# Palestine Polytechnic University

**College of Engineering and Technology**

**Mechanical Engineering Department**

**Graduation Project**

## Potential of Using Concentrated Solar Power in Plastic Industry

## “Feasibility Study”

By:

Nakhleh Makhlouf Ibrahim Alian

Ibrahim Abuawwad

Supervisor:

Dr. Husein Amro

Submitted to the College of Engineering

In partial fulfillment of the requirements for

The Bachelor degree in Automotive Engineering

**Hebron, December 2017**

Palestine Polytechnic University

College of Engineering and Technology

Mechanical Engineering Department

Hebron- Palestine

Potential of Using Concentrated Solar Power in Plastic Industry

“Feasibility Study”

Project Team:

Nakhleh Makhlouf

Ibrahim Alian

Ibrahim Abuawwad

Submitted to the College of Engineering

In partial fulfillment of the requirements for

The Bachelor degree in Automotive Engineering

Supervisor Signature

…………………………

Testing Committee Signatures

……………….. ………………

Department Head Signature

……………………

**December 2017**

# Dedication

To Our Families

To our Supervisor Dr. Hussein Amro

To Our Teachers and Friends

To our Kingdom Jerusalem

To Every ambitious person suffering in this life

To all who fight for Freedom and Justice

To all who made this work is possible

Ibrahim Abuawwad

Nakhleh Maklouf

Ibrahim Alian

Acknowledgment

We would like to express our gratitude for everyone who helps us during this project, starting with our supervisor Dr. Hussein Amro who didn’t keep any effort in encouraging us to do this job. Thanks for continues support and kind communication which great effect on our performance. Thanks with great appreciation to our families and the Mechanical Engineering Department.

# Abstract

This project aims to make a feasibility study for using the Linear Fresnel Collector system in plastic industry. System has been chosen after studying the current situation of the solar radiation in Palestine and the thermal consumption in the plastic industry with taking “Royal” company as a case study. Solar radiation in Palestine has been studied and found that Palestine has a good potential in using solar thermal energy, by taking royal as a case study the project aims to cover about 20% of Royal thermal consumption, the solar collector design and simulation has been done using TRANSYS program and the feasibility study determined the success of the project economically.

يهدف هذا المشروع الى دراسة الجدوى الاقتصادية لاستخدام نظام الطاقة الشمسية Linear Fresnel Collector في الصناعات البلاستيكية تم اختيار النظام بعد دراسة وضع الاشعاع الشمسي في فلسطين والاستهلاك الحراري للصناعات البلاستيكية في شركة رويال التجارية الصناعية والتي هي حالة المشروع . دراسة وضع الاشعاع الشمسي بينت ان فلسطين لديها القدرة والامكانية لاستخدام الانظمة الشمسية في مجال الصناعات البلاستيكية لتغطية الاحمال الحرارية. تم أخذ هدف المشروع وهو تغطية ما نسبته 20%. من الحمل الحراري في شركة رويال التجارية الصناعية , تم عمل تصميم ومحاكاة للنظام المحدد باستخدام برنامج TRANSYS و عمل دراسة الجدوى التي اثبتت نجاح المشروع اقتصاديا.

## Contents:

Dedication……………………………………………………………………………...... III

Acknowledgment…………………………………………………………………….... IV

Abstract……..…………………………………………………………………………V

List of figures ……………………………………………………………………….... VIII

List of tables ……………………………………………….……………………….…... XI

1. Chapter 1: Introduction ….……………………………………………………..……1
    1.1. Palestine Profile ……………………………………………………………………1
        1.1.1. Energy Resources …………………………………………………....……….2
        1.1.2. Fuel Demand……………………………………………….……….....….3
        1.1.3. Energy Consumption by Sector……………………………….……………4
        1.1.4. Energy Prices………………………………………………………………….4
    1.2. Economic Figures………..……………………………………………………6
    1.3. Industry in Palestine…………………….…………………………………………6
    1.4. Problem Definition…………………….…………………………………………..8
    1.5. Project Objectives……………………..……………………………………………9
    1.6. Literature Review……………………………….……………………………….9
2. Chapter 2: Solar Collectors ………………………………………………………...11
    2.1. Non-Concentrated Solar Collector………………………………………...……12
        2.1.1. Flat Plate Collectors…………………………………………………….………12
        2.1.2. Evacuated Tube Collector……………………………………………………14
    2.2. Concentrated Solar Collectors……………......................................…………….15
        2.2.1. Parabolic Trough collector……………………….…...………………………..15
        2.2.2. Linear Fresnel Collector………………………...……………………………..16
        2.3. Conclusion ……………………………………....……………………………19
3. Chapter 3: Fundamentals ……………………………………………………………..21

3.1. Solar Geometry ……………………………………………………………………21
3.1.1. Lines of Latitude and longitude ……………………………………………21
3.1.2. Angles ……………………………………………………………………22
3.2. Sun Path ……………………………………………………………………26
3.2.1. Sun Position ……………………………………………………………27
3.2.2 The Sun ……………………………………………………………………27
3.3. Solar Radiations……………………………………………………………27
3.3.1. Solar Radiation Calculations…………………………………………29
3.3.2. Solar Radiation Measurements ………………………………………29
3.4. Case Study …………………………………………………………………31
3.4.1. Technical Assessments ………………………………………………31
3.5. Extrusion Machines…………………………………………………………34
3.5.1. Parts of Plastic Extrusion Machines …………………………………35
3.5.2 The Design of Heaters…………………………………………………36
3.5.3. The Feasibility Study…………………………………………………36
4. Chapter 4: System modeling and Design ……………………………………37
4.1 System Structure ……………………………………………………………37
4.2. System Simulation …………………………………………………………38
4.3. Simulation Results …………………………………………………………40
4.4. Conclusion …………………………………………………………………46
5. Chapter 5: Feasibility study…………………………………………………47
5.1. Economical assessment ……………………………………………………47
5.2. System Advisor Model (SAM) ……………………………………………48
5.2.1. The Solar Field …………………………………………………………48
5.2.2. The Collectors and Receiver …………………………………………49
5.2.3. The Thermal Storage …………………………………………………49
5.2.4. System Cost ……………………………………………………………50
5.3. Financial Analysis …………………………………………………………50
5.4. Conclusion and Recommendation …………………………………………53

## List of figures


| Figure number | Figure name | Page number |
|---|---|---|
| 1.1 | Renewable energy types | 1 |
| 1.2 | Palestine profile | 2 |
| 1.3 | Electricity sources | 3 |
| 1.4 | Imported electricity sources | 3 |
| 1.5 | Energy consumed by sector | 4 |
| 1.6 | Fuel prices | 5 |
| 1.7 | Electricity prices | 5 |
| 1.8 | GDP per capita | 6 |
| 1.9 | Electricity consumption in Hebron | 7 |
| 1.10 | Electricity participants in Hebron | 7 |
| 1.11 | Royal electricity consumption | 8 |
| 2.1 | Flat plate collectors | 12 |
| 2.2 | Flat plat collectors components | 13 |
| 2.3 | Evacuated tube collector | 14 |
| 2.4 | Parabolic through collector | 15 |
| 2.5 | linear Fresnel collector | 16 |
| 2.6 | Novatec solar AG power plant | 16 |
| 2.7 | Fresnel collector LF-11 module | 17 |
|  | Reference conditions(ISLFCLF-11 Data sheet) |  |
| 2.8 | Reference conditions | 18 |
| 2.9 | Characteristic collector curve | 19 |
| 3.1 | Lines of latitude | 21 |
| 3.2 | lines of longitude | 22 |

| | | |
|---|---|---|
| 3.3 | Hour Angle Distribution | 23 |
| 3.4 | The Declination Angle | 23 |
| 3.5 | Annual variation | 24 |
| 3.6 | Solar Azimuth angle | 26 |
| 3.7 | DNI Map | 28 |
| 3.8 | The Pyrheliometer | 30 |
| 3.9 | The Pyrometer | 30 |
| 3.10 | Palestine map | 31 |
| 3.11 | LFC system efficiency | 32 |
| 3.12 | Royal Power consumption | 32 |
| 3.13 | Modules distribution on the roof | 34 |
| 3.14 | Extrusion machine | 35 |
| 3.15 | Heat Exchangers Design | 36 |
| 4.1 | System Structure | 37 |
| 4.2 | Solar collector System in TRANSYS | 38 |
| 4.3 | Parabolic trough outlet temp. in January | 41 |
| 4.4 | Parabolic trough temp. in July | 41 |
| 4.5 | Collector useful energy in January | 42 |
| 4.6 | Collector useful Energy in July | 42 |
| 4.7 | Heat Exchangers Temp. in series | 43 |
| 4.8 | Heat Exchangers Temp. in parallel | 43 |
| 4.9 | Flat Plate collector Temp. in January | 44 |
| 4.10 | Flat Plate collector Temp. in July | 44 |
| 4.11 | Flat Plate Heat Exchangers Temp. | 45 |

| | | |
|---|---|---|
| 4.12 | Flat Plate Tank Temperatures | 45 |
| 5.1 | Collector Geometry | 49 |
| 5.2 | System Direct cost | 50 |
| 5.3 | The project Cash Flow Diagram | 51 |

## List of tables


| Table number | Table name | Page number |
|---|---|---|
| 1.1 | Techno-Economic Data | 10 |
| 3.1 | General Data | 33 |
| 3.2 | System Dimension | 34 |
| 4.1 | TRANSYS Types | 39 |
| 4.2 | The system parameters best values | 40 |
| 5.1 | Financial Assessment variables | 47 |
| 5.2 | The solar field parameters | 49 |
| 5.3 | The project cash flow | 51 |
| 5.4 | The project payback period | 52 |
| 5.5 | The project present value | 52 |

# 1. Introduction

Renewable Energy sources (RES) are the energy supplies that are refilled in a natural processes as fast as we use them figure 1.1 below shows the renewable energy types. The sun is the source for the renewable energy directly like the solar systems as our project or indirectly like wind power and biomass. RES will be exhausted if we use them faster or more than they could be refilled. Several types of RES are used today like: Hydropower, biomass, Geothermal, wind power and solar power (which we will focus on in our project).

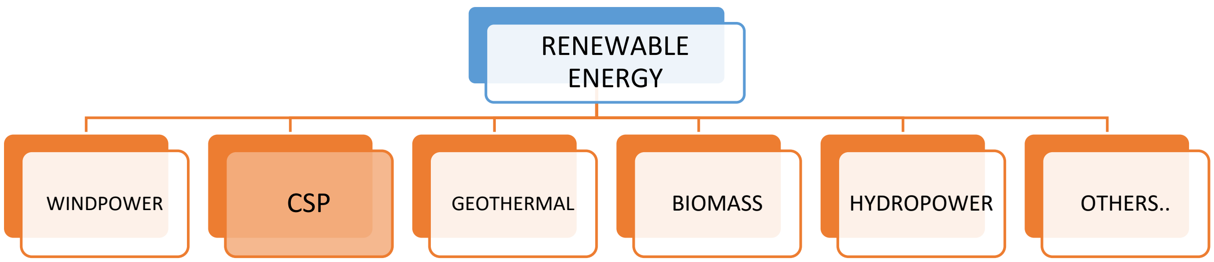


Figure 1.1: Renewable energy types

Solar power comes directly from the sun, here the sun power used to produce the electricity or collect the heat by a solar collectors systems to be used in factories. The concentrated solar Power (CSP) is much available and suitable with a reduction of the cost also it has the future potential. Some countries has the suitable location from the sun side can make the future using this technology (CSP) like KSA and South Africa.

This project studies the situation of energy in Palestine, the consumption of electricity in the industrial sector especially the plastic sector with taking “royal” company as a case study to show the consumption and factors affect this situation. By studying the sun and its radiation in Palestine the project makes the solar energy a possible solution with many choices. The comparison between collector types and choosing the Linear Fresnel Collector (LFC-11) with studying the characteristic curve in Palestine location leads to make a system design for the plastic extrusion machine. The project makes a feasibility study for using the LFC-11 for this sector using special software.

### 1.1. Palestine Profile.

The occupied Palestine located in the Middle East in a two areas" Gaza and West Bank" between the 30, 31 north the equator and 34, 45 east of Greenwich with a total area of 6220 $km^2$ (World Bank, 2017).The figure 1.2 below shows the location of Palestine and its borders (Google Maps, 2017).


Figure 1.2: Palestine profile (Google map, 2017)

#### 1.1.1. Energy Resources

Palestine has a population of 4,422,143 (World Bank, 2015), with a continuously growth which increase the demand on energy sources which are limited for many reasons from the occupation to the small area. Palestine has to import all its consumption of fuel and the most of its electric consumption (87%) from the "Israeli" market, Jordan and Egypt (Palestinian Central Bureau of Statistics, 2015).Figure (1.3) shows the distribution of electricity resources in Palestine, the most of it is imported, about 8% of the total electricity consumption is produced by the Palestinian Electricity Company (PEC) in Gaza and the last part (5%) is self-generated. As for the imported part of electricity which is imported by the Palestinian government from Egypt about 3% ,96% form "Israel" as shown in figure 1.4 on the next page  (Palestinian Energy and Natural Resources

Authority, 2016) The local energy resources are quite limited to the solar energy used in heating water mostly or biomass for cooking and heating.

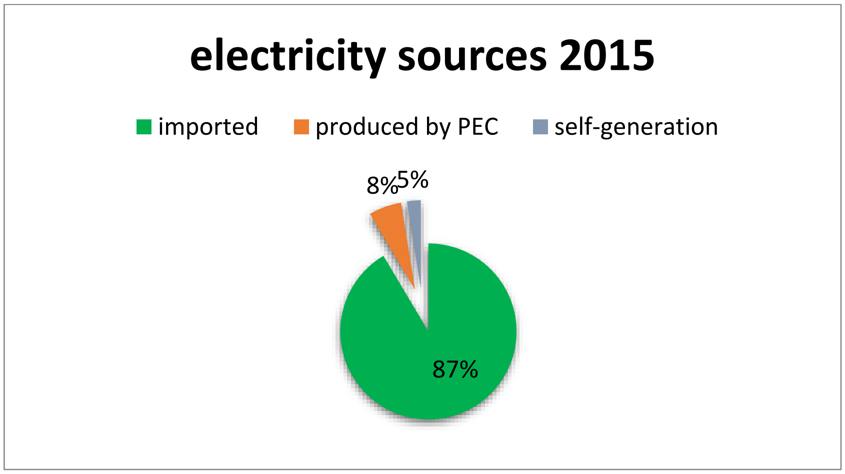


Figure 1.3: Electricity sources (PCBS, 2015)

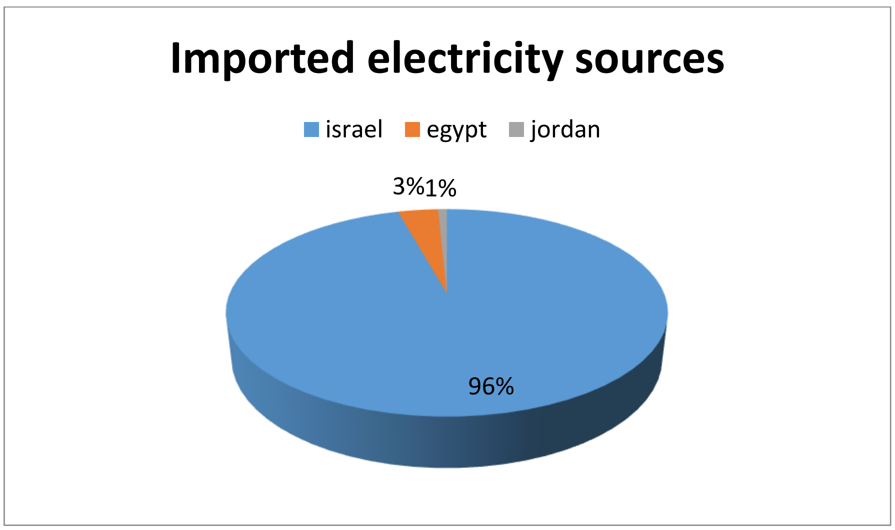


Figure 1.4: Imported electricity sources (PCBS, 2015)

### 1.1.2. Fuel Demand

The fuel situation in Palestine is very complicated because of the occupation and the peace agreements. So Palestinian authority compelled to buy the crude oil and its products from "Israel" with a very high price and taxes. Arab countries like Qatar and Saudi Arabia with the Donor countries gives a part of the Palestinian demand on fuel, but this depends on the relations between countries and affected by fighting with Israel.

### 1.1.3. Energy Consumption by Sector

In 2015 the PCBS statistics shows that 45.7% of the final energy consumed by the transport sector and 39% by the households as shown in figure 1.5 below. It is worth to mention that residential sector contributes to larger part of increase in the total final energy consumption due to the large expanding of the housing sector.

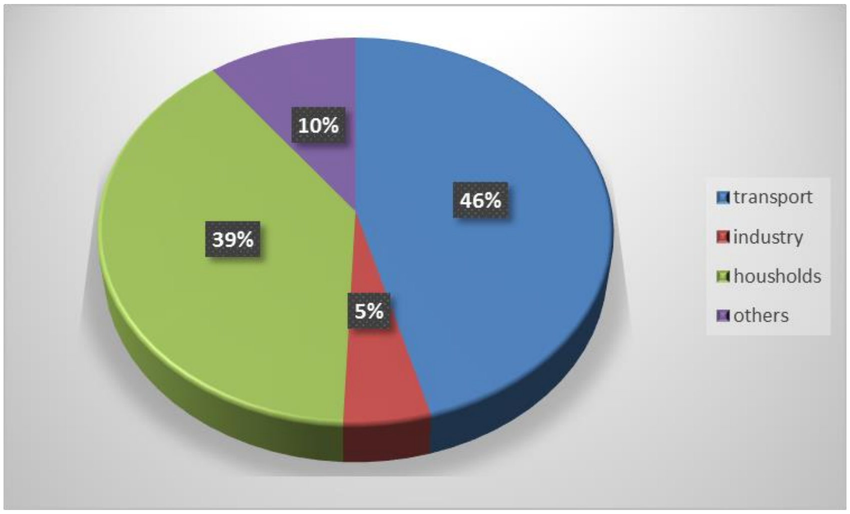


Figure 1.5: Energy consumed by sector (PCBS, 2015)

### 1.1.4. Energy Prices

The prices of energy products are somehow depends on Israeli pricing due to the international peace agreements,  some extra values are usually added to compensate the big losses of energy and shortages in revenues and for development projects such as rural electrification projects. No subsidizing policy is pursued in Palestine, thus customers are always eligible for changes of prices according to world market and directly affected by Israeli tariffs Figure (1.6) shows the fuel prices in Palestine during 2015. The kWh rate is used in pricing consumed electricity, thus the prices of KWh units is flat (not progressive) to all consumed units, thus the price of kWh is usually called here the Flat Rate, meaning applicable to all consumed units the Figure (1.7) shows the electricity prices in Palestine in 2015(Hebron Municipality, 2015) it shows that prices is highest while comparing it with the middle east prices that's shown on Figure (1.7) (World Bank, 2016). Each electric utility has its own tariff system. In all facilities, electrical meters are used to monitor the consumed quantity and fixed monthly fees are added to each invoice to cover the depreciations and development of electrical services and facilities. So we found that the tariff system is not unified. Prices of electricity in Palestine are the most expensive if compared to other countries in the region since almost all energy consumed is imported and it is heavily taxed. It reaches the average of 0.13 €/kWh. The average price paid to Israeli Electric Company is 0.07 €/kWh including V.A.T.

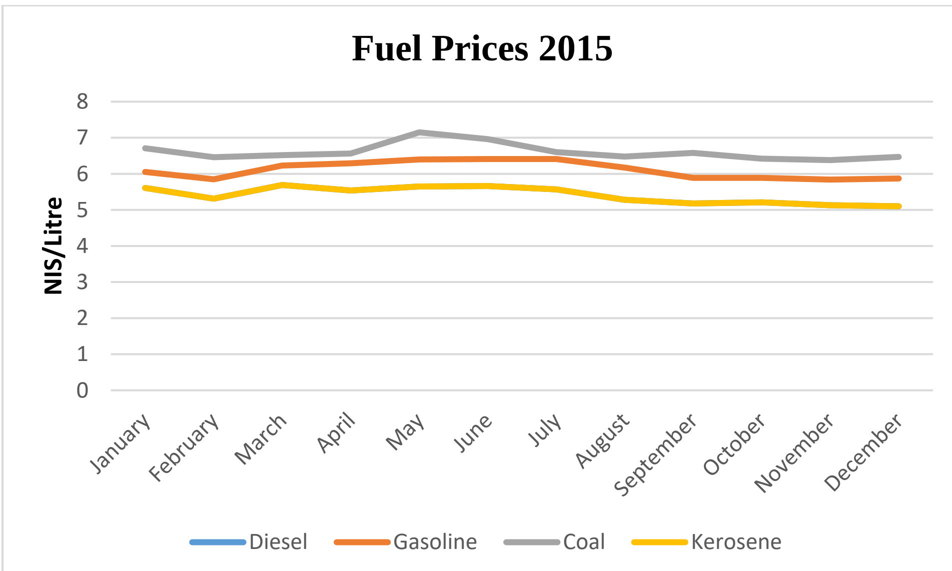


Figure 1.6: Fuel prices (PCBS, 2015)

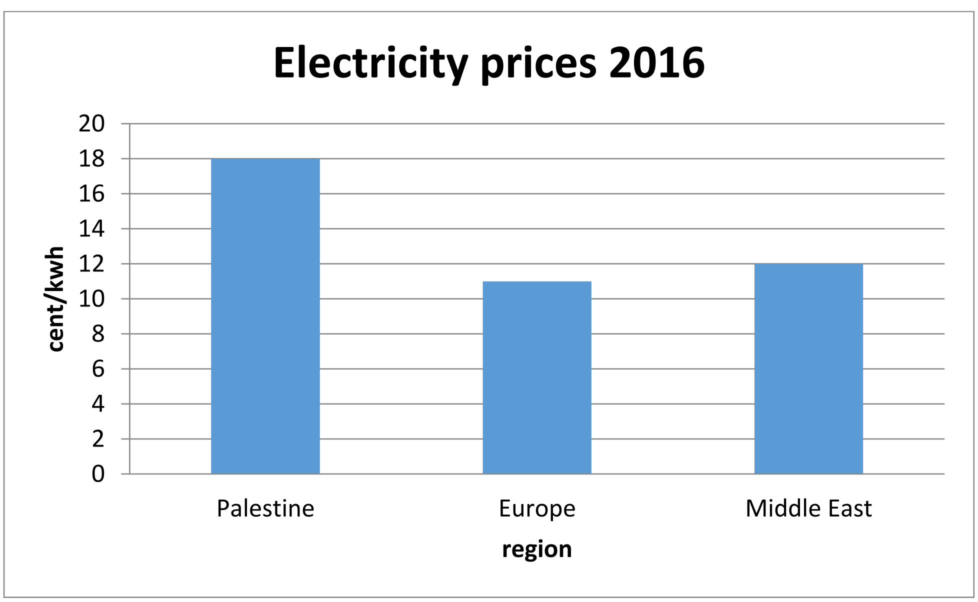

Figure 1.7: Electricity prices (World Bank, 2016)

### 1.2. Economic Figures

Several problems have contributed to the continuous deterioration of the political, economic, social and environmental conditions and hindered development initiatives. The lack of a Palestinian infrastructure for close to four decades has impeded any realistic progress on the Palestinian economy.  Most of Palestinians works in agriculture, personal services and industry beside the trade. The trading economics website using the PCBS characteristics shows with the Figure (1.8) below that the Palestinian GDP per capita in USD is rising with high rates in last 10 years.


Figure 1.8: GDP per capita in USD (World Bank, 2016)

### 1.3. Industry in Palestine

The industrial sector in Palestine has a wide variety of products and related subsectors to each other's. It lacks the proper availability of raw materials for the continuity of the sector activities. But the great advantage is the hard working and flexible business from the community as a driving force. This achieve to several successes with the certain conditions. Industry in Palestine employs 13% of the workforces and 16% of the GDP (Palestinian Federation of Industries FDI, 2014)

As for the plastic industry which we focus on for using the CSP to cover the high heat needed, it distributed with a various parts in West Bank with focusing on pipes in Hebron and Ramallah. In Hebron (the study field) the plastic industry consumed 36% of the total electrical energy consumed by the industrial sector with a sharing of 6% of the industrial participants in Hebron municipality sa shown in figure 1.9 and 1.10 below. Between 40%-60% of this energy used in Plastic processing(Hebron Muncipality,2017) such as extruding  as we will show in details in the following chapters.

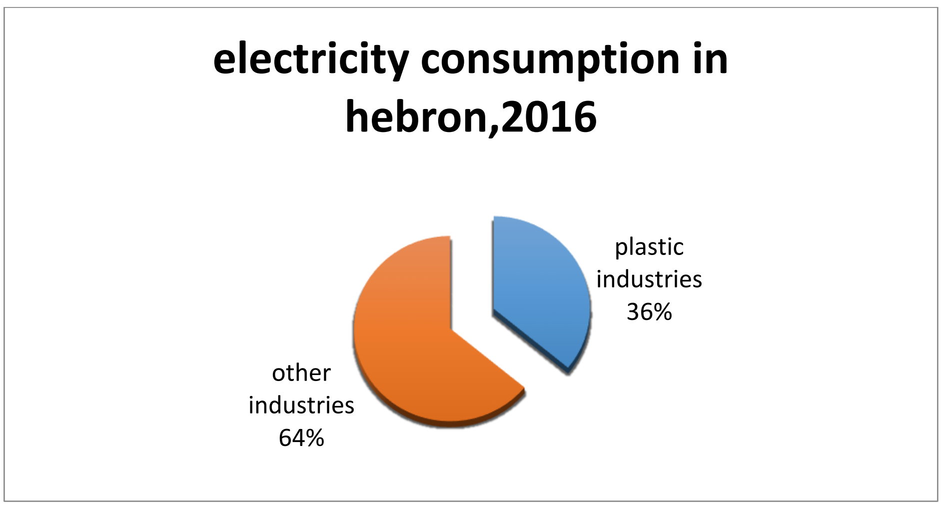


Figure 1.9: Electricity consumption (HM, 2017)

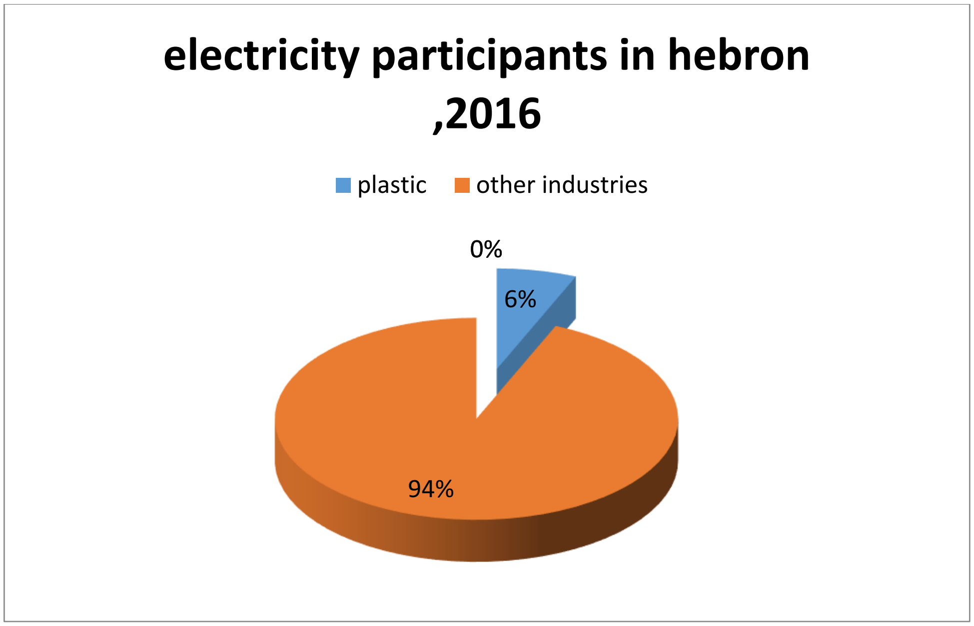

Figure 1.10: electricity participants in Hebron (HM, 2017)

### 1.4. Problem Definition

The industry in Palestine as the statistics shows faces many problems and has a complicated situation from the occupation and the lack of proper material to the high prices and the situation of energy which a big burden on the companies, especially the ones that needs the energy in high rates like the plastic producers as shown in Figures (1.9) and (1.10).For our case study (Royal industrial Trade company which is one of the biggest plastic producers in Palestine) depends on the electricity in its all processes so they have a high rate of consumption reaches 600,000 Kwh per month as shown in the Figure (1.11) below (Hebron Municipality, 2016) from lighting to running the machines and heating the plastic which is the main process in the factory. Royal machines catalogues shows that 60% of the electricity are needed for the heaters. So it's clear that this consumption is for heating the plastic and the problem is: the dependence on electricity for these processes cost a lot of money (about 400,000 Nis/month) (Hebron Municipality, 2016).So we need another source of heat to reduce the costs and being less dependence on the electricity from the municipality which is using the Concentrated Solar Power systems to cover this need. CSP systems provide this need with a high efficiency and less costs for a long time, the project studies this solution and makes a feasibility study for it.

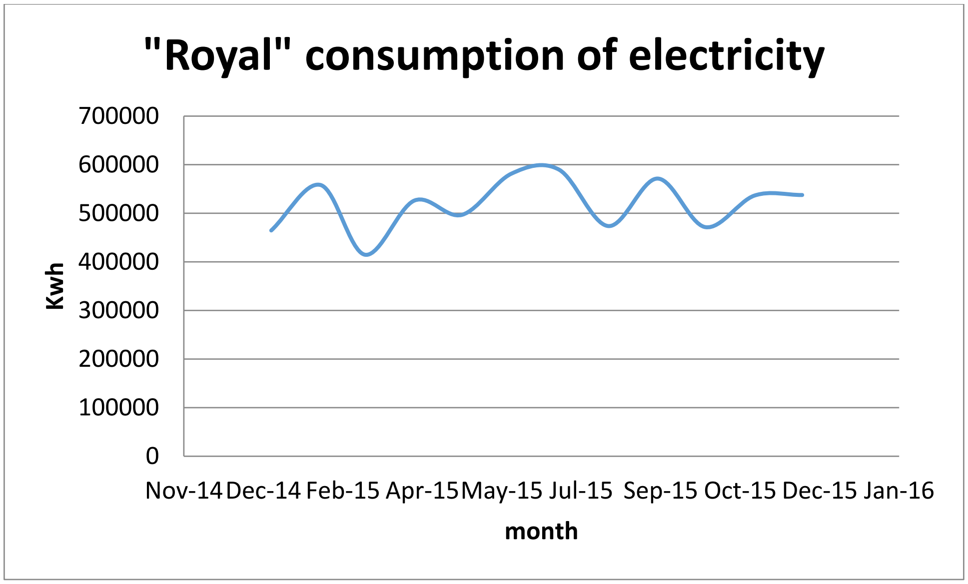


Figure 1.11: "Royal" consumption of electricity (HM, 2017)

### 1.5. Project Objectives and Outline

This project comes from the energy problem and costs which affects the industry in Palestine especially the plastic sector because of the high needs of electricity. The main objectives of the project is to proof the feasibility of using CSP as an alternative of electricity in the production lines in the plastic factories for heating the plastic and its processes. The project shows the suitable CSP system, its costs and the quantity of parts needed with the Palestine weather situation, also show its efficiency in a graph over the year. Chapter two shows the CSP types with its output, advantages versus disadvantages with a comparison between the types. Using the CSP needs calculations with respect of the weather data and power you need which is shown in chapter three. Our project will define in chapter four the software's and programs uses in the CSP systems calculations. In the last chapter the project will show the conclusion of calculations with its output, the potential of CSP in Palestine and how much is it feasible.

### 1.6. Literature Review

From many years ago CSP technology takes place in the industrial sectors around the world as an energy source for many reasons from the clean source to the improving of the cost efficiency in the future. For example, CSP offers the possibility of making storage systems. This will make the CSP more attractive comparing with other RE sources. An example of the adoption of heat storage systems in CSP is Solana 1, a 280 MW plant in Phoenix, USA. (CSP today, 2016).

Mining companies in Chili due to the large consumption of energy use the CSP. For example, Minera El Tesoro, located in the Chilean Atacama desert, is currently the largest CSP plant in South America. The plant substitute more than 55% of the diesel fuel currently used in the process, and also incorporates thermal energy storage. (CSP today, 2016). Table (1.1) shows Techno-Economic Data of Mineral El Tesoro CSP plant.

Table 1.1: Techno-Economic Data of Mineral El Tesoro CSP plant.

| | |
|---|---|
| Estimated investment | 14 million USD |
| Plant capacity | 10 MW thermal |
| Surface area | 7 Ha |
| CSP Technology | Parabolic Trough (PT) |
| Number of PT collectors | 1280 |

CSP used around the world for producing electricity for example In may2014 Italy started using Linear Fresnel Collector with a 9870$m^2$ area which generate a 3000 MWH/yr.(NREL,2015). Also Egypt in 2011 started using the parabolic trough technology to generate a 34 GWH/yr. of electricity in a 130000 $m^2$ area. (NREL, 2013).

## 2. Solar Collectors

A solar thermal collector collects heat by absorbing sunlight. A collector is a device for capturing solar radiation. Solar radiation is energy in the form of electromagnetic radiation from the infrared (long) to the ultraviolet (short) wavelengths. The solar collector is the main part of a solar thermal system that transforms solar radiant energy into heat that can be used for heating swimming pools, hot water preparation, space heating and even as heat for industrial processes (Solar Thermal Systems Manual).

The Solar Collectors have many types and designs every type has a specific parameters and every type has a specific work condition and different efficiency.

The solar thermal systems classified into two type by the collection method:

1- Non-concentration collector like the flat plate or evacuated tube collectors.
2- Concentrating collector, collector that directs radiation onto the receiver, like Fresnel lens, parabolic trough collector and Central Receiver (Concentrating Collectors - Power Generation).

The last classification of the solar collectors have different application this application depends on the temperature range as shown:

| | |
|---|---|
| LOW TEMPERATURE: | T< 100 ºC |
| Domestic water, swimming pool heating | |
| MEDIUM TEMPERATURE | T< 400 º C |
| Electricity production | |
| HIGH TEMPERATURE | T> 400 º C |
| Electricity produce, blast furnace... | |

### 2.1. Non-Concentrated Solar Collector

In the non-concentrating type, the collector area (the area that intercepts the solar radiation) is the same as the absorber area (the area absorbing the radiation). In these types the whole solar panel absorbs light (Norton, Brian (2013). Harnessing Solar Heat. Springer.*)*

This type has a different designs like the Flat plate collectors and the Evacuated tube collector.

#### 2.1.1. Flat Plate Collectors (FPC)

Flat-plate collectors in Figure (2.1) are the most common solar collectors for use in solar water-heating systems in homes and solar space heating. A flat-plate collector consists of an insulated metal box with a glass or plastic cover (the glazing) and a dark-colored absorber plate. Solar radiation is absorbed by the absorber plate and transferred to a fluid that circulates through the collector in tubes. In an air-based collector, the circulating fluid is air, whereas in a liquid-based collector it is usually water.

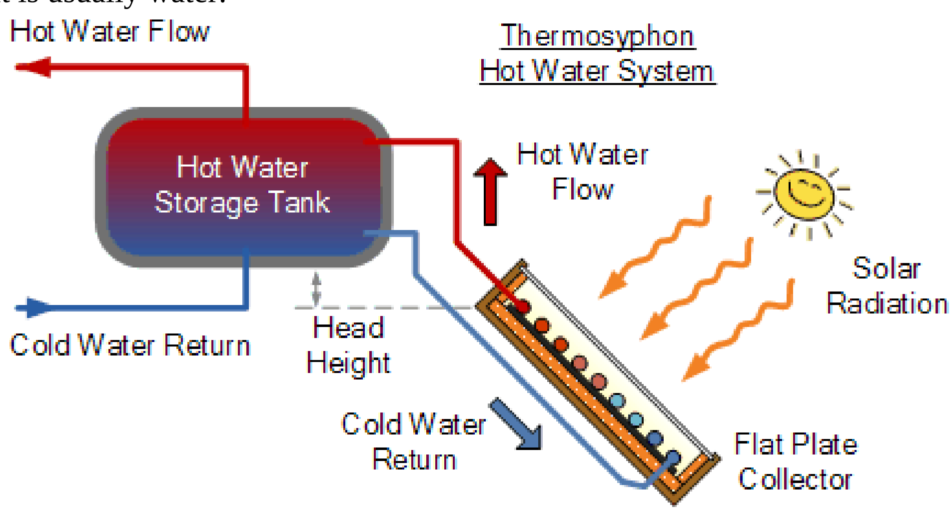


Figure 2.1: Flat plate collectors (FPC) (alternative-energy-tutorials)

Flat-plate collectors heat the circulating fluid to a temperature considerably less than that of the boiling point of water and are best suited to applications where the demand temperature is 30-70°C (86-158°F) and for applications that require heat during the winter months (Encyclopedia of Alternative Energy).

The main compounents of the Flate Plate Collectors are shown in the Figure (2.2):

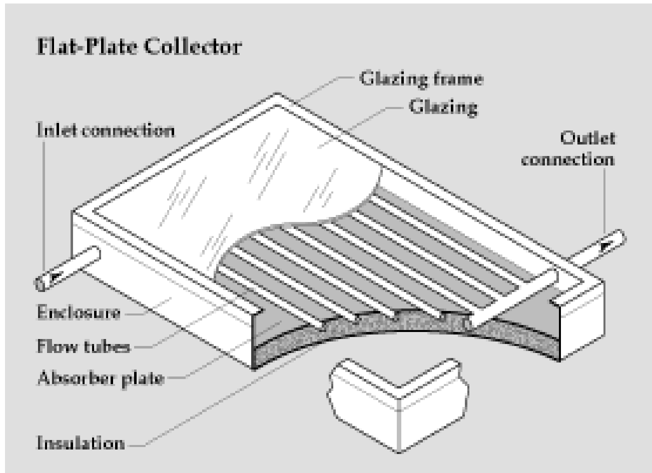


Figure 2.2: Flat plate collector's components (AE_flat_plate_solar_thermal_collector)

**-Advantages of a Flat-Plate Solar Collector**

- Since flat-plate collectors absorb energy coming from all directions above the absorber (total irradiance), tracking is not required.
- Therefore, many flat-plate collectors are firmly fixed to a mounting structure and rigid plumbing is frequently used to connect them to the rest of the system.
- Since moving structures, motors, and tracking control systems are avoided the complexity of the system is reduced.

**-Disadvantages of a Flat-Plate Solar Collector**

- Flat plate-collectors are subject to a high heat loss factor (about 2.9 to 5.3 W/m²). They have lower energy ratings at 100°C than the evacuated tubecollectors. Thus, they are used for heating domestic water (G.4 Solar collectors).

### 2.1.2. Evacuated Tube Collector (ETC)

In the Evacuated tube collector Figure (2.3) the absorber plate is a metal strip down the Center of each tube. Convective heat losses are suppressed by virtue of a vacuum in the tube. The absorber plate uses a special heat pipe to carry the collected energy to the fluid.

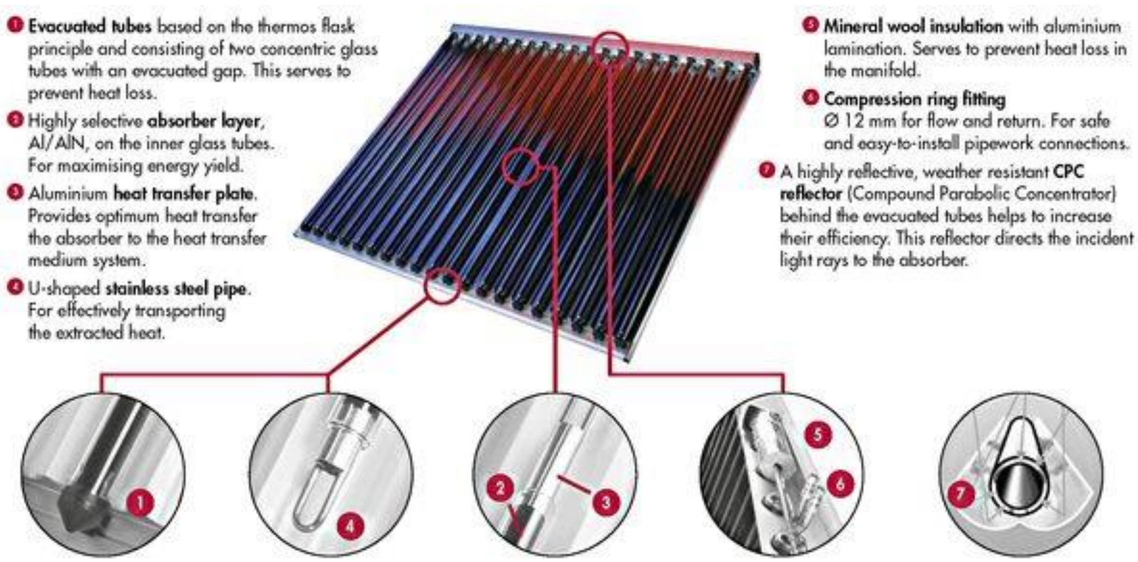


Figure 2.3: Evacuated tube collector (linuo-ritter-international)

**-The advantage of Evacuated Tube Collector**

1- Evacuated tubes contain practically no water and so they can resist freezing conditions.
2- The curved shape of the tubes allows thermal absorption from a greater range of sun angles, and therefore for a greater portion of the day.
3- Ideal for high temperature applications such as boiling water and steam production.

**-The disadvantage of Evacuated Tube Collector**

1. They are more expensive to have supplied and installed than most other types of solar hot water.
2. Evacuated tube, solar hot water systems require more maintenance than the FBC.

### 2.2. Concentrated Solar Collectors

Concentrating solar collectors is a power generation technology that uses mirrors or lenses to concentrate the sun's rays, in most of today's CSP systems, to heat a fluid and produce steam. The steam drives a turbine and generates power in the same way as conventional power plants (renewable energy technologies: cost analysis series).

#### 2.2.1. Parabolic Trough Collector

Collectors made up of individual curved mirrors reflect solar radiation onto an absorber tube located in the focal line. This tube contains a medium, usually heat-transfer oil, which is heated to about 400 degrees Celsius. Steam is generated in a heat exchanger, ultimately driving a turbine in the same way as steam in conventional power stations. This turbine then sets a generator in motion.

**-Advantages of Parabolic Trough Collector**

This medium that used can be reach high temperature level and a high steam pressure ranges depend on the type of the fluid used in the system, in Figure (2.4) a diagram of a parabolic trough solar farm (top), and an end view of how a parabolic collector focuses sunlight onto its focal point.

**-Disadvantages of Parabolic Trough Collector**

1. Level surfaces are required to set up parabolic mirrors.
2. Heat transfer oil and liquid salt both need heat exchangers.
3. The absorber tube also swings, which requires additional pipe fittings and increases the number parts subject to wear and tear.

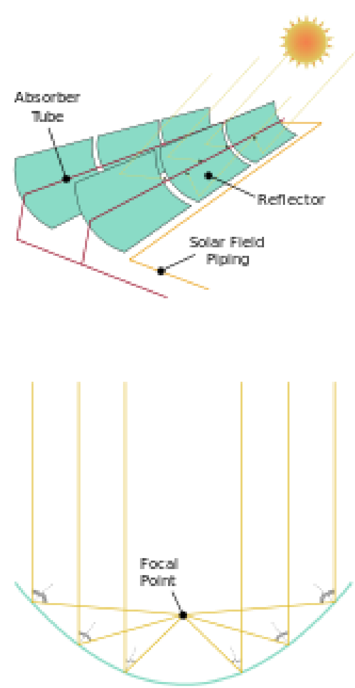


Figure 2.4: Parabolic Trough collector (Wikipedia)

### 2.2.2. Linear Fresnel Collector (LFC)

A long and narrow mirrors reflect solar radiation onto a permanently installed absorber tube as shown in Figure (2.5), the mirrors are all aimed at one single focal line. There is no requirement for swivel fittings, which are prone to wear and tear.

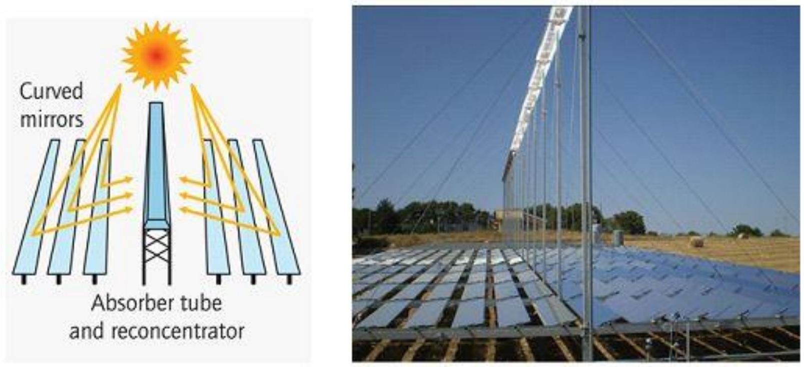


Figure 2.5: Linear Fresnel collector (The energy backyard, concentrated solar power)

The first commercial Fresnel power plant in Europe was built by Novatec Solar AG Figure (2.6) (at that time Novatec Biosol), it situated in Murcia/Spain and has an electric power of 1.4MW. It started commercial operation in March 2009 (Advanced CSP Teaching Materials Chapter 6 Linear Fresnel Technology).

Figure 2.6: Novatec Solar AG power plant (solar-thermal-project-support-for-a-fresnel-power plant)

**-Advantages of Linear Fresnel Collector**

1. The mirrors all have the same curvature and this means they are cheaper to manufacture.
2. Low wind load on Rooftop installation
3. Good weight spread

**-Disadvantages of Linear Fresnel Collector**

Flat and level surfaces are a necessity. They are less efficient due to lower operating temperatures. However, there have been positive developments which permit higher temperatures with corresponding increases in efficiency.

One of the published designs of linear Fresnel collector in the markets is Industrial Solar linear Fresnel collector LF-11 this type has a high efficiency and operating temperature range 63.5% and 400°C respectively each module of the design consist of 11 mirror each module generate a thermal energy reach 12.3 KW .

The Industrial Solar linear Fresnel collector LF-11 Figure (2.7) is a linear focusing solar system for generating process heat in the range of 100 kW to 10 MW at pressures up to 120 bar (standard 40 bar) and temperatures up to 400°C. Different heat transfer fluids can be used like pressurized water or thermal oil, but it is also possible to directly generate or even superheat steam.

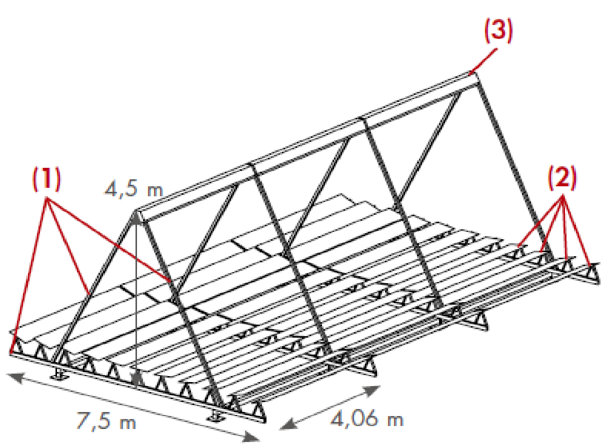


Figure 2.7: Fresnel collector LF-11 module (Industrial Solar linear Fresnel collector LF-11 Data Sheet)

Main components of the system are:

1- supporting structure (1)
2- primary reflectors (2)
3- receiver, consisting of secondary reflectors and vacuum absorber tubes (3)
4- Control systems for the primary reflector tracking and the solar array output.

**The Advantages of the Industrial Solar Linear Fresnel Collector LF-11:**

**-Advantages are:**

• Simple power control

• optimized stow positions for various weather conditions, protection during hail and sand storms

• Self-cleaning position in rain

• Easy maintenance access to individual rows, thereby allowing continued operation of the plant

The maximum operating temperature is 400 °C, Thermal output under reference conditions in Figure (2.8) (Industrial Solar linear Fresnel collector LF-11 Data Sheet):

12.3 kW per standard module

562 W/m2 in terms of aperture surface area of primary reflectors

377 W/m2 in terms of total installation surface area

*reference conditions:

30°C ambient temperature 900 W/m2 direct normal radiation

160°C inflow temperature Azimuth angle 90°

180°C outflow temperature Zenith angle 30°

Figure 2.8: Reference conditions (Industrial Solar linear Fresnel collector LF-11 Data Sheet)

Due to these conditions the efficiency of the system describe as shown in Figure (2.9):

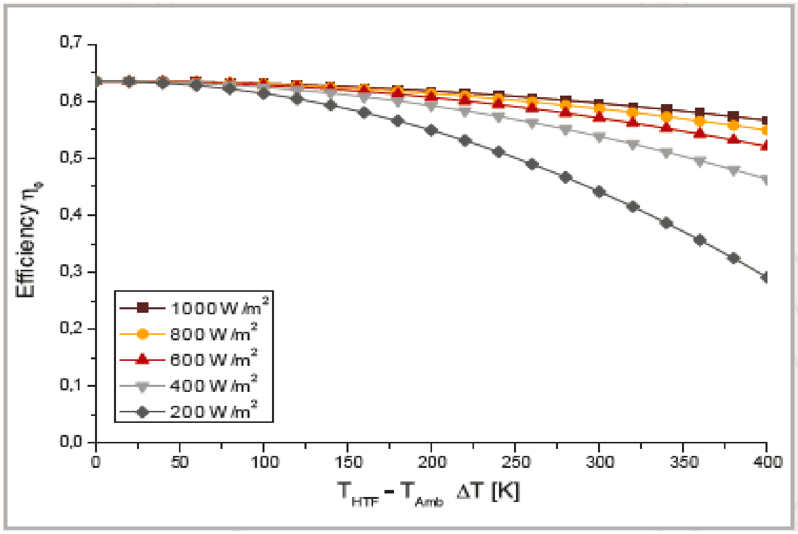


Figure 2.9: (Characteristic collector curve) (Industrial Solar linear Fresnel collector LF-11 Datasheet)

## 2.3. Conclusion

Palestine is a country blessed with the high amount of solar projection throughout the year, Palestine is a small country that can exploit this advantage in reducing the cost of importing energy through exploitation the solar radiation by using the solar collectors systems, that will reduce the amount of emissions and the cost of the imported fuels that used in industrial sectors, electric production and homes boiling systems.

Every System of the solar collectors systems has advantage and disadvantage depends on the cost and the performance, the most efficiency system is the parabolic but it has a high construction cost and a high maintenance cost.

Linear Fresnel collector is good choice to be applied in Palestine because of the site of Palestine and the high range of sun hours per year and a good solar radiation amount so it doesn't need to have a controller to track the sun rays, the Fresnel solar collector system can be used for generating process heat in the range of 100 kW to 10 MW at pressures up to 120 bar (standard 40 bar) and temperatures up to 400°C.

The Flat plate collectors used for low range of Temperature that cant used for industrial sectors, So the best choice for medium cost range and good efficiency is the linear Fresnel collectors.

# 3. Fundamentals

The basic Fundamentals of solar energy which it is the solar geometry and solar thermal technologies and solar process heat and how it will make the sun radiation a variable value every hour and it will determine by identified all these Fundamentals also the sun position angle will be the main factor to know how much the performance of the solar collectors.

## 3.1. Solar Geometry

The sun provides FREE solar radiation and heat for our environment. The earth travels in an elliptical path around the sun, The number of hours of sunlight we receive each day is a product of both the incline of the axis of the earth, at 23.5 degrees from the perpendicular, and it position relative to the sun on its yearly rotation. The winter solstice for the northern hemisphere occurs about December 22, as at that time the sun is directly overhead at noon in latitude 23.5 degrees South (the Tropic of Capricorn). The summer solstice occurs about June 22 when the sun is directly overhead at noon at latitude 23.5 degrees North (the Tropic of Cancer).ds

### 3.1.1. Lines of Latitude and Longitude

**-Latitude**

Lines of latitude measure north-south position between the poles. The equator is define as 0 degrees, the North Pole is 90 degrees north, and the South Pole is 90 degrees south. Lines of latitude are all parallel to each other, thus they are often referred to as parallels. One degree of latitude is 60 nautical miles, 69 statute miles or 111 km. One minute of latitude is 1 nautical mile, 1.15 statute miles, or 1.85 km.

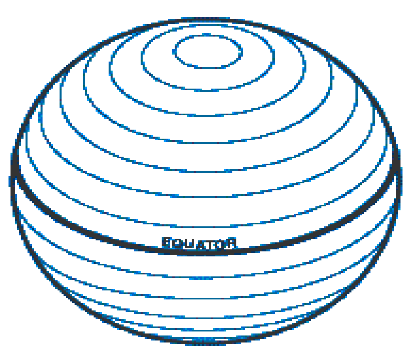


Figure 3.1: Lines of latitude (maptools)

**-Longitude**

Lines of longitude, or meridians, run between the North and South Poles. They measure east-west position. The prime meridian is assigned the value of 0 degrees, and runs through Greenwich, England. Meridians to the west of the prime meridian are measured in degrees west and likewise those to the east of the prime meridian are measured to by their number of degrees east.

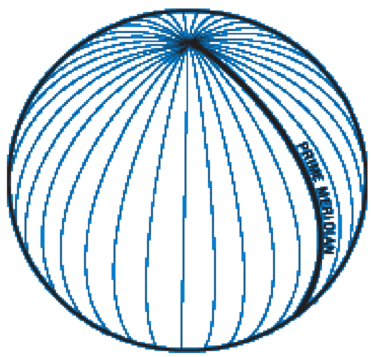


Figure 3.2: Lines of longitude (maptools)

### 3.1.2. Angles

Besides the three basic **angles** (latitude, **hour angle**, and sun's declination).

Several other **angles** are useful in **solar radiation** calculations. Such **angles** include the sun's zenith **angle** θH, altitude **angle** β, and azimuth **angle** φ.

**-Hour angle**

The hour angle, ω, is the angular distance between the meridian of the observer and the meridian whose plane contains the sun. Thus, the hour angle is zero at local noon (when the sun reaches its highest point in the sky). At this time the sun is said to be ‘due south’ (or ‘due north’, in the Southern Hemisphere) since the meridian plane of the observer contains the sun. The hour angle increases by 15 degrees every hour.

So to calculate the hour angle we know that every one hour equal 15 degrees so, the hour angle measures time after solar noon in terms of one degree for every four minutes and the equation will be like following:-

| | |
|---|---|
| $Hour\ angle\ =\ 15 * (hr_{hr0})$ | (1) |

Where hr0: hour of solar noon (equal to 12.00) as sown in Figure (3.3):

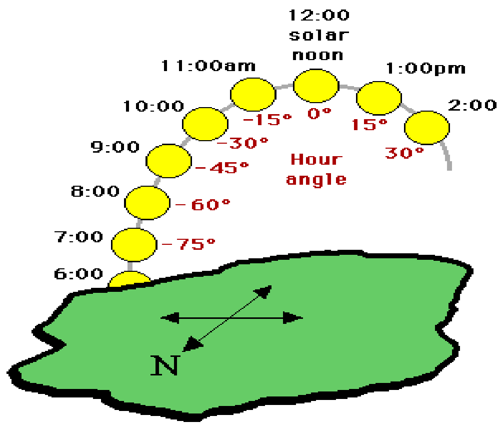


Figure 3.3: Hour angle distribution (sustainable_by_design_sunangle)

**-Declination angle**

The declination of the Sun in Figure (3.4) and Figure (3.5), δ⊙ is the angle between the rays of the Sun and the plane of the Earth's equator. The Earth's axial tilt (called the obliquity of the ecliptic by astronomers) is the angle between the Earth's axis and a line perpendicular to the Earth's orbit.

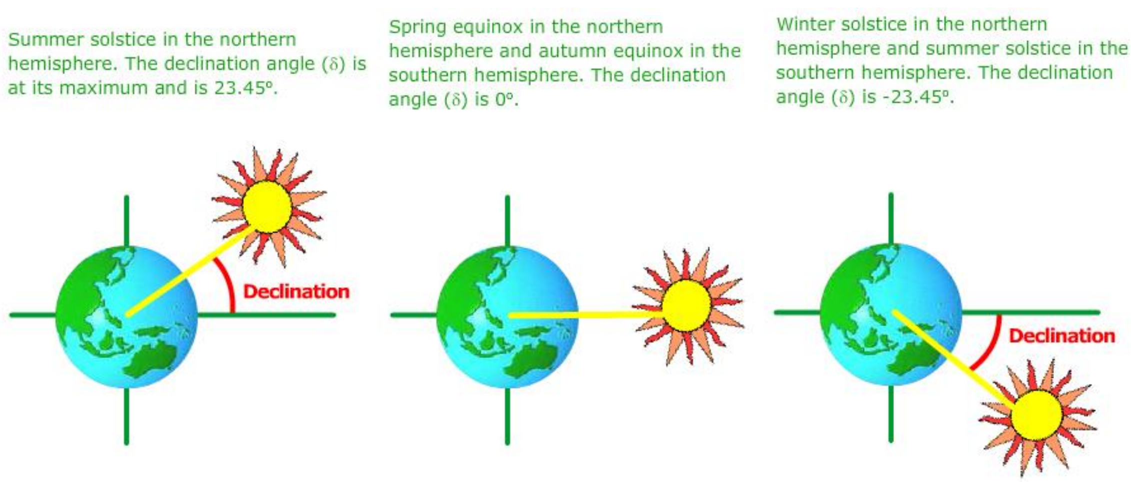


Figure 3.4: The declination angle (-23.45, 0, 23.45) (pveducation/declination-angle)

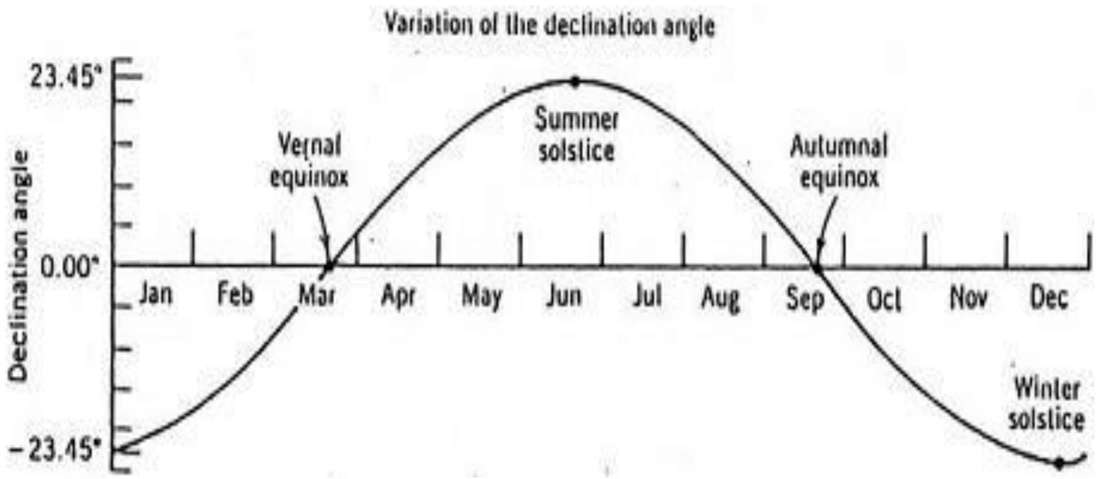

Figure 3.5: Annual variation of sun declination angle (Kalogirou, 2009)

The declination angle can be calculated by following equation:

$$\delta = -23.45° \times \text{Cos}\left(\left(\frac{360}{365}\right) \times (\text{d} + 10)\right) \quad (2)$$

The declination angle can also be defined in other ways. The equations:

$$\delta = 23.45° \times Sin\left(\left(\frac{360}{365}\right) \times (d + 284)\right) \quad (3)$$

$$\delta = 23.45° \times Sin\left(\left(\frac{360}{365}\right) \times (d - 81)\right) \quad (4)$$

**-Altitude angle**

The altitude angle is the vertical angle between the sun and the wall section. It is always measured with respect to an imaginary line, running perpendicular to the wall. The altitude angle (sometimes referred to as the "solar elevation angle") describes how high the sun appears in the sky. The angle is measured between an imaginary line between the observer and the sun and the horizontal plane the observer is standing on. The altitude angle is negative when the sun drops below the horizon. In this graphic, replace "N" with "S" for observers in the Southern Hemisphere.

The altitude angle is calculated as follows:

$$\sin(Al) = [\cos(L) * \cos(D) * \cos(H)] + [\sin(L) * \sin(D)] \quad (5)$$

Al = Solar altitude angle

L = Latitude (negative for Southern Hemisphere)

D = Declination (negative for Southern Hemisphere)

H = Hour angle

**At the Summer Solstice**

For the Summer Solstice the sun will be above the horizon for the longest period of time in the northern hemisphere, unlike at the southern hemisphere also at the northern hemisphere will have the longest day for daylight there.

**At the winter Solstice**

For the solstice The Sun shines down most directly on the tropic of Capricorn in the southern hemisphere on the occasion of the winter solstice. In fact, the Sun remains below the horizon everywhere within the Arctic Circle on this day.

**-The azimuth angle**

The azimuth angle Figure (3.6) is the horizontal angle at which the sun's rays are falling on a wall. It is always measured from with respect to due south. Thus it is always given as east of south or west of south. The solar azimuth angle is the angular distance between due South and the projection of the line of sight to the sun on the ground. A positive solar azimuth angle indicates a position East of South, and a negative azimuth angle indicates West of South. Note that in this calculation, Southern Hemisphere observers will compute azimuth angles around +/- 180 degrees near noon.

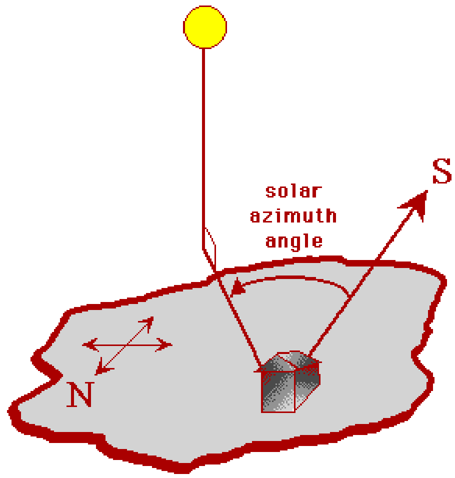


Figure 3.6: Solar azimuth angle (solarbasic)

The azimuth angle is calculated as follows:

$$\cos(Az) = \frac{(\sin(Al) * \sin(L) - \sin(D))}{(\cos(Al) * \cos(L))} \qquad (6)$$

L = Latitude (negative for Southern Hemisphere)

Az = Solar azimuth angle

D = Declination (negative for Southern Hemisphere)

Al = Solar altitude angle

The sign of the azimuth angle also needs to be made equal to the sign of the hour angle when using the above equation.

### 3.2. Sun Path

Sun path refers to the apparent hourly and seasonal motion of the Sun across the sky (and the length of daylight) as the Earth rotates and orbits the Sun. The relative position of the Sun is a major factor in the heat gain of buildings and in the performance of solar energy systems.[1] Accurate location-specific knowledge of sun path and climatic conditions is essential for economic decisions about solar collector area, orientation, landscaping, summer shading, and the cost-effective use of solar trackers.

### 3.2.1. Sun Position

The Earth's rotation about its axis causes the fixed stars to move in the sky in a way that depends on the observer's geographic latitude. The time when a given fixed star crosses the observer's meridian depends on the geographic longitude. To find the Sun's position for a given observer at a given time.

### 3.2.2. The Sun

The Sun is the ball of fire in the sky that the Earth goes round, and that gives us heat and light. And it is the center of our solar system and it is a gaseous body having a highly compressed core, which the Sun's mass consists of hydrogen (~73%), and the rest is mostly helium (~25%), in which energy is generated by thermonuclear reactions (at about 15 million kelvins) .

## 3.3. Solar Radiation

The radiation, or energy we get from the sun. In which it is the most important source of energy for life on Earth. It is also known as short-wave radiation.

Or it is the intensity of radiation from the spherical black body, whose temperature is 5785K and diameter is 696,106 m, per square meter on a spherical surface whose radius is 150,109m and with the Sun placed at its center.

Solar radiation comes in many forms, such as visible light, radio waves, heat (infrared), x-rays, and ultraviolet rays. Measurements for solar radiation are higher on clear, sunny day and usually low on cloudy days. Figure (3.7) shows the average sun radiation in Palestine and surrounding region.

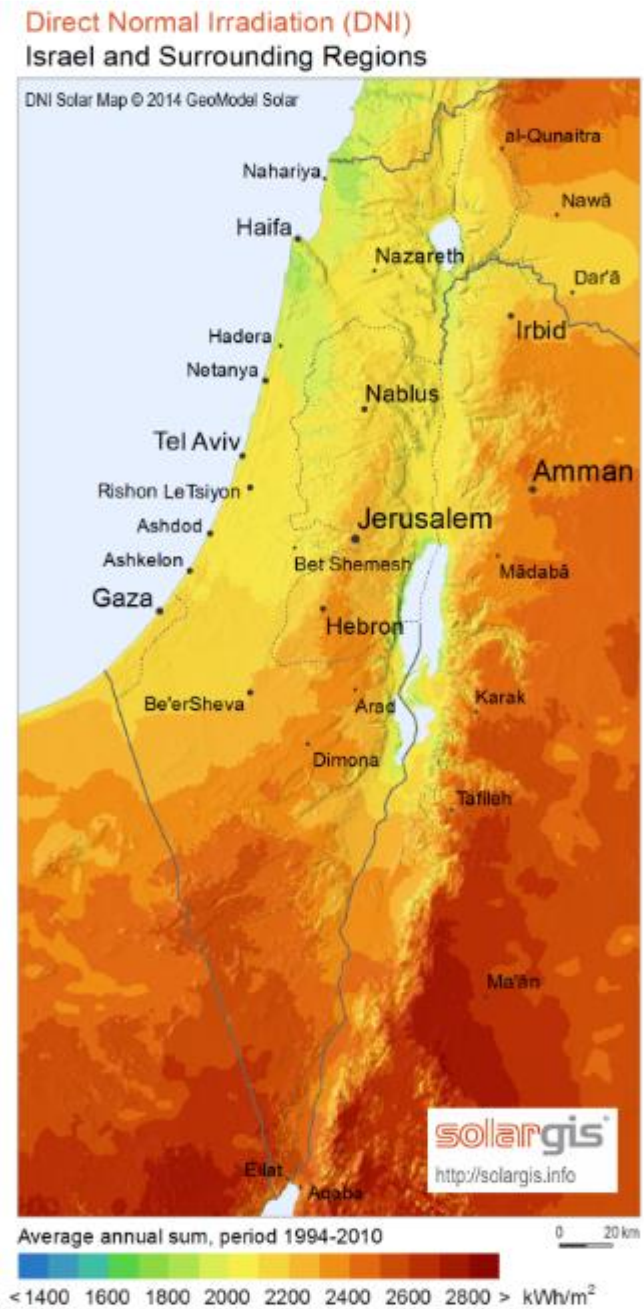


Figure 3.7: Direct Normal irradiation in Palestine (solargis)

### 3.3.1. Solar Radiation Measurements

The amount of solar radiation in the atmosphere would be less than the amount that reaches the ground and the solar radiation divided for tow specific types and from them we can find how much the amount of solar 1radiation that reaches the ground:

- Direct radiation: radiation from the sun that reaches the earth without scattering or wasting in sky and in the clouds.
- Diffuse radiation: Solar rays reaching the ground after a change in direction by particles in the atmosphere.
- Global radiation: is of the sum of the direct and the diffuse solar radiation.

Which the global radiation equal the direct radiation plus the diffuse radiation so the equation of global radiation is:

$$Globaltot = Dir(tot) + Dif(tot)$$

Where:

Global (tot): the total global radiation

Dir (tot): the total direct radiation

Dif (tot): the total diffuse radiation

### 3.3.2. Solar Radiation Measurements

Experimental determination of the energy transferred to a surface by solar radiation requires instruments that will measure the heating effect of direct solar radiation and diffuse solar radiation. There are two general classes of solar radiation measuring devices. The instrument used to measure direct normal or beam radiation is referred to as a pyrheliometer (Figure 3.8). The other instrument, called a pyranometer, is able to measure total radiation within its hemispherical field of view. A pyranometer can also be used to measure diffuse radiation alone by shading the sensing element from the sun's direct rays.

Figure 3.8: The Pyrheliometer (db_pyrheliometer_e)

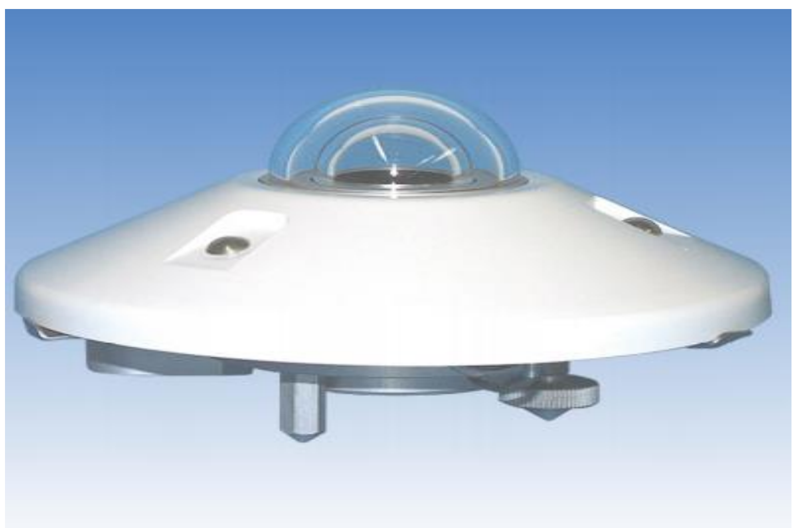

Figure 3.9: The Pyrometer (Kipp_Zonen_cm21_pyranometer)

### 3.4. Case Study

This section shows the technical assessments for covering 20 % of "Royal" thermal consumption which suits the extrusion machine demand in the plastic processing. "Royal" company which located in Hebron south of west bank as shown in Figure (3.10) below (maps, 2017)


Figure 3.10: Palestine map (maps, 2017)

#### 3.4.1. Technical Used

From the data sheet of Solar Linear Fresnel Collector LF-11 the efficiency of the system is about 63.5% and produce 12.3 KW for every module.

The Figure (3.11) show the efficiency of the system in Hebron the curve is affected by the change of the ambient temperature and the normal direct radiation in several days of amount on winter 2016.

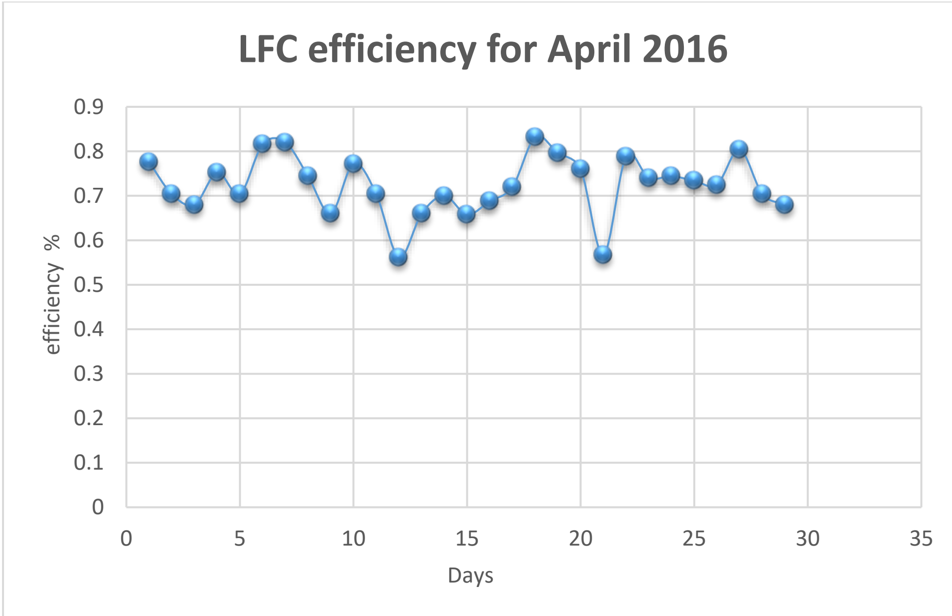


Figure 3.11: LFC system efficiency

As shown the Average efficiency of the system is about 75% which is higher than the standard efficiency of the manufactured parameters, for these data the system is expected to produce 14.5 Kw per standard module.

For the case study, the total power consumption is 540 MW every month as shown in Figure (3.12):

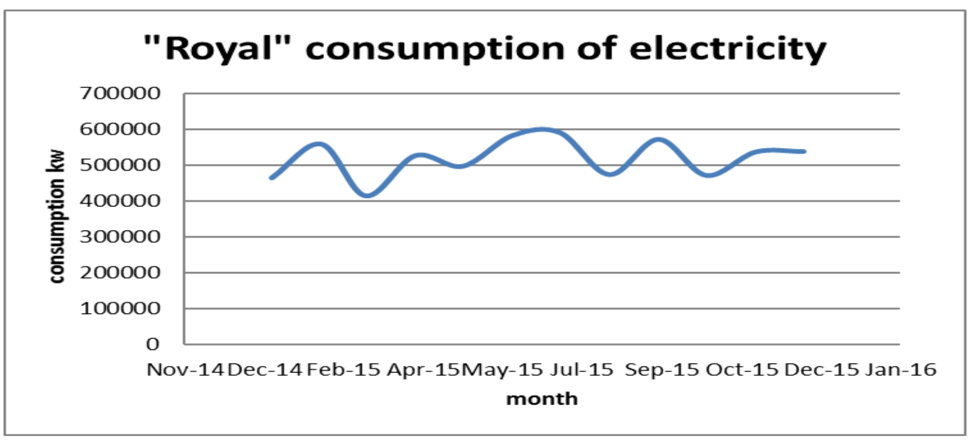


Figure 3.12: “Royal” factory Power consumption (Hebron municipality)

The factory consume 18 Mw in each day the total thermal power consumption of these amount is about 60%, which it's about 10.8 Mw every day, the LFC design consider to cover 20% of the thermal power about 2160 Kw, this 20% is about 12% of the total energy consumption in "Royal" the consumption is consider to be the consumption of an extrusion machine.

The minimum required number of modules to cover the 20% of the thermal consumption:

$$\#\text{ of modules} = \frac{\text{thermal power requered to cover in the project}}{\text{LFC thermal output}} = \frac{2160\text{ Kwh}}{145\text{ Kwh}}$$
$$= 15\text{ module}$$

For a safety factor 1.5 used, about 1080 Kwh the system need more 7 modules, so the total number of modules for the system is 22 module.

From the standard specifications of the LFC system shown in Table (3.1):

Table 3.1: General Data (Technical Data Industrial Solar linear Fresnel collector LF-11)

**General data of the basic module**

| | |
|---|---|
| Module width | 7.5 m |
| Module length | 4.06 m |
| Aperture surface of primary reflectors | 22 $m^2$ |
| Receiver height above primary reflector | 4.0 m |
| Height of primary reflector above ground level | 0.5 m |
| Recommended minimum clearance between parallel rows | 0-0.5 m |
| Specific weight (related to installation surface area) | 27 $kg/m^2$ |
| Maximum operational wind speed | 100 km/h |
| Maximum wind speed stowed | 180 km/h |
| Life expectancy | +20 years |

A 22 module required this area dimensions as shown in Figure (3.12) and Table 3.2:

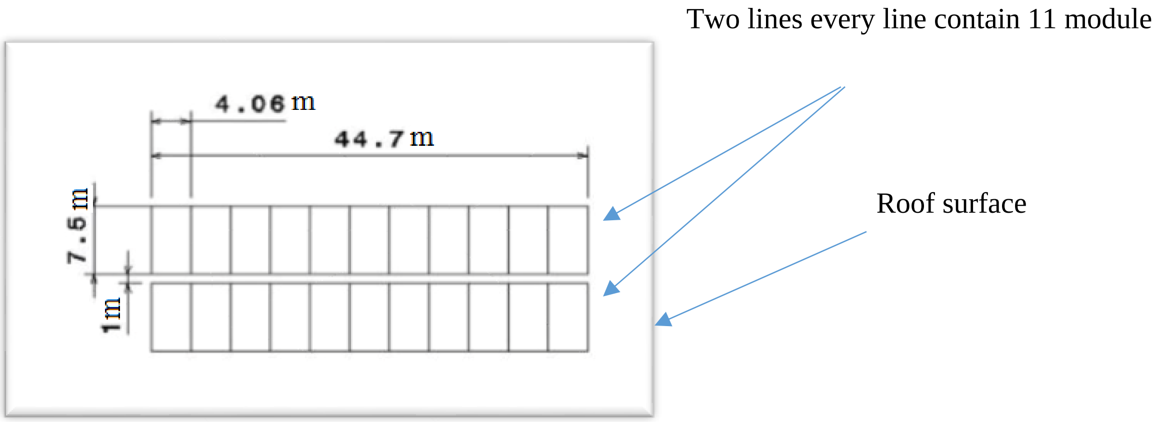


Figure 3.13: Modules distribution on the roof

Table 3.2: System Dimension

| | |
|---|---|
| Row length | 44.7 m |
| Row Width | 7.5 m |
| System Height | 4.5 m |
| Space between the two rows | 1 m |
| Total Area | 715.2 m^2 |

The system will produce 3190 Kwh of thermal power at an average ambient temperature of 25 C and an 1800 Kwh/m^2.

For the 10 hours' work of the system in the factory every day an average of 31.9 M joule of thermal energy will be produced from the system and it will be the output of the solar collector system.

### 3.5. Extrusion Machines

Extrusion is widely used in various industries. In this experiment, we investigate plastic extrusion by the screw extruder shown in Figure (3.13).Such extruders are most common in plastic industry as in “Royal factory”. In this extruder the screw rotates and develops sufficient pressure to force the material to move forward, while the material is being heated to become in a liquid phase by using multiple heaters, which works on electrical power, then it goes through a die and produce products with desired shape.

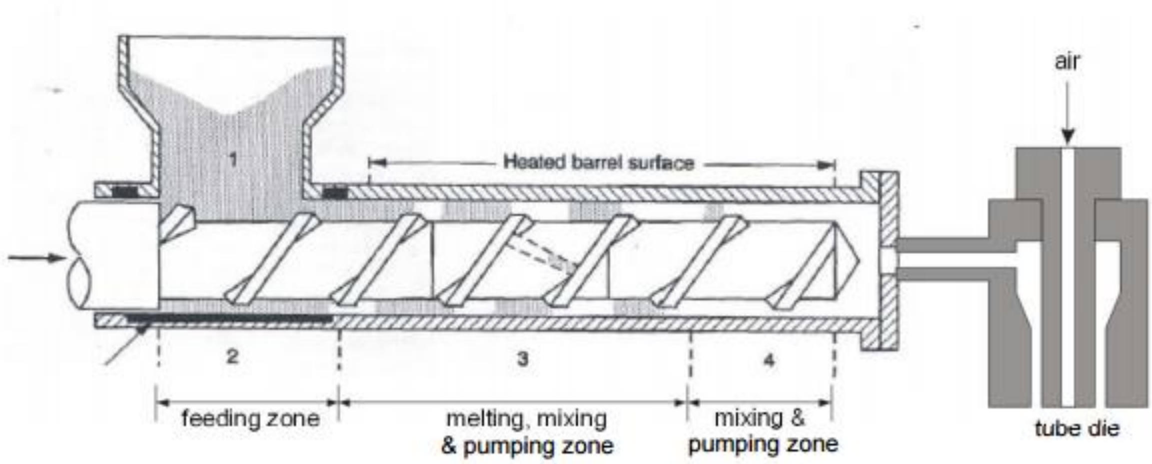


Figure 3.14: Extrusion Machines (Polymer Extrusion)

### 3.5.1. Parts of Plastic Extrusion Machines

Plastics engineers use plastic extrusion machines to turn raw plastic granules or pellets into processed forms. Extrusion machines are optimal for creating plastic sheets, or long pieces like pipes and gutters. Plastic extrusion machines process at high volumes with little post-processing refinement.

- Hopper

The hopper is a large funnel that holds the raw plastic in either granular or pellet form. The hopper sends a continuous stream of raw plastic by using a screw which rotates and develops sufficient pressure to force the material into the heating barrel of the extrusion machine. It works between stages 1-4.

- Heated Barrel

The heated barrel of a plastic extrusion machine is a long, horizontal cylinder. The cylinder is heated internally through the use of a heating jacket. As the plastic is fed into the cylinder by the hopper, the plastic melts from the heat. A helical screw down the center of the cylinder rotates and pulls the molten plastic down its length. It works between stages 3-4.

➢ Die and Mandrel

An air-cooled die which is located at the end of the heated barrel. Which can be replaced to fit the desired output shape and design. The intended shape of the plastic is cut into the die. Air passes along the metal die to cool the plastic as it passes and harden it into shape. A mandrel may also be located after the die to produce a hollow shape.

### 3.5.2. The Design of Heaters

The design will contain a tank and pipes and three heaters will replace the electric heater used in the extrusion machine as shown in the Figure (3.15).

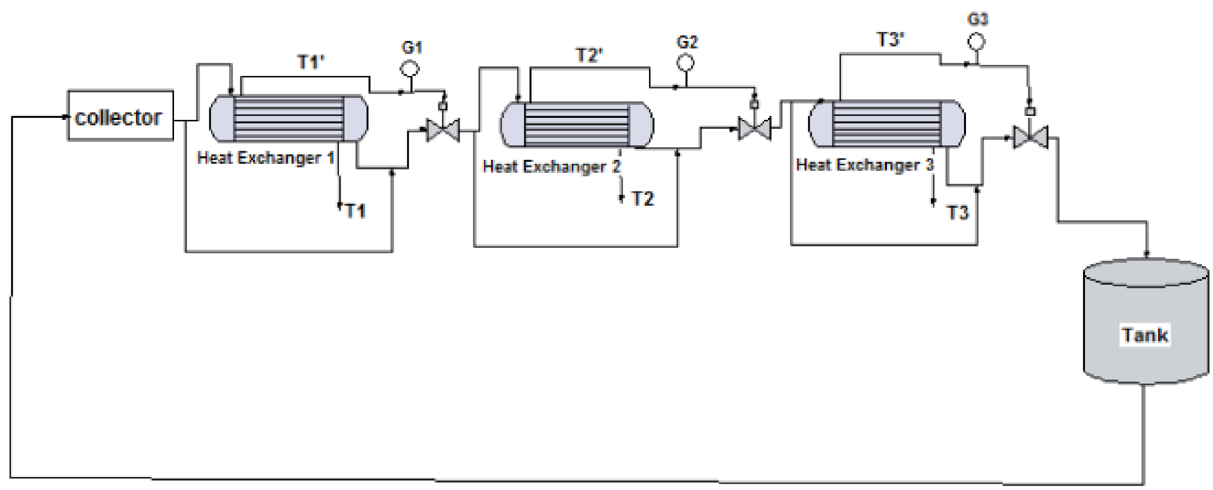


Figure 3.15: Heat Exchangers Design

### 3.5.3. The Feasibility Study

The feasibility study of the project will be focused on the cost of the parts and building the system, the period to recover the value of the project and if the project will be successful or not.

The feasibility study will be calculated by special software (system adviser model) and (homer).

# 4. System Modeling and Design

The main Problem in Solar power systems is to estimate the suitable size of the components and the most efficient parameters in each component. This chapter shows the components of the parabolic trough, Flat Plate and Linear Systems using TRANSYS simulation program with a Comparison between these systems to choose the suitable one for the project objective.

## 4.1. System Structure

The system structure is always a deficient copy of the real system which used to understand the system developing and how the real system work. It's clear that there's no such a unique way to make a system structure, Figure 4.1 below represents the TRANSYS system structure by follow the arrows and the block shows the main components of the project that build by the TRANSYS.

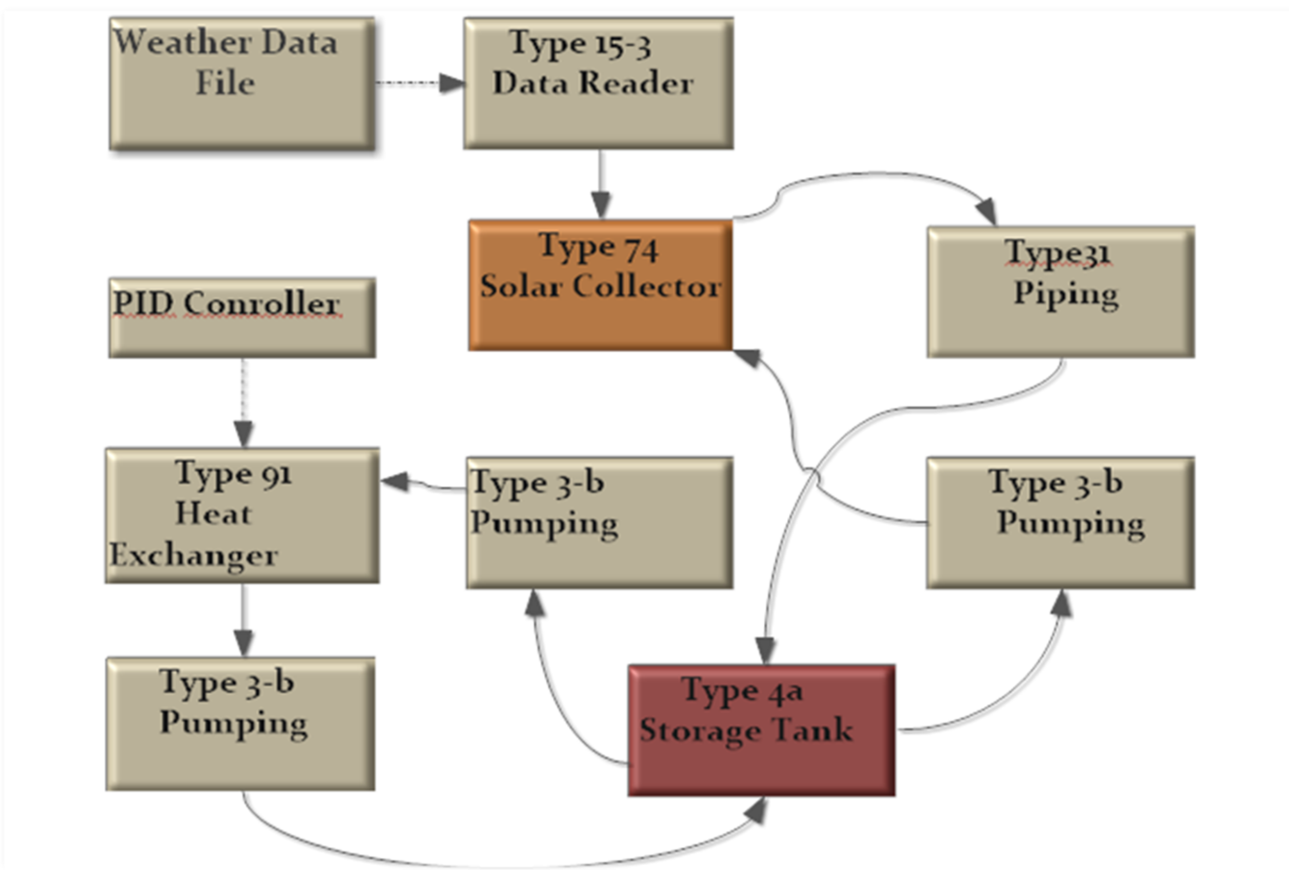


Figure 4.1: System Structure

## 4.2. System Simulation

The meteorological year of Palestine has been used to simulate the Parabolic and the Flat plate Solar systems in TRANSYS Program. The meteorological Year Contains the climate information like the sun radiation and the ambient temperature for a specific location, it represents the weather data from the hourly measurements in the meteorological stations.

As a purpose for this study the composition of the collector system should be simulated as shown in figure 4.2 below(Solar collector System in TRANSYS) The Molten Salt flows through the pipes from the Solar collector to the storage tank then using the pump the fluid flows through the flow divider values to the zero capacitance sensible heat exchangers. The fluid returns to the cold side of the storage tank using pumps, to complete the closed fluid cycle the pumps return it to the other side of the collector. The pumps are timely controlled and a PID controller controls the temperatures of the heat exchangers.

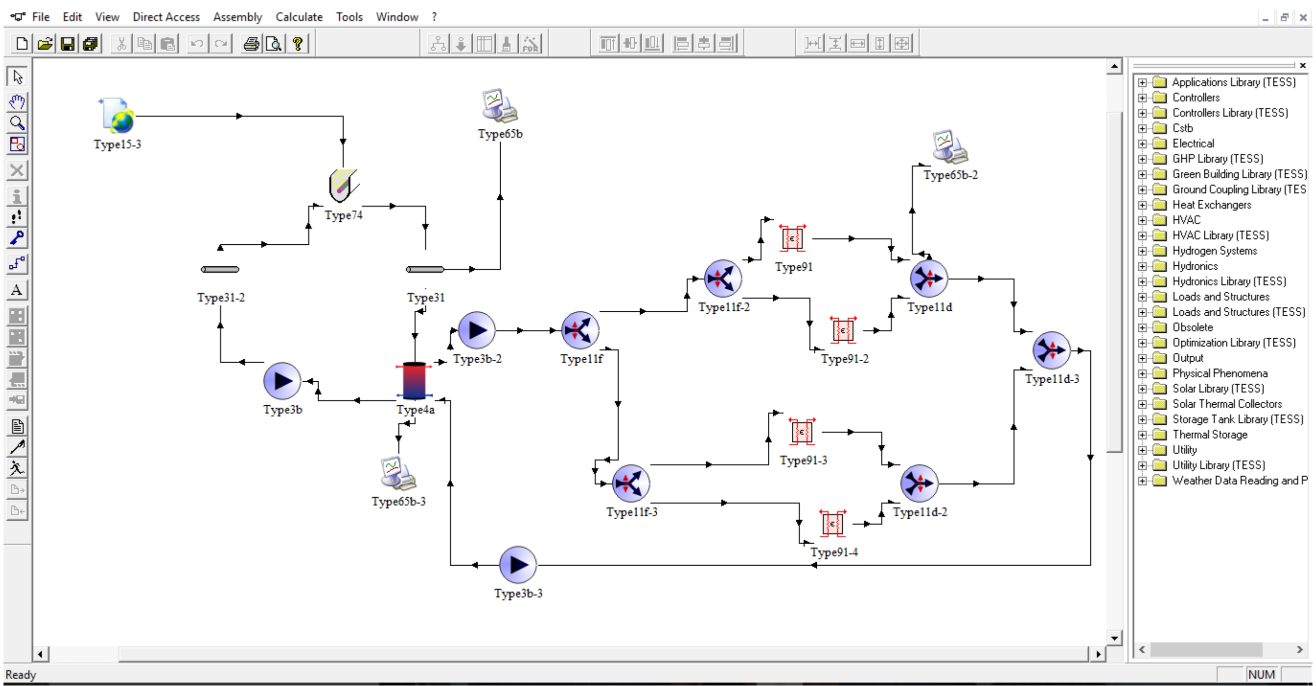


Figure 4.2: Solar collector System in TRANSYS

Table 4.1: TRANSYS structure types regarding the project represents the types and components used in the system simulation.

Table 4.1: TRANSYS Types

| Type | Description |
|---|---|
| **Type 15-3** | Weather Data Reader |
| **Type 74** | Solar Collector |
| **Type 31** | Pipes |
| **Type 3b** | Hydraulic Pump |
| **Type 4a** | Storage Tank |
| **Type 11f** | Flow Divider Valve |
| **Type 65b** | Output Data Device |
| **Type 11d** | Duct Tee |
| **Type 91** | Heat Exchanger |

TRNSYS is an extremely flexible graphically based software environment used to simulate the behavior of transient systems. While the vast majority of simulations are focused on assessing the performance of thermal and electrical energy systems, TRNSYS can equally well be used to model other dynamic systems such as traffic flow, or biological processes. The arrows in the TRANSYS system simulation represents the direction of information’s in the output Data Devices and the liquid direction in the Collector, pipes, flow Valves and pumps and every type shown in the table 4.1 represent the components of the project that used in the simulation program TRANSYS and shown in figure 4.2 .

### 4.3. Simulation Results

In TRANSYS simulations every component of the project required some parameters to give results for the Parabolic trough System and Flat plate and these main parameters is shown in the table 4.2 and the simulation done for two situations: firstly with four heat exchangers connected in series and secondly connected in parallel. In order to reach the best performance of the system many runs are carried out by changing the parameters that affects the efficiencies of the collector. By changing the flow rates, pipe types, the storage tank size and the system fluid.

Table 4.2: The system parameters best values

| Parameter | Type/ value |
|---|---|
| Collector Inlet flow rate | 100 kg/hr |
| Kind of Fluid “specific heat” | 1.56 kJ/Kg.k |
| Pipes Diameters | 75 mm |
| Storage Tank size | 25 $m^3$ |
| Heat Exchangers flow rate | 2000 Kg/hr |
| Storage Tank Flow rate | 100 Kg/hr |

The net energy which equals the useful energy that collected from the collector and the losses from the tank to the surrounding area increases by increasing the collector flow rate which depends on the collector outlet temperature, so the energy is low with low flow rates because the energy in the collectors doesn’t used effectively as the temperature produced. By comparing the useful energy collected from the collector and the relieved energy the optimum size of the tank is to be 25 $m^3$. This also agrees with other types of collectors like the Flat Plate one.

The results recorded for the most efficient month which is July and January the less one , the graphs below represents the Temperatures in degrees Celsius for the Parabolic collector and flat plat on the collector output, the heat exchangers once connected in series and the other one in parallel and the tank cold side. The useful energy from the collectors represented in figure in term of (kj/hr).

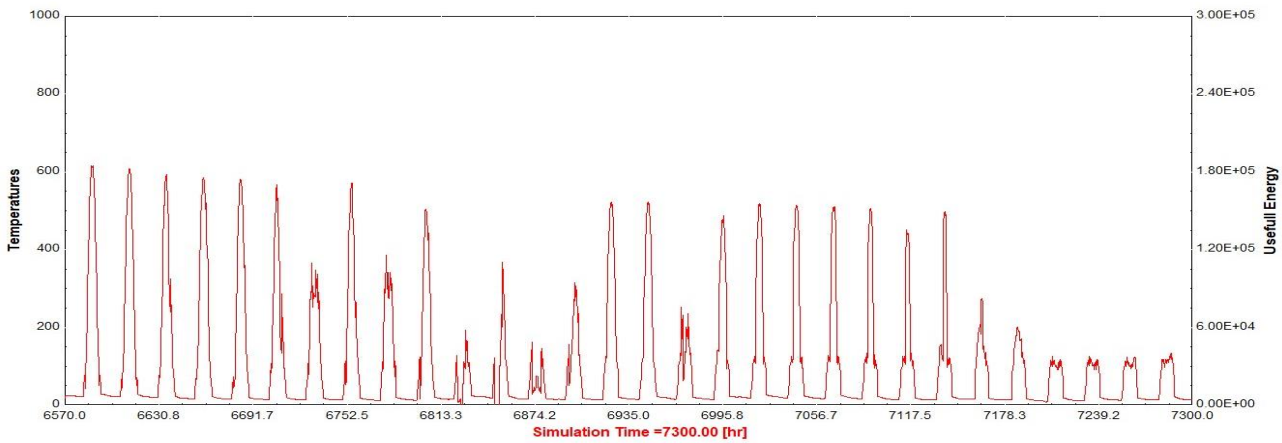


Figure 4.3: Parabolic trough outlet temperatures (celsius) in January

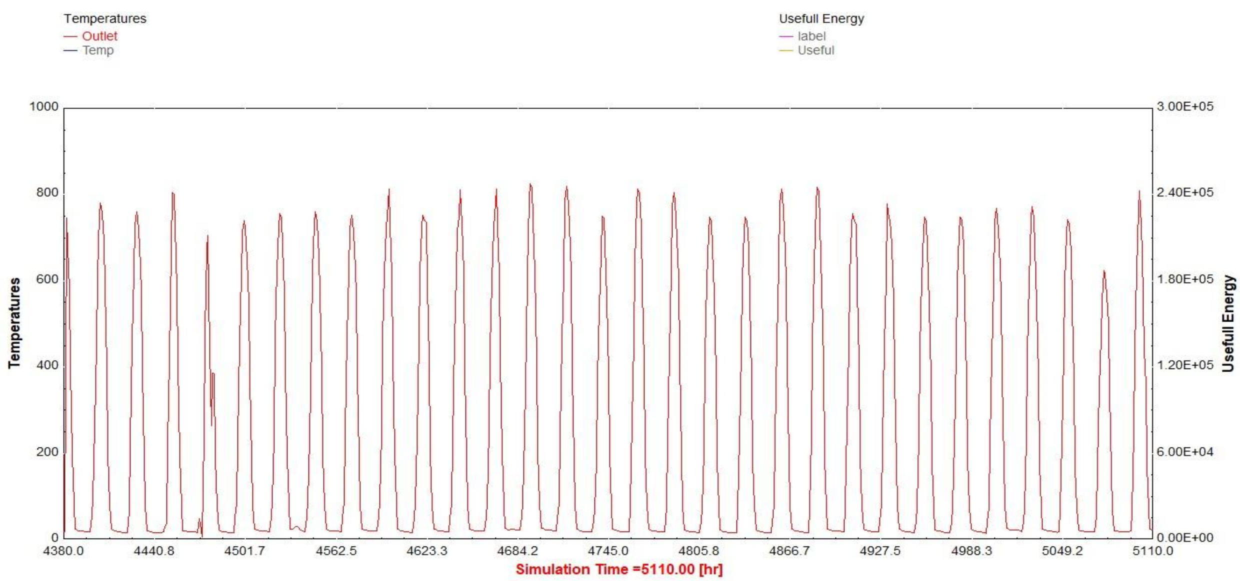


Figure 4.4: Parabolic trough temperatures (celsius) in July

From the figures above it’s clear that July is more efficient than January due to less hours of sunshine efficient over the year. The collector temperatures at the working hours is more than expected which make the parabolic trough a good choice beside the linear Fresnel collector which is chosen for this study.  Figure 4.5 and 4.6 on the next page show the useful energy gained from the collector.

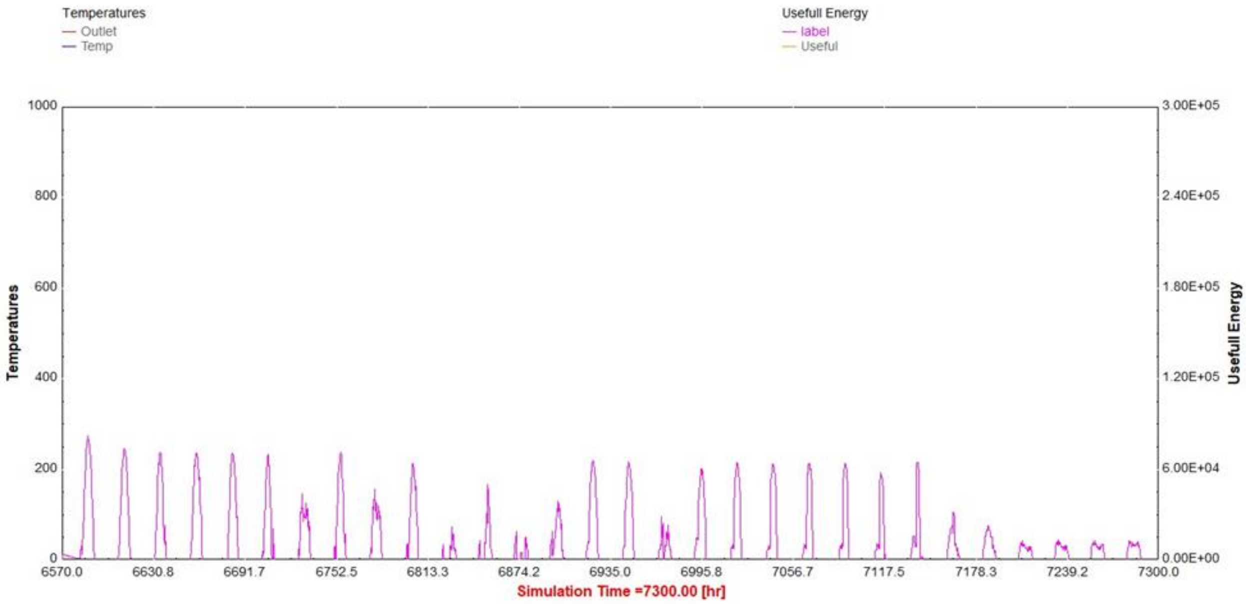


Figure 4.5: Collector Useful Energy (kJ/h) in January

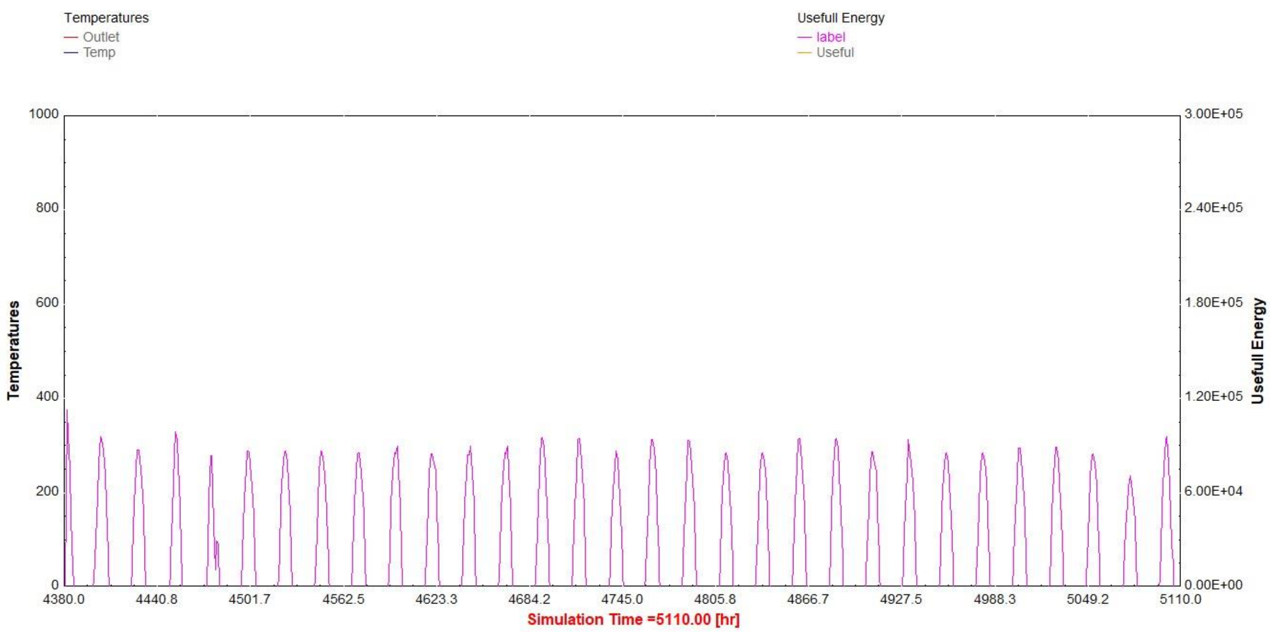


Figure 4.6: Collector Useful Energy (kJ/h) in July

The Figures above shows how the useful energy changes with time.

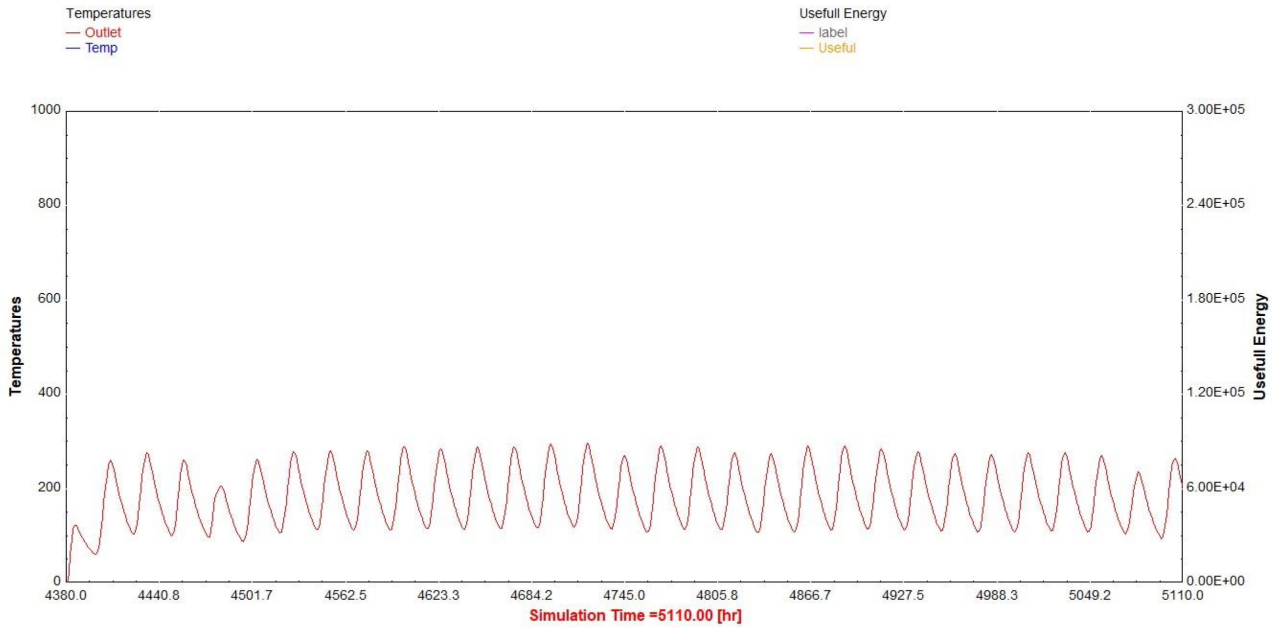


Figure 4.7: Heat Exchangers Tempreatures (celsius) in Series

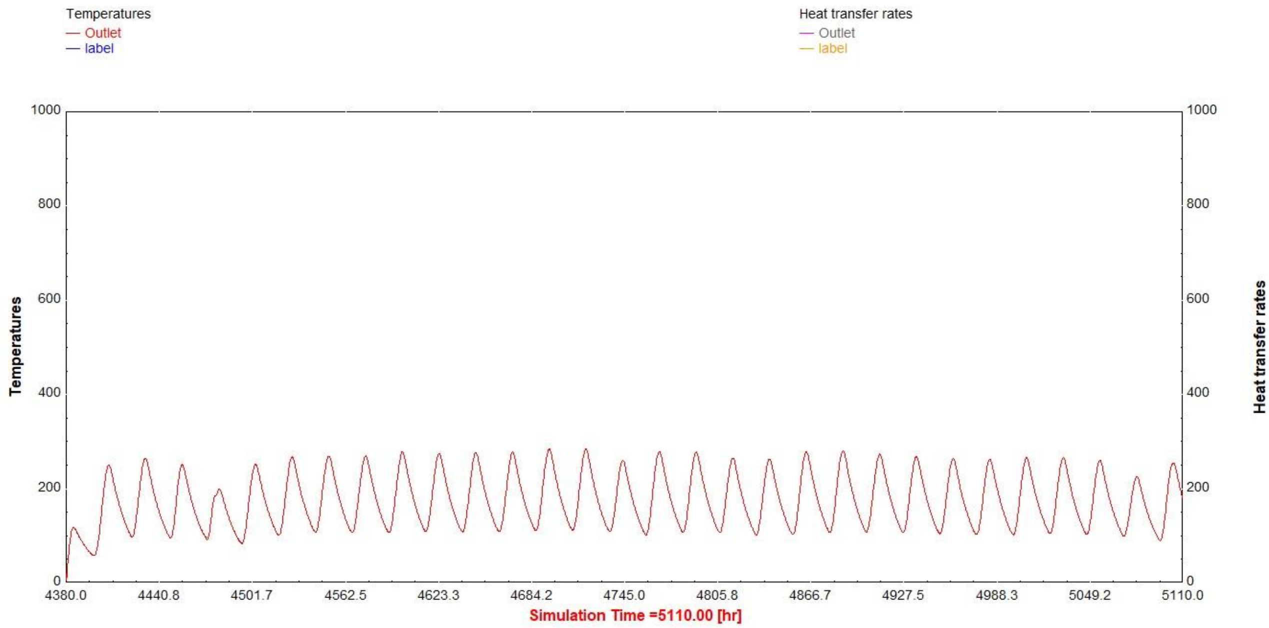


Figure 4.8: Heat Exchangers Temperatures (Celsius) in Parallel

The figures represents the heat exchangers temperature which about 200 C the working temperature.

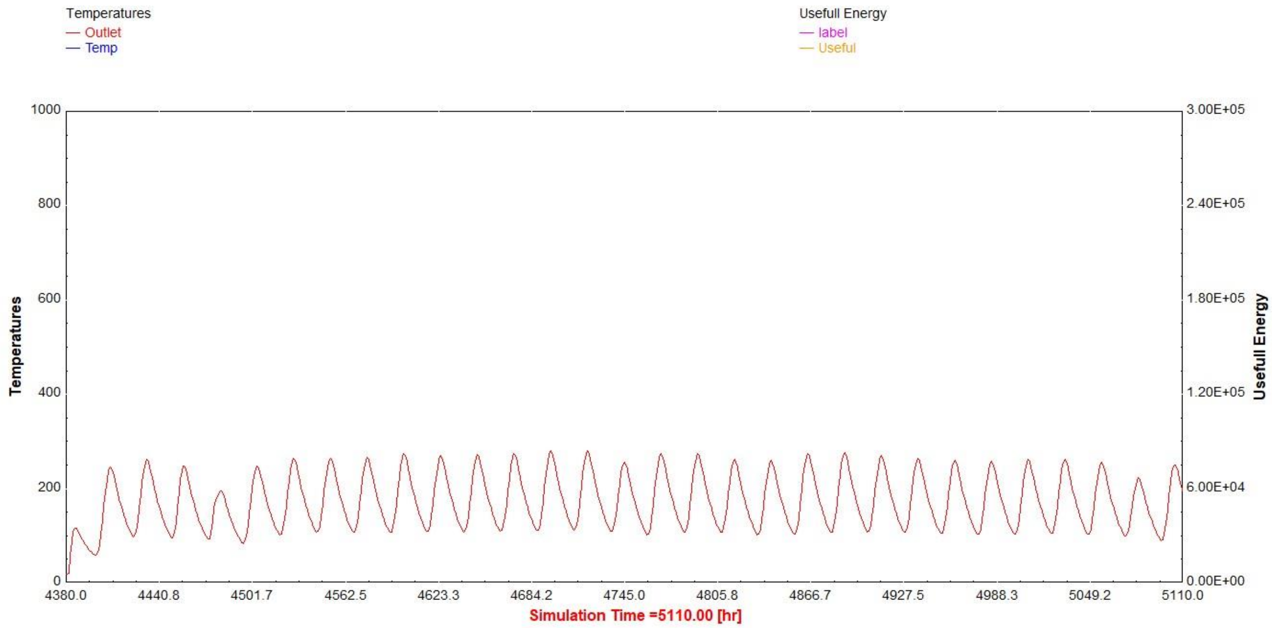


Figure 4.9: Flat Plate collector Temperatures (Celsius) in January

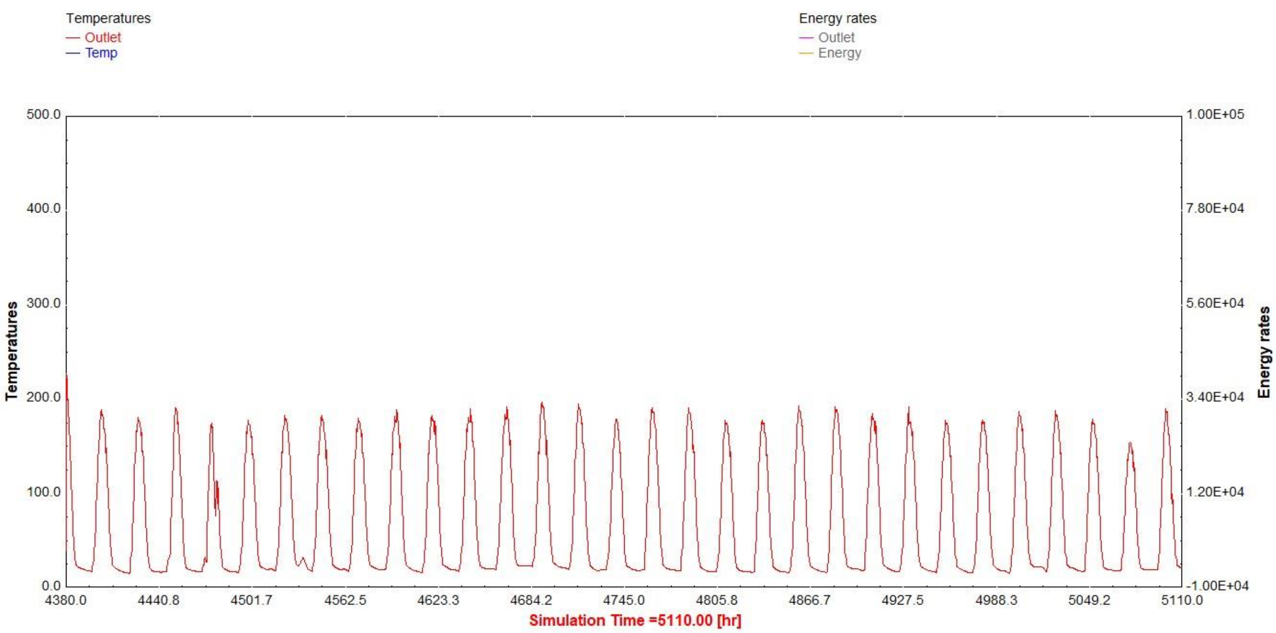


Figure 4.10: Flat plate Temperatures (Celsius) in July

Figure 4.9 and 4.10 Shows the Flat Plate temperatures which has been simulated for comparison with the other type.

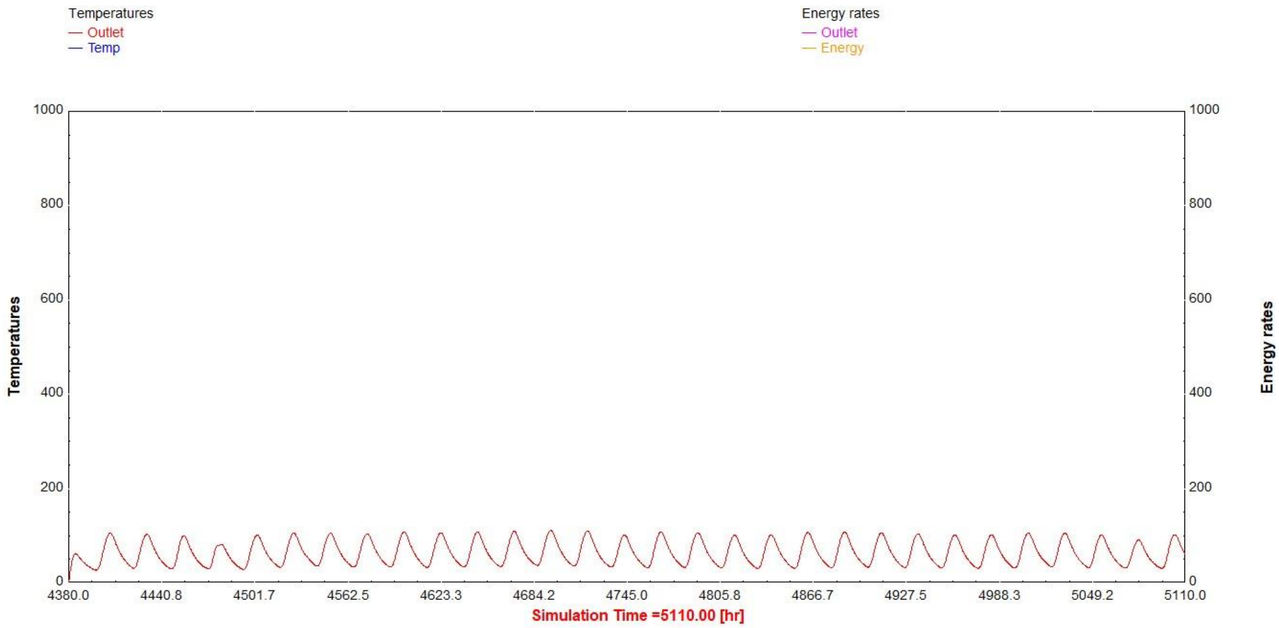


Figure 4.11: Flate Plate Heat Exchangers Tempratures in celsius

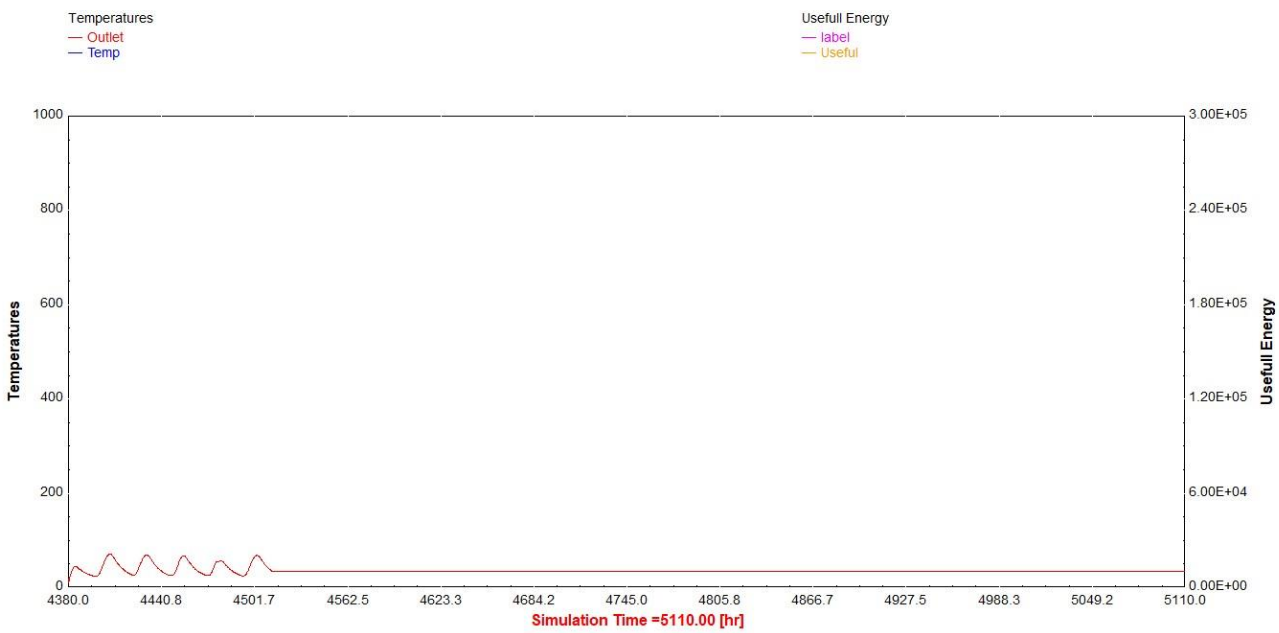


Figure 4.12: Flat Plate Tank Temperatures in celsius

From the figures above the Flat Plate temperature doesn’t met with the project objective.

To summarize the simulation figures shows that the parabolic trough is the appropriate collector type for the project problem which is very closely to the linear Fresnel collector the project choice. In order to determine the effectiveness of using these systems the simulation results represents that the flat plate temperature is around 200 C so it doesn't fit with the project and it has a low temperature on the heat exchangers. Parabolic trough simulation figures represents that the system is suitable for the project ion the company working hours (8:00 am to 15:00 pm) with an excellent temperature on the heat exchangers which controlled using a PID controller. Knowing that the load temperature is around 200 C.

## 4.4. Conclusion

From the simulation it's clear that the Parabolic Trough collector and the Linear Fresnel have a high efficiency for the situation of Palestine through the year which supports the project idea, The Parabolic collector output temperature reaches About 600 degree and the flat plate about 250 degree and for this project the temperature of the Linear Fresnel is enough (about 500 Degree).

# 5. Feasibility study

## 5.1. Economical assessment

The total project cost is divided for more than one zone the investment (fixed cost), the operation cost (running),the fixed cost include all solar collectors and the other component such as pipes, heaters, tanks and other component that paid to build the project and make it ready to operates. While the operating costs include the operation and maintenance costs.

The saving electrical energy will be the income of the project which is equivalent to the thermal energy used in the machining at the factory which means that the income depend on the cost of the kWh that been used on the thermal energy.

Many parameters affect the costs and the retain income to this project like the electrical prices growth rate and project capital costs, operation costs .as well as some technical parameters like: project geographical location, DNI, and the technology performance at local conditions. In the economical assessment, some parameters were fixed. Due to focusing on a certain city (Hebron) and a specific solar thermal technology (LFC), some parameters like DNI, the technology performance.

Overall cash flow projection and its analysis is used to obtain Net Present Value (NPV) and Internal Rate of Return (IRR). Furthermore, the Payback period (PBP) as well as the Levelized Cost of Energy (LCOE) are calculated. In the first cost estimation for this Project, investment cost has been analyzed according to current market values as well As actual projects experience form previous Industrial Solar GmbH installations. Table 5.1 summaries the indicators of the financial assessment.

Table 5.1: Financial Assessment variables

| | |
|---|---|
| **%IRR** | **Internal rate of return** |
| **CF** | **Cash flow** |
| **PBP** | **Payback period** |
| **NPV** | **Net present value** |

NPV is the difference between the present value of cash inflows and the present value of cash outflows. NPV compares the value of money today to the value of that same Amount in the future. If the NPV of project is positive, it should be accepted given that there is no other investment with higher NPV.

The IRR is "The discount rate often used in capital budgeting that makes the net present Value of all cash flows from a particular project equal to zero" (Investopedia, 2014). The higher the project's IRR, the more desirable it is to undertake the project. The private sector mostly expects an IRR at least 15%. The payback period is "the length of time required to recover the cost of an investment.

The payback period of a given investment or project is an important determinant of whether to undertake the position or project, as longer payback periods are typically not desirable for investment positions" (Investopedia, 2014). Private sector prefers projects with 2-6 years payback period. Sensitivity analysis has been conducted for Levelized Cost of Energy (LCOE) and the IRR. LCOE is often used as a convenient summary measure of the overall competiveness of different generating technologies. It represents the cost per kWh of erection and operating a generating plant over an assumed financial life. The key inputs to calculate levelized costs include capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs. The LCOE does not count for the interest rate of loans. While the IRR counts for the interest rate and it is considered as a dynamic tool in private sector, to compare between different available alternatives.

### 5.2. System Advisor Model (SAM)

In order to determine the feasibility of the proposed project Excel and System Advisor (SAM).

The SAM program used to determine the Specification of the system from pipes, collector system, storage and the total capital cost of the system.

The SAM take the Radiation and the temperature from a weather file.

#### 5.2.1. The Solar Field

The Heat Transfer Fluid that used in the system is the Hitec Solar Salt that has a min operating temp of 238 C and a max temp of 593 C and the solar field have an automatic mirror washing system to clean the mirrors with a field parameters shown in Table6.2 below.

Table 5.2: The solar field parameters

| Parameter | Value | Unit |
|---|---|---|
| Field aperture | 715.2 | m2 |
| Irradiation at design | 1000 | W/m2 |
| Design-point ambient temperature | 30 | ‘C |
| Design-point wind velocity | 4 | m/s |

### 5.2.2. The Collectors and Receiver

The Collector Geometry and receiver As Shown in figure 6.1 below:

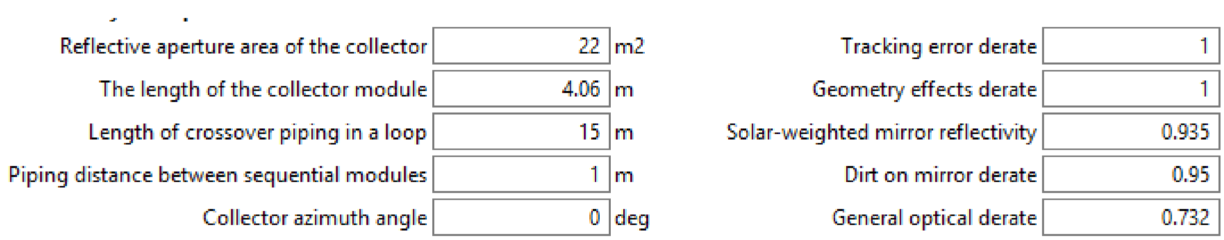


Figure 5.1: Collector Geometry

### 5.2.3. The Thermal Storage

The Thermal Storage With Total Volume of 25 $m^3$ consist of two tanks in series each tank has a diameter of 1.5 m And the minimum tank fluid height 1 m and the height of HTF when tank is full is 8m, the loss coefficient from the tank 0.4 $W/m^2.k$ , the estimated tank heat loss 0.00838633 MWt.

The tank has an electric heater that work to keep the heat of fluid in the tank over 200 C.

### 5.2.4. System Cost

The Total Cost of the System consist of Direct and Indirect Capital Cost, The Direct Capital cost consist of the site improvement And the Materials and the components of the system as shown in figure 5.2.

| **Site Improvement** | **10$/m²** | **9680 $** |
|---|---|---|
| **Solar Field** | 150$/m² | 145200 $ |
| **HTF system** | 100$/m² | 96800 $ |
| **Storage** | 30$/kWht | 12906.8$ |
| **Contingency** | 5 % | 18630$ |
| **Total direct cost** | | 391216.2$ |

Figure 5.2: System Direct cost

SAM Advisor shows the total direct and indirect cost of the project equals 470000$ consists of the site improvement and the solar system price with a maintenance cost of 15000$ per year.

## 5.3 Financial Analysis

The financial analyses for this project was done with two certain specific parameters: The first one is that the money saved from replacing the electric system is the profit of the project. The second one is that the project life is less ten years which is the supplier guarantee that includes the project efficiency and output.

The Thermal load in Royal Company costs 60% of its electricity consumption( 600,000 Kwh) per month this means that Royal thermal load costs about 820,000 $ per year. For the extrusion machine about 150,000 $ is the electricity costs compared with 75,000 $ for the solar system in the first ten years and 15,000 $ after that Economic analysis for the project done using Excel spreadsheet and the result as follow:

1. Project Cash Flow: By determining that the project initial cost is 470000$ with a maintenance and reliability cost equals 15000 $ yearly with a saving money (profit) of 145000 $ the project cash flow shown in Table 5.3: The Project cost over its life and Figure5.3: The project cash flow Diagram.

Table5.3: The project cash flow

| Year | costs | Revenue | Cash Flow | IRR |
|---|---|---|---|---|
| 0 | -470000 | 0 | -470000 | |
| 1 | -15000 | 145000 | 130000 | |
| 2 | -15000 | 145000 | 130000 | |
| 3 | -15000 | 145000 | 130000 | -9% |
| 4 | -15000 | 145000 | 130000 | 4% |
| 5 | -15000 | 145000 | 130000 | 12% |
| 6 | -15000 | 145000 | 130000 | 17% |
| 7 | -15000 | 145000 | 130000 | 20% |
| 8 | -15000 | 145000 | 130000 | 22% |
| 9 | -15000 | 145000 | 130000 | 24% |
| 10 | -15000 | 145000 | 130000 | 25% |

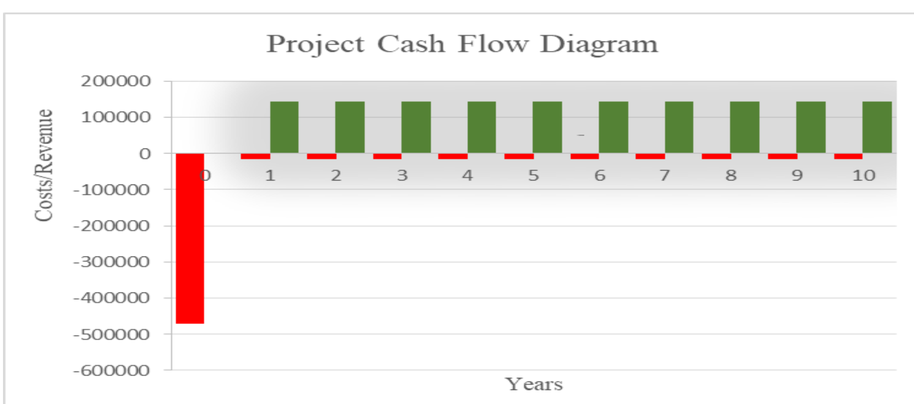


Figure 5.3: The project Cash Flow Diagram

2. The Internal Rate of Return: The project start to give a revenue after get back its cost by the fourth year with a rate of 4% which increasing due to its life.
3. Payback period: Table 5.4: below shows the cumulative results of its money to calculate the Payback period which equals a three years and five months.

Table 5.4: The project payback period

| End of year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cash Flow | -470 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 |
| Comulative | -470 | -340 | -210 | -80 | 50 | 180 | 310 | 440 | 570 | 700 | 830 |
| | | | | | | | | | | | |
| Pay Back Period | | 3.38 | | Years: | 3 | Months | 5 | | | | |

4. The project net present value with an interest rate of 5% is positive which means the project is accepted as shown in Table 5.5: The present value of the project.

Table 5.5: The project present value

| | |
|---|---|
| Cost NPV | 576,620.0 $ |
| Revenue NPV | 1,030,000.0 $ |
| PV +/- | 453,380.0 $ |

The economic analysis shows that the project is fully accepted with a high internal rate of return and a short payback period. The high positive present value of the project makes the company sure about its profit.

### 5.4. Conclusion and Recommendations

For the situation of energy of Palestine as a country suffering from occupation and doesn't control its sources and forced to import its need of energy with a high prices and taxes the renewable energy is a good solution for industry which is a sector that consumed a high rate of energy.

As an industrial energy consumption sector the Plastic industries faces the problem of energy from many sides. Royal Industrial Trade Company has been taken as a case study from the plastic high production costs.

The Solar Collector system has been taken as a renewable source of energy to replace the electric source. The situation analyzed and the extruder has been taken as the goal, taking a Solar Collectors producer and studying its datasheet with Palestine profile data and simulates the system with TRANSYS program before the economic study with SAM Advisor and excel sheets the study has been completed.

A 0.36 $MW_{th}$ is to be supplied for heat industrial process in Palestine using the LFC-11 Solar Collector System which has been studied and analyzed with respect to Palestine weather data and the extrusion machine in Royal industrial Trade Company to work from 8:00 am to 15.00 pm daily. The system economically analyzed by obtaining the net present value of 453 thousand dollars , the internal rate of return and the payback period of three years and five months.

The recommendation to make a study for the using of the solar collectors in Palestine and make a data base for the solar DNI and NERC for main industrial cities in Palestine in the Palestinian central bureau of statistics and make courses, conferences and trainings for using this systems in Palestine because the amount of information and experiences in this field is too poor so we recommend:

1- Add a special courses in the solar systems in the academic plan of the mechanical engineering students.
2- Make conferences for the industrial company's about the advantages of using these systems.

3- Make a special training for building and fixing this type of systems.
4- To make a real system design with all components.