Efficiency of Solar Domestic Hot Water System: The Case of Famagusta Northern Cyprus

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ABSTRACT

Due to the Cyprus's climate and geographical potential, the ideal energy source for obtaining power is solar energy. The main aim of this research is the development and validation of a new methodology for installation of solar thermal collectors on rooftops to achieve higher performance. This methodology follows of solar geometry and local parameters. Therefore, because of plenitude of mid-rise residential buildings in Famagusta City, two cases including Haci Ali multi-story building and Social Housing Building are analyzed. Cyprus has no energy resources of its own. Therefore, more than 94% of the total primary energy is imported to the island. High cost energy consumption due to lack of consideration in design and construction phases and available free source of solar energy are important issues here. The flat plate collectors are typically connected in rows or parallel form designs so that the desired design would be achieved to provide the temperature for a given application. It has proved that the collectors do not work as well while sun duration that causes decreasing the rate of irradiant solar absorption in winter is the main problem of this thesis. The performance of thermal solar system was calculated by the performance of water storage tank volume. No changes occurred with regard to the height and width ratio (diameter) of the water storage tank. Obviously, a capacity of 150 liter is desirable for solar thermal system. The overall performance of the solar system will be affected if the volume of storage tank is increased or decreased. It is worth noting that, shading impact due to surrounding elements or neighbor buildings is another problem resulting to less energy performance for the mentioned collectors. In other words, collectors are not able to provide hot water for residential buildings when climatic seasonal and architectural parameters restrain absorption rate of solar energy by collectors in Famagusta city.

Keywords: Solar Thermal Collector, Energy Performance, Solar Absorption, Orientation, Shading Problem

ÖZ

Kıbrıs'ın iklimi ve coğrafi potansiyeli nedeniyle , enerji elde etmek için güneş enerjisi ideal bir enerji kaynağıdır. Bu araştırmanın temel amacı, yüksek performans elde etmek amacı ile çatılara güneş enerjisi kollektörleri kurulumu için yeni bir metodoloji geliştirmiş ve uygulanmıştır. Ayrıca bu metodoloji güneş geometri ve yerel parametrelerini izler. Bu nedenle, Mağusa şehrinde verimlilik açısından orta katlı konutlar arasında Hacı Ali çok katlı bina ve Sosyal Konut Binası olmak üzere iki olgu incelenmiştir. Kıbrıs herhangibir enerji kaynağına sahip değildir. Bu nedenle toplam enerji ihtiyacının % 94” ü dışardan alınır. Tasarım eksikliği ve doğru incelenmemesi sebebiyle mevcut tasarımlar yüksek oranda verimli enerjiyi elde edememesi ve güneş enerjisinin sınırsızca heryerde elde edilebilmesi burdaki iki önemli problem sayılır. Genellikle yassı kollektörlerin bağlantıları satır veya parallel formdadır böylece istenilen tasarım verilen uygulamalar için gereken sıcaklığı üretebilmektedir. Bu tezin asıl problemi mevcut kollektörlerin güneşli saatlerde verimli çalışmaması bu nedenle kış aylarında güneş emiliminin azalmasıdır. Termal güneş sisteminin performansı su deposu performansı üzerinden hesaplanmıştır. Su depolama tankının yüksekliği ve genişliği oranında herhangibir değişiklik yapılmadı. Net görülüyorki su deposu için 150 litre solar sistemlerde ideal bir hacimdir. Depolama tankının hacmini arttırıp azaltmak güneş sisteminin genel performansını etkileyebilir. Mevcut kollektorlerin performansının düşmesindeki ayrıca neden olarak çevre elemanlarıdır bunlar komşu binalarının gölgelendirmesi veya başka çevre faktörleri olabilir. Diğer bir deyişle, Famagusta şehrinde, mevsimsel değişiklikler ve mimari hatalardan dolayı kollektörlerin güneş enerjisi üretme performansı azalmıştır.

Anahtar Kelimeler: Güneş kollektörü, Enerji performansı, Güneş Emilimi , Yön, Gölgeleme Sorunu.

DEDICATION

I would like to express my immense gratitude to my family, Without their constant encouragement and support, thesis could not have been realized.

To My Family

ACKNOWLEDGMENT

I am heartily thankful to my supervisor, Assist.Prof.Dr. Harun Sevinc, whose encouragement, supervision and support form the preliminary to the concluding level has enabled me to develop an understanding of the subject.

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Chapter 1

INTRODUCTION

1.1 Introduction

Due to overuse of fossil fuels, and resulting CO2 production leads to global warming which is now significant threat to the human life and planet. Utilization of renewable energy sources, especially solar energy can help to solve this problem and contribute towards sustainable development. Construction sector being responsible for more than 50 percent of world's energy consumption, have a great liability towards the use of renewable energy sources.

In recent decades, there is growing research on the use of non- renewable energy instead of fossil fuel, because solar energy is endless, free and prevents harm to human life and environment. Utilization of passive and active solar energy and promotion of low-carbon buildings for energy production, can help create energy-efficient buildings and help reduction greenhouse gas emissions.

Buildings with integrated solar thermal collectors, can help improve aesthetical problems and also generate energy via ecological consideration. Buildings with integrated solar collector, can affect the form of buildings aesthetic. Regarding the number of people living in Famagusta city and the development of residential buildings more attention has to be given to the topic of energy efficiency. In buildings subsequently, the rate and cost of energy consumption in residential buildings in Famagusta has become more noticeable.

1.2 Research Problem

Due to Cyprus's climatic potential, the ideal energy source is solar energy. Although application of solar collectors on rooftops of buildings in Cyprus is widely seen, large proportion of total energy generation cannot be predicted. This is due to inappropriate orientation of solar collector which affects the efficiency of solar collectors.

It should be noted that, collectors are not able to provide hot water supply for buildings when climatic seasonal and architectural parameters researching such as cloud, radiation angle and inappropriate orientation restrain absorption rate of solar energy. Some of the other problems are low installation, low quality of collectors (due to low quality materials especially in absorber element and insulation materials), lack of technical information and in most cases, the solar systems used on the roof are not efficient. This will result in heat loss of hot water storage tanks especially at nights during cold season. The most noticeable problem about collectors of Famagusta residence are their incorrect orientation and wrong installation, this prevents the catching of maximum amount of solar radiation and also displays an aesthetic problem.

1.3 Research Aim and Question

The research focuses on developing optimum installation of thermal solar collectors on rooftop in order to achieve higher efficiency of solar collectors. This can be helpful to reduce energy cost in multi-storey buildings and enhancing collectors` performance simultaneously. Subsequently, optimization of the building integrated thermal solar collectors in multi-storey buildings are considered through the most appropriate orientation, inclined angle and installation area. The use of this system can have better implications in the future and can have an influence on future building generation and use of solar collector. Thesis will attempt to find answer to following questions.

1) What type of solar collectors exist?

2) Which types is most efficient?

3) What are the factors that help reduce efficiency of solar collector?

1.4 Research Structure Methodology

Comparative analysis types of research methodology are used in this thesis to propose a practical model of solar collectors use in Famagusta. Data collection is based on personal observation and documentation which includes photos and measurement as well as review of literature from necessary resources such as books and databases.

1.5 Limitation and Scope

The limitation and scope of this study focus on solar thermal collector`s requirements and its efficient use in multi-story buildings in the city of Famagusta, Northern Cyprus with hot-humid climatic characteristics. The main focus is to become more competent about energy efficiency issues and especially about solar collectors. In the case of performance of solar collectors and to cover the gap in winter, new strategies and ideas will be presented in the thesis. The thesis will be limited particularly on the problems of hot water supply in winter season by solar collector.

Chapter 2

DEFINITIONS AND BASIC PRINCIPLES

2.1 Definition of Renewable Energy

Renewable energy sources (RES) get the energy they require from accessible energy currents, by means of constant natural process, including sunlight, wave power, hydropower, wind, biological processes like anaerobic digestion, and geothermal energy. Renewable energy can be defined as a form of energy coming from a resource that is substituted by a natural process to an extent which is identical or even faster than the level at which resource is used. Renewable energy is sustainable energy subdivision.

Tidal power except for geothermal, most forms of renewable energy originate from solar energy. The energy of wind comes from winds, and these winds are created as a result of the sun's irregular heating of atmosphere of the Earth. Hydropower is heavily dependent on rain, that is over a new influenced by sunlight to evaporate and change it into water. The same is true with fossil fuels, which originate from solar energy too, for fossil fuel is taken from plants as well (Meinel AB, Meinel M.P,1975). Nevertheless, despite the fact that fossil fuels are utilized to such a degree and that they are supposedly renewable over long time, exploitation of which occurs at such high degrees that the reduction of these resources seems very imminent, so they are no longer regarded as renewable (Dincer I,1998).

It is possible to use renewable energy resources directly, or generate some other forms of energy that are more convenient. Among direct uses of energy solar ovens, water,geothermal heating and windmills can be taken into account (Dincer I,1998). Humans manage renewable energy expansion by the use of renewable energy sources. Recent fondness in developing renewable energy has links with worries concerning overuse of fossil fuels which is linked to environmental, sociopolitical risks in regards to extensive exploitation (Dincer, I., Rosen Ma,1998).

People need supply of electricity for fulfilling their everyday activities such as cooling,bathing,etc. Most of this energy is derived from fossil fuels, including gas,oil and coal. These energy sources are not renewable meaning if they are used up, next generation not have access to more of it. Fossil fuels play a significant part in global climate change as they release carbon dioxide into the atmosphere when burned (Sayigh Aaw,2001).

Fossil fuels are not endless, therefore humans should think about shifting to some other sources such as renewable energy. These sources are continuously there, like sunlight, wind, and water. Furthermore, compared to fossil fuels, they are much more environmentally friendly (Lysen E,2003). Most renewable energy sources used nowadays are expensive, inefficient, or have several shortcomings. For instance, wind may be used well in a region if there is enough wind and wind speed the whole year, but it might not be used really well in a region having little wind speeds. Nevertheless, renewable energy is significant due to the advantages it offers. The main benefits include environmental benefits, energy it provides for future generations, employment and better economy as well as safe and clean energy.

2.1.1 The Use of Solar Energy as a form of Renewable Energy Source

A study carried out by the National Statistics of Japan showed that renewable energy comprises 13.3% of the world's main energy requirements. Making use of localy available resources, tackling environmental challenges, public recognition and energy policy are among some of the key challenges considered to increase the percentage of this contribution. There have been numerous research activities for many years throughout the world to employ solar energy (Mark, A.,Delucchi,M.Z,2010).

Concerns for global issues have been the main causes for these activities including global warming, the high cost of gas and oil. According to International Energy Agency (IEA), the production of crude oil and fields of crude oil to be developed will be declined towards 2030, which is very low considering the world's use of oil (Sale,D.M,2011).

The sun releases a massive amount of energy everyday known as solar energy. Energy of sun emitted everyday is more than the world's consumption of energy in one year. The source of this energy is the sun itself. The sun is a big gas ball formed of hydrogen and helium similar to many stars. Energy is made in the sun's inner core in a process known as nuclear fusion. The sun's energy travels 93 million miles to get to earth within 8 minutes. This is the speed of light solar energy travels, that is, 300,000 miles in one second.(3.0 x 108 meters per second) (Sale,D.M,2011).

Only a low portion of the visible light which the sun radiates in space gets to the Earth, but is sufficient to providing all the energy requirements.Solar energy emitted reaches every hour the Earth is sufficient to supply energy needs for one year. That is why, solar energy is regarded as a renewable energy source. Nowadays, solar energy is used for hot water heating and generating electricity.

2.1.2 The History of Solar Energy Utilisation

Employment of solar energy has a long history and it is certainly not something recent. discovered the use of this energy dates back to the 7th Century BC at the time it was used as a way to make fire out of glass or mirror. However, nowadays it has a wide range of usage. However today there are solar-powered constructions as well as vehicles.

The first use took place when magnifying glass was utilized to focus sun's light in order to make fire and make ants burn. Then for some religious purposes, the Greeks and Romans used the sun's rays for lighting torches. As early as 212 BC, the Greek scientist, Archimedes, used this reflective feature of bronze-covered shields to concentrate the rays and launch fire at Roman's wooden ships surrounding Syracuse. Although this achievement cannot be proved, the Greek navy (1973) copied the same experiment and successfully set fire to a wooden ship as far as 50 meters. Burning mirrors was also used in China to light torches to serving religious purposes. Romans in their bathhouses implemented solar energy. There, the sun's heat found a way inside the houses through big south-facing windows (1^{st}-4^{th} century AD). In ancient Rome, houses as well as public buildings had sunrooms. They were so popular that according to the Justinian Code "sun rights" were introduced to guarantee the sun is accessible to everyone (Dincer I,1998). Anasazi were the ancestors of Puebloans in North America who settled in cliff houses facing south that trapped the sun's warmth in winter. Established in Kramer Junction, California, world's biggest solar thermal power station started working in 1986. The solar field consisted of rows of mirrors focusing the solar energy on a pipes system in which the circulation of heat fluid performed. As a result of circulation of the heat transfer fluid, steam is generated powering a typical turbine to make electricity (Sale,D.M,2011).

William Bailey is another famous pioneer in solar thermal technology. More ergonomic compact design has been created in 1909 by William Bailey. In addition he was a solar thermal energy market organizer (Norton, 1992). The system created by Bailey was placed the tank on the roof of the structure and a collector beneath. Also it was the first thermosyphon system. The greatest improvement on the old system which was implemented by system of Bailey was the availability of hot water during the day and night. California and Florida start to spread the use of solar water heating system in 1930.

Nearly 30% of Pasadena California homes are integrated with hot water system powered by solar energy in the beginning of 20^{th} century. Solar thermal heating systems were manufactured in Florida which was a booming solar industry.

During the Second World War, copper was used for military aims. So that, copper noticeably was used for thermal industry and affected on a drop off in interest in solar thermal energy.

The industry of solar heating technology became limited to California and Florida due to the freezing in the winter time. Water heating system was utilized in over 50 % of Miami homes after the Second World War.

In case of Northern Cyprus, after 1974 Northern Cyprus had big energy problems. They decided to use solar collectors for hot water supply.

2.1.3 The Use of Active Solar Systems in Buildings

Solar energy for heating as well as to generate electricity is non-polluting that needs the least retention. Still, when they are merged to buildings, architecture faces some challenges. The main reason of having solar energy is not only for its effectiveness but also for its cost; however, the architectural features should be taken into account when they are integrated. In fact, these systems are installed in construction as a multifunctional component that enhances the architectural quality in addition to supplying free energy (Anthony,L.B.R.,July 2012). It is worth saying that these facilities should not be considered as systems developed to generate heat or electricity; rather, they must be seen and dealt with as systems that have a role in the architecture of the building. Therefore, as it appears, they improve the architecture, highlight it and make a distinction from the mass. They cannot only represent adaptation, change or innovation, they can also maintain traditional properties. As a result, both the construction and the landowner will hold a positive image with regards to architecture (Giorgia,R.M.V,2013). Solar systems are used to heat a liquid. Then, they direct the solar heat to a storing system or to an internal space to be used later. Whenever the solar system is unable to supply sufficient space heating, another supplementary (backup) system delivers the heat. The main usage of liquid systems is when storage is involved, and these systems are better used in radiant heating system, big boilers having hot water radiators, coolers and absorption heat pumps. Liquid systems along with air systems can reinforce forced-air systems.

2.1.4 Energy and Cost Efficiency of Solar Collectors

The collector efficiency is indicated as the quotient of operational thermal energy as opposed to solar energy received. In addition to thermal loss, there is always optical losing (Johanson Tb,1993). The conversion factor, also referred to as visual efficiency h0, specifies the percent of the solar rays going through the collector's clear cover (transmission) and the percent that is absorbed(Rosen MA,1996).It is chiefly the outcome of the cover's rate of transition and the absorber's absorption rate. Special costs of collectors are significant, too. Compared to flat-plate collectors (153,34 to 613,55 Euro /m²) or even plastic absorbers (25,60 to 102,26 Euro /m²), evacuated-tube solar collectors are noticeably more expensive (511,29 - 1278,23 Euro /m² collector surface). Nonetheless, a good solar collector is not necessarily a good solar system. Instead, all parts must have high quality and comparable capacity and strength as well (Mark, A.,Delucchi,M.Z,2010).

2.1.5 An Overview about Solar Water Heating

Solar water heaters are known as solar domestic hot water systems. When the whole energy costs are taken into account, solar water heaters are economical concerning the lifespan of the system (Dincer I,1998). In spite of the fact that the initial cost paid for installation of solar water heaters is more than that of traditional water heaters, because solar radiation is free available. Moreover, they do not pose any threat to the environment. These heaters can be advantageous if radiation is unshaded in northen hemisphere such as south orientation in Famagusta. The function of these systems is to utilize solar energy to heat either water or a fluid transferring heat, e.g. an antifreeze mixture, inside the collectors, which are usually installed on a roof. The hot water is saved in a water sorage tank like a typical gas water storage tank. Some systems employ an electrical pump for better circulation of the fluid inside the collectors. It is conceivable to use solar water heaters in any climate. The function of the system is based on the climate as well as the amount of solar energy. It also depends on the coldness of the water in the system. Efficient operation of the system is related to the cold water. A backup system is needed in all climates. In practice, it is necessary for many buildings to have a conventional water heater serving as the backup system (Siddharth Arora,.S.C.,2011).

2.2 Types of Solar Collectors According to their Base of Systems

In general, the thermal collectors consist of two systems such as air-based and water-based collector systems. Depending on their performance, both of the systems are sustainable (Kalogirou, S.A, 2004). Moreover, to use air-based collectors on the roof, a double-skin facade or system of central air handling can be utilized (Transpired air collector). Most air-based collector system that are used in projects of renovation have had more or less particular designs up to now, based on International Energy Agency task 20 report (Figure 1,2,3) (Haller et al., 1999).

2.2.1 Air-based Collector Systems

They are basically designed for space heating or preheating air circulation (Kalogirou, S.A, 2004). When they serve as pre-heating air-ventilation, the collectors are usually located on facade of the building very close to spaces from which the fresh air enters into the building. By doing, so the ducts become shorter and efficiency increase throughout the space-heating period (low solar angles are favourable). In spite of employing storage components, the purpose of designing an air-based collector system concerns utilizing the building structure to store more heat (Kalogirou, S.A, 2004). In addition, it is possible to use a double-skin facade or a central air-handling system to utilize air- based collectors that is installed on the roof. According to a reportage via International Energy Agency task 20 (Haller et al., 1999), most systems of air-based collector which has been used in renovation projects have had special designs until now (Figure 1,2,3).

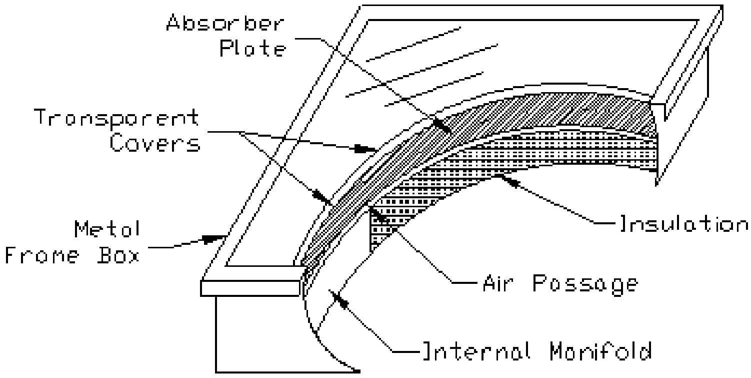


Figure 1. Collector system with rectangular tunnel heat exchanger
http://home.earthlink.net/~jschwytzer/air_collector.gif

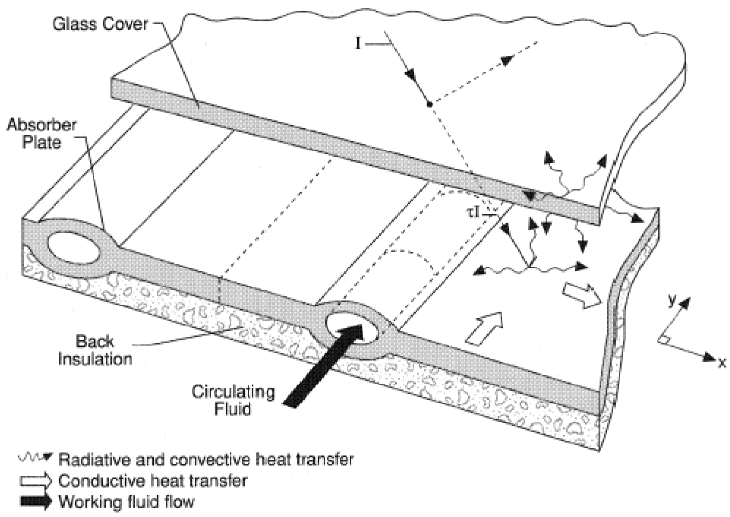


Figure 2. Fluid Conductivity in Solar Collector
http://www.thermopedia.com/content/5557/SOLAR_ENERGY_FIG1.gif

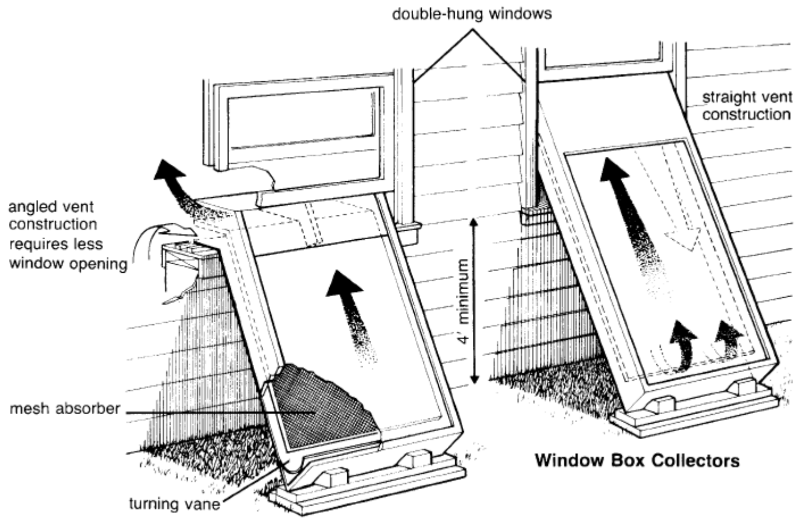


Figure 3. Window box of air based collector.
http://www.exposingtruth.com/wp-content/uploads/2013/08/Solar_Air_Window_Box_Collectors.gif

Air-based collector is a type of solar collector, in which instead of a liquid air functions as a medium for transferring heat. Consequently, holders store the heat gained from solar energy. Then they can be filled with pebbles, for instance (Kalogirou, S, 1997). The energy thus collected from air-based solar collectors can be used for heating of air- ventilation, space, or drying crop. The following table1, lists several types of air-based collectors and their relevant suitability for three primary usages.

Table 1. Air-based collector systems corresponding suitability

Type of Collector	Air-ventilation heating	Space heating	Crop drying
Unglazed perforated plate	very good	Poor	very good
Glazed flat-plate	good	Poor	good
Back-pass	fair	No	fair-good
Trombe wall	no	Good	No

Among collector types the first three have simple designs. Liquid-based collectors are typically heavier than these collectors because of not having pressurized piping. There are some problems in the collectors like freezing or boiling water or liquid which do not exist in air-based collectors. It has been made possible in all four of these air-based collectors to be joined into construction and shape some sections of a building's envelope.

Compared to water collectors these systems do not have the problems related to corrosion, freezing and overheating. In addition, unlike water collectors, air is considered as a medium transferring heat faster; furthermore, rock acting as a medium is cheap for storing heat. However, air collectors are not that common because heat storage of air and rock is low. Eventually regulating them is hard too.

2.2.2 Water-Based Collector Systems

These economical systems are sometimes referred to as hydraulic collectors. These features make storing of solar gain easy and serve well both for space heating and domestic hot water production as well. Their medium is chiefly made up of water charged with glycol varying in percentages to keep it from frost due to the particular climate. Because water stores heat well, it can exchange high quality heat through the absorber and storage. The solar energy obtained can be saved in water storage tanks having good insulation and used for household space heating or hot water supply. Depending on technology, systems of hydraulic are divided to four types including glazed flat plate collectors,evacuated tubes, unglazed flat plate collectors and unglazed plastic collectors (Munari Probst, 2012). In this study flat plate collectors had been analyzed after reviewing other types.

2.2.2.1 Glazed Flat Plate Collectors

These collectors are the most common ones exploited for domestic hot water besides space heating. A flat-plate collector is basically made up of a metal box insulated by cover which is either glass or plastic (the glazing) and an absorber plate in dark-colour. Solar radiation is absorbed by the absorber plate (Wazwaz, 1992). Then it is transferred to a liquid that circulates via the collector in tubes. (Figure 4). These collectors make the circulating liquid heat at degrees less than 100°C- temperature of boiling water- and are really suitable in applications where the required temperature is 30-70°C or for those that need heat throughout the winter (Munari Probst, 2012).

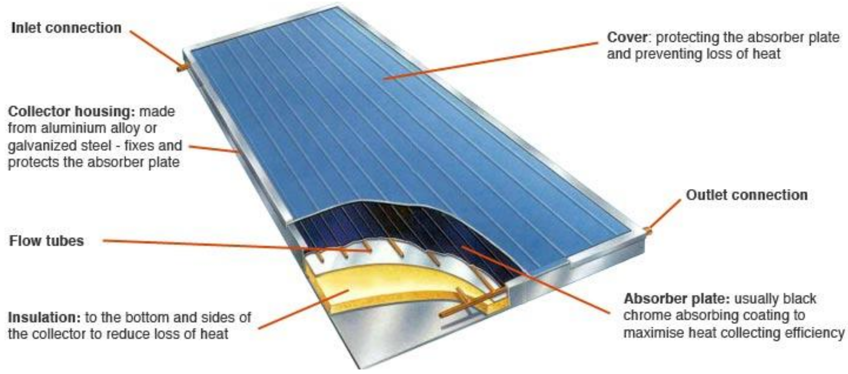


Figure 4. Parts of flat plate solar thermal collector
http://mcensustainableenergy.pbworks.com/f/1260939446/solarcol2.jpg

2.2.2.2 Unglazed Flat Plate Collectors

Compared to glazed or evacuated collectors, unglazed flat plate collectors are simpler from technical point of view. They consist of several layers and are assembled without requiring various jointing. These are formed of a special metal plate, that acts as an absorber, rear insulation and absorber warmed up a hydraulic circuit (Figure5). Different than glazed collector, the absorber is not insulated by a covering glazed and active temperature is relatively lower. 60-65°C can be reached as the temperature of these collectors. This is the degree suitable for swimming pools, space-heating systems of low temperature, and domestic hot water (DHW) pre-heating. A perforated plate collector which is a special type of unglazed collector is used to preheat air-ventilation in commercial complexes (Munari Probst, 2012).

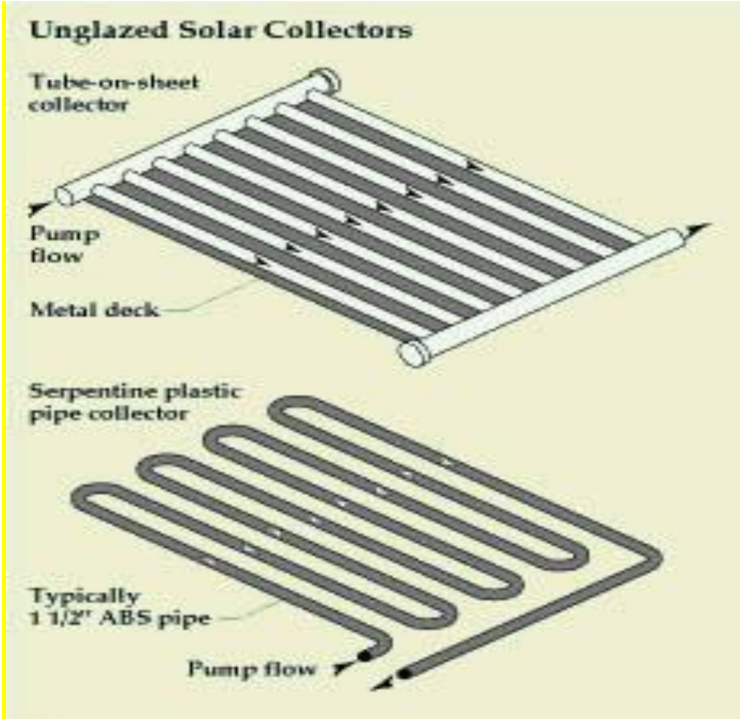


Figure 5: Unglazed flat plate solar thermal collector http://www.usc.edu

Unglazed flat plate collectors are not as widely used as typical solar collectors with glazing. When the protective transparent cover is not present, the thermal losses decrease; however, the thermal losses grow by convection and radiation when the ambient air is in contact with the absorber directly. In addition unglazed collector is better for efficient operation in low temperatures because of the sensitivity of the absorber to wind speed is considerable. While unglazed collectors are cheap, it is an advantage for economical solar thermal energy uses in such a temperature range, including preheating of water for domestic or industrial application, space heating, water heating of pools, air heating for agricultural applications or industrial and so on.(Tripanagnostopoulos et al., 2000).

2.2.2.3 Unglazed Plastic Collectors

Unglazed plastic collectors are usually shaped of rubber or black plastic that has been alleviated to tolerate ultraviolet rays, but are not insulated (Figure 6). However, huge amount of the absorbed heat is lost due to not being insulated, especially under windy and low temperature conditions. Heat is driven into the air and then heat is trapped during hot and windy nights outside (Norton, 1992).

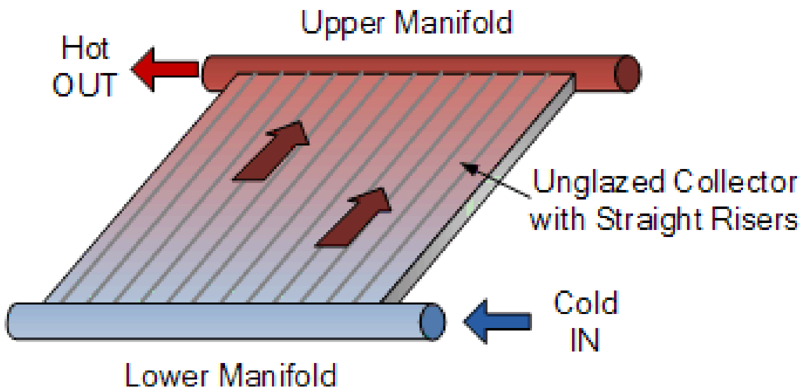
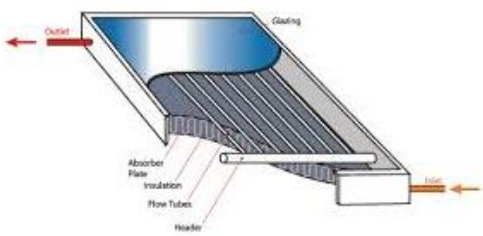
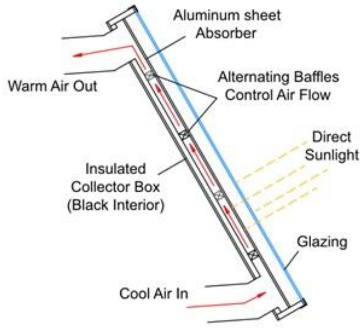


Figure 6 . Unglazed plastic plate solar thermal collector http://www.alternative-energy-tutorials.com

Table 2. Types of Solar collectors according to their Base of Systems

<table>
<tr><th>System Type</th><th>Collector Type</th><th>Figure</th></tr>
<tr><td rowspan="3">Air-based</td><td>Glazed flat-plate</td><td>
</td></tr>
<tr><td>Back-pass</td><td>
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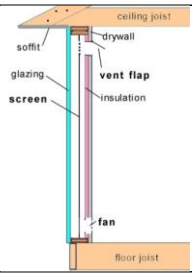
<tr><td>Trombe wall</td><td>
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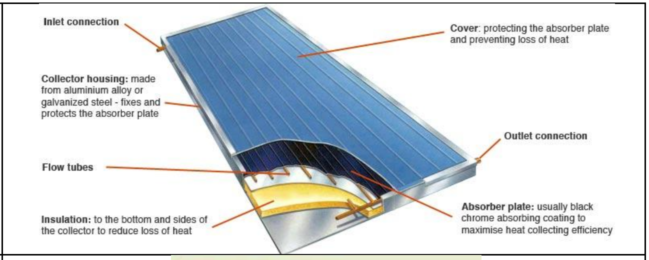
<table>
<tr><td rowspan="3">Water-based</td><td>Glazed flat plate collectors</td><td>
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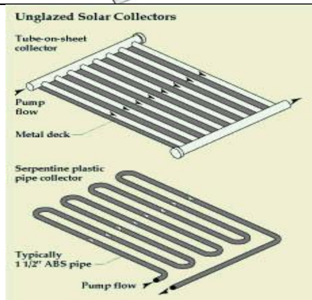
<tr><td>Unglazed flat plate collectors</td><td>
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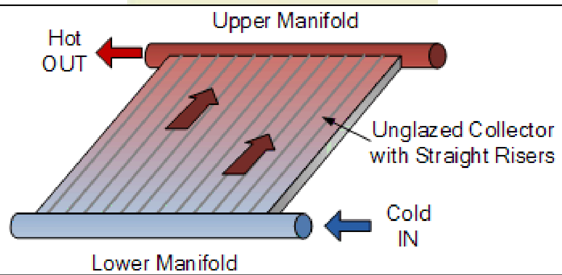
<tr><td>Unglazed plastic collectors</td><td>
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2.3 Types of Solar Collectors According to their Motion

Solar energy collectors are special type of heat exchangers which convert solar energy to radiant energy and temperature the heated to interior by means of transport medium. The solar collector is the main component of solar systems. This device can absorb the entering solar radiation, changes it into heat, and transmits it to a liquid (water ,air or oil) flowing inside the collector. Therefore, the stored solar energy is received from the circulating liquid straightly to the equipment of space conditioning or hot water to a tank of thermal energy which can be used on cloudy days or at night. (Y. Tripanagnostopoulos, 2003).

Solar collectors are categorized into two parts such as concentrating and non-concentrating (stationary). A non-concentrating collector has the similar area for absorbing radiation of sun and intercepting, while a sun-tracking solar collector have concave reflection planes that captures and concentrates the sun's rays to a smaller zone. After the solar radiation received, the radiation flux increases. Various types of solar collectors such as glazed and unglazed flat plate solar collectors are existing in the market.

2.3.1 Stationary Collectors

Basically, the motion of solar energy collectors recognizes type, e.g. they can be stationary, in service temperature, single and two axis tracking (Table3). Testing before implementation is needed for motionless solar collectors. The collectors have a fixed position and are not tracking the sun (Kalogirou, S.A, 2004). This category is divided into three types of collectors:

1. Flat plate collector (FPC);

2. Stationary collector;

3.Evacuated tube collector (ETC);

Table 3. Solar energy collectors (Kalogirou, S.A, 2004)

Motion	Collector type	Absorber type	Concentration ratio	Indicative temperature range (°C)
Stationary	Flat plate collector (FPC)	Flat	1	30–80
	Evacuated tube collector (ETC)	Flat	1	50–200
	Compound parabolic collector (CPC)	Tubular	1–5	60–240
Single-axis tracking			5–15	60–300
	Linear Fresnel reflector (LFR)	Tubular	10–40	60–250
	Parabolic trough collector (PTC)	Tubular	15–45	60–300
	Cylindrical trough collector (CTC)	Tubular	10–50	60–300
Two-axes tracking	Parabolic dish reflector (PDR)	Point	100–1000	100–500
	Heliostat field collector (HFC)	Point	100–1500	150–2000

It should be mentioned that the ratio of concentration is determined by the opening space divided by the absorber space of the collector.

2.3.1.1 Flat-Plate Collectors

Figure 7 indicates a typical flat-plate solar collector. Whenever solar radiation goes via a clear cover and hits the black surface that has high absorptivity, a huge amount of this energy is absorbed via the surface and then shifted to transportation medium in the tubes, and then they are carried away to be stored or used. The bottom of the plate of absorber and the wall of casing are insulated in the best way to decrease conduction damages. Either the fluid tubes are joined to the plate of absorbing by welding, or remain an integral element of the plate. The header tubes with wide width join the tubes at both ends (Seitel Sc,1975).

The clear cover is employed to decrease convection casualties from the plate of absorber by means of the keeping of the motionless air layer located between the plate and the glass. Furthermore, once the glass is clear to the short wave light gained via the sun, radiation losses from the collector reduces but to long-wave radiation of thermal discharged through the plate (effect of greenhouse) it is approximately opaque (Kalogirou S,2000). The position of flat-plate collectors are typically everlasting and therefore do not need any tracking of the sun. The orientation of the collectors is exactly in the direction of the equator line, best position in northern hemisphere is south facing and in southern hemisphere is north facing. The collector’s best tilt angle is equivalent to the latitude of the location having an angle varies between 10 to 158 degree, which is relatively dependent on the application (Kalogirou S,2000). A flat-plate collector usually is made up of the following elements as shown in Figure 8 below.

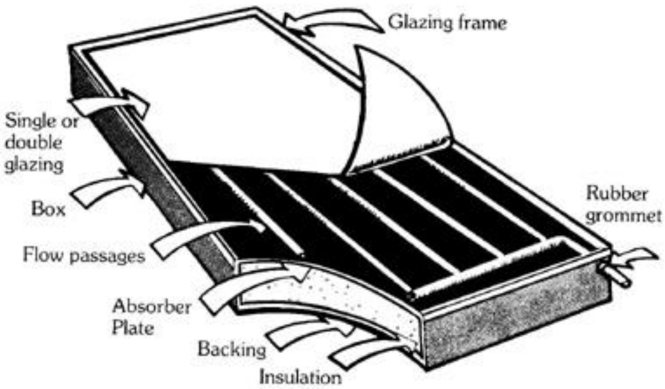


Figure 7. Flat-plate collector
https://energy.mo.gov/sfimages/division-of-energy/solar_panel.jpg?sfvrsn=0

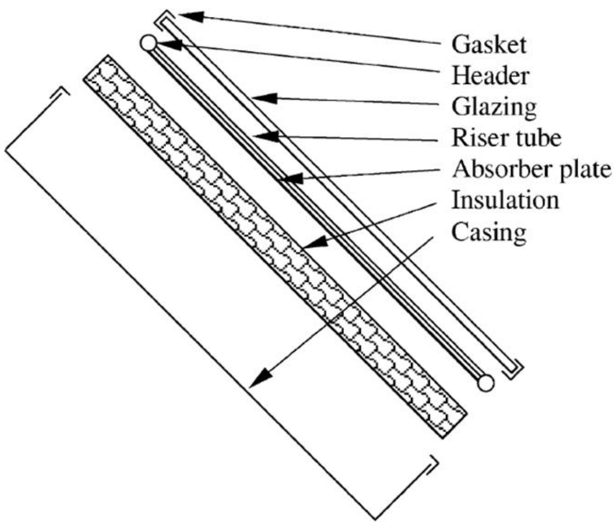


Figure 8. Details of a flat-plate collector.
http://freespace.virgin.net/m.eckert

Table 4. Different types and definitions of solar collctors

Types	Definition
Glazing	One or several sheets of glass or other material radiation-transmitting.
Tubes, fins, or passages	Conductance of heat transfer fluid from input to output.
Absorber plates	Flat plates with groove tubes are attached.
Insulation	Minimising the heat loss from the collector.
Container or casing	Keep the components and prevent from dust, moisture, etc

Flat-plate collectors are available in various materials and in different design and it can be used for heating fluids (air,water,water plus antifreeze). Their main aim concerns collecting sufficient amount of solar energy as cost effectively as possible. The collector has to have a long-lasting effective life as well, although solar ultraviolet radiation has adverse effects; corrosion and obstruction happen because of acidity the fluid is alkaline and hard water freezes moisture and dust must be removed from the glazing and some fracture happens on the glazing. All of the aforementioned can be owing to thermal extension, hail, sabotage or other reasons. Tempered glass can minimize these causes (Kalogirou, S.A, 2004).

2.3.1.1.1 Glazing Materials

To covering solar collectors glasses has been used widely because it can diffuse almost 90% of the receiving shortwave solar radiation when it transfers nearly not any of the long-wave radiation released external by the plate of absorber (Wazwaz, 1992). The glass that has a small percentage of irion has high transmission for solar radiation (Between 85% to 90%) and actually does not transfer long-wave radiation (5.0–50 mm) which sun-heated surfaces released it.

Both the plastic films and sheets have high shortwave transmission, however due to the transmission band of most usable variations occurs at the central part of the radiation spectrum, long-wave transmissions can take place as high as 0.40. The capacity of plastics to maintain temperature without damaging or having dimensional change is limited. Not all kinds of plastics can be resistant to ultraviolet radiation for a long time, also plastics are very flexible, especially as thin sheets, and do not get harmed by stones, rain, etc. The existing commercial glass for greenhouse and window having the conventional incidence transmittances for both grades of windows is approximately ranging from 0.87 to 0.85, respectively. However, transmittance differs to a great extent with the angle of incidence whenever there is direct radiation. In addition, antireflective coverings and surfaces can largely improve transmission significantly. Dirt and dust do not have much influence on collector glazing, and a rainfall happening now and then is enough to sustain the transmittance within 2–4% of its extreme rate.

The glazing must allow adequate amount of solar radiation and minimize the loss of heat going up. In spite of the fact that glass is essentially checkmated to the long-wave radiation released through collector sheets, glass temperature increases as a result of absorption besides the heat loss going through the surrounding atmosphere increases via radiation and convection. Several models of transparently insulated flat-plate collectors and combination of parabolic collectors have been developed in recent decade.

Cost effective transparent insulating titanium (TI) material that can resist high temperatures have been produced so that these collectors would be commercially viable. Benz et al (1998) developed a sample of such flat-plate collectors, which are coated by titanium. It was proven in the test that the effectiveness of the collector was equal to that of evacuated collectors. Nevertheless, such commercial collectors are not provided in the market.

2.3.1.1.2 Collector Absorbing Plates

Glazing of the collector plate absorbs adequate level of radiation, and at the same time little heat is lost upward and then downward via the rear part of the casing. The plates of collector transmit the recollected heated the transportation liquid. In the case of shortwave solar radiation, the absorption level of the collector surface is influenced by the material quality and color of the coating. It is common to use black color; however, different colour coatings have been suggested merely for aesthetic reasons. Once surfaces undergo optimum electrolytic besides chemical treatment, high-level solar radiation would be developed (Arvizu & Balaya, 2010).

Conventional selective surfaces necessarily are made up of a thin upper layer, which can absorb high amount of shortwave solar radiation but they are somehow clear to long-wave thermal radiation, saved on a surface that is highly reflective and has low emittance for long-wave radiation. Elective surfaces are mainly significant when the temperature of the collector surface is more than the surrounding air temperature. A cost effective method has been recently recommended for the development of selective solar absorber surface. A solar collector, which is energy-efficient, must be capable of absorbing solar radiation, converting it to thermal energy and conveying it to a heat transfer medium with the least loss at each stage. Various design criteria and physical mechanisms can be used to develop an optimum solar surface. Solar collectors are available in two layers whose optical feature vary. Such absorbers are called tandem absorbers (Orel Zc,2002).

Nowadays, commercial absorbers are formed by the process of electroplating, iodization, evaporation, sputtering and using solar color selection. A lot of advancement over recent years in the application of vacuum techniques for the manufacture of the absorbers with fin was based on low-temperature treatments.

Electrochemical and chemical procedures employed for their commercialization were completed more easily than those in the metal industry. However, the requirements for solar absorbers by traditional wet processes used in high temperature applications were carried out with difficulty when it came to low heat emission and high temperature stability (Konttinen P,2003).

Thus, sputter deposition in a large scale was technologically advanced in the last 70 second. Having economical characteristics, at the present time vacuum techniques are appropriate and do not pollute the environment more than the wet processes, which is considered an advantage. In case of fluid-heating collectors, paths have to be built-in or joined to the plate firmly. A main problem occurs while obtaining a good thermal link between tubes and absorber plates without requiring any additional costs in terms of labor force or materials.Copper, aluminium, and stainless steel are among the materials that are commonly used for collector plates (Colonbo U,1992).

Bumpy UV-resistant plastics are employed for treatments in low temperature treatments. Once the heat transfer liqude is in contact with the whole area of the collector, the material for thermal conductivity is not considered. Figure 9 illustrates different designs belongs to absorber plate in air heaters and solar water implemented with varying levels of efficiency. In figure. 9A is shown a linked plate design, where the liquid passages are built-in on the plate to make good thermal directress possible between the fluid and the metal. In figure. 9B and C is shown heaters of liquid with tubes, which are joined, brazed, or strips of copper or sheet of upper or lower. Because its resistance to corrosion, copper tubes are used more often. In order to find economical bonding methods, a research was conducted to test clamps, twisted wires, thermal cement, and clips. As shown in figure. 9D, one way to extend heat transfer area between tube and plate, is to apply an extruded rectangular tubing. In the process of developing an assembly, thermal cement, and blazing, mechanical pressure can be utilized. Because of high plate temperature occurring at inactive conditions, soft bond must be avoided.

To neutralize coefficients of low heat transfer that exist between metal and air, some kind of extended surface (Figure. 9E) can be used; therefore, heating air or other gases with flat-plate collectors would be possible. It is also possible to implement metal or fabric matrixes (Figure. 9F), or thin corrugated metal plates (Figure. 9G), in which selective surfaces are deposited to the metal surface if it is necessary to have a high level of performance (Seitel, 1975). Thus, a large contact surface would be required to absorb surface and air. Decreasing heat loss from the absorber can be carried out via a selective surface that can reduce irradiative heat transfer or by lessening convection. Francia (1961), based on his studies in the field, suggests that devising a honeycomb made of transparent material and placing it between the glazing and absorber, would be beneficial. Figure 9 shows another type of collector, which is the unglazed, non-coated, and solar collector. Such collectors are usually economical components, industrial and domestic water preheating proposes, swimming pool heat up, heating up space and air for agricultural and industrial proposes are the applications which are related to provide less efficient solar thermal energy.

Until now flat-plate collectors are the most common types as collector. Flat-plate collectors are typically used at low temperature up to 100 ◦C, although some novel types of collectors are exploiting vacuum insulation or transparent insulating (TI) can achieve a little more values. Original standard flat-plate collectors can rise up to stagnation temperatures even over 200◦C, through using highly selective coatings, and by application of collectors, temperatures as high as 100 ◦C may be achieved.

Recently, the industry has provided developed techniques such as applying ultrasonic welding machinery. By using such a technique, not only the speed but also the quality of welds, would be enhanced. On risers, this technique can be used for the welding of fins; thus, heat conduction would be improved. Since welding can be conducted at room temperature and consequently welded parts would not be deformed, it can be said that this is the chief benefit of this procedure. The collectors having selective coating are referred to as advance flat-plate collectors and the specified conventional type is depicted in Table 5.

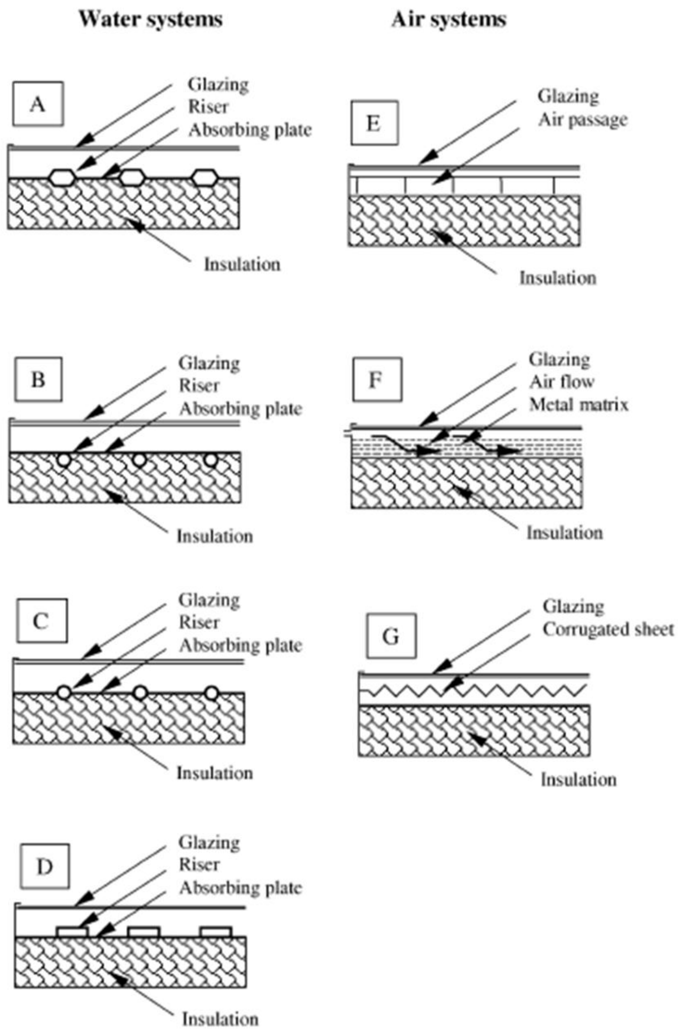


Figure 9. Different type of flat-plate solar collectors (Kalogirou. S.A, 2004)

Table 5. Characteristics of a typical water flat-plate collector system

Parameter	Simple flat plate collector	Advanced flat plate collector
Fixing of risers on the absorber plate	Embedded	Ultrasonically welded
Absorber coating	Black mat paint	Chromium selective coating
Glazing	Low-iron glass	Low-iron glass
Efficiency mode	$nv_s(T_i - T_a)/G$	$nv_s(T_i - T_a)/G$
G_{test}-flow rate per unit area at test conditions (kg/s m^2)	0.015	0.015
c_o-intercept efficiency	0.79	0.80
c_1-negative of the first-order coefficient of the efficiency (W/m^2 °C)	6.67	4.78
b_0-incidence angle modifier constant	0.1	0.1
Collector slope angle	Latitude +5 to 10°	Latitude +5 to 10°

2.3.1.2 Evacuated Tube Collectors

Some types of collectors were developed to be used in different climates, named as conventional simple flat-plate solar collectors. These advantages however are decreased to a great extent when climatic conditions become undesirable on cold, cloudy or windy days. Besides, internal materials might be corrupted due to the effects of weathering such as condensation and moisture, and as a result performance will be reduced and system might fail. As illustrated in Figure 10, evacuated heat pipe solar collectors (tubes), which are occupied with a heat pipe inside a vacuum-sealed tube, work differently compared to the other collectors existing on the market. Evacuated tube collectors have shown that a selective surface together with an ideal convection suppressor leads to a good performance at high temperatures. The vacuum envelope decreases losses coming from convection and conduction, so compared to flat-plate collectors the collectors can operate at higher temperatures. Similar to flat-plate collectors, they can collect direct and diffuse radiation as well.

However, at low incidence angles their effectiveness is higher. Considering daylong performance, this effect provides advantage for evacuated tube collectors in comparison to flat-plate collectors. In order to optimize heat transfer, evacuated tube collectors utilize some materials to change the phase from liquid to vapor and vice versa. These collectors maintain a heat pipe (a thermal conductor with high efficiency) installed inside a vacuum-sealed tube. Then the pipe- a sealed copper pipe- is attached to a black copper fin filling the tube (absorber plate). A metal tip attached to the sealed pipe protrudes from the top of each tube (condenser) (Michel Y. Haller1, 2013).

Through a cycle of evaporating-condensing some fluid goes by the heat pipes (e.g. methanol). The liquid in the cycle become vaporized by solar heat, and then it condenses and releases its hidden heat in the heat sink which the vapor goes in it first. In a repetitive procedure the condensed liquid comes back to the system of solar collector. As shown in Figure 10 the metal will be poured into a heat exchanger after the tube were installed. Inside the tube water or glycol goes though the different which causes the water to be heated by the tubes.

The heated liquid loses its heat to water or process in the storage tank by passing through another heat exchanger. Since the phase-change temperature is lower than condensation or evaporation it is impossible, freezing and overheating causes the heat pipe supply an important protection. The obvious feature of the evacuated heat pipe collector is the self-limiting temperature control. A heat pipe inside a vacuum-sealed tube produced evacuated tube collectors.

Several absorber shape types of evacuated tube collectors are available on the market. Various producers have provided evacuated tubes equipped with multiple parabolic collector reflectors. Recently, an all-glass evacuated tube collector is introduced by a manufacturer, which is considered as a significant step to increase effectiveness and more lifetime. Another type of such collectors is known by the name of dewar tubes.

Two concentric glass tubes are implemented in the above-mentioned type in which the space between the tubes has been evacuated (vacuum jacket). One benefit of such a design is that it is made completely of glass; therefore, penetration of the glass envelope for extraction is not required.

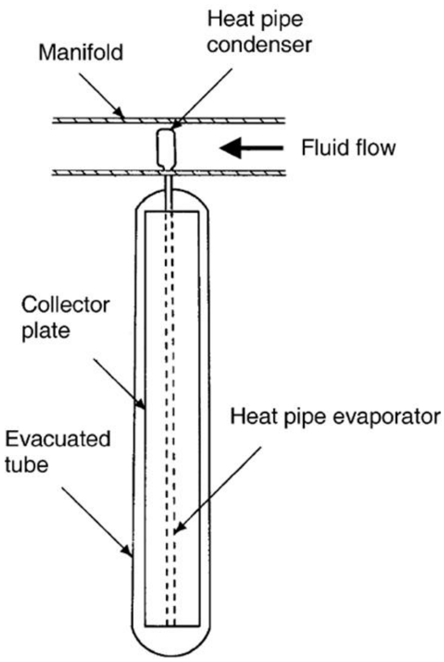


Figure 10. Details of an evacuated tube collector. (Oussama Ibrahim, 2014)

Table 6. Characteristics of a typical evacuated tube collectors system (Oussama Ibrahim, 2014)

Parameter	Value
Glass tube diameter	65 mm
Glass thickness	1.6 mm
Collector length	1965 mm
Absorber plate	Copper
Coating	Selective
Absorber area for each collector	0.1 m^2
Efficiency mode	$nv_s(T_i - T_a)/G$
G_{test} : flow rate per unit area at test conditions (kg/s m^2)	0.014
c_0 : intercept efficiency	0.82
c_1 : negative of the first-order coefficient of the efficiency (W/m^2 °C)	2.19
b_0 : incidence angle modifier constant	0.2
Collector slope angle	Latitude +5 to 10°

Single envelope system is less economical because of the leakage loss which causes no heat from the tube. The features of a conventional evacuated tube collectors are illustrated in Table 6. An integrated compound parabolic collector (ICPC) is another variation of collectors that have been designed lately. This evacuated tube collector type has a reflective material which is fixed at the bottom of the glass tube. The collector consists of vacuum insulation and non-imaging stationary concentration formed in a single unit. A tracking integrated compound parabolic collector has been manufactured in another design, which works well in application of the high temperature.

2.3.2 Sun Tracking Concentrating Collectors (STC)

The reduction of collector area from which the heat losses occur increases energy supply temperatures. Small area is enough for collecting a huge amount of solar radiation, even by flat-plate collector temperature at high level can be attained. This is carried out through placing an optical device between the source of radiation and the surface that absorb energy. Some benefits of concentrating collectors over the typical flat-plate types include the followings aspects:

1. Compared to a flat-plate system, achieving optimum thermodynamics is made possible via flowing fluid, which gains higher temperatures in a concentrator system; while solar energy collecting surface is same in both systems.

2. Achieving a thermodynamic balance between temperature level and its function is possible with a concentrator system. This function can be used with thermionic, thermodynamic, or other devices with higher temperatures.

3. Due to the small heat loss area in relation to the receiver area, the thermal efficiency is higher.

4. Since reflecting surfaces in a concentrating collector need less material and are simpler in their design compared to flat-plate collectors, each unit area of the solar collecting surface in concentrating collector would decrease the financial costs.

5. The economic advantage of these collectors is that the absorption area per unit of collected solar energy is fairly small and it would be possible to have surface and vacuum insulation, consequently heat losses would be decreased and the collector would work optimal. Disadvantages of these collectors include:

1. Depending on the concentration ratio, concentrator systems collect less diffuse radiation.
2. Some form of tracking system is necessary in an attempt to enable the collector to follow the sun path.
3. It is possible that solar reflectance losing of the solar reflecting surfaces over time so it is necessary to clean and overhaul them periodically.

Concentrating collectors can be designed in different ways. They can be segmented same as cylindrical, parabolic or reflectors. Receivers can be glazed cover or uncover with several shapes like convex, flat, cylindrical or concave. Concentration ratio can change by different order of magnitude, ranging from the minimum single unity up to maximum of 10000, the ratio of opening to absorber regions. The high amount indicates high temperatures at which energy can be supplied but subsequently requirements for accurancy in an aesthetical quality. The location of the optical system in these collectors have increased.

The sun motion might be followed by conventional concentrating collectors when the sun is moving in the sky. There are two methods to track the motion of the sun. Altazimuth is the first method which a device is needed to turn in altitude to an azimuth, therefore, the concentrator can follow the sun precisely provided that it is properly implemented. In general, this system is applicable in paraboloidal solar collectors. In the second system, there is only one-axis tracking, i.e. the sun is followed by the collector only in one direction; from north to south or from east to west. This system is often used by parabolic trough collectors (PTC) (MC Munari Probst, 2012).

In order to neutralize the sun motion, these systems must be adjusted continuously and accurately. As illustrated in Figure 11, the first type of solar concentrator is a flat-plate collector with a simple flat reflector. This reflector can attain the amount of direct radiation, which reaches the collector. The aperture area of the collector is larger than the absorber area is the main reason why the collector is called concentrator, but in fact, the system is fixed. In this method, the collector causes the entire energy to soak up at any time during the day for any latitude randomly and the collector azimuth angles, so reflectors can be simply anticipated.

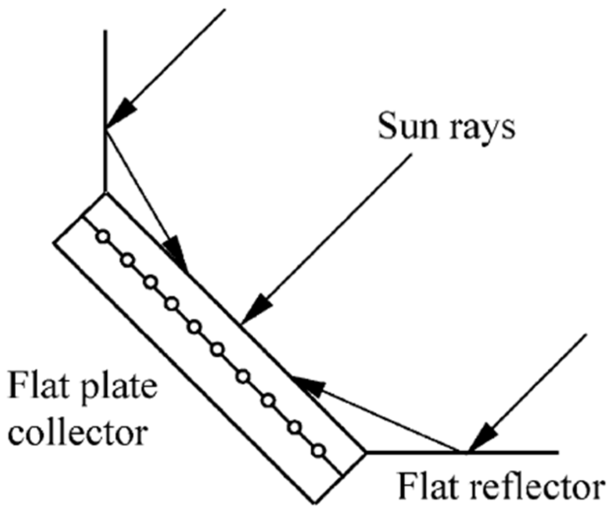


Figure 11. Flat plate reflectors. (Kalogirou. S.A, 2004)

Seitel and Perers et al (1975) presented some other important studies in this field. Another kind of collector, which is covered below the stationary collectors (the compound parabolic collector), is categorized as concentrator collector. Its being stationary or tracking depends on the acceptance angle. In using tracking, one or reflections mounted on the parabolic surfaces, can collect and concentrate radiation, because the amount of concentration is typically small and this makes it significantly rough or intermitted.

As discussed before in this chapter, as a disadvantage of the concentrating collectors, except low rations of concentration, incapability can be mentioned, the use of indirect components of the radiation of the sun, including the diffuse element that cannot be concentrated by most collectors. Yet, concentrating collectors are advantageous in collecting direct solar radiation with the axis of their sun-tracker facing north-south at sunrise on summers days, when sun radiation is on an east-west line. Anything except for diffused radiation from the faced sky portion can be received by south-facing flat-plate and this happens long before a fixed. Therefore, in the areas where there are almost no clouds, flat-plate collector can absorb less radiation in comparison with concentrating collector per unit of aperture area.

The process of concentrating collector is that solar energy changed into heat before concentrating as light form. Concentration can be achieved by reflection or refraction of solar radiation through using mirrors or lenses. The reflected or refracted light is gathered in a focal zone, and as a result increases the energy flux in the target. Additionally, concentrating collectors are classified as non-imaging and imaging models. This classification is based on the image of the sun being concentrated at their receiver or not. Compound parabolic collector is a non-imaging collector and all other collectors types are considered to be of imaging type, which include:

1.Parabolic trough collector (PTC);

2.Linear Fresnel reflector (LFR);

3.Parabolic dish (PD);

4.Central receiver (CR).

2.3.2.1 Parabolic Trough Collectors

A high performance solar collector is needed for providing high temperatures with optimal efficiency. Parabolic trough collectors (PTCs) allow process heat applications in systems with light structures and low cost technology up to 400◦^{C}. Parabolic through collectors can successfully generate heat at temperatures ranging from 50 to 400 ◦^{C} (Kalogirou S,2003).

By twisting reflective material sheet to a parabolic form, parabolic through collector can be developed. In order to lower lead loses glass tube coat a metal black tube which is located along the focal line of receiver (Figure.12).

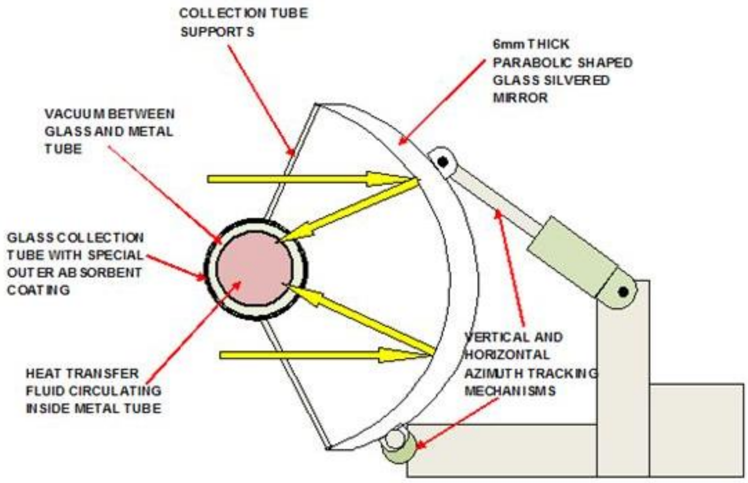


Figure 12. Details of a parabolic collector. (Scott. W, 2010)

Once the parabola is directed towards the sun, parallel rays incident on the reflector are reflected onto the receiver tube. Using a single axis tracking of the sun is enough to develop long collector modules. To track the sun from south to north in an west-east direction it is possible to orientate the collector. Moreover it is possible to orientate in the direction of south to north and track the sun from the direction of east to west. The benefit of the just mentioned tracking approach is that collector is not necessarily adjusted all day long, and it is permanently towards the sun at noon but as the incidence angles get larger during the first and late hours of sun radiation, the collector's performance decreases (Kalogirou S,2003). The highest cosine loss of north-south orienting troughs occur at noon and the lowest one in the mornings and evenings when the sun is to east or to west. Compared to a horizontal east–west trough field, a horizontal north–south field generally collects a little more energy over the period of one year. Nevertheless, in the case of north–south field, high amount of solar energy is generated in summer and less in winter.

More annual continues delivered output in summer and less in winter could be collected in east-west field in comparison to the north-south. More energy is necessary in winter or summer and the reason for this need is the orientation usually depends on the weather and use. The most progressive of solar thermal technology is the main focus of parabolic trough technology because of significant experience with the systems. The components which are sustained from the ground with the both ends pedestal simple shape are the parabolic through collector's requirements to be developed.

For solar thermal electricity generation and application of handling heat, the most advanced technology is parabolic trough collectors which can produced heat at temperature up to 400 ◦C. As a well-known application such systems, the power plant of Southern California as solar electric generating systems (SEGS) have an overall installed capacity of 345 MWs. Another vital implementation same as previous collector is used at the platform with purpose of conduct to experimental of study in Southern Spain.The total installed capacity of the Parabolic through collector is 1.2 MW.

The parabolic trough has a linear receiver. Generally in other to make exterior surface receiver a tube is installed along the central line (Figure.12). The size of the reflected solar image and also trough industrial tolerances determines the ratio of concentration and the size of the tube. Selective coating with a high absorbance for solar radiation coated the receiver surface, but in case of thermal radiation loss it has low emittance.

In order to reduce the heat lost coefficient usually surrounds the receiver tube, a glass cover tube can reduce the receiver convective heat loss. However, its unfavorable feature is that in order for the reflected light to get to the absorber, it should pass through the glass and in case the glass is clean, the rate of transmittance falls about 0.9. In order to enhance transmissivity, the glass envelope is usually covered by an antireflective. Evacuation of the space between the glass cover tube and the receiver is required to decrease convective thermal loss out of the receiver tube and as a result increases the collector's performance, especially in applications of high temperature (Benz N,1998).

Concerning mass production, in order to reach cost effectiveness , both the collector structure should have a high toughness to weight ratio for maintaining the least material content and the collector structure should be in line with low labour manufacturing procedures. Several concepts have been recommended including steel framework constructions with central rotation tubes or double V-trusses, or fibreglass. A new design of this type of collectors is the development of EuroTrough, a novel parabolic trough collector, in which an advanced lightweight structure is utilized to achieve cost effective solar power generation. Environmental test data shows that, in spite of the availability of adhesive reflective materials, whose lifespan is 5 to 7 years, it seems that mirrored glass is preferred.

The design of this collector type is presented in several publications. To have a certain accuracy level of sun tracking, replacing the first the position of the collector during the end of the day or night, and tracking during the frequent clouds, a mechanism should be considered.

Furthermore, in order to protect collectors, some tracking mechanisms are implemented. To avoid the collector being prone to dangerous environmental and operational conditions, such as gusts of wind, and too much heating and breakdown of the thermal fluid flow mechanism, these mechanisms put the collector away from central point. The acceptance angle of the collector would influence the accuracy required to track mechanism.

Different type of tracking mechanisms, ranging from simple to complex, have been suggested. Classifying them include electrical/electronic and mechanical systems. The electronic systems usually represent enhanced reliability and tracking correctness. These mechanisms are divided into the following groups:

1) First group uses engines with sensors, which control them electronically, and identify the amount of the solar radiance.

2) Second group employs engines, which are controlled by computer and equipped with feedback control. Sensors that measure the solar fluctuation on the receiver are responsible for this feedback control.

A tracking mechanism having three resistors has been devised. The resistors are light-dependent and distinguish the concentration, sunny and cloudy, and day or night conditions. Using a control system, they guide cycle engines to change the direction of the collector depending on path solar when there are under cloudy conditions and to return the collector to the east at night.

The advantages of parabolic trough collectors are the cost effectiveness and modification of the technology. For example, in order to reduce maintenance cost, in one system, the collector is equipped with an automatic washer. During the 80s, after conducting some studies, over time, and developing commercial parabolic trough collectors, several manufacturers entered in the field and began to develop collectors, which had one-axis tracking and their temperatures ranged from 50 to 300 ▫C.

2.3.2.2 Parabolic Dish Reflector (PDR)

Figure 13 shows a point-focus parabolic dish reflector, which is equipped with two axis to follow the sun, it focuses on the center of the dish which is the place for solar energy onto a receiver. The dish is structured in such a way that tracked the sun completely and mirrored the rays into the thermal receiver.

Hence, double tracking mechanisms like those that were described in previous chapter are used so that there are two directions to track the collector. The radiant solar energy will be converted to thermal energy by receiver in a circulating flux.

By the combination of a motor-generator to the catcher directly, thermal energy can be change into electricity, or entering a central power-conversion system by conveying through pipes. The minimum temperature for parabolic system is 1500 ◦C. Usually the parabolic dishes are called as a distributed receiver system because the receivers are distributed over the collector field. Several essential advantages of parabolic systems are as follows:

1) The efficiency of them are more than all types of collectors because they are always directing the sun.

2) The range of focusing ratio varies from 600–2000 (nm), parabolic system are completely efficient at system of power conversion and thermal energy absorption.

3) With containing the receiver components and modular collector they can either work independently or as a component of a huge system of dishes (Y. Tripanagnostopoulos, 2003).

The parabolic dish engine is the main application of such kind of concentrator. The parabolic dish engine system are such a power generator in which instead of consuming coal or crude oil can generate electricity, it employs solar energy. The component of power conversion and the solar dish concentrator are the major elements of these systems.

By separation receivers, systems of parabolic-dish can produce electricity from a central power converter by absorbing sunlight and supply it through a heat-transfer flux to the systems of power-conversion. Pumping needs piping layouts, and thermal losses are the impacting design issues which are the requirements to circulate heat transfer fluid throughout the collector (Malik Mas,1985).

Energy saving in electricity consumption instead of heated liqued is the way for small generator are the central point of dishes to provide energy. The heat engine and thermal receiver are made up of the power conversion system. The process of the system is that the first thermal receiver absorbs the sun energy concentrated ray, then it changes to heat and at the end it heated to heat motor. The thermal getter absorbs the rays of sun's energy, changes it to heat, and discharges the heat to the heat motor. A thermal getter can serve as an array of tubes with a cooling fluid circulating inside. Hydrogen or helium is used as the heat transfer medium, which is generally used as the working fluid in an engine. Heat pipes are another kind of thermal receivers. In order to send the heat to the engine the system employs conducing and boiling of an intermediary.

The heat transferred from the thermal receiver is captured and used by the heat engine system to generate electricity. The engine-generators are made up of several parts: a receiver, that heats the fluid of the engine and changes thermal energy into mechanical work, by absorbing the collected solar radiations; an alternator which is mounted on the engine and converts the heat into electricity; discharging extra heat to the atmosphere by a waste-heat exhaust; fitting the operations of the engine to the current solar energy by a control system. The thermal energy cannot be stored in the distributed parabolic dish system. Though it can work with fossil fuel with hybrid manner whenever there is no sunshine. The most common type of heat engine employed in dish-engine systems is the Stirling engine. Microturbines and concentrating photovoltaics are among other viable power conversion technologies that are being assessed for prospective applications (Bancha K, 2003).

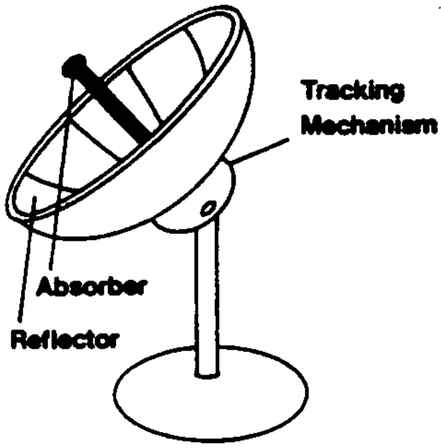


Figure 13. Schematic of a parabolic dish collector.http://www.builditsolar.com/Projects/Concentrating/SOLRCONC_files/25P08.GIF

2.4 System Types

2.4.1 Passive Solar Systems

Systems, which are not equipped with a pump or other mobile parts, are called “Passive” solar hot water systems. If the water temperature inside the solar collectors, which are located on the roof and carry the water through the system, changes, it will have some influence on heating systems (Watson,1992).Since passive solar systems do not have any mechanical parts, they cost less than the systems equipped with a pump (active systems). However, their efficiency level is not the same as the active systems. Nevertheless, passive systems are more consistent and may have a longer lifespan (Giorgia Rambelli, 2013). Batch and thermosiphon are two basic kinds of passive systems (Figure14).

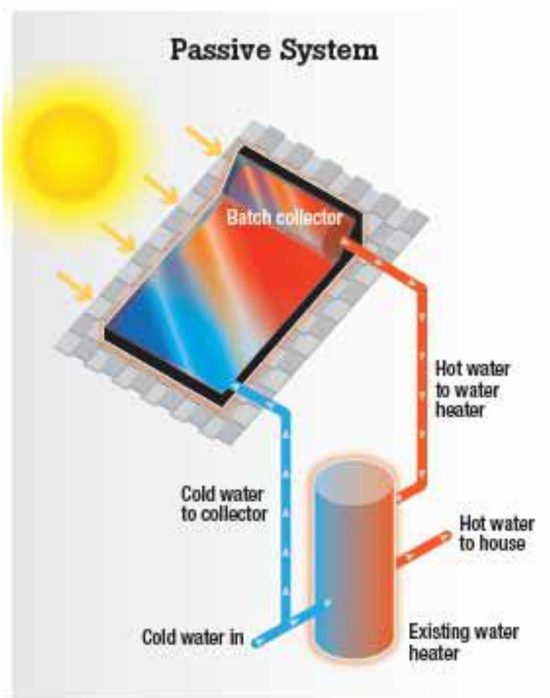


Figure 14. Passive solar water heating system integrated by a batch collector.
http://solartribune.com

2.4.2 Active Systems

Active solar water heating systems are equipped with electrical pumps and rely on them in carrying the fluid through the collector. These systems can be typically divided into two types: direct and indirect. It means that hot water comes directly from the solar collectors (one loop) and poured into the tank, or is carried indirectly by two loops which are detached by a heat exchanger and circulate water (Spate F,1999). The indirect system is generally used in places where temperatures are under freezing outdoor temperature. An anti-freeze solution is employed in such systems like a water glycol mixture, which serves as a medium of heat transfer and flows inside the collectors to prevent freezing (Figure15).

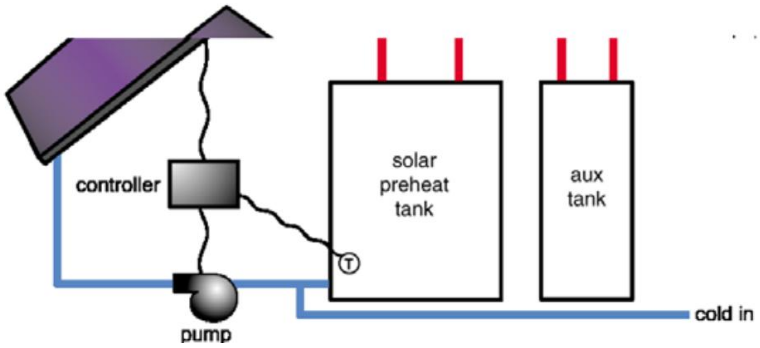


Figure 15. An active, direct solar water heating system.
http://tecc.kr/eng/sub0301

2.5 Technical Considerations of Solar Water Heating System

Technical parameters considered include installation, insulation and system's balance. Because, these parameters impact on the efficiency of collectors.

2.5.1 Connecting Pipes

The collector is connected to the tank with pipes (plastic or copper pipes) that go from the collector to the tank via a heat exchanger and back to the collector. It is very important that the water can circulate in the pipes without obstacles (e.g. sharp bends).

Here, it is very important that the heat does not get lost on the way. To ensure this, try to make the distance between the collector and the tank as short as possible, and make sure the pipes are very well insulated.

2.5.2 Absorber Coatings

Matt black paints have been widely used as coatings of absorber surfaces for many years, because they are relatively cheap and simple to apply. Some form of pre-treatment of the plate surface is usually necessary to ensure satisfactory paint adhesion. It is important to note that well applied painting methods can withstand, without degradation, high temperatures and very severe condensations in the collector, due to frame deformations and cover tightness failures.

Black paints are strong emitters of thermal (infra-red) radiation and at high temperatures they produce significant heat losses from the front cover of the solar collector.

Collector heat losses can be substantially reduced by the use of selective coatings, which have a high absorptance for solar radiation, but a low emittance for thermal radiation. Good selective surfaces are expected to have an average absorptance of greater than 0.95 and an average thermal emittance of around 0.1.

Collectors with selective coating have high efficiency either in increased operating temperature of the collector or in locations with rather low irradiance. The specific application will determine the need for selective coating in the absorber. Specialised companies produce the copper fin in rolls (of large width) with selective coating, which they cut to the width required by the individual collector manufacturers. Assurances should be required for the reliability of the selective coating (suitability to high temperatures, long life, preservation of the selective properties). The manufactures of the solar absorber have to combine (weld or "fit") the fin with the tubes .

Another commercially available product consists of aluminium fin with selective coating and with a copper tube combined to it. The product has a fixed fin width and it is sold in rolls. Solar collector producers have to cut it and to expand to copper tubes (with non-circular cross section) with compressed air.

It is to be noted that semi-selective paints are available in the market. They have lower emittance for thermal radiation than the black paints. They offer the advantage of collectors with relatively high efficiency with moderate increase in the cost. Companies exist that are specialized in the production of absorbers (black paint or selective coating), which they sell to interested parties.

2.5.3 Installation

Installing a solar water heating (SWH) system without any electrical or gas or other fuel support is desired except for very rare cases. Most of the solar water-heating systems are equipped with a supportive built-in electric heating element in the tank. It might be required on cloudy days to be operated to guarantee a consistent source of hot water (Malik Mas,1985).

Whether the temperature of a system is stable or not, it is based on the amount of warm water consumed per day in relation to the size of the hot water reservoir/tank. If the ratio of the hot water consumed per day is high in relation to the tank, the water in the reservoir must be heated more. This causes the water temperature vary significantly on daily basis, which become subject to hazards of overheating or underheating; however, it depends on the systematic design. Since the level of heating that must take place everyday related to hot water consumption rather than to the size of water storage tank. It is desired to have a large water storage tank (i.e. equal to or even larger than daily usage) which helps to prevent water temperature fluctuations (Kalogirou, S.A, 2004).

A large solar water heating system is preferred in comparison to a small system regarding to its economical benefits. Since the price of a system does not linearly depend on the size of the collector group, a larger collector system has a lower cost if the price per square meter is considered. Therefore, it is advantageous to use a system which can meet almost all of the domestic hot water needs instead of a collector which provides only a small portion of it.

It rarely happens when all installations are required to be replaced again concerning solar hot water storage. The present storage can be good enough considering their size (to be large enough). They can be later equipped with direct systems, and the indirect ones can be mounted on them using internal and external heat exchangers (Dincer I,1999).

When insulating a solar water heating system, attention must be paid to insulate completely all of the water pipes connecting the solar collector and the water reservoir tank, the reservoir tank (or "geyser") itself. Efficient installation of the coatings greatly minimizes the heat loss of the hot water system. If coatings on the pipe are insulated at least for two meters on inlet of the cold-water, the heat loss of the water tank will be reduced significantly. The installation of a "geyser blanket" surrounding the water storage tank has the same effect. In cold climates, the installation of coatings and overall insulation are often carried out even when a solar water heating system is not available.

The most efficient pumps are developed in way to start very slowly in low light levels, so if it is connected uncontrolled, they may cause a small amount of unwanted flow early in the morning – for example when there is enough light to run the pump while the collector is still cold. This is especially important when someone wants to avoid the cooling of hot water in the storage tank. In such cases, a solar controller might be necessary.

If the tubes and pipes are separated, the size of collectors can be changed with the help of modularity of an evacuated tube collector. Therefore, by having a variety of larger tubes, the collector size can change to fit the requirements in different climatic conditions.

With regard to energy output, the collectors that are installed on the roof and are directed towards the sun perform much better than the wall-mounted collectors do, especially, in the sites close to the pole. Nevertheless, customers only think about useful energy output; it is the only important aspect concerning the collectors. Accordingly a wide range of wall-mounted slope collectors can occasionally generate more useful energy as the energy in winter is a little more while some energy remain unused in summer.

2.5.4 Insulation of Solar Water Heating Systems

Insulation is the main factor to prevent heat losses. Insulation is needed for the collector, for the piping and for the tank. In a well insulated tank, the warm water can be kept warm for several days.

• Insulation must be heat-resistant, otherwise it will melt if it gets too hot. Natural materials like wood fibre or cellulose can be used up to max. 100°C (for the tank and the pipes).

• The thickness of the insulation material should be at least 5 mm.

• Insulation must be installed in a way that no water can enter inside the insulation. When insulation gets wet, its effectiveness will be significantly reduced.

• Attention: If mineral wool used, glass wool, etc. it should be awared of the fact that inhaling the fibers is dangerous for your health and can cause cancer. These materials should be carefully handled .

Solar energy systems must be adjusted so that they can generate the required temperature by energy systems. Therefore, when the domestic hot water reaches 140 °F (60 °C), the heat transfer fluid must be sufficiently hot for supplying thermal temperature. If not, an additional heating system will use more energy leading to more energy costs (Schweiger H,1997). Making use of an additional heater will not be beneficial because it will turn on and off and, therefore, cannot function on a regular basis. The insulation behind the absorber normally has to be 1-meter thick (Atlas R-Board polyisocyanurate rigid insulation board). Because of the possible high temperatures at the rear side of the absorber, it is a good idea to employ the polyiso insulation rather than polystyrene (Anthony Lopez,2012).

Concerning the determination of optimal insulation thickness, a number of techniques have been presented. Due to some economic conditions, ET1 Method3 that has recently been developed has improved insulation selection, especially the expenses concerning life cycle. It becomes very popular because once energy costs increase, more insulation is required. Some simple points regarding the technique include:

a. The heat condition and fluid-two-tube heat transfer causes the thermal resistance to present by the tube wall which is not considered. (resistance = 0).

b. Thermal radiation which is made on the surface is constant or even ignored. The percentage of the thermal resistance because of the heat transfer coefficient between the surrounding air and the insulation's outer surface (or jacketing) expect to be constant.

c. The different real and presumed diameter and the wall which employed in different kinds of tube (e.g. plastic, copper, steel) which can have an effect on heat lost is not considered. The final thickness and heat transfer area miscalculations can cause impact on the thermal resistance to the heat coming from the tube parallel with the third assumption. The major proposes of this study are as follows: (1) analyze the heat lost coefficient sensitivity to changes in the variables definition. (2) In order to construct designed graph of convenient insulation and tables, the way is that to use the most dominant of these in the model of combined heat economic/transfer. Considering these items, the following can be established as the annual heat losing for the pipes, optimal insulation, their thickness and size of the tank for solar system.
In this analyzes one should consider the outdoor and indoor piping of four operating fluids; Indoor water-filled tanks are considered in this analysis. The following variables are effective:

(1) Ambient temperature and wind velocity.

(2) Piping or storage tank hot fluid temperature.

(3) Piping material and nominal size.

(4) Working fluid type: Water, SO-SO% (by weight) ethylene glycol-water solution, silicone liquid, hydrocarbon heat transfer liquid

(5) Insulation thickness.

(6) Insulation thermal conductivity.

(7) Piping design pressure gradient (which determines liquid flow velocity).

(8) Insulation surface emissivity.

(9) Annual system usage factor.

(10) Annual payback on capital.

(11) Cost of solar heat.

(12) Cost of insulation material, jacketing and labor.

2.5.5 Loading and Balancing of the System

There is a challenge in using renewable energies that usually happens in the incompatibility between the time energy required and the time energy is used. Therefore, storage tanks consist of an integral part in hot water system because they combine the timing of an alternating solar resource with that of the hot water.

In case of the systems that supply the heat for indoor usage, using 1 to 2 gal (3.8–7.5 L) of storage water for each square meter of collector's area is usually sufficient. Once a load-side heat exchanger is used, the fluid can be potable water or non-potable water. In smaller systems, the fluid is usually stored in glass-lined steel tanks. It is possible to keep solar heated water in a single system or the storage for such water could be a separate tank that is connected to the tank of another conventional gas or even electric water heater (a "two-tank" system). In cases in which one or two tanks are employed, water is heated by solar energy before use. A solar system is capable of heating water up to 60 °C on hot days.

There is not any major difference between commercial solar hot water systems and the ones used at homes. The only difference is that the heat changer as well as piping are bigger. The storage tanks in such applications are generally steel with an interior coating. The sizes of the elements depend on the size of collector array. There is an energy backup such as electrical component in many systems. They can also be connected to a central system working with a certain fuel. In case of a temperature fall, water is heated in the tank, and such a feature allows the system to operate throughout the year in any climatic conditions. When it is necessary for solar hot water to operate in a building, a large tank may fit the requirements. Figure16 shows some of the failures of typical storage types.

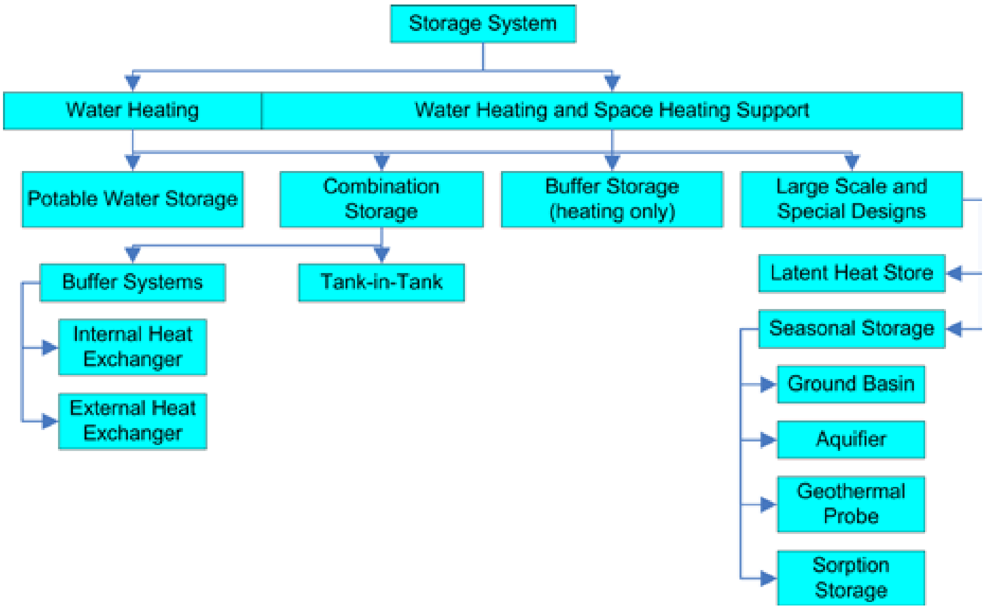


Figure 16. Different type of water storage system and their application. (US. Army Crop of Engineers, 2011)

Most large systems have stratified storage tanks where cooler temperatures are at the tank bottom and the hotter temperatures are at the top. The cooler fluid is drawn off the tank bottom and is sent to the collector system for heating. It may go directly to the collector or be used to cool the heat transfer fluid that is then sent to the collectors. Using this cooler water, increases the collector efficiency. The heat transfer fluid is held in the collector until it reaches the desired hot temperature. This is accomplished by stopping the fluid flow or by slowing the flow in the collector until the desired temperature is reached.

2.6 Solar Thermal Collectors and Their Applications

All the solar systems which employ the solar energy and its application depends upon the solar collector such as flat-plate, compound parabolic, evacuated tube, parabolic trough, fresnel lens, parabolic dish and heliostat field collectors used in these system (Kreider Jf,1977). The solar collectors are used for domestic, commercial and industrial purposes. These include solar water heating, which includes thermosyphon, integrated collector storage, direct and indirect systems and air systems, space heating and cooling consisting of space heating and service hot water, the parabolic trough which causes the systems of thermal power, industrial process of heat that includes water, air and steam generation systems, refrigeration, system of dish and power, solar furnaces and applications of chemistry (Table7).

It should be identified that the thermosiphon is a physical effect and points to a method of passive heat exchange depending on natural convection, which flows a fluid without the need for mechanical pump. Thermosiphoning is employed for circulation of liquids and volatile gases in heating and cooling uses, like heat pumps, water heaters, boilers and furnaces. Furthermore, thermosiphoning takes place in air temperature grades such as those used in a wood fire chimney or solar chimney.

Table 7. Different types of solar collectors (http://web.cut.ac.cy)

Motion	**Collector Type**	**Absorber Type**	**Concentration Ratio**	**Temperature Range (◦C)**
Stationary	Flat plate collector (FPC)	Flat	1	30-80
	Evacuated tube collector (ETC)	Flat	1	50-200
	Compound parabolic collector (CPC)	Tubular	1-5	60-250
Single-Axis Tracking	Linear Fresnel reflector (LFR)	Tubular	15-45	60-300
	Parabolic trough collector (PTC)	Tubular	15-45	60-300
	Cylindrical trough collector	Tubular	10-50	60-300

	(CTC)			
Two-axes tracking	Parabolic dish reflector (PDR)	Point	100-1000	100-500
	Heliostat field collector (HFC)	Point	100-1500	150-2000

2.6.1 Orientation of Collector in Relation to Sun Path

The orientation of the collector is determined by three angles (Figure 17):

• The azimuth* angle γ, which is also referred to as "compass orientation": this angle in a leveled surface exists between the collector and the direction towards south. As defined, due south, pointing the equator, is an orientation of 0˚.

• The tilt angle β ("sky-ward orientation"): the angle between the collector and the horizontal surface.

•The altitude angle α, the angle between the vector perpendicular to the collector plane and the projection of the Sun's central beam to the collector surface.

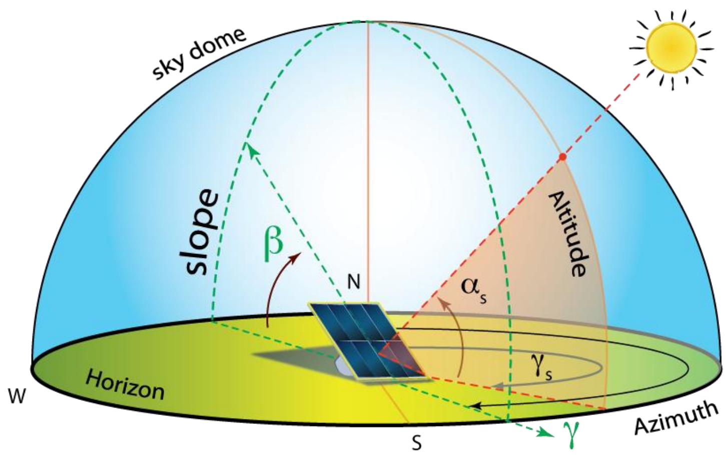


Figure 17. The angle of azimuth,tilt and altitude. www.e-education.psu.edu

Any supporting structure of collectors regarding their flat and suitable surface will not expensive. The provider of the collector generally supplies any relevant devices like brackets, etc. which are suitable for several surfaces such as tiled or sheet metal roofs, brick or wood walls etc. The equipment should be strong enough to undergo climatic changes such as wind and snow. Both the structure and installation have to meet the needs of the latest standards and relevant rules. The orientation will not be desirable if the installation occurs consistent with an existing structure (e.g., a wall surface). Actually the effects that these issues have, are not typically as assumed before mounting. Figure 18 shows the low positioning of the sun in winter and its high positioning in summer.

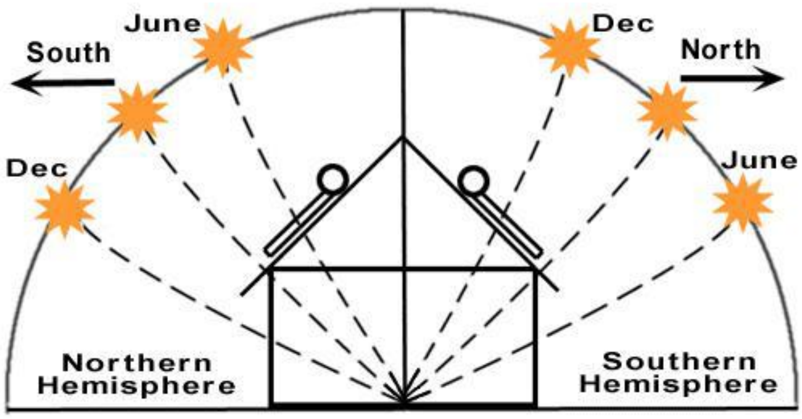


Figure 18: Solar Collector Orientation   http://www.solarcollectorinc.com

Once a solar collector is in a vertical position to the sun, it collects the most sunlight. It would be perfect if the collector were tilted in according to the sun's position in throughout the year; rather turn to follow the solar path from east to west throughout the day. A collector can have east-west tracking either with an active or passive tracking system, and can generate 20 to 40 percent extra energy, which depends on time. In case of stable non-tracking system, solar collectors are normally installed southward. It is the orientation that makes the maximum solar radiation intercepted throughout the year. There is an exception regarding this rule in which unusual climate changes or huge amount of water occurs. For example, if a cloudy weather in the morning and sunny weather in the afternoon, happens a change in collector or orientation westward can increase the entire collected solar energy.

2.6.2 The Use of Materials in Solar Collectors

It was not until 20 years ago that the absorber sheet was almost provided from copper, considered as one of the best thermal conductors. However, making such collectors in cooper was too expensive, so designers switched their attention to develop qualitative products with cheaper materials.

A major problem in solar collectors is the use of material regarding corrosion resistance. Nowadays, all solar water heaters are almost still made of copper water pipes. The second best and accessible conductor for the sheet is aluminium while the conductivity is not as good as copper (SERI,1987). Depending on their accessibility and cost effectiveness, various materials have been indicated as follows in Table 8 (Kalogirou S,1997).

Table 8.Physical properties of conductors and their availability.
(M.A. Alghoul, 2005)

Material Type	Thermal Conductivity (W/m) at 25$^{\circ c}$	Specific Heat Capacity-Cp (kj/kg K)
Iron	80	0.46
Steel	46	0.5
Stainless Steel	16	N/M
Brass	109	N/M
Aluminum	250	0.91
Copper	401	0.39
Silver	429	0.23
Gold	310	0.13

2.6.3 Placement of Solar Collectors

Installation of solar collectors is limited appropriate area. Having access to systems installed on the roof requires stairs or ladders. Mounting the collectors on the ground can impact negatively on green spaces, so that land area will be limited. Therefore, it seems reasonable to mount big collectors on parking lots. The collectors can provide shading for vehicles because they are placed both near the buildings and near the ground level so that their maintenance would be easy. Figure19 illustrates solar collectors' location in a parking area.

When a roof placement is used (Figure20), it is recommended that the expected durability of the roof is the same or even more than that of the system. When the distance between collector field, the mechanical room, and storage tank increases, level of loss increases and thus has to be decreased to the lowest level.

Figure 19. Solar hot water collectors place above parking area (http://www.yourhome.gov.au/energy/hot-water-service)

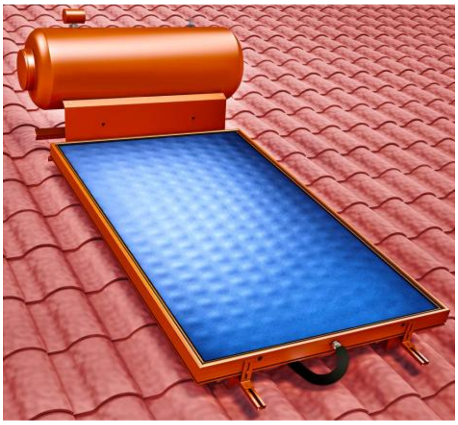


Figure 20. Rooftop Solar collectors
(http://www.yourhome.gov.au/energy/hot-water-service)

2.6.4 Blocking of Solar Radiation by Shading

Less radiation is caused by shading that can extent to the collector plane. The collector’s positioning decision is probably affected by anything cause shade over the collector plane like mountain ranges extending on the horizon, closeness to high buildings, closeness to trees (especially when having leaves in winter), and closeness to roof structures. Local fog may lead to a loss in sunbeams. It is possible to avoid shading when the sun hours are at peak during a day: 9 a.m.–3 p.m.

The loss occurring whenever there is radiation as a result of shading must be considered during simulations because the potential output will be calculated. (Figure21). Location and climatic conditions play a significant role. Shade, fallen leaves, snow should be taken into account (Figure 22).

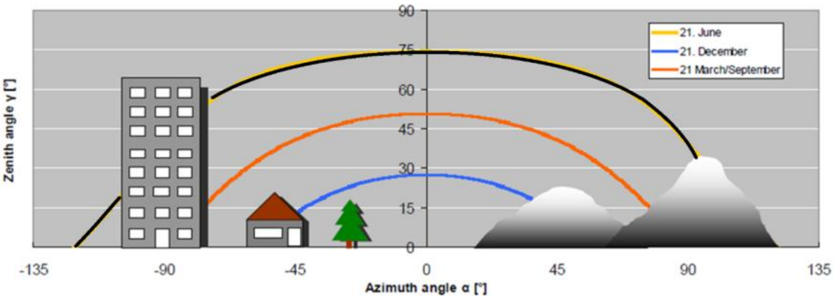


Figure 21. The impact of shading. www.harvestingrainwater.com

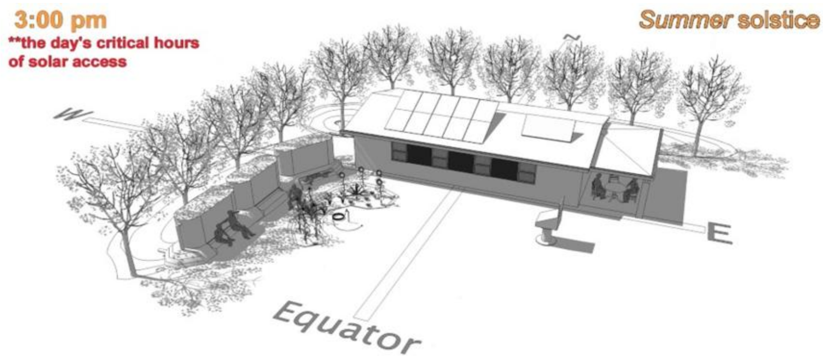


Figure 22. Suitable place of collectors and the impact of shading.
www.harvestingrainwater.com

2.7 Standard about the Amount of Hot Water in Winter

There is no differentiation between winter and summer in the studies related to hot water consumption. According to the Canadian hot water consumption, it can be assumed that on average, the typical family of four uses 125 to 250 litres (28 to 56 gallons) of hot water per day in winter. Usually the highest demand occurs during the morning rush and after dinner. Some days you may use more or less hot water, depending on your activities.

Table 9. Calculating Typical Hot Water Consumption from Newfoundland, Canada
http://www.newfoundlandpower.com

baths (1/2 full)	34 – 43 litre	
dishwasher (per load)	42 - 65	
Dish washing (by hand)	7-16	
personal use (per person, per day)	15	
hot wash/warm rinse(Laundry)	135	
hot wash/cold rinse(Laundry)	87	
warm wash/cold rinse(Laundry)	41-54	
Showers	Energy Efficient Showerhead	Standard Showerhead
5 minute	22	54
10 minute	44	110
15 minute	64	160

Chapter 3

ANALYSIS OF EFFICIENCY OF SOLAR COLLECTORS IN MULTI-STORY BUILDINGS IN FAMAGUSTA, NORTHERN CYPRUS

3.1. Data Collection Method

The present problem-solving research is a case study concentrating on the buildings with several stories in various parts of Famagusta like Canakkale and Sakaraiya. Data collection is carried out through implementation of qualitative and quantitative studies.

Efficiency of collectors in Famagusta is required; observations, participations and individual interviews were performed for qualitative researches. Moreover, some assessable data are employed in the quantitative method including such as climatic status, data concerning collector`s installation, positioning and further dimensional characteristics. Comparative analysis concerning data taken from qualitative and quantitative studies have been carried out to reach the desirable results and enable specific discussion concerning these buildings.

One of the key features with regard to qualitative research is personal observation. In practice, the initial purpose of observation is to ensure that the data are both valid and flexible. In the present research, data collection process is based on the precise personal observation. Furthermore, investigations regarding the current conditions of the buildings have contributed in gaining some information concerning the implementation of solar thermal collectors in buildings with several stories in various parts of Famagusta (Gazimağusa), North Cyprus.

For instance, for the data collection, all collectors as well as surfaces of the buildings have been counted individually. Then the data have been divided in some categories to simplify the evaluation process. The evaluation of collectors was definitely the main purpose of the observation and interview with houses which point out the process in winter with hot water supply.

The most significant tool used in this study are photos about buildings' envelopes and their essential characteristics. It has significantly facilitated to assess the impact of the sun and the shadows on the buildings. After identifying the building's location and sun's position, the collectors have been analyzed finally to work at their optimum level through implementing the solar strategies.

3.2 The Climate of Famagusta Northern Cyprus

Figure 23. Location of Gazimağusa (Famagusta) in North Cyprus (Edited by author. URL:(http://en.wikipedia.org/wiki/File:Cyprus_location_map.svg)

Famagusta, is located at 35°7'N, 33°55'E (Figure 23). Its climate is hot humid Mediterranean or dry-summer subtropical (Köppen-Geiger classification: Csa) moderately varying throughout the seasons. In summer season, it is hot and humid because high-pressure systems caused by subtropical conditions are dominant, at the same time in winter season, the temperatures are moderate, and it is rainy owing to polar weather front. Such changes in climate generally takes place on the west regions of the island at the latitudes of 30° and 45°. The island experiences plant life in summer. It is the hottest month, the average of Mediterranean climate is typically more than 22.0 °C and the average of cold climate ranges between -3°C and +18°C monthly, and it is more than 10°C at least for four months (Markus Kottek ,j. 2006).

A fixed scale is employed by the average temperature charts (Figure 24). Being at the intervals of 10 °C these charts consist of major grid lines on the left axis. Minor gridlines are located at the intervals of 2.5 °C. Locations in the northern hemisphere run from January to December and in the southern hemisphere from July to June, so that the middle of the chart always corresponds with the high sun period for the hemisphere (Ozay, 2005).

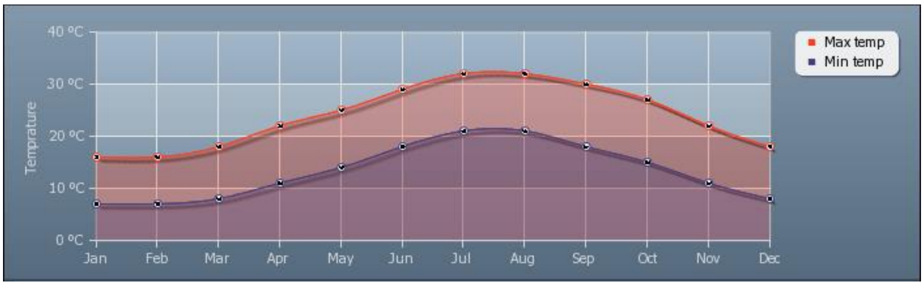


Figure 24. Maximum & minimum annually average temperature in Famagusta. URL: http://www.weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Famagusta,Cyprus.

Generally, sunlight hours varies from 5:29 in December to 12:32 per day, in July with the longest and the shortest days of the year being 14:22 and 9:37 hours long, respectively (Figure25). The longest and the shortest day differ for 4:44 hours.

Therefore, out of possible 4383 hours, every year experiences an average of 3328 hours of sunlight, i.e. an average of 9:06 hours of sunlight in a day. Therefore, it is sunny for 75.9 % hours during a day. It is mainly cloudy, hazy or less sunny for the rest 24.1% of daylight. At Famagusta, the angle of solar radiation at midday is 55.2° on average above the horizon.

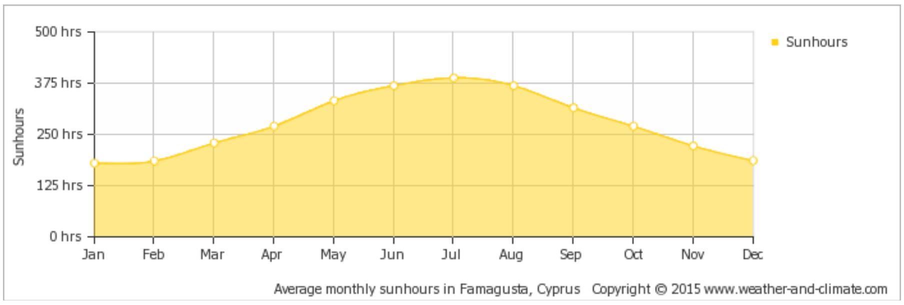


Figure 25. Average monthly hours of sunshine in Famagusta. http://www.weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Famagusta,Cyprus, (2015)

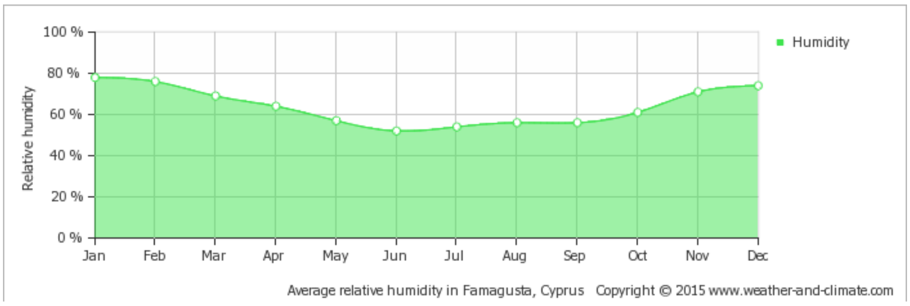


Figure 26. Average annually humidity in Famagusta. http://www.weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Famagusta,Cyprus, (2015)

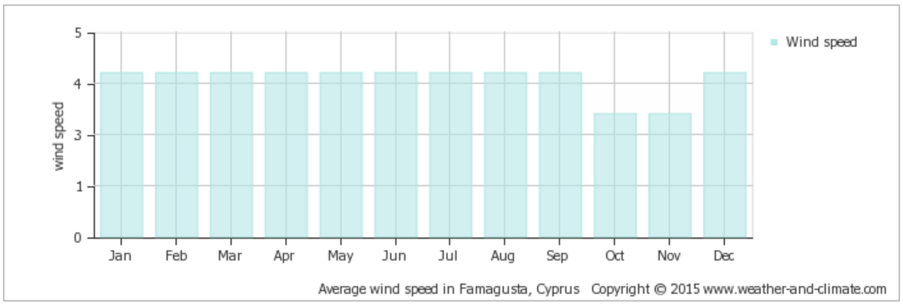
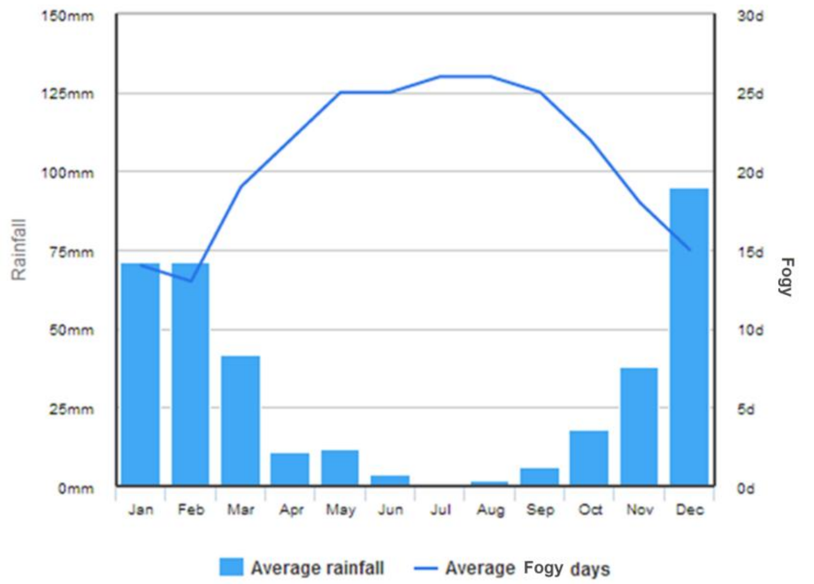


Figure 27.Average annually wind speed in Famagusta. http://www.weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Famagusta,Cyprus, (2015)

Famagusta experiences an average of 403.5 mm rainfall annually (33.6 monthly). Generally, the rate of rainfall is 47 days a year with over (0.1 mm), in other words, there are 3.9 days with some rain and snow per month. July experiences the driest weather conditions with an average of 0.5 mm of rainfall. The wettest weather takes place in December when the average of rainfall is 106 mm (Figure 28).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mm	71	71	42	11	12	4	0	2	6	18	38	95
Days	14	13	19	22	25	25	26	26	25	22	18	15

Figure 28. Monthly average precipitation consists of: rain,hail & snow.http://www.holiday-weather.com/famagusta/averages

Analysis of above mentioned data shows the average cloudy,sunny & mild days as follows in Table 9:

Table 10. Average cloudy,sunny & mild days in Famagusta. www.holiday-weather.com

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cloudy days	12	11	10	7	4	2	1	1	2	5	7	11
Sunny days	10	10	12	13	16	17	17	17	15	13	11	10
Mild days	9	8	9	10	11	11	12	13	13	13	12	10

3.3 The Role of Climatic Conditions on Absorption Rate of Solar Collectors in Famagusta

Based on the data mentioned before concerning Famagusta's climatic conditions, this region has a high capability for solar energy to be employed in collectors. The main significant issue to be considered is the number of rainy days in which the hot seasons outlast cold seasons. In other words, the amount of precipitation (rainfall and snow) per millimeter in winter is more than that of in summer, but the number of cloudy days in summer is influential in the efficiency of collectors. Nevertheless, February experiences less rate of sunlight compared to June when the rate of sunshine is three times more. This shows that solar collectors must be employed with the highest rate of sunshine. On the other hand, the factors such as precipitation and humidity have to be taken into consideration. In fact, the collectors' rate of absorption rate is less compared to the normal solar radiation. This is mainly due to the fact that ozone layer reflects some amount of solar radiation and clouds disperse some other portion. Both the foggy and rainy day analyses influence collectors' efficiency in different manner.

For instance, July experiences the extreme rate of sunshine in Famagusta, where no precipitation takes place, but the amount of fog increases in July, which means that the fog and clouds obstruct collectors'performance negatively.

3.4 The Role of Orientation on Energy Absorption and Collectors Efficiency in Famagusta

Proper orientation plays an important role with regard to solar energy absorption, which in turn reduces the efficiency of the collectors. A study has been carried out on two multi-story buildings in the following parts of Famagusta (Figure29,30,31,32). The reason of selecting these two cases is their similarity with other prevalent examples of Famagusta. In other word, these cases represent majority of collectors used in Famagusta city.

Figure 29. View of Haci Ali Multi-Story Building

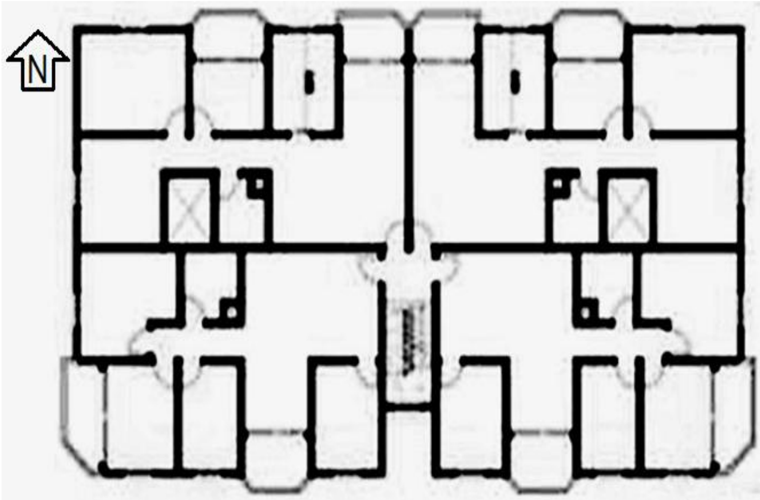


Figure 30. Ground Floor Plan of Haci Ali Multi-Story Apartment


Figure 31. View of Social Housing Complex

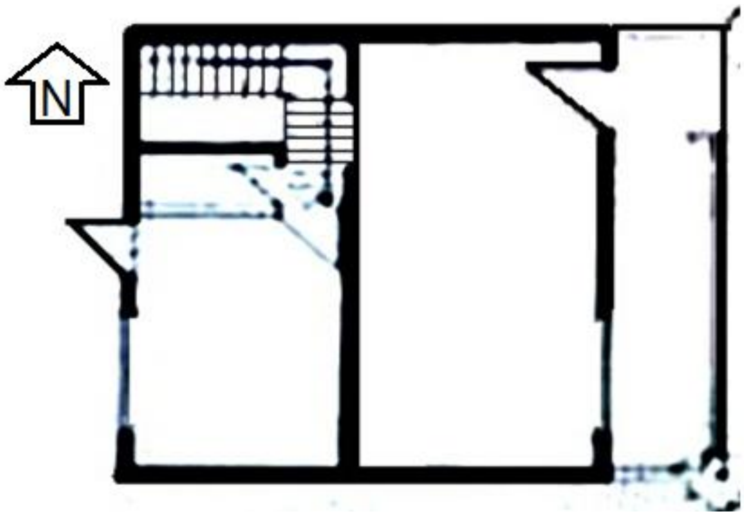


Figure 32. Ground Floor Plan of Social Housing Complex

One example is the Haci Ali Apartment Building in Famagusta (Block H), a multi-storey building. It consists of twelve apartments in three floors. The apartment building is located to 25 degree of southeast.

Figure 33. Orientation of Haci Ali Buildings on Site

Haci Ali Apartment Building is oriented at 25(SE) degree (figure33). Haci Ali Apartment Building has a flat roof and has two sets of solar collector systems. Here a flat-plate solar collector system with harp tubes has been used. The water storage tank height is 100 cm and the angle of flat plate collector is about 40 degree.

The other example is the two-story Social Housing Complex near the EMU in Famagusta. It consists of two units in two stories. The apartment building is orientated to 45(SW) degree. The roof is sloped and there are two sets of solar collector systems placed in varies directions. The orientation of one is just parallel to building while the other is to southwest (figure34,35). Here a flat-plate solar collector system with harp tubes has been used. The shape of both water storage tanks and the plate angle are similar to Haci Ali apartment building.

Figure 34. Orientation of Azimuth as Row House Unit

Figure 35. View of Social Housing Complex with Single Storey

In order to improve the use of solar energy, the main building should be orientated to southward, with 15 degree to southeast. This range comprises sites, buildings and collectors' angle. Therefore, most of the buildings taken into account in Famagusta are not oriented properly regarding to solar criteria. Some parts of the building`s orientation is to south at a maximum level. However, northern and eastern sides will have the least exposure to the sun.

Sometimes street directions in the city affect the building's angle as opposed to solar criteria. Consequently, orientation of the building can modify this problem throughout the designing process; however, concentrating on the orientation of the collectors can be the most influential factor to make the current condition more efficient(Ozay, 2005).

3.4.1 Building Orientation

Based on the solar criteria, street orientation in the city affects the building`s orientation. As a result, such problems may be highlighted depending on the building's orientation during design process. However, proper orientation is assumed to be the most influential factor in making the current condition much better. The orientation angles of Haci Ali buildings and social housing buildings with one floor in Famagusta are about 25 degree and 45 degree (Figure36,37).

Figure 36. The Azimuth Angle of Haci Ali Blocks on Site (Case I)

Figure 37. The Azimuth Angle of Social Housing Complex on Site (Case II)

3.4.2 The Orientation of Solar Collectors Located on the Roof

The orientation angle of the collectors on the roofs of buildings in Famagusta is like the orientation of the buildings angle like Haci Ali Buildings, which are inaccurate (figure38).

Figure 38. The Azimuth Angle of Collectors in Haci Ali Apartment

However, some collectors run separately. For example, the collectors' orientation angles in Social Housing Complex do not match with the orientation angle of the building. Two important points exist here, which are effective on collectors' energy performance as well as the building's aesthetic problems. First of all, the orientation of the collectors are in different angles. In addition, the collectors are oriented in opposite directions on top of the roof. Nevertheless, the orientation of collector matches an optional slope (figure39).

Figure 39.Different Orientation of Solar Collectors in Social Housing Complex

3.4.2.1 Shadow Analysis of the Collectors

Shading is supposed to be the most important factor playing a significant role concerning varying performance of the collectors, especially shading caused by trees, chimneys or another building. The worst scenario takes place when shading completely blocks the collectors; the solar collectors cannot run at all. Therefore, preventing complete shading as much as possible must be considered the whole time; however, it can be restricted very early in the morning or late in the evening.

For example, in winter the collectors' bottom components in Haci Ali's apartment building are all blocked and are under shadow. Concerning the collectors, the signs of dew appear on the glass surface, particularly in the evening. It is clear that these marks have effect on the overall performance of the collectors as well as their durability (figure 40).

Figure 40. The effect of shading on solar collector energy performance by studying case examples

3.4.2.2 The Role of Tilt Angle

To understand the angle of solar radiation,it is helpful to find the correct orientation of the collectors in which they are exposed to solar rays for a long time; the rate of energy output increases. Flat-plate solar collectors are placed in a fixed position on the roofs in Famagusta (Figure 41).

Figure 41. Tilted Angles of the Collector in Haci Ali Apartment in Famagusta

3.5 Analysis of Water Tanks and Heat Exchanger

The position, distance, height, capacity, and insulation must be considered in the analysis of water tanks. There must be a heat exchanger in the tank. It is used to transfer the heat from antifreeze liquid to the water tank that flow through the heat exchanger (Figure 42).

Figure 42. The Water Tank

3.5.1 The Position of Water Tanks

The most important factor regarding the position of the water tank is to mount it on top of the roof, rather than locating it indoors. There is an increased dead load of the building if the tank is mounted on the roof, which is a disadvantage for the collector`s performance. However, some stored thermal energy is lost at nights. On the other hand, it is a good idea to mount the water tank at the back of solar collectors, since it casts no shadows on the collectors.

3.5.2 Capacity of Water Tanks

Tanks must contain some space for the installation of a solar storage in the hot press or boiler room. The following table 10, provides an idea of the size of standard solar water tank depending on the number of people in a household:

Table 11. Capacity of Water Tanks (www.sei.ie/reio.htm)

Number of People in the Household	**Volume of the Solar Hot Water Tank**
2-3	100-200 litres
4-5	200-300 litres
6-7	300-400 litres

On the other hand, a water tank having a capacity of 0.6 m^3 at the back of solar collectors can store hot water. In addition, a barrel with a capacity of 0.2 m^3 for storage of expanded hot water is compulsory. The following table 11 compares the capacity of two case examples in Famagusta.

Table 12.Comparing the capacity of two cases

Present Data			**Standard Data**	
Case-Study	**Number of People in the Household**	**Volume of the Solar Hot Water Tank**	**Number of People in the Household**	**Volume of the Solar Hot Water Tank**
Social Housing	2-3	600 litres	2-3	100-200 litres
Haci Ali Multi-Story Building	3-5	600 litres	6-7	300-400 litres

3.5.3 Height and Distance of Water Tanks

In the process of solar heat circulation, the heat is conveyed from the collector to the hot water tank. If the least heat loss is desired, the space between the collector and the tank must be as short as possible; it should be mentioned that mounting the tank on rooftop must be avoided.

Considering these issues, galvanized pipes having a perimeter of 15 mm to 18 mm are employed to make the best use of heat transportation. In these structures, galvanized pipes with a diameter of 18 mm were employed. The fitting for these pipes are ½ inches (Figure 43).

Figure 43.Height and Distance of Water Tanks of Solar Collectors in Social Housing Complex

3.5.4 Insulation

The pipes of this system are equal to 30 mm, but they are not appropriately insulated with a 30 mm –polyurethane foam pipe. The insulation would be able to resist high temperatures. In addition, the outdoor section should be UV-radiation and withstand climatic conditions. However, the foams do not cover the whole pipes either (Figure 44).

Figure 44.The insulation of Collectors in Haci Ali Apartment

Chapter 4

RESULTS AND RECOMMENDATION

4.1. Building Orientation

The solar collectors are required to be placed in a best direction to get the highest amount of solar radiation. However, some variables must be considered in determining the greatest direction. This is absolutely essential in any kind of collectors capturing solar energy. This chapter is dedicated to identify the finest position of solar collectors in Famagusta.

Table 13. The Azimuth Angle of the Case Examples

	Case 1: Haci Ali Multi-Story Building	**Case 2: Social Housing**	**Optimum Rate**
Azimuth Angle of the Building	25◦ (SE)	45◦ (SW)	15◦-25◦ (SW)

Consequently, none of the orientation angles are optimum since the orientation angle of Haci Ali multi-story building and that of Social Housing have the rates of 25° (SE) and 45◦ (SW), respectively, which are not optimum as the best rate is 15°-25° (SW) according to the studies(Table 12). In practice, changing the orientation angle of the building is not a viable option, but the importance of solar energy and its planning in Famagusta city is recommended (Figure 45).

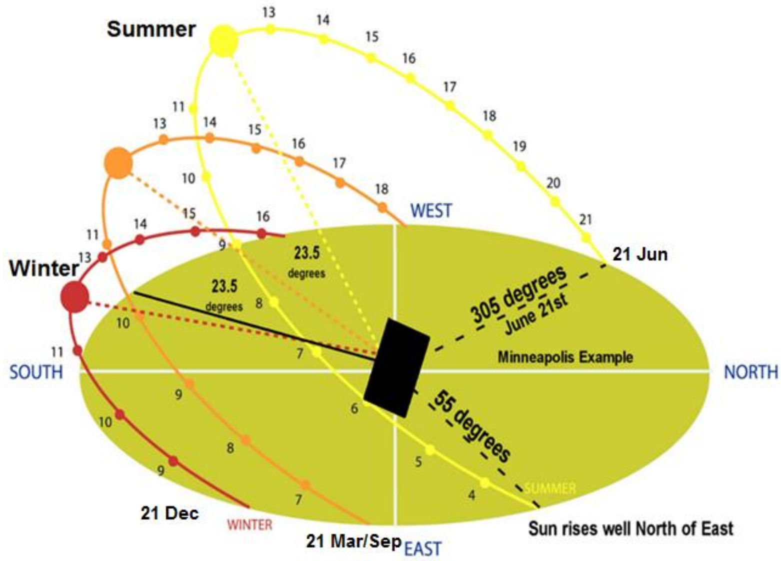


Figure 45. Optimum azimuth angle for Famagusta

4.2. The Orientation of Collector

The orientation angle of collectors of Haci Ali Multi-Story Building are equal of the building orientation, but the orientation angle of one of the collectors is different in Social Housing Complex. The table13 shows the present recommendations of the orientation angles of these cases.

Table 14. The Existing Orientation of the Case Examples and Recommendations (Ulgen, 2006)

	Case 1: Haci Ali Multi-Story Building	**Case 2: Social Housing**		**Optimum Rate**
		Type 1	**Type 2**	
Azimuth Angle of the collector on building	25◦ (SE)	45◦ (SE)	45◦ (SW)	15◦-25◦ (SW)
Tilt Angle of Collectors	45◦	45◦	45◦	55.15◦

In the two case studies above, the tilt angle of collectors is fixed, and this has a negative influence on their efficiency. Nevertheless, fixed angle is favored as it is the easiest position for mounting the collectors. However, the solar altitude angle is higher in summer compared to winter, adjusting the tilt angle of the collector depending on the season can help to gain 25 % more solar energy throughout a year. The effects of angle adjustments are illustrated in table14. The comparison varies a little in various latitudes. The second stage involves adjusting the tilting level of the collector at a given horizontal angle. According to some books and articles concerning solar energy like Keith Lauer (Celluloid Collectors Reference) and tilting degree must be the same as latitude to which 15 degrees must be added in winter and from which 15 degrees must be subtracted in summer. Such changes would enhance the efficiency of the collectors, which means they work up to 4 % better than their position without adjustments.

Table 15. Recommended Position of Collector (http://www.solarpaneltilt.com)

Collector Position	**Fixed**	**Adj.summer and winter seasons**	**Adj. every 4 seasons**
% of optimum ((latitude degree or 35) + 15))	71.1%	75.2%	75.7%

The following table 15 shows an outline regarding the most optimum tilt angle of the collectors depending on the season for gaining the most rate of solar energy.

Table 16. Best tilt angle of collectors (http://www.solarpaneltilt.com)

Latitude	**Average Angle for Summer**	**Average Angle for Spring and Fall**	**Average Angle for Winter**
(Famagusta) is 35°	23	46.5	70

The most amount of solar energy is captured in winter (81%-88%) provided that the collector is adjusted at winter angle. However, in other seasons, the rate of efficiency is lower than winter (it is 74%-75% in spring and fall and 68%-74% in summer) since the sun covers a vast area of the sky and, as a result with a fixed position will not have enough efficiency to attain the desired amount of the solar energy (Figure 46).

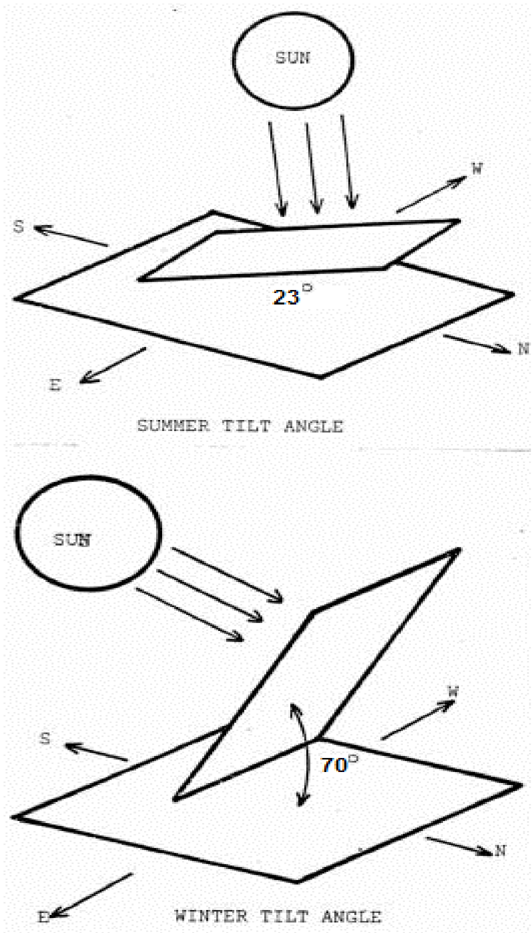


Figure 46. Average solar collector tilt angle in Famagusta
http://www.solarpaneltilt.com

It is recommended that a solar collector have a fixed tilt angle so that it can capture the most amount of solar energy during the year. A solar collector with a fixed angle is ideal; however, it must be mentioned that a fixed angle has its own deficiencies. As it was mentioned earlier, it gains less solar energy than an adjusted angle.

Some examples are provided in the following table16 for the latitude of Famagusta. It presents the collectors' average insolation annually as well as the amount of the energy captured compared to the best tracker.

Table 17. Optimum Absorption of Collectors in Famagusta (Ulgen, 2006)

Famagusta Latitude	Fixed angle	% of optimum
35°	29.7	71%

It is concluded that based on Keith Lauer's Celluloid Collectors Reference, when the range of latitude is between 25° and 50° , like Famagusta with the latitude of 35° , the optimum tilt angle would be an average of 70° in winter, and 23° in summer.

4.3 Shading

The performance of solar flat plate collectors have been taken into consideration in recent two decades. They are employed to generate low-temperature heat by using solar radiation. As it was noted earlier, shadow does not influence the performance of Social Housing Complex. Unlike Social Housing Complex, the lower parts of Haci Ali Building are covered by shadows in winter. Looking closely at the collectors, a sign of dew is seen on its glass particularly at sunset. It is clear that the amount of the energy captured by the collector is affected consequently, and so is its survival period. (Figure 47).

Figure 47. The effects of shading on solar collector's energy performance by roof access

The main use of flat plate collectors is for hot water supply and space heating. The flat plate collectors are typically connected in rows or parallel form designs so that the desired design would be achieved providing the temperature for a given application. The arrays are commonly sorted out in parallel rows as well as columns in which the collectors are directed towards the equator and are tilted at the best tilt angle as is shown in figure 48.

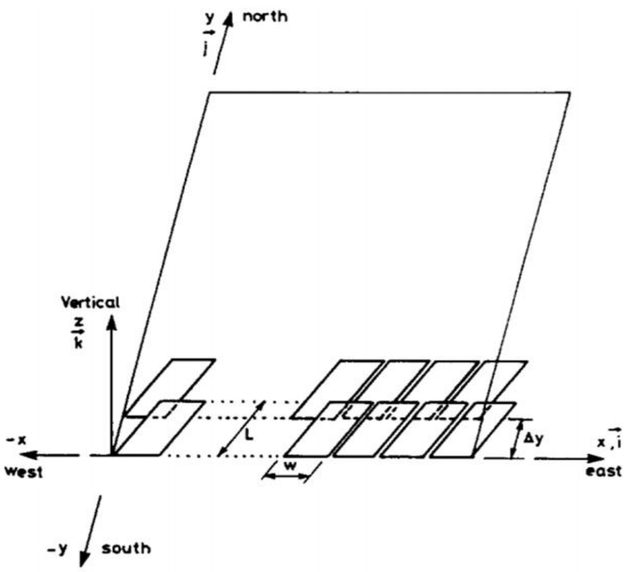


Figure 48. Collectors field geometry

For example, concerning the collector field illustrated in figure 48, the orientation of all collectors are towards the equator, that is, south in the northern hemisphere and they are tilted over the horizontal plate. The collector field includes some parallel rows shown as the distance Ay where each row has N collectors; however, N usually varies in all rows. The collectors' dimensions are W and L as shown in the figure 49.

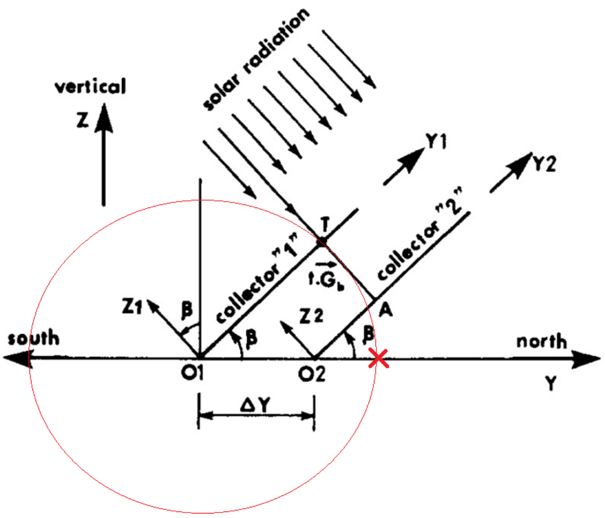


Figure 49. Collectors Best Installation to Avoid Shading

One of the important features of planning concerns the position of solar panels. As a result, the other factors besides shadowing must be taken into consideration. In order to enhance the performance of the collectors in the buildings, the following table17 is suggested.

Table 18. Advantages, Disadvantages and Recommendation on Shading

Type	**Case 1: Haci Ali Multi-Story Building**	**Case 2: Social Housing**		Recommendation
		Type 1	**Type 2**	
Advantages	-	no shadow	no shadow	Changing the Place of Collectors
Disadvantages	Aesthetically not very appealing	Aesthetically not very appealing	Aesthetically not very appealing	-

However, it must be noted that another problem in Famagusta regarding the collectors is shading. Hence, it is suggested that the water tanks should be installed in internal places rather than rooftop.

4.4 Water Storage Tank

Once energy systems, which gain their energy via solar systems, are employed, there is a reduction for the consumed energy financial costs for the domestic heating, hot water heating decreases; and fossil fuels will be avoided. A lot of key elements play an important role in a solar system with a perfect design including suitable area for locating the thermal solar collector, the volume of tank, collector's tilt degree, and the quality of the used components (Skalík,2014). Water storage tanks are not suitable in case of Famagusta. The table18 shows their characteristics.

Table 19. Water Storage Tank of the Case Examples

	Case 1: Haci Ali Multi-Story Building	**Case 2: Social Housing**	**Optimum Rate**
Diameter	45 cm	45 cm	100~200 cm
Height	90cm	90cm	100~200 cm

The optimum rate is for standard family. As is clear, the standard family means capacity of hot water is for 4 person.

One of the significant factors of the thermal solar systems is concerned with designing a suitable storage tank with an appropriate volume. Once too large tanks are designed and installed, they will impose a series of disadvantages in residential buildings such as spending too much money and a limited space for the installation as well. Another weak point occurs when the tank becomes extremely hot. This heat is usually not consumed and even after some time gets cold. Therefore, it leads decreased performance of the system (Skalík,2014).

The performance of thermal solar system was calculated by the use of storage tank volume. No changes occurred with regard to the height and width ratio (diameter) of tank. Figure 50 shows how the volume of storage tank affects the thermal solar system's performance. In this example, obviously, a capacity of 150 liter is desirable for solar thermal system. The overall performance of the solar system will be affected if the volume of storage tank is increased or decreased. The higher ratio will lead to better performance. At first, there is a strong relationship when total volume is between 105 and 160 liters. In such a range, the system performances vary about 6% (2% per 1 liter). This relationship decreases between the range of 160 and 240 liters (0.3% per 1 liter), and becomes an almost linear dependence when it is about 240-290 (0.1% per 1 liter) (Skalík, 2014).

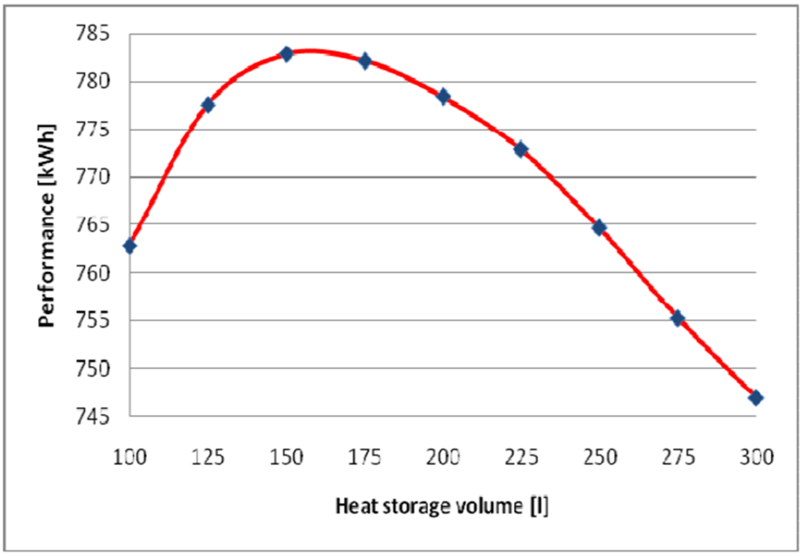


Figure 50. The impact of heat storage volume on performance of solar thermal system (Skalík,2014)

Consequently, the cylinder-shaped tank is considered in the selection of proper height/diameter ratio. This is very important since using a tank with a diameter much bigger in relation to the height prevents efficient heating of domestic water through spiral. Therefore, it is concluded that if with a ratio of 2, the performance of the system will improve. However, there should be a logical limit so as not to design very thin tanks with the result of thermal loss. It can also lead to rather small storing capacity in relation to the height of tank. Furthermore, when the height/diameter ratio is 2 or more, an optimum thermal stratification happens for the spiral tank. Therefore, height/diameter ratio is equal two or more than the ratio suggested.

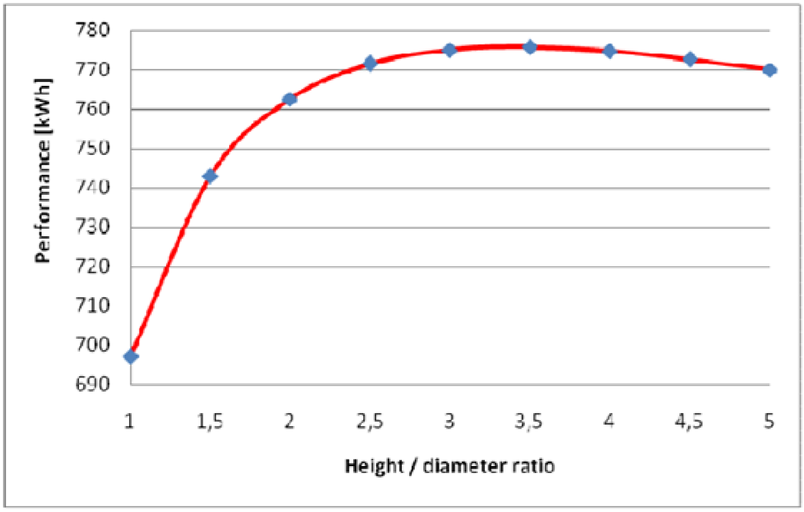


Figure 51. The impact of height/diameter ratio on performance of solar thermal system (Skalík,2014)

Once the height/diameter ratio of the hot water tank reaches 3.5, the thermal solar system is desirable as shown in figure 51 With regard to height/diameter ratio, any rate less or higher than 3.5 would affect the performance of thermal solar system. It is possible to enhance the system performance by 31 % if four parameters of the solar thermal system are used successfully. These parameters include heat loss coefficient, the area of the aperture, the volume of the tank, and height/diameter ratio.

4.5 Heat Loss in Winter/Insulation

In order to make the most use of amount of solar energy absorbed in winter and during the year, the collector's tilt must be adjusted according to winter settings. Adjusting the tilt in other seasons, helps get more solar energy; however, sufficient amount of energy is absorbed when it is adjusted according to winter settings. In the following table 19, the tilt angle is set at winter settings throughout the year. It shows the rate of insolation on the collector daily with an average rate over the season.

Table 20. Latitude 35° for Famagusta

Season	Insulation Constant on collector	% of winter performance
Winter	5.2	100%

The insulation constant on collector calculated uses different unit, therefore it does not have any special unit. The collector insulation constant it will be 5.2 by appropriate solar collector and water tank, best tilt angle of collectors and their orientation.

Nowadays, based on the differences between inlet fluid temperature of a collector (Ti) and the ambient temperature (Ta), the Solar Rating and Certification Center (SRCC) ranks collectors in various categories. Hence, the collectors with the best performance in water temperature range are required.

In case of seasonal heating, an uninsulated and unglazed collector will beat out a flat plate, concentrating or evacuated tube collector at a fraction of the cost.That is because an unglazed collector heats water at the temperature of 27$^{\circ c}$ when it is also 27$^{\circ c}$ outside. Under such circumstances, the collector runs at the temperature close to that of the air around, that is, the ambient air temperature, and as a result, no heat loss occurs. Consequently, an insulated rectangular frame, which has a glass coating, is not required (Table 20).

Table 21. Category of Collectors Application in the Climate of Famagusta

Category	(T inlet –T ambient)		Heating Application
C	20 $^{\circ C}$	2$^{\circ C}$	Water Heating in Warm and Hot Climate

Once the temperature begins to rise, designing a collector that can preserve the most of heat in addition to insulation of the collector to prevent heat losses seems necessary. Depending on location and season, collectors operating on water run at around +6 degrees celcius of the ambient temperature while domestic hot water collectors are developed to run in cold months and at high temperatures ranging from (-4) – (+52) degrees celcius above ambient temperature (Table 21).

Table 22. Category of Solar Insolation Level under Different Sky Conditions in Famagusta latitude of 35 degrees (http://www.solarpaneltilt.com)

Category	Solar Insolation Level
Clear Day	6.39 kWh / m3
Mild Cloudy Day	4.72 kWh / m3
Cloudy Day	3.06 kWh / m3

Solar collector performance is calculated with this formulation:

Solar collector`s performance = solar insolation level (kWh / m3) $\times$ days.

Solar collector`s performance in clear days: 6.39 kWh / m3 $\times$ 161 =1028.79

Solar collector`s performance in mild cloudy days: 4.72 kWh / m3 $\times$ 131 = 618.32

Solar collector`s performance in cloudy days: 3.06 kWh / m3 × 73 = 223.38

In summary, other renewable energy sources for instance geothermal energy (heat pumps) might be one alternative to gap the bridge for hot water supply in cloudy days. The use of heat pumps could enhance the performance of present collectors in Famagusta. Flat plate collectors are usual in Cyprus because of their eassy maintenance but their performance are lower than thermosiphon and evacuated types of solar collectors. On the other hand, replacing heat water solar collectors with photovoltaics can be better alternatives for these systems because they generate electric power with low rate of energy waste. However, using wind power in Famagusta city can not be ignored because of its great potential in this climate.

Chapter 5

CONCLUSION

The application of renewable energy systems based on solar collectors can reduce the use of fossil fuels and domestic hot water supply. Performance of solar collectors depends on local and solar criteria such as appropriate solar collector and water tank, tilt angle of collectors and their orientation.

None of the orientation angles are optimum since the orientation angle of Haci Ali multi-story building and that of Social Housing have the rates of 25° (SE) and 45° (SW), respectively, which are not optimum because the best rate is between 15°-25° (SW). In practice, changing the orientation angle of the building is not a viable option; however, solar energy is so important, the implementation in buildings of Famagusta is recommended here.

The collectors of Haci Ali Multi-Story Building are equal of the building, but the orientation angle of one of the collectors is different in Social Housing Complex. The tilt angle of collectors is fixed, and this has a negative influence on their efficiency. Nevertheless, fixed angle is favored as it is the easiest position for mounting the collectors. However, the solar altitude angle is higher in summer compared to winter, adjustment of the tilt angle of the collector (according to the season) can help gain 25 % more solar energy throughout a year.

It is recommended to have a fixed tilt angle, to get the most energy over the whole year. A fixed angle is convenient, but notes that there are some disadvantages. As mentioned above, it captures less solar radiation than if it is adjusted angle.

It is concluded that based on Keith Lauer's Celluloid Collectors Reference, when the range of latitude is between 25° and 50° , like Famagusta with the latitude of 35° , the optimum tilt angle would be an average of 70° in winter, and 23° in summer.

The performance of solar flat plate collectors have been taken into consideration in recent two decades. They are employed to generate low-temperature heat by using solar radiation.

The flat plate collectors are typically connected in rows or parallel form designs so that the desired design would be achieved to provide the temperature for a given application.

One of the important features of design concerns is the position of solar panels. As a result, the other factors besides shadowing must be taken into consideration.

It must be noted that another problem in Famagusta regarding the collectors is shading. Hence, it is suggested that the water tanks should be installed in internal places rather than rooftop.

One of the significant factors of the thermal solar systems is the problem of suitable storage tank with an appropriate volume. Once too large tanks are designed and installed, they will impose a series of disadvantages in residential buildings such as financial cost and space limitation and the installation as well.

The performance of thermal solar system was calculated by the performance of water storage tank volume. No changes occurred with regard to the height and width ratio (diameter) of the water storage tank. Obviously, a capacity of 150 liter is desirable for solar thermal system. The overall performance of the solar system will be affected if the volume of storage tank is increased or decreased. The higher ratio is the better performance. At first, there is a strong relationship when total volume is between 105 and 160 liters. In such a range, the system performances vary about 6% (2% per 1 liter). This relationship reduces the ranges between 160 and 240 liters (0.3% per 1 liter), and becomes an almost linear dependence when it is about 240-290 (0.1% per 1 liter). Consequently, the cylinder-shaped tank is considered in the selection of proper height/diameter ratio.

Once the height/diameter ratio of the hot water tank reaches 3.5, the thermal solar system is desirable. With regard to height/diameter ratio, any rate less or higher than 3.5 would affect the performance of thermal solar system.

It is possible to enhance the system performance by 31 % if four parameters of the solar thermal system are changed. These parameters include heat loss coefficient, the area of the aperture, the volume of the water storage tank, and the height/diameter ratio.

In order to make the use of high amount of solar energy absorbed in winter and during the year, the collector's tilt must be adjusted according to winter settings.

For seasonal heating, an uninsulated, unglazed collector will beat out a flat plate, concentrating or evacuated tube collector at a fraction of the cost. That is because an unglazed collector heats water at the temperature of 27℃ when it is also 27℃ outside.

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