PAKISTAN NAVY ENGINEERING COLLEGE

Energy & Exergy Analysis of Double Side Triangular Enclosure Solar Water Heater

A Thesis/A Dissertation

By

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ABSTRACT

Energy Debate is the key issue for the last few decades of the whole world. With combustible fuel ever so becoming sacred, the need for alternative or renewable energy sources is every increasing day by day. Most of the developed countries already fulfilling their electricity demands complete with these renewable energy sources. Wind, Solar and few other ways of extracting energy from the mother nature have been deployed over the last couple of decades. Fortunately, Pakistan have huge Solar Potential, which only means the Solar Energy can help Pakistan reach its national Power needs.

This Thesis is based on one of the way to use solar power for domestic purpose. Heating water is one of those applications of Solar energy. With Energy demand is increasing energy, it is important to reduce the load on national grid. This thesis provide a detailed and energy and exergy analysis of the Double Sided Triangular Enclosure Solar Collector (DSTESC). This analysis is being done with respect to Karachi weather and optimization has been done with its design in order to get the optimize desired result. The parameters has been varied and then compared in order to study the relationship between the performance as well as the efficiency of the Soalr Collector. This thesis is a detailed description of the thermal processes that happen in a Solar collector as well it interpretation in Solar collector.

ACKNOWLEDGMENTS

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CHAPTER I: INTRODUCTION

1.1 Introduction

Oil is the fuel that is being used as a primary source of energy during the 20th century. The innovation of airplanes, usage of electricity in home and industries and mass production of Gasoline cars continuously boosted the consumption of Oil throughout the century. This made Oil prices go higher and higher and also made us dependent on this source of fuel. But during the last few decades, the need for alternative sources of energy has also gained some ground as the exploration of oil has become ever so difficult.

Scientists and Engineers have developed and found few ways to harness energy from sources other than Oil & Coal. The primary focus has been developed on sources which are clean as well as renewable in nature. These sustainable or renewable energy sources include wind, Solar, Geothermal, Tidal and few others. Many Developed and developing countries have been deploying renewable energy sources in order to meet the requirements for their energy consumptions. Denmark is leading the way in Wind energy. Similarly, Germany has produced 7,630MW of Energy from its solar way in 2012 (Woolfson, 2000), which is approximately. 40% of Pakistan Total Energy demand.

One application of Solar energy is for the purpose of residential heating such as Solar Water Heater. In developed countries, these residential small scale solar systems have been deployed in order to reduce the need for the household energy consumption and also to lower the electricity bill.

1.2 Overview

With the continuously increase in oil prices in the World throughout the last few decades made human go to greater length in order to harvest energy from other sources. Many innovations design based on Renewable sources have been in development for a quite a while now. These sources include Wind, Solar, Tidal, Geothermal and others. This Thesis is based on harvesting the power of Sun i.e. Solar Energy.

Sun is definitely the biggest source of continuous energy in our solar system. It is hot plasma and continuously giving burning and giving out energy by the process of Fusion. It is a spherical body with 1,392,684 km diameter and has a mass of 1.989×1030 kilograms making it the largest planet in our entire solar system . It is consist of helium and mostly hydrogen (Natural Forcing of the Climate System, 2007-09-29.)

The Sun gives approx. 174 Petawatts of solar radiation to Earth`s upper atmosphere [3]. Sun transfers its energy in the form of heat and light to Earth. Heat Transfer from Sun to the Earth occur in the form of all conduction, convection and radiation. Radiation occurs in space and when the sun rays enter the Earth`s atmosphere, convection and then conduction takes over.

Solar Energy is being tapped for over hundreds of years from ancient times. In recent times, this process has really caught on. One way to capture Sun`s energy is to design and used solar collectors. Over the years great research and improvements have been done in the development of solar collector.

Research focus of this thesis is to validation and analysis of the design of an existing Solar collector for the usage of solar water heater. This analysis include the energy analysis as well as the detailed exergy analysis and their comparison. The weather of Karachi will be taken into consideration when doing the calculations and validating the results.

1.3 Thesis Organization

This thesis is divided into five chapters. Chapter 1 is the introduction of the thesis topic. Chapter 2 gives the detail background as well as the literature review needed to do this thesis. It explains the basis of solar collectors as well as the other terminologies used in this thesis.

Chapter 3 is comprised of the methodology that is being involved in doing this thesis. It gives the detail about the basic tools used as well as the technique applied.

Chapter 4 is the main body of the thesis. It included complete energy and exergy analysis. In chapter 4, Mathematical modelling is also there. Complete description of the processes and Results is being formulated. From the results, a strong explanation is also given in chapter 4.

While chapter 5 topic is conclusions and recommendations.

CHAPTER II: BACKGROUND AND LITERATURE REVIEW

2.1 Background

Solar Energy can be captured by a couple of ways, i.e either by active method or passive method. Active method uses technology like Photovoltaic cells etc. They make use of solar energy directly falling onto the surfaces of those cells and convert to that solar radiation directly to electrical energy which is being stored in a battery for future use. The passive approach to use solar radiation is capture heat in order to convert water into steam which then is use for the generation of Energy. A great way to capturing solar radiation has been in the residential applications. Solar water heater is being one of that.

Solar Water heater is basically a glass panel with Absorbing bottom plate (high in capturing heat). The heat from the bottom plate then is being transferred to the fluid which pass through the pipes attached to the Absorber plate.

2.2 Solar Water Heater System

Solar water heater is a great example of harnessing solar power for residential purposes. In many developed countries, residents have deployed this system in order save on electricity bills as well to play their part in reducing carbon footprint. Typically, this system is comprised of a flat plate collector, a storage tank and pipes.

Solar collector is basically a absorbing plate inside a glass enclosure. The glass enclosure is to create a green house effect over the absorbing plate. The absorbing plate is usually made up a material with high thermal conductivity. There are also tubes or pipes attached to this absorbing plate where the working fluid (fluid needed to gain heat) passes.

A storage tank is used for the purpose of storing water, when hot water is to be used by anyone, cold water is pumped to the collector so that it can be heated by solar rays.

A typical Solar water system can be seen as in the figure 1 (Honsberg).

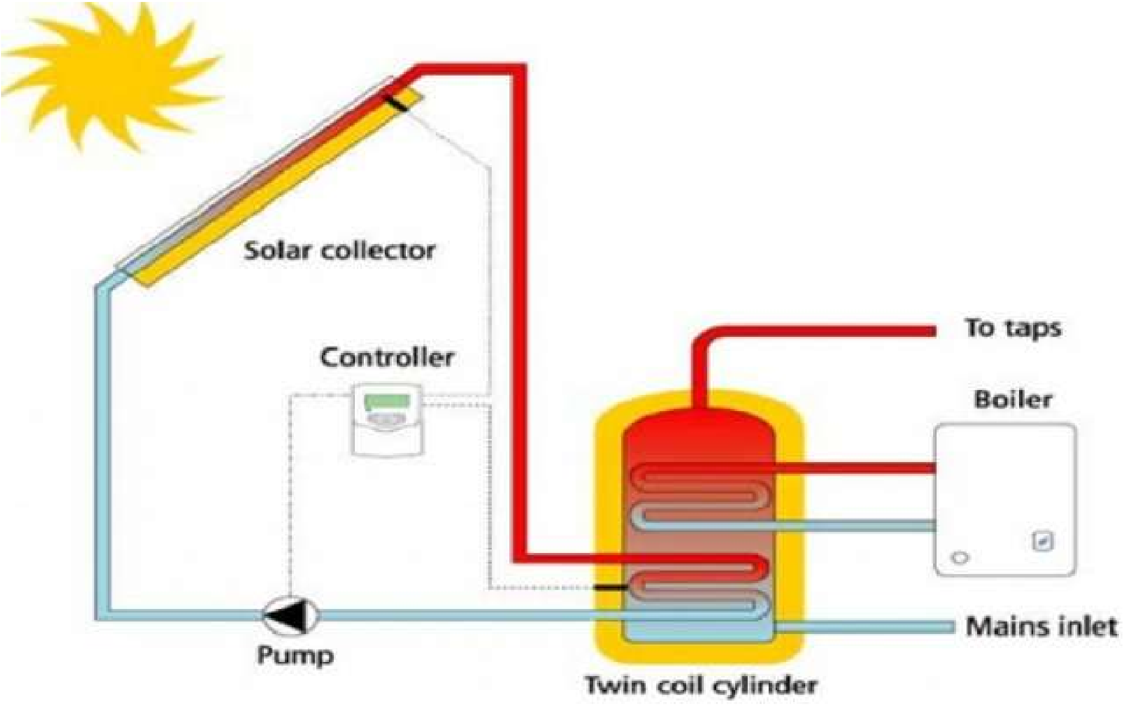


Figure 1 Solar Water Heating System (Honsberg)

Even tough, there are various components in a solar water heater system, but this thesis is limited to the parts of solar collector and their performances throughout the year.

2.1.1 Collectors Absorber plates

The absorber plates can be made of metals, plastics or rubber compounds. Whatever, the material is chosen, it has to be high in absorbance as well in thermal conductance. Few examples of most commonly absorbing materials are copper, aluminum and steel. Various rubber (ethylene propylene compounds) are also used due to the fact that they are very cheap as compared to the materials mentioned above. But their usage is limit to solar collector up to certain range of temperatures.

Heat transfer through the collector can be obtained by using energy balance equation

$$E_{in} + E_g - E_{out} = E_{st} + Q_{cond} \tag{1}$$

where

E_{in} is the amount of solar energy entering the absorber plate.

E_g is the amount of energy generated in the absorber.

E_{out} is the amount of energy leaving the absorber, thus the thermal energy losses from the plate.

E_{st} is the amount of energy stored in the absorber plate material.

Q_{cond} is the amount of heat conducted to heat carrier fluid

The most important property of the absorber plate is the capacity of the plate to absorb heat. This property is called absorption. The absorption of few common coatings are given as follows. (Exel, 2000)

Material	***Absorbance µm***
Flat black paint	0.97-0.99
Aluminum paint (bright)	0.3-0.5
Alkyl enamel	0.9
Black acrylic paint	0.92-0.96
Black inorganic paint	0.89-0.97
Black silicone paint	0.86-0.94
Parson black	0.981
Ceramic enamel	0.9

Table 1 Absorbance of common materials (Exel, 2000)

2.1.2 Covering Material

The cover over the absorbing plate is required in order to reduce the heat loss to surroundings. As the cover makes use of the greenhouse effect to keep the environment warmth inside the solar collector. Glazed and common glass are usually the material used in the solar collector. Single and double glazed glass as a cover plate are also a common practice.

The property of the cover glass from which it is selected is its transmittance. The more the glass transmits the solar rays, the more energy the absorber will attain. The commercially available grades of window and green-house glass have normal incidence transmittances in the range of 0.85-0.93, respectively. Transmittance is a function of angle of incidence. [ASHRAE,2005]

2.1.3 Insulator

The absorber plate from bottom end must be attached a good insulator in order to minimize the heat loss from the collector. The most common insulating materials used in solar collectors are given in Table (Soltau, 1992)

Material	*Thermal Conductivity*	*Maximum Service Temperature (℃)*
Glass fibre	0.032	343
Polystrene foam	0.034	64
Polyurethane foam	0.023	104
Isocynaurate foam	0.025	121
Phenolic foam	0.033	135

Cellular plastic	0.40	100
Foamed glass	0.058	900
Mineral fibre	0.04555	843
Perlite	0.048	816
Calcium silicate	0.055	649

Table 2 Most commonly used insulation materials (Soltau, 1992)

2.2 Double Side Triangular Enclosure Solar Water Heater

PNEC has developed Double Side Triangular Enclosure Solar Collector (DSTESC). The Paper (Shafiq R. Qureshi, 2014) has been given the detailed examination of working of the this arrangement of Solar collector as well as the calculation of experimental of theoretical values. The model is based on the configuration of the Solar collector described in the paper.

Figure 2 Actual photograph of the Solar collector (Shafiq, 2014)

the tubes attached to the absorbing plate is taken to Ethylene- Propylene- Dimer M- Class synthetic rubber (EPDM). The reason for choosing EPDM tubes over copper tube is the fact is EPDM is way cheaper than copper but when compare with thermal conductivity of copper, EPDM is also close with copper properties. So from economic point of view, the absorber plate has EPDM tubes. The thickness of these tubes were to taken minimum in order to avoid any heat loss though the thickness of the EPDM. The temperature difference between inside and outside of the tube is being taken same in order for simplicity. Though when calculating the exact temperature difference on this Solar collector with very less thickness tubes, thin shell theory is applied. (Hans Dieter Baehr, 2006)

The insulating material for this solar collector is made up of 3inch slab of Expanded Polystyrene foam (EPS) with a thermal conductivity of 0.03 W/m.K.

2.3 LIITERATURE REVIEW

. This thesis is its complete evaluation of energy as well as exergy performances of the solar collector throughout the year round the clock for the climate of Karachi,Pakistan with making reference (Shafiq, 2014) In the research paper, theoretical as well as experimental values are compared. Other than that, it has completely has given the description of the geometry of the solar collector.

The Mathematical developement of the solar collector has been given by (Beckman, 2013).This book gives a brief description of heat transfer processes including how to calculate various dimensionless numbers in order to calculate coefficient of heat transfer. It also explains the full the full theory of various processes takes place in heat transfer. In the text (Beckman, 2013) acomplete documentations has been given about flat plate solar collectors. There is also a well documentation of how to find the heat loss coefficient in order to calculate the total heat loss of the year.

Ehsan et. Al 2009e (Ehsan MOHSENI-LANGURI, 2009) has given the complete energy and exergy mathematical model for the flat plate solar collector. This research paper provide a complete detail of all the energy as well as the exergy analysis of a flat plate collector in the winter for the city of toronto.

Ahmed et. Al 1989 (Ahmad, 1989) has contributed a lot towards obtaining the solar data of Karachi, Pakistan, same was used as reference dring mathematical analysis.

Other than that, various research papers and articles have been studied and reviewed for the purpose to completely evaluate the performances of the Solar collector. All of those are mentioned in References.

The design of the solar collector was selected on the bases of the all the sources and references that during a day , a flat plate solar collector only trap solar radiation in a small window of time i.e it start working around 10am in the morning and works up upto 3 pm. To maximize the solar radiations throughout the day, DSTESC design maximizes the heat gained by the collector. And to support the theoretical claims, a complete energy and exergy analysis is required.

Application of exergy analysis is necessary to optimize the design of the DSTESC which is based on the geometry as well as its built material. The method for exergy analysis was being done using the approach of calculating the entropy generation from irreversibility of the system. The exergy balance equation (E.M. Languri, 2009)is applied to the system in order to obtain the irreversibilities of the system.

Other than that the material of the selection used for the absorbing plate in Solar collector is chosen to be EPDM ethylene propylene diene monomer rubber which is used as an alternative to copper tubes due to its high thermal conductivity as well as its low cost comparatively. These tubes are considered to be taken as very thin due in order to maximize the heat transfer from the solar collector to the fluid.

CHAPTER III: METHODOLOGY

In this chapter, the complete methodology is given. This includes various methods adapt for the thesis. It also includes various assumptions on which the results given in the next chapter is based upon.

3.1 SolarAngles

Since the biggest variable in the performance of the solar collector is the sun, therefore, it is important to understand the position of the sun during the day before proceeding.

The various angles the sun makes during the day or through the year can be seen by the figure no 3

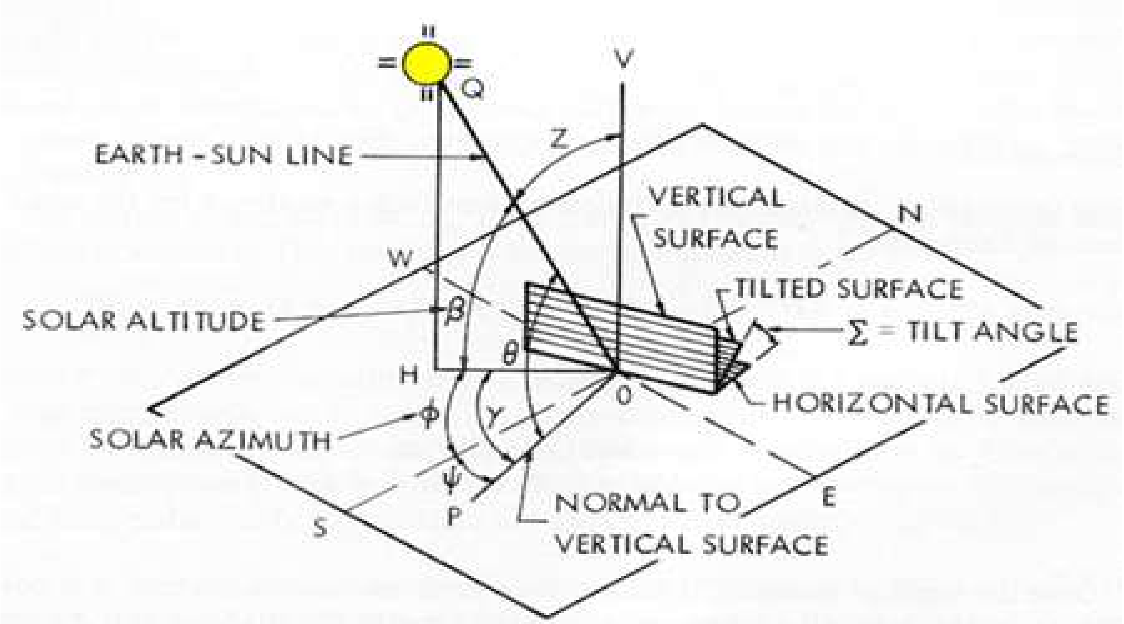


Figure 3 Nomenclature of Solar Angles (Honsberg)

The azimuth angle (Honsberg) is the direction from which the sunrays are coming. At 12pm , the sun is always directly south in the northern hemisphere and directly north in the southern hemisphere. Tough azimuth angle changes over the year. In order to absorbs the maximum solar radiations the collector must be rotated and position differently during different times. But for the sake of simplicity the solar collector is assumed to in position with the azimuth angle during the whole year.

Solar Altitude is the angle of the sun above the horizon. At sunrise and sunset, the solar altitude angle is maximum.

Z in the measure of zenith angle which is the angle the sun makes with the vertical axis which only means at noon, the zenith angle will be zero and will be greatest at sunset or sunrise.

3.2 Angle calculation

The flat plate solar collector doesn't start trapping solar radiation when the angle of incidence becomes low than the critical angle of the glass. The glass with around 39 °critical angle will not start functioning till the zenith angle become somewhat less of the critical value. Therefore the limitation the Flat plate solar collector has that it doesn`t start working early. Like in the month of January in Karachi the angle of incidence of sun is 40 °around 10am in the morning. What it means that the Flat Plate solar collector will start capturing solar radiation as early as 10am (Ahmed, 1989), which will cause the Flat plate solar collector to work less hour during a day. The same situation will occur in the evening. The flat plate solar collector stops working early as early as 3pm. So this flat plate collector will result in less heat capturing.

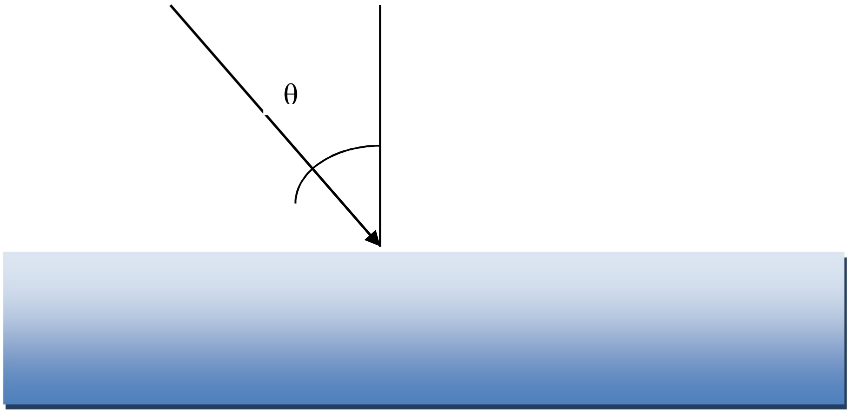


Figure 4 Angle of incidence of flat plate collector

Now suppose the zenith angle or the solar angle with respect to the vertical is than angle of incidence (θ) in case of flat horizontal plate collector. The flat plate will absorb heat energy from the sun as far the angle of incidence remains less than its critical angle. Now if the same angle of sun with vertical θ is above the triangular enclosure. The angle of incidence will become ψ will become the difference of slope angle α and θ. or in mathematical term

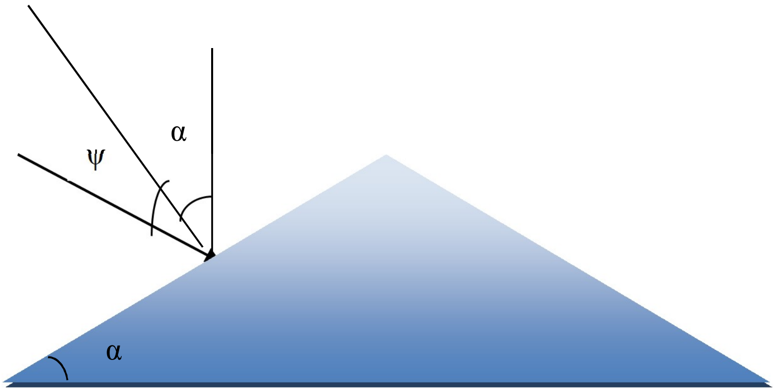


Figure 5 Angles with respect to DSTESC

therefore,

$\psi = \theta - \alpha$

where,

ψ = angle of incidence for the DSTESC

θ = Solar angle with respect to vertical axis

α = DSTESC slope angle with respect to horizontal

In case of ψ becomes negative it means it will be angle of incidence from the opposite side of the enclosure or angle of incidence will be the sum of θ and α for the first side. and the after

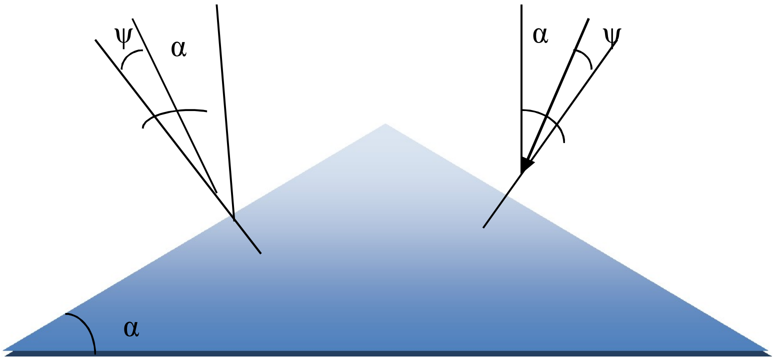


Figure 6 clarification of different angle of DSTESC

Or at noon or when the solar angle with respect to the vertical will become zero, then the angle of incidence ψ with equal to the angle of the enclosure α. After the noon, the angle of incidence ψ will lean towards the opposite side of the enclosure.

The main advantage of picking this arrangement of solar collector helps the entrapment of solar radiation as early as possible as 8am or even before that if the critical angle is more than 35 ˚. Similarly, the triangular enclosure will keep on working until late in the evening.

The table below will give the values of angle of incidence of DSTECS with different α throughout the day

α	*0*	*20*	*25*	*30*	*35*
Slope Angle	θ	ψ	ψ	ψ	ψ
Solar Hour	Flat Plate	DSTECS	DSTECS	DSTECS	DSTECS
8	70	50	45	40	35
9	55	35	30	25	20
10	40	20	15	10	5
11	25	5	0	-5	-10
12	10	10	-15	-20	-25
13	-5	15	-20	-25	-30
14	-20	40	-5	-10	-15
15	-35	15	10	5	0
16	-50	30	25	20	15

17	-65	45	40	35	30

Table 3Angle of incidence at various slope angle of the Solar collector throughout the day

The negative value of angle of incidence suggests that angle of incidence is on the opposite side of the normal and will also be the angle of incidence falling on the other side of the solar collector. In other words, at approx all time there is a way for DSTESC will capturing solar radiation on any side.

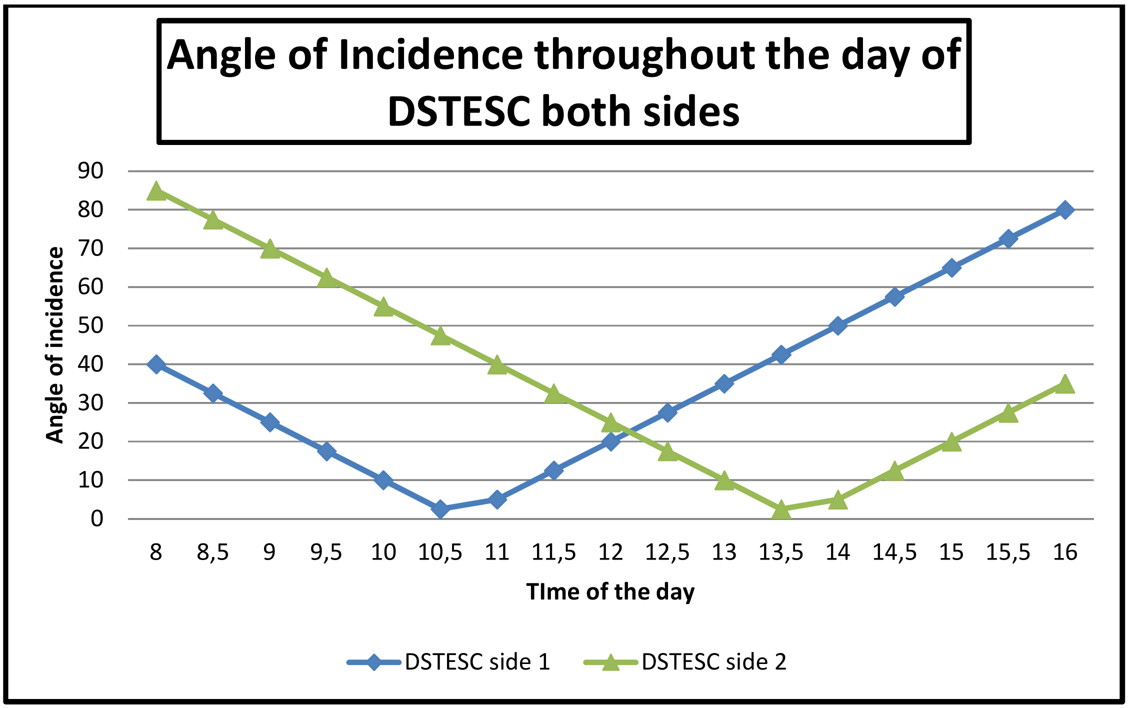


Figure 7 angle of incidence at various time of the day

or alternatively, it can viewed from the line graph that how DSTESC can have longer solar radiation capturing time.

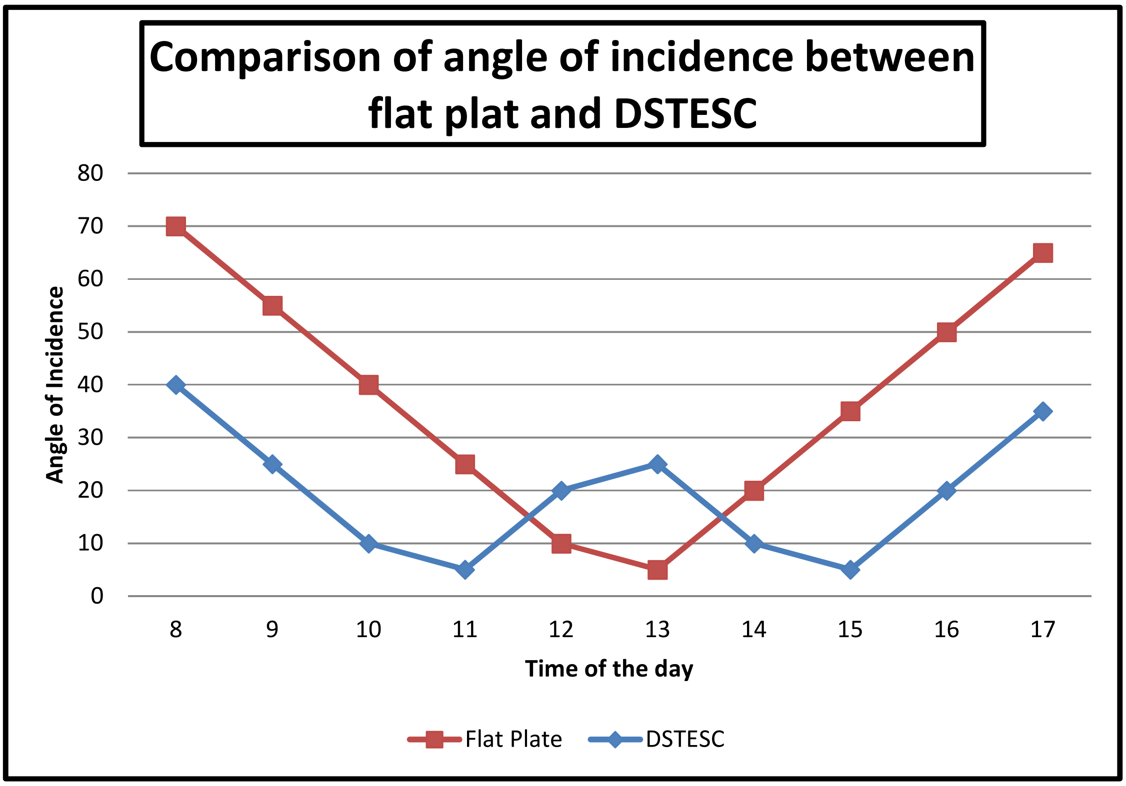


Figure 8 angle of incidence of flat plate vs DSTESC

3.3 Flat plate solar collector corresponds to the Triangular Enclosure of the same area

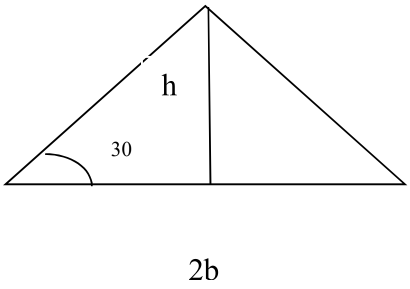
Since, Calculation method (Beckman, 2013) is for the calculation of heat loss of a flat plate collector. Therefore it was necessary to find out what will the dimensions of the flat plate collector which will be corresponding to the DSTESC as far as it area above the heated plate is concerned.

Let the triangle with following parameters as shown in the figure

base= 2b

height= h

Angle= 30 degree



now, its area will be

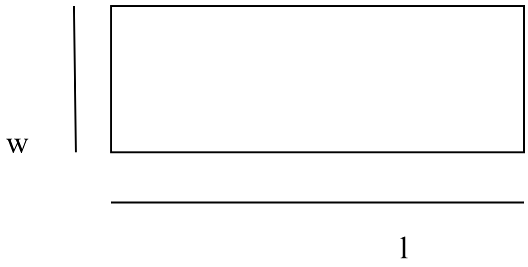
$Area=0.5(2b*h)$

or

$Area=0.5(2b*0.577b)$ with $h=0.577b$

$Area=0.577b^2$

Now ,Consider a rectangle with sides as shown



$length=l$

$width=w$

thus, $Area= l*w$

If the base of both rectangle and triangle are taken as equal

then, $l=2b$

$0.577b^2=2b*w$

or $w=0.3535b$ (height of rectangle will be 0.3535 times the height of the triangle)

which means that the width or cover-plate spacing of the flat plate will be equal to 0.3535 times the half the base of the DSTESC.

This value will be useful in order to calculate the overall heat loss coefficient as it will corresponds to the distance between the glass and the absorber plate.

Now let us consider the triangle with b=0.75 m

which corresponds to its base=1.5 m

therefore,

Area =0.577(0.75^2) = 0.324 sq m

3.4 Computer Softwares

In order to compile the result and performances of the collector, it was necessary to make use of the proper tools such as a spreadsheet software. Other than that, a more professional and analytical way for approaching the target was to use a technical software. By the method of calculating heat loss (Duffie, 2013) make use of the trial and error method. Simple spreadsheet software just doesn`t able to do this job. Thus, the need to generate a code in the programming computing software MATLAB in order to obtain the heat loss coefficient. A template of the code written is being attached in appendix A.

Other than that, to find out the temperature distribution in the solar collector, one way was to find computer aided engineering software like ANSYS to obtain the temperature distribution over a period of time. But since thesis is not regarding the design rather to evaluate the performance parameters for the region of Karachi, therefore a more subtle approach was needed. CFD finite difference method is being applied using MATLAB Pdetool. MATLAB Pdetool is a differential equation solver module built in Matlab itself.

A parabolic heat equation is being solved by the MATLAB of which further details are given in the next chapter of this thesis.

CHAPTER IV: ENERGY & EXERGY ANALYSIS

Solar collector uses the principle of active solar heating. They use the direct sunlight to heat fluid. In most of the residential applications, it is water. The solar radiation from the Sun falls onto the surface i.e. the bottom plate which then transfer the heat to the flowing fluid.

4.1 Heat Gained by the Solar Collector

The Heat Gained by the Solar Collector depends upon the Solar Radiation of the sun and the product of transmittance of the glass cover and the asorbance of the bottom plate. The mathematical relation is given by (Ganji, 2011)

$$Qin = Gc.Ac.\tau\alpha \tag{2}$$

where,

Gc = Solar Radiation falling on Earth`s Surface per unit area (W/m^2)

Ac = Area of the Plate (m^2)

τα = product of transmittance and absorbance of the covering glass and the absorber plate

4.1.1 Solar Radiation

After obtaining the data from the (NASA)for the latitude and longitude for the Karachi region. And obtaining the Average Solar hours per day (Ahmed, 1989)].

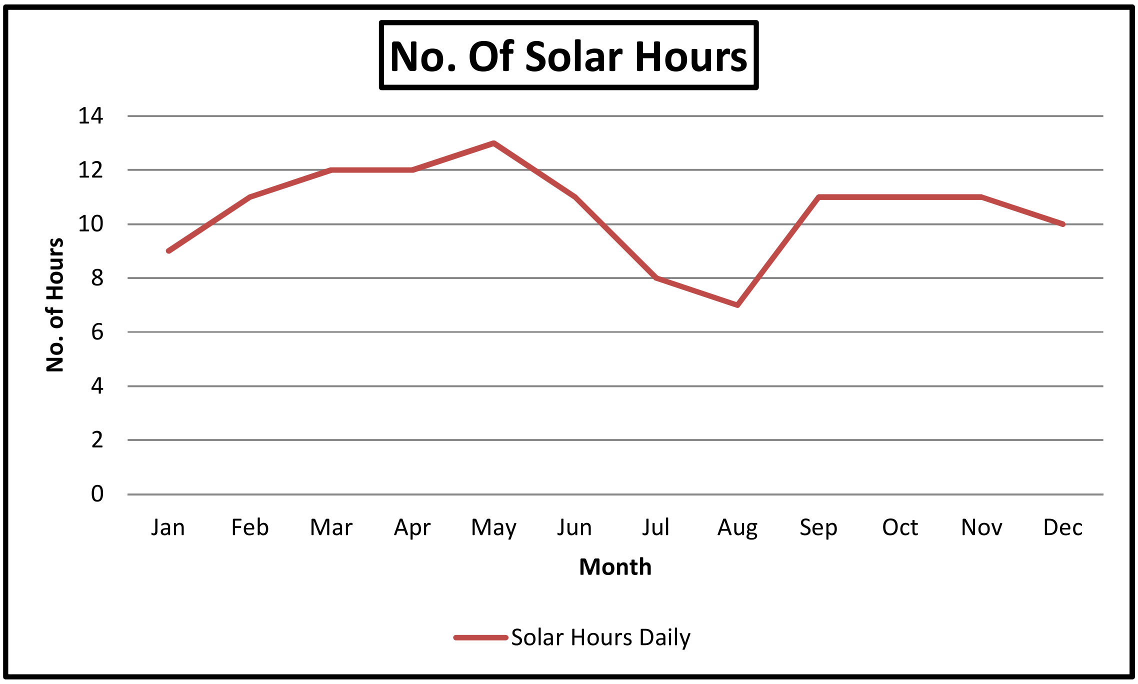


Figure 9 Average No of hours per day

As it can be observed that maximum solar hours per day happens in the month of may and early June. Around July and August, the climate of Karachi become cloudy with monsoon rain expectation which results in less solar hours.

The average Solar radiation per hour of each month has been calculated below. Solar Monthly Data of Karachi (monthly average data) .

Karachi	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Ann*
kWh/m^2/day	4.39	5.18	5.3	6.65	6.67	6.40	5.44	5.27	5.62	5.24	4.50	4.11	5.45

Solar Hours	9	11	12	12	13	11	8	7	11	11	11	10	10
Av Hourly Radiation	487	470	441	554	513	581	680	752	510	476	409	411	519

Table 4 Average Monthly Data for Karachi (NASA)

But the result from this won't give accurate results as Solar radiation intensity level changes throughout the day and taking the average value won't necessarily give the right results.

Therefore it is necessary to consider the hourly data for the energy and exergy calculations. Since the Nasa Solar Energy Source (NASA) o provide monthly average data i.e. it is necessary to obtain the solar data from some other source. The Phd. Thesis (Ahmad, 1989) has given complete documentation of the solar hourly data, which is being used in order to do the calculations. The figue below show the Solar Radiation at hour interval throughout the day.

Solar Data	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***	***16***	***17***
Jan	215.75	310.2	480.4	519.8	676.1	685	595	446.3	294.4	202.05
Feb	261.95	353.9	560.1	680	738.5	741.3	672.4	571.8	343.1	253.35
Mar	329.2	427.5	605.2	730.2	821.1	810.7	724.3	582.6	425	321.2
Apr	393.85	492.1	678.3	791.4	877.1	866.3	782	666.9	468.9	378.6
May	425.9	518.8	637.9	703.7	837.2	849.1	748.5	629	516.6	414.65

Jun	407.9	511.2	618.2	712.6	810.1	821	715.4	599.6	503.1	398.95
Jul	336.2	414.1	532	621.7	711.6	698.4	630.2	541.1	410	325.35
Aug	325.9	410.2	524.6	612.8	650	638.7	598.8	514.1	424.3	337.25
Sep	343.55	445.8	590	708.2	780.3	767.7	690.5	601.4	434.6	328.65
Oct	270.85	365	554.3	701.8	778.6	763.7	695	545.4	354.2	261.15
Nov	222.85	328.5	504.2	611.7	705.6	697.8	621.3	498.7	311.2	206.4
Dec	180.25	263.1	437.2	590.1	642.6	658.3	560.9	434.6	288.1	193.9

Table 5 Hourly Solar data of Karachi (Ahmed, 1989)

As Karachi lies in Northern Hemisphere in which June is Summer while January is in the Winter season. Thus, it can be clearly seen that maximum solar radiations falls in the month of June with comparatively very few in the month of January . Or it can seen by the line graph below

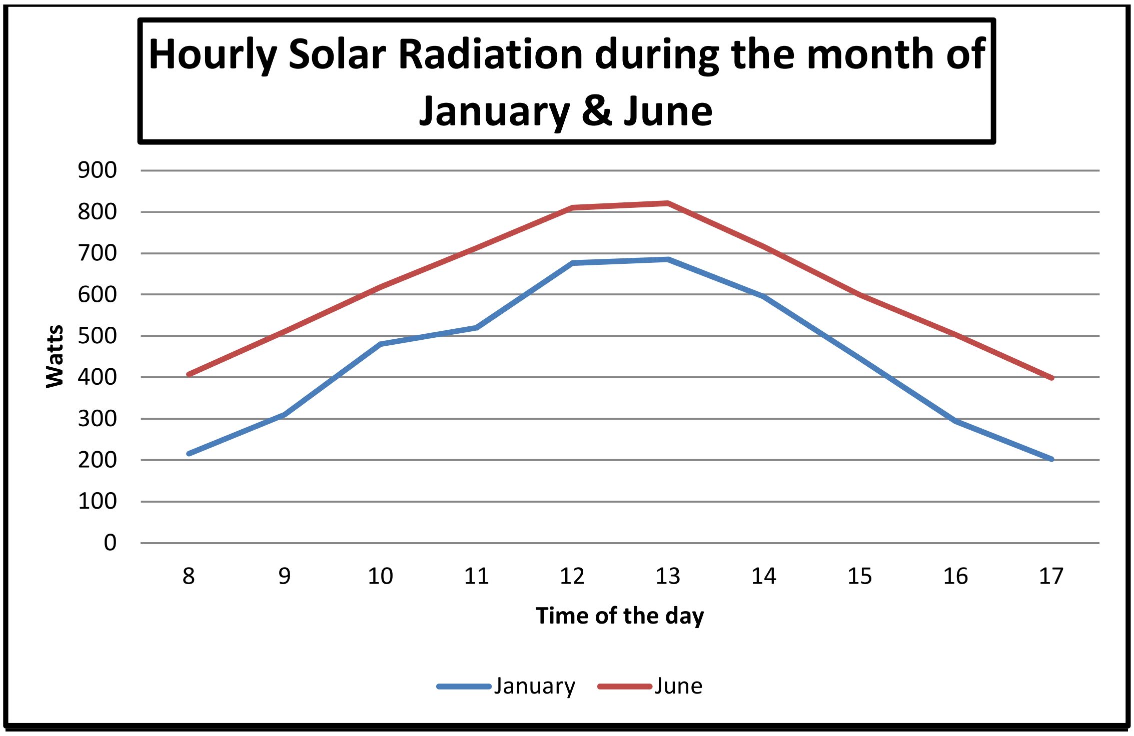


Figure 10 Hourly Solar Radiation

4.1.2 Transmittance-Absorbance

The transmittance τ of a glass is a function of angle of incidence of the Solar Radiation. Thee absorptance α of the black plate for solar radiation also depends on the angle of incidence ψ *too*. The values of transmittance and absorbance as well as their product is given in the table 6 (Exel, 2000).

Variable	*0°*	*60°*	*70°*	*80°*	*90°*
τ	0.9	0.8	0.65	0.35	0
α	0.92	0.85	0.75	0.60	0
τα	0.83	0.68	0.49	0.21	0

Table 6 Transmittance & Absorbance (Exel, 2000)

By interpolating, the remaining value of the transmittance-absorbance product of various angles can be calculated and it can be visualized as below.

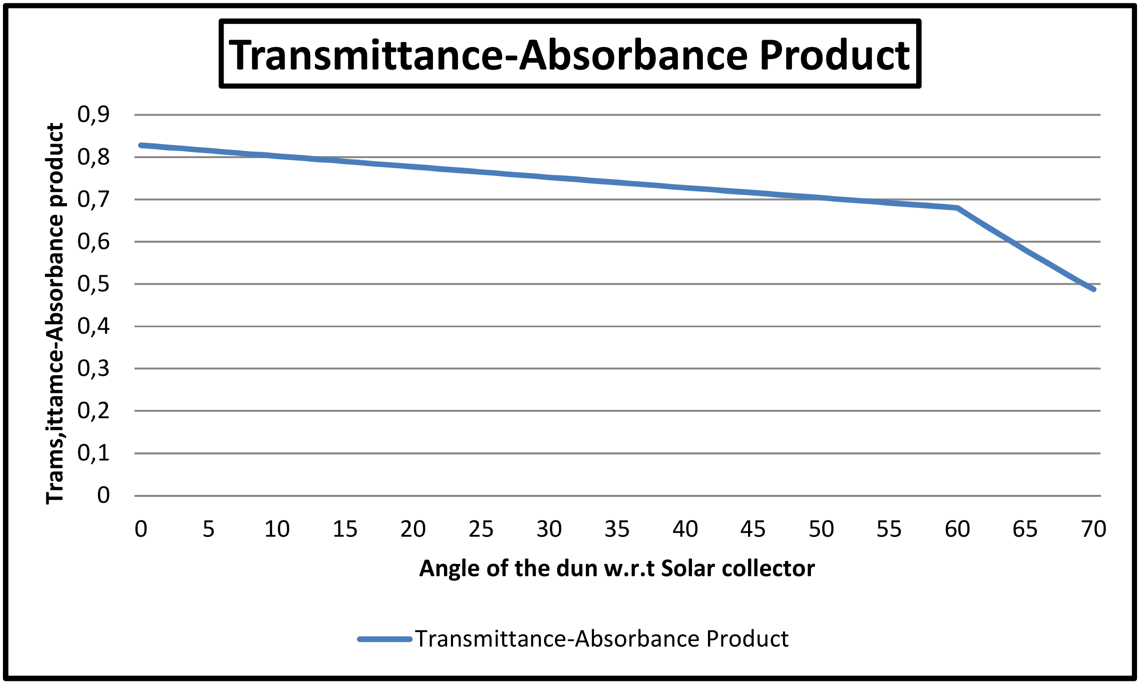


Figure 11 Transmittance-Absorbance variation with angle of incidence

The graph above clearly gives a clear picture that up to angle of incidence 40 or above˚, the product of the transmittance and absorbance doesn't vary much as compared to the variation of the product after angle of incidence goes above 60 ˚. But since the angle of incidence of DSTESC remains 0-40˚during the day, therefore, we only need the values in this domain.

4.1.3 Area of the Collector

According to the specification of the Double Side Triangular Enclosure Solar Collector design by PNEC (Shafiq, 2014), the area of the bottom plate exposed to direct sunlight is 6 square meter. Since the Solar Water Heater is specifically designed to use in the month of January in order to lower the energy consumption, therefore the figure below gives an idea of how much energy falling onto the surfaces.

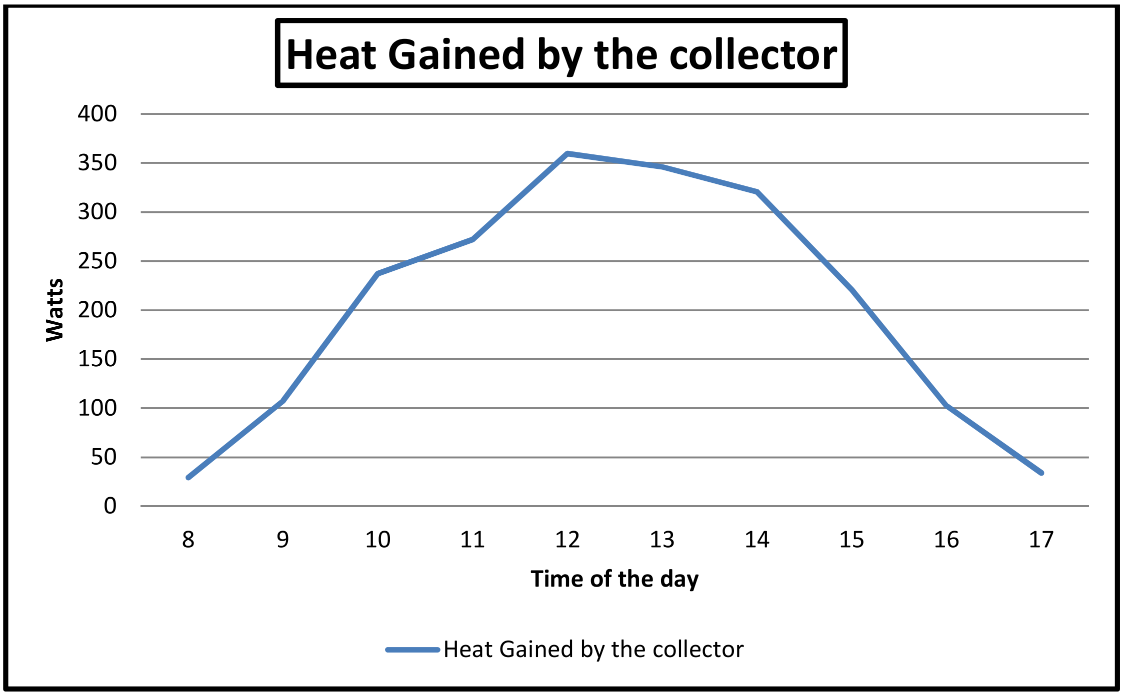


Figure 12 Total Heat Gained for January

4.1.4 Solar Heat Gained

Well, it's understandable after the above details of the parameters on which the total heat gained by the collector depends upon. With the Solar Radiation variation throughout the year and throughout the day makes solar heat gained vary too. While the other parameter transmittance-absorbance product changes very tiny throughout the year, its effect will be negligible. But still, it`s variation has been taken into account.

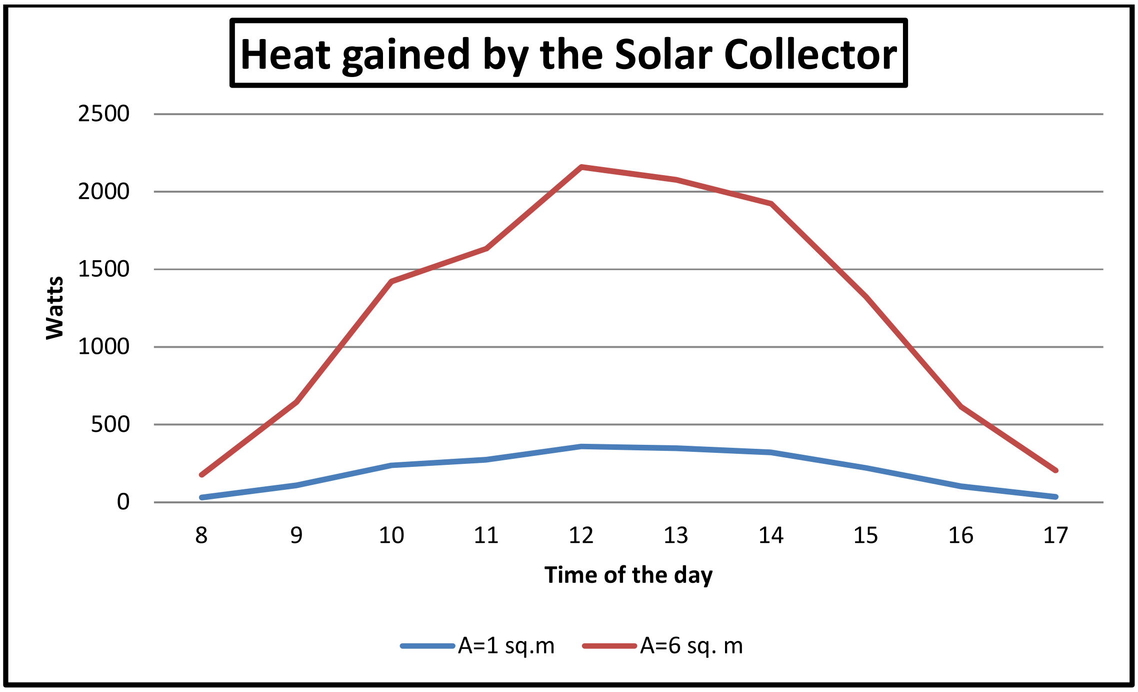


Figure 13 Total Heat gained in summer/winter

We can clearly see from the above graph that the values of the total heat gained will be highest with the winter remains the lowest. With other periods of the year, it will remain in between the two. But, keeping in mind, the parameter above is not the Net heat gained by the collector. Infact, it is the maximum amount of heat energy the solar collector will take if there aren`t any losses within and to the surrounding.

4.2 Heat Loss by the solar collector

From the previous topic, we observed the total heat gained by the collector. But that study didn`t give the whole picture. Obviously, there will be energy losses within the system as well as outside the system.

In order to obtain Heat loss from the collector to the surrounding, it is important to consider the triangular enclosure with discrete heating from the bottom plate and natural convection taking place at surface of the plate. The Heat loss depends upon two parameters

- ✓ The overall Heat loss coefficient
- ✓ The Temperature difference between plate and the surroundings

4.2.1 The overall Heat loss coefficient

In order to find the overall heat loss coefficient, first consider the Flat plate solar collector.

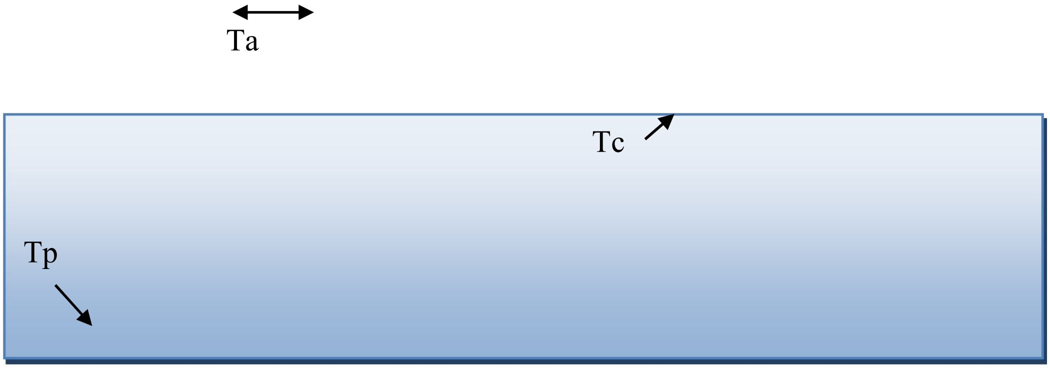


Figure 14 Temperatures corresponding to the flat plate collector

here,

Ta= Ambient Temperture

Tc=glass cover temperature

Tp=plate temperature

now, the heat will loss from the plate to the surface of glass cover and then to the atmosphere.

The resistance diagram of the system can be shown as

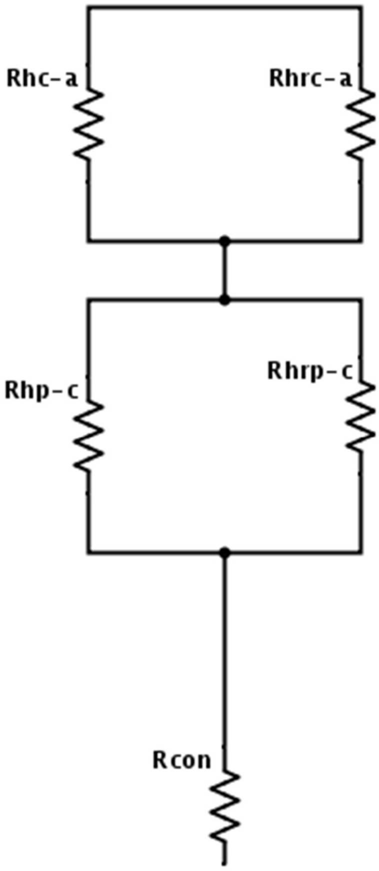


Figure 15 Resistances of Heat Transfer (Beckman, 2013)

where,

R $_{h,c-a}$ = Resistance of convective heat flow from cover to atmosphere

R $_{hr,c-a}$ = Resistance of radiative heat flow from cover to atmosphere

R $_{h,p-c}$ = Resistance of convective heat flow from plate to glass cover

R $_{hr.p-c}$ = Resistance of radiative heat flow from plate to glass cover

R $_{con}$ =Resistance of conductive heat transfer from outside to inside of pipe

and by definition (Incropera, 2006) Resistance to heat transfer is actually the reciprocal of heat transfer coefficient. Thus, this leads to convective heat transfer coefficient between the cover plate and the atmosphere is

$$Rh_{c-a} = \frac{1}{h_{c-a}} \tag{3}$$

and the remaining resistances of heat transfer in the flat plate system will be

$$Rh_{r,c-a} = \frac{1}{h_{r,c-a}} \tag{4}$$

$$Rh_{p-c} = \frac{1}{h_{p-c}} \tag{5}$$

$$Rh_{r,p-c} = \frac{1}{h_{r,p-c}} \tag{6}$$

where, h and h $_r$ are the convective and radiative heat transfer coefficients.

from (Duffie, 2013), the radiative heat transfer coefficient between the absorber plate and the glass plate is given as

$$h_{r,p-c} = \frac{\sigma(T_p + T_c)(T_p^2 + T_c^2)}{\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_c} - 1} \tag{7}$$

here, ε_p and ε_c are emittance of plate and cover respectively. and σ is the Stefan Botlzmann constant.

this radiative heat transfer coefficient will be responsible for radiation heat loss from the plate to the cover in the flat plate collector system.

$$h_{r,c-a} = \varepsilon_c \sigma(T_c^2 + T_a^2)(T_c + T_a) \tag{8}$$

from above equations, radiative heat transfer will be calculated easily, but for the convective heat transfer coefficient, the convective heat transfer theory (Incropera, 2006) will be used. For the calculations of convective heat transfer coefficient, the dimensionless numbers Nusselt Number, Grashoff Number and Rayleigh Numbers must be obtained.

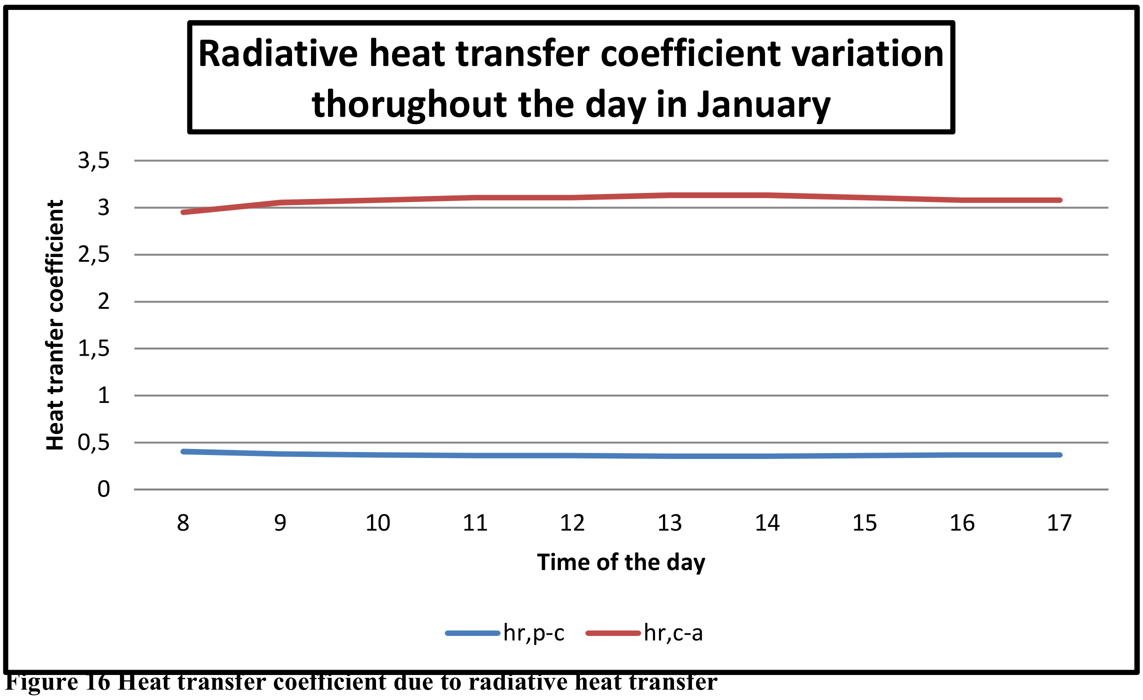


Figure 16 Heat transfer coefficient due to radiative heat transfer

from the above graph it is observed that the radiative heat loss from the cover plate to atmosphere is way more then it happen inside the collector. It also shows that at the middle of the day, it is the greatest with the ambient temperature is maximum.

By definition of Nusselt Number (Incropera, 2006), Nusselt number is defined as the ratio of convective heat transfer to the conductive heat transfer . Or mathematically, it is the ratio of convective product of convective heat transfer coefficient and length to the thermal conductivity.

$$Nu = \frac{hL}{k} \tag{9}$$

where,

h=convective heat transfer coefficient

L=characteristic length

k=thermal conductivity

similarly, Rayleigh Number is the relationship between buoyancy and viscosity within the fluid. Numerical formulation of Rayleigh Number is given as

$$Ra = \frac{g\beta^{`} \Delta T L^{3}}{\upsilon\alpha} \tag{10}$$

g=acceleration due to gravity

β=coefficient of volumetric expansion

ΔT=difference in temperature

L=characteristic length

υ=kinematic viscosity

α=thermal diffusivity

While Prandlt Number is the ratio of momentum diffusivity (kinematic viscosity) to thermal diffusivity. Thus,

$$Pr = \frac{\upsilon}{\alpha} \tag{11}$$

with Grashoff Number is the ratio of Rayleigh to the Prandtl Number. And is defined as atio of the buoyancy to viscous force and given by

Gr=Ra/Pr

For finding out the values of convective heat transfer coefficients between the plate and the cover, we needed to calculate the these dimensionless numbers. In a more recent experimental study using air, Hollands et al. (1976) [13] give the relationship between the Nusselt number and Rayleigh number for tilt angles from 0 to 75◦ as

$$Nu = 1 + 1.44[1 - \frac{1708(\sin 1.8\beta)^{1.6}}{Ra\ \cos\beta}][1 - \frac{1708}{Ra\ \cos\beta}] + [(\frac{Ra\ \cos\beta}{5830})^{\frac{1}{3}} - 1] \quad (12)$$

with β is the tilt angle of the collector. With the value of Nusselt Number, the convective heat transfer coefficient between the plate and cover is easily calculate. This will lead to finding out the overall heat loss coefficient in the flat plate system . And it is given as

$$U_t = (\frac{1}{h_{c,p-c} + h_{r,p-c}} + \frac{1}{h_w + h_{r,c-a}}) \quad (13)$$

with h_w is wind convective heat transfer coefficient which will be function of wind speed as well as ambient temperature. For the characteristic length of L=0.4242m, the variation of overall heat loss coefficient in the month of January can be seen from the graph below

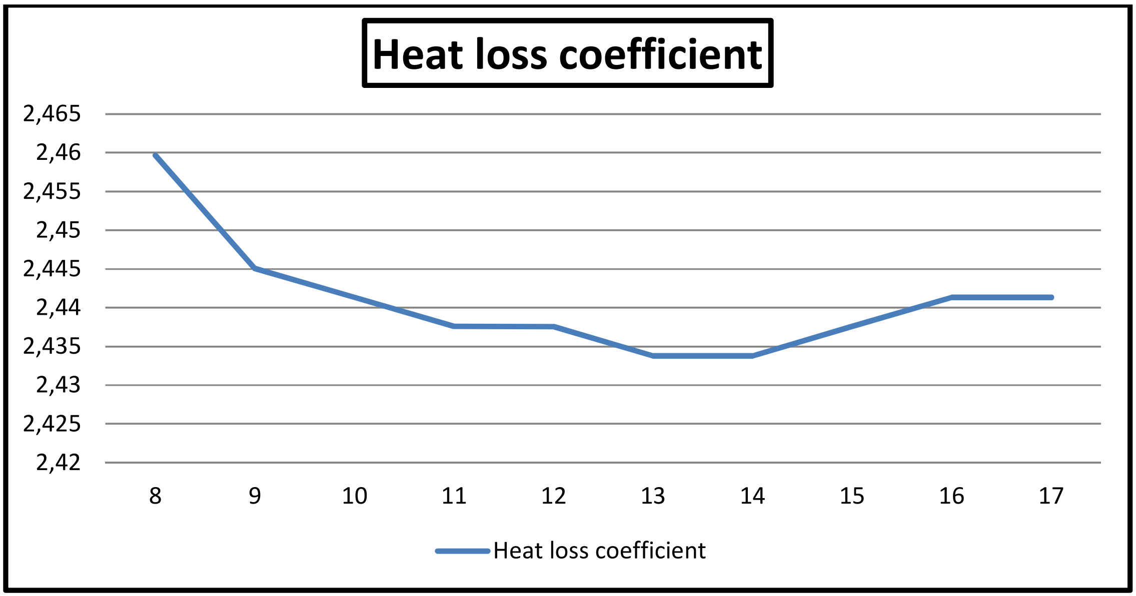


Figure 17 Heat loss coefficient during the solar hours

the graph describes the picture of heat loss coefficient through the collector. It is maximum where the surrounding temperature is minimum which is at the beginning of the day. Which will lead the maximum heat transfer loss.

Keeping that in mind if the this heat loss due to the radiative and convective heat loss coefficient which is occurring in the Solar Collector. The heat loss due to conduction will occur due to the material of the absorber plate as well as the coating over it, the material chosen for the absorber plate is Ethylene Propylene Diene Rubber (EPDM). The choice of EPDM is due to the fact that it is cheap and a great alternative for copper. Keeping the thickness of EPDM tubes minimum will help in achieving the great heating.

Another Important factor in the amount of heat being absorbed by the absorber plate is the color of the plate or the surface with it coated. For reference black body is the perfect color for absorbing all the radiations falling on it. An comprehensive comparison is given in the table 7 for the color of the material with respect to the solar radiation absorptivity.

Surface Color	*White Smooth Surfaces*	*Grey to dark Grey*	*Green,Red and Brown*	*Dark Brown to Blue*	*Dark Blue to Black*
Absorb Factor	0.25-0.4	0.4-0.5	0.5-0.7	0.7-0.8	0.8-0.9

Table 7 Absorb Factor of the Surface with different colors

Absorb factor by definition is the fraction of radiation captured by the surface. Black surface absorb the most radiation i.e the thermal energy in the case of solar radiations. It is due to the fact that white color reflects more and darker color absorbs more.A comparison is shown in the figure 18 on the case how much thermal energy in watts is lost when the absorber plate is coated in different colors. EPDM has a maximum efficiency or the absorbance capability of almost 90% which also varies according to the mass flow rates (M.J.O'Keefe, 1988). For the sake of simplicity a black EPDM material is considered which absorbs almost 86% of the solar radiations (Duro last).

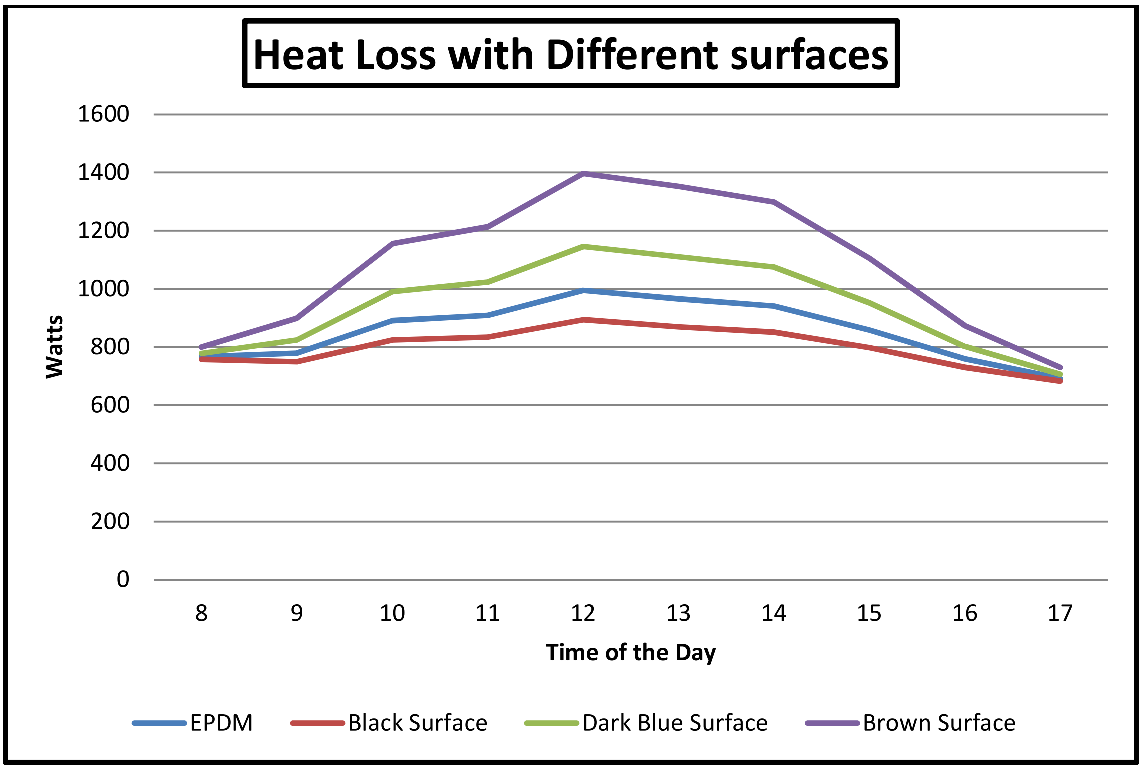


Figure 18 Heat loss for different Materials

This figure shows that the lighter the color of the surface of the absorbing plate, the less solar radiations captures and more is the heat loss. With Brown surface an approx. 1400 watts of solar energy is lost. EPDM material which in used in this solar collector absorb 86% of the solar radiations falling on it (Duro last).

4.2.2 Heat Loss

From the section of Heat loss coefficient, it is clearly understandable the maximum heat loss will during the part of the day where coefficient has the maximum value provided the difference between the inlet and outlet temperature of the fluid remains constant. By plotting the graph of heat loss during the summer and winter season, we will be able observe the how heat loss is a function of ambient temperature.

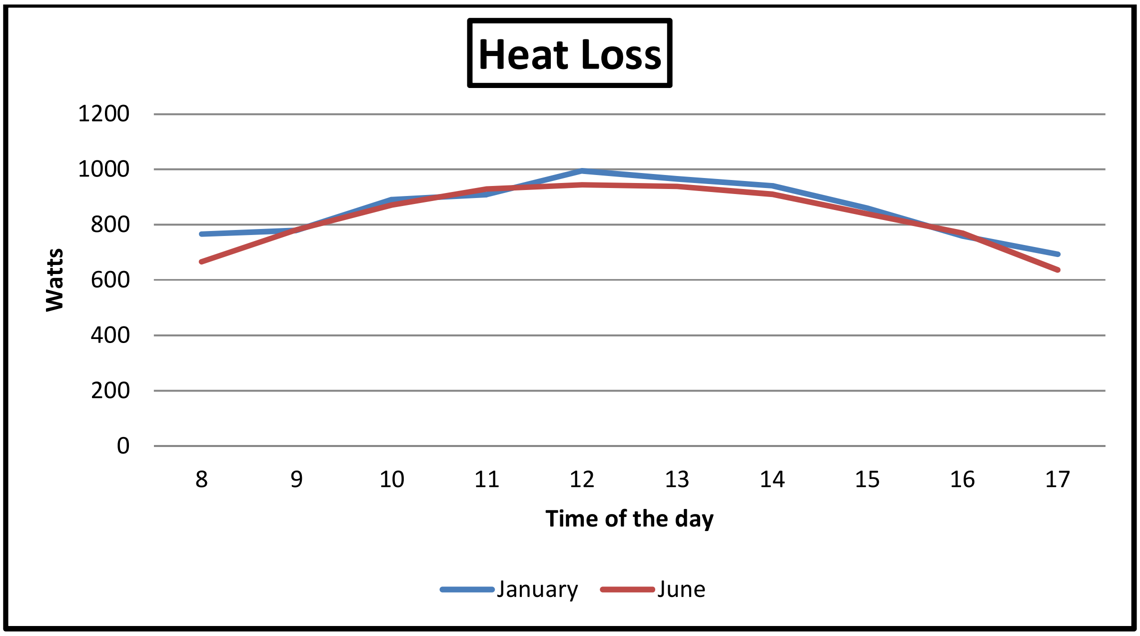


Figure 19 Heat loss in Watts

The above figure indicate clearly how the heat loss in the winter will almost the same as compared to the summer. This can be explained even tough the heat loss is same but during summer more heat is going to be captured, which is further elaborated in the 4.3. Here, winter means the month of January while summer is showing the heat loss of a typical day in the month of June.

4.3 Net heat collected by the Solar collector

Net heat collected by the collector will the difference between the total heat gained and the heat loss during that particular time or

$$Q_{net} = Q_{in} - Q_{out} \tag{14}$$

As from the above sections we did see that the Total Heat gained by the collector in the summer is the greatest and in the month of January is the minimum. But the total heat loss in the winter season was maximum with summer having the least heat loss. This will lead the difference in net heat transferred to the collector during summer and winter even bigger. This can be seen graphically as the line graph shows the line portraying the net heat gained values of the collector even far apart as compared to the total heat gained.

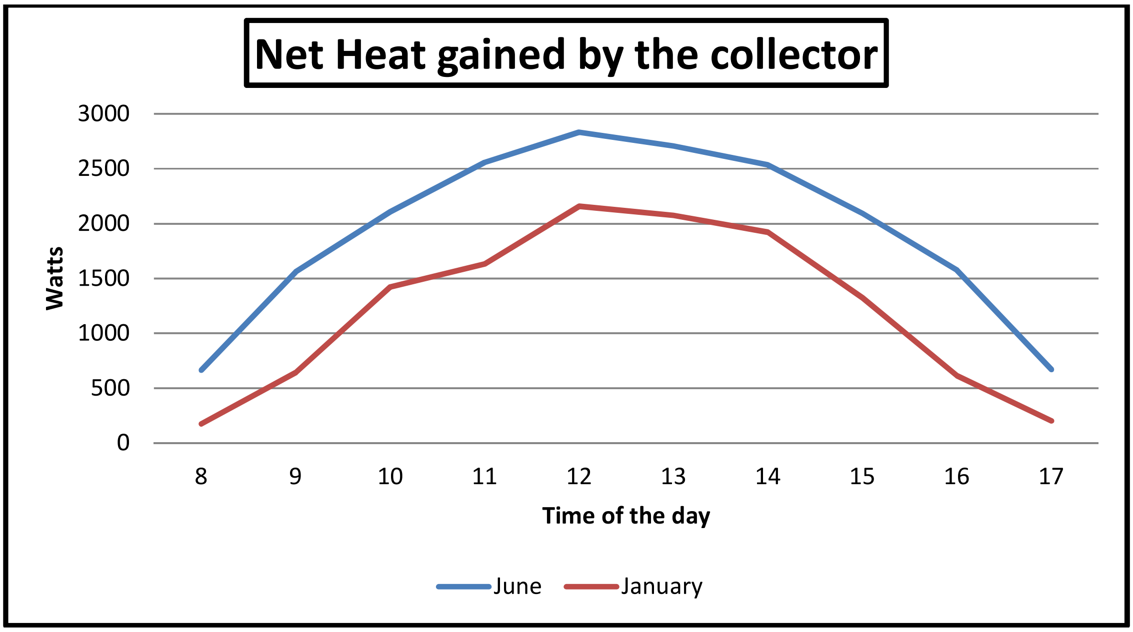


Figure 20 Net heat gained by the Solar collector

The figure 20 shows that the in the month of june almost 2800 Watts are being absorbed by the absorber plate at noon which is the most during the year in Karachi. Furthermore, in winter the heat gained is less than in summer.

4.4.Temperture Achieved

The value of heat gained is a parameter doesn`t give the whole picture of the working of the DSTESC. Exit temperature also provide a complete basis of working of the solar collector. The Temperature achieved is a function of heat gained by the collector, mass flow as well as the inlet temperature of the water. Mathematically,

$$Te = Ti + \frac{Q_{net}}{mC_p} \tag{15}$$

here,

Q_{net} = Net amount of heat gained by the collector

m = mass flow rate of the collector in kg/s

C_p = Specific heat capacity

Ti = Inlet temperature of the water

To = Outlet Temperature of the water

The temperature achieved is a function of heat gained by the collector and thus, the temperature achieved will be maximum in summer where the solar radiations at its peak.

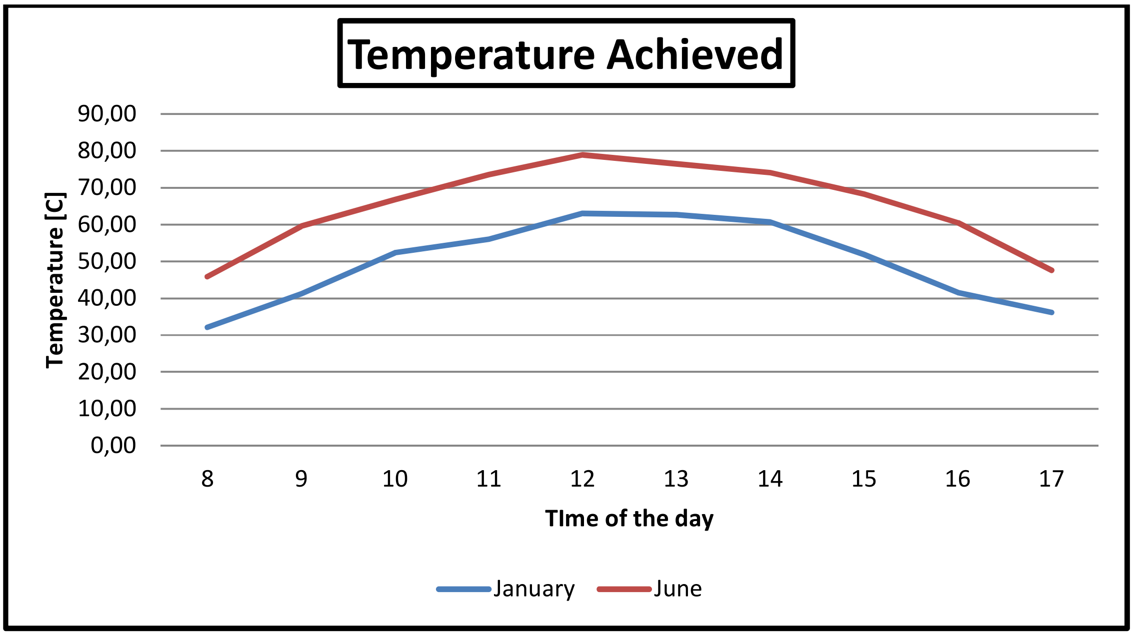


Figure 21 Maximum Temperature Achieved

The temperature achieved even at 9am in the of January is around 40 ℃ and this is where the DSTESC has advantage over it. The flat plate collector wont be start working before 10am in the morning due to the fact of solar angle is way larger than the critical angle at that instance of the day. The maximum temperture during winter, the collector will acheive is approx. 63 ℃ which is more than useful.

Now, keeping in mind that this collector is being designed for the community housing which require approx. 65 litre/ hour flow rate. Therefore, the above calculations only shows the temperature acheived at this particular flow rate. As from the equations, the heated temperature of the water is also a function of mass flow rate, which will also provide a basis for whole new calculations.

If the mass flow rate of the fluid is more than the value given above, the temperature acheived will be way less due to the fact that there will be less time to heat the water. And oppositely, the temperature achieved will be way more if the mass flow rate will be lower than the value corresponding to 65 litre/hour (Shafiq R. Qureshi, 2014).

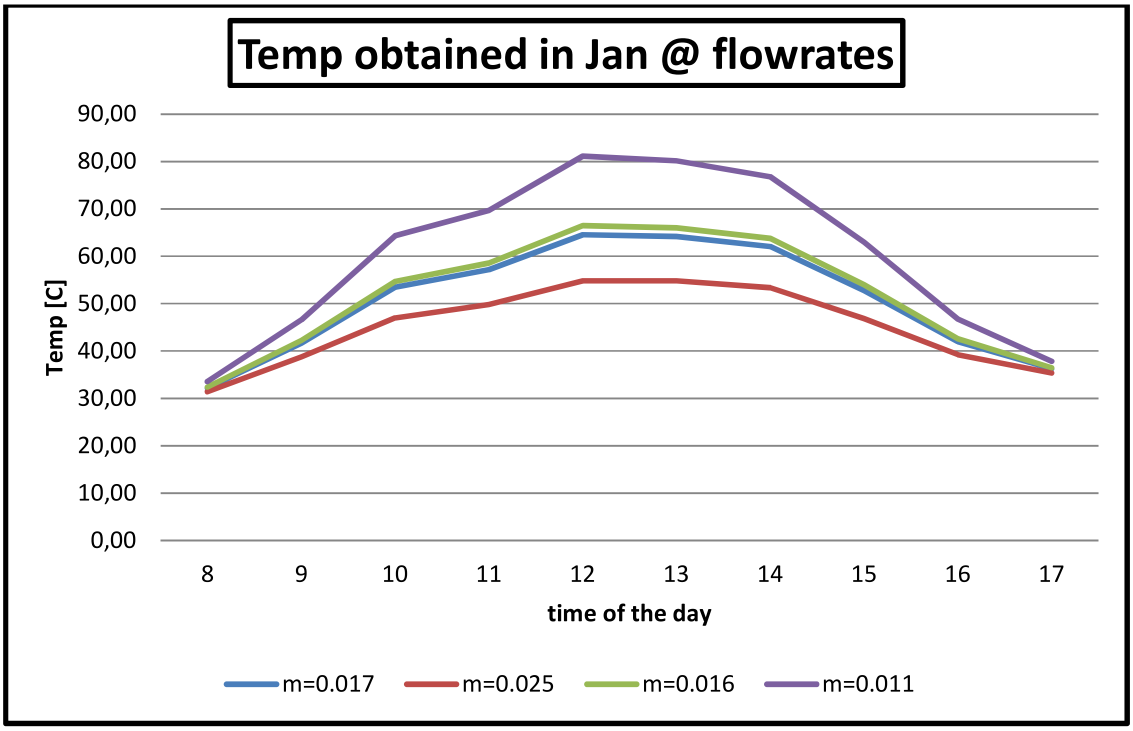


Figure 22Temperature obtained at various flow rates

The figure shows how linearly the temperature of the heated water changes with respect to the changes in the mass flow rates of the rates. All the values of mass flow rates are given in kg/s. 65 litre/hour will correspond to the mass flow rate of 0.017 kg/s.

4.4.1 Temperature Distribution inside the collector

After calculating the maximum temperature the plate can achieve, it is necessary to also find out the temperature distribution inside the collector in order to observe the difference between the flat plate collector and the Double triangular encolosure solar collector. This step is necessary to see whether the heat loss will be more or less in one of the two types of collector. The equation for the detemination of solar collector will be done by solving the Partial Differential Equation of Convective Heat Transfer, which is

We will solving Pde for the given geometry using Matlab

$$\rho CT - \nabla(grad(T)) = Q + h(T_{ext} - T) \tag{16}$$

with,

k=0.0275 (W/m.K)	Thermal Conductivity of air @ Mean Temp
rho=1.1 (kg/m^3)	Density of air @ Mean Temp
C= 1.007 (kJ/kg.K)	Specific Heat Capacity
Text=36 deg C	Cover Temperature
T=70 degree C	Hot Water Temp
h=4.5655 W/m ^{2} .K	Overall heat transfer coefficent

for this purpose, I use Matlab pdetool module which is a Partial Differential Equation Solver Module. It uses Graphical user Interface rather than command prompt.

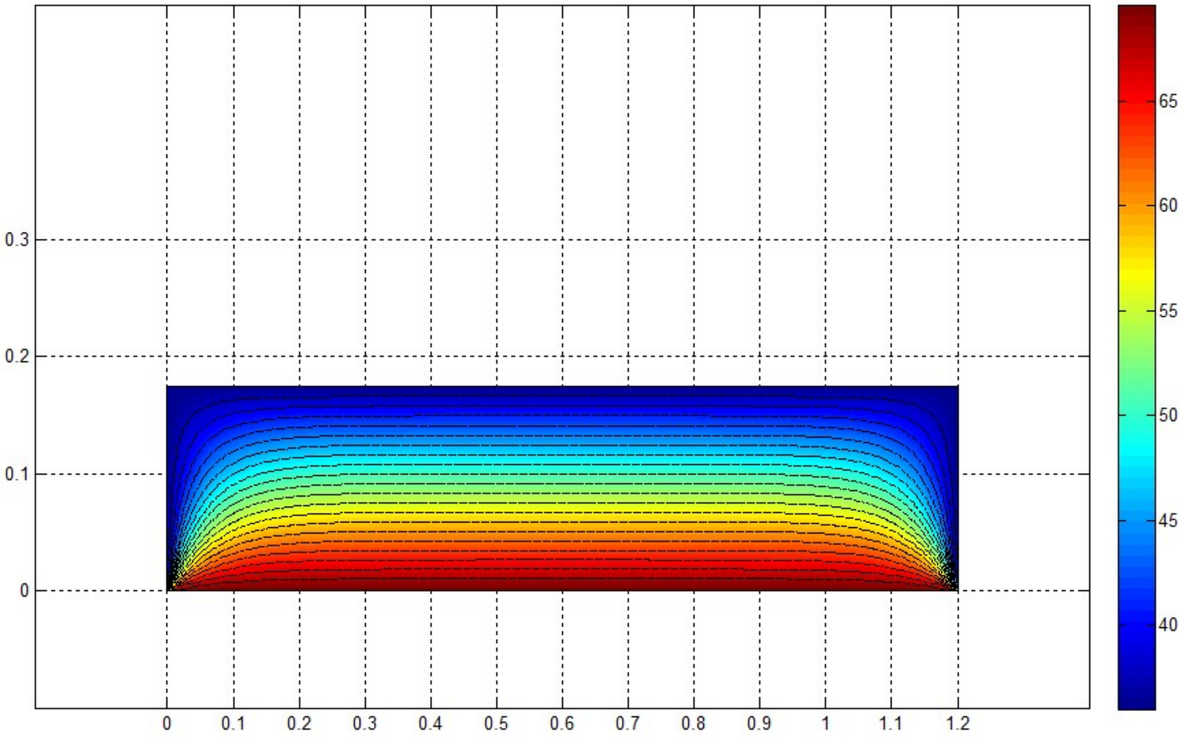


Figure 23 Temperature Distribution of a Flat plate Solar Colector

Since it can be seen as the cover temperature is on the three sides, the heat loss will be from all three sides, But if we see the temperature distribution of doule side triangular enclosure solar collector, It will be interesting story as DSTESC only have two side seprating the solar collector to the environment. By using the Matlab Pdetool and with the same parameters but with the triangular geometry, the temperature distribution obtained is given in the figure

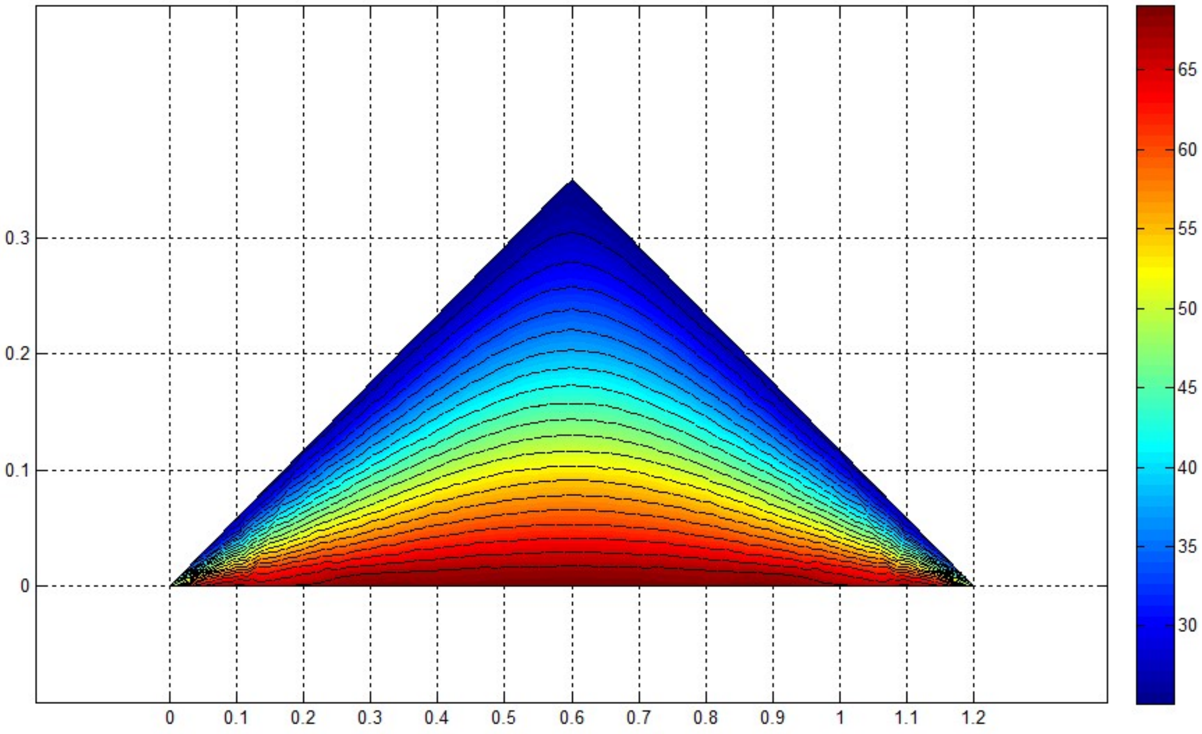


Figure 24 Temperature Distribution of a DSTESC.

The contour clearly represents the maximum and minimum temperatures within the solar collector. The DSTESC temperature gradient is quiet the same as it rectangular counterpart. Which clearly indicates that rectangular solar collector will lose same heat energy if not more than the Triangular one.

4.5 Energy Efficiency

Efficiency is the measure of hou much energy is being converted to heating the water. Energy efficiency is given by the equation 17 which is a ratio of amount of solar radiation captured to the amount of total solar radiation falling on the surface of the collector.

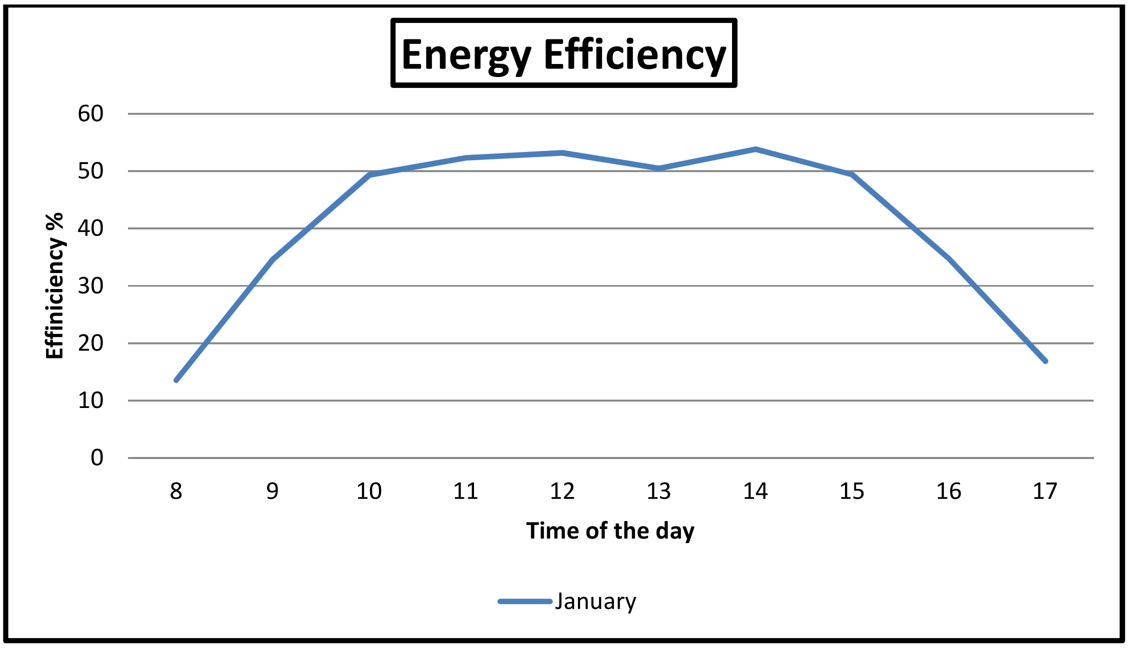


Figure 25 Energy efficiency during the day

The amount of heat gained by the collector is more during the day and thus will lead to higher thermal energy efficiency at the middel of the day.SImilarly, the energy efficieny is minimum at the the morning as well as in evening. .

In the month of January the maximum energy of the solar collector is in the range of 54% which increases in the warmer months , shown n figure 26.

The energy efficiency throughout different months is plotted in figure 25. For the sake of simplicity, the 15th date of each month is selected and is plotted in the figure 25 which also follows the same pattern. In order to take the average of the the whole month of the average accounting for all the days in a month and taking average of it and plotted in figure 26

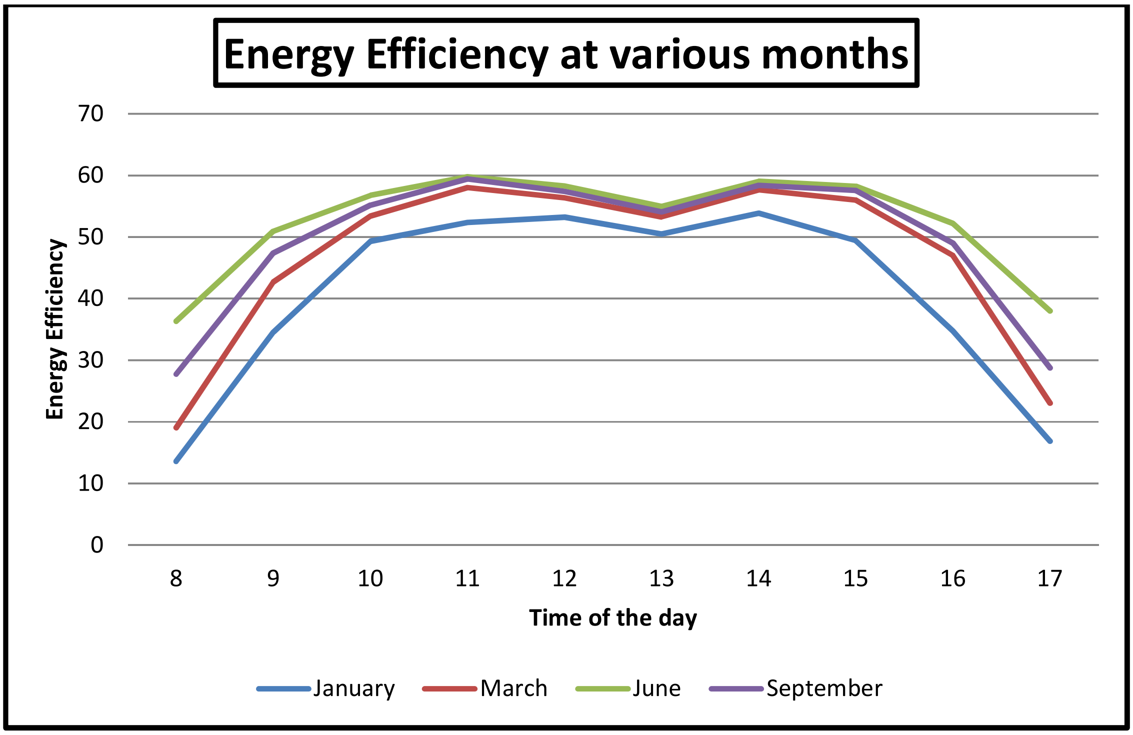


Figure 26 Energy Efficiency at various months

The figure show how the energy effciency is a function of weather conditions all over the year in the city of Karachi. The max average is in the month of June which suggests that the hotter the climate or the more solar radiation is there, the more the energy efficieny of the solar collector is. In the winter season the efficiency is least as the heat loss is the greatest in these months. The dip in the middle shows the changing of the cover surface for the heat absorbance.

4.6 Exergy Analysis

After the energy analysis, it is desired to do exergy analysis of the complete system. Exergy is the useful energy that is being used by the system. Exergy can be destroyed by irreversibility of a process.

4.6.1 Irreversibility

There are two main sources of entropy generation in a solar air collector as given by Bejan et al. [14], one due to the friction of passing fluid, and the other one being due to the heat transfer change in ambient temperature. The exergy balance equation for a steadystate and steady flow process is

$$\dot{I} = \dot{Ex}_{heat} - \dot{Ex}_{work} + \dot{Ex}_{i} - \dot{Ex}_{o} \tag{17}$$

Where,

$\dot{Ex}_{heat}$ = Exergy Destroyed due to heat

$\dot{Ex}_{work}$ = Exergy Destroyed due to work

The exergy destroyed due to heat can be given by a simple relation.

$$\dot{Ex}_{heat} = \left(1 - \frac{T_o}{T_s}\right)\dot{Q}s \tag{18}$$

and also since no work is being done by the collector i.e Exergy Destroyed due to work will be negligible.

$\dot{Ex}_{work}$ =0

and the other two components of exergy are as

$$\dot{Ex}_i = \sum \dot{m}_{in}\left[\left(h_{in} - h_o\right) + T_o\left(s_{in} - s_0\right)\right] \tag{19}$$

$$\dot{Ex}_o = \sum \dot{m}_{out}\left[\left(h_{out} - h_o\right) + T_o\left(s_{out} - s_0\right)\right] \tag{20}$$

where,

m=mass flow rate of the fluid

h=enthalpy of the fluid

s=entropy of the fluid

T=temperature

by taking $\dot{m}_{in} = \dot{m}_{out} = \dot{m}$

as the mass flow inlet of the fluid will be equal to the mass flow rate outlet

and replacing by applying basic thermodynamics principles

$$h_o - h_i = C_p(T_o - T_i) \tag{21}$$

$$s_o - s_i = C_p \ln(\frac{T_o}{T_i}) \tag{22}$$

and from the total energy gained by the system (2)

$\dot{Q}s = G.A.\tau\alpha$

we get, the Irreversibility of the solar collector expression as

$$\dot{I} = \left(1 - \frac{T_a}{T_s}\right) G.A.\tau\alpha - \dot{m} C_p\left(T_o - T_i\right) + \dot{m} C_p \ln\left(\frac{T_o}{T_i}\right) \tag{23}$$

Now, we need to calculate the Irreversibility of the solar collector throughout the year. For the month of January it is varied throughout the day in a pattern as shown in the figure 28

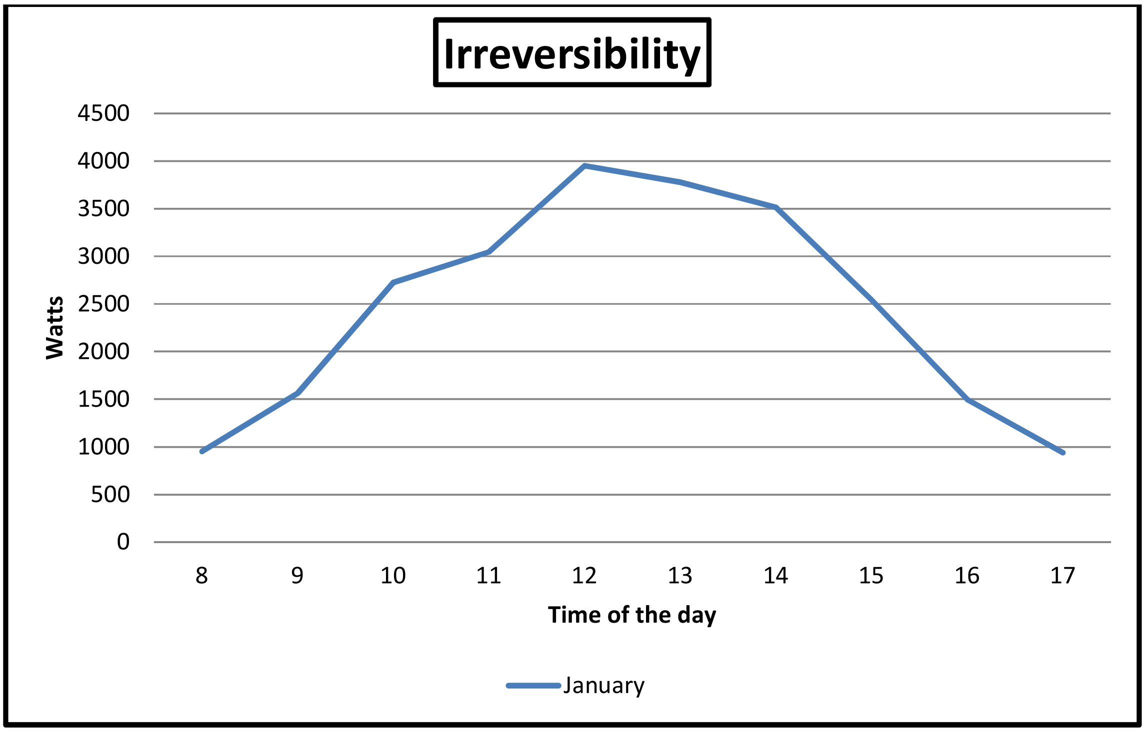


Figure 27 Irreversibility of the solar collector during the day

This means here, the more the ambient temperature or the more the solar radiation is falling on the solar collector, the more the Irreversibility of the system is. As can be seen in the middle of typical day in January, the Irreversibility is higher as compared to the start or end of the day. As we see from equation 23 hat Irreversibility of the system depends upon parameters which are the solar raditaion, ambient temperature and also one of those parameter is mass flow rate. Thus by varying the mass flow rate, the result is shown in figure 29.

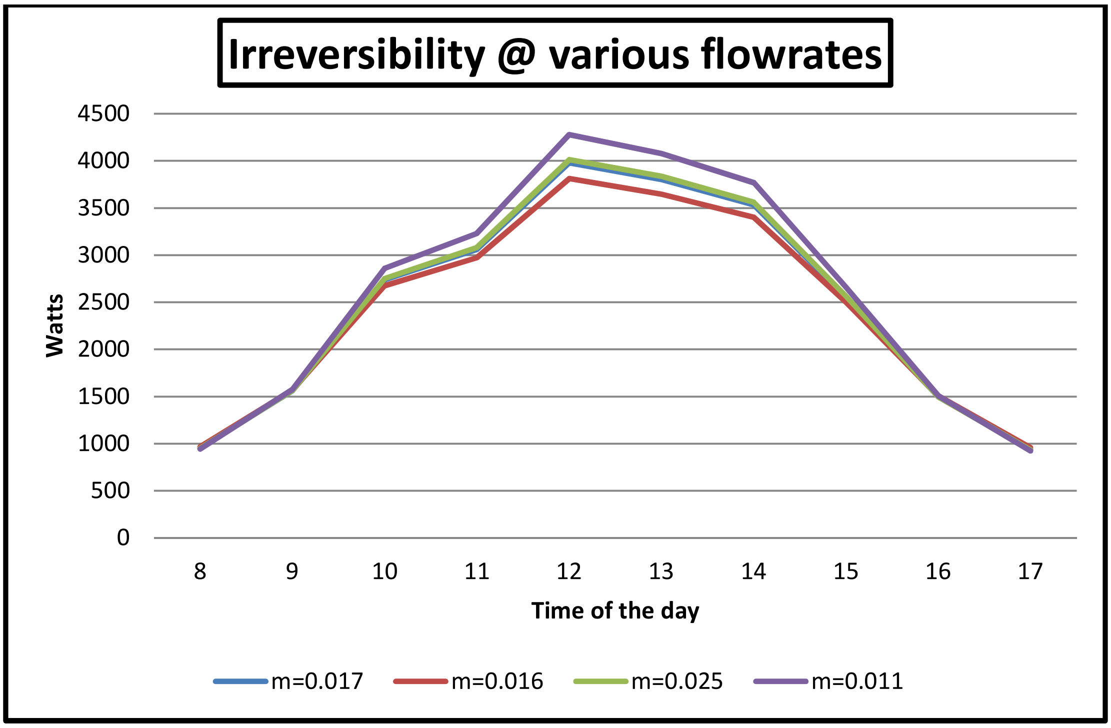


Figure 28 Irreversibility at various mass flow rates

The lower the mass flow rate, the higher will be the Irreversibility. Lower mass rate means higher temperature achieved or more heat transfer occurs which certainly increase the level of Irreversibility of the system.

4.6.2 Entropy Generation

By the definition of irreversibility, it is defined as the product of Entropy generated and the ambient temperature. Mathematically it is given as

$$\dot{I} = \dot{S}_{gen} T_o \tag{24}$$

or alternatively can be written as

$$\dot{S}_{gen}=\frac{1}{T_o}\left[\left(1-\frac{T_a}{T_s}\right)G.A.\tau\alpha-\dot{m}C_p\left(T_o-T_i\right)+\dot{m}C_p\ln\left(\frac{T_o}{T_i}\right)\right] \quad (25)$$

Entropy generation is a function of Irreversibility and Irreversibility is a function of ambient temperature, this will similar plot like the plot of Irreversibility. It also follow the same curve which is of the irreversibility.

4.6.3 Exergy Efficiency

As energy efficiency, calculating exergy efficiency is as important in order to analyze the solar flat plate system for the weather of Karachi completely. From (E.M. Languri, 2009) , exergy efficiency is given as

$$\eta_{ex}=1-\frac{\dot{I}}{\dot{Ex}_{heat}}=1-\frac{\dot{S}_{gen}T_o}{(1-\frac{T_o}{T_s})\dot{Q}_s} \quad (26)$$

In the month of January, as Energy efficiency varied from morning to the evening,the Exergy efficiency round the day will follow the same pattern. In the middle of day it will be maximum and at the start and the end of the day it will be the lowest. The average value of exergy efficiency round the day in the month of January.

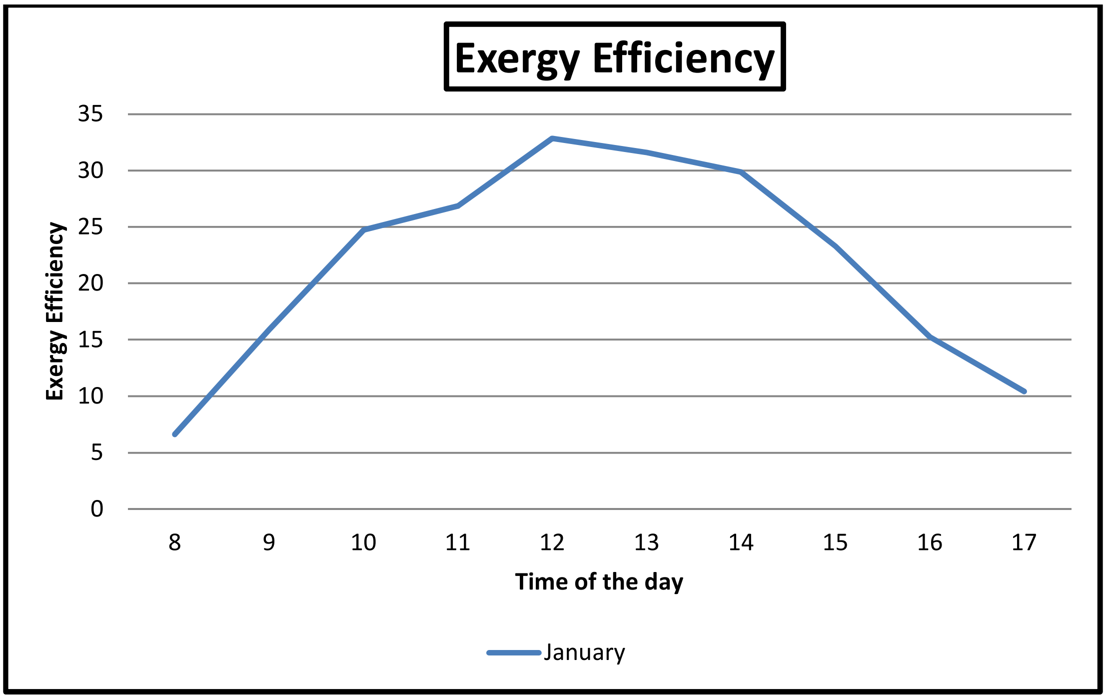


Figure 29 Exergy efficiency

Even though the Irreversibility in the middle of the day is maximum but that doesn`t make exergy efficiency in the middle of the day less. Exergy efficiency rises upto 33% in the month of January. But since Exergy is a function of Irreversibility and Irreversibility is a function of mass flow rate, then it only means exergy efficiency will also vary with different mass flow rates. The more the mass flow rate, the less the time for the fluid to gain heat, which will raise the temperature less and so does will make the Irreversibility and exergy efficiency low with the increase of mass flow rate. It can be represented by the figure 31.

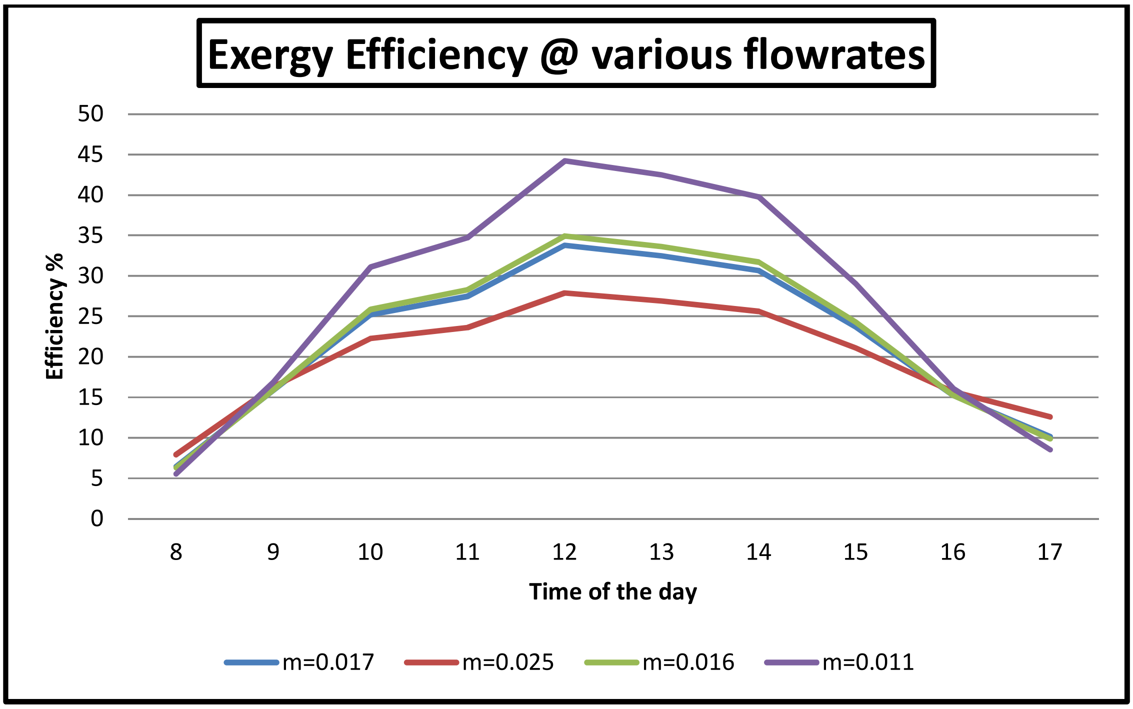


Figure 30 Exergy efficiencies at various mass flow rates January

As seen in the figure, the more the mass flow rate , the less the exergy efficiency of the system. As for greater efficiency, the more time is required to heat the fluid.

4.7 Energy vs Exergy Efficiency

As exergy is the useful energy that is being utilized by the system, which means exergy efficiency is less than the energy efficiency at all periods of time. If we to plot energy & exergy efficiencies on a same graph, it will be like this

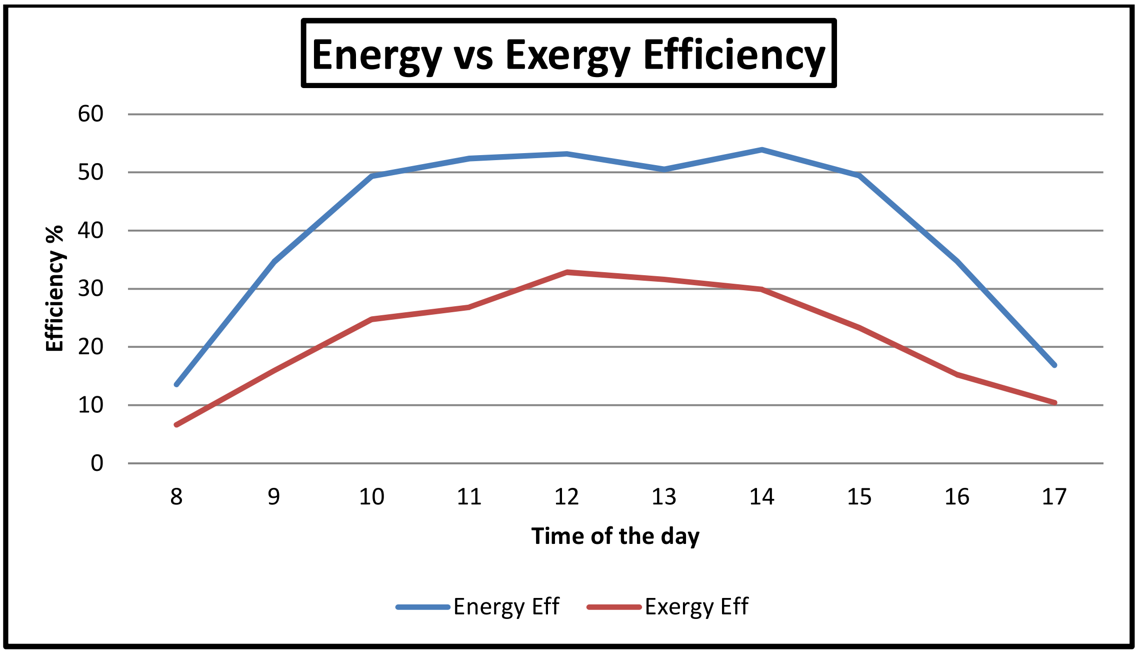


Figure 31 Energy & Exergy Efficiency during January

it clearly shows the performance of the solar collector is a function of solar radiations and the ambient temperature. The figure 32 also show that that there is a large difference between the energy and exergy efficiency.

CHAPTER V: CONCLUSION AND RECOMENDATIONS

5.1 Conclusions

The main objective of the thesis is to evaluate the performance of a Solar collector for the climate of Karachi. This has been done using data taken by various sources and by different tools. All of these evaluations are based on theoretical values rather than experimental values. Various Performance curves have been given during the last section suggests that Solar energy is vastly available for the region of Karachi.

This particular arrangement of solar collector completely has advantage over the flat plate collector. Also it has been observed the higher the solar radiation of the sun falling on the collector, the more efficient the solar collector will become.

Since Hourly solar data obtained was approx 20 years ago and there is no source of current hourly solar data for the region of Karachi, therefore it is difficult to determine the error between the theoretical values and the actual values.

But the main purpose of the selecting this type of solar collector was to evaluate its parameters and compare it to the flat plate solar collector.

And in the figure number 32, it is shown the range of temperature which the flat plate solar collector with the same EPDM and area will achieve the temperature in the month of January.

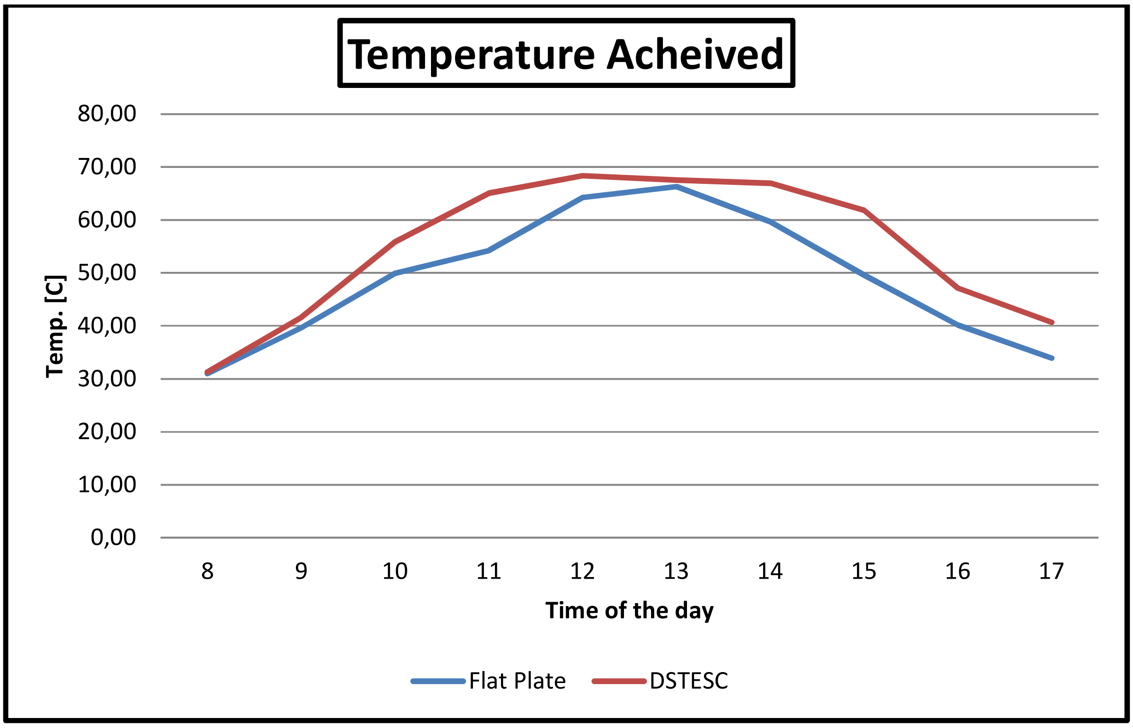


Figure 32 Flat plate vs DSTESC (Temperature acheived)

The figure 32 shows how the temperature achieved with DSTESC is higher than the flat plate collector. In the case of flat plate collector at approx. noon when the angle of incident is 0 degree, the solar radiation is falling directly on the Flat plate collector. But in DSTESC, the solar collector has the sun at 0 degree of incident twice which make it trap the heat twice at maximum intensity. And with the mathematical model showing that the heat loss is less in the case of DSTESC as compared to the heat loss in the flat plate, the overall temperature achieved is more in this type of configuration.

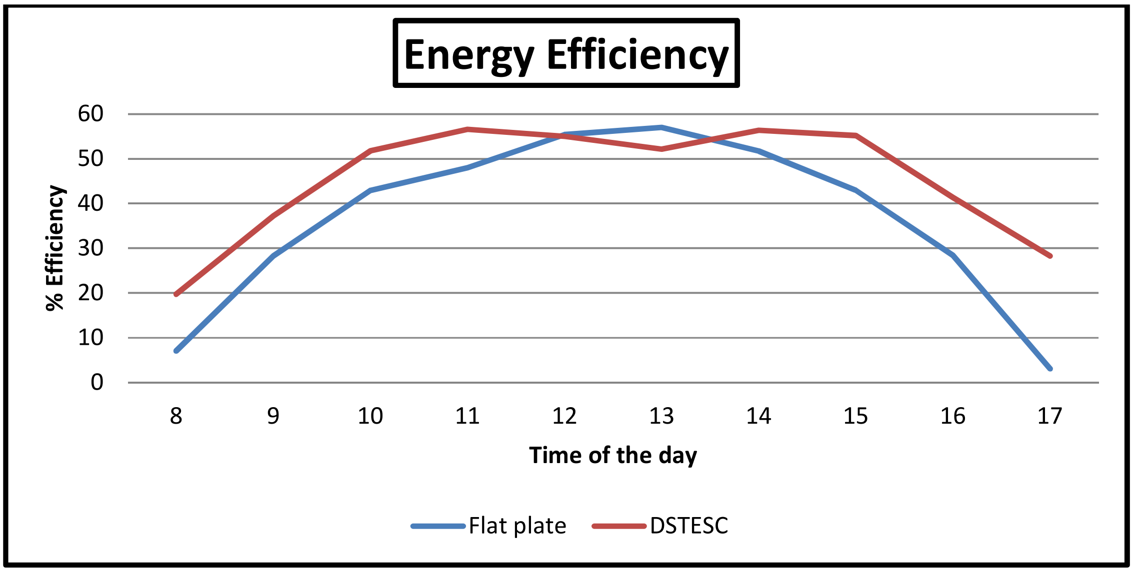


Figure 33 Energy Efficiency (Flaste plate vs DSTESC)

On the whole this type of configuration was more helpful in such a way that where the sun tracking system cannot be deployed which is quite expensive, the DSTESC makes the best possible use of solar radiation without the use of the tracking system. Other than that, it has been written about the various parameters that how they influence the performance of this configuration of solar collector.

5.2 Recommendation

This thesis provide a good basis of the calculation of the solar collector performances. Experimental methods can be applied to this thesis for future work and research. It is recommended therefore that further studies should focus on the experimental values. Furthermore after calculating, an error analysis can also be performed in order to evaluate the performance of this solar collector in real life situation.

Other than that a whole new calculations can be done on further optimization of design of the solar collector. Many more configurations can be analyzed and tested for achieving the optimum design with the maximum thermal efficiency. These new configurations can be redesigning the cover plate for the maximizing the trapping of solar energy as well the selecting the right material for the absorbing plate. It will be of great interest to observe the result using different configurations such as a parabolic solar collector and a flat plate collector with round edges.

In a country like Pakistan, where each year electricity shortfall takes place, this is a one of the way to reduce energy demand for domestic purposes.

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Appendix A

Program for calculating the heat loss coefficient for the month of January

```
% Tpk= plate temperature in Kelvin
% Tc= cover temperaure in celsius (assumed)
% Tck= cover Temperature in Kelvin
% Ta= hourly ambient temperature from 8am-5pm (Celsius)
% ec= cover emittance
% ep= plate emittance
% sigma= stefan-boltzman constant
% Tak= hourly ambient temperature from 8am-5pm (Kelvin)
% Tak2= square of hourly ambient tempertaure from 8-5 (Kelvin)
% hrc= radiative coeffienct from cover to air
% Tp= plate temperature in celsius
% Tm= mean temperature (celsius)
% Tmk= mean temperture (Kelvin)
% L= plate to cover distance
% v= kinematic viscosity
% k= thermal conductivity
% g= acceleration due to gravity
% Ra= Rayleigh Number
% B= tilt angle in radians
% Nu= Nusselt Number
% h= convective heat transfer coefficient
% Ut= overall heat transfer coefficent
% Tc1= calculated value of cover temperature
% Qo= heat loss
% Qin= heat gain
% q= net heat gain


Tpk=70+273;
Tc=[29.5604635358053,32.6721616666302,33.4526193566660,34.2352087630422,34.2
370031813435,35.0189639265837,35.0189345638836,34.2360584326085,33.453500276
8897,33.4525861668075];
Tck=Tc+273;
Ta=[20  24  25  26  26  27  27  26  25  25];
ec=0.95;
ep=0.88;
sigma=5.67e-8;
hrp=(sigma*(Tpk^2 + Tck.^2).*(Tpk-Tck))./((1/ec)+(1/ep)-1)
Tak=Ta+273;
```

```
Tak2=[400   576 625 676 676 729 729 676 625 625];
hrc=ec*sigma*(Tck.^2 + Tak2).*(Tck+Tak)
Tp=70;
Tm=(Tc+Tp)/2;
Tmk=Tm+273;
L=0.4242;
v=17.6e-6;
k=0.0275;
g=9.8;
Ra=(g*(Tp-Tc)*0.7*L^3)/(Tmk*v^2);
B=45*pi/180;
Nu=1.+1.44*((1-(1708*sin(1.8*B)^1.6)/Ra*cos(B))*(1-
(1708/Ra*cos(B)))+((Ra*cos(B)/5830).^0.33)-1);
h=Nu*k/L;
Ut=1./((1./(h+hrp))+(1./(10+hrc)))

Tc1= Tp - (Ut.*(Tp-Ta))./(h+hrp);
Qo=Ut.*(Tp-Ta)
```

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for the Degree of

Master of Science

Thesis: Energy & Exergy Analysis of Double Side Triangular Enclosure Solar Water Heater

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