating, The design and construction of this type of collector are simple, It is a box made up of metal consisting of copper pipes running in parallel called risers. The fluid flows through these risers. The top of the box has a dark-colored absorber plate and the rest of the faces of the box are insulated to prevent the heat losses. On absorbing the radiation from the sun, the circulating water inside the risers heats up. This type of collector is mainly used for domestic purposes where the temperature required is not too high like heating of tanks, pools or tubs. [5]

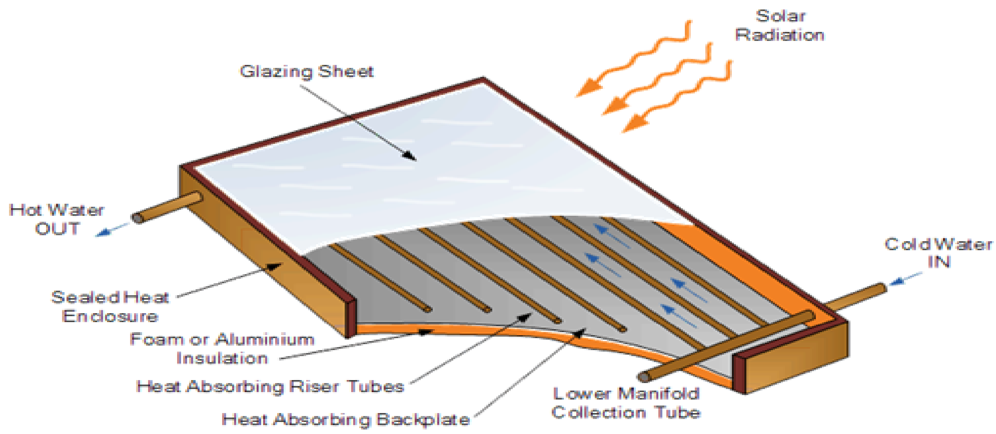

Figure 1. 6 Flat plate

The plate is constructed in two different ways

1.4.1.1.1 Direct heating system

In this method, cold water from a tank is pumped into the plate which gets heated up and this water can be used for various household purposes. This is a kind of Open-loop system. [5]

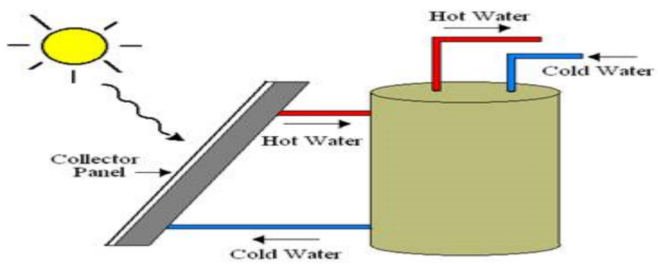

Figure 1. 7 Direct heating

1.4.1.1.2 Indirect heating system

In this type of system, a water tank is designed in such a way that it contains a spiral of pipe inside it. The ends of this pipe are connected to the collector. The hot water from the collector flows into the pipes inside the tank and radiates its heat into the tank before returning to the collector. This cycle continues. So, it is known as a closed-loop system. [5]

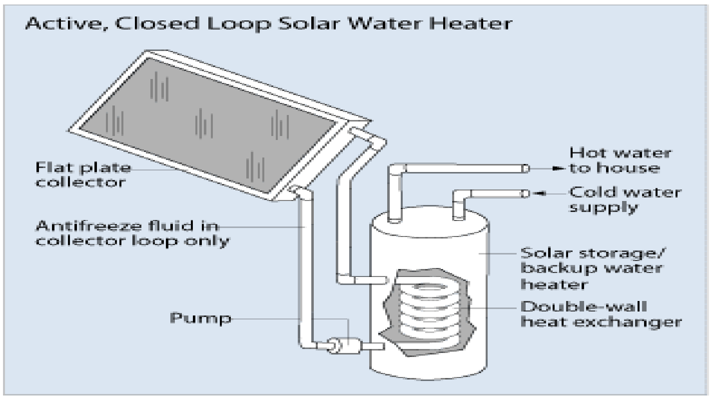

Figure 1. 8 Representation of Indirect heating system

1.4.1.2 Evacuated tube collector

It consists of a number of rows of parallel transparent glass tubes connected to a header pipe and which are used in place of the blackened heat absorbing plate we saw in the previous flat plate collector. [6]

These glass tubes are cylindrical in shape. Therefore, the angle of the sunlight is always perpendicular to the heat absorbing tubes which enables these collectors to perform well even when sunlight is low such as when it is early in the morning or late in the afternoon, or when shaded by clouds. Evacuated tube collectors are particularly useful in areas with cold, cloudy wintry weathers. [6]

Figure 1. 9 Evacuated tube collector

There are two types of evacuated tubes collectors

1.4.1.2.1 Direct flow evacuated-tube collectors

It has two pipes that run down and back, inside the tube. One pipe is for inlet fluid and the other for outlet fluid. Since the fluid flows into and out of each tube, the tubes are not easily replaced. Also, should a tube break, it's possible that all of the fluid could be pumped out of the system - if a closed loop is used, or your water will flow out as in a broken pipe, if an open loop is used. [7]

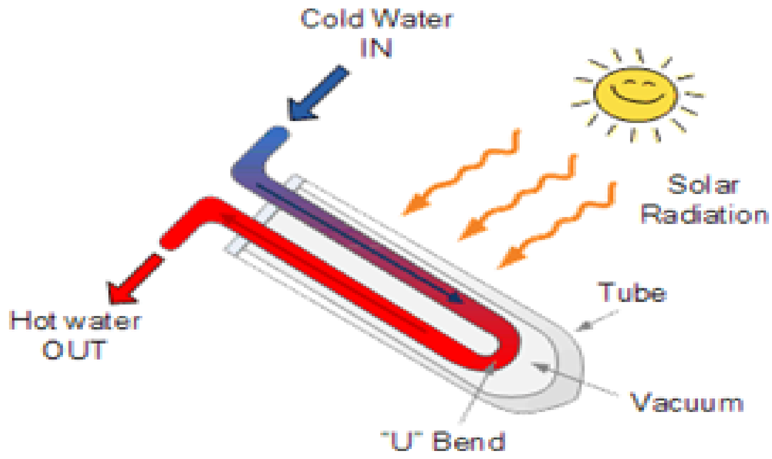

Figure 1. 10 Direct flow evacuated tube collector

1.4.1.2.2 Heat pipe evacuated-tube collectors

In heat pipe evacuated tube collectors, a sealed heat pipe, usually made of copper to increase the collector efficiency in cold temperatures, is attached to a heat-absorbing reflector plate within the vacuum-sealed tube. The hollow copper heat exchanger design within the tube is evacuated of air but contains a small quantity of a low-pressure alcohol/water liquid plus some additional additives to prevent corrosion or oxidation. [6]

In this type, the heat pipe is attached to an absorber plate inside a vacuum-sealed glass tube. The heat pipe is filled with a combination of water and a small quantity of alcohol. On absorbing radiation from the sun, the water heats up to form vapors and rise to the top of the pipe. The top portion of the pipe is connected to a copper heat exchanger, called the “manifold”. The heat energy of the vapor is transferred to the water or glycol fluid flowing through the connecting manifold. Once, the heat gets transferred, the vapor cools down to become liquid and gets back in the pipe from the manifold to get reheated again, this cycle continues. [5]

1.4.2 Concentrating collectors

It has a large receiver area which concentrates the radiation on a small absorber area. The major disadvantage of concentrating collectors is that they can only utilize the beam radiation [10].

Concentrating solar collectors can be fixed-position or tracking, in which part of or the entire collector moves to align with the position of the sun over the day. Tracking can either be on one axis, with simpler mechanisms but slightly less output, or two axes, which produces the most power. [8]

Concentrating collectors rely on specular sun for their function, so they work best in clear, dry climates. Most concentrating collectors are mounted on free-standing structures which permits them to track, though there are some that resemble flat plate collectors and can be mounted directly onto building surfaces. [8]

Higher temperatures can be achieved with concentrating collectors than flat plate, which permits a wider range of applications. High-temperature collectors can be used for absorption chilling, process loads and can even be used to generate electricity via a steam turbine. A potential benefit of high-temperature concentrating thermal systems is their ability to store energy as heat. Hot fluids or molten slats can be stored in insulated tanks from which heat can be extracted later for direct use as heat or to generate steam for electricity. As renewable energy becomes a larger part of the electrical grid, the ability to store energy for use when the sun is not shining or the wind not blowing will become more important. [8]

Concentrating solar collectors can achieve higher temperature ranges because the solar radiation is concentrated onto a smaller area, compared with non-concentrating collectors. Moreover, at higher temperature, the thermal efficiency is higher compared with non-concentrating collectors, as a result of smaller heat loss area compared with solar collector aperture area. [8]

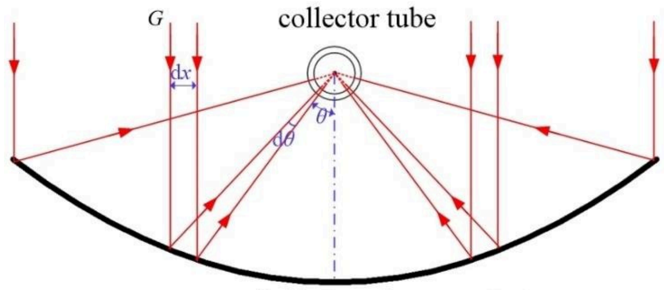

Figure 1. 11 Drawing of concentrating collectors

1.5 Evacuated tubes solar heater

The evacuated tube collector (ETC) consists of a number of sealed glass tubes which have a thermally conductive copper rod or pipe inside allowing for much high thermal efficiency and working temperature compared to the flat plate solar collectors which were mentioned before in the types even during a freezing cold day. the problem with flat plate collectors is that they are “flat”. This produces one limitation to their efficiency as they can only operate at maximum efficiency when the sun is directly overhead at midday. At other times, the sun’s rays are striking the collector at varying angles bouncing off the glazing material thereby reducing their efficiency. Solar hot water systems that use Evacuated Tube Collectors as their heat source overcome this problem because the solar collector uses individual rounded tubes which are always perpendicular to the sun’s rays for most of the day. This allows a solar hot water system using an evacuated tube collector to operate at a much high efficiency and temperature for a much longer period than single flat plate collector installed system. Also, another advantage of solar evacuated tube technology is that the weight and roof structural problems caused by standard flat plate systems are eliminated as the solar tubes are not filled with large amounts of heavy water. [6]

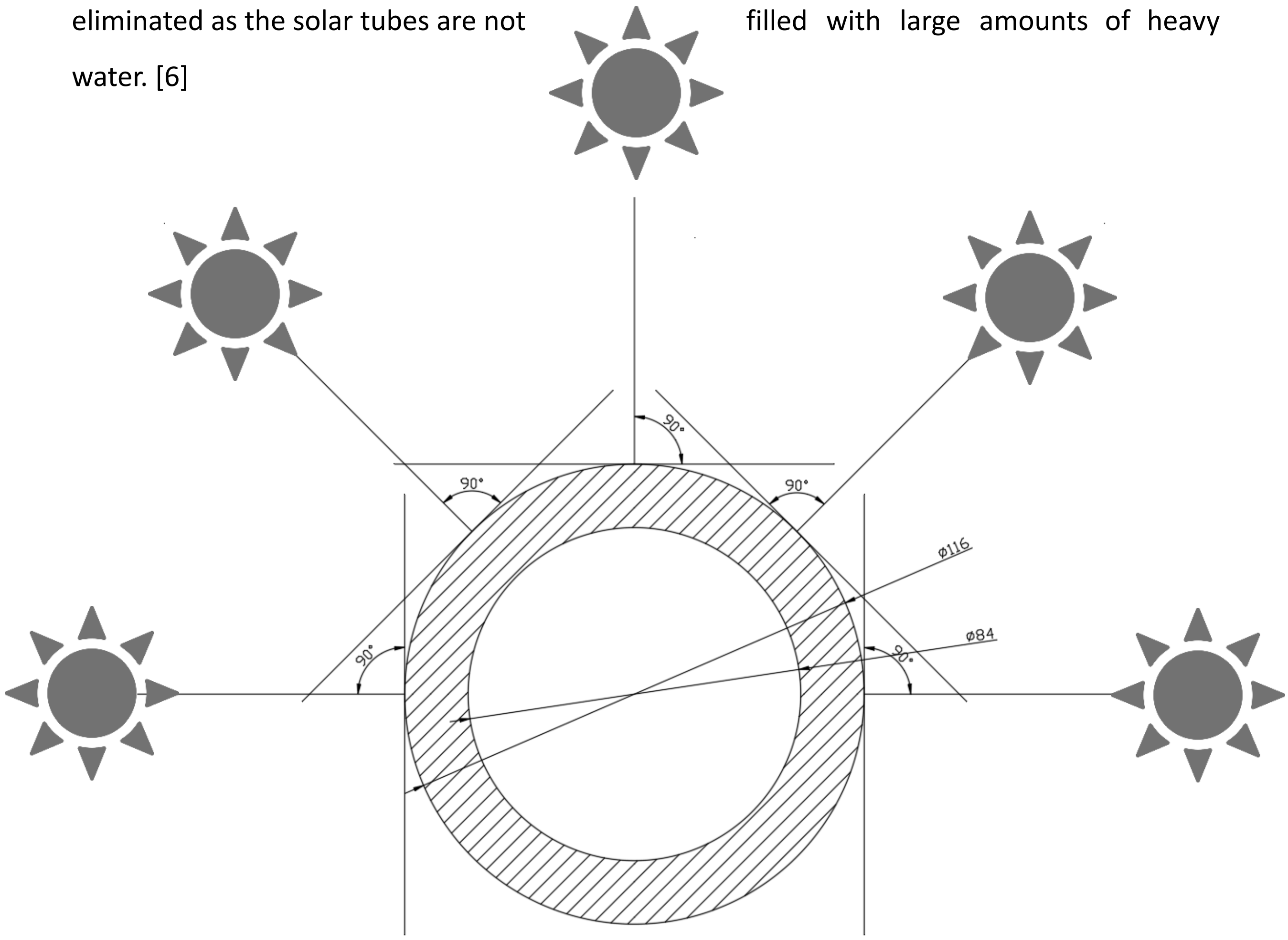

*Figure 1. SEQ Figure_1. * ARABIC 12: Illustration of normality of sun rays on vacuum tubes*

The Evacuated tube collector consists of a number of rows of parallel transparent glass tubes connected to a header pipe and which are used in place of the blackened heat absorbing plate we saw in the previous flat plate collector. Evacuated tube collectors are made up of a single or multiple rows of parallel, transparent glass tubes supported on a frame. Each individual tube varies in diameter from between 1" (25mm) to 3" (75mm) and between 5′ (1500mm) to 8′ (2400mm) in length depending upon the manufacturer. Each tube consists of a thick glass outer tube and a thinner glass inner tube, (called a “twin-glass tube”) or a “thermos-flask tube” which is covered with a special coating that absorbs solar energy but inhibits heat loss. The tubes are made of borosilicate or soda lime glass, which is strong, resistant to high temperatures and has a high transmittance for solar irradiation. Unlike flat panel collectors, evacuated tube collectors do not heat the water directly within the tubes. Instead, air is removed or evacuated from the space between the two tubes, forming a vacuum (hence the name evacuated tubes). This vacuum acts as an insulator reducing any heat loss significantly to the surrounding atmosphere either through convection or radiation making the collector much more efficient than the internal insulating that flat plate collectors have to offer. With the assistance of this vacuum, evacuated tube collectors generally produce higher fluid temperatures than they’re flat plate counterparts so may become very hot in summer [6]

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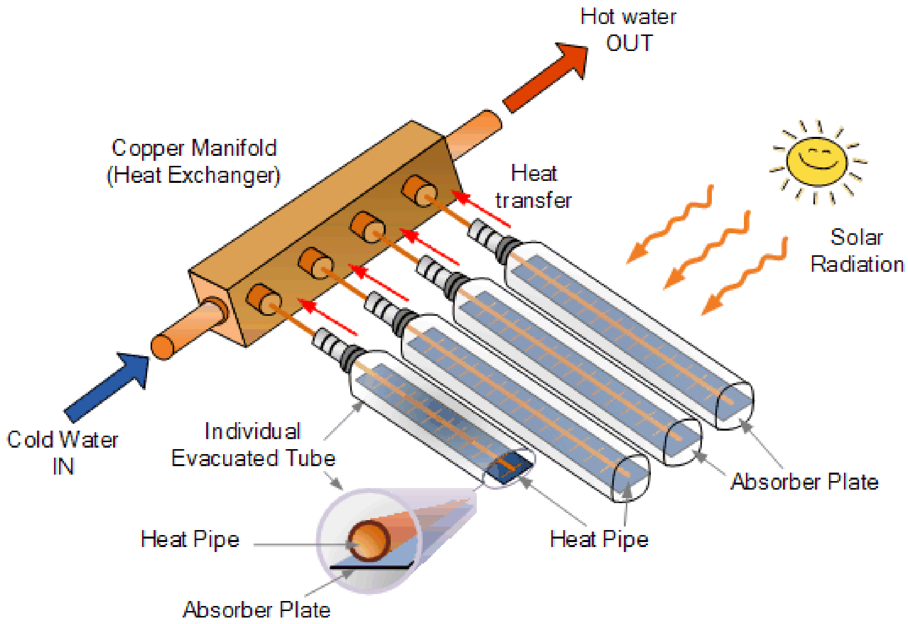


Figure 1. 13 Evacuated tube collector

1.6 Applications on high temperature air flow

The heated air that solar air heater produce can be used for:

- Industrial purposes
- Agricultural purposes
- Household purposes
- Camp or camping purpose [9]

1.6.1 Industrial purposes

Air pre-heating for combustion processes, that means thousands of applications Drying minerals, coal, paper, bricks, food industry products, etc. Especially the drying of brown coal would be very important for power plants. Space heating for warehouses, factories, etc. [9].

Industrial ventilation air heating applies to buildings requiring large volumes of outdoor air to replace air exhausted from painting, welding, automotive fabrication, or other manufacturing operations. 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 6, in industrial buildings where there is no existing air distribution system, 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 a low-cost method of delivering make-up air throughout the building. A recirculation damper system incorporated into the fan compartment mixes warm indoor air with cooler solar collector air to maintain the constant delivered air temperature. The ratio of indoor (recirculated) air to solar air heating system (outdoor) air varies continuously with changes in the solar collector outlet air temperature, while a duct thermostat operates the damper system. [10].

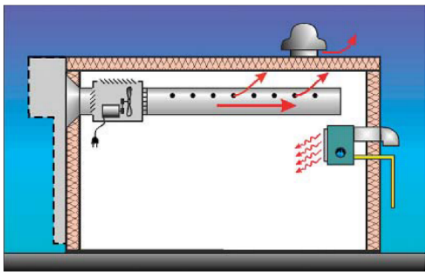


Figure 1. 14 Industrial purpose

1.6.2 Agricultural purposes

It has been established that the majority of plants will perform well overall in temperature conditions of between 12°C and 30°C. in cold climates, the structure of a greenhouse cannot adequately maintain the optimum temperatures during the day and night. This calls for a heating system that is of a reasonable cost [11].

Agricultural solar greenhouses are constructed in a way to harvest solar energy during the day and store it for the night. The structure is composed of collectors that are made of special material. This heat can also be stored in a heat storage system for long term use in winter maybe. Solar PV panels can also be used to convert light from the sun into electricity, which can then be stored in accumulators and used for heating, later. [11]

Using solar energy to dry crops and grain is one of the oldest and most widely used applications of solar energy. This is the cheapest technique that allows crops to dry naturally in the field, or to spread grain and fruit out in the direct sunshine after harvesting. One of the disadvantages of this method is that the crops and grains are subject to damage by animals such as birds, rodents, or by wind, and rain, and contamination by dust and dirt. Some solar dryers have better structure and size, protect the grain and fruit, reduce the losses, dries the food faster and uniformly, producing a higher quality product as compared to that of open-air methods. [12]

Figure 1. 15 Agricultural purpose

1.6.3 Household purposes

Take advantage of solar energy and cut your utility bills all at the same time by installing solar air heaters. Solar air heaters are designed to transfer sunlight into heat, which then circulates throughout your home, warming it to cozier temperatures. Conveniently, these solar heating systems are highly simplistic and built to work with your existing HVAC systems, such as your gas furnace or heat pump unit [13].

Fuel prices may increase at any time, but sunshine will always be free. And this is why many people are turning to solar air heating systems to keep their homes comfortable during the winter season [14]

Profit from your roof space: find local deals on solar in your area, eliminate your power bill, and join the solar revolution.

Solar air heating systems are typically used to help supplement existing heating systems. It works together with the existing main heating system to provide heat in the home which results in a lesser need for the primary heating system to produce heat. This translates to reduced fuel cost of as much as 30% [14]

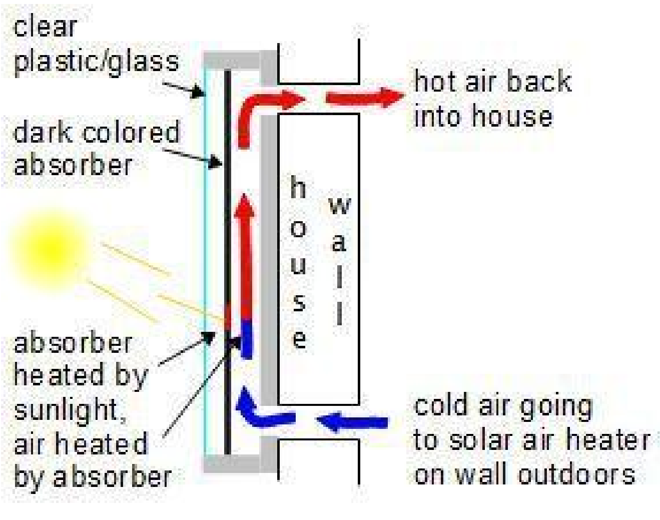


Figure 1. 16 Household purposes

Chapter two

2.THEORITICAL ANALYSIS

2.1 Evacuated tube solar collector configuration

This chapter will discuss a mathematical study for a system of glass evacuated solar collector tubes with coaxial fluid conduit, with forced convection flow. [15]

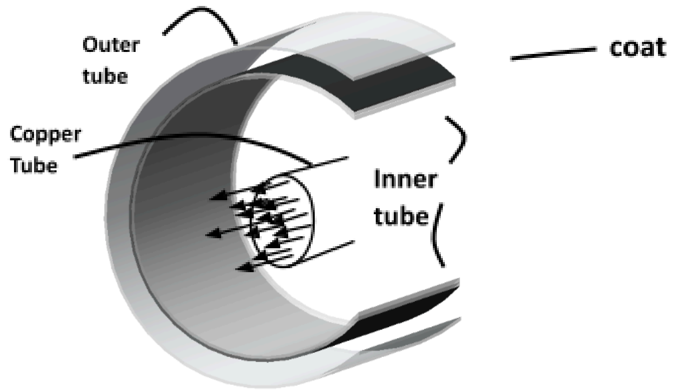


Figure 2 . 1 Evacuated tube

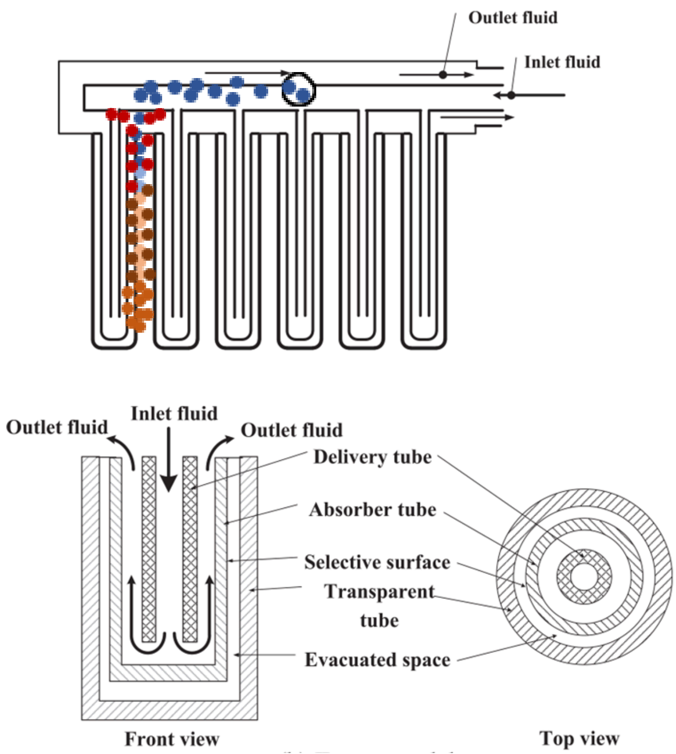


Figure 2 . 2 schematic diagram

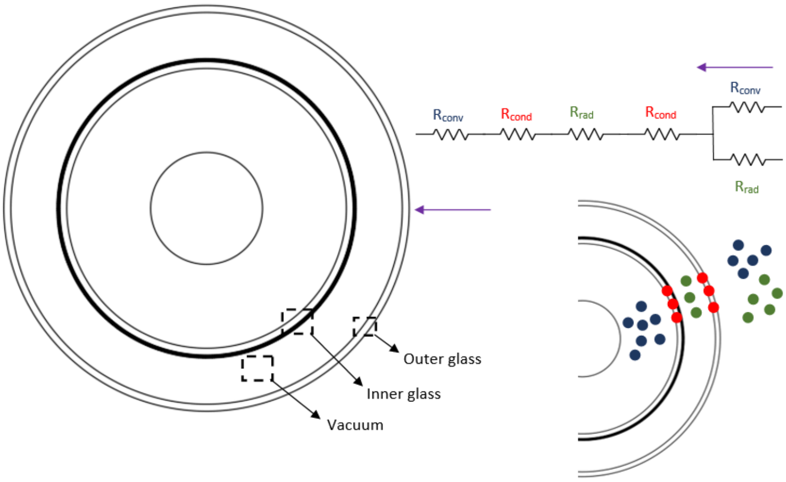


Figure 2 . 3 Simple representation for system configuration

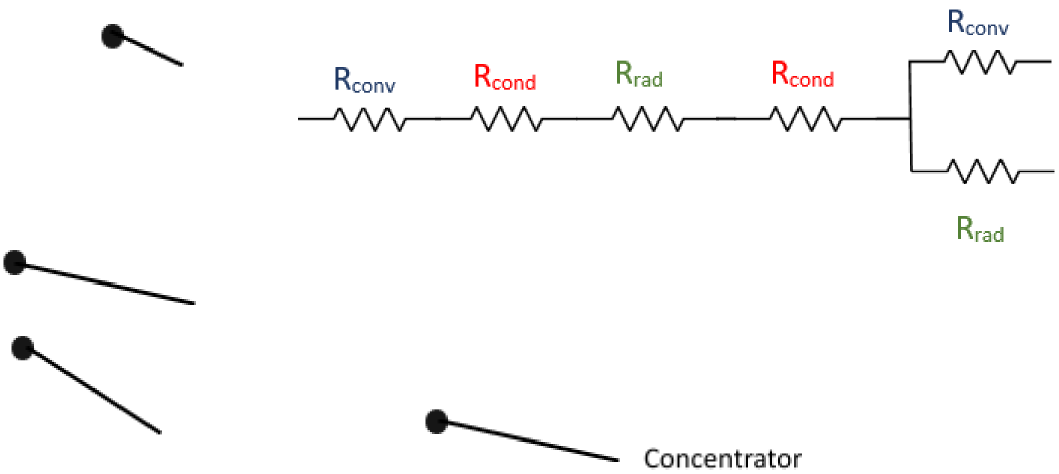


Figure 2 . 4 Thermal circuit

2.1.1 Nomenclature, Subscripts and Greek symbols

Nomenclature:

Table 2. 1 Nomenclature for theoretical analysis

T_{C_o}	Outer temperature of the cover tube	T_{r_i}	Inner temperature of the receiver
T_{C_i}	Inner temperature of the cover tube	T_f	Working fluid temperature (air)
T_{r_o}	Outer temperature of the receiver	h_r	radiative heat transfer coefficient (W $K^{-1}m^{-2}$)
k	thermal conductivity (W $K^{-1}m^{-1}$)	Nu	Nusselt number
Pr	Prandtl number	Q	Heat transfer rate (W)
Re	Reynolds number	T	temperature (k)
U	overall heat transfer coefficient (W $K^{-1}m^{-2}$)	V_{wind}	wind velocity (m s^{-1})
h_C	convection heat transfer coefficient (W $K^{-1}m^{-2}$)	S	Solar irradiance (W/m^2)
G_b	Beam radiance	A_{ro}	Outer area of the receiver

Greek symbols:

Table 2. 2 Greek symbols for theoretical analysis

α	absorptance	τ	Transmittance
v_a	Kinematic viscosity	ε	emittance
σ	Stefan–Boltzmann constant (5.67×10^{-8} W m^{-2} K^{-4})	ρ	Reflectivity

2.1.2 Energy equations

Absorbed solar radiation by the receiver

$$S = G_b * \rho_{collector} * \tau_{cover} * \alpha_{reciever} * \gamma_{intercept}$$

The term gamma intercept represents the rays that couldn't reach the evacuated tube.

Heat flow rate gained by the fluid

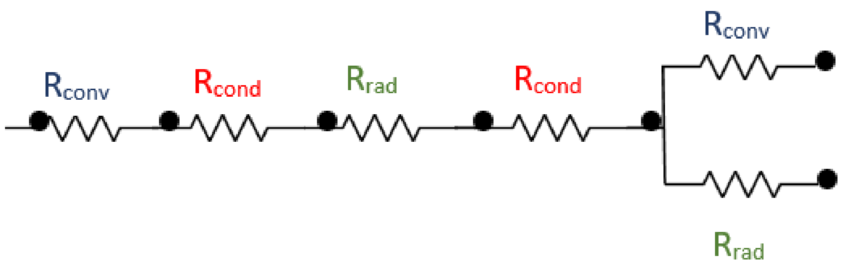
$$Q^\circ_{useful} = m^\circ_f * C_{pf} * \left(T_{fo} - T_{fi}\right) = \left(S * A_{ap}\right) - Q^\circ_{loss}$$

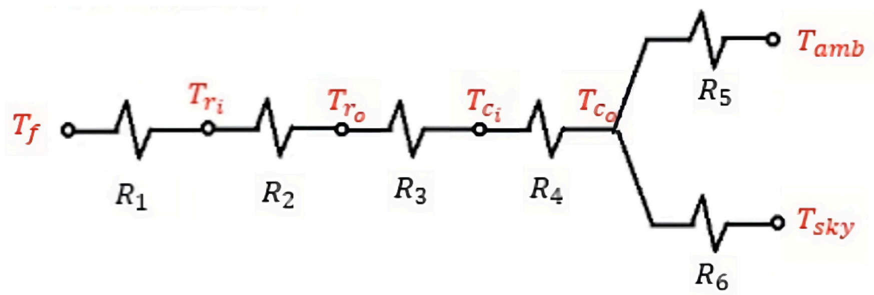
Where A_{ap} is the projection on the receiver.

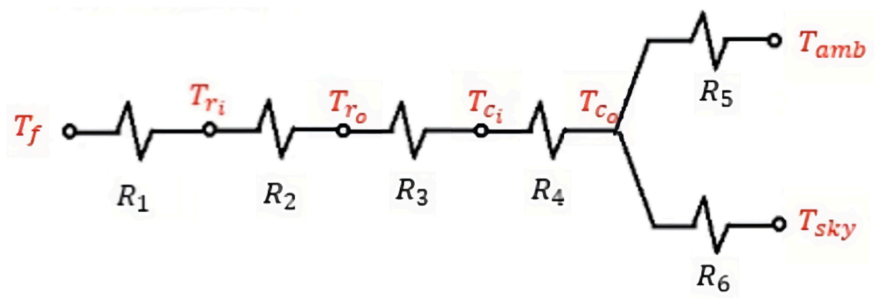
The Q_{loss} can be calculated by:

$$Q^\circ_{loss} = A_{ro} * U_r * \left(T_{ro} - T_{amb}\right)$$

Overall heat transfer coefficient







$$R_1 = \frac{1}{\pi * D_{ri} * L * h_f}$$

$$R_2 = \frac{\ln ln\left(\frac{D_{ro}}{D_{ri}}\right)}{2\pi * L * K_r}$$

$$R_3 = \frac{1}{\pi * D_{ro} * L * \varepsilon * \sigma * \left(T_{ro}^2 + T_{ci}^2\right) * \left(T_{ro} + T_{ci}\right)}$$

$$R_4 = ln\frac{\left(\frac{D_{co}}{D_{ci}}\right)}{2\pi * L * K_c}$$

$$R_5 = \frac{1}{\pi * D_{co} * L * h_a}$$

$$R_6 = \frac{1}{\pi * D_{co} * L * \varepsilon * \sigma * \left(T_{co}^2 + T_{sky}^2\right) * \left(T_{co} + T_{sky}\right)}$$

To calculate h_a:

$$N_u = \frac{h_a * D_{co}}{k} = 0.3 * \left(\frac{V_{wind} * D_{co}}{v_a}\right)^{0.6}$$

$$h_a = \frac{0.3 * k}{D_{co}} * \left(\frac{V_{wind} * D_{co}}{v_a}\right)^{0.6}$$

$$T_{avTable\ value} = \frac{T_{Co} + T_{ambient}}{2}$$

After calculating the T average value, the properties of air table at 1atm will be used to get the values of K and v_a as shown in (figure2.5)

Temp T, °C	Density ρ, kg/m³	Specific Heat c_p	Thermal Conductivity k, W/m•K	Thermal Diffusivity α, W/m•K	Dynamic Viscosity μ, kg/m•s	Kinematic Viscosity ν, m²/s	Prandtl Number Pr
-150	2.866	983	0.01171	4.158×10^{6}	8.636×10^{-6}	3.013×10^{-6}	0.7246
-100	2.038	966	0.01582	8.036×10^{6}	1.189×10^{-5}	5.837×10^{-6}	0.7263
-50	1.582	999	0.01979	1.252×10^{5}	1.474×10^{-5}	9.319×10^{-6}	0.7440
-40	1.514	1002	0.02057	1.356×10^{5}	1.527×10^{-5}	1.008×10^{-5}	0.7436

Figure 2 . 5 Simplified image for Air properties table at 1 atm

To calculate overall heat transfer coefficient:

$$A * U = \frac{1}{\Sigma R_{eq}}$$

2.2 INTEGRATED PARABOLIC CONCENTRATOR DESIGN

Nomenclature

Table 2. 3 Nomenclature for integrated parabolic concentrators

.

θ	**Is the angle between the bottom of the receiver and the tangential point T.**	**P**	**The point on the line of involution.**
T	**Tangential point.**	P_m	**Width of the parabola (aperture of parabola).**
θ_m	**The minimum θ at the cusp of reflector.**	T_m	**The tangential point at the cusp.**
θ_A	**The half acceptance angle.**	**r**	**The radius of the cylindrical receiver.**
lG	**The gap between the bottom of receiver and the cusp of the reflector.**		

2.2.1 Design Process

Nonimaging optics is a branch of optics that deals with the optimal transfer of light radiation between a source and a target. Unlike traditional imaging optics, nonimaging optics does not attempt to form an image of the source. Instead, it is concerned with designing optical systems that maximize the amount of light that is transferred from the source to the target. Since the emergence of non-imaging optics, the designs of CPCs have been extensively studied by various research groups. [16]

Form angle (0 to 90) :

$$\rho(\theta) = \overline{PT} = \left(r + L_G\right) \sin sin\, \theta_m + r(\theta - \theta_m)$$

From angle (90 to 270) :

$$\rho(\theta) = \frac{r\left\{\theta_A + \frac{\pi}{2} + \theta - 2\theta_m + 2\tan tan\, \theta_A - \cos cos\, (\theta - \theta_A)\right\}}{1 + \sin sin\, (\theta - \theta_A)}$$

The concept of reflection area and involution area is simple first the involution area, this area is typically smaller than the reflection area, because the reflector is curved to focus the light onto a smaller area. This allows the CPC to concentrate more light onto the receiver, which increases the efficiency of the concentrator. The involution area determines all the amount of light that is absorbed by the receiver, while the reflection area represents some of light that is absorbed by the receiver not all light.

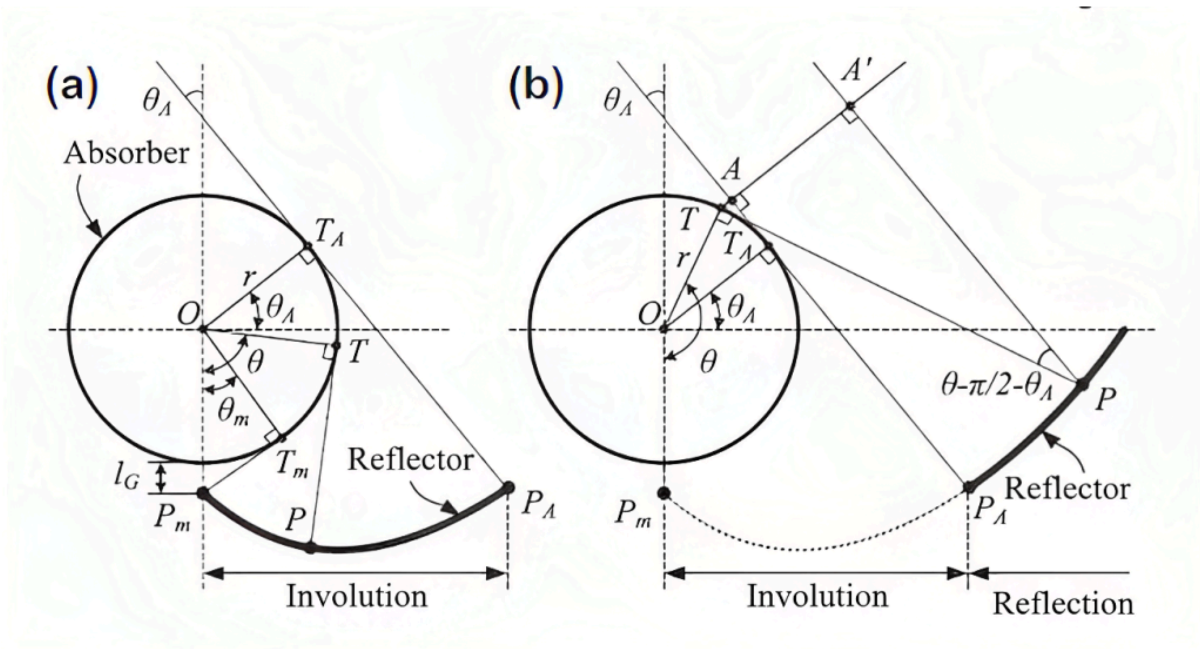


Figure 2 . 6: Two sections of XCPC: (a) Involution (b) Reflection

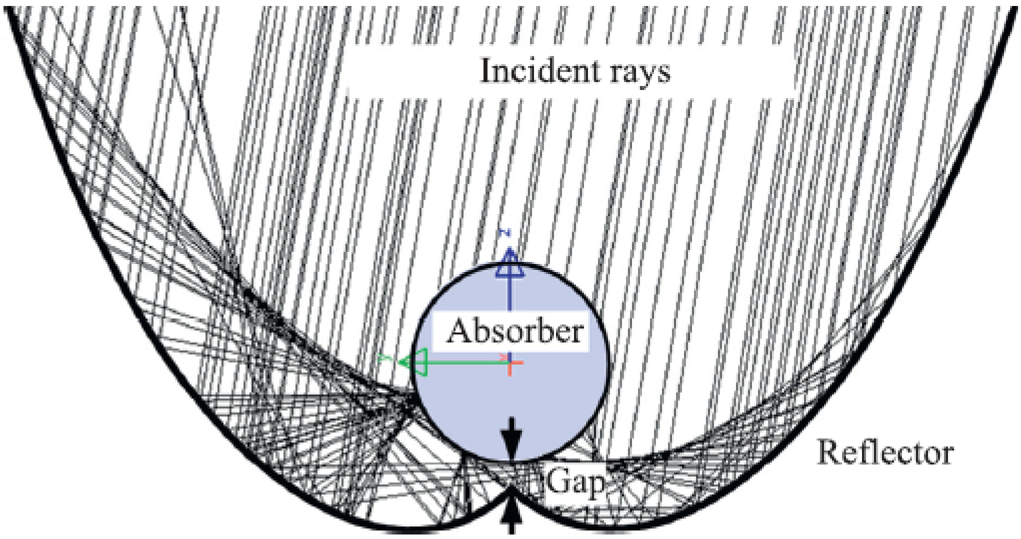


Figure 2 . 7: Ray-tracing for XCPC and rays by gap loss with the incident angle of 10°

According to School of Mechanical Engineering, Shanghai Jiaotong University's Journal paper, they tended to simplify the design of the CPCs to be able to manufacture by eliminating the curved area beneath the tube as shown in the following figure: [17]

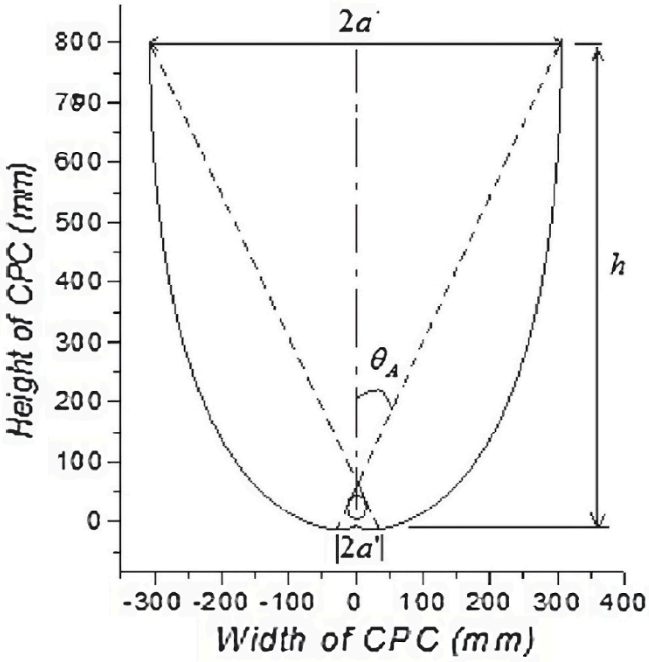


Figure 2 . 8: Standard CPC

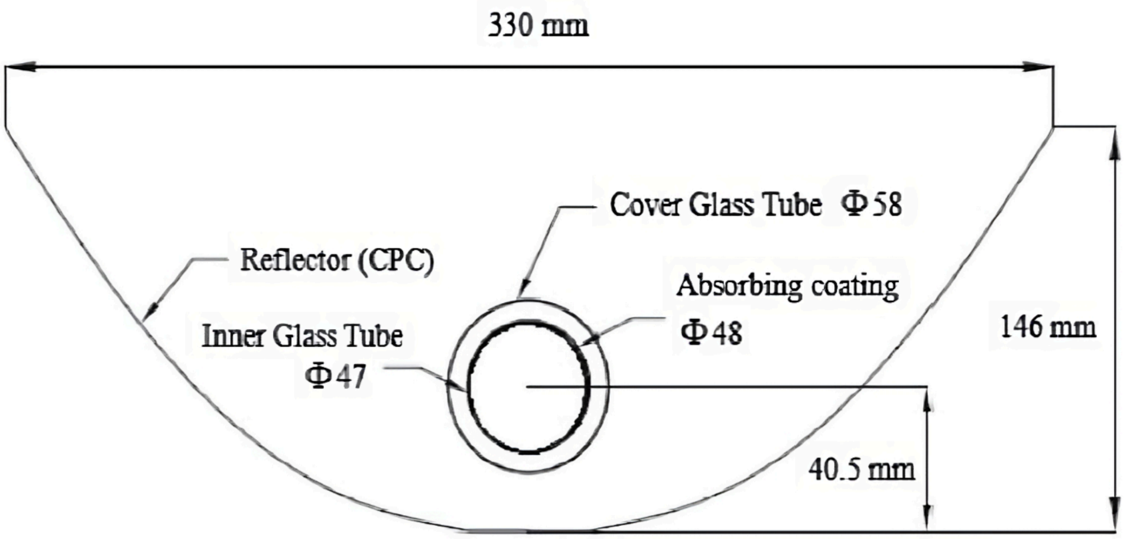


Figure 2 . 9: Simplified CPC

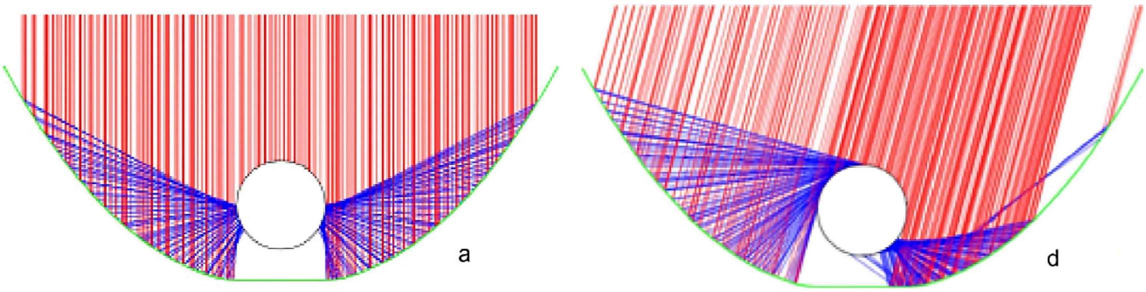


Figure 2 . 10: Simulated ray-tracing results of simplified CPC at incident angles of (a) 0° and (d) 15°

Figure 2 . 11: Early design Process for our concentrator

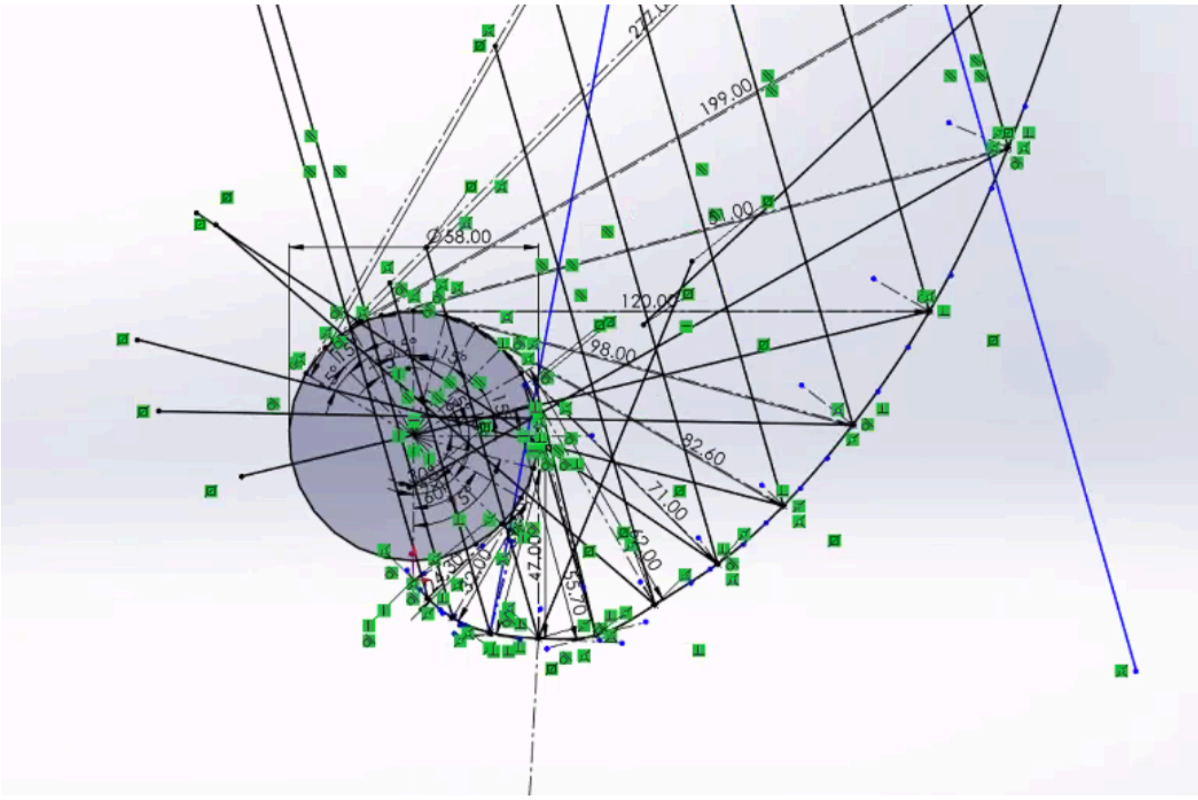


Figure 2 . 12: The length of the tangential line at different angles forming the parabolic shape

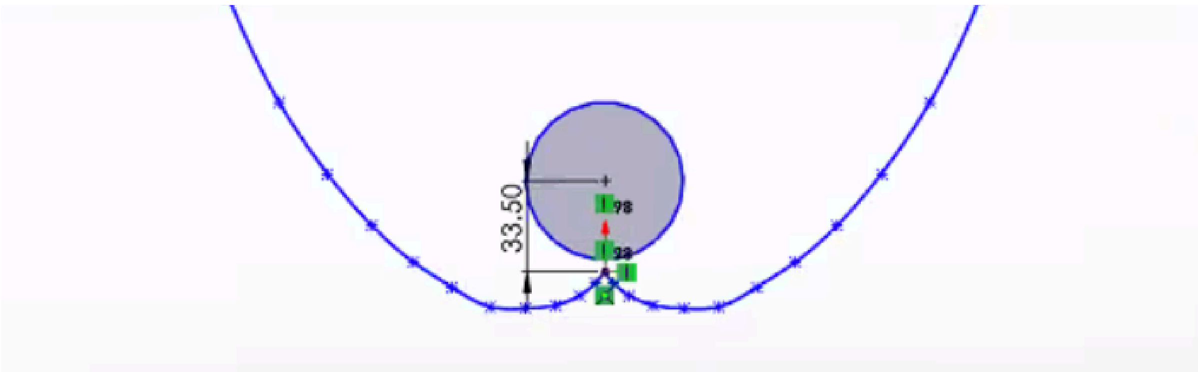


Figure 2 . 13: Advanced design process

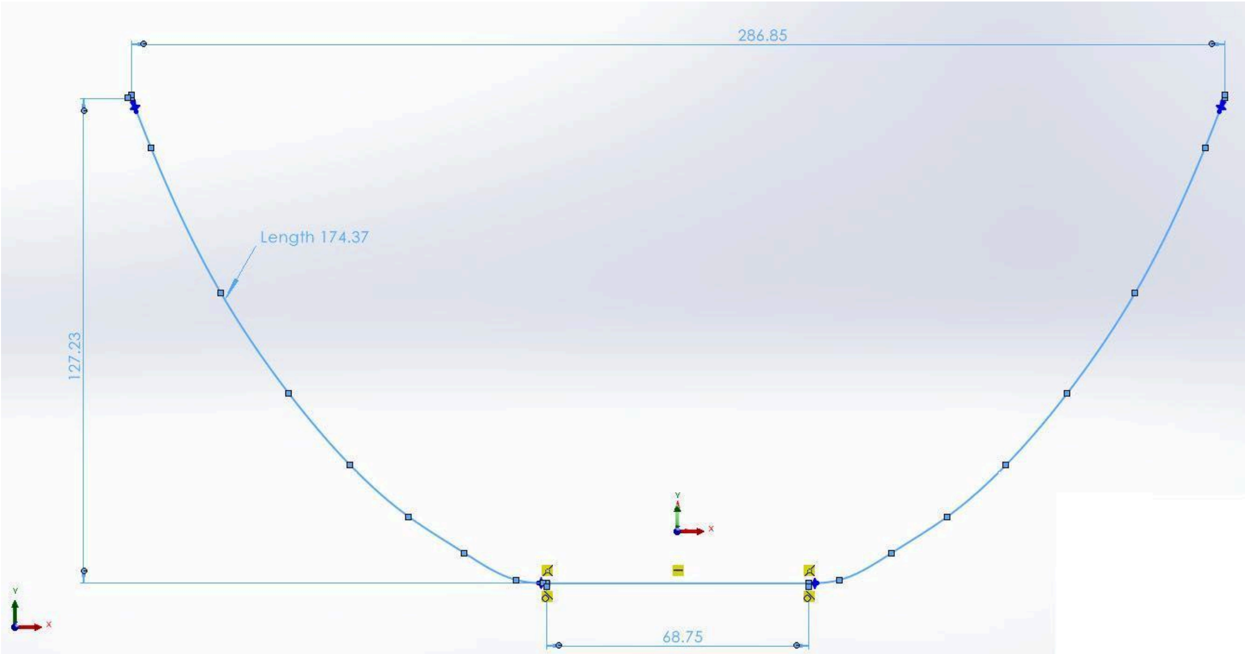


Figure 2 . 14: Last designed CPC simplified

Figure 2 . 15: Parabolic concentrator integrated with evacuated tube

2.2.2 Material Selection

The previous (fig.2.10) shows the CPC that had been designed and made in real life from polished chrome material. Polished chrome sheets that have a mirror-like appearance are typically achieved through a process known as chrome plating, also referred to as chromium electroplating. However, it's important to note that chrome plating involves depositing a layer of chromium onto a surface.

Polished chrome, while highly resistant to corrosion, can potentially be affected if the surface is scratched deeply enough to expose the underlying material. The chrome layer acts as a protective barrier against corrosion, but if it is breached or damaged, the underlying material, usually a base metal like steel or brass, may become susceptible to corrosion.

Our choice falling on polished chrome because the materials available was aluminum and stainless steel. Considering the cost, the highest was stainless steel then aluminum then the polished chrome. Considering their Reflection Factor, the following data found:

Table 2. 4 Materials Reflection factor

Material	Reflection Factor (%)
Aluminum, polished (poor)	**65 - 75**
Stainless steel	**55**
Polished Chrome	**60 - 70**

So, the choice was on polished chrome considering its high surface finish and its reasonable price. [18]

2.3 Arduino Serial Communication

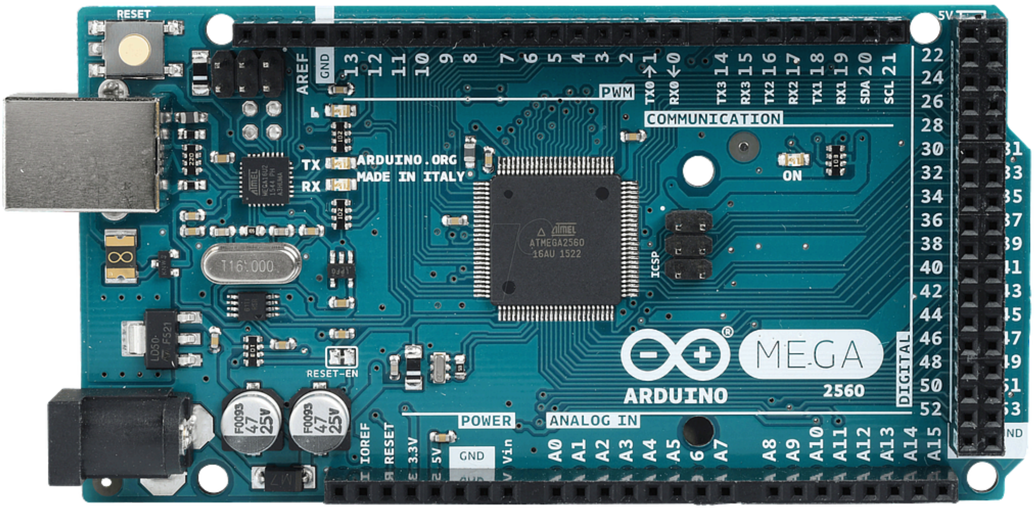


Figure 2 . 16: Arduino Mega 2560

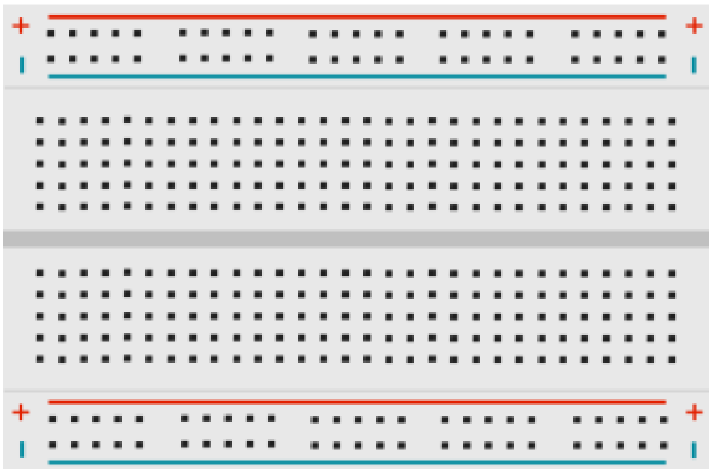
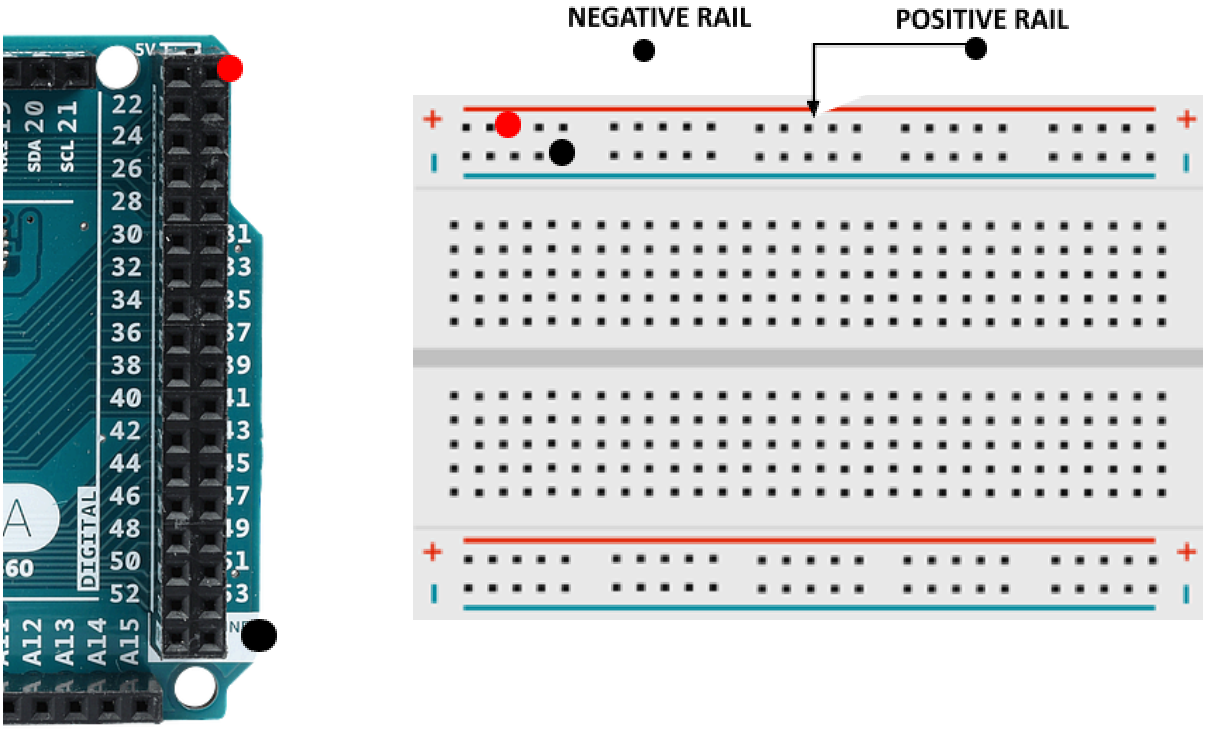


Figure 2 . 17: Breadboard

The connection between the Arduino and the breadboard starts with the following:



The Arduino is connected to the breadboard from 5v and GND then the sensors are connected were each sensor had a VCC and GND connectors that goes along the positive or negative rail in the breadboard. Its not important where the sensor is connected among the Same rail as its all connected as shown in the following figure:

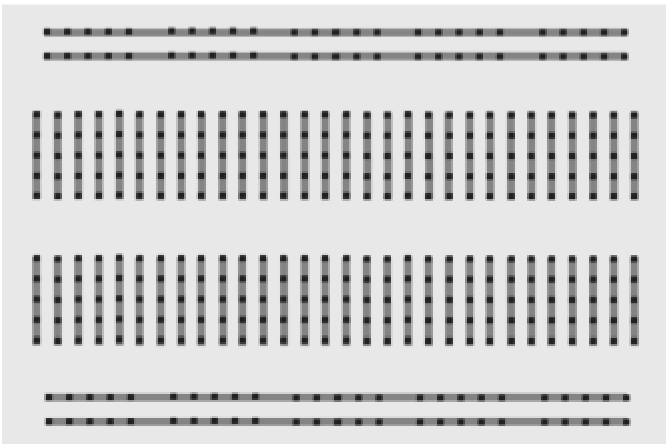


Figure 2 . 18: Breadbord Transparent View

The previous (Fig.2.17) shows the connected lines each line in gray is all connected meaning that if a positive were put in a point all points connected to it are positive too.

The sensors are connected according to the following Tables:

Table 2. 5 Arduino connection wires color

SENSORS	SCK	CS	SO	GND	VCC
1	Green	Blue	Magenta	Black	White
2	Gray	Orange	Yellow	Brown	Red
3	Orange to green	Red to blue	brown to Magenta	brown	Red
4	Green	Blue	Magenta	Black	White
5	Orange to blue	Red to magenta	brown to gray	black	white
6	Green	blue	Magenta	black	white
7	Green	blue	Magenta	black	white
8	brown	red	orange	brown	red
9	Green	Blue	Magenta	black	white

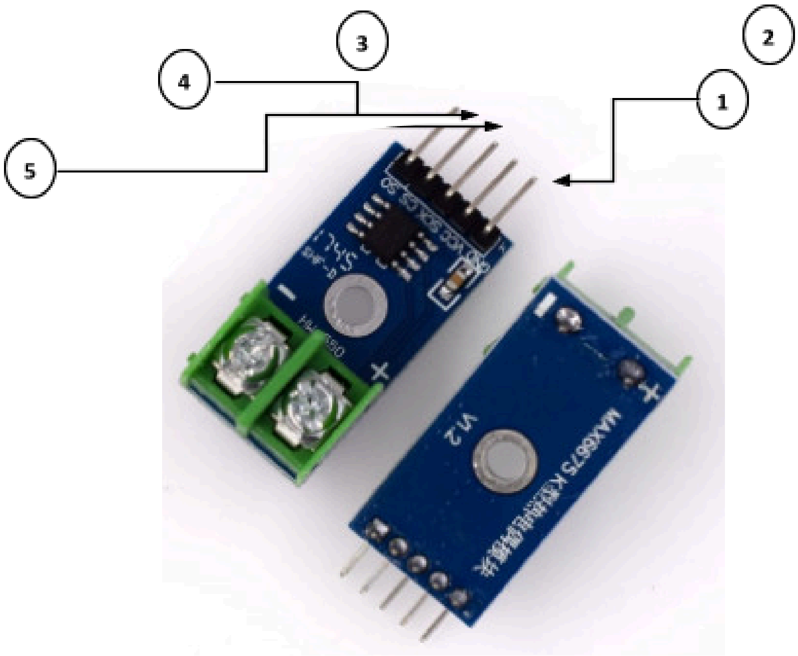
Table 2. 6 Arduino connection numbers

<table>
<tr><th>SENSORS</th><th>SCK</th><th>CS</th><th>SO</th><th>GND</th><th>VCC</th></tr>
<tr><td>1</td><td>6</td><td>5</td><td>4</td><td colspan="2" rowspan="9">BreadBoard</td></tr>
<tr><td>2</td><td>9</td><td>8</td><td>7</td></tr>
<tr><td>3</td><td>13</td><td>11</td><td>10</td></tr>
<tr><td>4</td><td>16</td><td>15</td><td>14</td></tr>
<tr><td>5</td><td>19</td><td>18</td><td>17</td></tr>
<tr><td>6</td><td>22</td><td>21</td><td>20</td></tr>
<tr><td>7</td><td>28</td><td>26</td><td>24</td></tr>
<tr><td>8</td><td>34</td><td>32</td><td>30</td></tr>
<tr><td>9</td><td>40</td><td>38</td><td>36</td></tr>
</table>

The previous Tables shows our Arduino connections Taking into example the Sensor 1:

From **(table 2.5)** SCK wiring is all green till connected to Arduino and it's connected in Arduino at pin number 6 from **(table 2.6)**

To get better understanding the following figure shows the senser SCK, CS, SO, GND and VCC:



NUMBER	NAM
1	GN
2	VC
3	SC
4	CS
5	SO

Figure 2 . 19: Temperature sensor

GND and VCC of each sensor is connected to the breadbord on the power rails and the SCK, CS and SO are connected to arduino according to givin data represented in (Table 5) by wires their colours are represented in (Table 6).

Chapter three

3. EXPERIMENTAL SETUP AND RESULTS

3.1 Project Overview

This device uses solar energy technology to heat the air, and it works by absorbing (evacuated tube) solar energy and transferring that energy to the air to raise its temperature, and since the evacuated tube is absorber coated, this work is done with an emissivity nears to one.

Figure 3. 1 Fully Assembled Device

3.2 Components and Dimensions

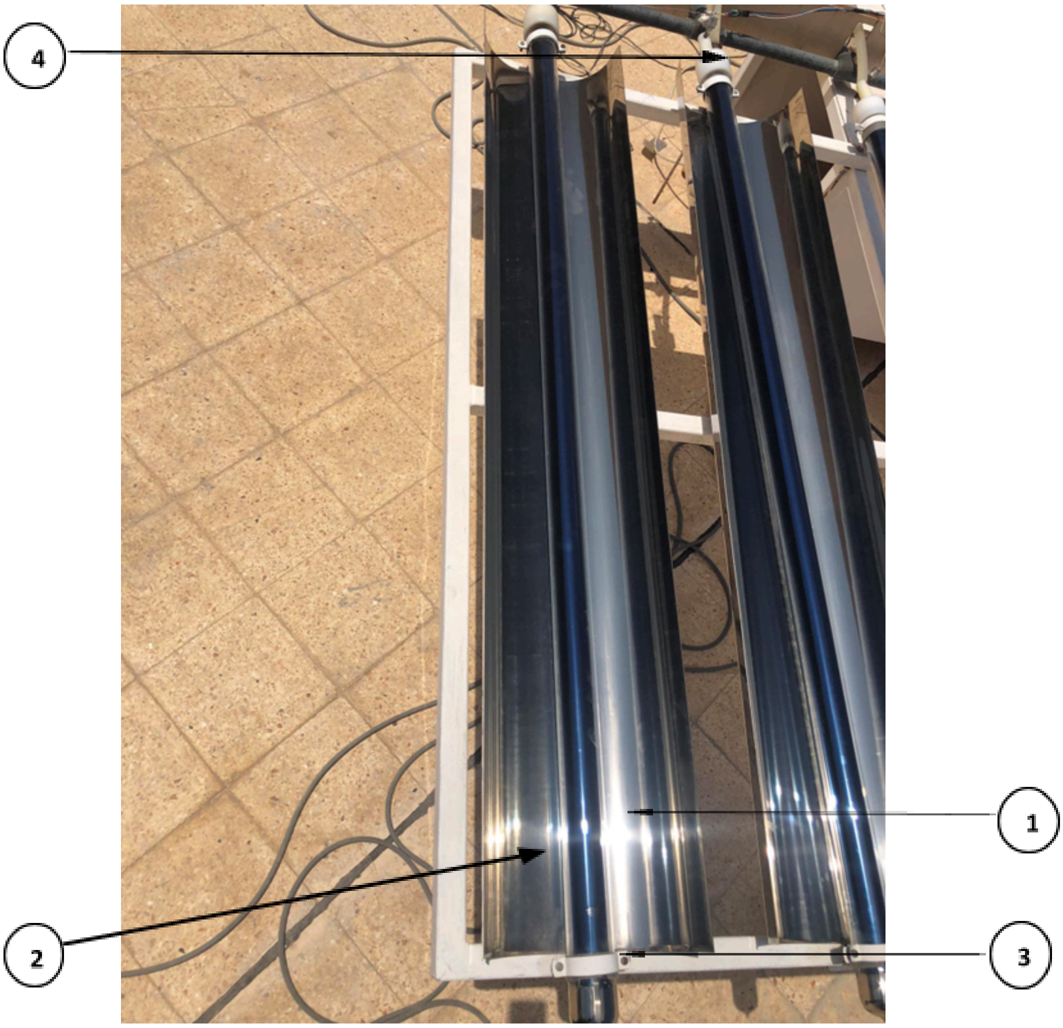


Figure 3. 2 Main components

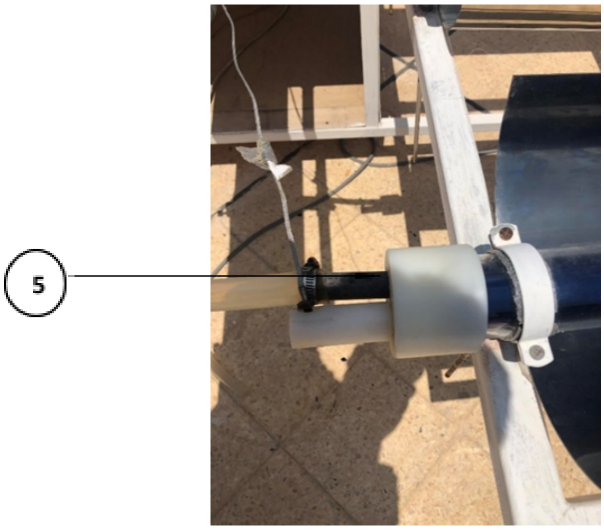


Figure 3. 3 Evacuated Tubes Assembly

Figure 3. 4 flow meter

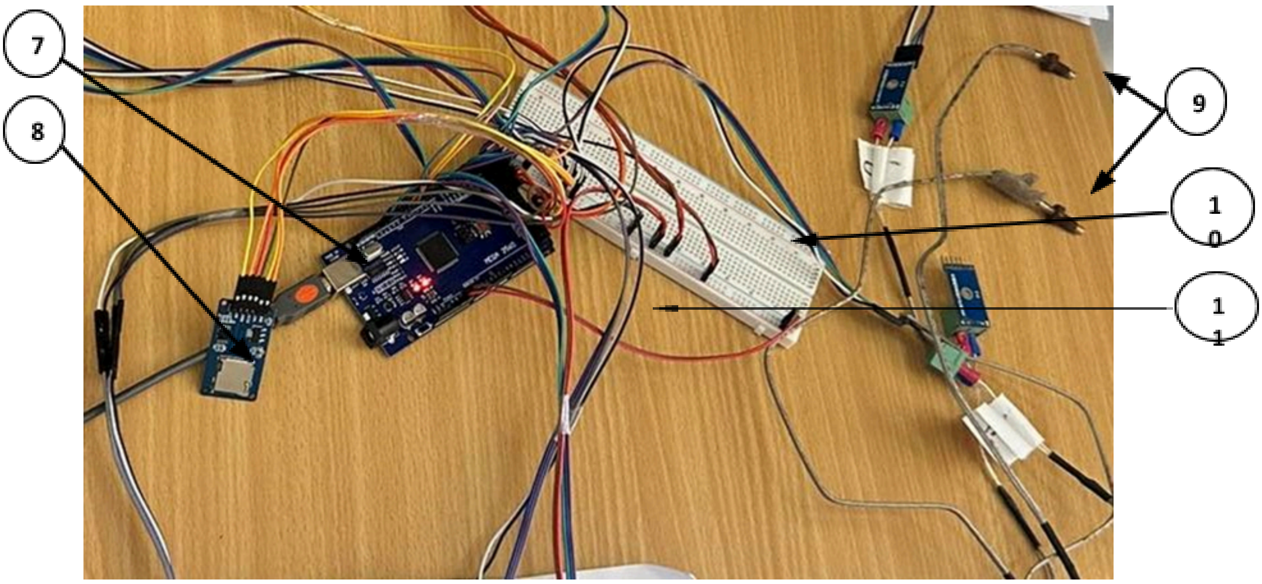


Figure 3. 5 Arduino Components

Figure 3. 6 Blower

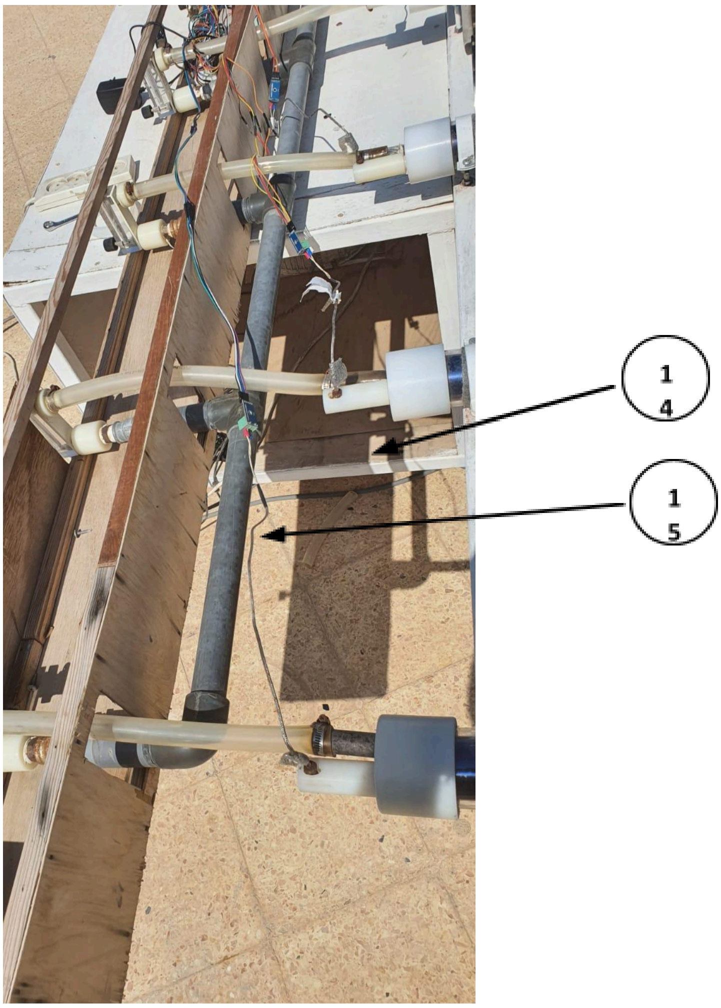


Figure 3. 7 Structure

3.2.1 Components

1- Evacuated Tubes

2- Collectors

3- U-Clamps

4- Teflon Thermoplastic

5- copper pipe

6- Air flow meter

7- Arduino mega 2560

8- SD card module

9- Thermocouple Sensor

10- breadboard

11- jumper wires

12- 1.5” Hose

13- Air Blower

14-table steel structure

15- Header

3.2.2 Component Description

3.2.2.1 Evacuated Tubes

They make use of a glass tube to surround the absorber with high vacuum and effectively resist atmospheric pressure. The vacuum that surrounds the absorber greatly reduces convection and conduction heat loss, therefore achieving greater energy conversion efficiency. Heat transfer air can flow in and out of each tube or being in contact with a heat pipe reaching inside the tube.

- Dimension: Outer diameter 5.8 cm , Inner diameter 4.2 cm and Length 180 cm
- Coating: SS-ALNx/Cu
- Glass: Borosilicate glass 3.3
- Vacuum Degree: P<= 5.0*10^(-3) (Pa)

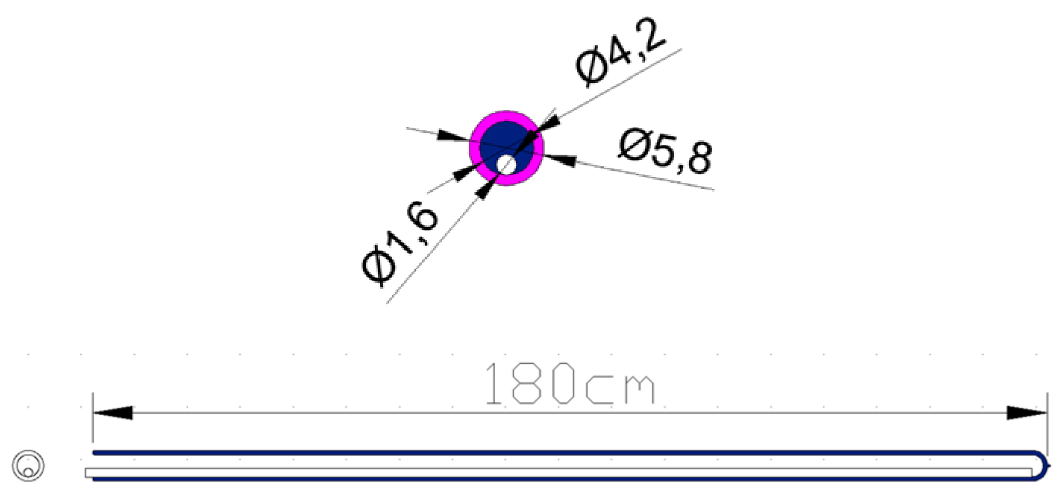


Figure 3. 8 Evacuated Tube dimensions

3.2.2.2 Collectors

It is a parabolic polished chrome sheet used as sun ray's reflector.

- Dimensions: As illustrated in (figure.3.9)

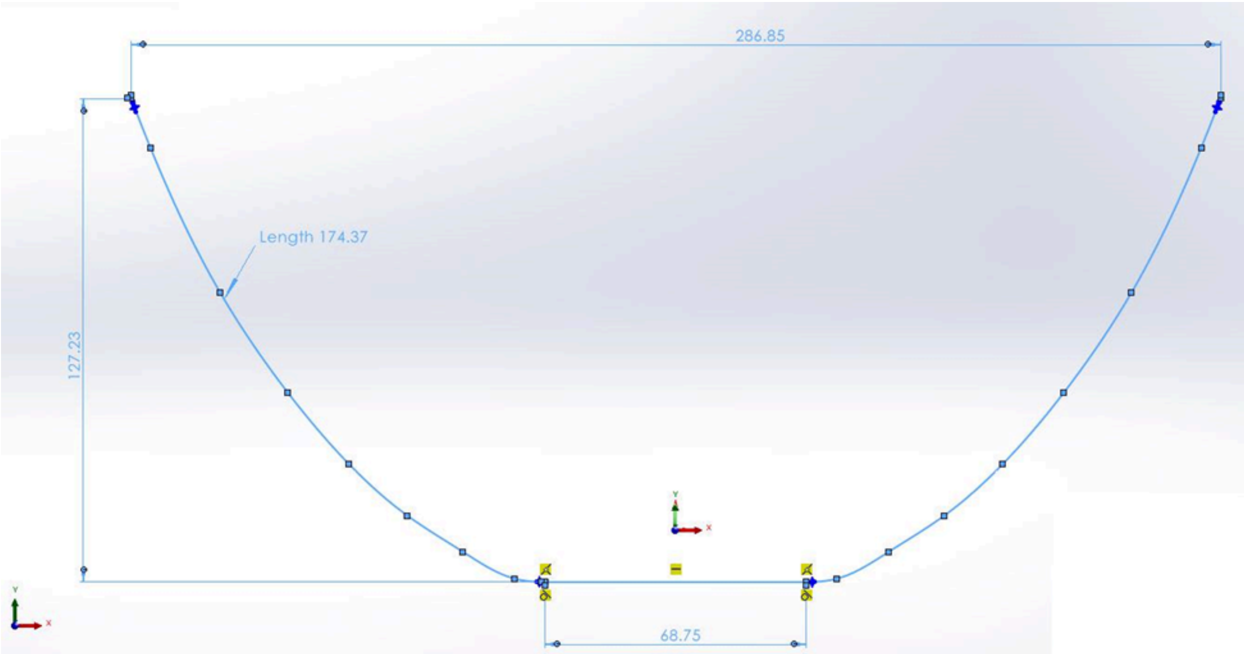


Figure 3. 9 Parabolic concentrator Dimensions

Figure 3. 10 Parabolic concentrator Real life shape

3.2.2.3 U-Clamps

It is a circular flat piece metal made of two pieces which are attached to each other using screws.

- Dimensions: Diameter 110 mm

3.2.2.4 Teflon Thermoplastic

It is used for the input and output air of the evacuated tube; it consists of two pieces A & B. Piece A fits over the beginning of the evacuated tube and is fitted with two rubber O-rings. Also, it has 2 holes, one is used to fixate the copper tube which the air enters through into the evacuated tube, and the second hole is used to fixate the Teflon piece B on the piece A. The piece B has 2 functions, it is responsible for the output of the hot air exiting the evacuated tube, and it is used to fixate the thermocouple sensor in the path of the hot air to measure its temperature.

- Scientific name: Polytetrafluoroethylene
- Operating temperature: -260 to 260 degrees Celsius

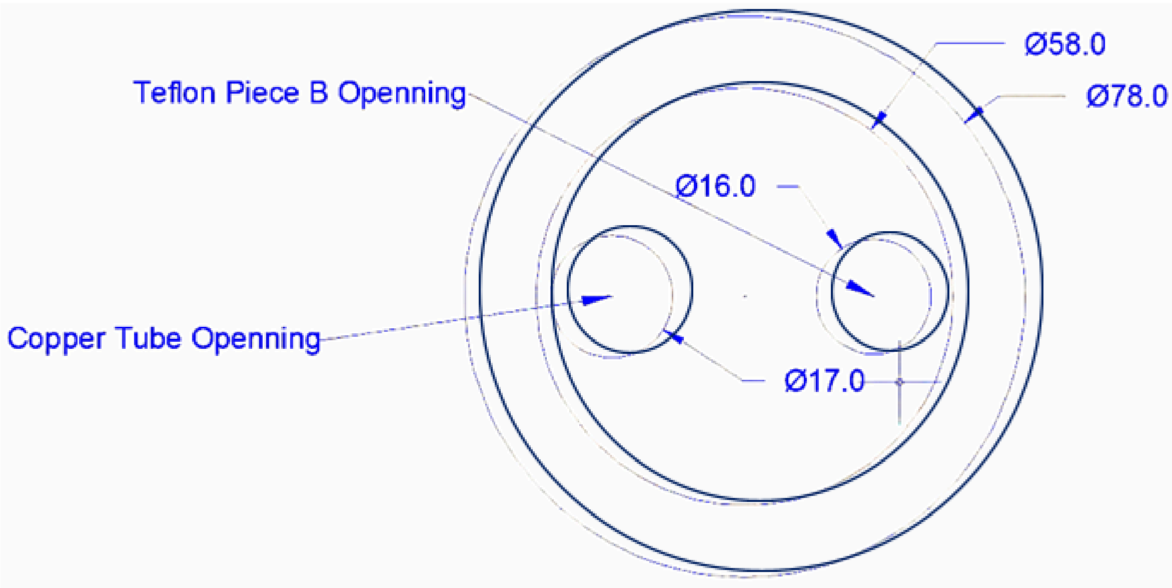


Figure 3. 11 Teflon thermoplastic elevation view

3.2.2.5 copper pipe

It used to increase the outlet air temperature as it is used as a path for inlet air.

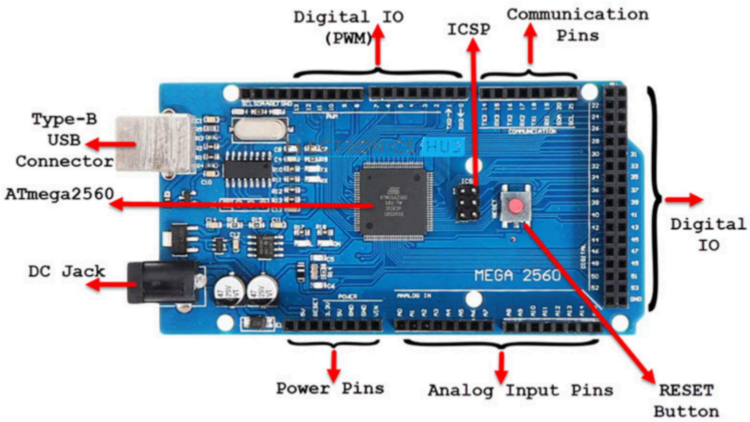
- Length: 180 cm
- Diameter:16mm

3.2.2.6 Air flow meter

100 LPM Panel air flow meter gas flowmeter with adjustable valve air rotameter.

3.2.2.7 Arduino mega 2560

The Arduino mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.



3.2.2.8 SD card module

The micro- SD Card Module is a simple solution for transferring data to and from a standard SD card. The pin out is directly compatible with Arduino but can also be used with other microcontrollers. It allows you to add mass storage and data logging to your project.

This module has SPI interface which is compatible with any SD card and it uses 5V or 3.3V power supply which is compatible with Arduino UNO/Mega.

SD module has various applications such as data logger, audio, video, graphics. This module will greatly expand the capability an Arduino can do with their poor limited memory.

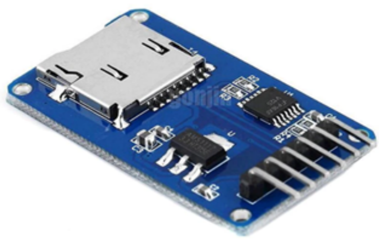


Figure 3. 12 SD card module

3.2.2.9 Thermocouple Sensor

A thermocouple is an electrical device consisting of two dissimilar electrical conductors forming an electrical junction. A thermocouple produces a temperature-dependent voltage because of Seebeck effect, and this voltage can be interpreted to measure temperature. It is connected with Arduino to collect the temperature data.

- Operating range: -200 to 1260 degrees Celsius

For better understanding: Seebeck effect, it describes the phenomenon where a temperature difference between two dissimilar materials or junctions generates an electric potential difference (voltage).

3.2.2.10 breadboard

It supports the thermocouple by -ve ground and +ve vcc.

3.2.2.11 jumper wires

It used to connect all thermocouple sensor to Arduino.

- Quantity: 170 male -female to attached thermocouple to Arduino and breadboard & 2 male – male to attached breadboard to Arduino

3.2.2.12 Table steel structure

It is the body of the device on which all components are installed. It consists of two frames, the first is 360 x 180 cm, and it is used to install the evacuated tube by means of u cups. The second frame is the actual body, and it has dimensions of 250 x 160 x 60 cm. The device is supported by wheel to make it easy to move and it is also supported by a blower seat with dimensions of 40 x 40 cm and they are installed together using the through bolt and nut.

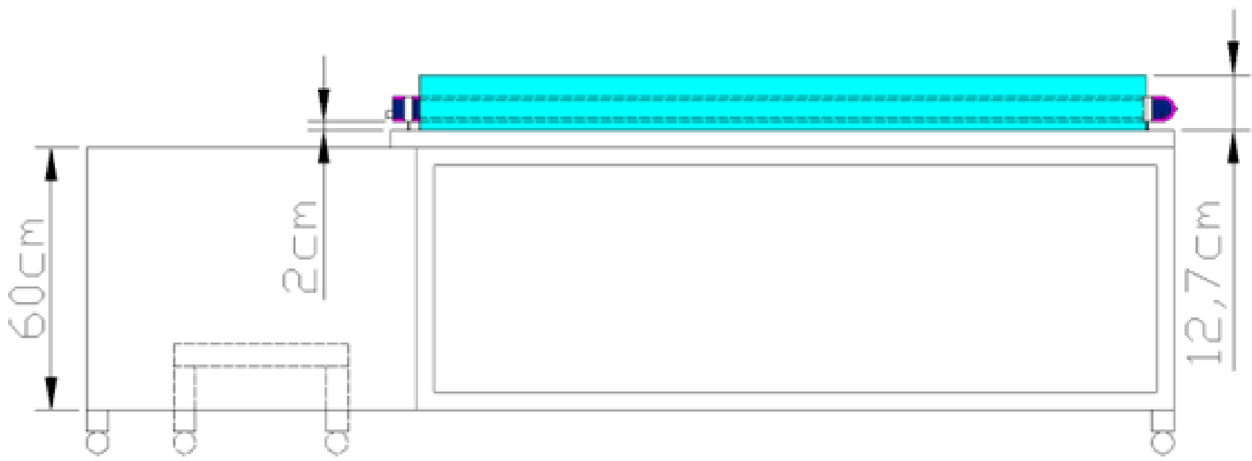


Figure 3. 13 Table elevation view

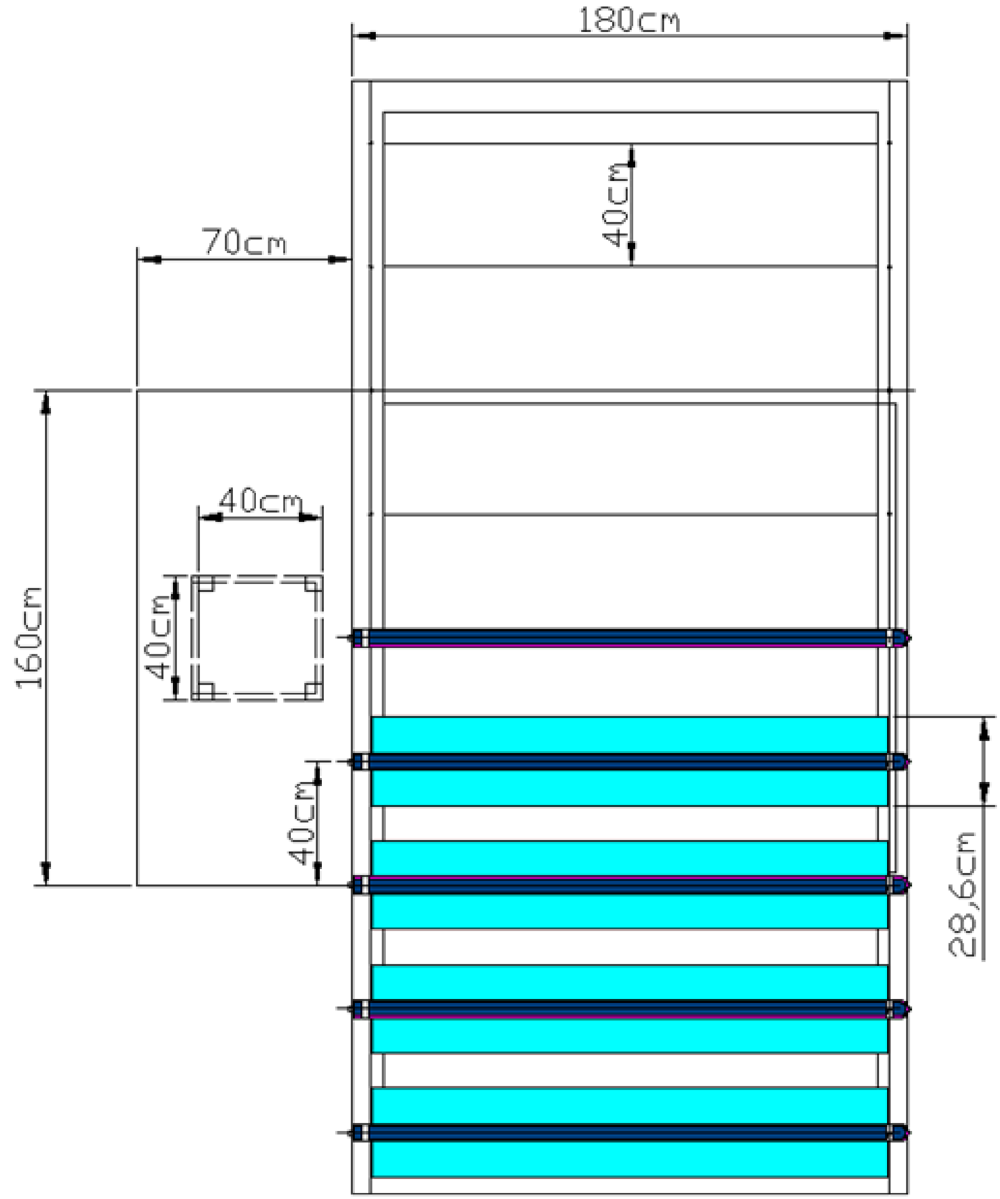
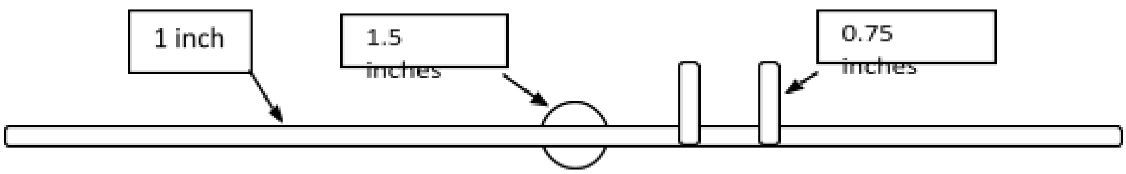


Figure 3. 14 Table Plan view

3.2.2.12 Header

The air distribution system facilitates the transfer of air from the blower outlet, which has a diameter of 1.5 inches, to the main header pathway, which has a diameter of 1 inch. Subsequently, the airflow is further channeled through a reduction section to the air flow meter, which has a diameter of 0.75 inches.



3.3 Experiments and results

3.3.1 Constant Flow Experiment

Time

The experiment conducted at Saturday 1st of July 2023 from 8:00 am to 5:00 pm

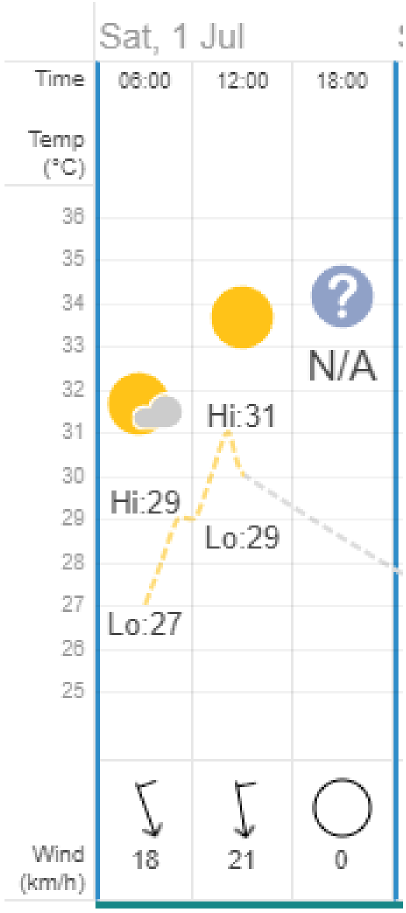


Figure 3. 15 Weather conditions at saturday first of july

Experiment steps

The blower is opened then accurately setting all flow meters to a uniform flow rate of 40 liters per minute (lpm) and ensuring the precise positioning of each thermocouple in their designated locations.

Results

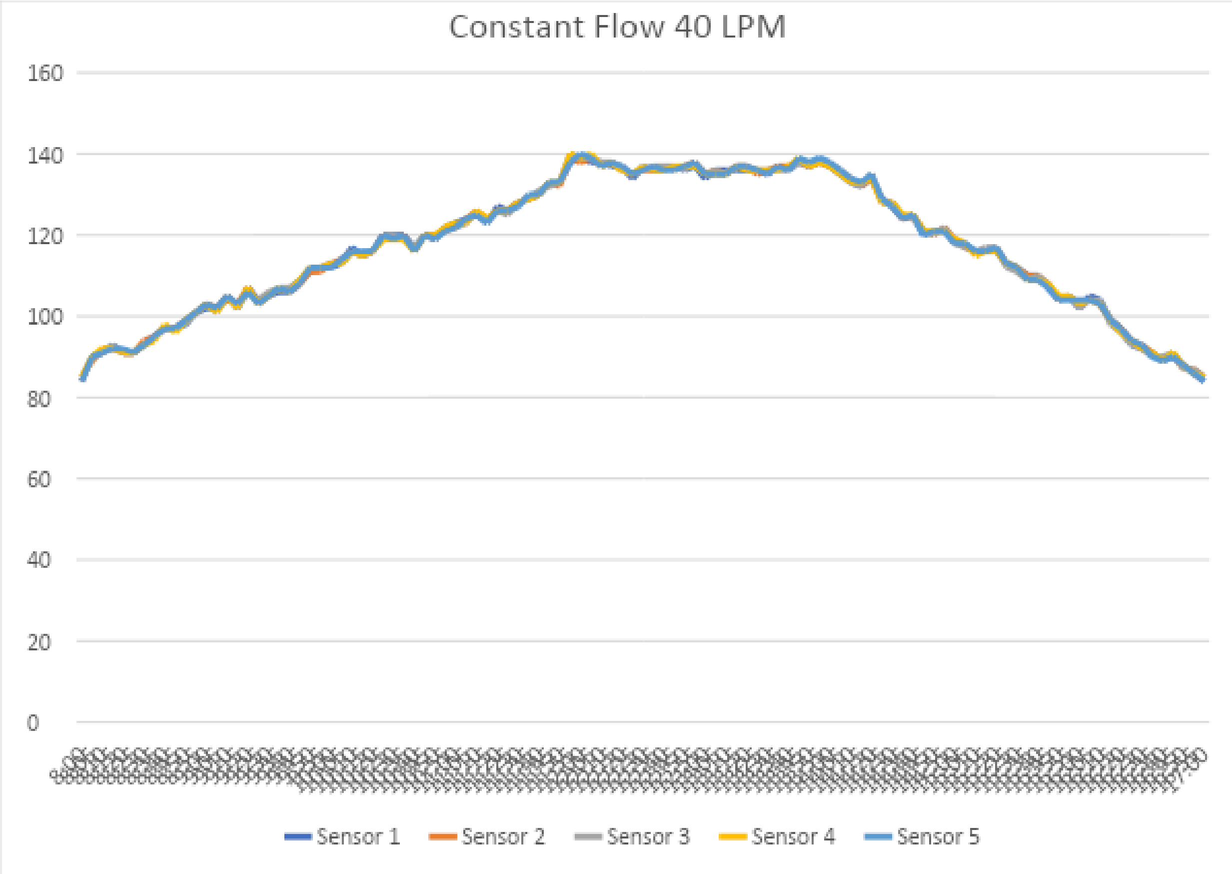


Figure 3. 16 Relation between temperature, time and flow

Explanation

According to

$$(t2 \; - \; t1) = \frac{Q}{m^{\circ} \, cp} \qquad [3.1]$$

$$m^{\circ} \; = \; \rho \, V^{\circ} \qquad [3.2]$$

the relationship between the volume flow rate and the mass flow rate is a direct relationship ($m^{\circ} \; \propto \; volume \; flow \; rate$) & ($(t2 \; - \; t1) \propto \frac{1}{m^{\circ}}$) Due to the constant volume flow rate, we find that all sensors read the same readings in the same certain hour in day from 8:00am to 5:00pm , $(t2 \; - \; t1) \propto Q$ we find that they peaked after 12:00.

- Maximum temperature reached for 40 LPM flow is 140 °C at 13:55

3.3.2 Constant Flow Experiment with Concentrators equipped

Time

The experiment conducted at Wednesday 5 of July 2023 from 8:00 am to 5:00 pm

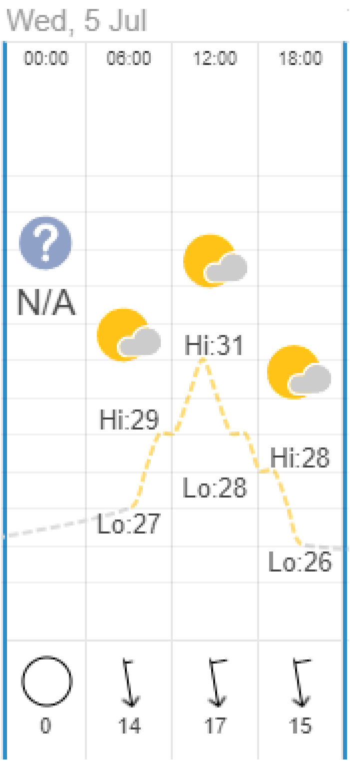


Figure 3. 17 weather conditions at wednesday 5 of july

Experiment steps

The blower is opened then accurately setting all flow meters to a uniform flow rate of 40 liters per minute (lpm) and ensuring the precise positioning of each thermocouple in their designated locations and the positioning of the parabolic concentrators under the evacuated tubes.

Results

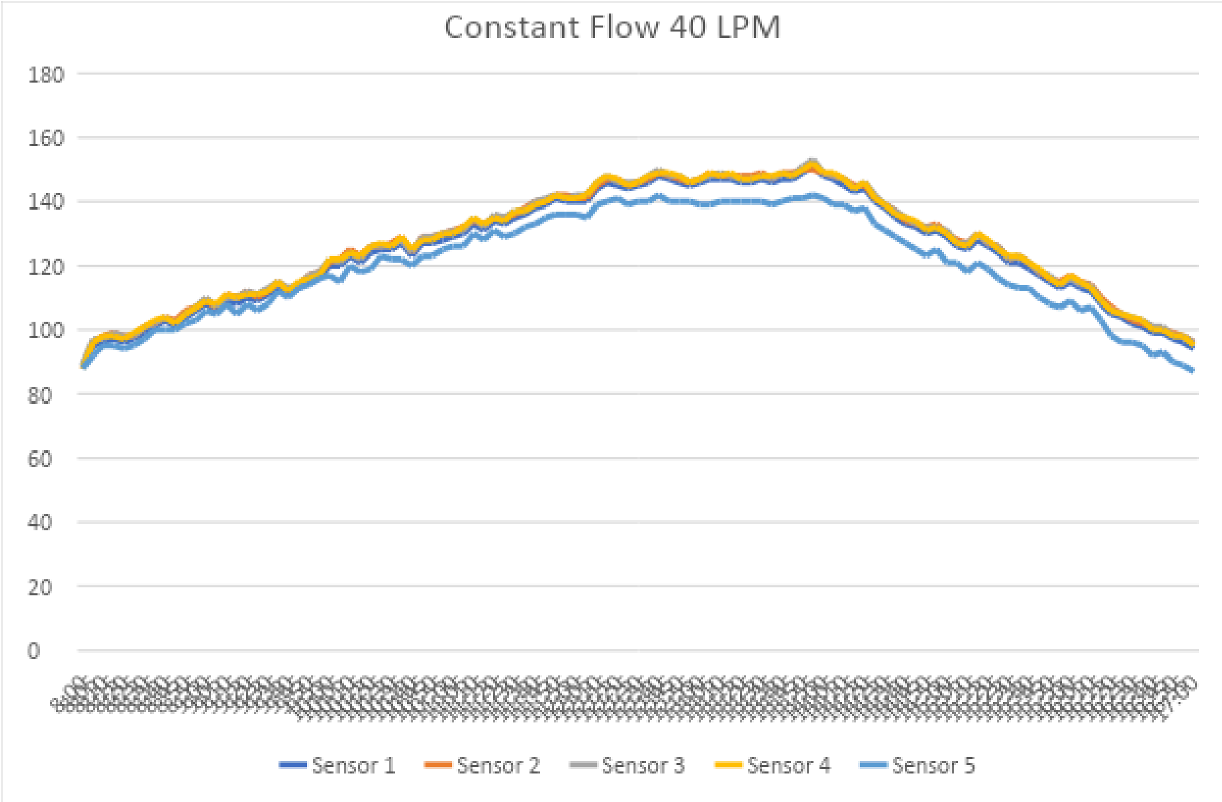


Figure 3. 18 Relation between temperature, time and flow

Explanation

According to equations [3.1] and [3.2], the relationship between the volume flow rate and the mass flow rate is a direct relationship ($m^{\circ} \propto volume\ flow\ rate$) & ($(t2 - t1) \propto \frac{1}{m^{\circ}}$) Due to the constant volume flow rate, we find that all sensors read the same readings in the same certain hour in day from 8:00am to 5:00pm, $(t2 - t1) \propto Q$ due to adding parabolic concentrators under the evacuated tubes. Which increase Q .we find that they peaked after 12:00. we find that the peak temperature of evacuated with parabolic concentrators is greater than without the peak temperature of evacuated without parabolic concentrators.

- Maximum temperature reached for 40 LPM flow is 142 °C at 13:55
- Maximum temperature reached for 40 LPM flow with mirrors is 153 °C at 13:55

The percentage increase was:

$$\frac{153-142}{142}(100) = 7.7\ \%$$

3.3.3 Variable Flow experiment

Time

The experiment conducted at Sunday 2 of July 2023 from 8:00 am to 5:00 pm

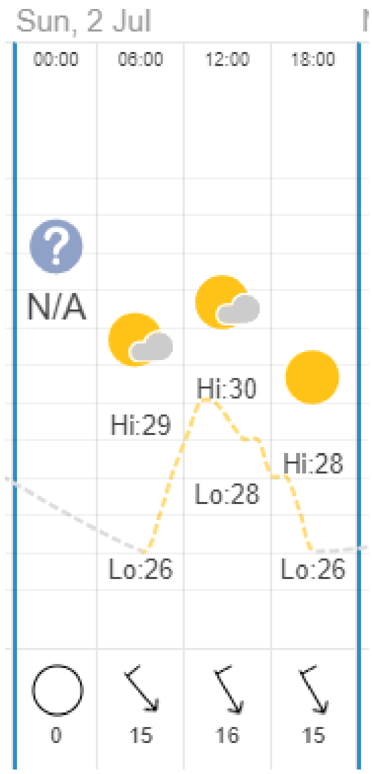


Figure 3. 19 Weather conditions at 2 of july

Experiment steps

The blower is opened then accurately setting Flow meters at 10 LPM, 25 LPM, 40 LPM and 55 LPM at sensors 1,2,3,4 respectively.

Results

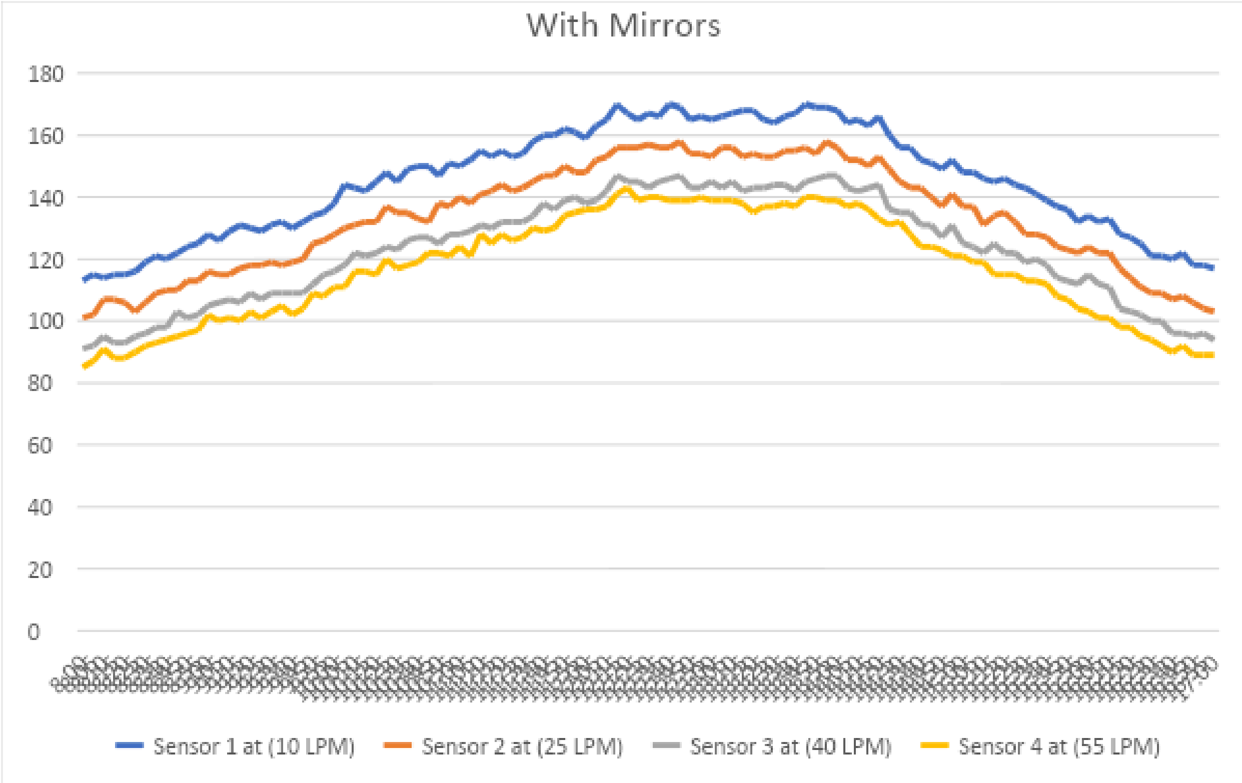


Figure 3. 20 Relation between temperature, time and flow

Explanation:

- Maximum temperature reached for flow 10 LPM is 170 °C at 12:15pm
- Maximum temperature reached for flow 25 LPM is 158 °C at 12:45pm
- Maximum temperature reached for flow 40 LPM is 147 °C at 12:15 and 12:45pm
- Maximum temperature reached for flow 55 LPM is 143 °C at 12:20pm

According to equations [3.1] and [3.2], the relationship between the volume flow rate and the mass flow rate is a direct relationship ($m^{\circ} \propto volume\ flow\ rate$) and ($(t2 \ - \ t1) \propto \frac{1}{m^{\circ}}$), due to volume flow rate variation, we find that the sensor has less flow rate read the maximum temperature and that the sensor has larger flow rate read the minimum temperature hour in day from 8:00 am to 5:00 pm. $(t2 \ - \ t1) \propto Q$ we find that they peaked after 12:00 pm.

3.3.4 Centric Gaskets

Time

The experiment conducted at Thursday 6 of July 2023 from 8:00 am to 5:00 pm

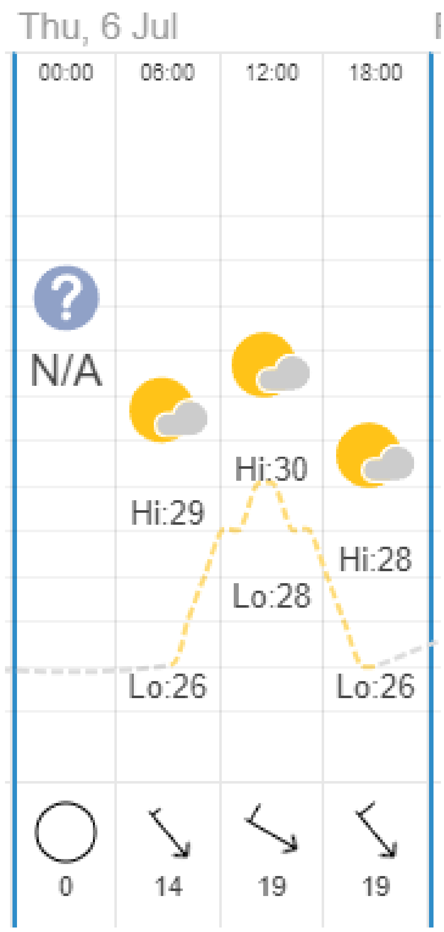


Figure 3. 21 Weather conditions at 6 of july

Experiment steps

The blower is opened then accurately setting Flow meters at 40 LPM and adding gaskets to the copper Tube where on the first copper tube 1 gasket added on the second 2 gaskets, on the third 3 gaskets and the last one 4 gaskets leaving the fifth tube with no gaskets.

Experiment images

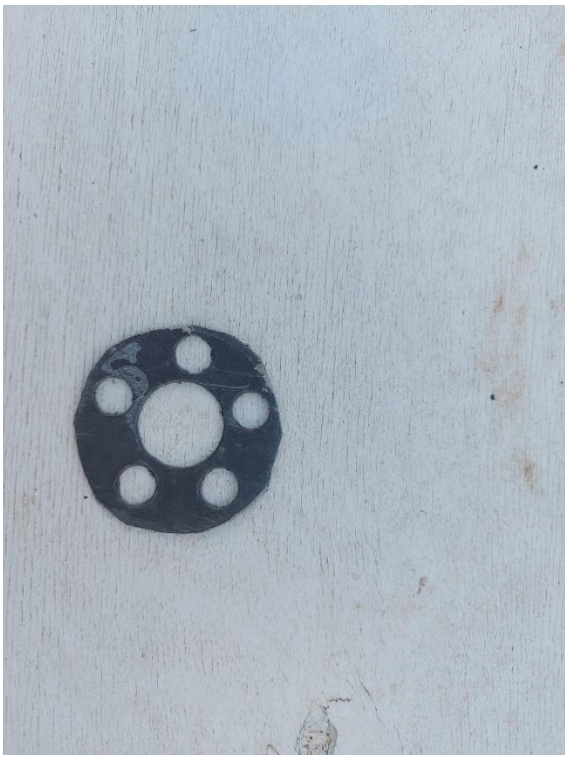


Figure 3. 22 Centric Gaskets

Figure 3. 23 Gaskets along the copper tube

Figure 3. 24 Gaskets along copper tube

Results

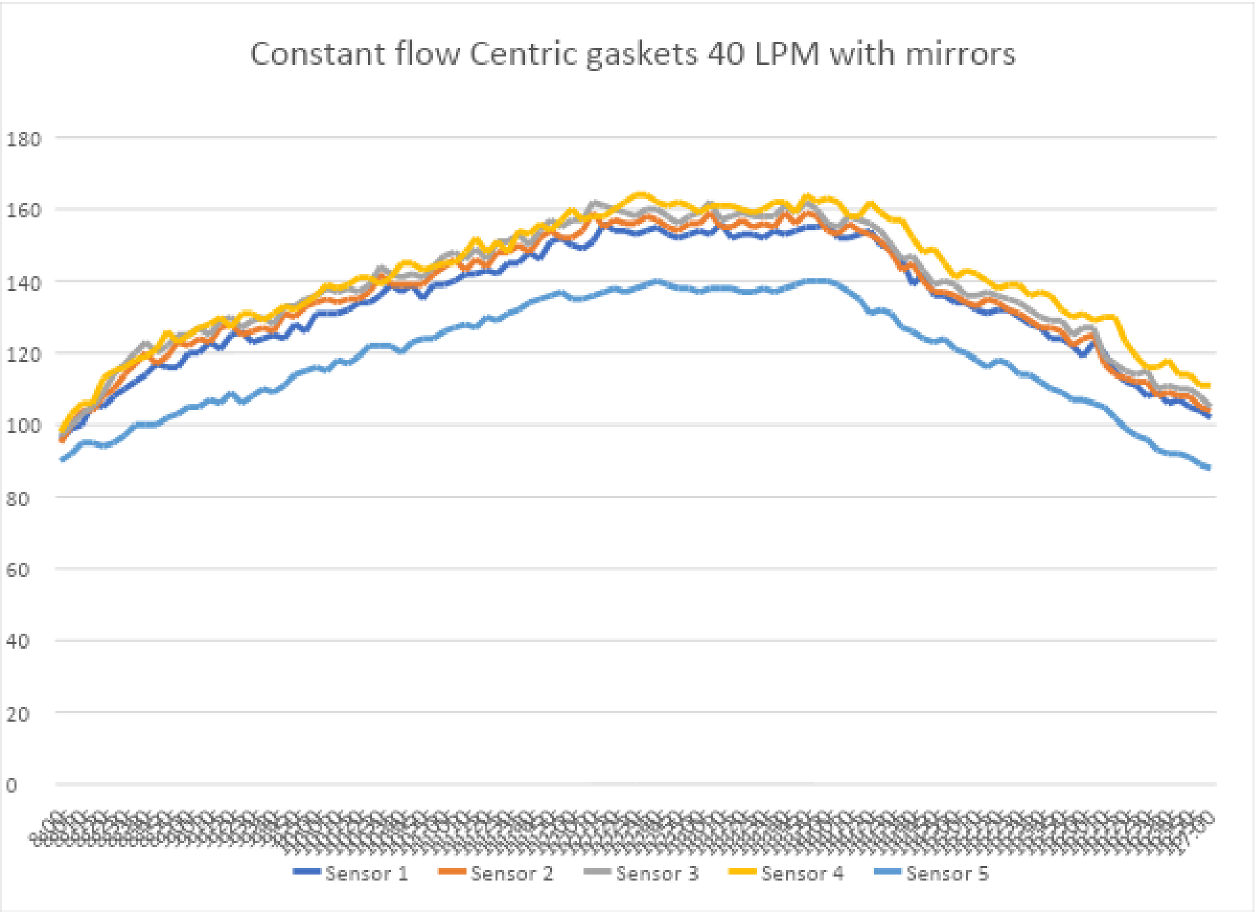


Figure 3. 25 Relation between temperature, time and flow

Explanation

- Maximum temperature reached for flow 40 LPM is 164 °C at 12:30 (Sensor 4)
  4 Gaskets

The introduction of an increased number of gaskets within the evacuated tube system results in a transition towards a more turbulent flow regime. This transition is accompanied by a significant rise in temperature as the flow traverses through smaller circular areas, wherein a reduced flow area is subjected to the intense solar radiation. The resulting turbulence induces an enhancement in convective heat transfer, leading to an overall temperature increase within the system.

3.3.5 Eccentric Gaskets

Time

The experiment conducted at Friday 7 of July 2023 from 8:00 am to 5:00 pm

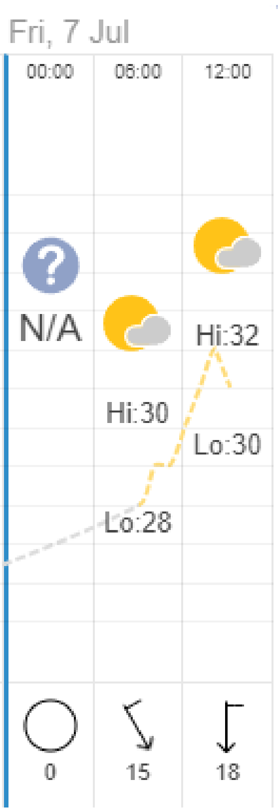


Figure 3. 26 Weather conditions in 7 of july

Experiment steps

The blower is opened then accurately setting Flow meters at 40 LPM and adding gaskets to the copper Tube where on the first copper tube 1 gasket added on the second 2 gaskets, on the third 3 gaskets and the last one 4 gaskets leaving the fifth tube with no gaskets.

Experiment Images

Figure 3. 27 Eccentric gaskets

s

Figure 3. 28 Eccentric gaskets

Figure 3. 29 Eccentric gaskets

Results

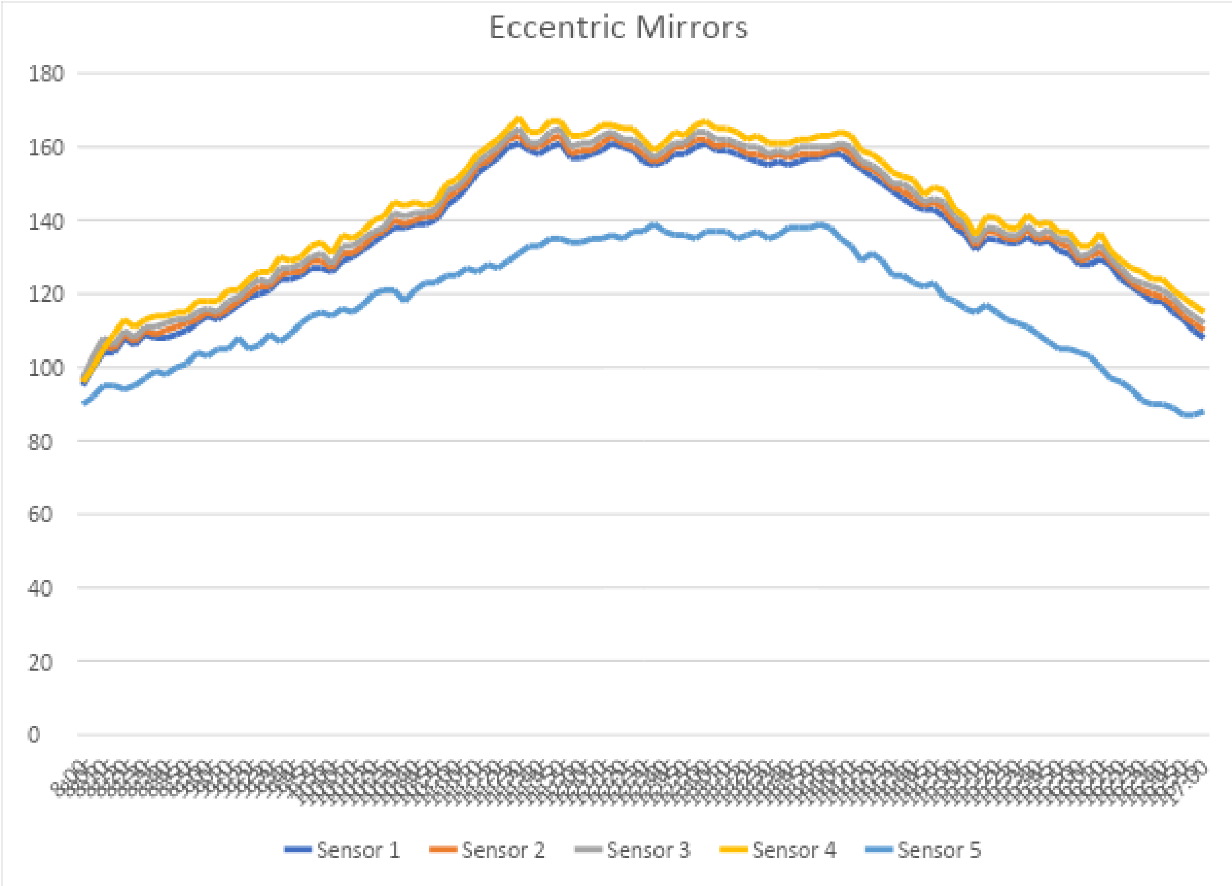


Figure 3. 30 Relation between temperature, time and flow

Explanation

- Maximum temperature reached for flow 40 LPM is 168 °C at 11:30 (Sensor 4) 4 Gaskets.

The introduction of an increased number of gaskets within the evacuated tube system results in a transition towards a more turbulent flow regime. This transition is accompanied by a significant rise in temperature as the flow traverses through smaller circular areas, wherein a reduced flow area is subjected to the intense solar radiation. The resulting turbulence induces an enhancement in convective heat transfer, leading to an overall temperature increase within the system. Also, important to notice the slight increase in maximum temperature in eccentric state compared to centric.

Black blanket

Also, important to notice the decrease in temperature from 15:05 to 15:10 due to a side experiment held were a black blanket passed over the Tubes for 5 minutes simulating a black cloud in a winter weather The decrease in temperature in this 5 minute was noticed to be 7°C

3.3.6 Rings and Helical spring (2mm)

Time

The experiment conducted at Sunday 9 of July 2023 from 1:00 am to 4:00 pm

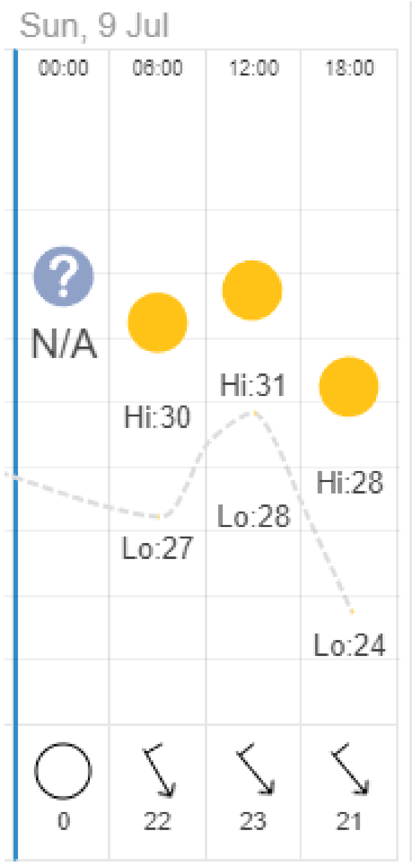


Figure 3. 31Weather conditions at sunday 9 of july

Experiment steps

The blower is opened then accurately setting Flow meters at 40 LPM and adding Rings to copper tube on sensor 2 and Spring on sensor 3 Leaving sensor 1 and 4 with no additions and sensor 5 with no collectors beneath.

Experiment Images

Figure 3. 32 Rings

Figure 3. 33 Rings on copper tube

Figure 2 . 20 Springs 2mm

Results

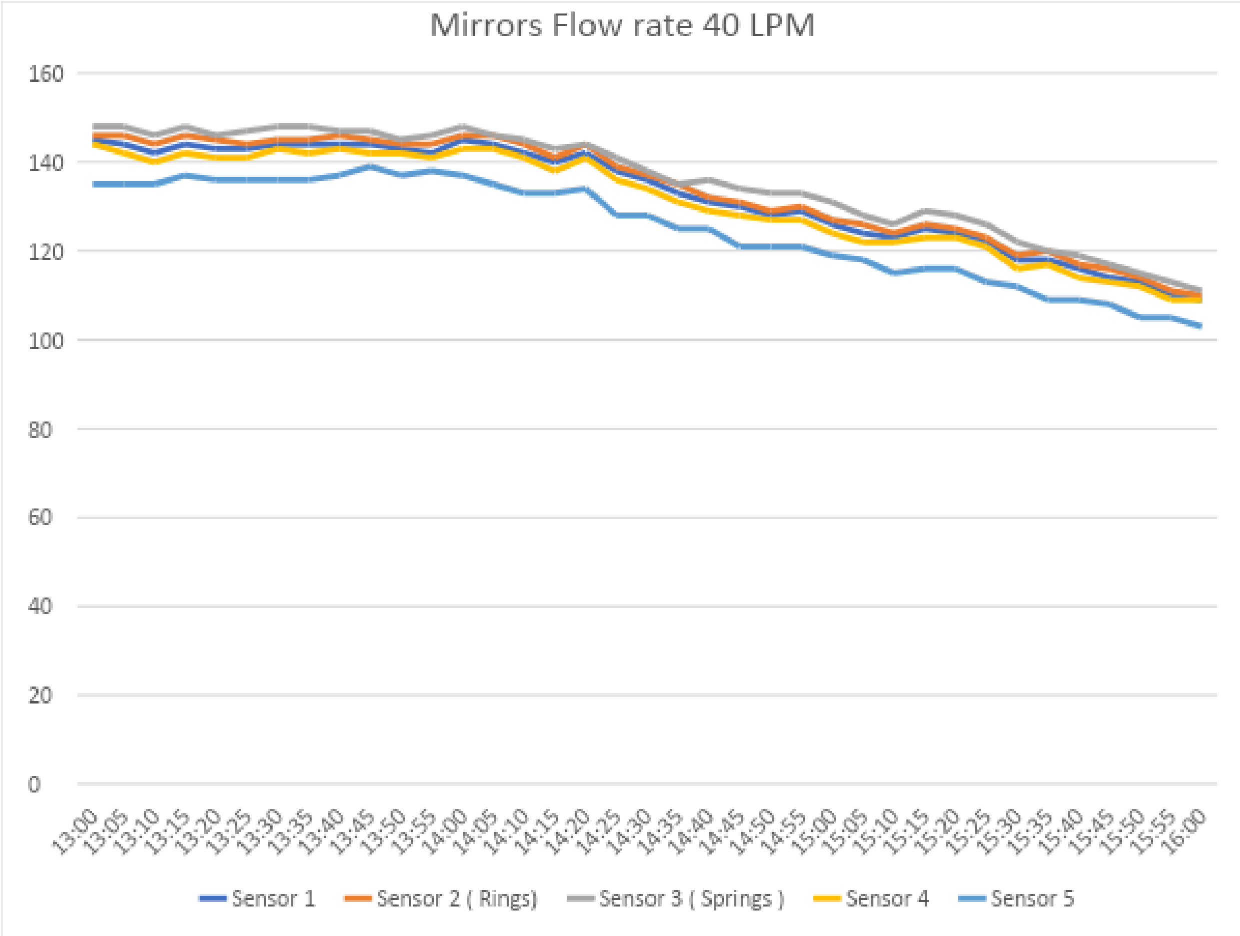


Figure 3. 34 Relation between temperature, time and flow

Explanation

- Maximum temperature reached for flow 40 LPM is 146 °C at 13:00 For rings
- Maximum temperature reached for flow 40 LPM is 148 °C at 13:00 For Springs

The presence of rings and springs of 2 mm diameter at a pitch of 5cm along the whole length of the evacuated tube which is 180cm Induces Turbulency inside the tube which results in increase of temperature.

Chapter Four

4. CONCLUSION

4.1 conclusion

The solar air heater represents a straightforward apparatus designed to use solar energy for the purpose of generating hot air, making it a viable renewable energy technology for space heating. Such systems offer the advantage of producing heat without any associated costs, with minimal maintenance requirements limited to occasional cleaning of the collectors and concentrators.

The system primarily comprises evacuated tubes, serving as the main component responsible for heat absorption. To facilitate the movement of air through the system, an air blower is employed. An air distribution assembly, constructed using PVC pipes of varying sizes (1.5", 1", and 0.75"), is utilized to convey air to each evacuated tube. In order to regulate and monitor the air flow directed to each tube, air flow meters are integrated into the air distribution assembly. These flow meters are positioned at the terminations of the air distributor to accurately measure the air flow rate supplied to each evacuated tube, thereby ensuring the appropriate amount of air is delivered and to control the amount of air flow.

Temperature measurements within the system are conducted using type-K thermocouples positioned at the inlet and outlet ports. The measurement system is integrated with an Arduino Mega 2560 and a breadboard, allowing for data collection and control. It is noteworthy that the evacuated tubes in the system are maintained at a zero-degree inclination.

The conclusion of the conducted experiments held was

Constant flow experiment: The passing time of day results in temperature increase considering various factors the most important of them is solar irradiance that leads to temperature increase in the flow.

Constant flow with concentrators: the temperature of the air outlet from the evacuated tubes integrated with parabolic concentrators are higher than the normal tubes.

Different flow experiment: This experiment shows that the flow rate in the evacuated tube is inverse with temperature as the flow rate increase the temperature decrease because the presence time in the tube decrease and the flow velocity decreases the heat gained from the evacuated tube.

Centric gaskets experiment: The centric gaskets added made a turbulent flow which resulted in increased temperature also important to note that the number of gaskets increment results in increase in turbulency.

Eccentric gaskets experiment: The eccentric gaskets added made a turbulent flow which resulted in increased temperature also important to note that the number of gaskets increment results in increase in turbulency.

Rings and Helical spring: The added springs and helical resulted in increase in surface area and some turbulency that showed its effect on the slight increase in temperature compared to

normal evacuated tubes not equipped, also important to note that increasing the diameter from 2mm to 4mm or 6mm will result in more turbulency and more surface area so the temperature in those case may be even higher.

4.2 Recommendation and Development

- **Tilt angle:** Adjusting the evacuated tubes at an inclination angle (Tilt angle) higher than zero in order to
  achieve a zero angle of incidence. the angle of incidence is the angle a ray of sun makes
  with a line perpendicular to a surface.
- **Heat storage tank:** As the lack of solar energy in night a storage tank would be a a great solution for hot air lack at night.

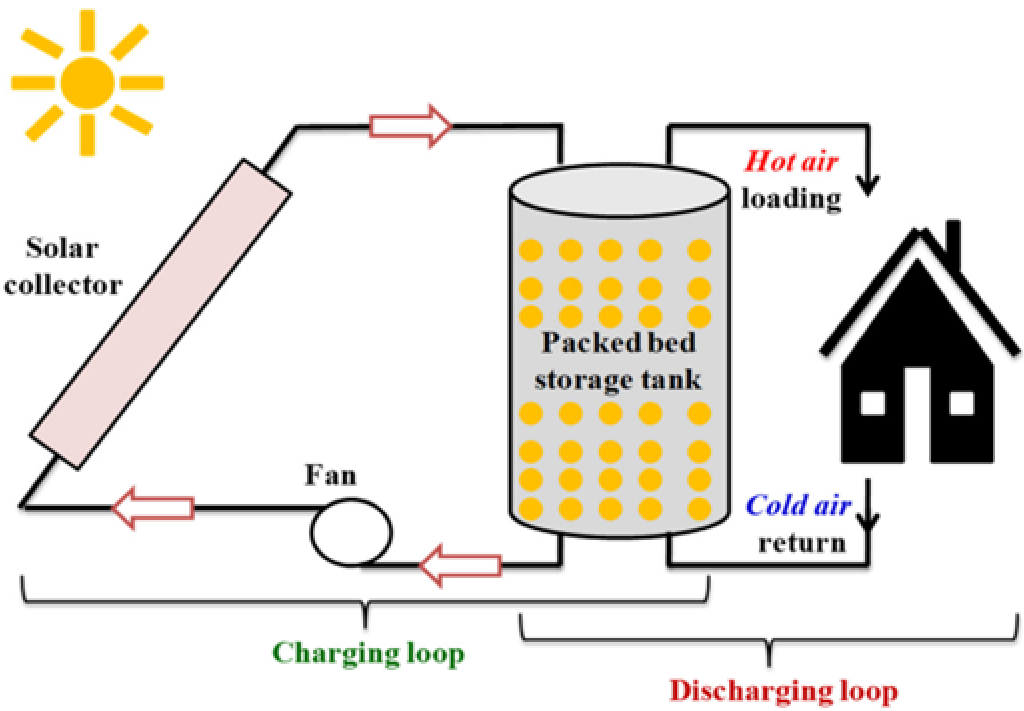


Figure 4. 1 Heat storage Tank

- Conducting the experiment through different times of the year in order to study the effect of different seasons and weather conditions through the year.

- Trying to automate the process of taking readings from poor temperature sensors due to necessity of human adjustment and presence of possible human error in mounting sensors.
- Trying to calculate the temperature of the following:
  1- Bottom of the copper tube
  2- Side of the copper tube
  3- Top of the copper tube
  4- Bottom of the vacuum tube
  5- Side of the vacuum tube
  6- Top of the vacuum tube
  7- Air inlet temperature

And compare those readings to the air inlet and outlet temperatures to have a better view of the temperature difference that will give a great background of possible developments.

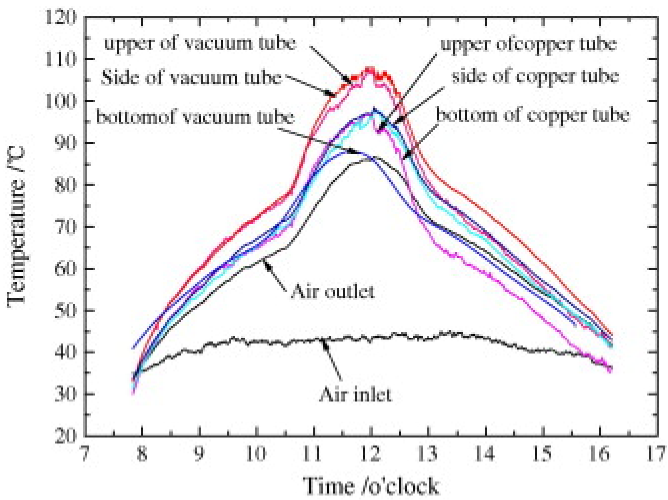


Figure 4. 2 A figure from a paper showing the readings suggested

- Periodic maintenance for stable performance over the year

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APPENDIX

Arduino Code

```
#include <SPI.h>
#include <SD.h>
#include <max6675.h>
const int chipSelect = 53; // SD card chip select pin
const int numSensors = 9; // number of analog sensors
const long readInterval = 300000;//300000; // read interval in milliseconds (5 minutes)
String fileName="ali.txt";
//thermocouple 1
int soPin_1 = 4;// SO=Serial Out
int csPin_1 = 5;// CS = chip select CS pin
int sckPin_1 = 6;// SCK = Serial Clock pin
float temp1=0;
MAX6675 Module1(sckPin_1, csPin_1, soPin_1);// create instance object of MAX6675
//thermocouple 2
int soPin_2 = 7;// SO=Serial Out
int csPin_2 = 8;// CS = chip select CS pin
int sckPin_2 = 9;// SCK = Serial Clock pin
float temp2=0;
MAX6675 Module2(sckPin_2, csPin_2, soPin_2);// create instance object of MAX6675
//thermocouple 3
int soPin_3 = 10;// SO=Serial Out
int csPin_3 = 11;// CS = chip select CS pin
int sckPin_3 = 13;// SCK =Serial Clock pin
float temp3=0;
MAX6675 Module3(sckPin_3, csPin_3, soPin_3);// create instance object of MAX6675
//thermocouple 4
int soPin_4 = 14;// SO=Serial Out
int csPin_4 = 15;// CS = chip select CS pin
int sckPin_4 = 16;// SCK = Serial Clock pin
float temp4=0;
MAX6675 Module4(sckPin_4, csPin_4, soPin_4);// create instance object of MAX6675
```

```
//thermocouple 5
int soPin_5 = 17;// SO=Serial Out
int csPin_5 = 18;// CS = chip select CS pin
int sckPin_5 = 19;// SCK = Serial Clock pin
float temp5=0;
MAX6675 Module5(sckPin_5, csPin_5, soPin_5);// create instance object of MAX6675
//thermocouple 6
int soPin_6 = 20;// SO=Serial Out
int csPin_6 = 21;// CS = chip select CS pin
int sckPin_6 = 22;// SCK = Serial Clock pin
float temp6=0;
MAX6675 Module6(sckPin_6, csPin_6, soPin_6);// create instance object of MAX6675
//thermocouple 7
int soPin_7 = 24;// SO=Serial Out
int csPin_7 = 26;// CS = chip select CS pin
int sckPin_7 = 28;// SCK = Serial Clock pin
float temp7=0;
MAX6675 Module7(sckPin_7, csPin_7, soPin_7);// create instance object of MAX6675
//thermocouple 8
int soPin_8 = 30;// SO=Serial Out
int csPin_8 = 32;// CS = chip select CS pin
int sckPin_8 = 34;// SCK = Serial Clock pin
float temp8=0;
MAX6675 Module8(sckPin_8, csPin_8, soPin_8);// create instance object of MAX6675
//thermocouple 9
int soPin_9 = 36;// SO=Serial Out
int csPin_9 = 38;// CS = chip select CS pin
int sckPin_9 = 40;// SCK = Serial Clock pin
float temp9=0;
MAX6675 Module9(sckPin_9, csPin_9, soPin_9);// create instance object of MAX6675
void setup() {
  Serial.begin(9600);
```

```
 // initialize SD card
  if (!SD.begin(chipSelect)) {
    Serial.println("SD card initialization failed.");
    return;
  }
  Serial.println("SD card initialized.");

  // create new file for data
  File dataFile = SD.open(fileName, FILE_WRITE);
  if (!dataFile) {
    Serial.println("Error creating data file.");
    return;
  }
  dataFile.close();

  // print header to data file
  dataFile = SD.open(fileName, FILE_WRITE);
  dataFile.println("Sensor 1, Sensor 2, Sensor 3, Sensor 4, Sensor 5, Sensor 6, Sensor 7, Sensor 8, Sensor 9");
  dataFile.close();
}

void loop() {
static unsigned long lastReadTime = 0;
  if(Serial.read()=='x')readDataFromFile(fileName);

  // check if it's time to read sensor data
  if (millis() - lastReadTime >= readInterval) {
    lastReadTime = millis();

    // read sensor data
    int sensorData[numSensors];
    sensorData[0] = Module1.readCelsius(); // read temperature of thermocouple 1
```

```
    sensorData[1] = Module2.readCelsius(); // read temperature of thermocouple 2
    sensorData[2] = Module3.readCelsius(); // read temperature of thermocouple 3
    sensorData[3] = Module4.readCelsius(); // read temperature of thermocouple 4
    sensorData[4] = Module5.readCelsius(); // read temperature of thermocouple 5
    sensorData[5] = Module6.readCelsius(); // read temperature of thermocouple 6
    sensorData[6] = Module7.readCelsius(); // read temperature of thermocouple 7
    sensorData[7] = Module8.readCelsius(); // read temperature of thermocouple 8
    sensorData[8] = Module9.readCelsius(); // read temperature of thermocouple 9
  // write sensor data to data file
    File dataFile = SD.open(fileName, FILE_WRITE);
    for (int i = 0; i < numSensors; i++) {
      dataFile.print(sensorData[i]);
      if (i < numSensors - 1) {
        dataFile.print(", ");
      }
    }
    dataFile.println();
    dataFile.close();

    Serial.println("Sensor data saved to SD card.");
  }
}

void readDataFromFile(String fileName) {
  // check if file exists
  if (!SD.exists(fileName)) {
    Serial.println("File does not exist.");
    return;
  }

  // open file for reading
  File dataFile = SD.open(fileName, FILE_READ);
  if (!dataFile) {
```

```
  Serial.println("Error opening file.");
 return;
 }

 // read data from file
 while (dataFile.available()) {
  String line = dataFile.readStringUntil('\n');
  Serial.println(line);
 }

 // close file
 dataFile.close();
}
```