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Study of Photovoltaic/Thermal collector technology for domestic water treatment

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Resumo

A radiação solar absorvida pela Terra desde que entra na atmosfera é de tal ordem de grandeza que bastaria uma hora de energia solar para suprir as necessidades de consumo energético para um ano inteiro (valores de 2002). Por outras palavras, um ano de energia solar, se utilizada na totalidade, é superior à energia alguma vez produzida usando combustíveis convencionais como carvão, urânio, crude, etc. Com o aumento das necessidades de consumo energético devido ao crescimento da população mundial, a energia produzida mundialmente com recurso a combustíveis convencionais aumentou 97 vezes desde 2004. De acordo com previsões da Agência Internacional de Energia Solar, em 2050 a utilização de energia solar contribuirá em cerca de 27% para a produção energética a nível mundial.

A escassez de água potável é um problema cuja resolução é vital para a vida humana. Esta problema está a alastrar por todo o globo devido às mudanças climáticas, que provocam secas em locais onde não existiam anteriormente. Normalmente é um problema que vem acompanhado pela falta de rede elétrica e dificuldades económicas. Assim, o uso de processos de purificação de água com base em formas renováveis de energia é mais apelativo, na maior parte dos casos em que há escassez de água.

Sabe-se que os patógenos podem ser eliminados aquecendo a água até uma temperatura superior a 100ºC. O projeto desenvolvido pretende estudar a possibilidade de purificar água, com recurso à energia solar disponível. O foco principal é analisar o projeto construtivo de coletores híbridos (fotovoltaicos e térmicos) e entender os requisitos para a sua boa performance. Parâmetros operacionais como temperatura do painel, temperatura da célula fotovoltaica, ou caudal de fluido térmico serão analisados, por forma a selecionar um parâmetro crítico. Serão abordadas métricas de performance como eficiência térmica, elétrica e eficiência de acordo com a 1ª e 2ª leis da termodinâmica, que serão integradas numa rotina de cálculo desenvolvida com Excel. Os resultados obtidos serão discutidos, por forma a obter as conclusões. O comportamento da temperatura atingida pela água é também estudado e discutido, bem como a possibilidade de aumentar essa temperatura com um coletor deste tipo.

Através deste projeto, elementos críticos necessários para analisar e projetar um coletor solar híbrido são identificados. O estudo foi conduzido, identificando os fatores que promovem o aumento da temperatura da água. Verificou-se que os valores de eficiência associados são reduzidos, se bem com o aumento da temperatura pretendido.

Palavras chave: Energia solar, produção de enrgia, água potável, purificação de água, eficiência energética, coletor PVT

Abstract

It is believed that one hour of the total solar energy received by the earth´s surface is of the same order of magnitude as total world consumption of non-renewable fuel for one whole year (2002 values). In other words, one year of solar energy, if completely utilized, it is more than the energy produced ever by the conventional fuels like coal, uranium, crude, etc. With the increase in demand of energy due to growth in human population, currently world is producing energy using conventional fuels around 97 times than we produced since 2004. According to the International Solar Agency prediction, by 2050 using solar energy will contribute about 27% of the whole energy production in the world.

Scarcity of potable water is a problem whose resolution is vital to human life. It is becoming more widespread all over the globe due to the climate changes, that cause droughts in places where they did not previously exist. This problem is often accompanied by the absence of the grid and economic difficulties. Thus, the use of water purification processes that rely on renewable forms of energy is more appealing, in most of the cases of potable water scarcity.

It is understood that, by increasing the temperature to more than 100 ºC shall kill the pathogens in the water. Thereby impure water becomes consumable. This project aims to study the possibility of water purification using the available solar energy. The main focus is to look into the design of hybrid photovoltaic/thermal (PVT) solar collectors and to understand the requirements for its performance. The operational parameters such as Inlet fluid teperature, outlet temperature, ambient teperature, solar radiance and etc, are to be critically analysed, discussed in order to propose an efficient design parameter. Performance metrics like thermal efficiency and electrical efficiencywill be approached. Thereby, related formulas to those performance metrics are framed. These formulas are solved using EXCEL. It is then plotted into graphs and discussed to know the output. Hence, values are given accordingly to the parameters. The behaviour of temperature parameter with efficiency values are studied and discussed. The understanding of possibility of increasing the water temperature is done as well.

Through this project, critical elements required to design and analyse a solar PVT model are identified. The study was conducted and understood the components that help in increasing the temperature. Therefore, the efficiency values achieved are very low though there is a peak increase the temperature.

Keywords: Solar energy, energy production, potable water, water purification, energetic efficiency, Photovoltaic/thermal collector.

Declaration of authenticity

I, Manibaalan Chokkalingam (1161616) declare that this dissertation is my original work, referred, gathered and utilized specially to fulfil the purposes and objectives of this study, and has not been previously submitted to any other university for a higher degree. I also declare that the citation information are true resources. Therefore, I have done to the best of my knowledge and honesty.

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Nomenclature

List of abbreviations

AM	Air mass
a-Si	Amorphous Silicon
ASTM	American Society for Testing and Materials
BIPV	Building Integrated Photovoltaic
COP	Coefficient of Performance
c-Si	Crystalline Silicon
DHW	Domestic Hot Water
DNI	Direct Normal Irradiance
ETC	Evacuated Tube Collector
EU	European Union
FCP	Flat Plate Collector
GNI	Gross National Income
IEA	International Energy Agency
NZEB	NetZero Energy Building
OECD	Organisation for Economic Cooperation and Development
PCM	Phase Change Materials
PV	Photovoltaic
PVT	Photovoltaic/thermal

RES	Renewable Energy Sources
R-O	Reversed osmosys
STC	Standard Test Conditions
USA	United States of America
USD	United States Dollar
UV	Ultra violet
ZEB	Zero Energy Building

List of Symbols

A_c	Cross sectional area of panel	(m^2)
a	Modified Heat Removal Factor	-
b	Overall Heat loss Coefficient	-
c	Specific heat capacity	(J/kgK)
G	Solar Irradiance	(W/m^2)
GB	Beam Radiation	(W/m^2)
GD	Diffuse Radiation	(W/m^2)
GR	Ground Reflection Radiation	(W/m^2)
G_T	Global irradiance	(W/m^2)
κ_g	Low irradiance correction factor	-
κ_α	Absorption Correction Factor	-
κ_γ	Module Temperature Correction Factor	-
κ_λ	Spectrum Correction Factor	-
κ_υ	Optical Reflection Correction factor	-
P_n	Nominal Power	(W)
$\dot{Q}$	Rate of Thermal Energy	(W)
T_{amb}	Ambient Temperature	(K, °C)
T_{in}	Inlet temperature	(K, °C)
T_n	Actual incident angle of solar radiation	(°)

T_{out}	Outlet Temperature	(K, °C)
T_r	Reduced Temperature	(K m^2/W)
T_υ	Light Transmittance factor	-
$\dot{V}$	Volumetric flow rate	m^3/s

Greek symbols

α_γ	Actual incident solar angle	
α_n	Normal incident solar angle	
Ω	Micro	
μ	Micro	
η	Efficiency	
η_0	Zero Loss collector Efficiency	
ρ	Density of the fluid	(kg/m^3)

1. Introduction

Availability of water and quality of drinking water has been a never-ending problem throughout civilization history, and especially since the second half of the 20th century, since world population has been increasing in an exponential scale. Globalization rate is known for the change in social and economic conditions over the world. A globalization rate of 1.6%, (Chow ,2009) together with environmental problems such as global warming, has created even more impact on this “water problem”: due to globalization, the consumption of the large natural water reservoirs has increased. Thereby, there is an increase in the demand for water. That leads to the need of preserving lakes, rivers, and other natural reservoirs. Simultaneously, contamination of groundwater has also become another major issue: from the dumping of plastics till the accumulation of industrial wastes, the surface and groundwater contamination has also led to waterborne diseases, like cholera or dysentery. Large levels of pathogens are found in the highly populate zones around the world. Therefore, by understanding the severity of this “water issue”, this project aims to contribute to a possible solution for the improvement of drinking water quality. The basic idea of this work arises from that need of provision of potable water, in places where the existing water is contaminated. As this problem is often accompanied by a lack of economic resources and electric grid, the focus of the work is to verify the possibility of using a cheap and abundant source of energy, such as solar energy, to purify water.

1.1 Context

This project is contextualized in the scope of water problematics, as previously explained. Every day, two million tonnes of waste is being discharged into the world's water reservoirs. There is an urgent need of solutions for waterborne diseases, as it is the most comon source of infectious disease for children below 5 years. Poor countries have the least access to clean drinking or usable water for domestic purposes. Over 70 % (Pero ,2015) of people in asian rural population feel the lack of water sanitary treatment. It is also a known fact that there is only 2% of the whole world water natural reservoirs available is drinkable or usable water for humans. (Pero ,2015) Therefore, the need of water with quality is a basic requirement for life preservation in the medium to long term.

On the other side, technology has improved at a remarkable rate. There are domestic level solutions available since late 20th century for the purpose of water purification and water treatment. Concepts such as distillation, deionizaiton, reverse osmosis, filtration, and photo oxidation are widely used in developing water purification technology in the market. Most of these concepts demand either huge cost investment or more usage of electricity. These two factors are difficult to overcome for the people who usually face the real problem. Especially in poor and developing countries, it is nearly impossible for the people to afford for these available technologies. Hence, there is an urgent need for a solution for this problem. One possible way can be simply use already existing commercial technology to serve this problem.

Solar energy is one of the energy resources available in an unlimited scale. As we all know there are many devices which harness the solar energy or the photonic energy to several useful purposes. Photovoltaic panels make use of the incident solar light in order to convert it into electricity. Solar thermal collectors receive solar radiation and recover it partially by heating a fluid like water or air, which are then used for heating applications, like domestic hot water, climatization or even industrial processes. It is possible with evacuated tube collectors reach higher temperatures, since they work with vacuum, which reduces termal losses. There also hybrid solar collectors, which are exactly the combination of the above mentioned thermal and photovoltaic collectors. It is also known as photovoltaic thermal (PVT) collectors. This type of collectors can be a solution, since they produce both heat, by transfering it to a fluid flow, and electricity. The produced electricity can be used to hipothetically trigger a reversed osmosys equipment, that can filter impure water, and a circulating pump. The hybrid PVT system can be extended to the purpose of not just to heat the water but also to the extent of purifying water, which requires a minimum temperature of 100ºC. Since there are different types of PVT collectors, the project will focus only in the use of flat plate PVT collectors, since they are the less expensive. The context of this project is to identify if the temperature of water can be raised to the boiling stage, and thereby purifying it, and simultaneously produce the minimum electrical energy in order to drive the reversed osmosys equipment and the circulating pump.

1.2 Goals

Under the scope of using a PVT flat plate collector to obtain drinking water, the main goals of this project are:

- Investigate the possibility of operating an electronic filtering device with the electric energy provided by the PVT collector. This provides the inlet filtered and clear water into the PVT collector.
- In order to verify if it is possible to obtain a water outlet temperature of 100ºC, several operating parameters will be investigated, for an application of the system in India, and therefore using typical values of the Indian climate. The following parameters will be tested:
    - inlet temperature,
    - solar radiation,
    - ambient temperature

The results are obtained through the application of the concepts of thermal and electrical efficiencies, using efficiency parameters of PVT collectors available in market.

1.3 Methodology

In the flow chart presented in figure 1.1, the main steps of the development of the project are outlined.

As the concept of the thesis is fixed, the scope of the project is analysed using literature survey. In this step, the concepts related to the core topic were discussed, based on several reference articles and journals. This allows the definition of the boundaries that frame the project. After this phase, the problem scope is identified: water scarcity and affordable water purification system. This step is followed by the analysis of the requirements. This way, the parameters that are required to study are identified, and the range of its possible values is proposed. In the further steps, the formulation is developed. A methodology to obtain the results for the proposed parameters is investigated, and it is found that it has to be based on the concepts of thermal and electrical efficiencies. In this work, values for those efficiency parameters will be chosen based on technical specifications of commercial PVT models existing in the market. The equations used are solved for determination of outlet temperature, using EXCEL, for a range of input values of inlet temperature, ambient temperature and solar radiation. Thermal and electrical efficiencies are also calculated. The results obtained are analysed, and the valid ones are selected and discussed.

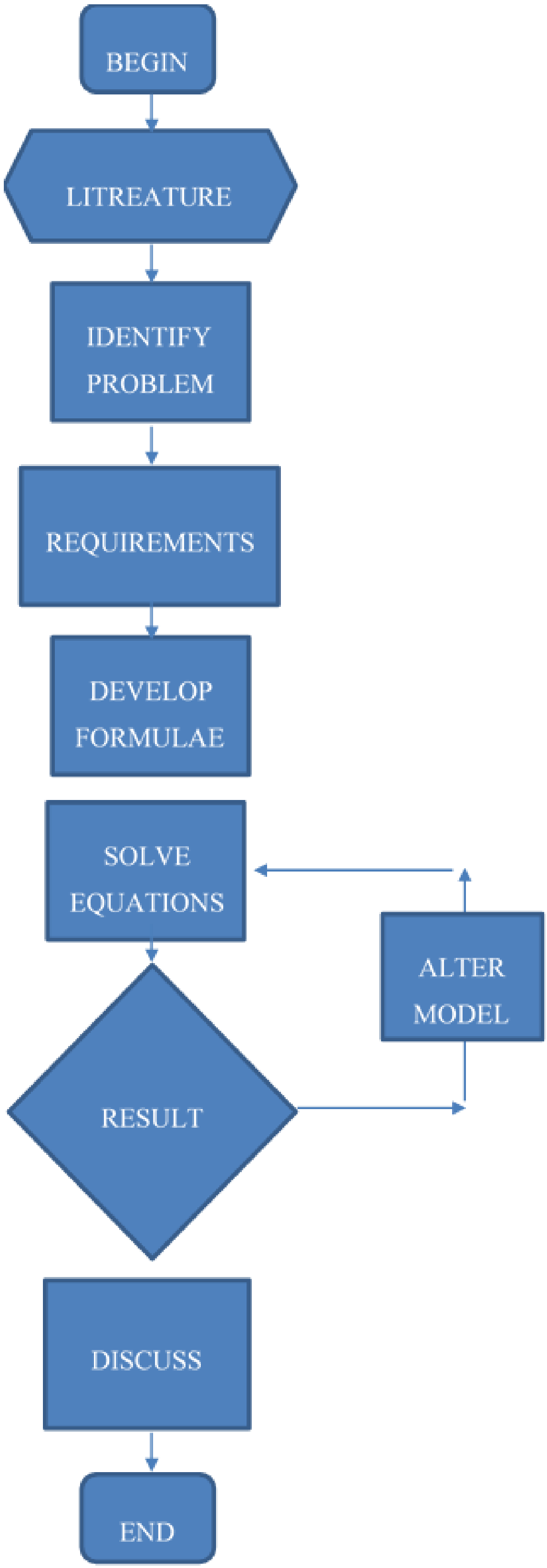

Figure 1-1 Project Working Methodology

1.4 Time line

The project demands for a minimum of four months of work, for which the timeline must be splitted into several sub tasks. Basically, the idea is to create sub tasks to have shorter deadlines and continuous project follow up. Those sequences are presented in figure 1.2, regarding the period from June to August, and figure 1.3 for the period from August to October.

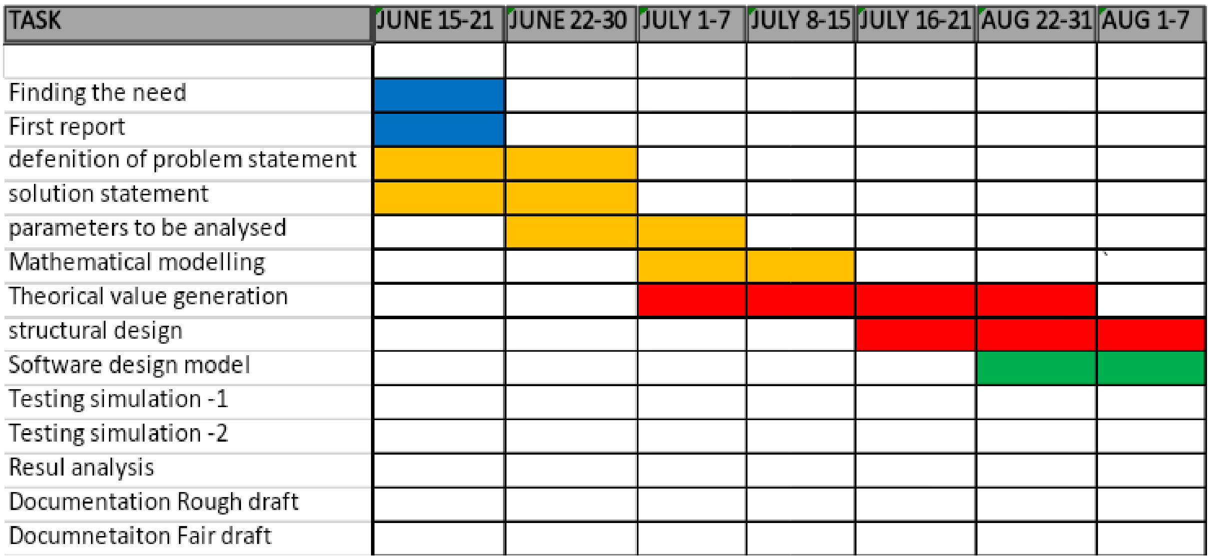

Figure 1-2 Timeline of the project (1) – June to august

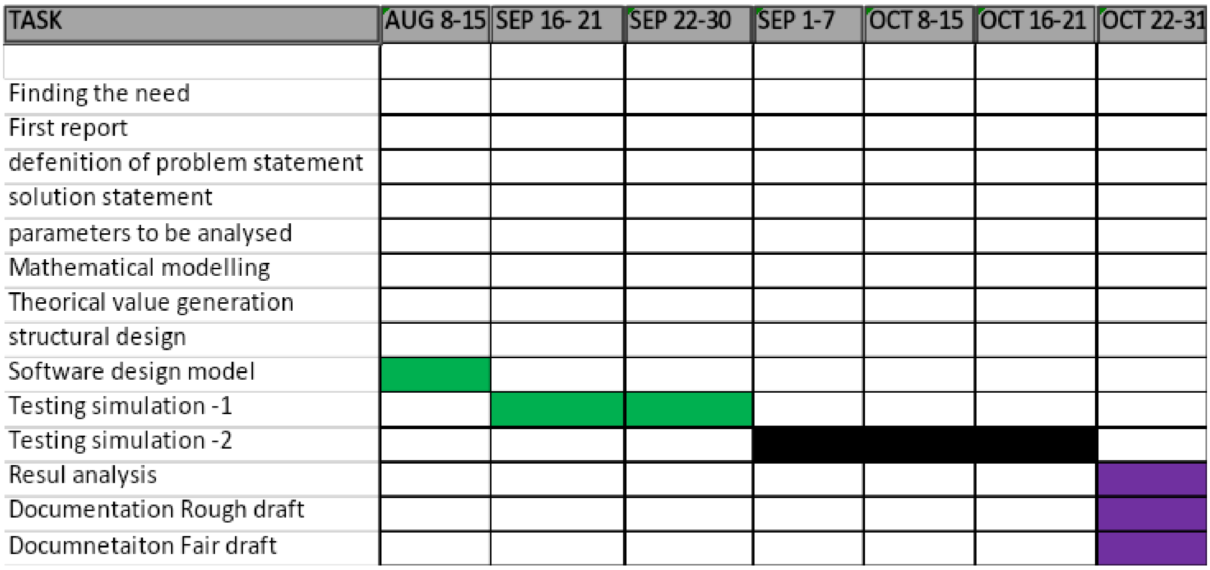

Figure 1-3 Timeline of the project (2) – August to October

1.5 Structure of the dissertation

The dissertation is divided into five chapters. The first chapter introduces the theme, contextualizing it and focusing its relevance. It defines the goals that are intended to be achieved with the project, gives an outline of the methodolgy followed, the timeline and the structure of present report.

Chapter 2 includes the literature review part. The concepts of water purification methods are explained briefly. The technical requirements for the water quality maintenance is discussed. The basic concept of solar energy and technologies based on it are discussed. Types of PVT collectors in the market are presented briefly.

In the third chapter the characteristics and features of the system that is proposed are presented. The operation cycle is discussed in order to understand the framework of the solution. Technical specifications of the components are also selected from comercial equipment available on market. Therefore the problem can be analytically identified and outlined.

The obtained results are presented and discussed in the fourth chapter. The results are grouped according on the influence of water inlet temperature (Tf_{in}), ambient temperature (Tamb), global radiation (G) in order to achieve water outlet temperature (Tf_{out}) of 100ºC. After this presentation, a crytical analysis of the requirements identified to achieve the goal of purifying the water is discussed.

The final fifth chapter concludes the project and synthesizes the outcomes of the project. The results are summarized and future works that can be adopted in this field are listed.

2. Bibliographic research

Throughout this chapter the fundamental notions that serve as a basis for the idealised system will be presented. For such, aspects to meet the requirements for quality of drinking water and technologies used for water filtration will be listed. With regard to equipment for capturing solar energy, different types of solar thermal collectors and photovoltaic cells will be presented.

2.1 Water purification requirements

The drinking water should satisfy a certain level of standard water quality measurements. The water is usually measured in Parts Per Million (PPM). There are some additional requirements as per the ASTM (American Society for Testing and Materials).

For clinical laboratory testing the most relevant standards are those of the Clinical and Laboratory Standards Institute (CLSI). For general chemical analysis and physical testing, the requirements for reagent grade water are covered by the standards set out by ASTM. Others include the international Pharmacopoeia standards (USP, EP and JP) which specify water for use in medical work and the International Organization for Standardization specification for water for laboratory use (ISO 3696:1987) (Michael ,2016). Most of the standards classify different levels of purity of water into different types or grades depending on the permitted levels of contamination. The ASTM standards requirements are listed below, in table 1 and 2.

Table 1 - Allowed parameter levels according to ASTM standards (Aste, 2016)

Parameter (unit)	Type I*	Type II**	Type III***	Type IV
Resistivity min. (MΩ-cm @25°C)	18.0	1.0	4.0	0.2
Conductivity max. (µS/cm @25°C)	0.056	1.0	0.25	5.0
pH @25°C	N/A	N/A	N/A	5.0-8.0
TOC max. (ppb or µg/l)	50	50	200	No limit
Sodium max. (ppb or µg/l)	1	5	10	50
Chlorides max. (ppb or µg/l)	1	5	10	50
Silica max.(ppb or µg/l)	3	3	500	No limit

* Type I water MUST be passed through a 0.2µm membrane.

** Prepared by distillation.

*** Requires the use of a 0.45µm membrane. Note: pH is not applicable to Types I, II and III as the electrodes used to take the measurement will contaminate the water and there is insufficient electrical conductivity for them to work accurately. (Michael ,2016) These ASTM standards are further subdivided into Types A, B and C that can be used in conjunction with the Type I, II, III or IV water above when bacteria levels need to be controlled. (Pero, 2015)

Table 2 - Bacterial count and endotoxin values (Aste, 2016)

Parameter (Unit)	Type A	Type B	Type C
Total bacterial count (CFU/100ml)	1	10	1000
Endotoxin (EU/ml)	0.03	0.25	N/A

Different levels of purity are required for different purposes, and the water used must be determined to be adequate for the purpose that is intended. Many applications may require additional treatments such as removal of nucleases for molecular biology applications. In order to acheive water purification, there are few methods through which technically water purification can be achieved.

2.2 Water purification methods

Water is the one of the best solvents in the nature. It dissolves in other solvable elements in nature. Therefore, there are high chances for the presence of microorganisms in water. These harmful micro-organisms create an unsafe water for drinking. There are several negative effects of drinking unsafe water or impure water. Some of the health pathologies caused are gastrointestinal problems, diarrheal, nausea, intestinal or stomach cramping, intestinal or stomach aches and pains.

Water may contain both solvable and dissolvable harmful contaminants. They can harm the human body from no physical damage to death. Few examples are e. coli bacteria, coliform bacteria, nitrates, lead, fluoride, arsenic, radium, radon, pharmaceuticals, herbicides, pesticides, chemicals, faecal matter, microbial pathogens, parasites and viruses.

There are several purification methods for cleaning water. Most commonly used methods are:

- Distillation
- Deionisation
- Reverse osmosis
- Filtration
- Photo-oxidation

Each of the above-mentioned techniques has its own advantages and disadvantages. It mainly differs based on cost and design complexity. Out of the techniques available, Reverse Osmosis (RO) and distillation are the main techniques that are helpful for our application. Therefore in the section 2.2.1 and 2.2.2 , the mentioned techniques are explained for further undersanding on its application and purpose.

A comparison between the different methods, and different types of filtration methods is presented in table 3.

Table 3 Comparison of diferente water filtration methods (Krish ,2007)

		Water Contaminants			
S.No.	Point of Use technologies that may remove small/ all contaminants	Protozoa	Bacteria	Viruses	Chemicals
1	**Filtration**				
a)	**Micro Filtration**	**Very High Effective**	**Moderate Effective**	**Not Effective**	**Not Effective**
b)	**Ultra Filtration**	**Very High Effective**	**Very High Effective**	**Moderate Effective**	**Low effective**
c)	**Nano Filtration**	**Very High Effective**	**Very High Effective**	**Very High Effective**	**Moderate Effective**
2	Reverse Osmosis Process	Very High Effective	Very High Effective	Very High Effective	Will remove common contaminants (metal ion,aqueous salts), including sodium chloride , copper, chromium , and lead; also reduce arsenic, fluoride, radium, sulfate, calcium , magnesium, potassium, nitrate, fluoride and phosphorus.
3	Distillation	Very High Effective	Very High Effective	High Effective	Will reduce most common chemical contaminants , including arsenic, barium, chromium, lead, nitrate, sodium, sulfate and many organic chemicals
4	**Ultraviolet Treatment Systems**	**Very High Effective**	**Very High Effective**	**High Effective**	**Not Effective**
5	**Water Softners**	**Ion exchange technology for chemical or ion removal to reduce the amount of hardness (calcium, magnesium) in the water , can also be designed to remove iron and manganese, heavy metals, some radioactivity, nitrates, arsenic, chromium, selenium and sulfates;does not protects against protozoa, bacteria and viruses.**			

2.2.1 Reverse Osmosis

Reverse osmosis it is a method of water treatment for purification using semi-permeable membrane. This membrane technology is not exactly a filtration method. In reverse osmosis, an applied pressure is used to overcome osmotic pressure, a colligative property that is driven by chemical potential which is a thermodynamic parameter. Reverse osmosis through a semi-permeable membrane can remove many types of molecules and ions from solutions, and is used in both industrial processes and the production of potable water. Reverse osmosis is most commonly known for its use in drinking water purification from seawater and in geographic regions where water contamination includes viruses and chemicals like metal ions, lead, arsenic, fluoride, radium, sulfate, magnesium, potassium, nitrate, fluoride and phosphorus. A schematic representation is showed in figure 2-1.

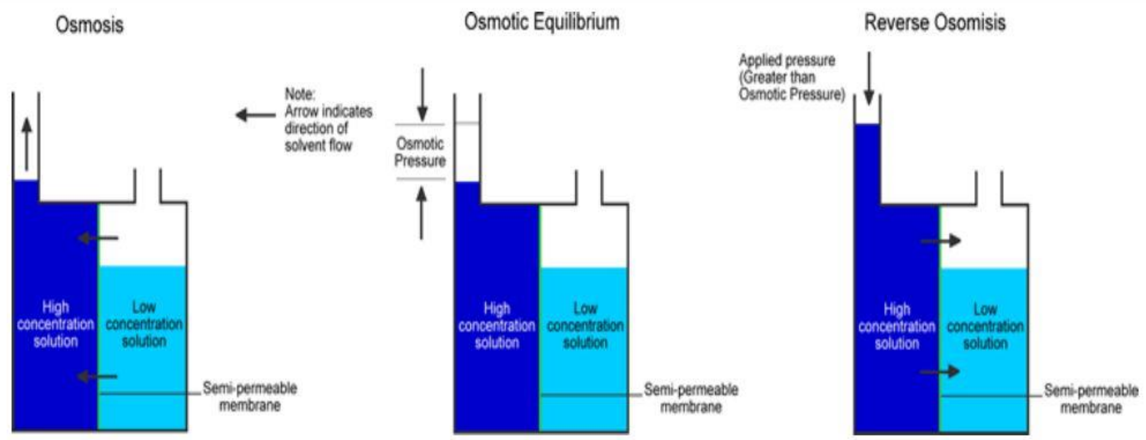

Figure 2-1 Reverse Osmosis working concept (Krish ,2007)

Reverse osmosis process uses a high pressure pump to increase the pressure at the impure side, and forcing the water to come across the semi permeable mebrane. The purification level is approximately 50 – 90%. The pressure applied is directly propotional to the impurity level of the water. The waste water thus produced can be recycled for similar out put. Usually the filtration is very high in the case of RO purification but, here in this project, the purpose of its usage is just to have pretreated and filtered water.

2.2.2 Distillation

Distillation is a proven technique for water purification. It has the capabilities to remove the impurity using a natural resource: the sun. In the technique, pure water is “removed” from the impure water. The impure water is boiled in a boiler, or in a transparent reservoir that allows the solar radiation heat the water til the saturation temperature. The steam passes to condenser and then is collected as pure water when the temperature drops down to ambient temperature. The impurities remain in the boiler, which must be removed periodically. The impurities can also be removed by dissolving acid. A scheme of the process is represented in figure 2-2.

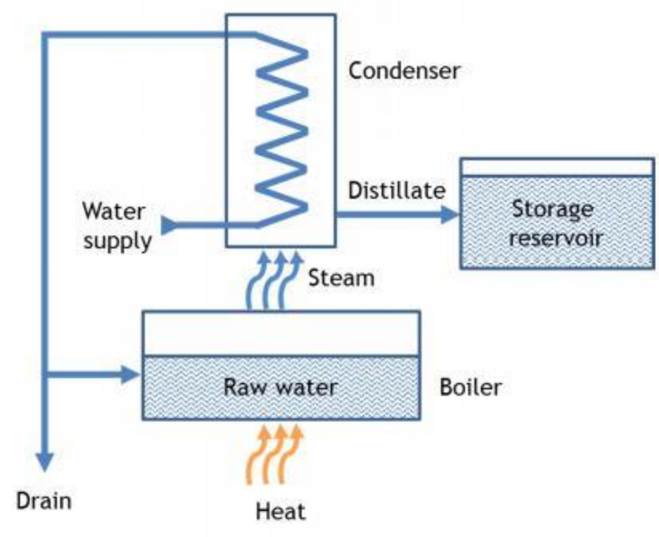

Figure 2-2 Distillation process for water purification (CEP ,2008)

There are few advantages that are to be noted in the case of distillation process (CEP ,2008):

- Removes all types of contamination, except dissolved gases and organic compounds with boiling points above 100°C.
- Capable of producing Type II or Type III quality water.
- Simple, relatively inexpensive equipment with little to go wrong.
- Visible process, unlike others which are "black box" technology.
- Reliable – the process is far less dependent on input water quality than other methods.
- Produces sterile water.

Some disadvantages of the purification of water using distillation method can be pointed out (CEP ,2008):

- Uses a lot of water and electricity
    - 3KW of electricity to produce 4 litres of distilled water.
    - Only about 6% of the water used is produced as distilled water.
- The distilled water needs regular descaling.
- Not an on-demand system. The distilled water must be produced and stored prior to use which increases the chances of it becoming contaminated either by leaching of material from the container or by contact with the air, which may introduce microorganisms.

Therefore, the major point behind the distillation process is to increase the boiling temperature of water above 100 degrees temperature. This allows to convert the liquid state water into superheated steam. This process of heating and cooling in a pressurized collection tank, is an inspiration for this project. This leads to the possibility of checking if solar energy can be sued to replicate the same process in order to purify the water.

2.3 Solar energy

The solar energy occurs from the nuclear reaction that takes place in the sun. This scenario can be explained by two concepts (Colombo ,2016):

- Electron-Volt approach: hydrogen (i.e., four protons) combines to form helium (i.e., one helium nucleus); the mass of helium nucleus is less than that of the four protons, mass lost in the reaction is converted to energy.
- Einstein approach: The energy released during these reactions can be computed using Einstein correlation: $E = mc^2$

The overall power generated by the sun is 3.85×10^{20} MW. Due to the limitation of solar angle of incidence from the sun, which is 32º, the actual amount of solar energy received in the earth is around 1367 W/m^2 (Bombarda ,2016). After entering on the earth atmosphere, solar radiation reaches earth's surface, after several losses. Solar radiation on earth´s surface can be distinguished in two componentes (Aste, 2016):

i. Beam radiation, or direct radiation: solar radiation received from the sun without having been scattered by the atmosphere.
ii. Diffuse radiation or sky radiation: solar radiation received from the sun after its direction has been changed by scattering to the atmosphere.

The proportion between the two components depends on many factors, such as the presence of clouds (i.e. water droplets) and air pollution (i.e. dust, micro sized matter).

Solar energy can be collected and transformed by photoelectric effect, generating electric energy, or be used as radiation in order to create heat that can be transferred into a fluid flow. The first situation is applied by the photovoltaic pannels, whereas solar thermal collectors operate according to the last one. A scheme of those diferente types of application is represented in figure 2-3, along with an "hybrid" application, that uses solar energy both by photovoltaic effect and heat transfer: the solar PV/Thermal technology.

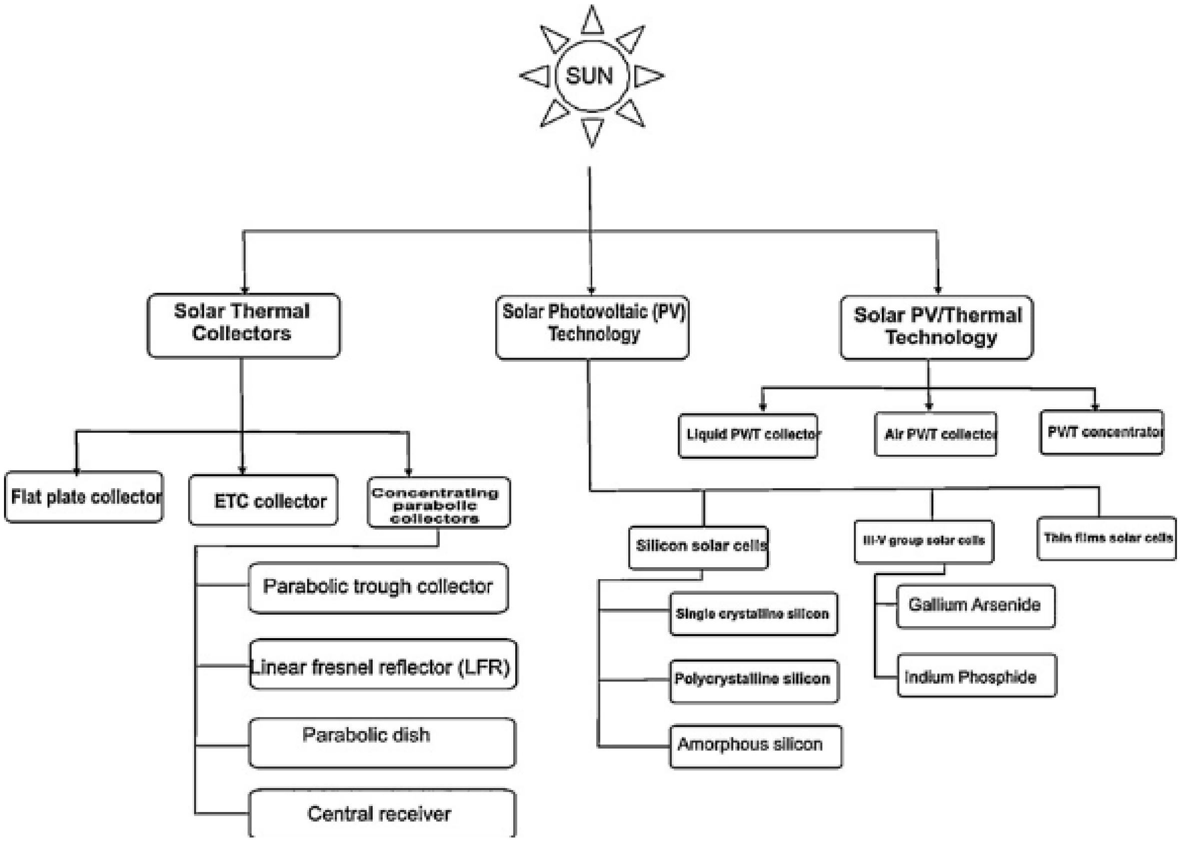

Figure 2-3 Applications of solar energy (Tyagi ,2012)

2.4 Solar thermal collectors

The energy from the sun has the capacity to heat any given fluid per unit area. The photonic energy from sun has different wavelength with various energy band widths. Majority of the energy can be used to heat using fluids such as air, water, phase change materials, nano fluids, and others can be used. The heated fluid flows to a thermal reservoir, or passes through a heat exchanger, in order to transfer the heat to the applications. Therefore, thermal energy from solar collector can be used for space heating or domestic water heating purposes

From the figure 2.3, it is understood that the solar thermal energy can be applied in three types of collector: flate plate collectors (FPC), ETC collectors, and concentrating parabolic collectors. Figure 2.4 gives a more complete idea on the categorization that is available for the solar thermal collectors.

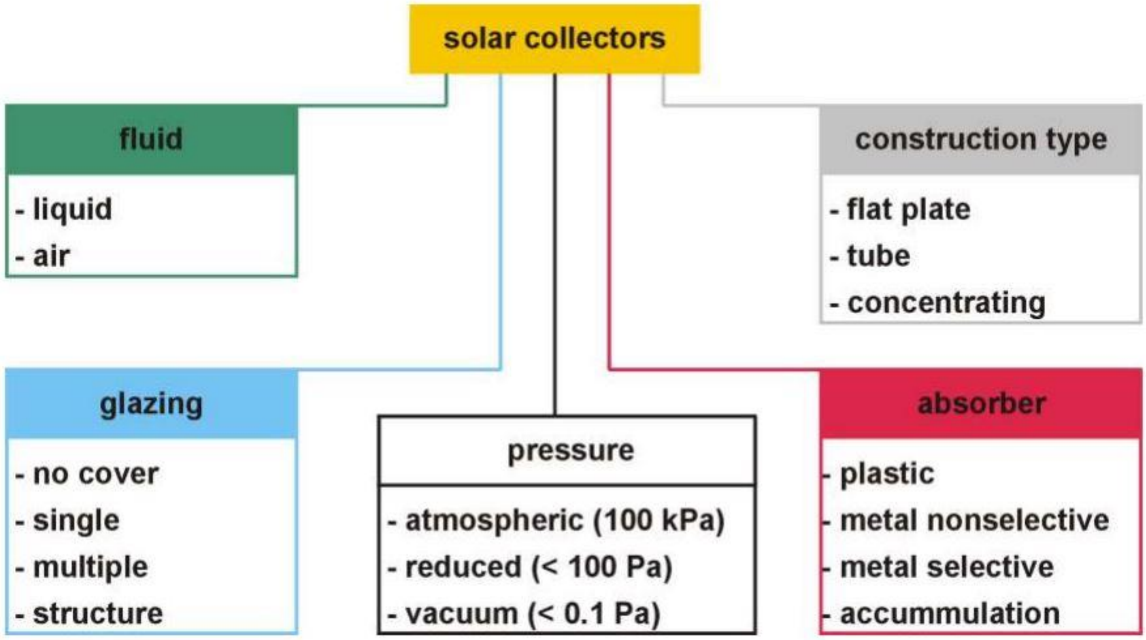

Figure 2-4 Classifications of Solar Collectors (Herrando ,2014)

As figure 2-4 shows, the solar termal collectors can be categorized based on the five critical elements of its functionality: type of fluid that is used during heat exchange, construction type, glazing components, pressure conditions and the types of absorber that can be used. (Tyagi ,2012). According to the fluid categories, there are two possibilities: either liquid based or air based. Depending upon the application, the fluid type is selected. In the construction based categorization, as it is discussed earlier, it exist flat plate, tubed or concentrating type of collector. In the glazing based categorization, it is possible to see collectors, without glaze, single, multiple and structural glaze. In case of pressure, there are three levels of pressure that can be acheived using boundary conditons such as atmospheric, reduced and vaccum state. In the atmospheric pressure condition, usually there is no pressure difference between inside the collector and its surroundings. In the reduced state, the collector cabin is completely sealed and there is drop in the pressure when compared to the external enviroiment. In the case of vaccum state, high pressure is achieved as there is no presence of air thereby, increasing the thermal heat transfer rate.

An example of flat plate solar thermal collector, with liquid as the tehrmal fluid, and its components is explained for detailed understanding. A scheme of a flat plate collector is represented in figure 2-5. Its main componentes, as well as its functions, are listed next.

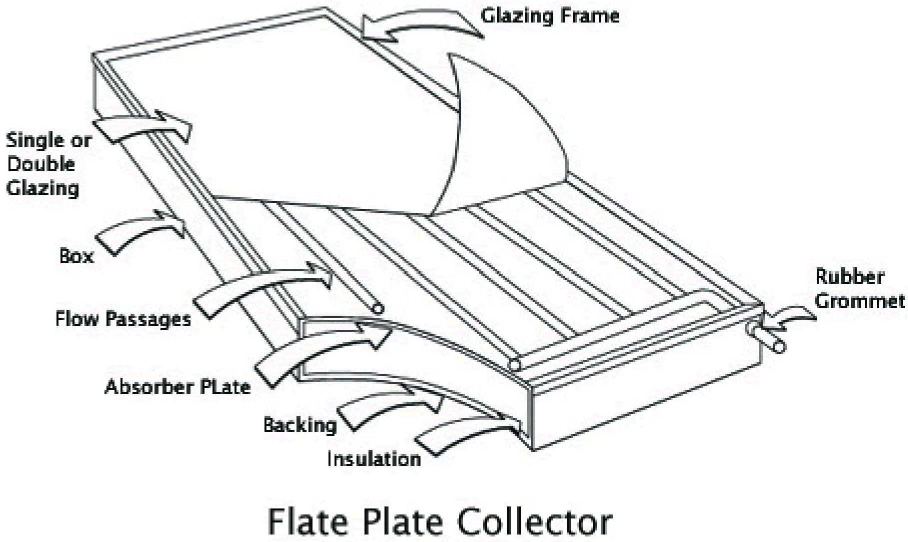

Figure 2-5 – Part description for a flat plat solar collector (Herrando ,2014)

- Front glass or glazing frame

This is the protection glass over the thermal collector. One of the purpose of the glass is to protect the collection area from the environmental dangers. The main funtion is to decrease the thermal losses from the interior of the collector to the surroundings. Also, as the glass is a selective surface: this means that it is transparent to short wave radiation (solar), but is opaque to the long wave radiation, that leaves the absorber plate on the interior of the collector. Therefore, that front glass also allows an increase of the heat absorbed. This is also named as “greenhouse effect”. Despite this, the existence of the cover causes optical losses, since it just let pass a percentage of the incident radiation, corresponding to its “transmissivity” (τ).

- Absorber plate

This part of the collector is critical when it comes to the overall heat transfer of the thermal system. The characteristic of absorber plate is that it should have higher heat transfer coefficient and thermal sustainability. The absorber technology has evolved from the past. Sheet and tube structure, also named “flat plate collector” are the most used types of absorbers in the market (Chow ,2010). These are commonly used in the solar technology related applications. Roll bond absorbers and micro channel arrays are used for high performance systems. The roll bond absorbers are used for many reasons, especially for its high level of heat exchange performance. Use of aluminium is more effective than the copper covers (Aste , 2013). The manufacturing process is to be considered, as it is extremely versatile.

- Flow channel or passages

This is the component in which the fluid (air, water or coolant) flows through. It can be found of two different shapes: cubical or cylindrical. For better heat transfer the tubes are connected to common headers on top and bottom. Water enters at the botom header, moves upward through tubes, where it gets warmed by absorber plate and finally exits at the top header. Some nano additives improve considerably the radiation absorption capacity of fluids like water. Use of such additives also improves the efficiency of flat plate collectors to a considerable extent, but with an extra cost.

- Insulation

Heat is lost to the environment from the solar collector as the temperature of the absorber plate rises and collector gets warmer. Mainly rear side of the absorber plate should be insulated in such a way that minimum heat is lost to surroundings, but this also happens through the lateral structure. Traditionally, most commonly used materials are mineral wool, rockwool, styrofoam etc. Evacuated chamber insulation is found to be most eficient, but it is very costly to create and maintain a vacuum. Another very efficient insulating material, though very cheap, is thin layers of aluminum foil.

- Casing

The casing is a non functional component, which supports all the other components of a flat plate collector and also acts as protection shield in adverse weather conditions. Normally it is made of metal sheets.

2.4.1 Thermal efficiency

The thermal efficiency parameters contributes to understand the performance of a thermal collector. It shows how the collector reacts to varying ambient conditions, thereby affecting the efficiency of the collector. The collector efficiency curve results from a function of a “reduced temperature difference”. That value depends on the fluid temperature (Tf), ambient tempearture (Tamb) and solar radiation (G). The reduced temperature is the ratio of a temperature difference and the solar radiation. The temperature difference respects to the mean fluid temperature, between the inlet and outlet, and ambient temperature. In figure 2-6 are represented efficiency curves for different types of solar thermal colletors, but in this case as a function of the temperature difference.

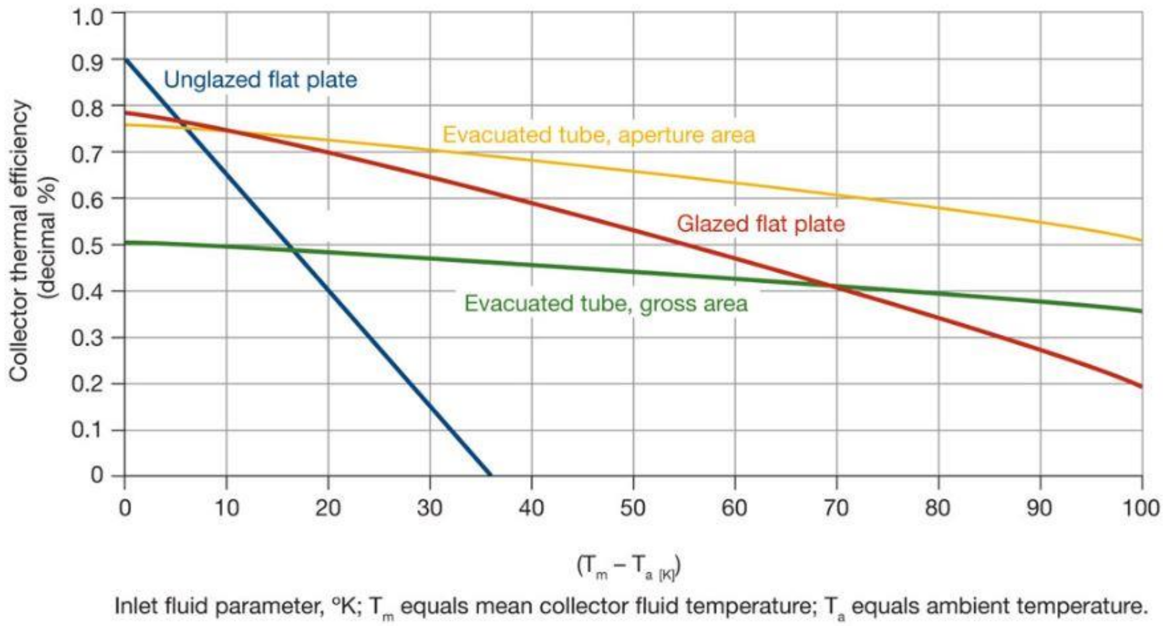

Figure 2-6 Collector Thermal efficiency Vs Reduced Temperature (Ahmad ,2014)

As it is seen in the graph, the unglazed flat plate tube has the highest maximum efficiency, since it doesn´t suffers the optical losses of the glass cover, but it has the highest slope, that represents the thermal loss coefficient. The rate of drop in efficiency is lower in glazed collector when compared with unglazed, which means that it has lower thermal loss coeffient. Evacuated tube collectors present the lowest heat loss coefficent, or, in other terms, have the most constant efficiency with the increase in reduced temperature values.

The thermal efficiency (η_{th}) represents the ratio of the useful heat by the total radiation incident in the collector. This concept can be written through equation:

$$\eta_{th} = \frac{\dot{m} * c * (T_{out} - T_{in})}{G * A} \quad (1)$$

where $\dot{m}$ is the mass flow rate, c is the specific heat capacity of the fluid, T_{out} and T_{in} are, respectively, inlet and outlet fluid temperature, G is the solar radiation and A is the área of the collector.

According to standards, solar collector thermal efficency (η_{Th}) is defined as presented in the following equation:

$$\eta_{th} = \eta_0 - a * \frac{(T_m - T_a)}{G} - b\, G \left[\frac{(T_m - T_a)}{G}\right]^2 \quad (2)$$

where, ‘a’ and ‘b’ are, respectively, the overall heat loss coefficient and the second order heat loss coefficient. This second parameter represents the dependence of the heat loss coeficiente with temperature. T_m is the mean fluid temperature and can be calculated as shown below.

$$T_m = \frac{(T_{in} + T_{out})}{2} \quad (3)$$

2.5 Photovoltaics

A French physicist, Edmond Bequerel, discovered that there are some materials which can create electrical pulses when exposed to solar radiations. Later, in 1876, Adam and Day found out that there are solid semiconductor materials which, when exposed to appropriate high energy, can generate electrons for an electric circuit. They designed the first PV cell with an efficiency of 1-2 % (Aste ,2016) A photovoltaic panel consists of number of cells arranged in a pattern with number of arrays. The total energy thus produced, depends on the area of the panel.

The electrical efficiency of a solar cell is affected by several parameters, mainly, the packing factor, solar radiance intensity, and the average temperature of the panel (Ahmad, 2014 and Tyagi, 2012). The higher the solar irradiance, the higher will be the discharge of electrons. The packing factor represents the percentage of area that is actually covered by the cells, given that part of the area of the panel is used for the electrical connections between the cells. An increase in the packing factor will lead to increase in the electricity generation per unit area. Also, an increase both in the solar radiation and the packing factor will increase the average pannel temperature.

2.5.1 Types of solar cells

Solar cell accounts for the conversion of solar photonic energy to electrical energy. Therefore its construction is very critical and needs to have molecular level perfection. Initially, silicon was used to construct solar cells and as it is known it is available in huge quantities. But as the generations grow, several other technologies improved and gave path to new types of solar cell those are based on nano technology.

The types of solar cell are followingly listed, based on the generation growth (Michael ,2016):

- First generation
    - Monocrystalline (Mono c-Si);
    - Polycrystalline (Poly c-Si); and
    - Amorphous Silicon Cells.

- Second generation
    - Amorphous silicon (a-Si , a-Si/ µc-Si)
    - Cadmium telluride (Cd-Te)
    - Copper Indium selenide (CIS) and Copper Indium Gallium Diselinde (CIGD)

- Third Generation
    - Dye Sensitized (DSSC)
    - Perovkite (cell)
    - Organic (PV)

2.5.2 Electrical efficiency

The electrical efficiency concept is analogous to the thermal efficiency. It is is the ratio between total electric power generated and the total solar incident radiation. This electrical efficiency data will serve as a critical parameter to determine conversion efficiency from solar to electrical in case of electrical efficiency

$$\eta_N = \frac{P_n}{G \cdot Ac} \tag{4}$$

where η_N is the nominal electrical efficiency of the module; P_n is the nominal power generated by the module; G is the solar irradiance incident in the module and Ac is the collector area (Chow ,2010).

Though we have the nominal efficiency value, it is important for us to know the actual value and it is important to measure the efficiency of the module under real conditions, considering variation of operational temperature of the cells, incident angle of solar irradiation and solar spectrum. It is possible to define the actual efficiency η_a by using the following correlation (Chow ,2010):

$$\eta_a = \eta_N * \kappa_\gamma * \kappa_\vartheta * \kappa_\alpha * \kappa_\lambda * \kappa_g \tag{5}$$

Therefore, the above parameters are critical and must be explained for better understanding.

- As discussed earlier in the equation $\eta_N$denotes the nominal efficiency that the module can deliver;
- κ_γ denotes the module temperature correction factor. In order to calculate this, PV power temperature coefficient (γ_{pv})must be known. Therefore, the equation is:

$$\kappa_\gamma = [1 - \gamma_{pv}(T_{pv} - 25)] \tag{6}$$

where Tpv denotes the temperature of the PV module.

- κ_ϑ denotes the value for optical reflection correction factor. It is defined as the ratio between the light transmittance factor corresponding to the actual incident angle of the solar radiation on the front surface of the module and that corresponding to the normal incident angle measured in STC, given by:

$$\kappa_\vartheta = \frac{T_\vartheta}{T_n} \tag{7}$$

- κ_α is the absorption correction factor, and is defined as the ratio between the light absorbance factor of PV cells corresponding to the actual incident angle of the solar radiation on the collector surface and that corresponding to the normal incident angle measured in STC, given by:

$$\kappa_\alpha = \frac{\alpha_\vartheta}{\alpha_n} \tag{8}$$

- κ_λ is the spectrum correction factor, function of the actual spectrum of the solar radiation on the collector surface with respect to that measured in STC and function of the adopted technology. This spectrum correction is important in the non-tropical zones of the world as the solar irradiation angle differs and difficult to avoid the correction factor.

$$\kappa_\lambda = 1.0547 - .0214 * AM - .0075 * AM^2 + .0004 * AM^2 \tag{9}$$

- κ_g is the low irradiance correction factor, which considers the power losses due to the low irradiance behaviour of the PV modules. It is a variable reduction factor, related to the specific PV technology. It depends on the radiation factor S, the ratio between the actual solar radiation (W/m^2) and the one in standard test condition (1000 W/m^2). For crystalline modules, low irradiance losses usually vary between 1% and 3% in the range of solar irradiance between 100 and 200 W/m^2 and are usually negligible above 200 W/m^2.

In order to measure the temprearture of the PV panel, the eqn (6) and Eqn(5) has to be equalized and derivate an Tpv equation as show below.

$$T_{PV} = \frac{\eta_a - \eta_n}{\eta_n * \gamma_{pv}} + 25 \tag{10}$$

2.5.3 Temperature effect in electrical efficiency

The electrical efficiency is strongly affected by the cell temperature. The rise in the panel temperature will lead to reduction in the electrical output of the cells. In other words, if PV module temperature increases, the cell efficiency decreases, thus allowing a drop in the voltage difference thereby lower electrical efficiency (Pero, 2015). The influence of the temperature in the electrical efficiency depends on the type of cells. Figure 2.7 shows this comparison.

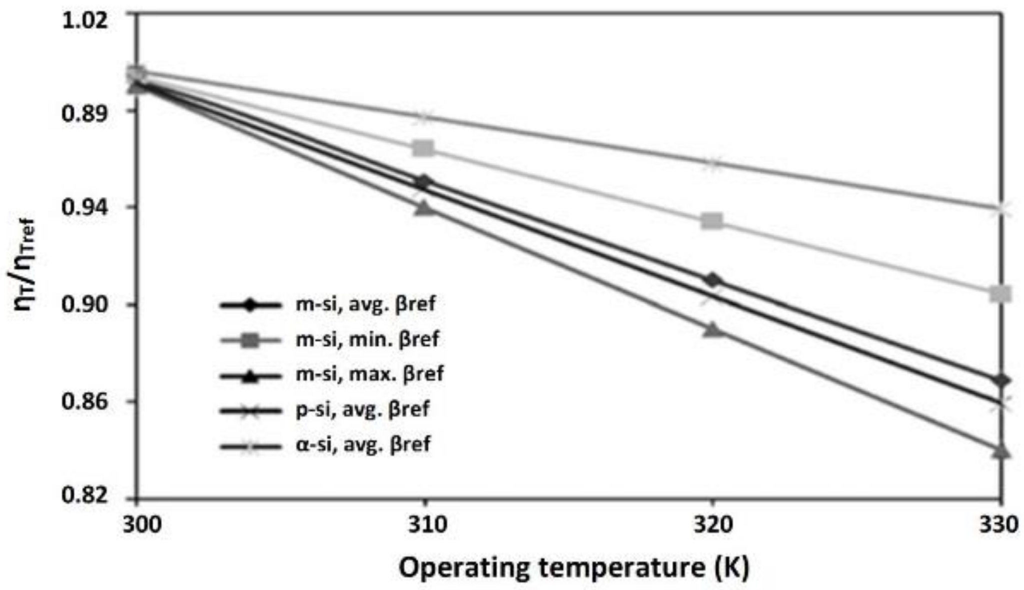

Figure 2-7 Thermal efficiency Vs Operating temperature graph (Pero, 2015)

2.6 Hybrid PV/T solar collectors

Important research has been made since 1970's in photovoltaic thermal collectors. This new concept has opened many gateways to improved concepts, multipurpose energy devices, innovation and mainly sustainable market. At this stage, the research and development work should be carried on, including thermal absorber design and fabrication, material and coating selection, energy conversion and effectiveness, performance testing, system optimization, control and reliability.

2.6.1 Types of PV/T collectors

Photovoltaics/thermal technology or thermo photovoltaics falls into two broad categories:

a) Flat plate PV/T collectors;

b) Concentrating PV/T collectors.

While flat plate collector appears like the normal thermal collector with a PV panel attached to an absorber plate with tubes, the concentrator PV (CPV) collectors aims at increasing the irradiance on a high performance PV cell. The primary aim of using concentrator photovoltaics is to decrease the area of solar cell. Besides using less area for the PV cells the concentrators has an added advantage increased cell efficiency under concentrated light. While having an advantage in terms of efficiency, CPV cells however have to be tracked continuously for getting the direct beam radiation. This adds to the cost and complexity to the overall system. As the cells are heated continuously, the increase in cell temperature causes a fall in the cell efficiency and therefore has to be kept cool. The heat thus recovered from the cells through cooling channels can be used as hot water for domestic applications.

In order to optimize the overall efficiency it is necessary to perform accurate and multi-objective classifications, taking into account of various parameters. Generally, a PVT collector is obtained by attaching a commercial PV module to a metal thermal absorber using mechanical or chemical bonding. Thereafter, different methods of fluid flow arrangement design, along with types of fluid that is used, can be combinated. A classification of PVT systems based on various heat transfer techniques (water, air, bi-fluid, etc.) is presented on figure 2-8. The PVT systems can again be classified depending on various system parameters like absorber plate designand fluid flow systems and shapes.

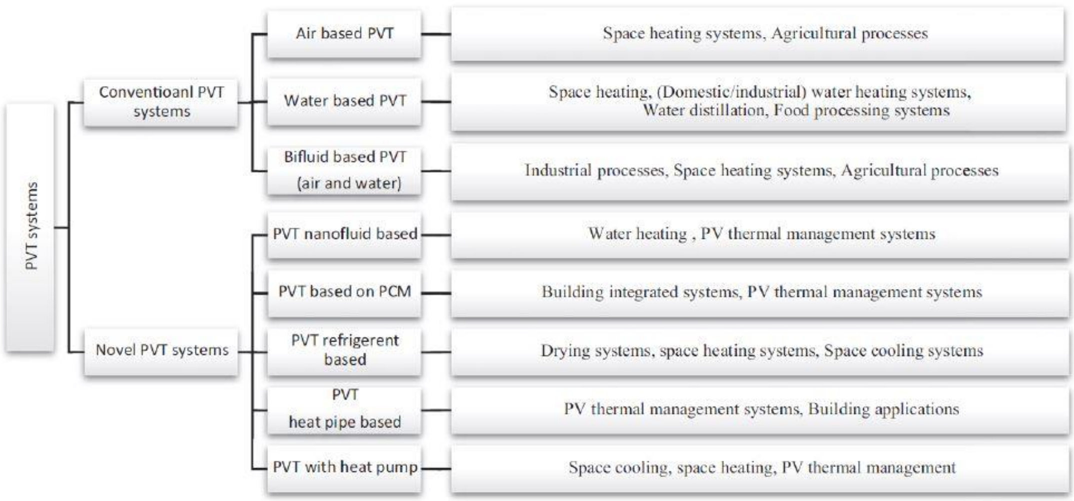

Figure 2-8 Classification of Solar PVT systems (Chow ,2009)

- Based on AIR

Air based PVT solutions are most economical and productive. They are suitable for cooling PV panels with air flowing over the hot surface in an airflow pattern. They are distinguished by several flow patterns and heat transfer techniques as shown in the figure

2.7 (Tyagi, 2012). Heat transfer in flows are mainly categorized as natural and forced flows. Forced heat transfer flow is preferred than natural, as it has higher conductive and convective coefficients. The only drawback in the case of forced heat transfer is the usage of electric fan for creating flow, which reduces the net-electricity produced by the PV.

- Based on Water

In higher temperature regions, air based PVT is difficult to implement due to factors such as heat carrying capacity and low density of air. Therefore, in such cases, water can be used as it has maximum heat carrying capacity when compared. Below, in figure 2-9, are represented the varieties of water channels designated to several PVT. [A], [B] are sheet and tube types. [C], [D] are two absorber types.

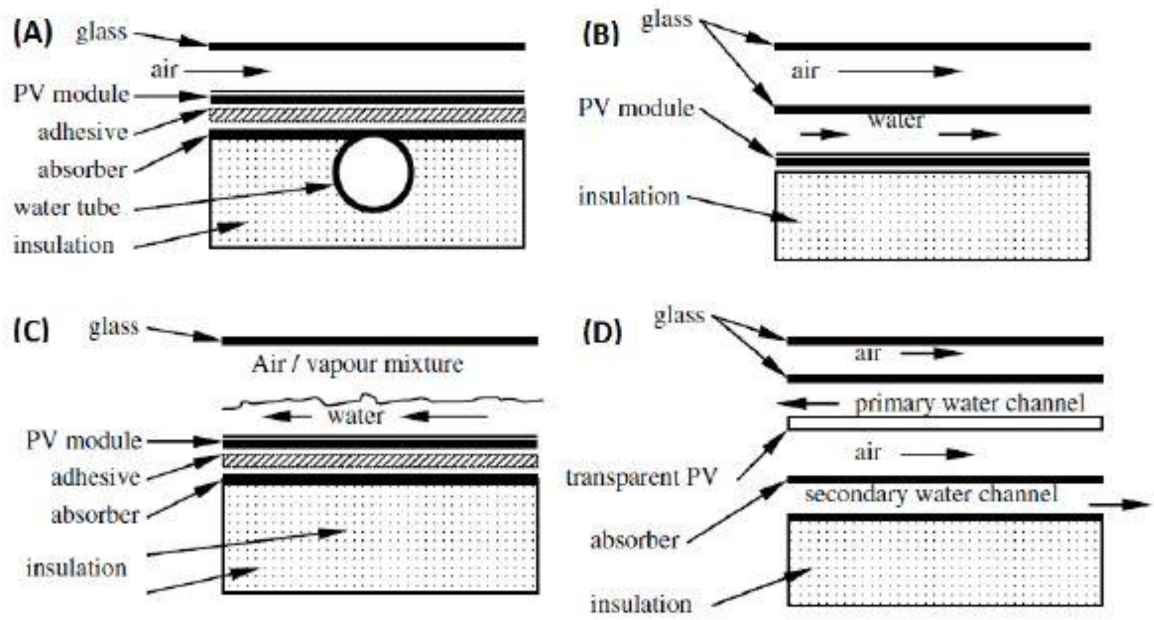

Figure 2-9 Types of layering in the channels (Michael ,2016)

- Based on Bi-Fluids

There are PVT systems which involve both the fluids, air and water. These are called bi fluid system, where the output will be hot water, hot air, and electricity. These are been used instead of using individually. Nanoparticle size can help in generating the purpose in a PVT system.

- Based on Nano fluids

Various research has been conducted in applying nano-fluids for the solar collector system. Conventional fluids like water, oil and glycol are treated to the size if 100 nm for using it as heat transfer fluid or optical fibres.

- Based on Phase change materials

Phase change materials (PCM) are substances with a high heat of fusion, which, melting and solidifying at a certain temperature, can store and release large amounts of energy. They have been used widely in many applications and quite extensively in solar water systems, but they were also found to be very efficient, if integrated with the PVT systems instead of in PV systems alone.

- Based on heat pipes

The main purpose of a heat pipe is to carry heat exchanging fluid without any external pump. The fluid inside the heat pipe is in vapour state then condenses to become liquid state after the heat transfer. This type of photovoltaic collector works for both water heating and cooling process. This also helps in space heating methods in a domestic purpose. These highly insulated heat pipes are mainly used in lower solar radiation and ambient temperature conditions. The PVT/a and PVT/w are essentially needed for the heat pipes to work under desired conditions. Usually in a low-level solar radiation sites, PVT/a is used commonly, and in the case of high-level solar radiation he main functionality of heat pipes can be tested under back surface of PVT panels.

2.6.2 Efficiency of PVT collectors and its issues

In order to understand the performace of water based PVT collectors, its thermal and electrical efficiency values are to be considered. The PVT concept offers an opportunity to increase overall efficiency by the use of waste heat generated in the PV module. It is well known that PVT systems enhance PV efficiency by PV cooling, by means of circulating a colder fluid, water, or air, at the underside of the PV module. For low-temperature water-heating, the uncovered PVT/w collector is recommended, since the reflection losses at the cover are virtually eliminated, while the front heat loss is small because of the low working temperature level.

PVT collectors have lower thermal efficiency than conventional solar termal collectors, especially at higher values of the reduced temperature. The reduction in PVT thermal efficiency with respect to traditional solar thermal collectors is due to 4 effects:

1. The absorption factor of the PV-surface is lower than the absorption factor of a conventional collector surface due to reflections of the PV laminate; (Colombo ,2016)

2. The PV-surface is not spectrally selective, resulting in large thermal radiation losses; (Colombo ,2016)

3. The heat resistance between the absorbing surface and the heat transfer fluid is higher due to additional layers of material which implies a relatively hot surface of the PVT-panel, leading to additional heat losses; (Colombo ,2016)

4. The energy that is converted to electricity is not available for the thermal output. (Colombo ,2016)

The absorptance of a PVT collector is proportional to the transparency of the covers. This has implications for electrical performance of PV whenever cover layers are present. Generally, for PVT collectors glass covers are adopted. Even if plastic materials can be used as they allow cost savings, but they have higher lower associated to thermal expansion and UV degradation (CEP ,2008). The electrical efficiency can be determined approximately with the formula (8). Typical values are 92% for low-iron glass and 96% for highly transparent glass, meaning 4-8% of efficiency loss. Another reason of efficiency drop is the condensation which appears on the glass cover when the weather is cold, leading to a decrease of efficiency up to 9%.

Further there are is another type of losses that occurs in an PV/T which is the reflection losses. The inbound solar rays are reflected by poor absorption of the materials or it might have low transmission factor. Typical solar thermal collectors have an absorption of up to 95%, while PVT absorbers are typically limited to 75–85% (Bombarda ,2016), depending on the PV type and the absorbing surface underneath. There are different aspects that affects the absorptance of PVT-collectors:

- Reflection of the additional glass which is present on glazed modules;
- Higher reflectivity and lower absorptivity of PV cells with respect to absorber plate used in solar thermal collector;

• Higher absorption in the opaque surface below the PV.

2.6.3 PV/T collectors in market

Despite it have particular applications, and are not an widespread technology, PVT collectors are already present in the commercial market. In the table 4 the list of leading manufacturers of Solar Hybrid Photovoltaic thermal collectors are mentioned. Almost in every part of the world there is a maufacturing facility, mainly because of the increase in demand and awarness of the solar field. Globally, the market share of different coutries is increasing, except United States. Initially, in 2000, China, had the least market share, and within the span of 18 years, it has a market share of 58%. Next to China, Taiwan is taking its position in manufacturing field. India is currently the largest importer of solar energy products and the growth of Solar PVT is phenomenal.

Table 4 List of PVT manufacturers (Fan ,2016)

Sl. No	Company Name	Plcae
1	Dual Sun	Europe
2	TESZEUS®	China
3	Convert energy	U.K
4	NREL	US
5	Solimpeks	Turkey
6	North Burn Solar	UK
7	Mornsun	America
8	Mornsun	Chine
9	Mornsun	Germany
10	Trinasolar	India
11	sunergsolar	Italy
12	Coolpvsolar	Chico

3. Characterization of the system

3.1 Operation Cycle

A scheme of the system that have been proposed is presented in figure 3.1.

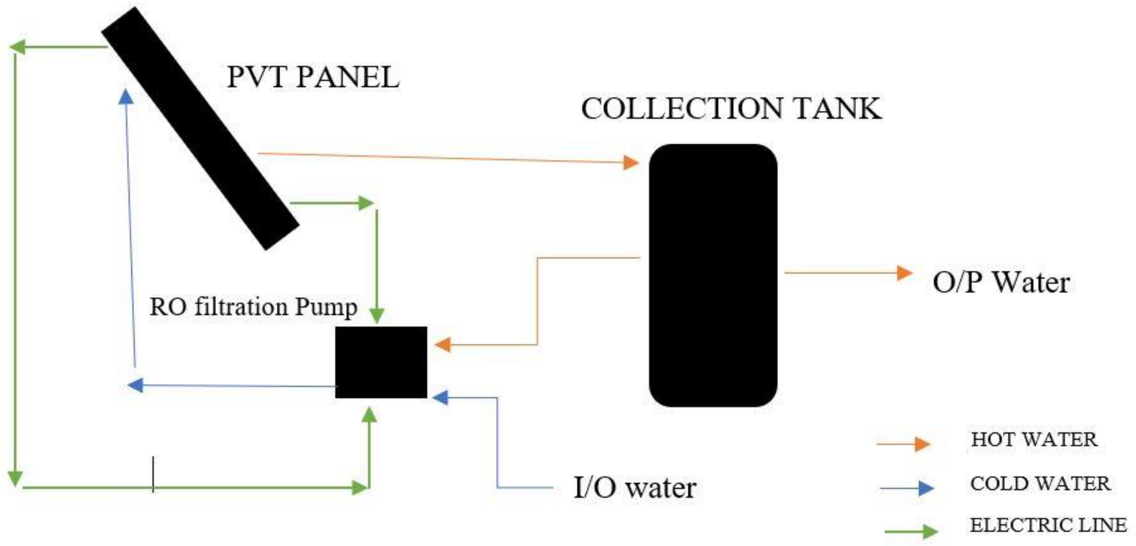

Figure 3-1 Proposed PVT operation cycle

In the above shown system, the conversion of cold water to hot water is unidirectional. The inlet cold water is the impure water that enters the RO purifier. Then it passes through the pump for water flow consistency. After which it goes through the channels of the collector and gets heated. It crossesthe boiling state and converts into steeam. The hot steam which is the pure water is sent to the collection tank for condensaiton. Therby, it completes the distillation process. Then the water is again recycled through the PVT thereby forming a cyclic loop. This will help to maintain water temperature. The main goal of the outout water is to be treated above 100° C and become purified.

3.2 Components of the system

3.2.1 R/O unit

The purpose of a reverse osmosis filter is to perform electric filtering using appropriate membranes. This is a prefiltering device used to filter the impure water to some extent before sending to the solar PVT collector tubes. This particular filter from the market is chosen as it has low wattage of 60W consmption and has enough mass flow rate pump capacity required. The R/O unit selected has the specifications presented on table 5. Figure 3-2 shows the R-O filter.

Table 5 Technical Specifications of RO Fileter (Fan, 2016)

R O FILTER	
Product Dimensions (H x D x W)	482 mm x 369 mm x 326 mm
Net Weight	10.8 kgs (approx.)
Gross Weight	15.2kgs (approx.)
Purification technology	RO (Reverse Osmosis) + SCMT (Silver Charged Membrane Technology)
8 Stage Purifying Technology	Pre-filter + Sediment filter + Carbon Block +ART™ + Side Stream RO membrane +MIN-TECH + ZX Double Protection Dual Filter (Silver Activated Post Carbon block + SCMT).
Membrane type	Thin film composite RO membrane
Material of construction for plastic parts	Food safe, non-toxic, engineering grade parts plastics
Pump type	Diaphragm pump, 24VDC, 0.45 Amps at 80 psi
Input Voltage	150 – 300 VAC, 50 Hz
Power rating (Max)	60 Watts
Pressure Rating***	7 psi to 30 psi
% Recovery**	Up to > 55%*
Heating element wattage	500 Watts @ 230 VAC
TDS reduction**	≥95% (approx.)

The rated power of the above selected model of RO filter is well within the range of output power produced by the solar PVT module. There are four main steps that happen before sending the water to the heating unit. First, it does basic prefiltering, where the membrane block all solid impurities to the micro level and does the filtering process. It is follwed by a sediment filtering, where all the heavy impurities are settled and collected in the sedement filter. It then passes through the carbon block phase, and the color changes happen in this phase of filtering. Finally it is treated with Polypropylene filter, after which is passed to the collector area.

Figure 3-2 Reverese Osmosis Filter

3.2.2 PV/T collector

From the PVT collectors that were found in the research, is was chosen one model with the lower heat loss coefficient. The specifications are presented in tables 6 and 7.

The core part of the system is the PVT collector. There are two major outputs that are used for this application. The electricity thus generated is used to input the pump and water filtration. The electric Reverse Osmosis filter will require a minimum amount of electricity. Therefore it becomes an integrated system. The thermal output is used to heat water above 100°C and purify water through distillation methodology. This particulat PVT has an electrical out put of 200 W which is required for operating other electrical components of the system. It also has a thermal output of 600 W. With the surface area of 1.37 m^2 has a flow rate of 65 L/hr. The manufacturer is listed the details as below.

Table 6 Technical Specifications of Solar PVT - 1 (Fan ,2016)

Power Volt	
Dimensions	828*1601*90
Gross Area(m2)	1370
Aperture Area (m2)	1326
Weight	24.4
Liquid Content	1.21
Absorber Panel	Mono-Crystalline
Number of Cells	72
Cell Dimensions (mm)	125*125
Nominal Power (w)	200
Nominal Current (A) Imp	5.28
Short Circuit Voltage (V) Isc	5.66
open Circuit Voltage (V) Voc	45.26
Heat Exchanger	Copper
Internal Piping	Copper
Test Pressure (Bar)	13
Maximum Operating Pressure	6
Cover Glass	PV Glass
Sealing	EPDM and Silicon

Table 7 Technical Specifications of PVT collector – 2 (Fan, 2016)

Maximum temperature	101
Base sheeting	Embosed- Aliminium
Rear Side	Aluminium
Product Warranty	10 Years
Product Guarantee	<10 Years
Temperature Coeff of Isc	.06 %/C
Temperature Coeff of Voc	.34%/C
Temprature Coeff of Pmax	.45%/c
Power Tolerance	3%
Module Electrical Efficiency	15.08%
Zero loss collector Efficiency	0.486
a (First order heat loss)	4.208
b (Second order heat loss)	0.067
MC4 Connector	JMTHY
Thermal Power	630 W
Flow rate	65 L/Hr
Country of manufacturing	Turkey
Name of manufacturer	Solimpeks solar energy corp

3.2.3 Pump

The purpose of the water pump is to regulate the flow through the solar collector and the mass flow rate of the selected pump is within the range of the flow rate that is required for the optimum performance of the collector. Technical specifications of the pump are presented in table 8, and the pump is represented in figure 3.3.

Table 8 Technical specificaton of water pump (Fan, 2016)

Brand	BalRama
Model Name	RO Booster Pump 75 GPD Water Purifier Motor
Type	Diaphragm
Usage Type	Domestic
Flow Rate	0.735 LPM
Total Head	1 m
Phase	Single-phase
Thermal Over Load Protector	No
Power Supply	24v DC, 36v DC
Power Rating	0.5 kW
Motor Power	1 HP
Weight	1.5 kg

Figure 3-3 Balrama Boosting water pump

The core part of the system is the process of solar photovoltaic thermal system There are wo major outputs that are used fpr twp applications. The electricity thus generated is used to input the pump and water filtration. The electric Reverse Osmosis filter will require a minimum amount of electricity. Therefore it becomes an integrated system. The thermal output is used to heat water above 100 ° C and purify water through distillation methodology. The specification above is selected under guidance and best of knowldge to suit the proposed system.

3.2.4 Collection tank

Table 9 Technical Specification for Collection Tank (Fan, 2016)

Collection Tank	
Material	(SS 316/ IS 1730 grade)
Thickness	20 gauge
Capacity	(0.91mm)for 100 lpd
Insulation Thickness	100 mm
Cladding Material	Aluminium
Temperature loss	<5 Deg in 10 hrs
Maximum Temperature	190 ° C

The critical purpose of a collection tank is to store the water and maintain the same pressure and temperature for longer time. The insulation system which can hold upto 190 ºC of the collection tank is to be ensured and the above selected collection tank is of a decent specificaiton. The maximum temperature and the collection volume are the main parameters for the selection of the tank.

3.3 Problem Defenition

The main idea of doing the numerical analysis is to understand the relationship between the inputs and the outputs of the system. The major thermal output expected in resuts is the outlet fluid temperature. Only when the temperature is above 100 ° and controlled, then the results are successful, and it can be concluded than a flat plate PVT collector can be used for obtain potable water. Another major aspect of the problem is to find the thermal efficiency of the system. On the other hand, it is also required to find the electrical efficiency of the system and understand other input to to output parameters.

Below are the major tasks to be achieved in the problem solving phase.

- In case of thermal efficiency analysis, the studied parameters are ambient temperature, fluid inlet temperature, and solar radiance.
- Efficiency parameters, η_0, *a* and *b* in equation 2 are considered constant values, based on the performance parameters on table 7.
- For the studied ranges of Tamb, Tfin and G, that are chosen according to indian climate, the thermal efficiency can be determined through equation 2, except for the unknown value of Tout. The other concept of thermal efficiency is also used, analitically, by equation 1. If both equations are matched, it is possible to determine

Tfout. The main goal of the project is to determine the values of the outlet temperature for various possible input parameters. In order to gain the values of the outlet temperature, equations (1) and (3) are matched in order to determine Tfout, resulting on the equation:

$$\frac{\dot{m} * c * (T_{out} - T_{in})}{G * A} = \eta_0 - a * \frac{\left(\frac{T_{out} + T_{in}}{2} - T_a\right)}{G} - b\ G\left[\frac{\left(\frac{T_{out} + T_{in}}{2} - T_a\right)}{G}\right]^2 \quad (11)$$

- Thereby the collector efficiency of the collector and the outlet temperature values can be found. The values of the studied parameters can be changed to understand how the system reacts to the changes.
- Other important results, such as the thermal efficiency, outlet temperature and the reduced temperature are to be found.
- Initial run shall have the ambient temperature and solar radiance as constant values. Vary the inlet temperature of the fluid and check the output values.
- Then, set the conditions for each fluid inlet temperature. The condition is to set the ambient temperature as constant and vary the solar radiance value that is taken in the monthly data.
- Then, consider the solar radiance value as constance and vary the ambient temperature for each inlet fluid temperature.
- The ranges chosen for the diferente parameters shall be taken for Chennai, India region: Latitude : 13.05 Longitude : 80.25
- Find out the output parameters and plot the graphs to understand the relationship.
- In the electrical part, the nominal power, solar radiance, panel area are the major inputs to find the electrical efficiency.
- Find out the actual electrical efficiency
- Compare nominal and actual efficiency values and note the relationship between panel temperatuer and the efficiency. Make sure the output power is within the range of operating conditons of the system.
- Use the equation (5) (6) (11) to solve this problem. Graphs are to be plotted for output values and conduct further analysis.

4. Result analysis and discussion

4.1 Influence of ambient temperature and Tfin

The fluid inlet temperature has a defenite impact in the mean tempreature and the reduced temperature values. Ultimately, this project checked the impact of fluid inlet temperature in the efficiency of the collector and the operational performance at the outlet temperature of 100° C. The values of the heat loss coffefficient were considered from the manufacturer values. For further analysis the values obtained can be verified in appendix – I. Based on the thermal efficiency of a collector formula equation (2) the fluid inlet temperature is varied to check the variation in the reduced temperatue and thermal collector efficiency.

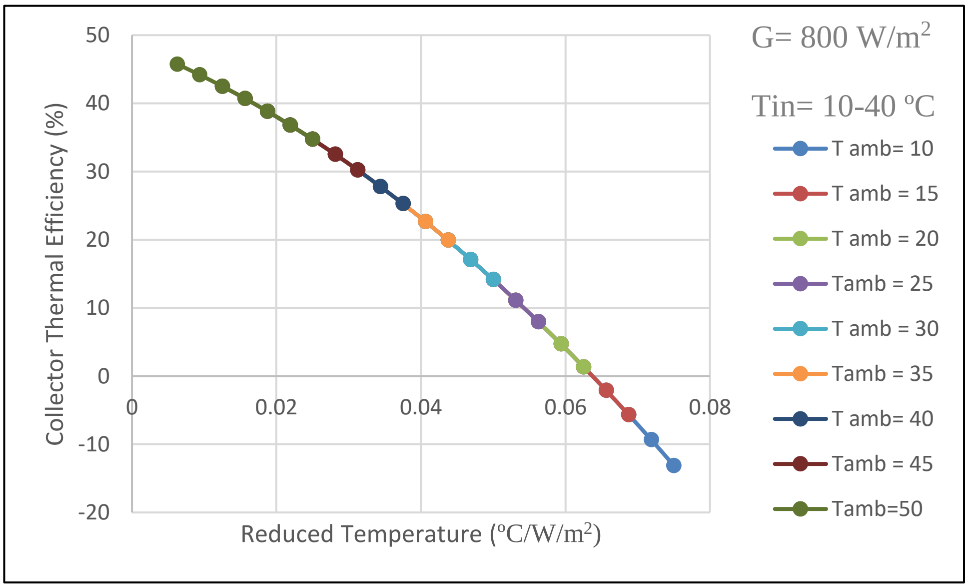

Figure 4-1 Influence of Tamb

The values of inlet fluid temperature are varied from 10° to 40° and also parallely, the ambient temperature value is varied from 10° to 50°. The graph was also plotted based on constant solar radiation of 800 W/m^2. The ambient temperature values are taken from the domestic conditions of Chennai, Tamil Nadu, India Latitude: 13.05 Longitude : 80.25. The results clearly depict the natural behaviour of a efficiency curve of the thermal collectors. The maximum efficiency value occurs with the highest ambient temperature and with least inlet temperature of fluid. Of course, the efficiency should be maximum for the maximum temperature difference of 90°. The correspondant value of reduced temperature will be at the minimum value. Therefore the over all pattern observed in this scenario is regarding ambient temperature. As the ambient temperature increases, the effiiency value increases in general. Parallely, the influence of inlet fluid tmeperature is also noted. The increase in inlet fluid temperature is also helping the thermal efficiency of the collector. The concept of inlet temperature being high, helps the temperature increasing rate. Thereby, achieving the 100°C mark. Therefore, achieving 100°C is possible with the below mentioned state with the maximum efficiency of 45.76%.

The maximum efficiency parameteric conditons to achieve the above mentioned state is as below table.

Table 10 Maximum efficiency parametric values

N0	0.486	
a1	4.208	
a2	0.067	
T amb	50	°c
Tin	10	°c
Tout	100	°c
G	800	W/m2
Tm	55	°c
Tr	0.00625	°c
Nt	45.76%	%

Therefore with the above mentioned values, the outlet temperature can be acheived as 100°C. The main purpose of the project is to achieve the 100° of water temperature and kill the microbial impurities. Therefore, the outlet water will be purified and have a usable condition.

4.2 Influence of solar irradiance

Solar radiance value determines the major input quality for the objective of this project. This value has a direct relation with the collector area. In this scenario of simulation, the ambient temperature was kept constant. The inlet fluid temperature was increased constantly with a rate of 5° for every simulation. The values of the solar irradiance was taken from the domestic geographic climate data of Chennai, Tamil Nadu, India Latitude : 13.05 Longitude : 80.25. For further analysis the values obtained can be verified in appendix – I.In the belw table, the solar irradiance values are calculated.

Table 11 Solar Irradiance values

MONTHS	kWh/m2/day	Monthly sunshine hours	average daily sunshine hours	W/m2
JAN	5.76	229.3	7.396774	778.7178
FEB	6.6	225	8.035714	821.3333
MAR	6.05	246	7.935484	762.3984
APR	5.91	260	8.666667	681.9231
MAY	5.78	262	8.451613	683.8931
JUN	4.85	156	5.2	932.6923
JUL	4.39	111	3.580645	1226.036
AUG	4.22	119	3.83871	1099.328
SEP	4.86	167	5.566667	873.0539
OCT	3.68	231	7.451613	493.8528
NOV	4.12	228	7.6	542.1053
DEC	4.92	224	7.225806	680.8929

The above mentioned values are implemented in the formula (2), and with the achievable condition of 100°C as outlet fluid temperature. The values used for solar irradiance are the monthly typical ones from january to december. Inlet fluid temperature values were varied from 10ºC to 40 ºC in order to identify the effect on the reduced temperature and the thermal efficiency of the collector. In the below graph, the pattern is observed.

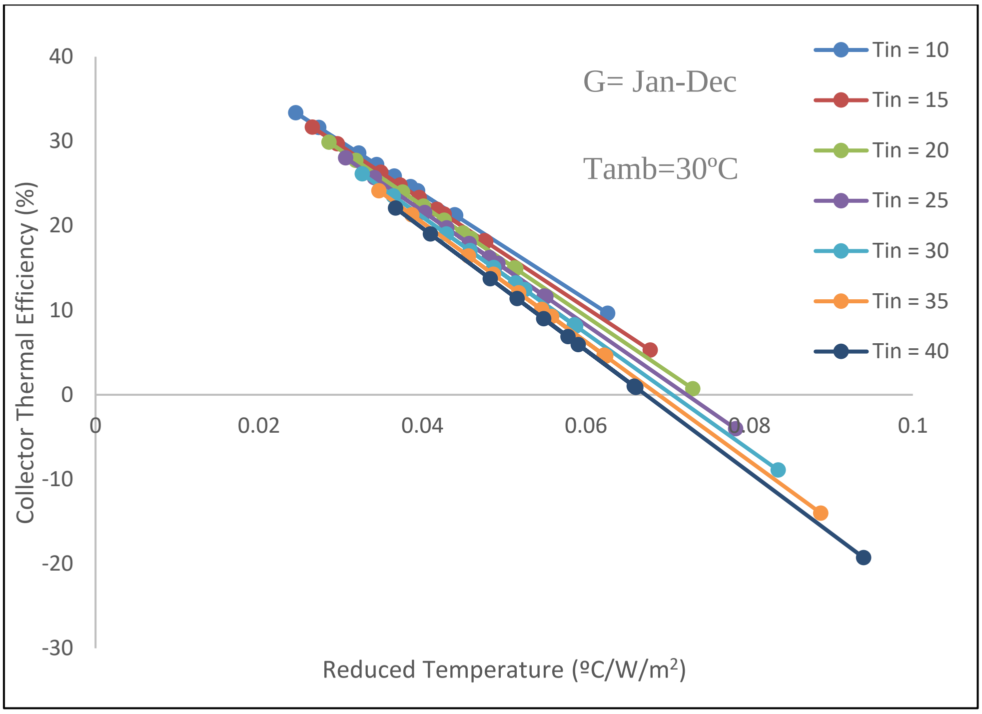

Figure 4-2 Influence of Tin

The above graph, shows that the increase in the reduced temperature leads to decrease in collector efficieiency. It is obvious that the increase in the collector efficiency is maximum with the maximum solar irradiance. At the same time, based on the combination of inlet temperature of the fluid, the net result will vary. As the intlet fluid temperature increases, there is a negative impact on the efficiency of the collector. The minimum temperature of the inlet fluid and the maximum radiance are the most efficient combination with which the collector efficiency can be maximized. Below are the best achieve result.

Table 12 Maximum efficiency paramter values

N0	0.486	
a1	4.208	
a2	0.067	
T amb	25	°c
Tin	10	°c
Tout	100	°c
G	1226	W/m2
Tm	55	°c
Tr	0.02447	°c
Nt	31.62%	%

Therefore the operating condition, which is desired to be 100°C, demands the above mentioned values to be implemented and achieved. In order to purificy the water, the efficiency of the collector is very low uptp 31.62% and not upto the commercial market standards. The solar irradiance required is also high upto 1226 W/m^2.

4.3 Influence on electrical efficiency

The electrical efficiency is over seen in this project apart from the thermal requirements. The system proposed includes certain electrical equipments. As mentioned, there are water pre filtering devices and pumping devices used in the system. The goal of calculating electrical efficiency is to verify the viability to feed the electrical devices thus used. The nominal electrical efficiency was calculated, after which the electrical efficiency was calculated. The losses were considered as constant factors. Therefore, for the varying solar irradiance, the efficiency outputs were calculated and found as below.

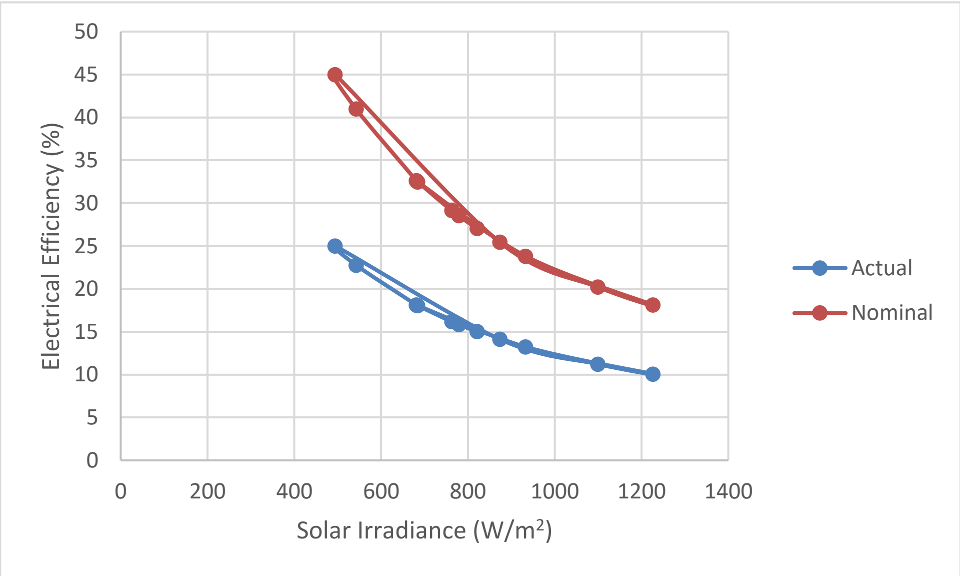

Figure 4-3 Electrical efficiency achieved for this system

The achieved results are lower than the expected commercial standard. The geographic data used to calculate is off standard. The maximum actual efficiency achieved was 22.77%, whereas, in the case of nominal efficieny, for the given input parameters, the maximum efficiency achieved is 44.99%. Therefore, with increase in solar irradiance, there is drop in the efficiency values.

5. Conclusions

The design study of solar photovoltaic thermal collectors has been approached in this project. One of the main objectives was to verify if the higher outlet temperatures are enough high so that this method can be used to purify water. The motivation for this project is to find non-expensive-processes for water purification that don´t need electrical grid. Thus, the use of solar energy and specifically PVT collectors was the solution proposed and studied. The main reason behind this design study is to understand the performance and operational parameters of solar photovoltaic thermal collectors. Gain information and knowledge in the field of Solar PV/T and use that to relate to water purifying possibility.

An in-depth assessment of the state of art that is available in the field of solar PVTs. The basic concepts of solar PVTs were dealt with. The information has been documented on a broader basis. The concept of solar energy and the functionality involved has been also considered for the study. The PVT systems ~~of~~ have been described in the project, in order to understand the combination of electrical and thermal systems. The combined system of electrical and thermal in a PV/T has been explained well established. The–PVT collector system was also explained. Different concepts of PVT system are also been presented. In the chapter 2 a literature survey on the PV/T concepts have been discussed. The classification of PVT is done to understand the broadness of the field of study. Based on which the complete literature survey has been made. On the other-hand the need for water purification and the purpose of this project had been discussed. The contaminants of a water content are explained with the measures that can be taken to purify it. The possibility of purifying the water if increased the temperature close to 100 ° is also explained in the specific section of document.

An integrated solar PVT collector with the collection tank and RO purification system has been drawn as a concept model diagram. The concept model diagram in the figure 3.1 had been drafted and the water flow and heat flow has been explained in the diagram. The technical components required to built the system were listed. The specifications of these components were found and documented. The formulation for calculating thermal and electrical efficiencies were done. The parameters such as fluid inlet temperature, solar irradiance, ambient temperature and cell temperature became the list of critical input data. Along with loss coefficients. The major outputs those were calculated are the fluid outlet temperature, thermal efficiency and electrical efficiency. These functional parameters were analysed using their corresponding results and discussed in the previous chapter.

This project led to understand overall working of a solar PVT collector. The critical parameters have been well understood. Though the efficiency achieved is low, the parameters involved are understood. In conclusion the temperature can be increased but there will be a drop-in efficiency. In order to avoid the reduction in efficiency values, the thermal losses have to be controlled effectively. The prospects of this project are to find out the design changes through which the thermal losses can be avoided and increase the outlet temperature. Upon the increase of outlet temperature, the water can be purified better and used for domestic purpose.

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Appendix I: Thermal Efficiency calculation for Tfin and ambient parameters

MONTHS	kWh/m2/day	Monthly sunshine hours	average daily sunshine hours	W/m2	Chennai, Tamil Nadu, India	Values	Tin °C	T amb °C	
JAN	5.76	229.3	7.396774	778.7178	Latitude : 13.05 Longitude : 80.25		20	January	24.6
FEB	6.6	225	8.035714	821.3333	Source: NREL		25	February	25
MAR	6.05	246	7.935484	762.3984	Annual Average : 5.08 kWh/m2/day		30	March	26.1
APR	5.91	260	8.666667	681.9231			35	April	26.2
MAY	5.78	262	8.451613	683.8931	Density	1000	40	May	28.2
JUN	4.85	156	5.2	932.6923	Mass flow	1.22E-02		June	28.4
JUL	4.39	111	3.580645	1226.036	collector area	1.64		July	29.7
AUG	4.22	119	3.83871	1099.328	Specific Heat of water	4.18		August	30.1
SEP	4.86	167	5.566667	873.0539	A	8.37		Septembe	30.7
OCT	3.68	231	7.451613	493.8528	B	0.586		October	30.9
NOV	4.12	228	7.6	542.1053				Novembe	32.4
DEC	4.92	224	7.225806	680.8929				December	32.9
				798.0189					28.76667

h0	a1	a2	tamb	Tin	Tout	G	Tm	Tr	2ªparcela	nt	3ªparcela	ht		Status
0.486	4.208	0.067	25	10	100	778.71	55	0.038525	0.162114	0.323886	0.077436	0.24645	24.645	ok
0.486	4.208	0.067	25	10	100	821	55	0.036541	0.153764	0.332236	0.073447	0.258789	25.87893	ok
0.486	4.208	0.067	25	10	100	762	55	0.03937	0.165669	0.320331	0.079134	0.241197	24.11969	ok
0.486	4.208	0.067	25	10	100	681	55	0.044053	0.185374	0.300626	0.088546	0.212079	21.20793	ok
0.486	4.208	0.067	25	10	100	683	55	0.043924	0.184832	0.301168	0.088287	0.212881	21.28814	ok
0.486	4.208	0.067	25	10	100	932	55	0.032189	0.135451	0.350549	0.0647	0.28585	28.58498	ok
0.486	4.208	0.067	25	10	100	1226	55	0.02447	0.102969	0.383031	0.049184	0.333847	33.38467	ok
0.486	4.208	0.067	25	10	100	1099	55	0.027298	0.114868	0.371132	0.054868	0.316264	31.62639	ok
0.486	4.208	0.067	25	10	100	873	55	0.034364	0.144605	0.341395	0.069072	0.272323	27.2323	ok
0.486	4.208	0.067	25	10	100	479	55	0.06263	0.263549	0.222451	0.125887	0.096564	9.656367	ok

h0	a1	a2	tamb	Tin	Tout	G	Tm	Tr	2ªparcela	nt	3ªparcela	ht		Status
0.486	4.208	0.067	25	15	100	778.71	57.5	0.041736	0.175624	0.310376	0.090879	0.219497	21.94967	ok
0.486	4.208	0.067	25	15	100	821	57.5	0.039586	0.166577	0.319423	0.086198	0.233224	23.32244	ok
0.486	4.208	0.067	25	15	100	762	57.5	0.042651	0.179475	0.306525	0.092872	0.213653	21.36526	ok
0.486	4.208	0.067	25	15	100	681	57.5	0.047724	0.200822	0.285178	0.103919	0.181259	18.12588	ok
0.486	4.208	0.067	25	15	100	683	57.5	0.047584	0.200234	0.285766	0.103615	0.182151	18.21512	ok
0.486	4.208	0.067	25	15	100	932	57.5	0.034871	0.146738	0.339262	0.075932	0.26333	26.33297	ok
0.486	4.208	0.067	25	15	100	1226	57.5	0.026509	0.11155	0.37445	0.057723	0.316727	31.6727	ok
0.486	4.208	0.067	25	15	100	1099	57.5	0.029572	0.12444	0.36156	0.064394	0.297166	29.71658	ok
0.486	4.208	0.067	25	15	100	873	57.5	0.037228	0.156655	0.329345	0.081064	0.248281	24.82809	ok
0.486	4.208	0.067	25	15	100	479	57.5	0.06785	0.285511	0.200489	0.147743	0.052746	5.274582	ok

h0	a1	a2	tamb	Tin	Tout	G	Tm	Tr	2ªparcela	nt	3ªparcela	ht		Status
0.486	4.208	0.067	25	20	100	778.71	60	0.044946	0.189133	0.296867	0.105399	0.191468	19.1468	ok
0.486	4.208	0.067	25	20	100	821	60	0.042631	0.179391	0.306609	0.09997	0.206639	20.66395	ok
0.486	4.208	0.067	25	20	100	762	60	0.045932	0.193281	0.292719	0.10771	0.185009	18.50092	ok
0.486	4.208	0.067	25	20	100	681	60	0.051395	0.21627	0.26973	0.120521	0.149209	14.92085	ok
0.486	4.208	0.067	25	20	100	683	60	0.051245	0.215637	0.270363	0.120168	0.150195	15.01947	ok
0.486	4.208	0.067	25	20	100	932	60	0.037554	0.158026	0.327974	0.088063	0.239911	23.99109	ok
0.486	4.208	0.067	25	20	100	1226	60	0.028548	0.120131	0.365869	0.066945	0.298924	29.89241	ok
0.486	4.208	0.067	25	20	100	1099	60	0.031847	0.134013	0.351987	0.074682	0.277306	27.73057	ok
0.486	4.208	0.067	25	20	100	873	60	0.040092	0.168706	0.317294	0.094015	0.223279	22.32795	ok
0.486	4.208	0.067	25	20	100	479	60	0.073069	0.307474	0.178526	0.171347	0.00718	0.717954	ok

h0	a1	a2	tamb	Tin	Tout	G	Tm	Tr	2ªparcela	nt	3ªparcela	ht		Status
0.486	4.208	0.067	25	25	100	778.71	62.5	0.048157	0.202643	0.283357	0.120993	0.162364	16.23638	ok
0.486	4.208	0.067	25	25	100	821	62.5	0.045676	0.192205	0.293795	0.114761	0.179034	17.90344	ok
0.486	4.208	0.067	25	25	100	762	62.5	0.049213	0.207087	0.278913	0.123647	0.155267	15.52667	ok
0.486	4.208	0.067	25	25	100	681	62.5	0.055066	0.231718	0.254282	0.138354	0.115928	11.59284	ok
0.486	4.208	0.067	25	25	100	683	62.5	0.054905	0.23104	0.25496	0.137948	0.117012	11.70121	ok
0.486	4.208	0.067	25	25	100	932	62.5	0.040236	0.169313	0.316687	0.101093	0.215594	21.55936	ok
0.486	4.208	0.067	25	25	100	1226	62.5	0.030587	0.128711	0.357289	0.076851	0.280438	28.04382	ok
0.486	4.208	0.067	25	25	100	1099	62.5	0.034122	0.143585	0.342415	0.085731	0.256684	25.66836	ok
0.486	4.208	0.067	25	25	100	873	62.5	0.042955	0.180756	0.305244	0.107925	0.197319	19.73187	ok
0.486	4.208	0.067	25	25	100	479	62.5	0.078288	0.329436	0.156564	0.196699	-0.04014	-4.01352	ok

h0	a1	a2	tamb	Tin	Tout	G	Tm	Tr	2ªparcela	nt	3ªparcela	ht		Status
0.486	4.208	0.067	25	30	100	778.71	65	0.051367	0.216152	0.269848	0.137664	0.132184	13.21841	ok
0.486	4.208	0.067	25	30	100	821	65	0.048721	0.205018	0.280982	0.130572	0.150409	15.04093	ok
0.486	4.208	0.067	25	30	100	762	65	0.052493	0.220892	0.265108	0.140682	0.124425	12.44252	ok
0.486	4.208	0.067	25	30	100	681	65	0.058737	0.247166	0.238834	0.157416	0.081419	8.14185	ok
0.486	4.208	0.067	25	30	100	683	65	0.058565	0.246442	0.239558	0.156955	0.082603	8.260322	ok
0.486	4.208	0.067	25	30	100	932	65	0.042918	0.180601	0.305399	0.115021	0.190378	19.03777	ok
0.486	4.208	0.067	25	30	100	1226	65	0.032626	0.137292	0.348708	0.087439	0.261269	26.12692	ok
0.486	4.208	0.067	25	30	100	1099	65	0.036397	0.153157	0.332843	0.097543	0.235299	23.52994	ok
0.486	4.208	0.067	25	30	100	873	65	0.045819	0.192806	0.293194	0.122795	0.170399	17.03986	ok
0.486	4.208	0.067	25	30	100	479	65	0.083507	0.351399	0.134601	0.2238	-0.0892	-8.91983	ok

h0	a1	a2	tamb	Tin	Tout	G	Tm	Tr	2ªparcela	nt	3ªparcela	ht		Status
0.486	4.208	0.067	25	35	100	778.71	67.5	0.054577	0.229662	0.256338	0.155409	0.100929	10.09289	ok
0.486	4.208	0.067	25	35	100	821	67.5	0.051766	0.217832	0.268168	0.147404	0.120764	12.0764	ok
0.486	4.208	0.067	25	35	100	762	67.5	0.055774	0.234698	0.251302	0.158817	0.092485	9.248458	ok
0.486	4.208	0.067	25	35	100	681	67.5	0.062408	0.262614	0.223386	0.177707	0.045679	4.567878	ok
0.486	4.208	0.067	25	35	100	683	67.5	0.062225	0.261845	0.224155	0.177187	0.046968	4.696816	ok
0.486	4.208	0.067	25	35	100	932	67.5	0.045601	0.191888	0.294112	0.129848	0.164263	16.42631	ok
0.486	4.208	0.067	25	35	100	1226	67.5	0.034666	0.145873	0.340127	0.09871	0.241417	24.1417	ok
0.486	4.208	0.067	25	35	100	1099	67.5	0.038672	0.16273	0.32327	0.110117	0.213153	21.31531	ok
0.486	4.208	0.067	25	35	100	873	67.5	0.048683	0.204857	0.281143	0.138624	0.142519	14.25192	ok
0.486	4.208	0.067	25	35	100	479	67.5	0.088727	0.373361	0.112639	0.252649	-0.14001	-14.001	ok

h0	a1	a2	tamb	Tin	Tout	G	Tm	Tr	2ªparcela	nt	3ªparcela	ht		Status
0.486	4.208	0.067	25	40	100	778.71	70	0.057788	0.243171	0.242829	0.17423	0.068598	6.859814	ok
0.486	4.208	0.067	25	40	100	821	70	0.054811	0.230646	0.255354	0.165256	0.090099	9.009866	ok
0.486	4.208	0.067	25	40	100	762	70	0.059055	0.248504	0.237496	0.178051	0.059445	5.944488	ok
0.486	4.208	0.067	25	40	100	681	70	0.066079	0.278062	0.207938	0.199229	0.008709	0.870925	ok
0.486	4.208	0.067	25	40	100	683	70	0.065886	0.277247	0.208753	0.198646	0.010107	1.010688	ok
0.486	4.208	0.067	25	40	100	932	70	0.048283	0.203176	0.282824	0.145574	0.13725	13.725	ok
0.486	4.208	0.067	25	40	100	1226	70	0.036705	0.154454	0.331546	0.110665	0.220882	22.08817	ok
0.486	4.208	0.067	25	40	100	1099	70	0.040946	0.172302	0.313698	0.123453	0.190245	19.02448	ok
0.486	4.208	0.067	25	40	100	873	70	0.051546	0.216907	0.269093	0.155412	0.11368	11.36804	ok
0.486	4.208	0.067	25	40	100	479	70	0.093946	0.395324	0.090676	0.283246	-0.19257	-19.257	ok

Appendix II: Thermal Efficiency calculation for solar irradiance

h0	a1	a2	tamb	Tin	Tout	G	Tm	Tr	2ªparcela	nt	3ªparcela	ht		Status
0.486	4.208	0.067	10	10	100	800	55	0.05625	0.2367	0.2493	0.169594	0.079706	7.970625	ok
0.486	4.208	0.067	10	15	100	800	57.5	0.059375	0.24985	0.23615	0.188961	0.047189	4.718906	ok
0.486	4.208	0.067	10	20	100	800	60	0.0625	0.263	0.223	0.209375	0.013625	1.3625	ok
0.486	4.208	0.067	10	25	100	800	62.5	0.065625	0.27615	0.20985	0.230836	-0.02099	-2.09859	Problem
0.486	4.208	0.067	10	30	100	800	65	0.06875	0.2893	0.1967	0.253344	-0.05664	-5.66438	Problem
0.486	4.208	0.067	10	35	100	800	67.5	0.071875	0.30245	0.18355	0.276898	-0.09335	-9.33484	Problem
0.486	4.208	0.067	10	40	100	800	70	0.075	0.3156	0.1704	0.3015	-0.1311	-13.11	Problem

h0	a1	a2	tamb	Tin	Tout	G	Tm	Tr	2ªparcela	nt	3ªparcela	ht		Status
0.486	4.208	0.067	15	10	100	800	55	0.05	0.2104	0.2756	0.134	0.1416	14.16	ok
0.486	4.208	0.067	15	15	100	800	57.5	0.053125	0.22355	0.26245	0.151273	0.111177	11.11766	ok
0.486	4.208	0.067	15	20	100	800	60	0.05625	0.2367	0.2493	0.169594	0.079706	7.970625	ok
0.486	4.208	0.067	15	25	100	800	62.5	0.059375	0.24985	0.23615	0.188961	0.047189	4.718906	ok
0.486	4.208	0.067	15	30	100	800	65	0.0625	0.263	0.223	0.209375	0.013625	1.3625	ok
0.486	4.208	0.067	15	35	100	800	67.5	0.065625	0.27615	0.20985	0.230836	-0.02099	-2.09859	Problem
0.486	4.208	0.067	15	40	100	800	70	0.06875	0.2893	0.1967	0.253344	-0.05664	-5.66438	Problem

h0	a1	a2	tamb	Tin	Tout	G	Tm	Tr	2ªparcela	nt	3ªparcela	ht		Status
0.486	4.208	0.067	20	10	100	800	55	0.04375	0.1841	0.3019	0.102594	0.199306	19.93063	ok
0.486	4.208	0.067	20	15	100	800	57.5	0.046875	0.19725	0.28875	0.117773	0.170977	17.09766	ok
0.486	4.208	0.067	20	20	100	800	60	0.05	0.2104	0.2756	0.134	0.1416	14.16	ok
0.486	4.208	0.067	20	25	100	800	62.5	0.053125	0.22355	0.26245	0.151273	0.111177	11.11766	ok
0.486	4.208	0.067	20	30	100	800	65	0.05625	0.2367	0.2493	0.169594	0.079706	7.970625	ok
0.486	4.208	0.067	20	35	100	800	67.5	0.059375	0.24985	0.23615	0.188961	0.047189	4.718906	ok
0.486	4.208	0.067	20	40	100	800	70	0.0625	0.263	0.223	0.209375	0.013625	1.3625	ok

h0	a1	a2	tamb	Tin	Tout	G	Tm	Tr	2ªparcela	nt	3ªparcela	ht		Status
0.486	4.208	0.067	25	10	100	800	55	0.0375	0.1578	0.3282	0.075375	0.252825	25.2825	ok
0.486	4.208	0.067	25	15	100	800	57.5	0.040625	0.17095	0.31505	0.088461	0.226589	22.65891	ok
0.486	4.208	0.067	25	20	100	800	60	0.04375	0.1841	0.3019	0.102594	0.199306	19.93063	ok
0.486	4.208	0.067	25	25	100	800	62.5	0.046875	0.19725	0.28875	0.117773	0.170977	17.09766	ok
0.486	4.208	0.067	25	30	100	800	65	0.05	0.2104	0.2756	0.134	0.1416	14.16	ok
0.486	4.208	0.067	25	35	100	800	67.5	0.053125	0.22355	0.26245	0.151273	0.111177	11.11766	ok
0.486	4.208	0.067	25	40	100	800	70	0.05625	0.2367	0.2493	0.169594	0.079706	7.970625	ok

h0	a1	a2	tamb	Tin	Tout	G	Tm	Tr	2ªparcela	nt	3ªparcela	ht		
0.486	4.208	0.067	30	10	100	800	55	0.03125	0.1315	0.3545	0.052344	0.302156	30.21563	ok
0.486	4.208	0.067	30	15	100	800	57.5	0.034375	0.14465	0.34135	0.063336	0.278014	27.80141	ok
0.486	4.208	0.067	30	20	100	800	60	0.0375	0.1578	0.3282	0.075375	0.252825	25.2825	ok
0.486	4.208	0.067	30	25	100	800	62.5	0.040625	0.17095	0.31505	0.088461	0.226589	22.65891	ok
0.486	4.208	0.067	30	30	100	800	65	0.04375	0.1841	0.3019	0.102594	0.199306	19.93063	ok
0.486	4.208	0.067	30	35	100	800	67.5	0.046875	0.19725	0.28875	0.117773	0.170977	17.09766	ok
0.486	4.208	0.067	30	40	100	800	70	0.05	0.2104	0.2756	0.134	0.1416	14.16	ok

h0	a1	a2	tamb	Tin	Tout	G	Tm	Tr	2ªparcela	nt	3ªparcela	ht		Status
0.486	4.208	0.067	35	10	100	800	55	0.025	0.1052	0.3808	0.0335	0.3473	34.73	ok
0.486	4.208	0.067	35	15	100	800	57.5	0.028125	0.11835	0.36765	0.042398	0.325252	32.52516	ok
0.486	4.208	0.067	35	20	100	800	60	0.03125	0.1315	0.3545	0.052344	0.302156	30.21563	ok
0.486	4.208	0.067	35	25	100	800	62.5	0.034375	0.14465	0.34135	0.063336	0.278014	27.80141	ok
0.486	4.208	0.067	35	30	100	800	65	0.0375	0.1578	0.3282	0.075375	0.252825	25.2825	ok
0.486	4.208	0.067	35	35	100	800	67.5	0.040625	0.17095	0.31505	0.088461	0.226589	22.65891	ok
0.486	4.208	0.067	35	40	100	800	70	0.04375	0.1841	0.3019	0.102594	0.199306	19.93063	ok

h0	a1	a2	tamb	Tin	Tout	G	Tm	Tr	2ªparcela	nt	3ªparcela	ht		
0.486	4.208	0.067	40	10	100	800	55	0.01875	0.0789	0.4071	0.018844	0.388256	38.82563	ok
0.486	4.208	0.067	40	15	100	800	57.5	0.021875	0.09205	0.39395	0.025648	0.368302	36.83016	ok
0.486	4.208	0.067	40	20	100	800	60	0.025	0.1052	0.3808	0.0335	0.3473	34.73	ok
0.486	4.208	0.067	40	25	100	800	62.5	0.028125	0.11835	0.36765	0.042398	0.325252	32.52516	ok
0.486	4.208	0.067	40	30	100	800	65	0.03125	0.1315	0.3545	0.052344	0.302156	30.21563	ok
0.486	4.208	0.067	40	35	100	800	67.5	0.034375	0.14465	0.34135	0.063336	0.278014	27.80141	ok
0.486	4.208	0.067	40	40	100	800	70	0.0375	0.1578	0.3282	0.075375	0.252825	25.2825	ok

h0	a1	a2	tamb	Tin	Tout	G	Tm	Tr	2ªparcela	nt	3ªparcela	ht		Status
0.486	4.208	0.067	45	10	100	800	55	0.0125	0.0526	0.4334	0.008375	0.425025	42.5025	ok
0.486	4.208	0.067	45	15	100	800	57.5	0.015625	0.06575	0.42025	0.013086	0.407164	40.71641	ok
0.486	4.208	0.067	45	20	100	800	60	0.01875	0.0789	0.4071	0.018844	0.388256	38.82563	ok
0.486	4.208	0.067	45	25	100	800	62.5	0.021875	0.09205	0.39395	0.025648	0.368302	36.83016	ok
0.486	4.208	0.067	45	30	100	800	65	0.025	0.1052	0.3808	0.0335	0.3473	34.73	ok
0.486	4.208	0.067	45	35	100	800	67.5	0.028125	0.11835	0.36765	0.042398	0.325252	32.52516	ok
0.486	4.208	0.067	45	40	100	800	70	0.03125	0.1315	0.3545	0.052344	0.302156	30.21563	ok

h0	a1	a2	tamb	Tin	Tout	G	Tm	Tr	2ªparcela	nt	3ªparcela	ht		Status
0.486	4.208	0.067	50	10	100	800	55	0.00625	0.0263	0.4597	0.002094	0.457606	45.76063	ok
0.486	4.208	0.067	50	15	100	800	57.5	0.009375	0.03945	0.44655	0.004711	0.441839	44.18391	ok
0.486	4.208	0.067	50	20	100	800	60	0.0125	0.0526	0.4334	0.008375	0.425025	42.5025	ok
0.486	4.208	0.067	50	25	100	800	62.5	0.015625	0.06575	0.42025	0.013086	0.407164	40.71641	ok
0.486	4.208	0.067	50	30	100	800	65	0.01875	0.0789	0.4071	0.018844	0.388256	38.82563	ok
0.486	4.208	0.067	50	35	100	800	67.5	0.021875	0.09205	0.39395	0.025648	0.368302	36.83016	ok
0.486	4.208	0.067	50	40	100	800	70	0.025	0.1052	0.3808	0.0335	0.3473	34.73	ok

G	Collector Area	Power	Nominal Efficiency	%	Tpv	Tcoeff	K1	K 2	K3	K4	Actual Efficiency	%	Gross
778.7178	1.62	200	0.1585385	15.85385	50	0.0025	0.9375	0.8	0.8	0.3	0.0285369	2.853694	28.53693748
821.3333	1.62	200	0.1503127	15.03127	50	0.0025	0.9375	0.8	0.8	0.3	0.0270563	2.705628	27.05627706
762.3984	1.62	200	0.1619321	16.19321	50	0.0025	0.9375	0.8	0.8	0.3	0.0291478	2.914778	29.14778281
681.9231	1.62	200	0.1810421	18.10421	50	0.0025	0.9375	0.8	0.8	0.3	0.0325876	3.258758	32.58757912
683.8931	1.62	200	0.1805206	18.05206	50	0.0025	0.9375	0.8	0.8	0.3	0.0324937	3.249371	32.49370589
932.6923	1.62	200	0.132366	13.2366	50	0.0025	0.9375	0.8	0.8	0.3	0.0238259	2.382589	23.82588774
1226.036	1.62	200	0.1006959	10.06959	50	0.0025	0.9375	0.8	0.8	0.3	0.0181253	1.812526	18.12526024
1099.328	1.62	200	0.1123021	11.23021	50	0.0025	0.9375	0.8	0.8	0.3	0.0202144	2.021437	20.21437429
873.0539	1.62	200	0.141408	14.1408	50	0.0025	0.9375	0.8	0.8	0.3	0.0254534	2.545344	25.45343698
493.8528	1.62	200	0.249987	24.9987	50	0.0025	0.9375	0.8	0.8	0.3	0.0449977	4.499766	44.99766246
542.1053	1.62	200	0.2277358	22.77358	50	0.0025	0.9375	0.8	0.8	0.3	0.0409924	4.099245	40.99244876
680.8929	1.62	200	0.181316	18.1316	50	0.0025	0.9375	0.8	0.8	0.3	0.0326369	3.263689	32.63688551