



MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES
IN PURE AND APPLIED SCIENCES



Design and Performance Analysis of a Compact Solar Energy Panel

Samir Naghiyev

MASTER THESIS

Department of Mechanical Engineering

Thesis Supervisor

Prof. Dr. A. Kerim KAR

ISTANBUL 2015



MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES
IN PURE AND APPLIED SCIENCES



Design and Performance Analysis of a Compact Solar Energy Panel

Samir Naghiyev

524613924

MASTER THESIS

Department of Mechanical Engineering

Thesis Supervisor

Prof. Dr. A. Kerim KAR

ISTANBUL 2015

MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES
IN PURE AND APPLIED SCIENCES

Samir Naghiyev, a Master of Science student of Marmara University Institute for Graduate Studies in Pure and Applied Sciences, defended his thesis entitled “**Design and Performance Analysis of a Compact Solar Energy Panel**”, on and has been found to be satisfactory by the jury members.

Jury Members

Prof. Dr. Abdulkerim KAR (Advisor)

Marmara University

Assist. Prof. Dr. Candeniz SEÇKİN (Jury Member)

Marmara University

Assist. Prof. Dr. Hasan KÖTEN (Jury Member)

İstanbul Medeniyet University

APPROVAL

Marmara University Institute for Graduate Studies in Pure and Applied Sciences Executive Committee approves that Samir Nagiyev be granted the degree of Master of Science in Department of Mechanical, Mechanical Engineering on 21.12.2015 (Resolution no: 2015/29-07).

Director of the Institute

Prof. Dr. Uğur YAŞI

ACKNOWLEDGMENT

Many thanks to Prof. Dr. Abdulkerim Kar for believing in me and providing better conditions to finish this idea and make it real. It was great pleasure to work with him and have his kind relationship. Information that he provided me was invaluable.

My love and my heart pulse for my family, especially for my mother and father. I owe them infinite gratitude. I always appreciated everything that you did for me, you do for me and you will certainly do for me, without you and Allah I would be nothing. I love you both.

TABLE OF CONTENTS

	Page Number
1. Intro.....	1
1.1 Human Development and CSP.....	1
1.2 Intended Purpose of the Project.....	3
2. Design options and selection criteria.....	4
2.1 CSP History.....	4
2.1.1 Modern CSP.....	6
2.1.2 CSP Technology types.....	7
2.2 PV History.....	9
2.3 Solar Spectrum.....	11
2.3.1 Solar Irradiation.....	13
2.3.2 Solar Geometry.....	15
2.3.3 Diurnal Rotation.....	15
2.3.3.1 Declination.....	15
2.3.3.2 Solar Time.....	17
2.3.4 Celestial Coordinate Systems.....	19
2.3.4.1 Horizontal Coordinates.....	20
2.3.4.2 Equatorial Coordinates.....	22
2.4 Optics.....	22
2.4.1 Concentration.....	22
2.5 Heat Transfer.....	24
2.5.1 Radiation.....	25
2.5.2 Convection.....	27
2.6 Geothermal Energy.....	29
2.7 Cu coating.....	30
2.8 Coolant Fluid.....	31
2.9 Kapton Tape.....	32
2.10 Glass wool.....	34
2.11 TEG.....	35
2.11.1 Seebeck Effect.....	35
2.11.2 Optimization of TEG Performance.....	37

2.11.2.1	Figure of merit ZT and Efficiency.....	37
2.11.2.2	Seebeck Coefficient.....	38
2.11.2.3	Electrical Conductivity.....	39
2.11.2.4	Thermal Conductivity.....	40
2.11.3	Advanced TEG materials.....	41
2.11.3.1	TI ₉ BiTe ₆ and TI ₂ SnTe ₅	41
3.	CSP-PV Panel design.....	43
4.	Engineering calculations and Analysis.....	55
5.	Application and experimental studies.....	68
6.	Conclusion.....	75
6.1	Conclusions.....	75
6.2	Recommendations.....	75
References	80

ABSTRACT

This thesis reports on the design and prototype production of a novel solar panel concept that allows high efficiency. Throughout applying this concept, concentrated solar flux heats the Copper sheet to high temperatures and geothermal heat exchanger cools the liquid in low temperatures. Under these conditions, Hot and Cold makes contact with sides of thermoelectric plate and heat exchange between hot and cold spots makes flow of electrons on semiconductor material that generates electrical charge. The mentioned model will produce electric energy, hot and cold water supply for general use (shower, dishes and etc.) and heating and cooling. This kind of application may need connection to smart grid for selling the remaining energy that is unconsumed.

Throughout the present work, concentrated solar flux of 93 lumens on 110x80x8 [cm] panel could get up to 205°C and geothermal heat exchanger cools other liquid to 20°C. The result of such a design is expected as 1000 W/h electrical energy and 90°C hot water, because of heat exchange on thermoelectric plate 50% of heat is losses by heat to electrical charge. With the special design and materials could support system to get higher efficiency and aimed to get 1677 W/h and 90°C of hot water.

Several parameters of the panel will be stable, such as dimension and structure. However, material optimization have bigger effect on efficiency. In that case, special liquid will be needed for higher heat exchange which have higher heat coefficient, specific absorber material that absorbs most of solar flux, special designed optics for better concentration and better material saving heat on liquids.

The development of the system concept, the detailed design and the components sizing are implemented through simulations of the system behavior using software as the Autodesk Inventor and Solidworks for 3D design software, TracePro for optical lens design, CoolPack for thermal dynamic properties, and MathCad for mathematical analyses and formulation.

ÖZET

Bu tez, yüksek verim sağlayan yeni bir güneş paneli kavramının tasarım ve prototip üretimini kapsamaktadır. Bu fikri uygulayarak, yoğunlaştırılmış güneş ışığı yüksek sıcaklıklar ve jeotermal ısı değiştirici bakır levha düşük sıcaklıklar ortamı oluşturur. Bu koşullar altında, sıcak ve soğuk ortamlar, sıcak ve soğuk noktalar arasında termoelektrik plakalı ısı değişimi tarafı ile temas elektrik yükü üreten yarı iletken malzeme üzerinde elektronların akışını yapar. Söz konusu model, elektrik enerjisi, genel kullanım (duş, yemekler ve vb) ve ısıtma ve soğutma için soğuk ve sıcak su temini için de imkanlar sunacaktır. Kullanılmayan elektrik enerjisinin akıllı şebekeye satılması için bağlantı gerekebilir.

Mevcut çalışma boyunca, güneş ışığını simüle eden 205°C sıcaklık ve jeotermal ısı değiştiriciyi simüle eden 20°C soğutucu sıvı kullanılarak 110x80x8 [cm] panelde 93 lümen güneş ışığı yoğunlaştırıldı. Böyle bir tasarım sonucu için termoelektrik plaka ısı değişiminde % 50 elektrik yükü kayıpları oluşabilir. Ortalama 1000 W/saat elektrik enerjisi ve 90°C sıcak su elde edilebileceği tahmin edilmektedir. Özel tasarım ve malzeme ile yüksek verim elde etmek için sistemini desteklemek ve 1677 W/saat enerji ve 90°C sıcak su almak mümkün olabilir.

Panelin çeşitli parametreleri boyutu ve yapısı gibi, stabil şekilde olacaktır. Ancak, malzeme optimizasyonu verimliliği üzerinde büyük etkiye sahiptir. Bu durumda, güneş akışını daha iyi konsantrasyon yapabilecek optik tasarım ve daha yüksek ısı katsayısına sahip yüksek seviyede ısı değişimi sağlayacak emici malzemeler gerekli olacaktır.

Sistem kurulumu, detaylı tasarım ve parçaları boyutlandırma işlemleri Autodesk Inventor ve Solidworks 3D tasarım yazılımı ile ve optik lens tasarımı ise TracePro kullanarak, termal için dinamik özellikleri tasarımı için CoolPack programı ve matematiksel analiz ve formülasyon için Mathcad yazılımı kullanılmıştır.

SYMBOLS

Ac : Projected area (m^2)

Ar : Receiver area (m^2)

CR : Concentration ratio

CRmax : Maximum possible concentration ratio

Tabs : Absorbed Temperature (K)

Ts : Temperature of the Source (K)



ABBREVIATION

CSP	: Concentrating Solar Power
CSP-PV	: Concentrating Solar Power-Photovoltaic
DECC	: Department of Energy's Dish Engine Critical Components
GDP	: Gross Domestic Product
HDI	: Human Development Index
LFR	: Linear Fresnel Reflector
PC	: Parabolic Concentrator
PV	: Photovoltaic
SEGS	: The Solar Energy Generating System

LIST OF FIGURES

	Page Number
Figure 1: World HDI and onsumption.....	2
Figure 2: Pifre's 1878 Sun-Power Plant Driving a Printing Press.....	5
Figure 3: Boing/SES DECC Dish Stirling System.....	5
Figure 4: Four sub types of CSP plants.....	8
Figure 5: Earth's Energy Budget.....	12
Figure 6: Solar Spectrum at the Surface of the Earth.....	14
Figure 7: Climate Graph of Istanbul.....	14
Figure 8: Declination Angles at Summer Solstice.....	16
Figure 9: Declination Angle versus Day of Year.....	16
Figure 10: Sidereal Time Shift.....	17
Figure 11: Shift in Solar Time.....	18
Figure 12: Analemma (Yearly Solar Shift).....	19
Figure 13: Horizontal Coordinate System.....	20
Figure 14: Altitude Angle vs. Time of Day for Istanbul.....	21
Figure 15: Azimuth Angle vs Time of Day for Istanbul.....	21
Figure 16: Receiver Temperature vs. Concentration Ration.....	24
Figure 17: Radiant Flux of a Blackbody.....	26
Figure 18: CuO coating machine.....	30
Figure 19: Cu water vs Al ₂ O ₃ water Thermal Conductivity.....	31
Figure 20: Aquarius satellite covered with Kapton tape and Aluminum film.....	33
Figure 21: Glass wool.....	34
Figure 22: P&N Junction.....	35
Figure 23: Peltier Module.....	36
Figure 24: Thermoelectric parameter	38
Figure 25: Crystal structure of Tl ₅ Te ₃ . Tl: black; Te: red.....	41
Figure 26: Crystal structure of Tl ₂ SnTe ₅ . Tl: black, Sn: cyan, and Te: red.....	42
Figure 27: CSP-PV Schematic.....	44
Figure 28: Geothermal Energy.....	45

Figure 29: Lens.....	46
Figure 30: 45° and 90° angle concentrated Sun rays with Lens.....	47
Figure 31: Concentration of Sun ray on all lenses demonstration.....	48
Figure 32: Sun power concentrated on Blackbody.....	48
Figure 33: Concentration versus Sunlight angle and Surface temperature versus Sunlight angle.....	49
Figure 34: Sunlight angle demonstration.....	50
Figure 35: Heat transfer through the system.....	51
Figure 36: CSP-PV Panel.....	53
Figure 37: CSP-PV parts.....	54
Figure 38: Electron doping.....	65
Figure 39: Temperature in the shadow.....	68
Figure 40: Temperature under the sun.....	69
Figure 41: Concentrated Sunlight on the probe	70
Figure 42: the magnifying glass	70
Figure 43: Uncovered solidier	71
Figure 44: Experiment apparatus.....	72
Figure 45: Hot surface temperature and cold water temperature.....	73
Figure 46: Measured voltage.....	74

LIST OF TABLES

	Page Number
Table 1: Solar energy and surface Meteorology of Istanbul.....	13
Table 2: Pipe surface roughness.....	62
Table 3: Al ₂ O ₃ water consantration properities	62
Table 4: Material electron table.....	65
Table 5: TEC1-12706 properties.....	74

1. INTRODUCTION

Concentrating solar power (CSP) is a unique renewable energy technology, which have the ability to provide electricity, refrigeration and water precaution in one unit. To improve life quality CSP will be extremely helpful for many people around the world who lack the energy needed to live a healthy life.

The world's population depends upon the energy. Health, life styles, transportation with car, life expectancy and education is directly dependent to people's daily energy consumption. These are important factors that determine a person's quality of life.

1.1 Human Development and CSP

One factor to measure the life quality is the Human Development Index (HDI). The HDI combines life expectancy, literacy, education and GDP per capita for different countries. As displayed on Figure 1, electricity use for different countries versus HDI and which is shows how clearly correlation between HDI and electricity consumption per capita.

Electricity provides for people to necessary clean energy to refrigerate foods and medicine, also energy to cook and clean water, and at night when there is little work that can be done outside to read and study. Electricity makes life much easier which small amount of electricity can dramatically change the life of a person. The approximation shows that the power requirement for basic healthy functioning in rural communities is about 0.08 kWh/day/person [6]. This is less than 1% of an average person's usage in the United States, yet most people cannot afford or do not have access to even this small amount.

Nearly two billion people have no access to electricity in rural areas [6]. To develop new infrastructure for these rural areas is mostly not feasible due to the extreme distance or needed totally new connections from existing grids. Because of very low electricity consumption it is not cost efficient to build new power plants in these areas. For solution this energy demand could be fulfilled by small-scale, economical and compact systems which is renewable energy for this purpose.

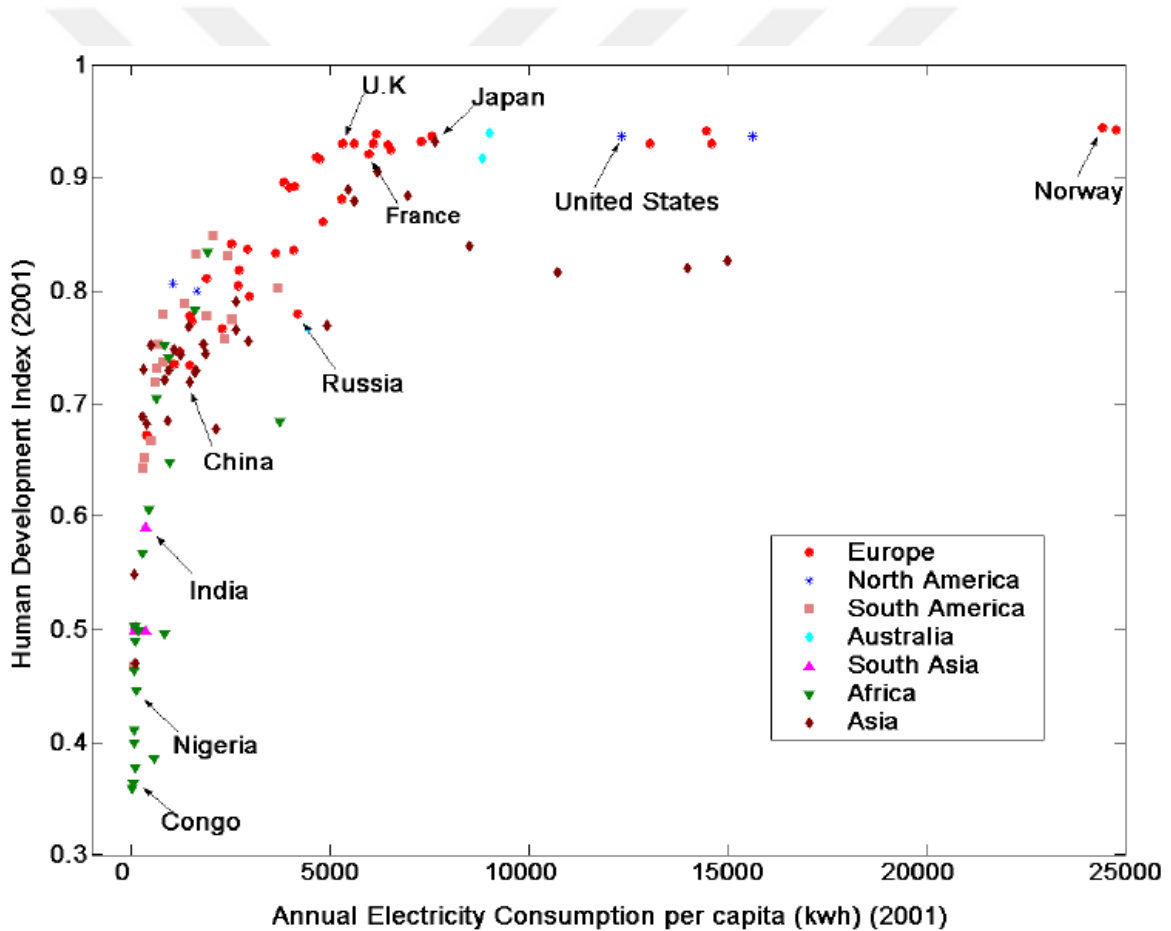


Figure 1: World HDI vs. Electricity Consumption

1.2. Objective of the Thesis

Sun is totally free energy source that provides for natural life every kind of needs. Sunlight makes nature to flourish with photosynthesis. Sun probably produced and delivered the materials which are critical for life such as heavy elements as oxygen, carbon, iron. Sun is the one of the 3 basic fundamentals that needed for the life to exist which are power source, liquid and atmosphere.

Sun is accessible for everyone in our solar system. Sun's power can deliver hot water, electricity and energy. Most areas in the earth receives large amount of sunlight and in average as much as 7.5kWh/m²/day [6]. This great opportunity could be used in advantage to provide the basic energy need in these regions. The most promising technologies nowadays are photovoltaics (PV) and concentrated solar power (CSP). These two technologies are very beneficial in practice. PV panels could be scaled in any size as modules. There are portable models but, they cost more and have low efficiency, but still very useful and promising big developments in time. Most universities and institution even companies are working on them, because the future of humanity depends on energy.

Other thing is less popular but more efficient and can provide not only electricity, hot and cold water, and heating and cooling purposes too. That kind of installation costs somewhere \$10000/kW [7]. But our purpose in this research is to produce low cost compact package for this type of renewable energy that could be accessible.

2. DESIGN OPTIONS AND SELECTION CRITERIA

This research is planned to design and experimentally build an economic solar energy system. The design will provide a PV panel and CSP with specifications which PV panel will be a lot easy to assemble and could be in different sizes and CSP will provide high energy and will be functional. The goal of this research is to provide at least 2 kW of power. The system must be easy enough to be constructed and maintained by non-technical personnel.

2.1 CSP History

Concentrating solar power is using a special method to increase the density of solar power in one area. Magnifying glass can demonstrate the concentration of the sunlight on the sheet of paper and how there will appear a flame is the basic principle of CSP. Sunlight shining on the curved glass is concentrating to a small point. Because all incoming energy is distributed almost evenly all over the surface of paper and then the magnifying glass concentrates this energy to a single point where temperature will rise dramatically. The paper will reach temperatures as high as 250 °C and this will combust the paper.

CSP has been theorized and contemplated by inventors for thousands of years. In ancient Mesopotamia priestesses ignite the altar fire using polished golden vessels. The great Greek scientist Archimedes used concentrated power (287-212 B.C.) [1]. Stories of Archimedes repelling the invading Roman fleet of Marcellus in 212 B.C. by burning their ships with concentrated solar rays were told by Galen (A.D. 130-220)[1]. Athanasius Kircher (1601-1680) set fire to a woodpile at a distance in order to prove the story of Archimedes [1].

Modern solar concentration was started by these scientists. Then solar concentrators were widely used as furnaces for metallurgical and chemical

experiments[8]. The reason that solar furnaces were preferred is they could get higher temperatures which could not be obtained using any fuel. Further applications opened for concentrated power when August Mouchot pioneered generating low-pressure steam to operate steam engines between 1864 and 1878. Abel Pifre made one of his solar engines operate a printing press in 1878 at the Paris Exhibition [1], but after extensive testing he declared the system was too expensive to be feasible. His press is shown in Figure 2. Pifre's and Mouchot's research began a burst of growth for solar concentrators.

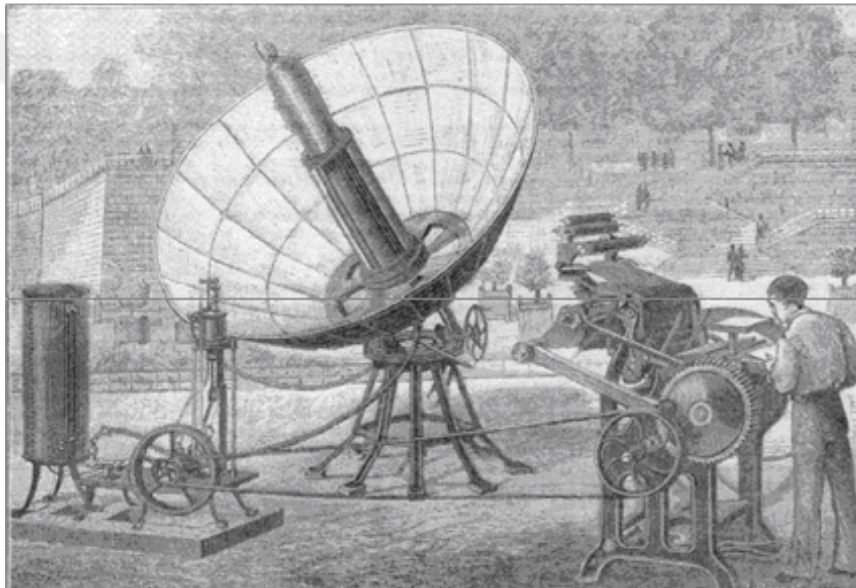


Figure 2. Pifre's 1878 Sun-Power Plant Driving a Printing Press [1]



Figure 3. Boing/SES DECC Dish Stirling System[2]

2.1.1 Modern CSP

The early twentieth century brought many new concentrating projects varying from solar pumps to steam power generators to water distillation. Shuman and boys made 50kW solar pump to pump irrigation water from the Nile in 1912. Steam was made using mirrored troughs in 1200m² collector field [9]. In 1920 J.A. Harrington pumped water up to 5m in to a tank using solar power steam engine. This was the first documented history that using solar power to pump stored water continual from inside a small mine [9].

Until the nineteenth century concentrating technology had made big leap, however explosion of cheap fossil fuels and World War II stopped researches on this technology. Nearly for five years advantage of solar power lost its potion and barely could made inch forward progress. Starting in the late seventies and early eighties, solar power came back to the forefront of researchers' agendas with oil and gas shortages. In 1977 in Shenandoah, GA, 114 7-meter parabolic dishes were used to heat a silicon-based aid for a steam Rankine cycle. The plant also supplied waste heat to a lithium

bromide absorption chiller. Total thermal efficiency of the plant was 44% that made it one of the most efficient system until implemented [3].

One of the modern systems made by the Department of Energy's Dish Engine Critical Components (DECC) project, that was built at the National Solar Thermal Test Facility, the systems thermal efficiency could reach as high as 29.4% which consisted of a 89m² dish [2]. Four high efficient sterling engines in this system converted the heat generated into electricity. Until then it was the most high efficient systems that utilized a steam cycle unmatched than any other cycles.

2.1.2 CSP Technology Types

CSP is a technology that has been popular for several decades already. One of the succeed practices on CSP was Solar Energy Generating System (SEGS) plants in the USA that have been operating over the 25 years and it produced power from solar radiation and all this years it could accumulate 9 TWh by 2002 [37]. The plants were constructed initially to demonstrate the technology and gain operational experience in these new types of plants. By the time oil crisis and expenses of oil based plant bring back the popularity of CSP plant and this ignited again the CSP advantages and there was continually investment on this technology. However, after the construction of the SEGS plants there was a long period in which little new development occurred in the CSP industry due to the oil price stabilizing again. In the last decade Stellenbosch University held to start notice of efficiency and advantages of CSP, of course this interest has been coming from as the climate change started to increase was more noticeable and as well as the fossil fuel prices started to rise again. The rising fuel costs and constant improvements in CSP technology have brought it close to grid parity.

CSP plants used various optical devices to heat fluid and change its phase to vapor to extract work from vapor using a heat engines and all this was came from sunlight. The method of concentrating sunlight as well as the type of heat engine used defines the type of solar thermal technology. Line focusing and point focusing are the

two most common methods of concentrating solar radiation. Concentration ratios are higher for point focus technology but these require two axis tracking as opposed to single axis tracking for line focus type is the most notable differences between the two major solar thermal types is that. Figure 4 below shows examples of the four sub types of CSP plants.

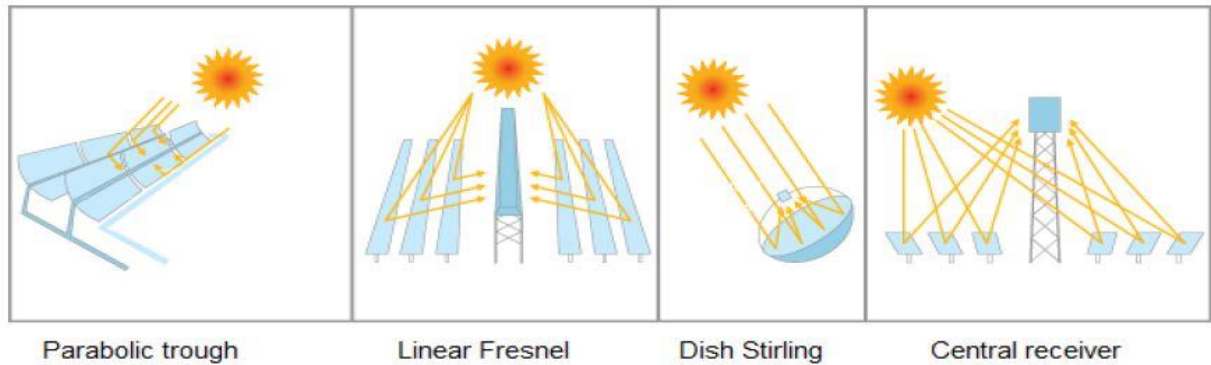


Figure 4. Four sub types of CSP plants

Parabolic trough plants are the most mature of the CSP technologies and the majority of worldwide installed capacity is of this type. They offer an acceptable performance level but some limitations do still exist. The curved mirrors are relatively expensive and aspects such as the need for flexible couplings and strong foundations to combat wind loads result in a high cost per kWh. The scope for future cost reduction is also limited. The other line focusing type, the linear Fresnel reflector (LFR), is comparatively new and offers much potential for cost reduction. It is not as efficient as the parabolic trough but is projected to have a lower investment cost per kWh [38]. The technology also uses simpler parts that could be manufactured locally.

Central receiver plants offer the highest potential efficiency of all CSP plants. The higher concentration ratio and working fluid temperature lends itself to combined cycle operation.

The more sophisticated nature of the technology means that at first, components would be manufactured abroad and therefore contribute less to a local CSP industry. The second point focus type, dish Stirling, and is a very scalable technology in terms of selecting the number of units to match the required load. Dish Stirling has much

potential for small scale off grid applications in Africa. It does not benefit much from economies of scale and therefore may not be appropriate for large base load installations.

2.2 PV History

Way back in 1876 the history of photovoltaic energy (aka. solar cells) was started. As the energy cost started to rise most people started to search for cheaper and affordable energy. One of them is alternative energy. As it is mentioned before there was always solar energy which is waited for billions of year to be harvested in the right way to produce electrical energy or solar power with some or different types of apparatus. For those interested, for more brief history of solar power is below explained how it came to be.

William Grylls Adams along with his student, Richard Day, discovered that when selenium was exposed to light, it produced electricity [39]. An electricity expert, Werner von Siemens, stated that the discovery was "scientifically of the most far-reaching importance"[39]. Maybe selenium cell were not so efficient, however it proved that light not the heat or any moving part could be converted light to electricity.

In 1953, Calvin Fuller, Gerald Pearson, and Daryl Chapin, discovered the silicon solar cell [39]. This time silicon cells produced enough electrical energy that could make work the small electrical devices. The New York Times stated that this discovery was "the beginning of a new era, leading eventually to the realization of harnessing the almost limitless energy of the sun for the uses of civilization."

In 1956 very first solar cells was available for commercially usage. Back then it was very costly even very expensive that anyone could purchase it, which 1 watt solar cell was \$300, this was an unreachable number for major people. Starting 1956 solar cell started to be used in small toys and radios or calculators and this way consumers was shown the availability of solar cell and practices made reliability to the

product.

In the late 1950's and early 1960's satellites in the USA's and Soviet's space program were powered by solar cells and in the late 1960's solar power was basically the standard for powering space bound satellites [39].

In the early 1970's a way to lower to cost of solar cells was discovered. This brought the price down from \$100 per watt to around \$20 per watt [39]. Researches was widely spearheaded by Exxon and most oil companies used solar cells to power waning lights on the top of the off-shore rigs.

The period from the 1970's to the 1990's saw quite a change in the usage of solar cells. By the time major application held in place such as on railroad crossing, in remote places to power homes, even in Australia solar cells used in microwave towers to expand telecommunication capabilities. Even in unhabituated deserts solar cells provided electrical power for pumps to bring water on the surface.

Today in a wide variety of places uses solar cells and solar powered cars are available too. There is even a solar powered aircraft that has flown higher than any other aircraft with the exception of the Blackbird. With the cost of solar cells well within everyone's budget, solar power has never looked so tempting.

Recent new technology provided solar cell more compact version that is very easy for installation and most of roofs are crowded with solar panels, this technology is well known and very popular and elegant way to approach to environment. Most celebrities and actor stared use solar power and bring it another king of populate and it became to most people's favor. All this mode a logical and feasible for industry and manufacture is widely separated over the countries and this industry is one of the profitable

2.3 Solar Spectrum

The Sun's power is coming from fusion reaction collide where hydrogen atoms fused together in high gravity and high temperature and high pressure, which is this collision produces enormous amount of energy. The byproduct of this reaction is huge amount of energy which is form of electromagnetic radiation. This radiated energy can travel infinite distances to nearby planets, such as Earth, or planets millions of light years away and the Sun emits 4×10^{26} W of energy and only 1 out of 7×10^{17} W reaches the Earth [8]. The Earth receives less than one billionth of the Sun's power output [8].

The all energy from sun fusion is carried out with Electromagnetic (EM) radiation. EM radiation is classified by it wave frequencies or wave length. The smallest wavelength of EM radiation is the gamma ray that is at less than 1 pm. The longest wavelength is the Radio wave and start at 1 mm. And other wavelength such as, microwaves, terahertz, infrared, visible, ultraviolet and X-rays are in between these two limits.

Most of the incoming solar energy from Sun is reflected atmosphere, clouds and Earth surface; absorbed by atmosphere, clouds, lands and oceans. A large amount of this incoming energy is radiated to space from clouds and atmosphere, as shown in Figure 5. Comparatively a small amount of this incoming energy is available on land to save.

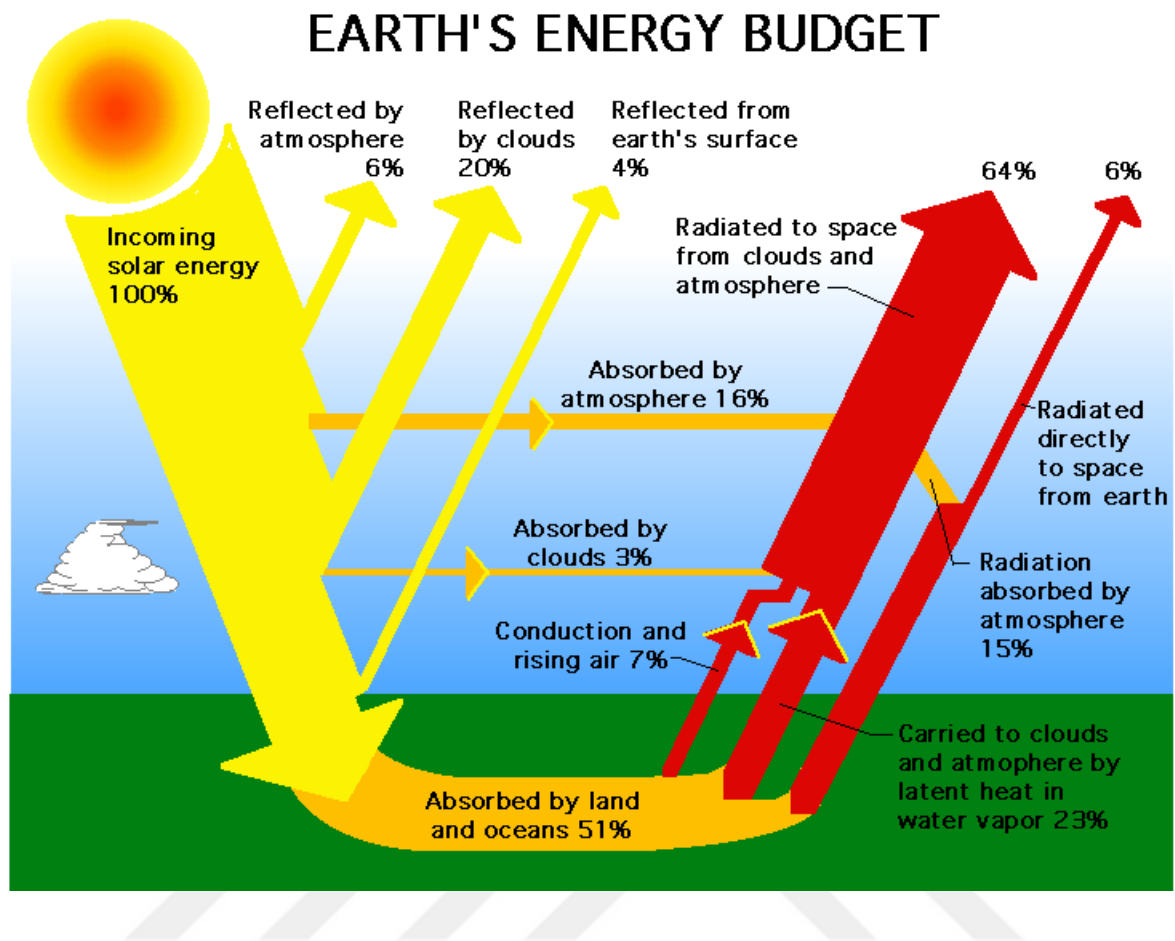


Figure 5: Earth's Energy Budget

The wavelength of the radiation emitted by the sun varies and can be approximated as a black body at 5800 K [1]. Figure 6 displays Earth's energy Budget where how the incoming solar energy radiated and reflected and absorbed. Only 43% of the radiation emitted is visible light, between the wavelengths of 380-750 nm. Of the Solar spectrum 8% of the radiation is ultraviolet, less than 380 nm, and 49% is infrared, 750 nm to 1 mm [8].

2.3.1 Solar Irradiation

All the extraterrestrial radiation that strikes the earth's atmosphere is identified as solar irradiation. This value has been measured as 1367 W/m^2 [3]. Solar flux is not stable which changes throughout the year and it depends on Earth's elliptic orbit and slightly tilted axis. As the extraterrestrial radiation gets through the atmosphere of earth some of this radiation will be reflected back to the space some will be absorbed by land some will be radiated to the space or some will be trapped in the atmosphere where it will make greenhouse effect that displayed in Figure 5 and this way it will keep the earth in the right temperature survive nature and living the creatures. So, this makes life possible on the earth which is mentioned before how important the sun is in process of flourishing life our world. The atmosphere not only keeps some of radiation in even some levels of atmosphere reduces incident solar radiation, it is kind of shelter and it protects life kind of insulation.

Table 1: Solar energy and surface Meteorology of Istanbul

Variable	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Insolation, kWh/m ² /day	1.48	2.20	3.39	4.81	6.35	7.27	7.49	6.47	4.84	2.93	1.78	1.25
Clearness, 0 - 1	0.37	0.40	0.45	0.51	0.58	0.63	0.67	0.64	0.59	0.47	0.40	0.35
Temperature, °C	5.97	5.64	7.60	11.82	16.32	20.71	23.09	23.33	20.57	16.52	11.50	7.59
Wind speed, m/s	6.92	7.23	6.36	5.34	4.86	4.65	5.41	5.77	5.49	6.57	6.42	6.91
Precipitation, mm	121	81	78	51	38	30	28	41	50	90	105	138
Wet days, d	18.7	16.2	14.1	11.0	8.7	6.0	4.2	5.4	6.7	11.6	14.1	17.6

Insolation can be classified into two types: direct normal insolation and diffuse insolation. The radiation that travels through the atmosphere without interference is the direct normal insolation. The scattered by particles in the atmosphere, eventually hitting the Earth at random angles, an effect that can be observed on a cloudy day is the diffuse insolation. This project is deals with direct normal insolation. The average amount of direct normal insolation throughout an average day for each month for Istanbul can be seen in Table 1 [3]. Also solar spectrum at the surface of the Earth is illustrated in Figure 6 and Climate Graph for Istanbul is displayed in Figure 7 [3].

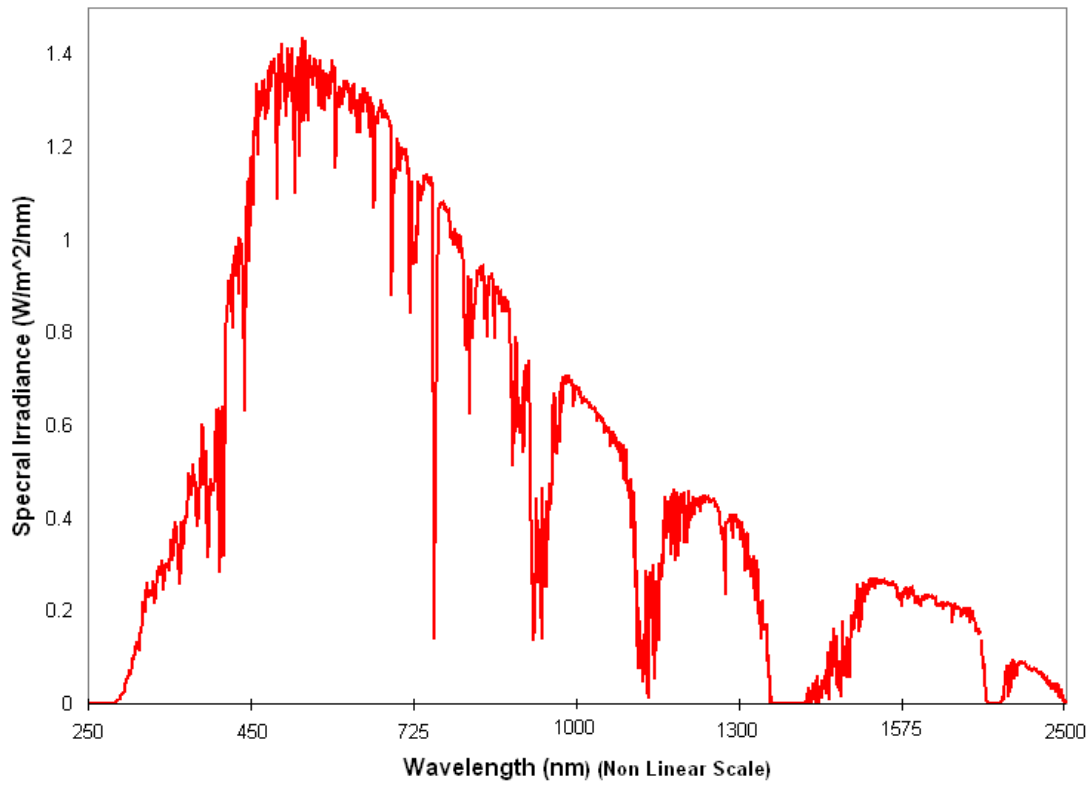


Figure 6: Solar Spectrum at the Surface of the Earth

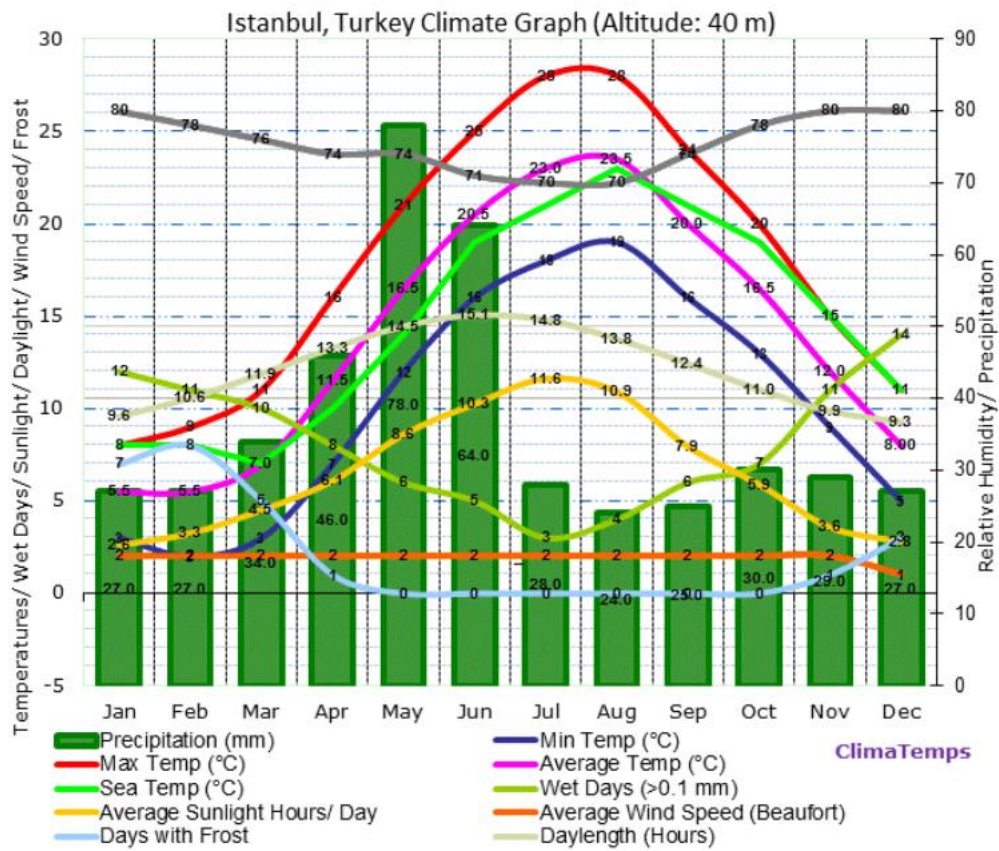


Figure 7: Climate Graph of Istanbul

2.3.2 Solar Geometry

The Earth is rotating about the Sun in an elliptical orbit at a rate of 1 rotation every 365 + 1 days. The Earth is on average 1.5×10^{11} meters away from the Sun [11]. Respect to earth's orbital plane it means pole of earth where earth axis of rotation is tilted at an angle 23.45° degrees. And tilting on the axis of earth makes sunlight and radiation differentiated throughout the year. From June through the September sunrays shine perpendicular to the surface of earth where the northern hemisphere is tilted toward the sun. But in winter months southern hemisphere will be tilted toward the sun and sunlight will hit the northern hemisphere surface at lesser angles. Sunlight will be spread over a larger area and is less intense when the incident sun angle moves away from zenith angle equal to zero.

2.3.3 Diurnal Rotation

Diurnal is the first and most basic motion of the Sun, or daily, rotation. As the earth rotates in its axil in every 24 hour that in seemingly the sun makes an apparent pass around the earth where this rotation is called rotation around the celestial axis. This axis could be different at times from our magnetic axis which is as much as 6° . It works like this way, if we will stand on the celestial equator during the day, the sun will pass directly overhead going from East to West. While the observer was lined up a telescope with an axis pointed directly at celestial north, than the rotation of the telescope will follow the sun 1° every 4 minutes.

2.3.3.1 Declination

Declination is described as apparent height of the sun in the sky. As earth in maximum tilting 23.45° which is accrued in summer is displayed in figure 8 the declination. As this process continuous the period will be fulfilled and it drop to the minimum of 23.45° . Declination cycle is demonstrated in figure 9. In conclusion, declination in principle analyses the movement through the sky in whole year.

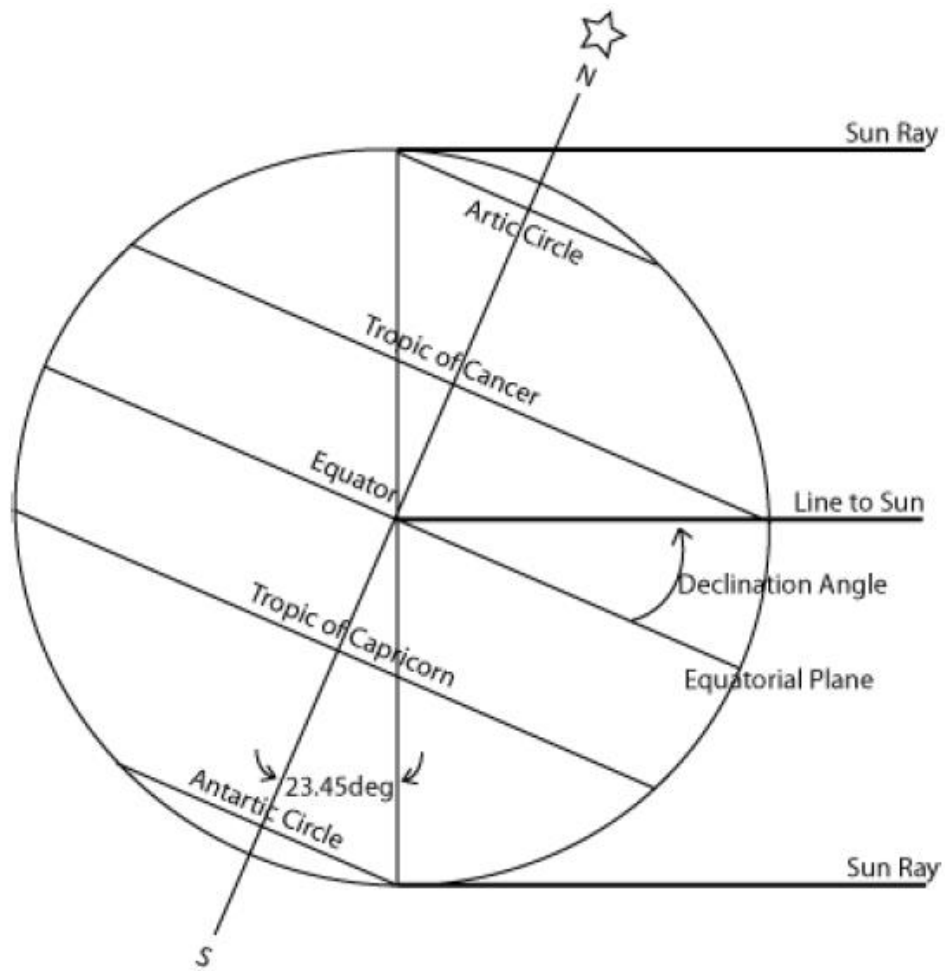


Figure 8: Declination Angle at Summer Solstice [8]

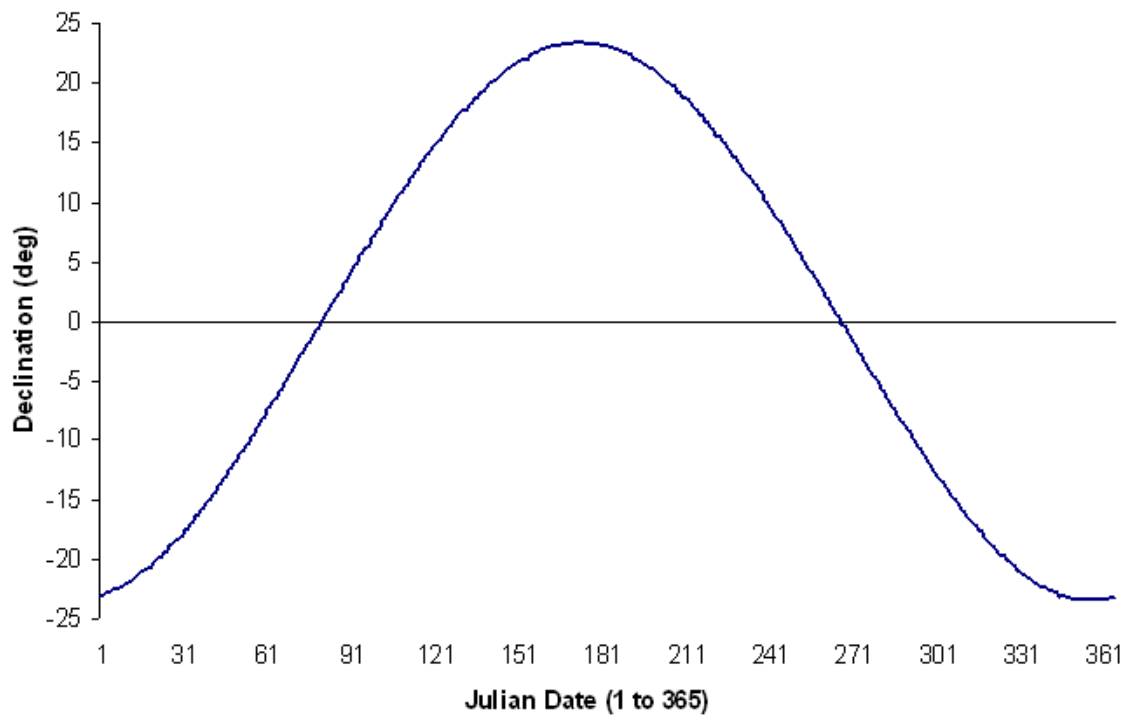


Figure 9: Declination Angle versus Day of Year

2.3.3.2 Solar Time

As the earth is following its elliptical path it crosses narrow sides of ellipse faster but it takes longer to cross the wide side where it visual sticks in same position much longer. Far more understanding of this optical illusion of sun's movement of its elliptical path is demonstrated on Figure 10. The time difference that takes to move from position 2 to position 3 is the mean time, which is the clock time we use in the earth.

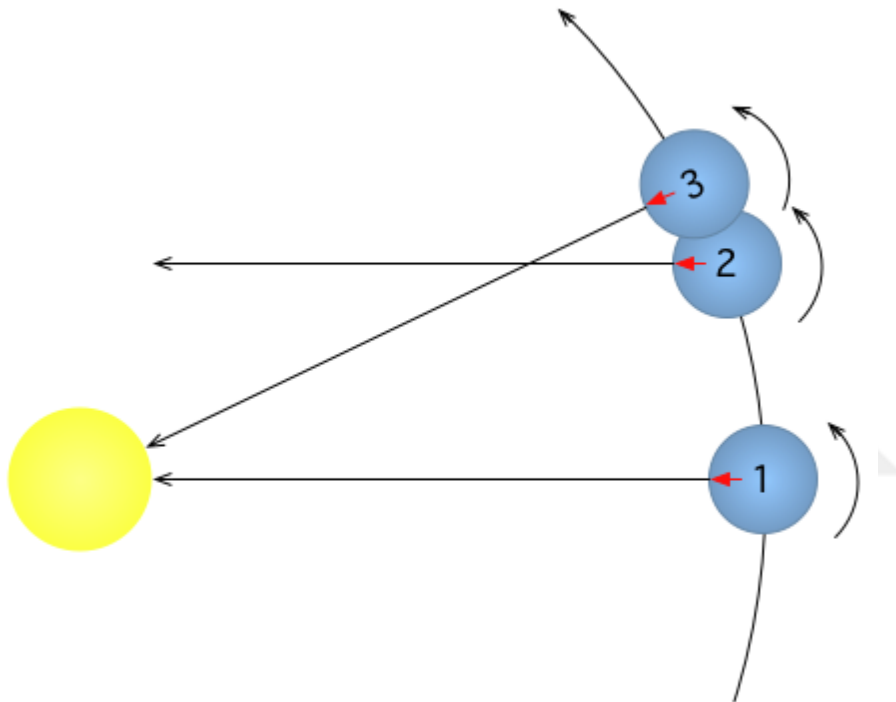


Figure 10: Sidereal Time Shift

As solar time drifts behind, the mean solar time will be ahead. This shift in time is shown in Figure 11. This shifting effect of sun should be counted in calculations, because the lacking will be $-/+4^{\circ}$ throughout the year.

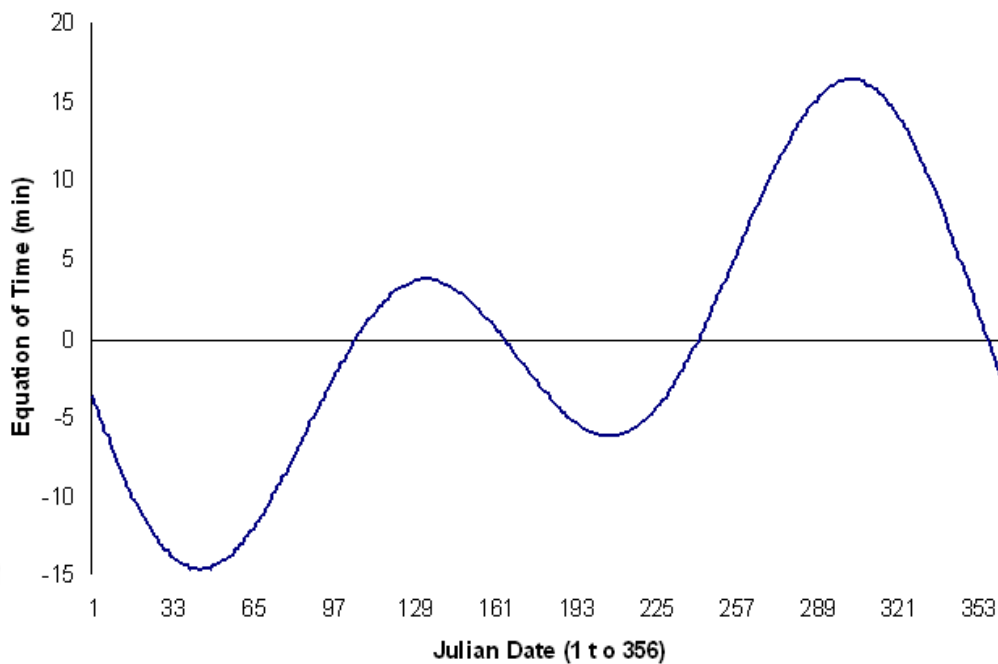


Figure 11: Shift in Solar Time

There are other factors that affect the position of the sun, such as dispersion and refraction, which is the result of as the light gets through the atmosphere there accrues errors. This illusion makes confusion for observe the apparent position where it differ from actual position. During the sun rise and sun set there are being the difference as much as 34 arc minutes, where sun seems to be slightly larger than the viewed size.

The net effect of the two major sources of solar shift can be seen in Figure 12. Figure 12 shows unsymmetrical profile that refers to as an Ana lemma. Ana lemma shows the position of the Sun at the same mean time every day of the year. To create this image it need the 3 parameters. Equation of time and declination is the two greatest factors that creates this image which was already discussed. The third parameter distorts the figure-8 from being symmetric horizontally and is caused by the difference in angle between the apse line and the line of solstices.

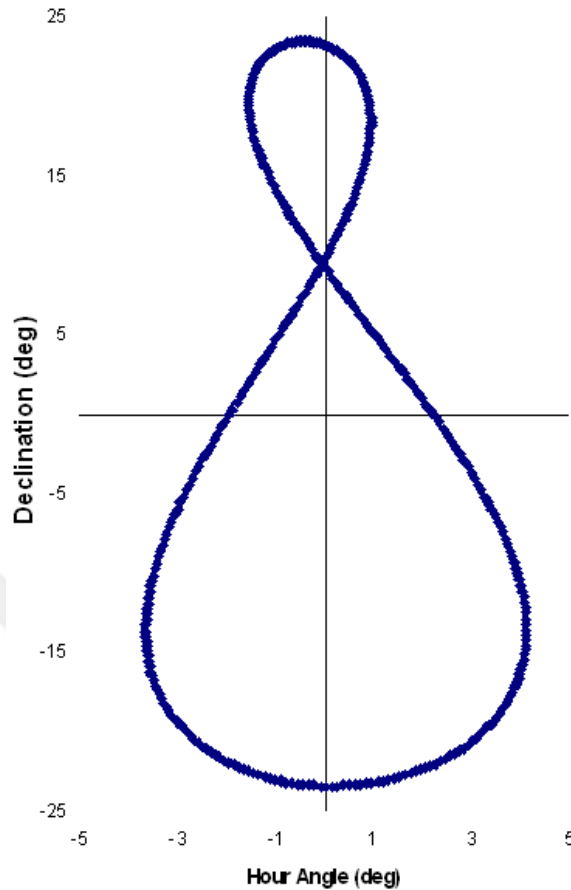


Figure 12: Ana lemma (Yearly Solar Shift)

2.3.4 Celestial Coordinate systems

The celestial coordinate system is important for bodies in the sky to pinpoint the exact position. Astronomers do use this coordinate system and they imagine it as a giant orb that is called the celestial sphere, which is surrounds the earth. This sphere is consist of all stars and planets that is imagined to be pointed on it. To find a particular star two angles are needed to denote the position of a star on the celestial sphere, which can be imagined as two planes. A particular location on the celestial sphere is pointed with a vector which is born where these planes intersect. For our application length of the vector is not important, only the direction of the body in the sky will be used. Coordinates based on different reference frames is given by the celestial coordinate system. To describe the location of objects in space using two coordinates and each system takes a different major axis and plane. There are two different systems horizontal and equatorial, which will be discussed in the following pages.

2.3.4.1 Horizontal Coordinates

The first coordinate system that we will discuss here is Horizontal, or alt-azimuth. If a person standing on the surface of the Earth takes their perceived horizon to be at plane. The zenith is called the normal line to this surface, directly above the person. The angle of a body is above the horizontal plane that described the altitude angle. If it is positive that means everything is above the plan, or if it is negative where everything is below the plane. The other parameter, azimuth angle, describes the angle a body is from a plane parallel to zenith connecting celestial north-south.

The chosen plane is 0° degree azimuth. The clockwise direction that runs in positive direction represents a left-handed. In Figure 13, positive azimuth and negative azimuth are clearly described. Figures 14 and 15 show the altitude and azimuth angle for the Sun for the equinox and solstices.

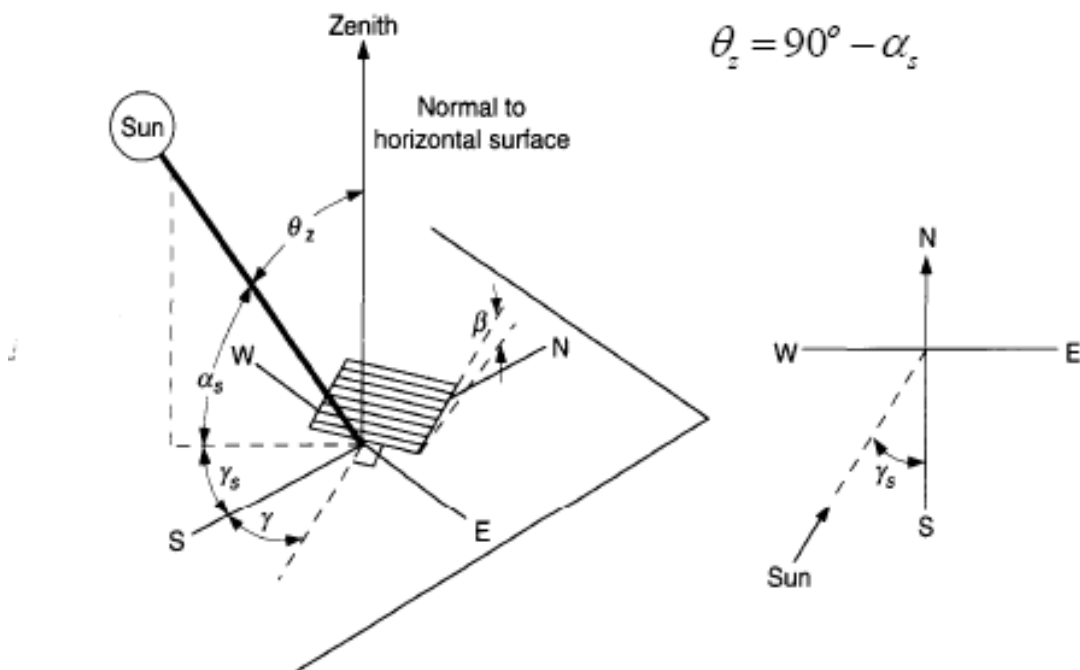


Figure 13: Horizontal Coordinate System

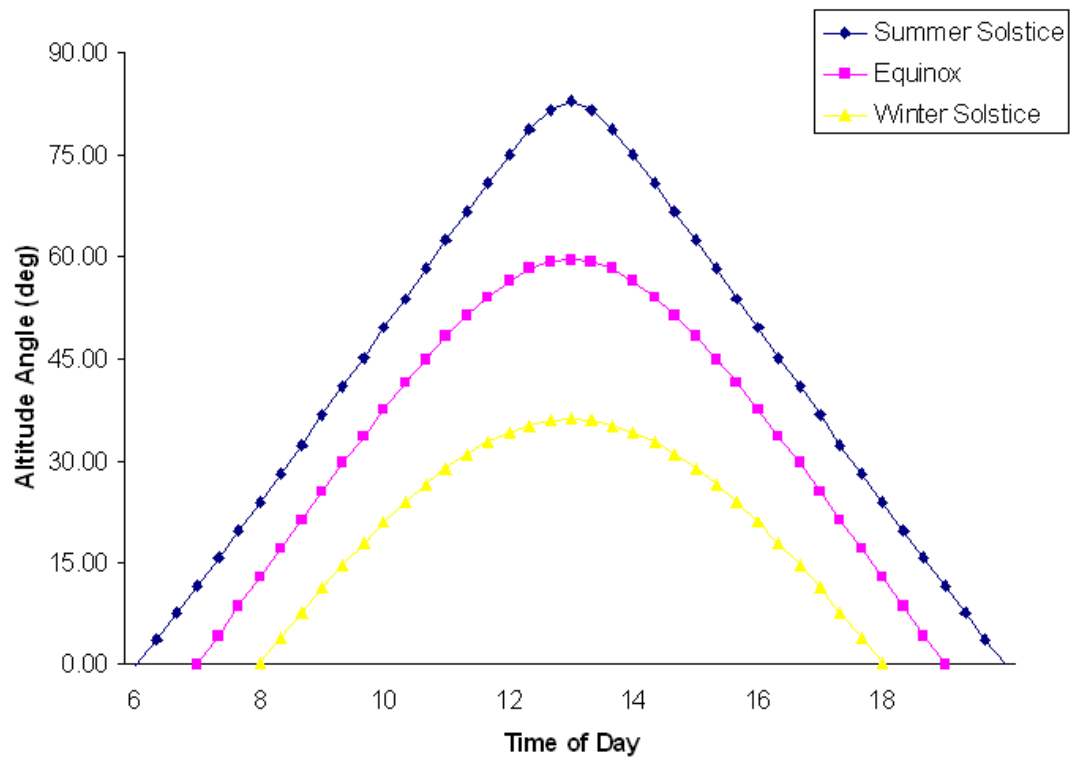


Figure 14: Altitude Angle vs. Time of Day for Istanbul

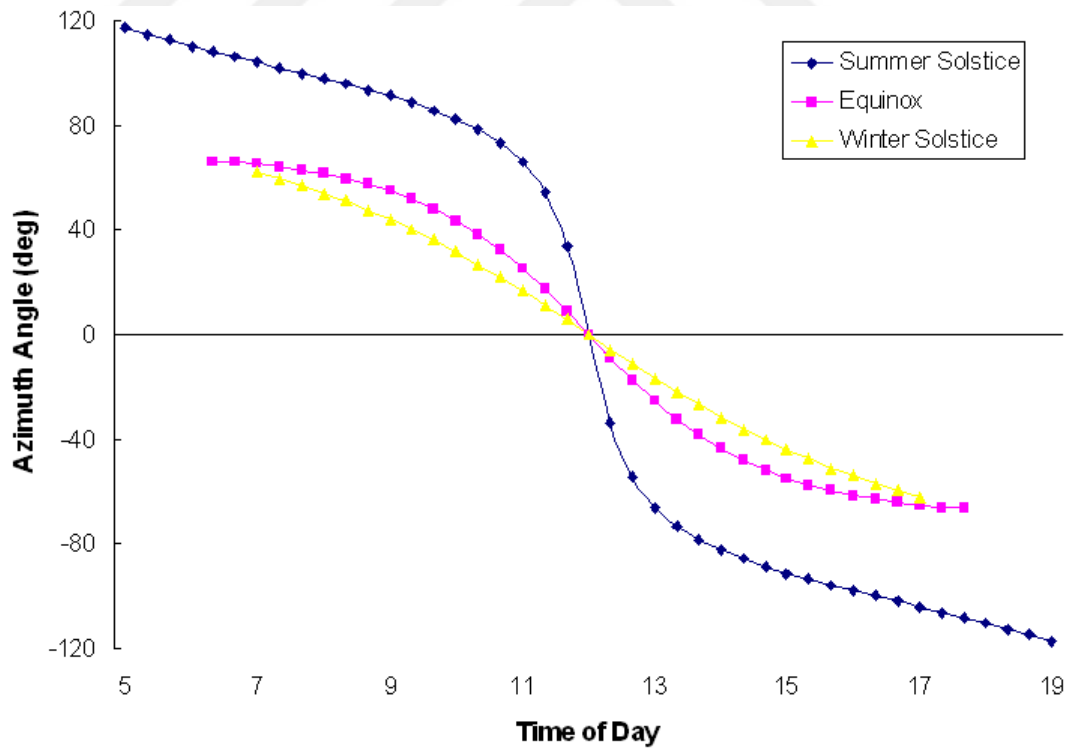


Figure 15: Azimuth Angle vs. Time of Day for Istanbul

2.3.4.2 Equatorial Coordinates

The last coordinate system that we will review is equatorial coordinate system. In the equatorial coordinate system, the fundamental plane lies along the celestial equator. The rotational axis of the earth is the normal vector in this system. Our geographical coordinates analogous to the celestial sphere is partitioned into sections. The angle above or below the celestial equator like latitude is described with Declination. Hour angle (H) is called the other coordinate, which is likened to longitude. The partition the 360° sphere into 24 hours to the hour angle uses units of hours, minutes, and seconds. 15° of arc is equal to one hour angle. The apparent motion of the sun is simplifies with following these coordinate. The change is constant throughout the day at 1° every 4 minutes in hour angle. By no more than 4 tenths of a degree per day is the declination change.

2.4 Optics

2.4.1 Concentration

The concentration ratio (CR) is a performance of the magnifying glass that can concentrate sunlight I one spot. The chosen optical lens is a parabolic concentrator (PC) and given by Equation 1[1] show the concentration ratio calculation formula. Ac is the area that projected with the concentrator, and Ar is the receiver area.

$$CR = A_d / A_r \quad (1)$$

The maximum possible concentration ratio for a 3-D collector with a source half angle is given in Equation 2 [17].

$$CR_{max} = 1 / \sin^2 a \quad (2)$$

As assumed the half angle is $1/4^\circ$ and in that case the maximum concentration with a 3-D concentrator will be around 20. The surface temperature where sunlight was concentrated is depend of the concentration number, temperature will be high as concentration gets higher. PCs are successful method in practice to get high temperatures. Of course it depend on the source temperature as well as concentration ratio. Neglecting conduction and convection equation 3 will give us the absorber temperature on the surface.

$$T_{abs} = T_s \left[(1 - \eta) \times \frac{\eta_{opt}}{\epsilon_{abs}} \times CR \times \sin^2 \theta \right]^{1/4} \quad (3)$$

where

T_s = Temperature of the source (K)

η = Efficiency of transferring heat to working fluid

η_{opt} = Optical efficiency of concentrator system

ϵ_{abs} = Emissivity of absorber

In Figure 16 is graphed as the concentration ratio versus maximum receiver temperature that used usual concentrator.

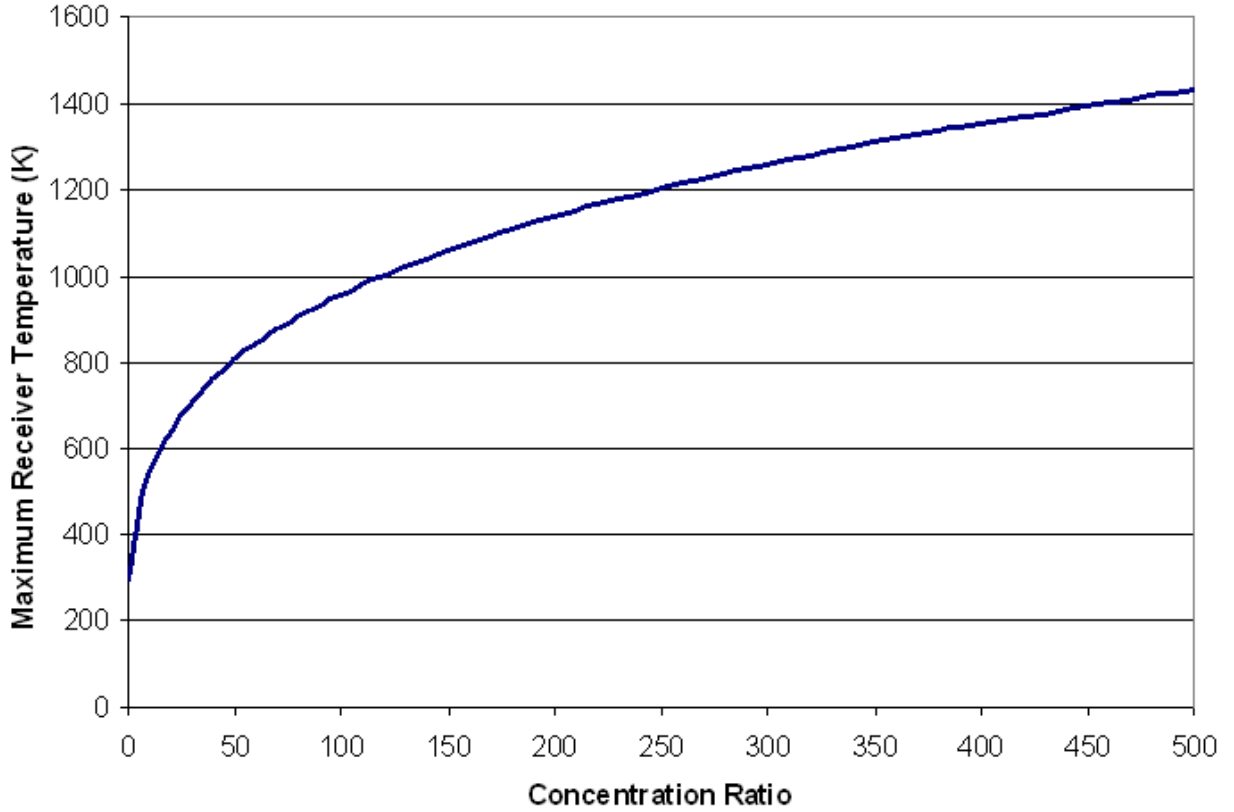


Figure 16: Receiver Temp. vs. Concentration Ratio

2.5 Heat Transfer

All kind of heat transfer will accrue on the receiver surface where concentrator will collect all sunlight on it and will make several line concentration. As the receiver gets to high temperature there will occurs conduction and this way fluid will do its job as it will be heated up with convection. With top view if the system, heat will be transferred with all kinds of modes: Conduction, convection and radiation. Equation 4 will calculate the thermal efficiency.

$$\eta_{therm} = \frac{Q_{out}}{Q_{in}} = 1 - \frac{Q_L}{Q_{in}} \quad (4)$$

In this equation:

$$Q_{in} = A_{dish} \cdot I$$

$$Q_L = Q_{rad} + Q_{conv} + Q_{cond}$$

where

Q_{in} = Energy incident on dish

I = Direct normal insolation

Q_{out} = Energy absorbed by working fluid

2.5.1 Radiation

All kinds of bodies emit the radiation. There is factor that radiation is deepened on such as surface temperature an emissivity. Emissivity is a material property that describes the rate of emission for a surface relative to a blackbody. Planck's law of blackbody radiation explains how a blackbody emits energy at a rate prescribed which blackbody is a material that emits the radiation as shown on Figure 17.

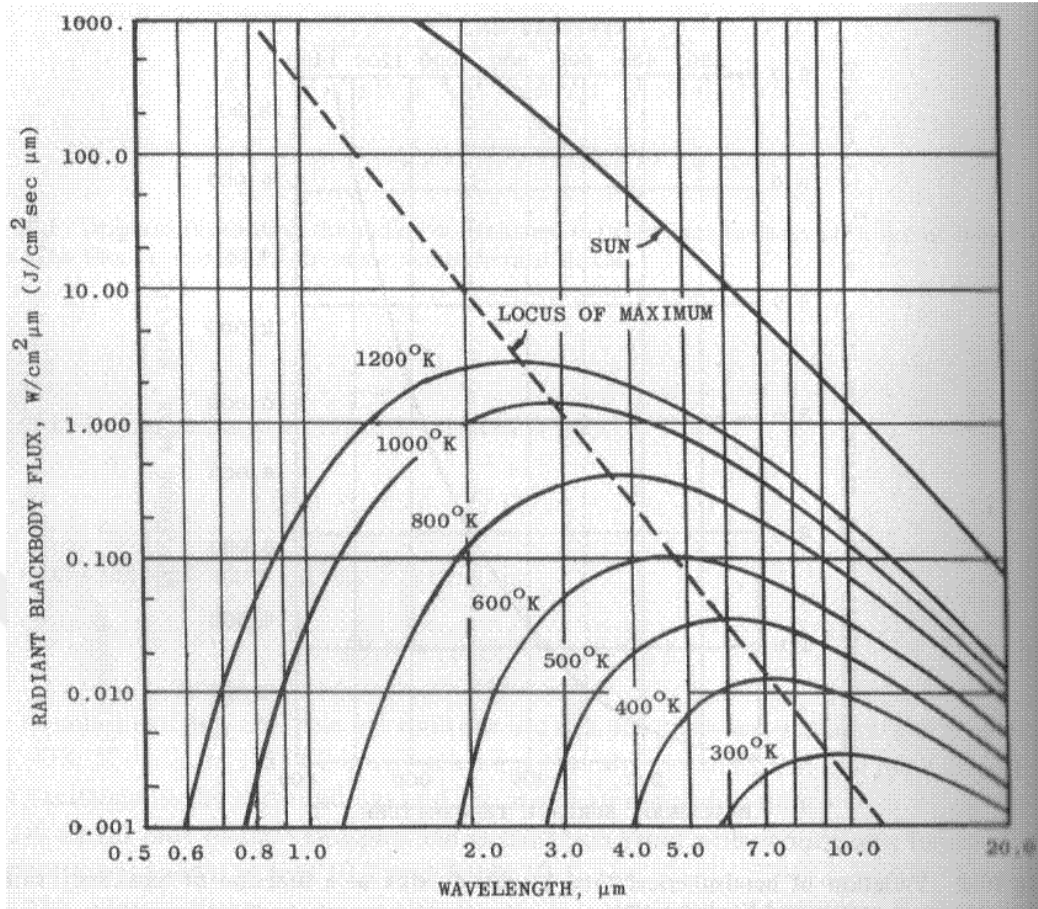


Figure 17: Radiant Flux of a Blackbody [1]

Equation 5 gives the net energy loss due to radiation for a cavity receiver [4]. However, some energy from receiver will be ejected to the wall and surrounding air. In that case to account for this effect there will be used effective emissivity. Equation 6 gives effective emissivity for a cavity receiver [4].

$$Q_{rad} = \epsilon_{eff} \cdot \sigma \cdot A_a \cdot (T_s^4 - T_\infty^4) \quad (5)$$

$$\epsilon_{eff} = \frac{\epsilon_{cav}}{\epsilon_{cav} + (1 - \epsilon_{cav}) \cdot \frac{A_a}{A_{cav}}} \quad (6)$$

where

A_a = Surface area of aperture

A_{cav} = Surface area inside cavity

T_s = Surface temperature of receiver

T_∞ = Temperature of surroundings

In this equation:

ϵ_{eff} = Effective emissivity of cavity

ϵ_{cav} = Emissivity of cavity surface

σ = Stefan-Boltzmann constant

2.5.2 Convection

Convection is another form of heat transfer that needs to use the fluid, in this project there is air and coolant fluid to carry out the heat using the convection. For convection heat transfer there is two case depend on motion, when the surrounding air is stationary than there will be natural convection and if there is motion in fluid this will be forced convection. This project will use both case, where air will have natural convection, but for coolant fluid there will forced convection. Equation 7 shows the natural convection [12].

$$Q_{cond} = \bar{h} \cdot A_{cav} \cdot (T_s - T_{amb}) \quad (7)$$

$$\bar{h} = \frac{\bar{N}_{uf} \cdot k_{amb}}{L} \quad (8)$$

$$N_u = 0.088 \cdot Gr^{\frac{1}{3}} \cdot \left(\frac{T_s}{T_{amb}}\right)^{18} \cdot \cos \theta^{2.47} \cdot \left(\frac{L}{D_{cav}}\right)^8 \quad (9)$$

In this equation:

$$s = 1.12 - 0.98 \cdot \left(\frac{L}{D_{cav}} \right)$$
$$Gr = \frac{g \cdot \beta \cdot (T_s - \bar{T}_f) \cdot L^3}{\nu^2}$$

where

\bar{h} = Average heat transfer coefficient

A_{cav} = Cavity area

T_s = Temperature of receiver surface

T_{amb} = Ambient fluid temperature

\bar{T}_f = Average fluid temperature

N_u = Nusselt number

Gr = Grashoff number

k_f = Thermal conductivity of ambient fluid

L = Characteristic length of aperture opening (diameter)

D_{cav} = Diameter of cavity

ν = Kinematic viscosity

θ = Angle receiver makes with zenith (at $\theta=0^\circ$ the receiver is horizontal)

g = Gravity

β = Volumetric thermal expansion coefficient

While sun at an angle 90° air traps inside the cavity. In that case the hot air cannot escape and the total convection lost can be neglected. By the tilt angle of sun decreases and thus makes convection heat loss get increase dramatically and light air escapes from the cavity.

Convection loss can be modeled and calculated with following equation. In equation 10 Nusselt number is related with surface tension and including the plane.

$$\bar{N}_u = 0.56(Gr \cdot Pr \cdot \cos \theta)^{\frac{1}{4}} \quad (10)$$

$$\theta < 88^\circ; 10^5 < Gr \cdot Pr \cdot \cos \theta < 10^{11}$$

$$T_e = T_w - 0.25(T_s - T_\infty)$$

$$T_\beta = T_\infty + 0.50(T_s - T_\infty)$$

2.6 Geothermal Energy

Geothermal Energy is the biggest heat pump that can be used as go heat exchanger [40], and this source has been used since 1940s. The basic principle is to use ground temperature as heat exchanger for several purposes instead of using the air temperature of surrounding atmosphere. comparing air source with geothermal, in cold winter day geothermal energy can reach up to 300% to 600% thermal efficiencies, while the air energy can only get up to 175% to 250% thermal efficiencies which geothermal energy more ahead. Other case of perfectness off geothermal energy source to use in this perfect , that this source has relatively constant temperature in all seasons, where the air source in winter very cold and in summer can get extremely hot temperatures, which system cannot adapt such system mostly. Temperature underground is depending the altitude and the deep, which has range of 7°C to 21°C. Because this system needs the condenser in summer and evaporator in winter and in this case ground is cooler in summer and warmer in winter than surrounding air.

Geothermal energy in this specification enables to use and gives the free energy source and every location can use this source. For houses it's just couple pipes winded up together and digged in enough deep and covered back. To build this system need very less capital comparing other energy system such as air-conditioning. This kind of models use only water pump to cycle water in the system, and couple meters long copper pipe under ground cover with land to function as heat exchanger. Because this system is easy to build and there is very less parts comparing other systems, it need less maintenance, it's more durable last long, quitter and they do not depend of the air temperature outside.

2.7 CuO Coating

Cuprum black is a great coating material for high absorbing surface application, which is solar collector most applied area. The old fashion technology of coating the surface was with spray and it takes big amount of time to produce one. The black coated surface is copper sheet and coating material is CuO coating that can absorb 97% of energy and emissivity is 50%. This machine in Figure 18 is the process how to make copper sheet that will coat with CuO. It's fast and effective for production.

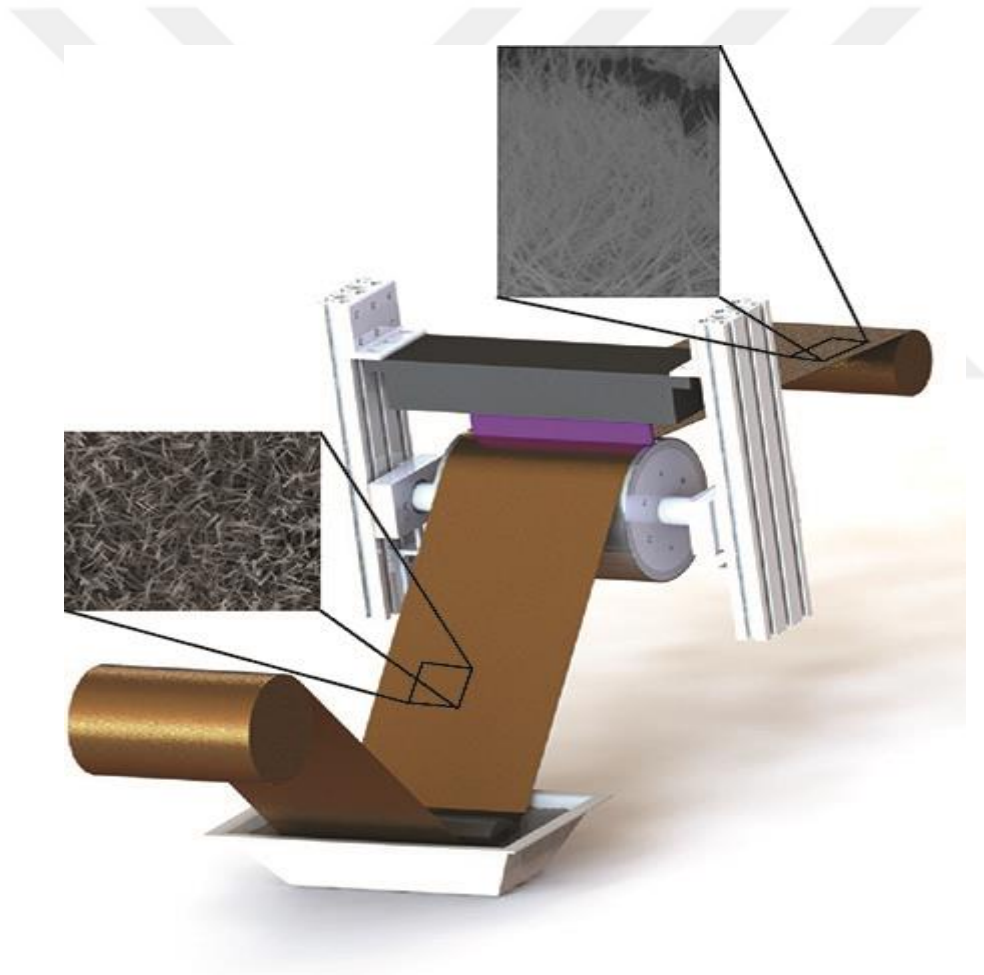


Figure 18: CuO coating machine

2.8 Coolant Fluid

It has been an important issue to increase the efficiency of heat exchange systems. Heat transfer fluids such as oil, water, etc., show poor heat conduction properties. Since thermal conductivity of heat transfer fluids is critical in determining the efficiency of an engine, numerous methods have been adopted to improve thermal conductivity of heat transfer fluids. Crystalline solids have much higher thermal conductivity than fluids. Therefore, fluids containing solid particles have been expected to display significantly enhanced thermal conductivity, relative to pure fluids.

Nano systems have been developed and studied intensively in wide areas, because of their characteristic properties and potential applications [13,14]. As nanotechnology developed, it was proposed that fluids containing nanometer-sized particles could be a new class of engineered fluids with high thermal conductivity [15]. These nanoparticle-suspended fluids, named Nano fluids, have been produced as nanotechnology developed rapidly, and many papers have reported enhancement of thermal conductivity of Nano fluids [16,18]. Increase of thermal conductivity was observed in a large number of Nano fluids, such as CuO, Cu, and Al₂O₃ Nano fluids [17]. CuO Nano fluids showed a 22 % increase of thermal conductivity [16].

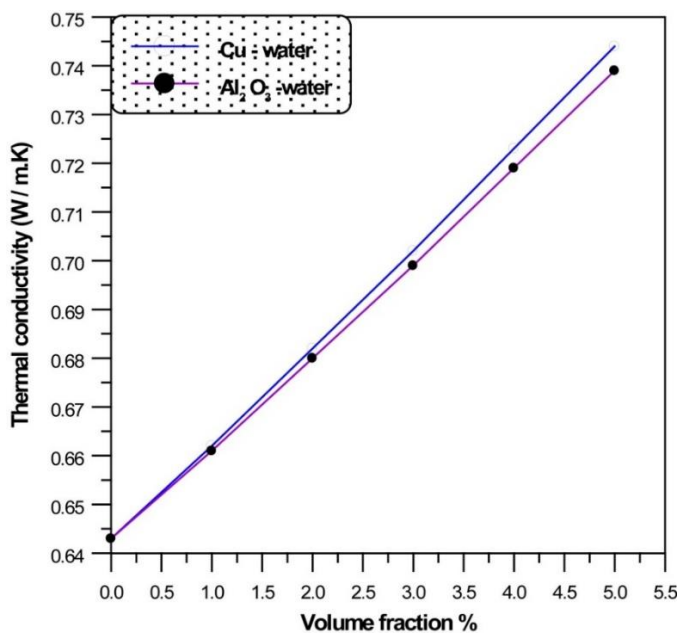


Figure 19: Cu water vs Al₂O₃ water Thermal Conductivity

Large enhancement of thermal conductivity of Nano fluids is hard to predict the effective thermal conductivity using the conventional theories [19,20]. Several methods was suggested to describe potential of experimental results how the thermal conductivity improves with Nano fluid, but there is not an exact mechanism to test that or monitor and it does not know yet how the thermal transport in Nano fluid is happening. Many factors, such as Brownian motion of nanoparticles, particle size, effect of surfactants, dispersion of particles, and thermal properties of dispersed particles, have been expected to influence the thermal properties of Nano fluids [21]. Large surface-to-volume ratio of nanoparticles, compared with micro-sized particles, can lead to potential significant enhancement of thermal conductivity of fluids.

2.9 Kapton Tape

Kapton tape is the most favorite in most application for industries because of its unique properties that combines of best ones. The most known ability of Kapton tape is in base it is polyamide and It have excellent electrical, physical, mechanical properties which could be applied in wide rang temperature surrounds and because of plastic base in could be design in open for any shape. Kapton is synthesized by polymerizing an aromatic anhydride and an aromatic diamine. Because it has no known organic solvent, that makes it excellent chemical resistance. Kapton tape is not flammable and it never burns or melts and have highest flammability rate of V-0

Because of best properties for the material Kapton tape can offer for variable application from extreme high temperature to lowest, it cannot be replaced with organic polymeric substances in this kind of application. Adhesives are available for bonding Kapton to itself and to metals, various paper types, and other films. Kapton polyimide film can be used in a variety of electrical and electronic insulation applications: wire and cable tapes, formed coil insulation, substrates for flexible printed circuits, motor slot liners, magnet wire insulation, transformer and capacitor insulation, magnetic and pressure-sensitive tapes, and tubing [8].

With a unique properties combined together in one material with can be in wide range of shapes one of the perfect form of application is film Kapton tape, so in this case I could be insulated the electrical conductivity in layer of my design which is durable in wide range of temperature, have excellent balance of electrical, thermal, mechanical, physical and chemical properties..

Here is the Aquarius satellite that is made by NASA that covered with Kapton tape and Aluminum film.



Figure 20: Aquarius satellite covered with Kapton tape and Aluminum film.

2.10 Glass wool

Glass wool Insulation have been used and now it is very populate all over the world because of its thermal and acoustic insulation properties, light weight, high tensile strength and exceptional resilience. Glass wool is the mostly used in temperature -50°C to $+250^{\circ}\text{C}$ and it accepted that is mostly suited and well-priced, so that why have wide world marketing price of approximately \$7 billion.

Glass wool consist of inorganic, fine and long fibers bonded together by high temperature binder. Distributed in such a way as to trap millions of tiny pockets of air in the product, the fibers (each of approx. 6 - 7 microns diameter) are creating its excellent thermal and acoustic insulation properties. Because it its superior tensile strength and resilience makes the product ideal for applications in which there will be vibration, jolting or high compression and the product is light gold in color. Glass wool also offers significant advantages during transport and installation because of the light weight and handle ability. In addition, Glass wool is chemically inert and has no impurities such as iron shots, Sulphur and chloride [18]. The product is non corrosive to metal and does not support mold grow.



Figure 21: Glass wool

2.11 TEG

2.11.1 Seebeck Effect

In 1821, Thomas Johann Seebeck [22] found that an electric current would flow continuously in a closed circuit made up of two different metals, if the junctions of the metals were maintained at two different temperatures, as shown in Figure 22 (left). This effect could have power-generation applications, which are currently popular in the automotive industries for utilizing the waste engine heat from exhaust systems.

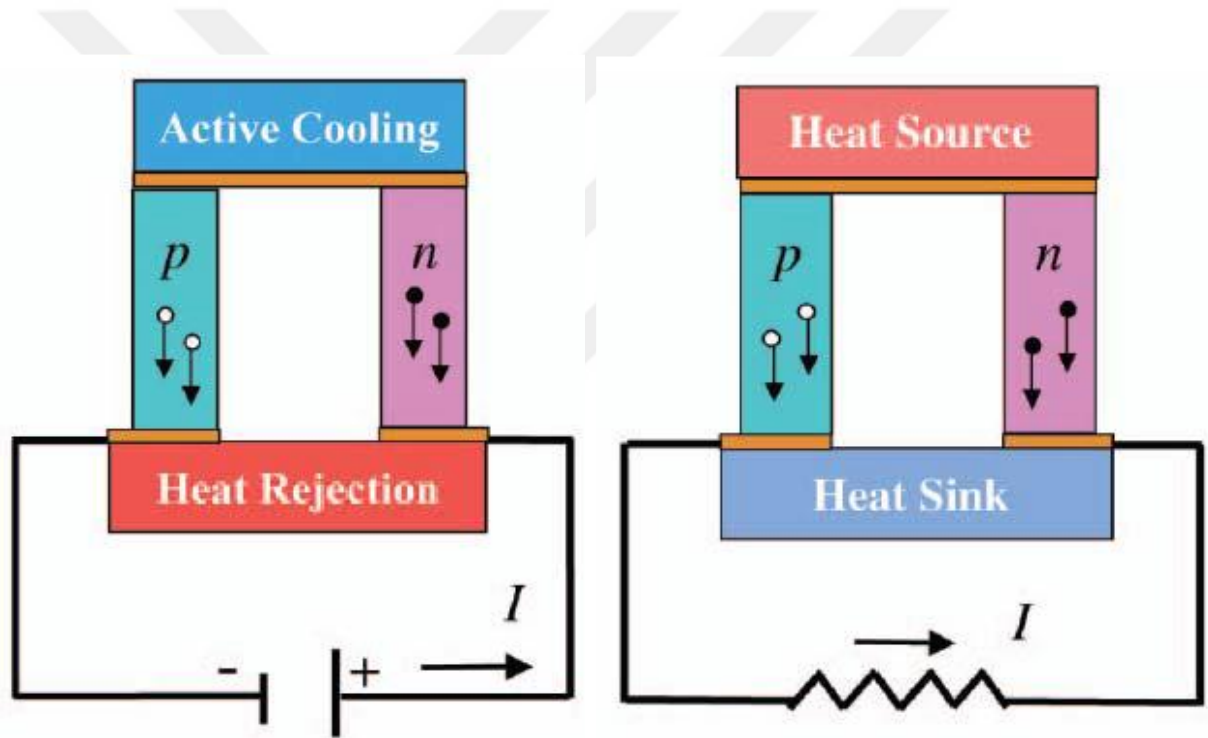


Figure 22: P&N Junction

It was later in 1834 that Jean Peltier [22] found that an electrical current would produce a temperature gradient at the junction of two different metals, which is the reverse of the Seebeck effect (Figure 22 right). The Peltier effect, on the other hand, serves as an idea for the thermoelectric refrigeration to replace the old cooling systems.

Employing the Seebeck effect, thermoelectric power generators convert heat energy to electricity as shown in Figure 22. When a temperature gradient is created across the thermoelectric device, a voltage gradient appears across the terminals. One of the well-known applications is the thermocouple for measuring the temperatures. Other applications for this technology include providing the power for the remote telecommunication, space probes and waste heat recovery for automotive.

When a voltage gradient is applied to a thermoelectric module, the positive and negative charge carriers in the pellet array absorb heat energy from one substrate surface and release it to the substrate at the opposite side. Using this simple approach to heat pumping, thermoelectric technology is applied to many widely varied applications: portable refrigerators, scientific thermal conditioning and so forth.

A typical thermoelectric module, shown in Figure 23c, consists of semiconductor pellets that have been doped so that there is only one type of charge carrier. The n-type or p-type pellets are arranged in order to be connected electrically in series, but thermally in parallel.

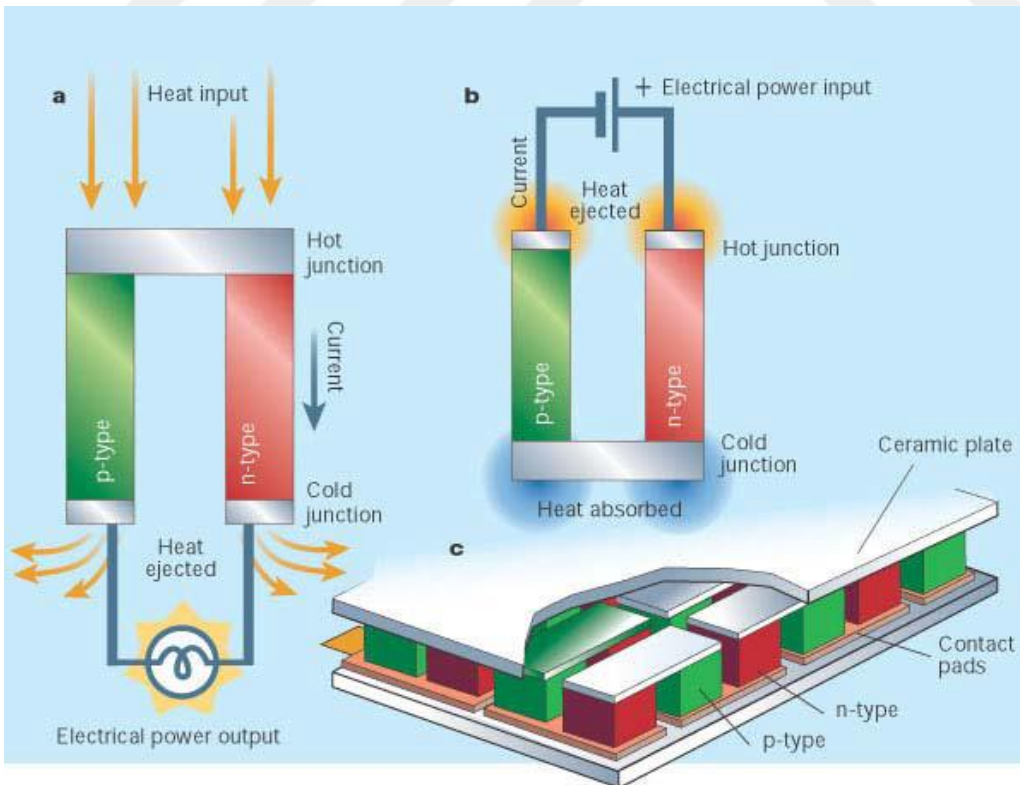


Figure 23: Peltier Module

2.11.2 Optimization of thermoelectric performances

As we discussed about thermoelectric devices above, it is easy to see that thermoelectric devices have many advantages, such as high reliability, no-moving parts, efficiency independent of size and environmentally friendly, compared with conventional cooling systems. However, thermoelectric materials have not been widely used in commercial applications because of the low efficiency.

2.11.2.1 Figure-of-merit ZT and efficiency

The major goal of thermoelectric material research is to design materials that will improve the efficiency of these solid-state devices. The efficiency (η) [23] of thermoelectric materials for power generation is defined as the output of electrical power (P) divided by the thermal power (Q) supplied:

$$\eta = \frac{P}{Q} = \frac{T_H - T_C}{T_H} \cdot \frac{\sqrt{1 + ZT} - 1}{\sqrt{1 + ZT} + \frac{T_C}{T_H}}$$

T_H and T_C are referring to the temperature of the hot and cold sides of the sample, respectively. Efficiency depends on material properties through the dimensionless figure of merit ZT [24]:

$$ZT = T \frac{S^2 \cdot \sigma}{k}$$

where T is the average temperature of the sample, S is the thermopower or Seebeck coefficient, σ is the electrical conductivity and κ is the total thermal conductivity. High ZT will lead to high efficiency. From the equation above, we can easily see that high ZT values can be achieved with a high Seebeck value (S) and high electrical conductivity (σ), but low thermal conductivity (κ). Unfortunately, these thermoelectric parameters cannot be treated independently and the correlations between them are rather complicated. Before we look into details of each parameter, let us have a look at what kind of materials might be good candidates for thermoelectric applications.

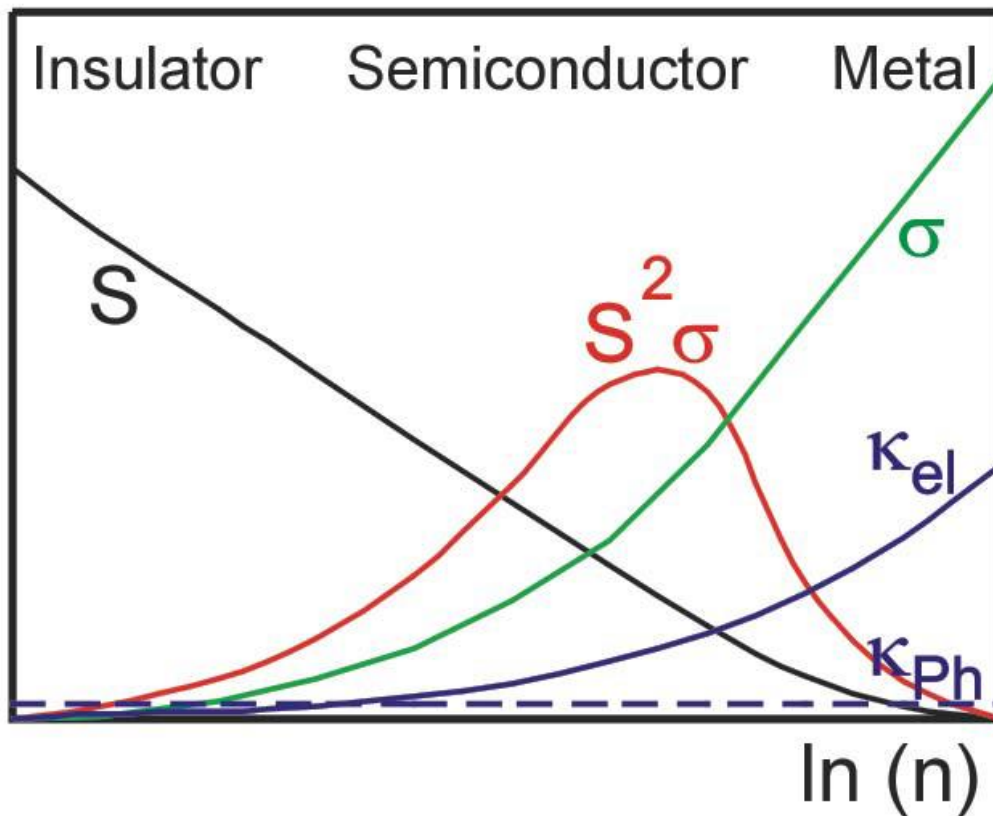


Figure 24: Thermoelectric parameter

As shown in Figure 24, insulators have high Seebeck coefficient but no electrical conductivity, and metals have high electrical conductivity but low Seebeck coefficient, and thus they are not good thermoelectric materials. The best thermoelectric materials are predicted to be semiconductors with small band gaps [22].

2.11.2.2 Seebeck coefficient

The Seebeck coefficient, e.g. thermopower, with a unit of (V/K) is a measure of the magnitude of an induced thermoelectric voltage in response to a temperature difference across that material:

$$S = \frac{\Delta V}{\Delta T}$$

The Seebeck coefficient can be derived from the Mott equation [25,26] with σ = electrical conductivity, k = Boltzmann constant, T = temperature, e = charge of an electron, and E = energy:

$$S = \frac{\pi^2}{3} \cdot \frac{k^2 T}{e} \cdot \frac{d \ln \sigma(E)}{dE} \Big|_{E = E_f}$$

One can deduce from the Mott equation that the Seebeck coefficient is inversely proportional to the DOS at Fermi level and directly proportional to the derivative of the DOS at Fermi level, i.e. large DOS are disadvantageous for a high Seebeck coefficient and flat band will be beneficial for a large Seebeck coefficient [27] :

$$S \propto \frac{1}{DOS(E_F)} \cdot \frac{d DOS(E)}{dE} \Big|_{E = E_f}$$

2.11.2.3 Electrical conductivity

Electrical conductivity (σ) is a measure of a material's ability to conduct an electric current, which is defined as [28]:

$$\sigma = \frac{L}{R \times A}$$

where R is the resistance of the sample, A and L being the cross area and length, respectively. A and L are constant for any experiment with fixed contacts. Electrical conductivity can also be explained by the equation [29] below:

$$\sigma = n \times e \times \mu$$

with n = the charge carrier concentration, e = charge of an electron and μ = mobility.

Generally, materials containing elements with small electronegativity differences are more likely to have higher mobility, e.g., electrons are more delocalized in these materials, leading to the high electrical conductivity.

2.11.2.4 Thermal conductivity

Thermal conductivity, κ , is the ability of a material to conduct the heat, which has two contributions, one from the electrical charge carriers, κ_e , and the other from the lattice vibrations (phonons), κ_{ph} . The overall thermal conductivity is the sum of the contributions by both charge carriers and phonons:

$$K = K_e + K_{ph}$$

For metals, the high thermal conductivity is the contribution of large numbers of electrons as charge carriers. Hence, the electronic contribution (κ_e) has the major impact for the thermal conductivity in metals, while the lattice vibrations have smaller effect. According to the Wiedemann-Franz relation [10], the thermal conductivity is proportional to the electrical conductivity for the metals at a certain temperature ($L = 2.45 \times 10^{-8} \text{ W}\Omega\text{K}^{-2}$):

$$K_e = L \times \sigma \times T$$

On the other hand, in semiconductors κ_{ph} is usually much greater than κ_e . Since the best thermoelectric materials were predicted to be semiconductors with small band gaps, one challenge is to minimize κ_{ph} . One way to do this is to synthesize compounds by using heavy elements. High atomic masses can reduce the atomic vibration frequencies resulting in lower thermal conductivity. This is one of the reasons that the elements like antimony, bismuth, tellurium, and lead are used quite often for current thermoelectric research. Another way is to introduce so-called “guest” atoms into the voids of the skutterudites [30,31] with CoAs_3 [32] structure type. These small “guest” atoms act like strong phonon scattering centers to reduce the lattice thermal conductivity dramatically, resulting in excellent thermoelectric properties.

2.11.3 Advanced thermoelectric materials

During the search for good thermoelectric materials since 1950s, some material systems stand out with the high potential for achieving excellent thermoelectric performances. These materials contain the high electrical conductivity and thermopower, while maintaining the relatively low thermal conductivity. In the following, we will discuss some advanced thermoelectric materials, and some of them are highly related to my research project as well.

2.11.3.1 Tl₉BiTe₆ and Tl₂SnTe₅

Recently, thallium chalcogenides such as Tl₉BiTe₆ [33] and Tl₂SnTe₅ [34] have been found to have excellent thermoelectric properties with extremely low thermal conductivities at room temperature, e.g., 0.39 Wm⁻¹K⁻¹ for Tl₉BiTe₆ and 0.5 Wm⁻¹K⁻¹ for Tl₂SnTe₅.

Tl₉BiTe₆ can be derived from the binary compound, Tl₅Te₃ [35,36] with the mixed 13 occupancy of Tl/Bi at the 4c site (Figure 1.7). Tl₉BiTe₆ exhibits the figure of merit of $ZT \approx 1.2$ at 500 K.

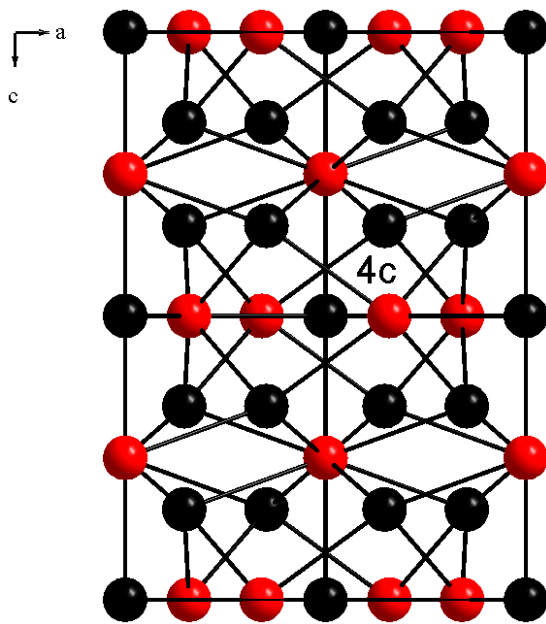


Figure 25: Crystal structure of Tl₅Te₃. Tl: black; Te: red.

Tl₂SnTe₅ also forms a the tetragonal crystal structure, with chains of SnTe₅²⁻ parallel to the *c* axis to and the cation Tl⁺ filling in the eight-coordinated voids shown in Figure 26. Tl–Te bonds (3.49 Å) in Tl₂SnTe₅ are relatively long compared with that of Tl₅Te₃ ranging from 3.15 to 3.36 Å. Such long bonds could produce very low-frequency phonons, which might be one of the key reasons for Tl₂SnTe₅ to have that low thermal conductivity resulting in a ZT₁₄ of 1 at 500 K. More information about thallium chalcogenides for thermoelectric applications will be disclosed in Chapter 3.

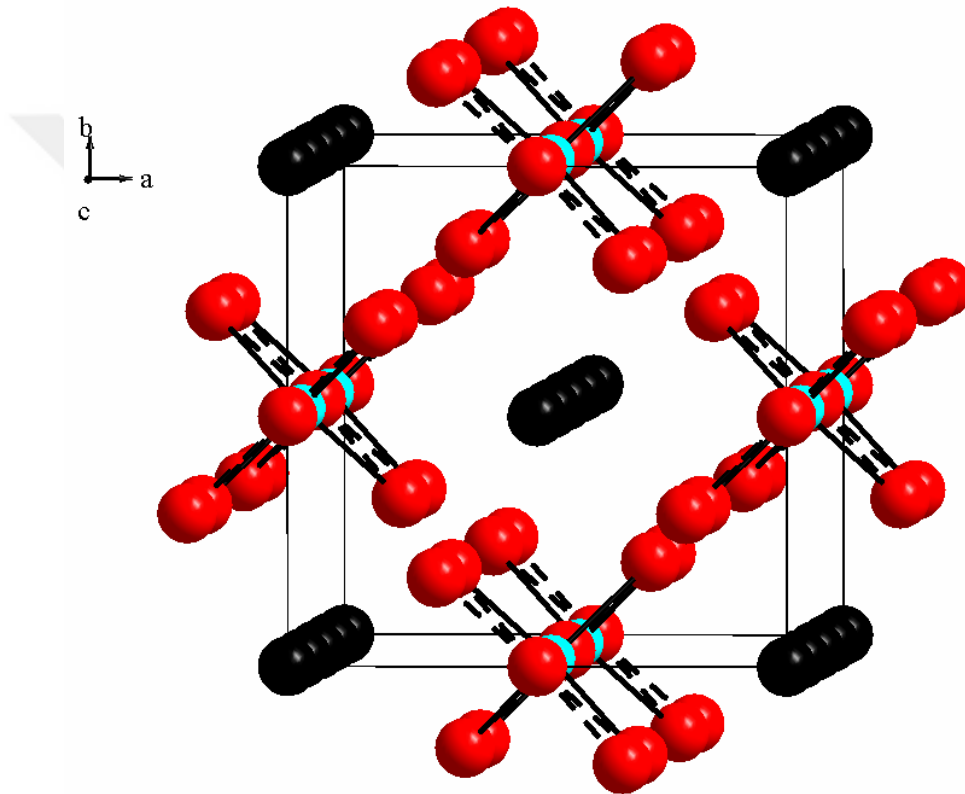


Figure 26: Crystal structure of Tl₂SnTe₅. Tl: black, Sn: cyan, and Te: red.

3. CONCENTRATING SOLAR POWER (CSP) AND PHOTOVOLTAIC (PV) PANEL DESIGN

Objective of this thesis is to use Sun as a power source to generate energy. As mentioned before there are lots of ways to acquire energy from Sun, but it should be one of the reliable and long-lasting and the most high energy density system. So, thermoelectric elements to generate electrical energy from heat is chosen, system is cooled with water. Output is electric energy for electric apparatus, cold and warm water for cooling and heating usage. This unique system will produce 1.677kW power output in ideal cases, in nominal conditions it can produce 1kW electrical power. Cool water will come in 15 to 20°C and warm water is expected to be in range of 50 to 90°C.

CSP-PV uses the thermoelectric material which is P-N junction is the core of system. P-N junction will help to gain energy from heat, while one side will be heated by Sun and other side will be cooled below 20°C. This thermal difference will excite the electron and this excitement will make electric flow which carrying this power flow make power supply system. To reach temperatures like below 205°C on hot side magnifier glass will make the job. Glass Magnifiers can concentrate sunlight in one point which this will make high temperature in one point, this will make it as a hot spot. By the way, this hot spot will be gather thermal heat on Copper plate which is painted to black. Painting to black that will increase absorption Sunlight, which will be coated with CuO. Cold side will be cooled with aluminum pipes. In the Aluminum pipe will flow solar power fluid which is will be cooled with geothermal system. This cycle will be monitored with controller. There will be water storage tank. The system in total is off-grid system which excess power will be transferred to grid.

Let's start specification and calculation of CSP-PV Panel. First system as like as in Figure 27 that demonstrates whole process. So, Sun rays concentrated on magnifier glass and then it makes hot point on black painted sheet which makes homogenous heat transfer. This homogenous heat transfers through the thermoelectric elements to the aluminum pipes which carrying the cold water.

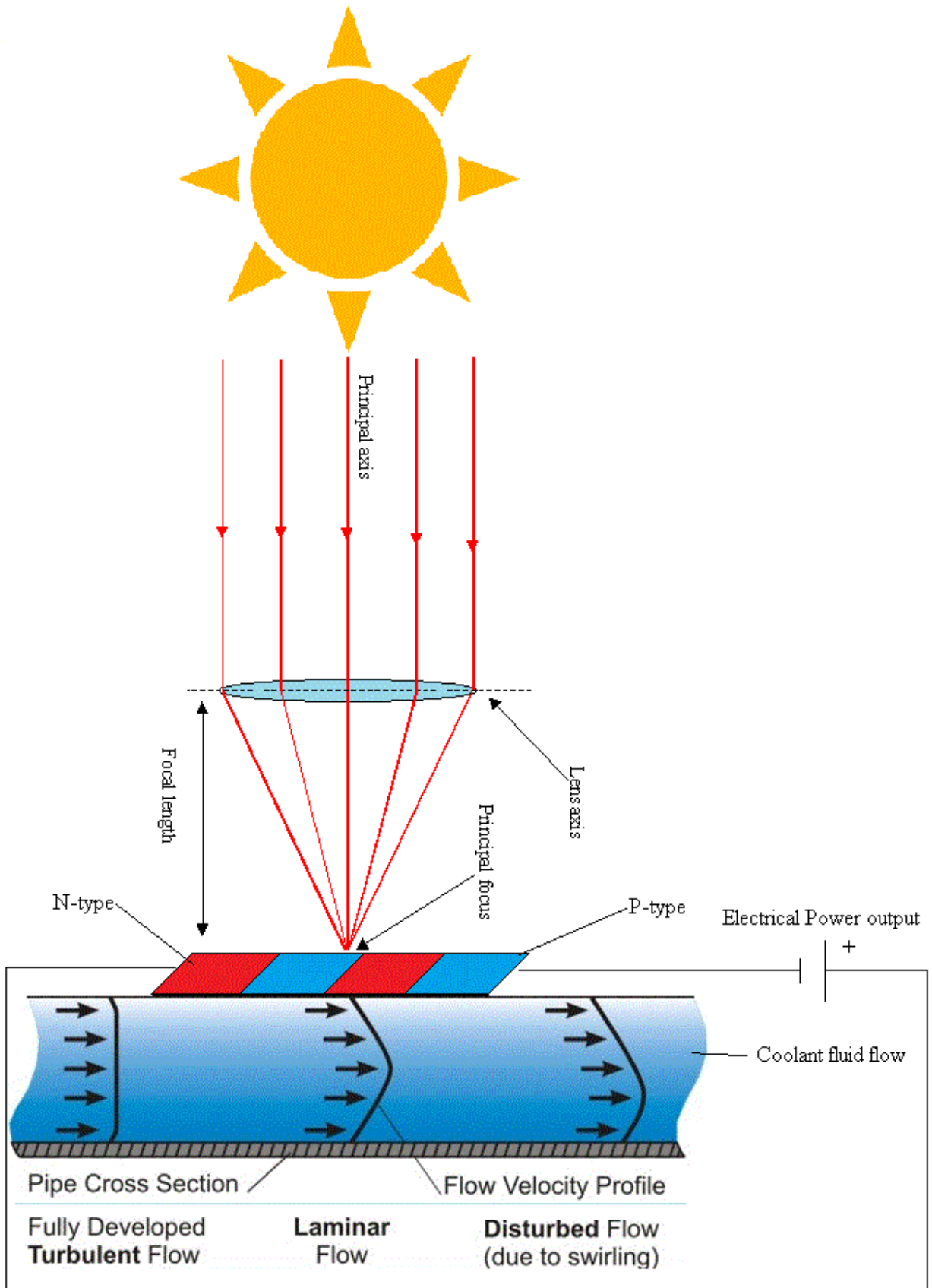


Figure 27: CSP-PV Schematic

The output product is hot & cold water and electrical energy. The hot water will be cooled again with geothermal energy source. There will be parallel system which can store the hot water.

Geothermal Energy is available in every place and under the shallow of ground below 3 meter there are very constant temperature with is waiting for use in various application. I just needs antifreeze fluid which is circulating in loop transferring its heat to the ground and this kind of loops could be vertical or horizontally designed. The refrigerant circulates through a cycle of condensing and evaporating between two heat exchangers. In this cycle there is no need of compressor to make compressed refrigerant to get in high pressure and high temperature than loose it pressure and temperature to make evaporation, it can just circulated in the loop under the ground and dumping the excess its heat and unlike other systems it just need fluid pump and its reversible. And in this kind of application the energy consumption from electric pump is very tiny comparing the Air conditioning system or HVAC.

Geothermal energy system is making CSP-PV much more efficient. Because the whole idea is make energy from alternative energy, which geothermal energy is saving that idea. Other way it very easy to get, very cheap, and onetime payment, and whole time it will serve. So, 3m under the surface of land there is 7 to 21°C temperature, which very constant whole season. But for us 20°C is very perfect as a Cold sink source. Using copper pipes and digging 3m and laying long pipeline which will serve as a heat exchanger. Here is the demonstration of geothermal energy system on Figure 28.

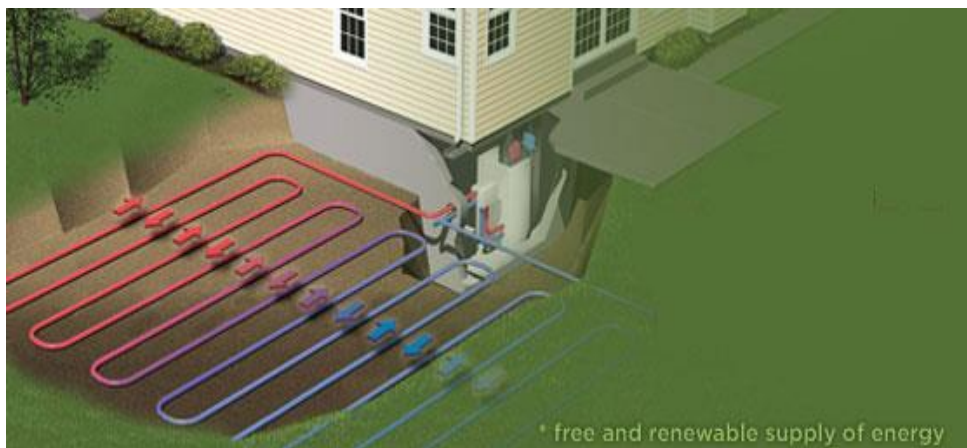


Figure 28: Geothermal Energy

Sun heat flux per meter square is taken as 1300kW/m^2 for Istanbul in summer season. If so CSP-PV panel have face are $110\text{cm}\times 80\text{cm}$. There is the most important job is done by magnifier glass. There are some specification of magnifying glass, let's say lens which they are depend on them.

First one is lens wide, concentration, Sun ray angle and focus length. These information will be enough to make nearly perfect lens. For more high quality of energy concentration the glass material is important too, which CSP-PV Panel lens will be BK7 optic lens. Which it have 95% optical efficiency and it mean the glass have 95% purity, much higher purity much better for concentration focus. And the BK7 is the most common glass type that in use of optical device lenses.

The most common used Lens shape is Plano convex lenses which is shown on the Figure 29.

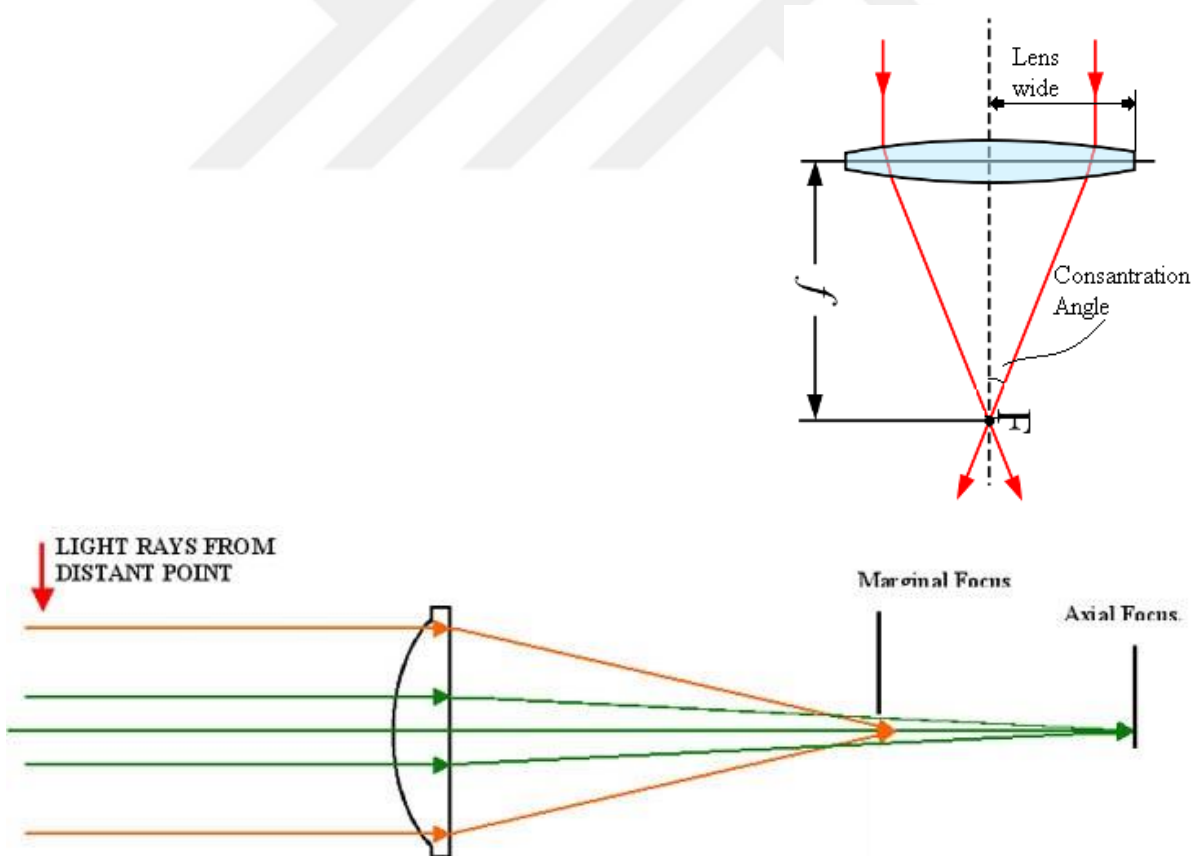


Figure 29: Lens

After couple calculation and simulation in TracePro software it gave results on Figures below. This kind of glass lens is easy to mold and process. Which very old fashion system, with technology it got easier.

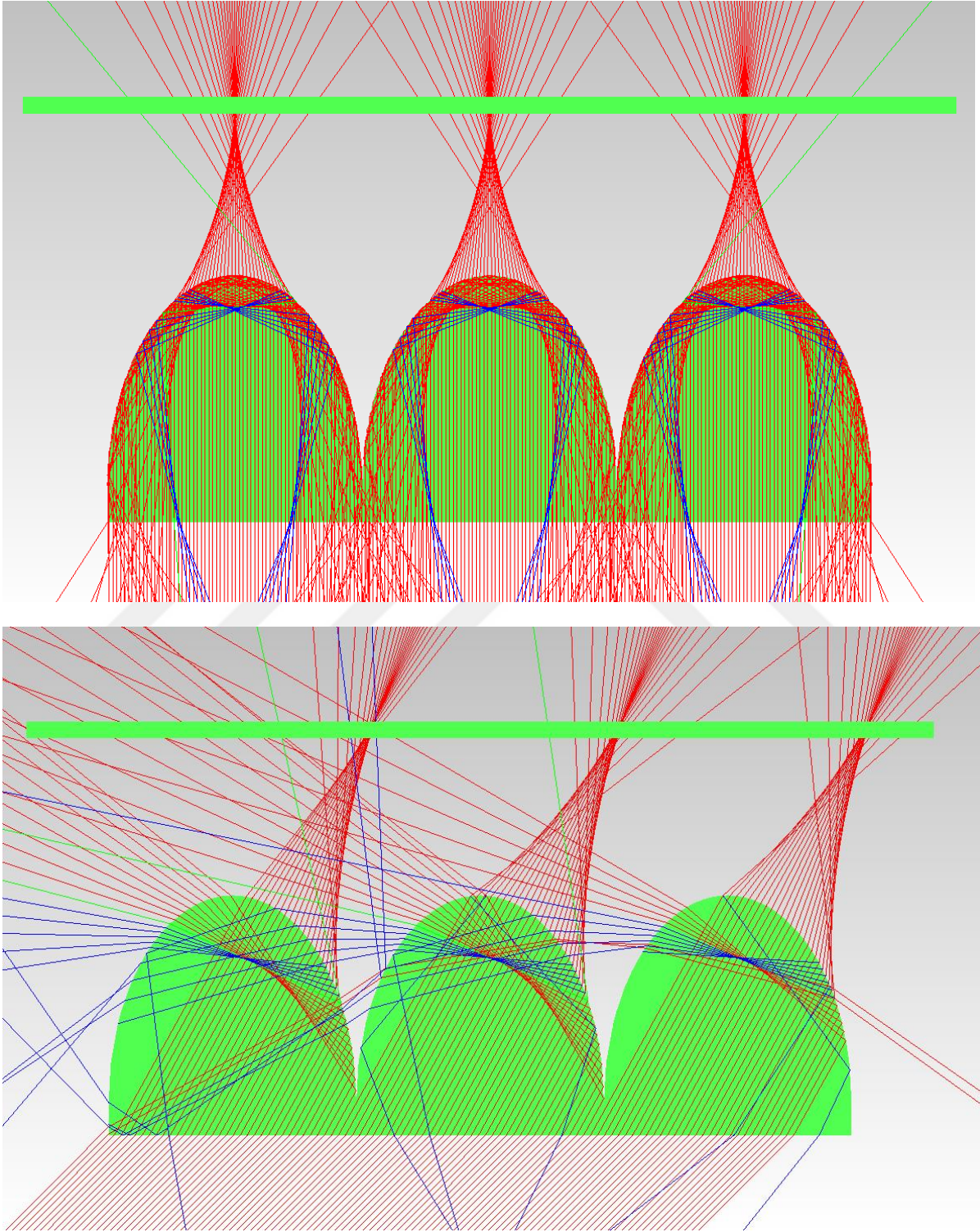


Figure 30: 45° and 90° angle concentrated Sun rays with Lens

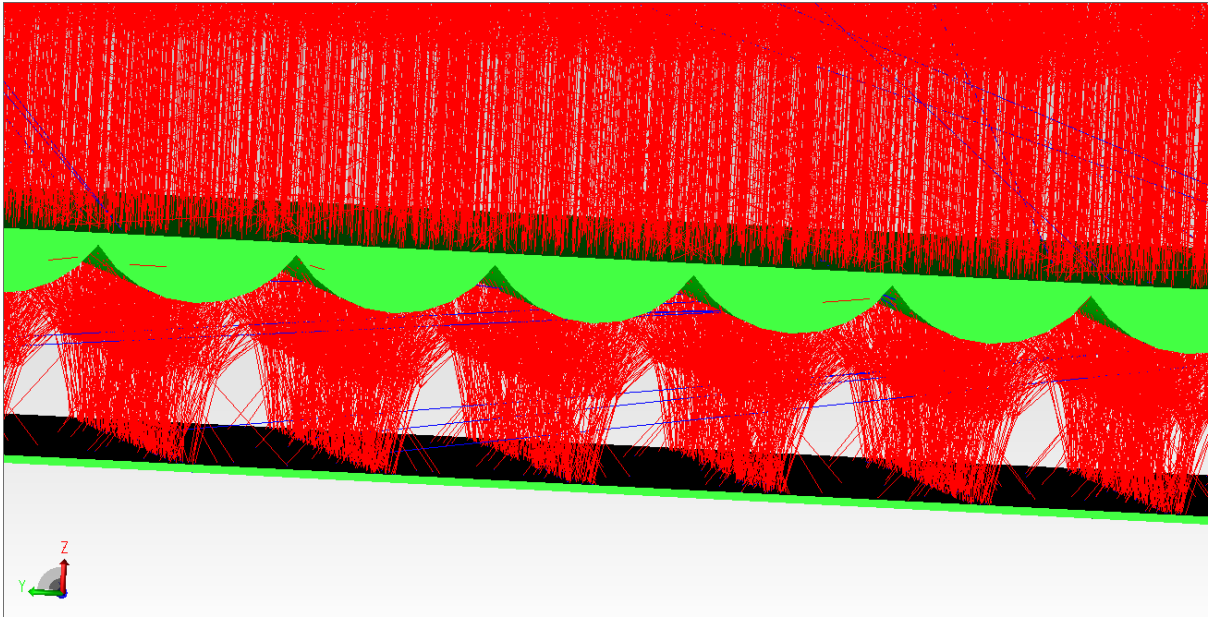


Figure 31: Concentration of Sun ray on all lenses demonstration

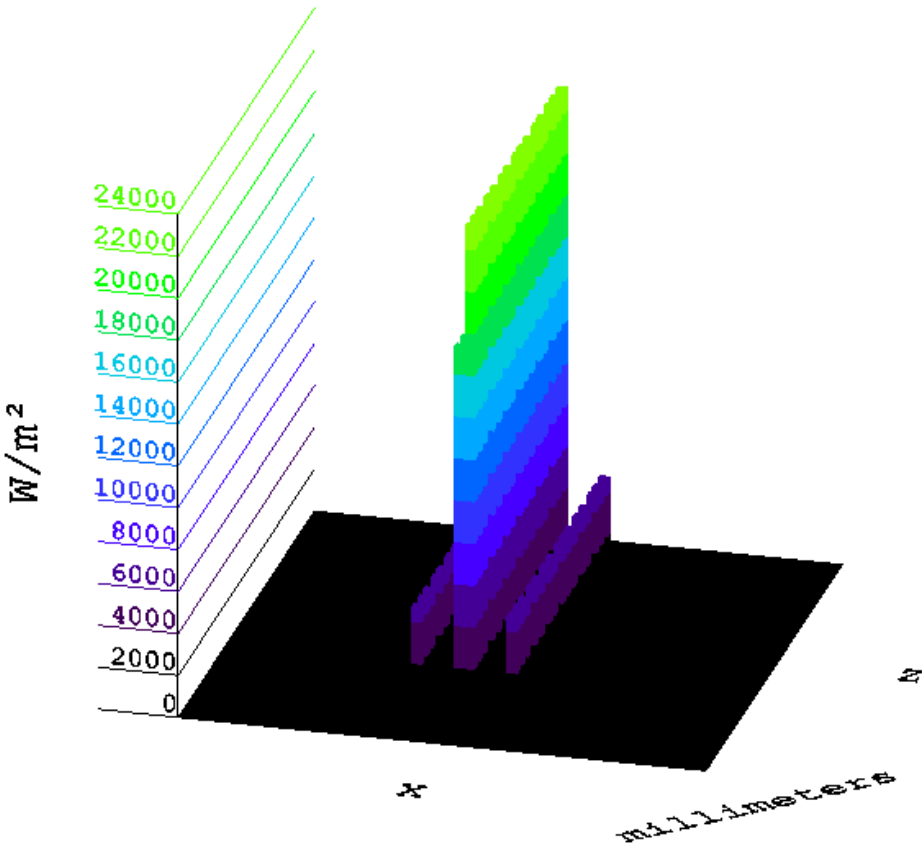


Figure 32: Sun power concentrated on Blackbody

In this simulation sun rays was given in different angles. Mostly concentration will be in 90 degrees when sun is on the top, focus point is touching the surface, but as the angle is changing focus point is getting away and the affects the radiation which heating the surface. As the sun ray angles change it makes difference in flux in other way the optical concentration is getting lower and this way consecration is change with this formula way.

This figure shows how consecration versus sunlight angle and temperature on the surface is changing. This king of figure give idea how the efficient rate is changing buy the time of the day

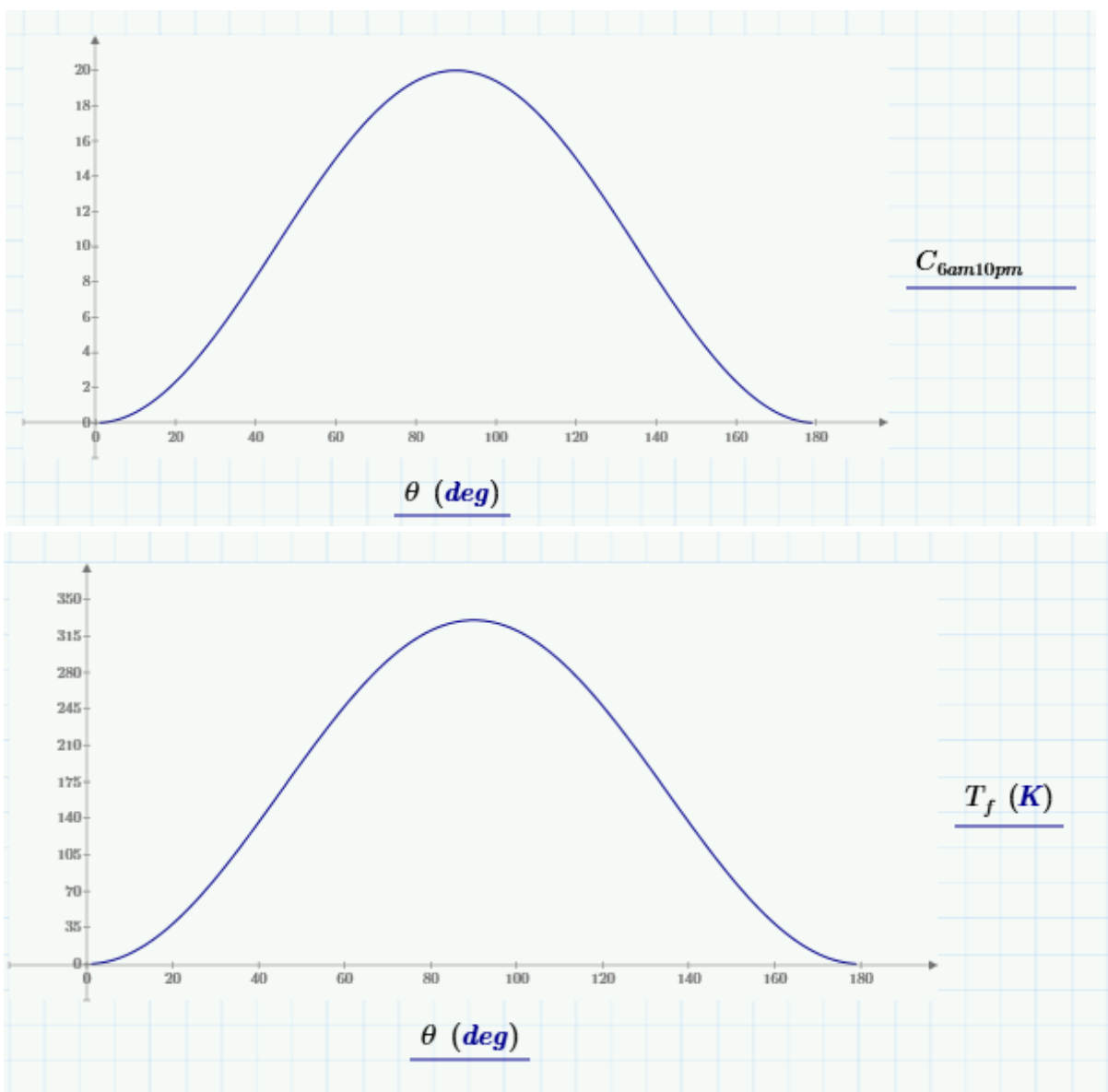


Figure 33: Concentration versus Sunlight angle and Surface temperature versus Sunlight angle

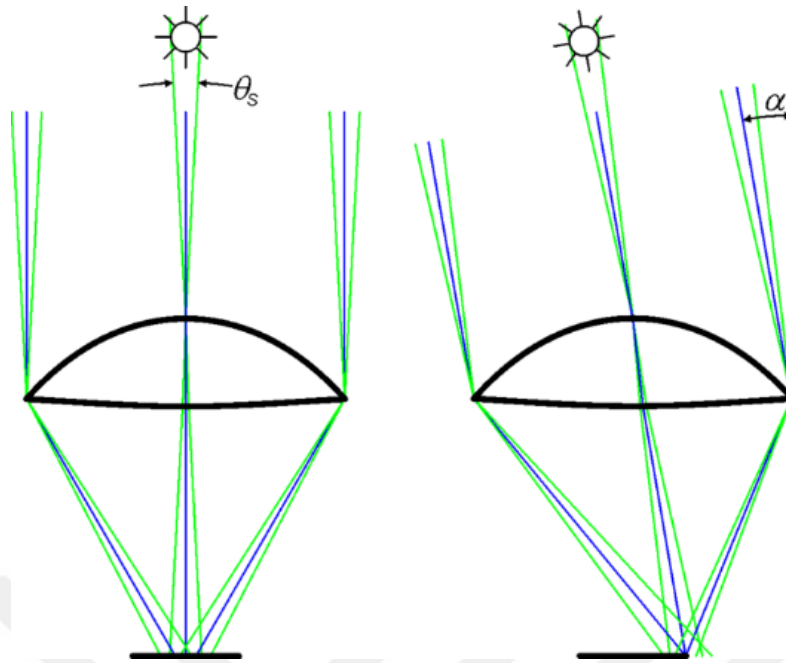


Figure 34: Sunlight angle demonstration

As it shown in simulation the focus length is 4.5cm with 2cm R1 the convex radius. Blue lines are the defects of lens that scatters there rays around, Red lines are the concentrated rays. The concentration is 20CR. This much Concentration can get to very high temperatures. Calculating that temperature and predict ion with radiation formula. Formula is depending of solar flux, concentration rate, concentrated area, purity of optical glass or lens, and coated area that absorbs the energy. To calculate the temperature, which have to divide total concentrated energy to Stephan Boltzmann number and area then get 4 degree of root. In the and it shows 787°C which is very high temperature. But it's the hot surface temperature and which point temperature is, and using black body it will distribute temperature homogeneously all over the place.

Heat transfer will collected on the copper sheet 0.5mm tick that coated with CuO then it get through the sheet. Then it will get to the TEG which the thickness 2mm. Between TEG and Copper sheet there will be Kapton tape to stop electricity conduction. Even after TEG there will be another Kapton will protect electricity escape. This process is to save energy and control the flow of electricity and for safety precautions.

After all this package under it all will be ellipsoid aluminum tubing that will provide cool liquid that will make cool side of system. Actually aluminum is weaker than the copper's heat transfer rate, but copper is hard to process and to make it as thick 0.2mm is very expensive. Because of aluminum can get that much thickness easily, so in total heat transfer it proves that it's better than copper tubing. And ellipsoid tubing is makes heat distribution internal flow more like in boundaries. Because it's so narrow as 4mm in outer dimension the flow will easily get turbulent flow which is effects good for better heat transfer. For better and faster cooling there will be couple pass. As much as the heat will be transferred that much there will be output as electric energy.

Heat will not transfer only through this system of course. Even CuO coating will reflect the some energy which will heat the internal air in between lens and Cu sheet. Because of Cu sheet will be hot it will transfer some energy to the air with convection and radiation. Even lens have internal heat resistant that heats lens and extra copper sheet and air heats the lens, in other side the wind and surrounding will make system to lose the heat. At some points Glazing is good choose to prevent the heat loose, but in other hand actually insulates system, prevents solar ray get in full power. Glazing do increases effaces but it makes system to give less output energy. So CSP-PV will not have any glazing. Here is the schematic of heat transfer in Figure 35

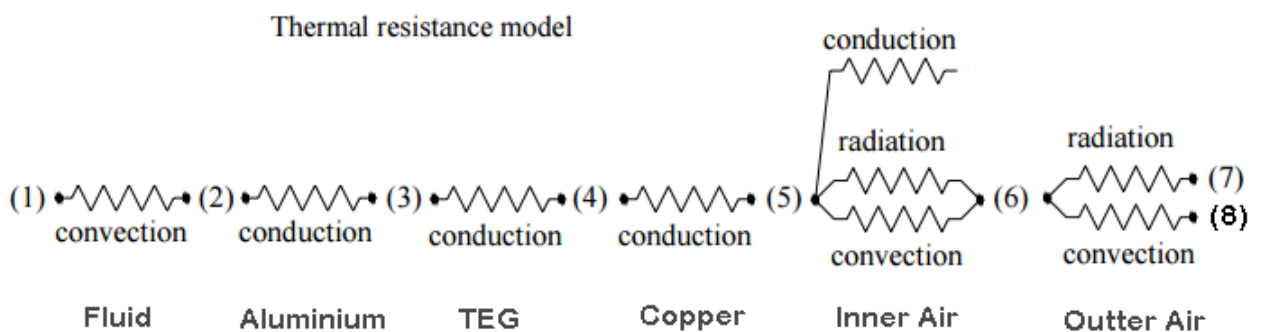


Figure 35: Heat transfer through the system

Insulation is used 20mm Glass wool, which saves high amount of energy. And glass wool is easy process and model and shape it for desired profile. It's essay to find and glass wool will resist to higher temperature, very high temperature flammability.

TEG is the heart of the system. All job is done by TEG. This is the apparatus that converts heat to Electric energy. The principle of TEG heating one side and cooling other side will make temperature Difference, which this difference makes the electricity. As much as this difference is bigger that much Electric energy it makes. It doesn't matter if hot side is 500°C and it will make more energy, no everything is depends of cool side.

The total design of CSP-PV with every details are shown in Figures 36-37.



Figure 36: CSP-PV panel

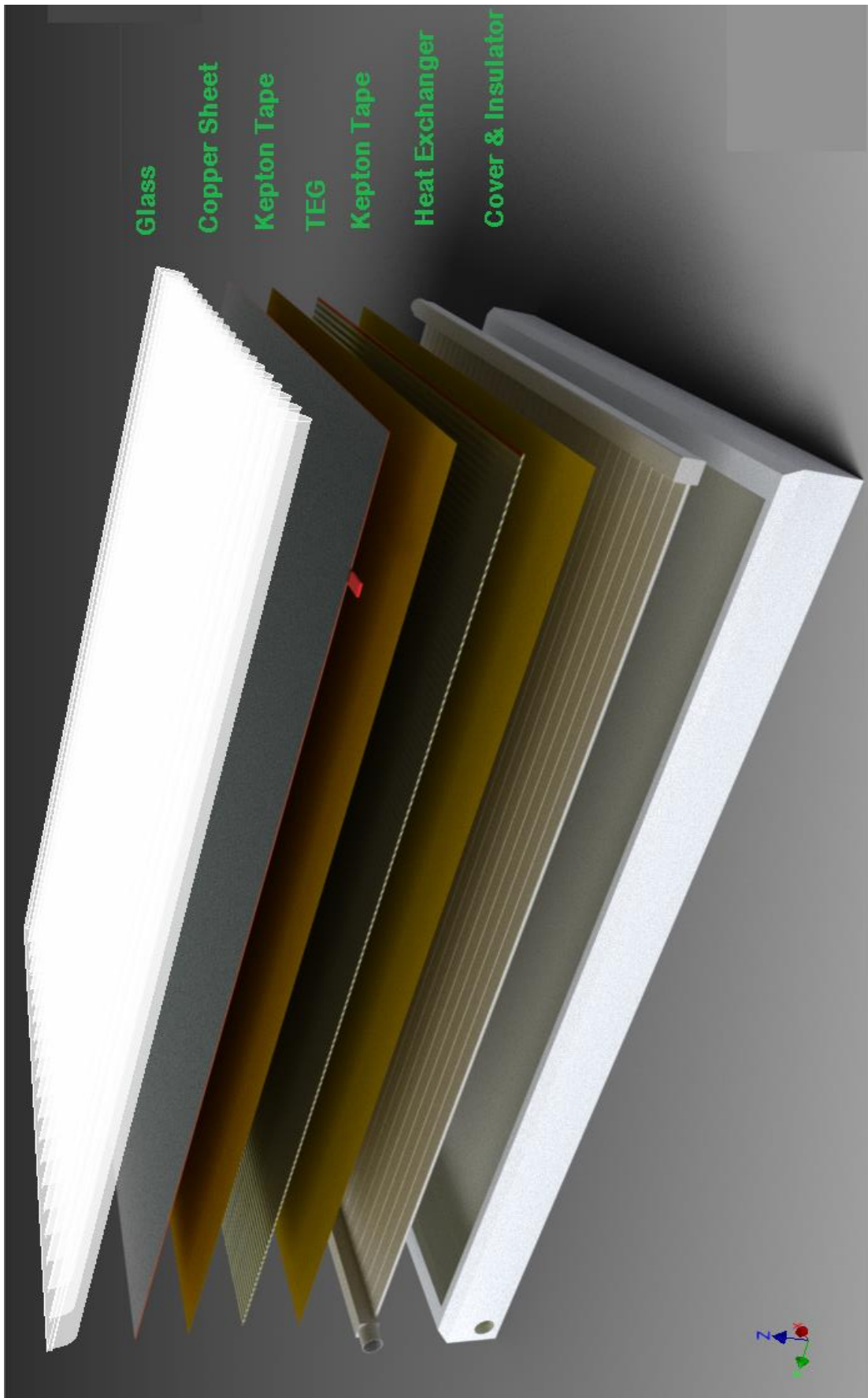


Figure 37: CSP-PV parts

4. ENGINEERING CALCULATION AND ANALYSIS

Before starting the calculation of the system we should know the solar heat energy that will be concentrated by the lenses.

$$Q_{solar} = \eta_{opt} \cdot J_{tur} \cdot C_{opt} \cdot A_{glass}$$

Q_{solar} – Solar heat energy

η_{opt} – Lens optical efficiency

J_{tur} – Sun Heat flux for Turkey

C_{opt} – Lens optical concentration

A_{glass} – Optical glass surface area; BK7 glass

Solar heat energy is depends lens optical efficiency, sun heat flux, lens optical concentration and lens surface area. We will used rectangle type lens consist of several parallel half tube type lenses.

$l_{glass} = 110 \text{ cm}$ Lens length

$w_{glass} = 80 \text{ cm}$ Lens wide

$A_{glass} = l_{glass} \cdot w_{glass}$ Lens area

$$A_{glass} = 0.88 \text{ m}^2$$

Sunlight flux for Turkey 1300 watt per square meter in average.

$J_{tur} = 1300 \frac{W}{m^2}$ Sunlight flux for Turkey

For this particular application we will use regular optical glass BK7 which have 95% purity and because lens very close to heated surface focus length will be 4.5cm and each half tube type lens wide 2cm, so there will be 20 such lenses.

$$\eta_{opt} = 0.95 \quad \text{95\% purity for fuse optical glass}$$

$$n = 1.5168 \quad \text{Refractive index}$$

$$f_{lens} = 4.5 \text{ cm} \quad \text{Lens focus length}$$

$$w_{lens} = 2 \text{ cm} \quad \text{Single lens one side wide}$$

$$\theta_{lens} = a \tan \left(\frac{w_{lens}}{f_{lens}} \right) = 23.9625 \text{ deg} \quad \text{Lens Focas angle}$$

Concentration of lens is depend particular base are of headed surface and glass area. This defines the potential of lenses.

$$A_{base} = 2mm \cdot 110cm \cdot 20 = 440cm^2$$

$$C_{opt} = \frac{A_{glass}}{A_{base}} = 20$$

Actually, for different day times there will be different lens optical consantration value and it is depending on sunlight ray angels.

$$\theta = \begin{bmatrix} \vdots \\ 178 \\ 179 \end{bmatrix} \text{ deg} \quad C_{6am10pm} = C_{opt}(\sin(\theta))^2 = \begin{bmatrix} \vdots \\ 19.6126 \\ 19.703 \\ \vdots \end{bmatrix}$$

Heat Transfer Calculations

TEG surface will be coated for improve sunlight energy absorbtion, because some metallic n and p type semiconductors can be reflective. And Copper will distributive heat homogeniuosly. Coating will be done with CuO and it will improve absorbtion and it will effect on totalt absorbed solar energy.

$$Q_{rad} = \alpha_{abs} \cdot Q_{solar}$$

$$\alpha_{abs} = 0.97$$

97% absorbtion with CuO coating

$$\epsilon_{emt} = 0.5$$

50% emissivity CuO coating

$$T_{sur} = 25^{\circ}C$$

Surrounding temperature

$$\sigma = 5.6704 \cdot 10^{-8} \frac{W}{m^2 \cdot k^4}$$

Stefan-Boltzmann constant

Blackbody are is the same as glass area. For the layers of heater there will be copper sheet that will be coated with CuP with have high conductivity, and Aluminum for heat exchange tubes which have less heat conductivity but tube is very tin this improves the conductivity comparing with Copper sheet, because to make such tin sheet with is impossible by today's technology. And TEG is very and it improves conductivity so there will be more electrical energy.

$$A_{BlackBody} = A_{glass}$$

All area are the same;

$$k_{Al} = 205 \frac{W}{m \cdot K}$$

Aliminium Heat Conductivity coefficient

$$k_{Cu} = 401 \frac{W}{m \cdot K}$$

Copper Heat Conductivity coefficient

$$k_{teg} = 0.5 \frac{W}{m \cdot K}$$

TEG Heat Conductivity coefficient

$$t_{Al} = 0.2mm$$

Aliminium tickness

$$t_{teg} = 2.5mm$$

TEG tickness

$$t_{Cu} = 0.5mm$$

Copper tickness

For particular calculation that gives number of input and possible output.

Concentrated Solar Radiation

$$Q_{solar} = \eta_{opt} \cdot J_{tur} \cdot C_{opt} \cdot A_{glass} = 21.736 \text{ kW}$$

Solar Radiation on the CSPV

$$Q_{rad} = \alpha_{abs} \cdot J_{tur} \cdot A_{glass} = 1.1097 \cdot 10^3 \text{ W}$$

Radiation absorbed with surface

$$Q_{rad} = A_{BlackBody} \cdot \sigma \cdot \epsilon_{emt} \cdot (T_s^4 - T_{sur}^4)$$

Homogeneous Temperature on surface

$$T_5 = \sqrt[4]{\frac{Q_{rad}}{A_{BlackBody} \cdot \sigma \cdot \epsilon_{emt}}} + T_{sur}^4 = 205.2471^\circ\text{C}$$

Absorbed CSR

$$Q_{radcon} = \alpha_{abs} \cdot Q_{solar} = 2.1084 \cdot 10^4 \text{ W}$$

Temperature on sides of copper sheet

$$T_4 = -\frac{Q_{rad} \cdot t_{Cu}}{A_{BlackBody} \cdot k_{Cu}} + T_5 = 205.2455^\circ\text{C}$$

Temperature on sides TEG

$$T_3 = -\frac{Q_{rad} \cdot t_{teg}}{A_{BlackBody} \cdot k_{teg}} + T_4 = 198.9405^\circ\text{C}$$

Heat Exchanger calculations

Importance of this calculation is because better heat exchange there will be higher electrical energy output. This heat exchanger are designed for higher efficiency and it achieved using elliptical tubes for more surface for contacting with TEG and coolant fluid that travels inside in such tubes will get to turbulent flow and this kind of flow makes heat exchange add more performance. So here is some detailed calculation of heat exchange.

$a=2\text{cm}$ $b=0.2\text{cm}$ 40x4mm Ellipsoid Aluminum pipe

$NR=1$ 1 Row of Aluminum pipe

$L_t = 110 \text{ cm}$ Pipe length

$L_m = 80 \text{ cm}$ Heat exchanger total wide

$NC = \frac{L_m}{2a} = 20$ Total Columns of Aluminum pipes

$N_t = NC \cdot NR = 20$ Total number of ellipsoid pipe

$Q_{flow} = 60 \frac{l}{min}$ Fluid flow rate

$$h_o = \frac{(a - b)^2}{(a + b)^2} = 0.6694$$

Outer Perimeter of ellipsoid pipe

$$P_o = \pi \cdot (a + b) \cdot \left(1 + \frac{3h_o}{10 + \sqrt{4 - 3h_o}}\right) = 8.1279 \text{ cm}$$

Inner perimeter of ellipsoid pipe

$$h_i = \frac{[(a - t_{Al}) - (b - t_{Al})]^2}{[(a - t_{Al}) + (b - t_{Al})]^2} = 0.6944$$

$$P_i = \pi \cdot [(a - t_{Al}) + (b - t_{Al})] \cdot \left(1 + \frac{3h_i}{10 + \sqrt{4 - 3h_i}}\right) = 80.2764 \text{ mm}$$

Single ellipsoid pipe outer cross area

$$A_o = \pi \cdot a \cdot b = 125.6637 \text{ mm}^2$$

Single ellipsoid pipe inner cross area

$$A_i = \pi \cdot (a - t_{Al}) \cdot (b - t_{Al}) = 111.9664 \text{ mm}^2$$

$$A_{surfaceout} = \frac{P_o \cdot L_t}{2} = 0.0447 \text{ m}^2 \quad \text{Single pipe outer surface area}$$

$$A_{totalsurfaceout} = A_{surfaceout} \cdot NC = 0.8941 \text{ m}^2 \quad \text{Total outer surface area}$$

$$A_{surfacein} = \frac{P_i \cdot L_t}{2} = 0.0442 \text{ m}^2 \quad \text{Single pipe inner surface area}$$

$$A_{totalsurfacein} = A_{surfacein} \cdot NC = 0.883 \text{ m}^2 \quad \text{Total inner surface area}$$

$$D_o = \frac{4 \cdot A_o}{P_o} = 0.6184 \text{ cm} \quad \text{Outer hydraulic diameter}$$

$$D_i = \frac{4 \cdot A_i}{P_i} = 0.5579 \text{ cm} \quad \text{Inner hidrolic diameter}$$

$$V_{fluid} = \frac{Q_{flow}}{NC \cdot A_i} = 0.4466 \frac{\text{m}}{\text{s}} \quad \text{Fluid Flow speed}$$

$D_{th} = 14 \text{ mm}$	Geothermal heat pump pipe diameter
$L = 10 \text{ m}$	Geothermal heat pump pipe length
$e = 1.5 \cdot 10^{-6} \text{ m}$	Roughness of aluminum pipe

Al_2O_3 fluid as a coolant, temporary coolant will be changed for more performance that will be used for geothermal heat exchanger. Because there are Al particular it will improve heat exchange. In this application we will use Al pipes just for better conductivity with land.

$$k_{Al_2O_3} = 0.739 \frac{W}{m \cdot K}$$

$$Cp_{Al_2O_3} = 4017.6 \frac{J}{kg \cdot K}$$

$$\rho_{fluid} = 1122.2 \frac{kg}{m^3}$$

$$\mu_{fluid} = 0.000672 \frac{kg}{m \cdot s}$$

Mass flow of fluid in geothermal pump

$$m_{fluid} = \rho_{fluid} \cdot Q_{flow} = 1.1222 \frac{kg}{s}$$

Mass flow of fluid in Heat Exchanger

$$m_{fluidheatexchanger} = \frac{m_{fluid}}{N_t} = 0.0561 \frac{kg}{s}$$

Reynold number for Heat Exchanger

$$Re = \frac{4 \cdot m_{fluidheatexchanger}}{\mu_{fluid} \cdot D_i \cdot \pi} = 1.9056 \cdot 10^4$$

If inner flows Reynold is more than 4000 it's turbulant. And if Reynold is less than 2300 flow is laminar.

Table 2: Pipe surface roughness

Surface	Absolute Roughness Coefficient - k -	
	(m) 10^{-3}	(feet)
Copper, Lead, Brass, Aluminum (new)	0.001 - 0.002	$3.33 - 6.7 \cdot 10^{-6}$
PVC and Plastic Pipes	0.0015 - 0.007	$0.5 - 2.33 \cdot 10^{-5}$
Stainless steel	0.015	$5 \cdot 10^{-5}$
Steel commercial pipe	0.045 - 0.09	$1.5 - 3 \cdot 10^{-4}$
Stretched steel	0.015	$5 \cdot 10^{-5}$
Weld steel	0.045	$1.5 \cdot 10^{-4}$
Galvanized steel	0.15	$5 \cdot 10^{-4}$
Rusted steel (corrosion)	0.15 - 4	$5 - 133 \cdot 10^{-4}$
New cast iron	0.25 - 0.8	$8 - 27 \cdot 10^{-4}$
Worn cast iron	0.8 - 1.5	$2.7 - 5 \cdot 10^{-3}$
Rusty cast iron	1.5 - 2.5	$5 - 8.3 \cdot 10^{-3}$
Sheet or asphalted cast iron	0.01 - 0.015	$3.33 - 5 \cdot 10^{-5}$
Smoothed cement	0.3	$1 \cdot 10^{-3}$
Ordinary concrete	0.3 - 1	$1 - 3.33 \cdot 10^{-3}$
Coarse concrete	0.3 - 5	$1 - 16.7 \cdot 10^{-3}$
Well planed wood	0.18 - 0,9	$6 - 30 \cdot 10^{-4}$
Ordinary wood	5	$16.7 \cdot 10^{-3}$

Table 3: Al₂O₃ water consantration properties

Material	ρ Kg/m ³	C_p J/Kg·K	k W/m·K	μ Kg/m·s
Pure water $c = 0\%$	981.3	4189	0.643	0.000598
Al ₂ O ₃	3600	765	36	-
Al ₂ O ₃ -water $c = 1\%$	1007.4	4154.7	0.661	0.000612
Al ₂ O ₃ -water $c = 2\%$	1033.6	4120.5	0.68	0.000627
Al ₂ O ₃ -water $c = 3\%$	1059.8	4086.2	0.699	0.000642
Al ₂ O ₃ -water $c = 4\%$	1086	4052	0.719	0.000657
Al ₂ O ₃ -water $c = 5\%$	1112.2	4017.8	0.739	0.000672

$$Pr = \frac{Cp_{Al_2O_3} \cdot \mu_{fluid}}{k_{Al_2O_3}} = 3.6534 \quad \text{Prandtl number}$$

$$f = 0.25 \left[\log_{10} \left(\frac{e}{3.7} + \frac{5.74}{Re^{0.9}} \right) \right]^{-2} = 0.0268 \quad \text{Darcy Friction Factor}$$

$$Nu_D = \frac{\left(\frac{f}{8}\right) \cdot (Re - 1000) \cdot Pr}{1 + 12.7 \cdot \left(\frac{f}{8}\right)^{\frac{1}{2}} \cdot \left(Pr^{\frac{2}{3}} - 1\right)} = 109.9404 \quad \text{Nusselt number}$$

$$h_{fluid} = \frac{Nu_D \cdot k_{Al_2O_3}}{D_i} = 1.4563 \cdot 10^4 \frac{W}{m^2 \cdot K} \quad \text{Heat transfer coefficient}$$

$$T_i = 20^\circ C \quad \text{Heat exchanger inlet temperature}$$

Heat exchanger output temperature

$$T_o = T_3 - (T_3 - T_i) \cdot \exp \left[-\frac{(\pi \cdot D_i \cdot L_t \cdot h_{fluid})}{(2.5 \cdot m_{fluid} \cdot c_{p_{Al_2O_3}})} \right] = 90.2113^\circ C$$

For such application it can ensure there could be 90 degree hot water output after coolant cycles in the heat exchanger and it very good harvest after the process.

Geothermal Heat Pump

Al_2O_3 fluid as a coolant, temporary coolant will be changed for more performance that will be used for geothermal heat exchanger. Because there are Al particular it will improve heat exchange. In this application we will use Al pipes just for better conductivity with land. In upper calculation the heat exchanger should be in capable of cooling the 90 degree hot coolant in to 20 degree of cool fluid.

$$Q_{cool} = m_{fluid} \cdot Cp_{Al_2O_3} \cdot (T_i - T_o) = -3.1655 \cdot 10^5 W \quad \text{Cooling capacity}$$

$$A_{th} = \pi \cdot \frac{D_{th}^2}{4} = 0.0002 m^2 \quad \text{Geothermal heat pump pipe area}$$

$$V_{fluidth} = \frac{Q_{flow}}{A_{th}} = 6.4961 \frac{m}{s} \quad \text{Fluid speed in heat pump}$$

$$Re_{th} = \frac{4 \cdot m_{fluid}}{\mu_{fluid} \cdot D_{th} \cdot \pi} = 1.5187 \cdot 10^5 \quad \text{Reynold number in heat pump}$$

$$ff = \frac{1}{-1.8 \cdot \log_{10} \left[\left(\frac{e}{3.7} \right)^{1.11} + \frac{6.9}{Re_{th}} \right]} = 0.1303 \quad \text{Darcy Friction Factor}$$

$$Nu_{Dth} = \frac{\left(\frac{ff}{8} \right) \cdot (Re_{th} - 1000) \cdot Pr}{1 + 12.7 \cdot \left(\frac{ff}{8} \right)^{\frac{1}{2}} \cdot (Pr^{\frac{2}{3}} - 1)} = 2.7851 \cdot 10^3 \quad \text{Nusselt Number for heat pump}$$

$$h_{fluidth} = \frac{Nu_{Dth} \cdot k_{Al_2O_3}}{D_{th}} = 1.4701 \cdot 10^5 \frac{W}{m^2 \cdot K} \quad \text{Heat transfer coefficient}$$

$$T_{land} = 20^\circ C \quad \text{Land temperature}$$

Output temperature

$$T_{\infty} = T_{land} + (T_o - T_{land}) \cdot \exp \left[- \frac{(\pi \cdot D_{th} \cdot L \cdot h_{fluidth})}{(m_{fluid} \cdot Cp_{Al_2O_3})} \right] = 20^\circ C$$

Thermoelectrical material calculation

So, here comes the most important item that makes energy from the heat. To make such material it need very good and deep material engineering to choose right elements. Choosing the element we have to be care fool with number free electron and it will make the N and P type semiconductor. More free electrons more energy density will acure. To choose them we can use table 4.

Bi_2Te_3 N-type semiconductor

Al-Mg₂Si p-type semiconductor

Bi_{0.5}Sb_{1.5}Te₃ p-type semiconductor

$N_A = 6.0221 \cdot 10^{23} \frac{1}{mol}$ Avogadro constant

$$Bi_2 = 2 \cdot 208.98 \text{ gm} = 417.96 \text{ gm}$$

$$Se_{0.6} = 6 \cdot 78.09 \text{ gm} = 468.54 \text{ gm}$$

$$Te_{2.4} = 2.4 \cdot 127.6 \text{ gm} = 306.24 \text{ gm}$$

$$Te_5 = 5 \cdot 127.6 \text{ gm} = 638 \text{ gm}$$

$$Sn = 118.71 \text{ gm}$$

$$Tl_2 = 2 \cdot 204.383 \text{ gm} = 408.766 \text{ gm}$$

$$Bi_{0.5} = 0.5 \cdot 208.98 \text{ gm} = 104.49 \text{ gm}$$

$$Te_3 = 3 \cdot 127.6 \text{ gm} = 382.8 \text{ gm}$$

Table 4: Material electron table

1	2	3	4	5	6	7	8
H·							
Li·	·Be·						
Na·	·Mg·						
K·	·Ca·						
Rb·	·Sr·						
Cs·	·Ba·						
Fr·	·Ra·						
		·B·	·C·	·N·	·O·	·F·	·Ne·
		·Al·	·Si·	·P·	·S·	·Cl·	·Ar·
		·Ga·	·Ge·	·As·	·Se·	·Br·	·Kr·
		·In·	·Sn·	·Sb·	·Te·	·I·	·Xe·
		·Tl·	·Pb·	·Bi·	·Po·	·At·	·Rn·

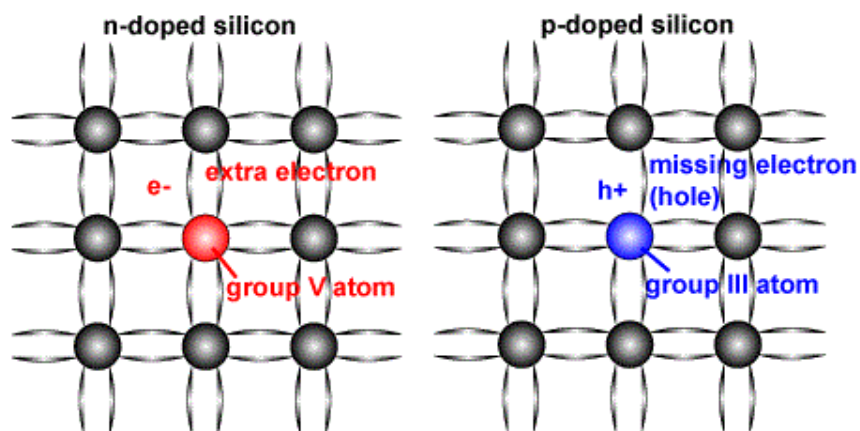


Figure 38: Electron doping

$$Sb_{1.5} = 1.5 \cdot 121.76 \text{ gm} = 182.64 \text{ gm}$$

$$Ni = 58.693 \text{ gm}$$

$$Al = 26.982 \text{ gm}$$

$$Mg_2 = 2 \cdot 24.305 \text{ gm}$$

$$Si = 28.086 \text{ gm}$$

And this is the right recipe with better free electron element as ingredient for high efficiency material. And here is some samples and free electron amount and hole number. As much as they are lot that much there will be less traffic for electrons and they can transport their energy on to another.

$$FreeElectrons = \frac{gm}{1000} \cdot \frac{mol}{Bi_2 + 2Te_3} \cdot N_A = 5.0882 \cdot 10^{17}$$

$$Holes = \frac{gm}{1000} \cdot \frac{mol}{2Mg_2 + Al} \cdot N_A = 4.8487 \cdot 10^{18}$$

$$FrElectrons = \frac{gm}{1000} \cdot \frac{mol}{Bi_{0.5} + Sb_{1.5} + 2Te_3} \cdot N_A = 5.7205 \cdot 10^{17}$$

$$Hole = \frac{gm}{1000} \cdot \frac{mol}{2Ni} \cdot N_A = 5.1302 \cdot 10^{18}$$

$$Holes - FreeElectrons = 4.3399 \cdot 10^{18}$$

$$Hole - FrElectrons = 4.5582 \cdot 10^{18}$$

$$\eta_{TEG} = \frac{P}{Q_{total}} = \frac{T_H - T_C}{T_H} \cdot \frac{(\sqrt{1+ZT}-1)}{\sqrt{1+ZT} + \frac{T_C}{T_H}} \quad \text{TEG efficiency}$$

P-electrical power ; ZT merit

Q_{total} – Thermal Power ; T_H T_C Temperature Hot and Cold

$$ZT = T_{avg} \cdot \frac{S^2 \cdot \sigma_{con}}{k}$$

T_{avg} -Average temperature on plate;

S-thermopower or Seebeck

σ_{con} -electrical conductivity

k-thermal conductivity

$$ZT_{Tl_2SnTe_5} = 1 \quad \text{at } 500K$$

$$\eta_{TEG} = \frac{T_3 - T_i}{T_3} \cdot \frac{(\sqrt{1 + ZT_{Tl_2SnTe_5}} - 1)}{\sqrt{1 + ZT_{Tl_2SnTe_5}} + \frac{T_i}{T_3}} = 0.0771$$

$$P = \eta_{TEG} \cdot Q_{solar} = 1.6768 \text{ kW} \quad \text{Output Electric power;}$$

This is the max possible output with this kind of material combination with different element.

5. APPLICATION AND EXPERIMENTAL STUDIES

To experiment and develop this idea we have to first go outdoors and make some measurements. Temperature in shadow (Figure 39), temperature under the sun (Figure 40). Measurements was made with digital LCD thermometer. Here is some specification info about sensor [41].

Here is some properties of temperature sensor that was used in experiment.

- Ultra compact, thin frame design
 - Perfect for using at home, office, and in vehicles
 - Powered by 2 x AG13 batteries (included)
- Remote sensor temperature range: -50°C to +70°C
- LCD working temperature range: -10°C to +50°C
 - Accuracy: 1%
 - 103cm cable
 - IPX2 water resistant [60]



Figure 39: Temperature in the shadow

It was noon at 13:34 on 22 December, 2014. The wind speed was 7m/s. to measure more accurately outdoor temperature under the sun, I cover thermometer's probe with thermal paste. Because probe was covered with very reflective and fancy

metal, for absorber the temperature and it showed very accurate temperature. After temperature get homogenous thermometer showed 13.2°C in shadow and 21.1°C under the sun. And thermal paste made easier to concentrated sun light on the thermometer probe (Figure 41). The magnifying glass is (Figure 42) very simple low quality magnifier that I bouth from kids hobby shop. The magnifaing 5cm in diameter. And the result is suprizingly 63.4°C.

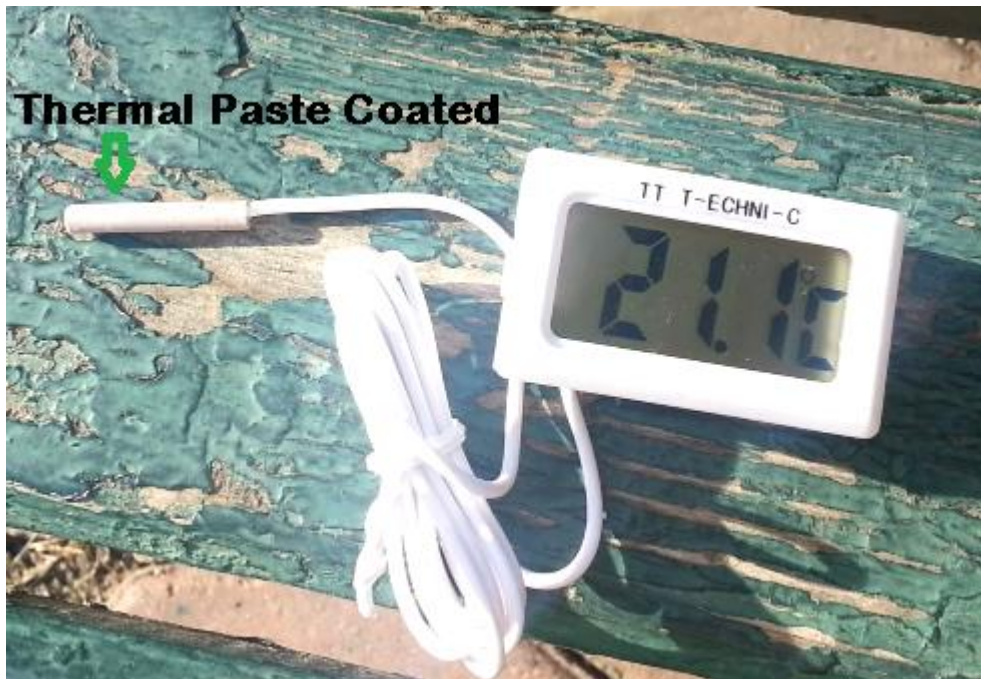


Figure 40: Temperature under the sun



Figure 41: Concentrated Sunlight on the probe



Figure 42: The magnifying glass

After outdoor measurements I tried to duplicate same conditions at my home on my small lab. To duplicate the heat source I used old solder (Figure 43) and I uncover it where there is heating winding in it. This solder has 30W heating capacity.

The complete system is demonstrated on Figure 44. After adjustment I measured exactly 63.4°C that I measured under the concentrated sun rays. I filled plastic box with cold water that have 19.1°C . It is close enough to the system I designed. I used TEC1-12706 as a thermoelectric generator to get Peltier effect. Its dimension is $4\text{cm}\times 4\text{cm}\times 3\text{mm}$. there some other information about TEG in table 4.

The experiment showed system can produce 1.04V (Figure 46) and 0.1A , which is 0.104W . The face area of TEG will be 16cm^2 and comparing to full scale design which 8800cm^2 . So prototype could be scaled 550 time. It means even with this kind of not ideal system I can produce 57.2W . Because all measurement was duplicated for winter and even this weak system can provide that much. In summer system probable will produce around 200W . Which full scale system having very big probability to produce theoretically numbers.



Figure 43: Uncovered solder

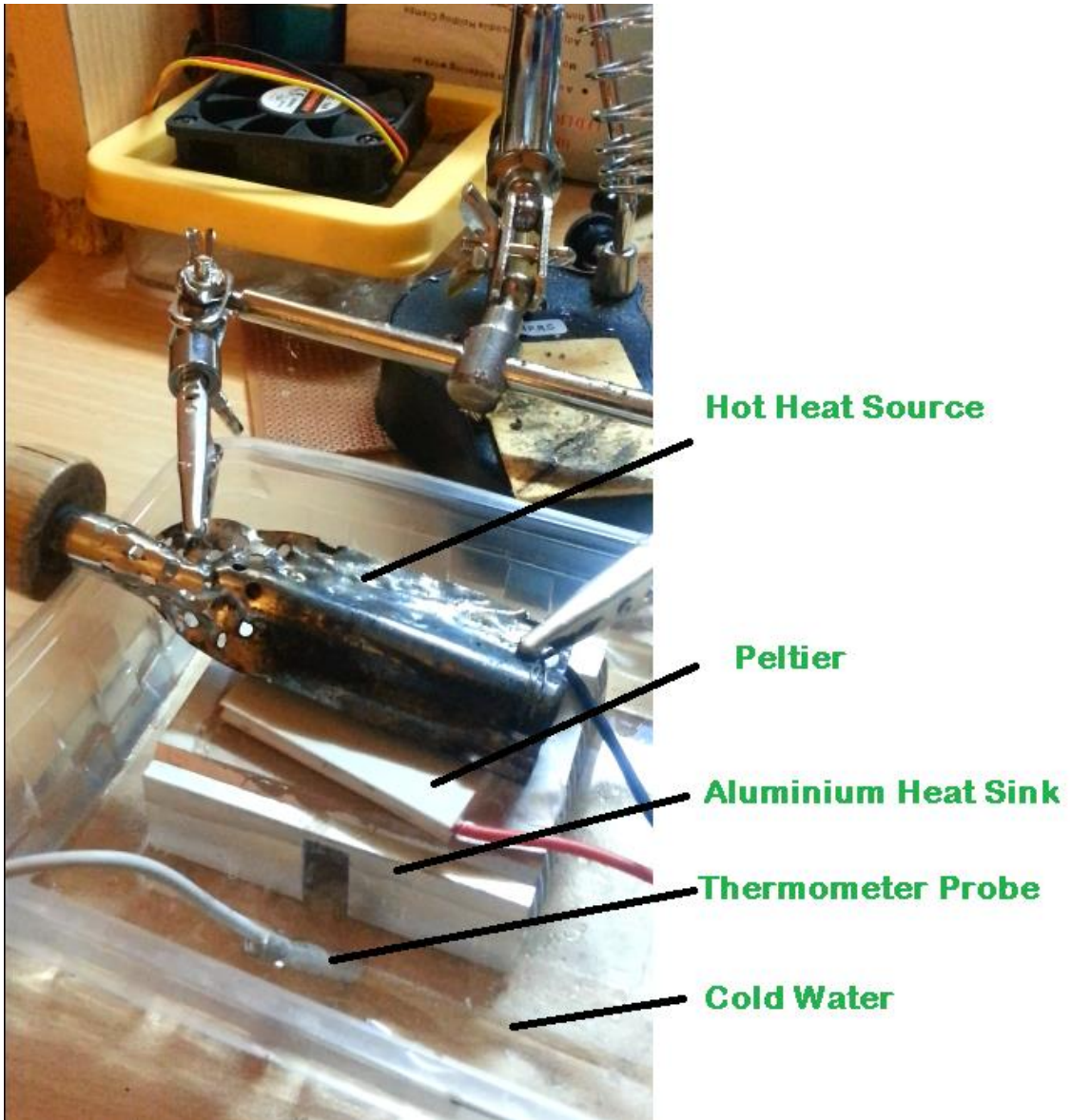


Figure 44: Experiment apparatus



Figure 45: Hot surface temperature and cold water temperature

Table 5: TEC1-12706 properties



Hebei I.T. (Shanghai) Co., Ltd.

Thermoelectric
Cooler

TEC1-12706

Performance Specifications

Hot Side Temperature (° C)	25° C	50° C
Qmax (Watts)	50	57
Delta Tmax (° C)	66	75
I _{max} (Amps)	6.4	6.4
V _{max} (Volts)	14.4	16.4
Module Resistance (Ohms)	1.98	2.30



Figure 46: Measured voltage

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This total thesis is proposing the possibility of TEG to produce theoretical result. Which this kind of apparatus can change world dramatically and make lots of things easier to get. Even TEG material could be shaped and processed with 3D printer to produce Peltier sheet. Using 3D printer may provide much thinner sheet which even can act as better PV. The system can provide electricity from heat and Sun light.

By the time there will be higher technology can provide much high possibility to combine different material together and work with them. Such apart unities can provide theoretical ideal scenery to get that much energy. It shows that even today's very poor material combination can provide high energy output comparing the solar panel, I mean compactable comparing energy density.

Even the test showed it's possible. Almost all materials are poorly made and assuming all kinds of loss even in that case it worked well. This kind of system can charge the regular phone. This kind of construction will be same size as the phone itself.

More options this system give hot and cold water this kind of application are very suitable for houses and heavy industry to provide this kind of free energy sources and with this kind of high performance. Several of this kind of full scale panel can provide total energy use for daily use even night hot water could be stored and electrical energy could be stored to in the batteries.

6. Recommendations

For recommendation, material choose is very important, because some materials are radioactive or some material are toxic. In this thesis there was not used any of such dangerous elements or material that can harm or make human to get in any trouble.

Other recommendation is to use sun following automatic system instead of expensive glasses for concentrated sun light. But better performance this kind of glass should be used even there is sun following system.

More options this system give hot and cold water this kind of application are very suitable for houses and heavy industry to provide this kind of free energy sources and with this kind of high performance. Several of this kind of full scale panel can provide total energy use for daily use even night hot water could be stored and electrical energy could be stored to in the batteries.

For maintained and yearly use the part should be very simple designed and use very less parts and it will make system more robust in case of less part less probability to break down. And part should be cheap and easy findable. Only coolant and TEG is special part, but there is very close performance fluid could be used and they are very unexpansive..


REFERENCES

- [1] Aden B Meinel and Marjorie P. Meilen., 1976, Applied Solar Energy, An Introduction. Addison-Wesley Publishing Company, Inc. Philippines, third edition edition,.
- [2] U.S. Department of Energy's Sun_Lab. August 2001, [www:energy.sandia.gov=sunlab=PDFs=boeing:pdf](http://www.energy.sandia.gov/sunlab/PDFs/boeing.pdf)
- [3] W.B. Stine and R.W. Harrigan. 1985. Solar Energy System and Design, [www:powerfromthesun.net:htm](http://www.powerfromthesun.net:htm).
- [4] Matt Anderson. 2007, Computer simulation of a solar dish power system for sustainable rural development. Master's thesis, Royal Institute of Technology, Page 42.
- [5] C. Christopher Newton. 2007, A concentrated solar thermal energy system. Master's thesis, Florida State University,
- [6] Brenton Greska and Anjaneyulu Krothapalli. 2007, Tri-generation concentrating solar power system for rural applications. Technical Report ES2007-36169, Sustainable Energy Science and Engineering Center,.
- [7] T. Mancini, P. Heller, B. Butler, B. Osborn, W. Schiel, V. Goldberg, R. Buck, R. Diver, C. Andraka, and J. Moreno. 2003. Dish-stirling systems: An overview of development and status. *Journal of Solar Energy*, 125:135-151.
- [8] Richard B. Bannerot, John R. Howell, and Gary C. Vliet. 1982. *Solar-Thermal Energy Systems, Analysis and Design*. McGraw-Hill, Inc.,
- [9] L.C. Spencer. 1989. A comprehensive review of small solar-powered heat engines: Part I. A history of solar-powered devices up to 1950. *Journal of Solar Energy*, 43(4):191-196,.
- [10] Frank Kreith and Jan F. Kreider. 1978. *Principles of Solar Engineering*. Hemisphere Publishing Corporation, New York.
- [11] John A Du_e and William A Beckman. 1991. *Solar Engineering of Thermal Processes*. John Wiley & Sons, Inc., second edition.
- [12] J. P. Holman. *Heat Transfer*. McGraw-Hill, 2002. ninth edition edition.
- [13] S. M. Kim, K. Kyhm, H.-S. Yang and K. S. Hong, *J.Korean Phys.* 2006. Soc. 49, S688

- [14] N. Chevalier, M. J. Nasse, M. Stark, J. F. Motte, J. C. Woehl, S. Huant, P. Reiss, J. Bleuse and F. Chandezon, *J. Korean Phys. Soc.* 2005, 47, 126
- [15] S. U. S. Choi, 1995, in *Developments and Applications of Non-Newtonian Flows* The ASME, New York,
- [16] S. Lee, S. U. S. Choi, S. Li and J. A. Eastman, *J. Heat Transfer* 121, 280
- [17] H. Q. Xie, J. C. Wang, T. G. Xi, Y. Liu and F. Ai, *J. Appl. Phys.* 91, 4568
- [18] X.W.Wang, X. F. Xu and S. U. S. Choi, *J. Thermophys.* 1999, 13, 474
- [19] J. C. Maxwell, 1904, *A Treatise on Electricity and Magnetism*, 2nd ed. (Oxford University Press, oxford.
- [20] T. K. Hong and H. S. Yang, *J. Korean Phys. Soc.* 2005, 47, 321.
- [21] S. P. Jang and S. U. S. Choi, 2004, *Appl. Phys. Lett.* 84, 4316.
- [22] Rowe, D. M. 1995, *CRC Handbook of Thermoelectrics*; CRC Press: Boca Raton, FL,
- [23] Snyder, G. J.; Ursell, T. S. *Phys. Rev. Lett.* 2003, 91, 148301-148304.
- [24] DiSalvo, F. J. *Science* 1999, 285, 703-706.
- [25] Mott, N. F.; Jones, H. 1958, *The Theory of the Properties of Metals and Alloys*; Dover Publication: New York, NY,.
- [26] Mahan, G. D.; Sofo, J. O. 1996, *Proc. Natl. Acad. Sci.* 93, 7436-7439.
- [27] Rao, A.; Ji, X.; Tritt, T. M. 2006, *Mat. Res. Bull.* 31, 218-223.
- [28] Kittel, C. 1996. *Introduction to Solid State Physics*; 7th ed.; John Wiley & Sons Inc.: New York,
- [29] Pollock, D. D, 1985. *"Thermoelectricity" Theory, Thermometry, Tool*; ASTM Publications: Philadelphia, PA,
- [30] Uher, C. 2000; *Semiconductors and Semimetals*; Academic Press: New York, Vol. 69.
- [31] Sales, B. C. 2002; *Handbook of the Physics and Chemistry of Rare Earths*; Elsevier Science: Amsterdam, Vol. 33.
- [32] Mandel, N.; Donohue, J. 1971, *Acta Crystallogr. B* 27, 2288-2289.
- [33] Wölfing, B.; Kloc, C.; Teubner, J.; Bucher, E. 2001, *Phys. Rev. Lett.* 86, 4350-4353.

- [34] Sharp, J. W.; Sales, B. C.; Mandrus, D. G.; Chakoumakos, B. C. 1999, *Appl. Phys. Lett.* 74, 3794-3796.
- [35] Bhan, S.; Schubert, K. J. 1970, *Less-Common Met.* 20, 229-235.
- [36] Schewe, I.; Böttcher, P.; Schnering, H. G. V. Z, 1989, *Kristallogr.* 188, 287-298.
- [37] NREL, 2002. Parabolic trough technology overview.
- [38] Häberle, Andreas, 2002. et al. "The Solarmundo line focussing Fresnel collector. Optical and thermal performance and cost calculations." *Solarpaces*. Zurich: Solarpaces,
- [39] Will Reece, 2000, The history of solar power
- [40] Energy.gov, 2012, Geothermal heat pump,
- [41] <http://www.dx.com/p/digital-compact-lcd-thermometer-with-outdoors-remote-sensor-15553#.VXRda8-qqko>

ÖZGEÇMİŞ

Personal information	
First name / Surname	Samir NAGIYEV
Address	Esentepe MH. Kardeşler SK. 20/1 Şişli – İstanbul Türkiye
Telephone	(+90555)-612 7191 (TR) (+99450)-467-7765 (AZ)
Education	M.Sc. Marmara Uni. Mechanical Eng. (Marmara Üniversitesi) 2015 B.Sc. I.T.U Mechanical Eng. (Istanbul Technical University) 2013
E-mail	nagiyevs@gmail.com
Nationality	Azerbaijan-Azərbaycan
Date of birth	11.04.1988
Gender	Male
Work experience	
Dates	May 30, 2008 – Jun 22, 2008
Occupation or position held	Internship
Main activities and responsibilities	Student Workshop
Name and address of employer	İTÜ (Istanbul Technical University) Gümüşsuyu
Type of business or sector	University
Dates	Aug 10, 2010 – Sep 07, 2010
Occupation or position held	Internship
Main activities and responsibilities	Process Control Department
Name and address of employer	TDİ A.Ş. (Turkey Maritime Organization INC.) and İDO A.Ş. (Istanbul Fast Ferries INC.)
Type of business or sector	Incorporation
Dates	Aug 15, 2011 – Sep 16, 2011
Occupation or position held	Internship
Main activities and responsibilities	R&D (AR&GE) Department (3 weeks) and Process Control Department
Name and address of employer	Baymak Mak. San. ve Tic. A.Ş. (Baymak Machinery Industrial and Trade INC.)
Type of business or sector	Machinery Industrial and Trade INC.
Dates	2009-2013
Occupation or position held	Manager
Main activities and responsibilities	Manager, Engineer.
Name and address of employer	Aphercon Engineering and Consulting, http://www.aphercon.com/
Type of business or sector	Engineering and Consulting

Education, training and scholarships	
Date	2008 -2012
Principal subjects/occupational skills covered	The International Association for the Exchange of Students for Technical Experience commonly referred to as IAESTE is an international organization exchanging students for technical work experience abroad. Students gain relevant technical training lasting from 4 weeks to 18 months
Name and type of organization providing education and training	ITU IAESTE (The International Association for the Exchange of Students for Technical Experience) http://www.iaeste.itu.edu.tr/
Level in national or international classification	Since 1948, the association has grown to include more than 80 countries worldwide and has exchanged in excess of 300,000 students. IAESTE exchanges around 7000 students annually playing an important role in giving technical undergraduates practical work experience and a global perspective.
Date	2010 -2012
Principal subjects/occupational skills covered	The Caspian Engineers Society (CES), non-profit organization, is founded on the principle of developing "Engineering Culture" across the Caspian region. It is our mission to develop engineers professionally, support regional industry by introducing world class experience and technology, and offer an engineering network.
Name and type of organization providing education and training	The Caspian Engineers Society (CES) http://thecsesworld.org/site/
Level in national or international classification	1st Professional Engineering Organization within the region 2009 BP Annual Engineering Award winner on the "People Development" nomination 2010 Institute of Chemical Engineers (UK Engineering Council) Annual Awards – Highly Commended on the "Education and Training" nomination 58 technical events during last 3 years 2000 students and young engineers attended event
Date	2009 - 2010
Principal subjects/occupational skills covered	Azerbaijani Oil & Gas Undergraduate Studies Scholarship Program .
Name and type of organization providing education and training	BP Caspian (British Petrol) http://www.bp.com/sectiongenericarticle.do?categoryId=9024815&contentId=7046267
Program provision	Program provides financial support to education equivalent to 5060 USD per year.
Date	2006 - 2008
Principal subjects/occupational skills covered	Istanbul Metropolitan Municipality Undergraduate Studies Scholarship Program.
Name and type of organization providing education and training	İstanbul Büyükşehir Belediyesi (Istanbul Metropolitan Municipality) http://www.ikb.gov.tr/en-US/Pages/Home_Page.aspx
Program provision	Program provides financial support to education equivalent to 700 TL per year.
Date	2013
Principal subjects/occupational skills covered	7th international robot contest referee under the coordination of Ministry of Education
Name and type of organization providing education and training	Ministry of Education(http://mtegm.meb.gov.tr/)
Program provision	Was invited as 7th international robot contest referee (100\$)

Personal skills and competences

Native language Azerbaijan—Azərbaycan

Self-assessment
European level (*)

Language
Language
Language
Language
Language

		Understanding		Speaking		Writing	
		Listening	Reading	Spoken interaction	Spoken production		
1	Turkish		C2		C2		C2
2	Russian		C2		C2		C2
3	English		C2		C2		C2
4	German		B1		B1		B1
5	Georgian		B1		B1		B1

Patent

Utility Model Patent (Faydalı Model Patenti) Başvuru no: 2011/04311, Evrak No: 2011-G-115011 <http://online.tpe.gov.tr/web/index.html>
(product review) http://www.youtube.com/watch?v=Z_vkTgazz5Y

Organizational skills and competences

Excellent managerial competence. Ability to inspire, lead and motivate people. Futuristic thinking. Excellent persuasive skills. Goal oriented. Decision-making. Excellent negotiation skills. Excellent project management skills. Passion for workforce transformation. Ability to engender continued learning and growth for self-development and staff development.

Computer skills and competences

AutoCAD, Autodesk Inventor, SolidWorks, Matlab, MathCad Prime PTC, Eagle PCB, SketchUp, CoolPack ,EES, Abaqus, Arduino, LabVIEW, WordPress, HTML, C++, Mathematica, MathCad, PhotoShop, Adobe Suite, PowerPoint, MS Office, DreamWeaver.

Artistic skills and competences

Guitar, Judo, Hunting, Bodybuilding.

Other skills and competences

As a foreign student in Turkey, living own self over the 7 year in Istanbul and being couple times abroad gave adaptively to abroad. Principally acceptable to travel abroad and have Passport since 2006, Date of Expiry is 13.06.2021.

Driving license

B-type full and clean Driving license (2006)

References

- 1. Asst. Prof. Dr. Nuri SOLAK**
I.T.U. Chemistry & Metallurgy Faculty
Metallurgical & Materials Eng. Dept.
Extractive Metallurgy Division
Phone: (+90212) – 285-3548
Fax: (+90212) – 285-3427
Mail: solaknu@itu.edu.tr
WebPage: <http://www.mme.itu.edu.tr/ogretim-uyeleri/nuri-solak/>
Address: I.T.U. Metallurgical & Materials Engineering Dep. 34469 Maslak – Istanbul/TR
- 2. Prof. Dr. Abdülkerim Kar**
Marmara University, Mechanical Faculty
Mechanical Eng. Dept.
Phone: (+90216) – 348-0292 Ext: 284
Mail: akar@eng.marmara.edu.tr
Webpage: <http://mimoza.marmara.edu.tr/~akar/>
Adress: Marmara University, Goztepe, Kadikoy, Istanbul/TR