

**AN INVESTIGATION ON THE PERFORMANCES OF  
DOMESTIC HOT WATER SYSTEMS IN TURKISH  
REPUBLIC OF NORTHERN CYPRUS**

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## ABSTRACT

Cyprus, as the island, is the world leading country in the usage of solar energy for solar domestic hot water systems (SDHWS). The study concentrates on how efficient these systems are used in Turkish Republic of Northern Cyprus (TRNC). The expected performances of SDHWS were initially estimated using the radiation data of the year 2007. The effect of collector tilt and azimuth angles on the performance of SDHWS were observed. A total of 10 laboratory tests were conducted with collector azimuth angles changing from 40°E to 40°W and 2 different tilt angles. 6 T-Type thermocouples were used with a data logger system to record the temperature data within the hot water cylinder (HWC). The results were compared with the estimated theoretical results and the efficiencies were found to be between 25 to 30%.

The performance of SDHWS in use in TRNC were tested by additional 10 on-site experiments. A total of 2 thermocouples were used in these test and only the temperature change at the upper and lower parts of the HWC could be measured. The energy absorption was calculated by assuming a linear temperature variation within the HWC. The efficiencies of SDHWS were determined to be as low as 15% to 25%, and 30% of the collectors tested were not working properly at all.

**Keywords:** Solar domestic hot water systems; performance measurements; thermosyphonic systems; solar radiation

## ÖZET

Kıbrıs adası güneş enerjisi ile sıcak su üreten sistemlerin kullanımı konusunda dünya lideri konumundadır. Bu çalışmada, bu sistemlerin Kuzey Kıbrıs Türk Cumhuriyeti'ndeki (KKTC) kullanım verimliliği üzerinde durmaktadır. 2007 yılı için verilen radyasyon değerleri kullanılarak sıcak su güneş enerjisi sistemlerinin performansları konusunda ön hesaplamalar yapılmıştır. Güneş panellerinin eğimlerinin ve güney istikametinden olan sapma açılarının etkileri incelenmiştir. 2 farklı eğim ile 40° doğu ve 40° batı arasında farklı açılarda toplam 10 laboratuvar deneyi yapılmıştır. Bu deneylerde, 6 adet T-Tipi ısıl çift kullanarak sıcak su deposu içerisindeki sıcaklık değişimleri kaydedilmiştir. Elde edilen sonuçlar ön görülen teorik sonuçlar ile kıyaslanmış ve verimliliklerin %25 ile 30 arasında değiştiği gözlenmiştir.

KKTC'de kullanımda olan sıcak su güneş enerjisi sistemlerinin performansları 10 farklı saha deneyi ile test edilmiştir. Bu ölçümlerde sıcak su deposunun sadece üst ve alt sıcaklıkları 2 ısıl çift kullanarak ölçülebilmektedir. Enerji hesapları doğrusal sıcaklık değişimi varsayımı ile yapılmıştır. Test edilen sistemlerin %30'unun düzgün çalışmadığı geriye kalanların verimliliklerinin %15 ile 25 arasın değiştiği belirlenmiştir.

**Anahtar Kelimeler:** güneş enerjisi sıcak su sistemleri; performans ölçümleri; termosifon tıptı sistemler; güneş radyasyonu

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## LIST OF ABBRIVIATIONS AND SYMBOLS

<b>SDHWS:</b>	Solar domestic hot water systems
<b>SWC:</b>	Solar water cylinder
<b>GMT:</b>	Greenwich mean time
<b>NEU:</b>	Near east university
<b>Lab:</b>	Laboratory

# **CHAPTER 1**

## **INTRODUCTION**

Fossil fuels are the most commonly used energy type all over the world. However, their reserves are diminishing every day. Besides, the usage of fossil fuels is causing global warming and pollution. Renewable energy sources like solar energy, wind energy, and many others are in demand (Jimenez and Lawand, 2000).

Solar energy, being the main source of energy, is used in wide range of applications such as power plants of solar thermal electric, photovoltaic cells, solar domestic hot water systems (SDHWS), passive solar energy systems, solar lighting, solar cars and boats, solar power satellite and solar updraft (Allen and You, 2002).

Solar domestic hot water systems (SDHWS) are widely used all over the world. Mainly, they consist of solar collectors and hot water storage tank. These systems can be classified as active and passive systems. In active systems, the circulation of water is forced by a pump where as in passive systems, it is natural.

Active solar water heating systems can be further classified as direct and indirect circulation systems whereas the basic types of passive systems integral collector-storage passive systems and thermosyphon systems. Active solar water heating systems are typically more expensive than passive systems, but usually they are less flexible and efficient (Kreith, F., 1982).

The location of Cyprus is within the latitude and longitude of 35°00 N, 33°00 E. It covers 9,250 km<sup>2</sup> land. Nicosia is the capital city of Cyprus. The latitude and longitude of Nicosia is 35°10' N, 33°22' E. Cyprus is the driest and hottest island in the Mediterranean Sea. Even though the rainy season is from November to March, there is 340 days of sunshine in the island. The hottest month are from May to August during which solar radiation values are relatively very high. Summer temperatures often rise above 30°C.

Cyprus is the world leader on SDHWS usage and thermosyphon type systems are used commonly. In this type of SDHWS the circulation of water in the system is maintained by natural circulation. The warmer water heated in the solar collector rises and stored in the hot water cylinder (HWC) as the cooler water in the HWC sinks and placed in solar collector for heating. The installation of collector must be below the cylindrical storage tank so that warm water will be rises to the tank by means of the natural circulation. These systems are reliable, and because of the heavy storage tank the contractors must pay careful attention to the roof design. (Energy Gov, n.d.)

In addition to design parameters installation and maintenance of SDHWS effect the efficiency of these systems. The direction and tilt angle of solar panels directly effects the efficiency of thermosyphone type SDHWS.

The study aims to investigate the effect of installation on SDHWS in general and also in North Cyprus. For this purpose analytical calculations, laboratory and on-site experiments were conducted. The results are demonstrated and discussed.

## CHAPTER 2

### LITERATURE REVIEW

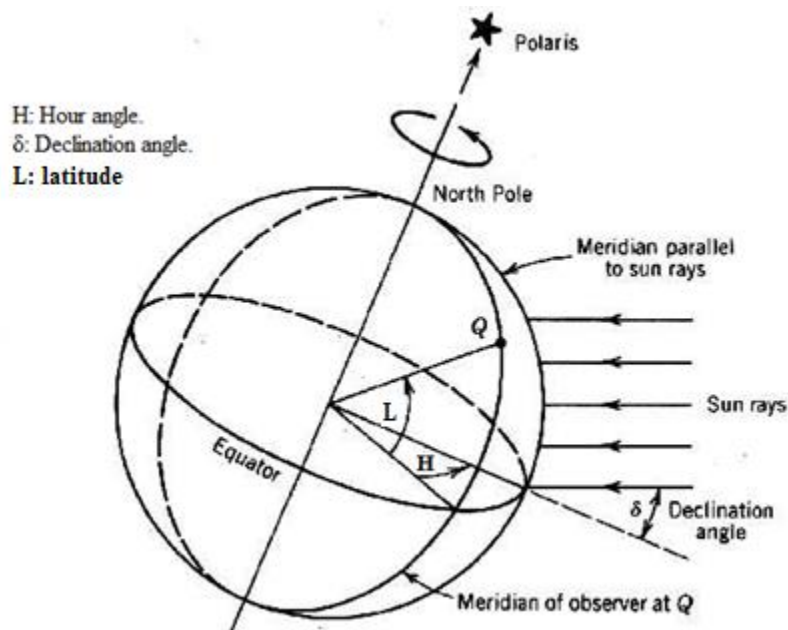
#### 2.1. Solar Angles

The radiation on any surface on earth is calculated by the radiation data of that location on horizontal surface. The data can be obtained from a meteorological office or by using pyranometer. For this calculations it is necessary to use the related solar angles. This section is reserved for the explanation of these angles (Kaler, J. B., 2002).

As shown in Figure 2.1, latitude,  $L$ , is the angular distance of a point on earth towards south (or north) of the equator. The declination is the angular distance of the sun to the north of the earth's equator, at southern hemi-sphere (Figure 2.1) and to the south in the northern hemi-sphere. The declination angle,  $\delta$ , for the Northern Hemisphere is (Rumbarge and Vitullo, 2003).

$$\delta = 23.45^\circ \sin \left[ \frac{N+284}{365} \times 360^\circ \right] \quad (2.1)$$

where  $N$  is the day number, with 1<sup>st</sup> January equal to 1. The sign of the declination angle is reversed for Southern Hemisphere.

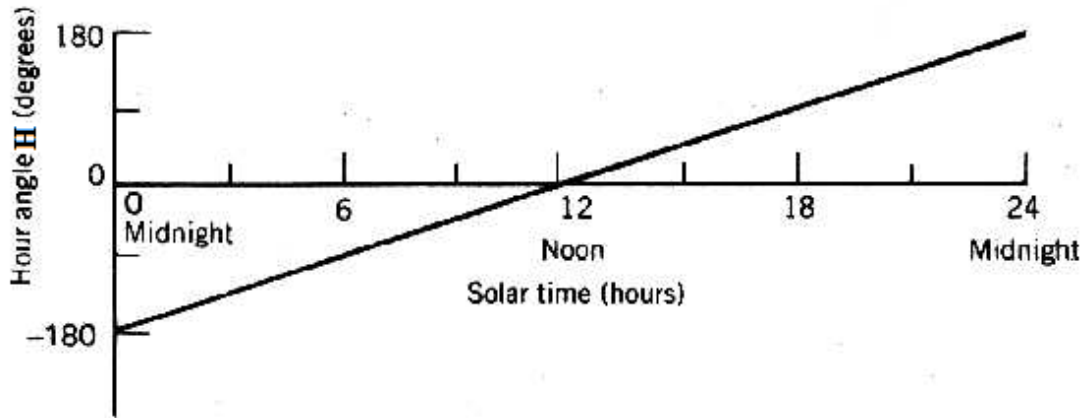


**Figure 2.1:** Latitude, Hour Angle, and Declination Angle of the Sun

The hour angle (H), also shown in Figure 2.1, is the azimuth angle of the ray of the sun caused by rotation of the earth which can be calculated as follows (Stine and Harrigan, 1985).

$$H = \frac{(\text{no of minutes past midnight, AST}) - 720 \text{ mins}}{4 \text{ min/deg}} \quad (2.2)$$

The hour angle is negative during the morning, positive during afternoon and  $0^\circ$  at noon. The variation of the hour angle during a day is shown in Figure 2.2.



**Figure 2.2:** Variation of Hour Angle During a Day

Solar altitude angle ( $\beta_1$ ), zenith angle ( $\theta_z$ ) and azimuth angle ( $\alpha_1$ ) are demonstrated in Figure 2.3 (Stine, W. B.; Harrigan, R. W., 1985). The solar altitude angle ( $\beta_1$ ) if you are facing the sun is the apparent angular height of the sun in the sky. Zenith angle ( $\theta_z$ ) is the complement of solar altitude angle ( $\beta_1$ ) and are both given by the equation;

$$\cos(\theta_z) = \sin(\beta_1) = \cos(L) \cos(\delta) \cos(H) + \sin(L) \sin(\delta) \quad (2.3)$$

where

$L$ : latitude ,

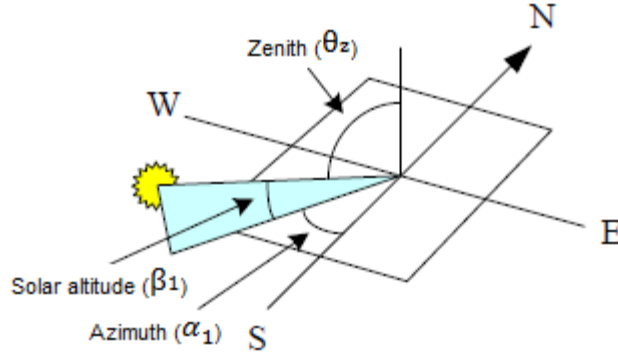
$\delta$ : declination angle (for Southern Hemisphere its negative)  $[-23.45^\circ \text{ to } +23.45^\circ]$ ,

$H$ : hour angle  $[-180^\circ \text{ to } +180^\circ]$ ,

The solar altitude ( $\beta$ ) at noon is  $\beta = 90^\circ - L - \delta$ . The sun rises and sets when its altitude is  $0^\circ$ , but not necessarily when its hour angle is  $\pm 90^\circ$ . Sunset or sunrise hour angle ,  $H_s$ , can be found from using Eq. (2.4) when  $\beta_1 = 0$

$$\cos(H_s) = -\tan(L) \tan(\delta) \quad (2.4)$$

where  $H_s$  is negative and positive for sunrise and sunset respectively. When the sun neither rises nor sets the absolute values of  $\cos(H_s)$  greater than unity will occur in the arctic zones.



**Figure 2.3:** Solar Altitude, Zenith and Azimuth Angles

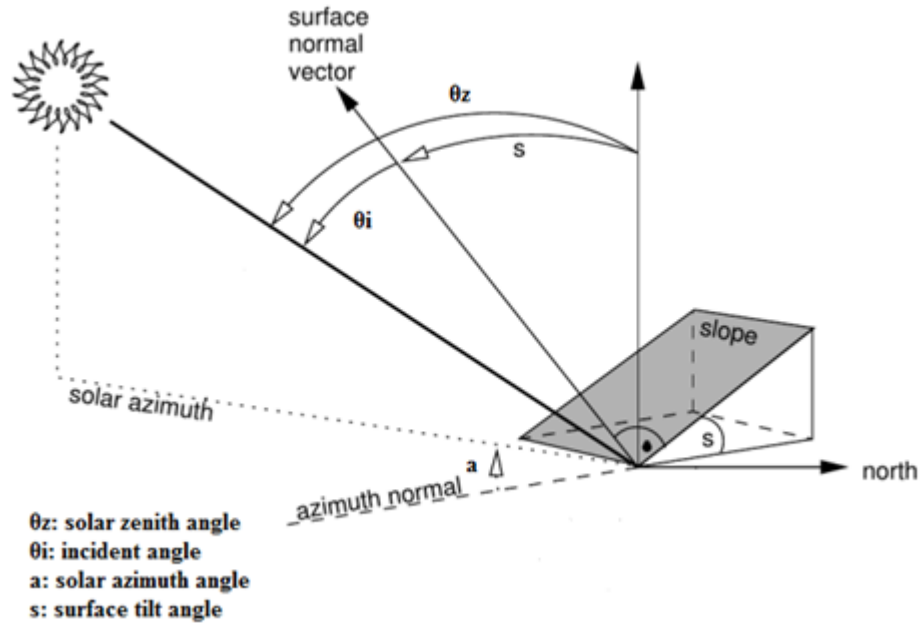
The solar azimuth ( $\alpha_1$ ) is the angle of the sun ray normal to the south and to the north in the southern hemisphere. Its cosine is given by:

$$\cos \alpha_1 = \frac{\sin \beta_1 \sin(L) \sin(\delta)}{\cos \beta_1 \cos(L)} \quad (2.5)$$

where  $\alpha_1$  during afternoon towards the west is positive, and during morning towards the east is negative, and therefore, the sign of  $\alpha_1$  should be the same of the hour angle.

Surface tilt angle it is the angle between the collector surface and the horizontal surface, whereas surface azimuth angle is the angle of deviation of the direction of collector surface from south being again positive towards west and negative towards east (Figure 2.4) (Ryan, B. C., 1977). In the northern hemisphere it is preferred to place solar collectors facing directly towards the south (surface azimuth angle =  $0^\circ$ ).





**Figure 2.4:** Surface Tilt, Surface Azimuth and Incidence Angles

Incidence angle ( $\theta_i$ ) is the angle between surface normal and sun ray as shown in Figure 2.4 and can be calculated as follows (Kalogirou, S. A., 2009).

$$\cos \theta_i = \sin L \sin \delta \cos S - \cos L \sin \delta \sin S \cos \Psi + \cos L \cos \delta \cos H + \sin L \cos \delta \cos L \sin S + \cos \Psi \sin H \sin S \sin \Psi \quad (2.6)$$

where

$L$ : latitude,

$\delta$ : declination angle (for Southern Hemisphere its negative)  $[-23.45^\circ$  to  $+23.45^\circ]$ ,

$H$ : hour angle  $[-180^\circ$  to  $+180^\circ]$ ,

$S$ : tilted angle

$\Psi$ : azimuth angle

The ratio (R)

$$R = \frac{\cos \theta_i}{\cos \theta_z} \quad (2.7)$$

can be used to find the radiation on the tilted surface,  $Q_t$  using the radiation data obtained from the meteorological office as follows:

$$Q_t = Q_{met} \cdot R \quad (2.8)$$

## 2.2. Calculation of energy absorption by hot water cylinder

Energy absorbed ( $Q$ ) by the hot water cylinder (HWC) can be calculated as follow:

$$Q = m \cdot C_p \cdot \Delta T = \rho \cdot V \cdot C_p \cdot \Delta T \quad (2.9)$$

where

$m$ : mass (kg)

$\rho$ : density (kg/m<sup>3</sup>)

$V$ : volume (m<sup>3</sup>)

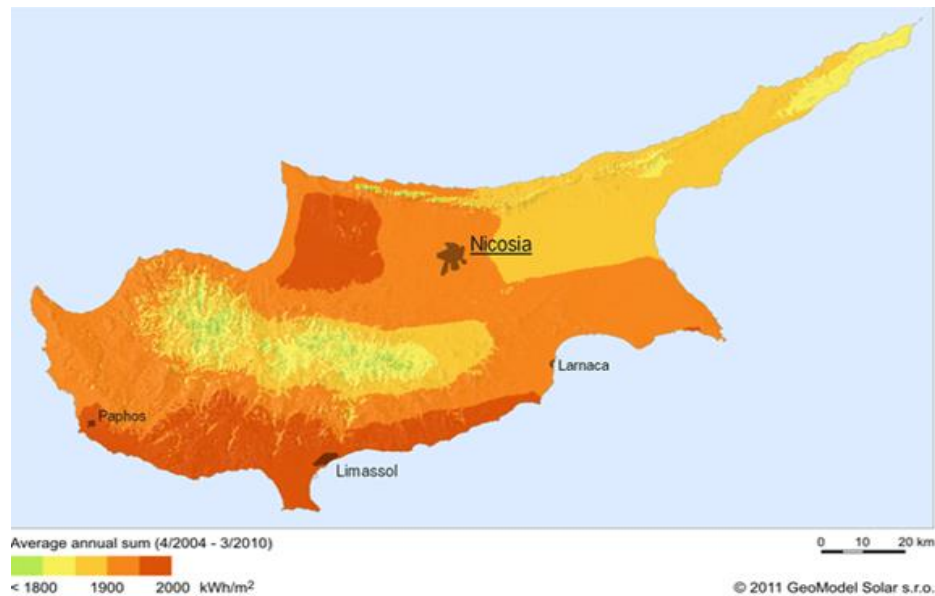
$\Delta T$ : change of temperature of the water in HWC (°C)

$C_p$ : specific heat of water (kJ/kg °C) (Bonan, G., 2016).

## 2.3. Importance of solar energy in Cyprus

Cyprus is the third biggest island in the Mediterranean with a zone of 9251 km<sup>2</sup> and a populace of around 700,000. Cyprus has no characteristic oil assets and depends altogether on imported fuel for its vitality request. The most imperative renewable vitality wellspring of Cyprus is the sun powered vitality (Sayigh, 2014).. The climatic states of Cyprus are transcendently exceptionally sunny with a normal day by day sunlight based radiation of around 5.4 kWh/m<sup>2</sup> on a level surface. In the swamps the every day daylight span fluctuates from 5.5 h in winter to around 12.5 h in summer. In the mountains, the cloudiest winter months get a normal of 4 h of splendid daylight every day though in July the figure achieves 12 h. Mean day by day worldwide sunlight based radiation changes from around 2.3 kWh/m<sup>2</sup> in the cloudiest months of the year, December and January, to around 7.2 kWh/m<sup>2</sup> in July (Kreith, 1982). The measure of worldwide radiation falling on an even surface with normal climate conditions is 1727 kWh/m<sup>2</sup> every year (Rumbarge and Vitullo, 2003). Of this sum, 69.4% achieves the surface as immediate radiation (1199 kWh/m<sup>2</sup>) and the staying 30.6% as diffuse radiation (528 kWh/m<sup>2</sup>).

Figure 2.5 shows the average annual radiation over the island. When compared with the world solar energy map given in Figure 2.6 it can be seen that Cyprus takes place at high solar energy region over the world (Kalogirou, 2003).



**Figure 2.5: Solar Energy Map of Cyprus**

### **2.3.1. Usage of solar domestic hot water systems in Cyprus**

The low populace, the verging on select dependence on oil for vitality needs, the moderately high cost of power, the sensible abnormal state of innovation and the populace acknowledgment of the use of sun powered vitality in Cyprus make the renewable vitality alternatives to a great degree feasible from a specialized, social and financial perspective (Sørensen, Breeze and Galen, 2009).

Cyprus started the assembling of sun based residential boiling hot water frameworks (SDHWS) in the mid sixties, at first by importing the safeguard plates and different adornments from Israel (Kumar and Prasad, 2000). The advancement in the initial six years was somewhat moderate. This is credited to the fairly defective configuration (spillages, low effectiveness and so on.) and to their somewhat high cost.

With further improvements in the development of authorities, the greater part of the specialized issues were understood and with the justification of generation, the expense was diminished or stayed steady and in this manner significantly more units were introduced. The business of SDHWS extended rapidly and today verging on each house has a SDHWS (Letcher, 2014).

Customary SDHWS in Cyprus are of the thermosyphon sort and involves two level plate sun based powers having a shield domain between 3 to 4 m<sup>2</sup>, a limit tank with farthest point between

150 to 180 liters and a cold water stockpiling tank, all presented on a suitable packaging. The sun controlled gatherers are of the level plate sort, made of copper or stirred steel protects and tubes. The risers are for the most part connected to the protection plate using distinctive methodologies. Generally speaking the risers fit in sections made on the protection plate, while in few cases securing is used to improve the contact. A right hand 3 kW electric submersion hotter is used for winter in the midst of times of low sun arranged insolation. In structures which are furnished with oil let go central warming systems the warmer is used as right hand through a glow exchanger fitted in the limit tank of the unit. Figure 2.7 shows the most well-known structure presented on a level housetop house (Goswami and Kreith, 2007). The mix of a weight unit allows the development of the cold water tank at a lower level. This improves the beautiful drawing in nature of the foundation. In multi-private structures different units are presented one by the other.

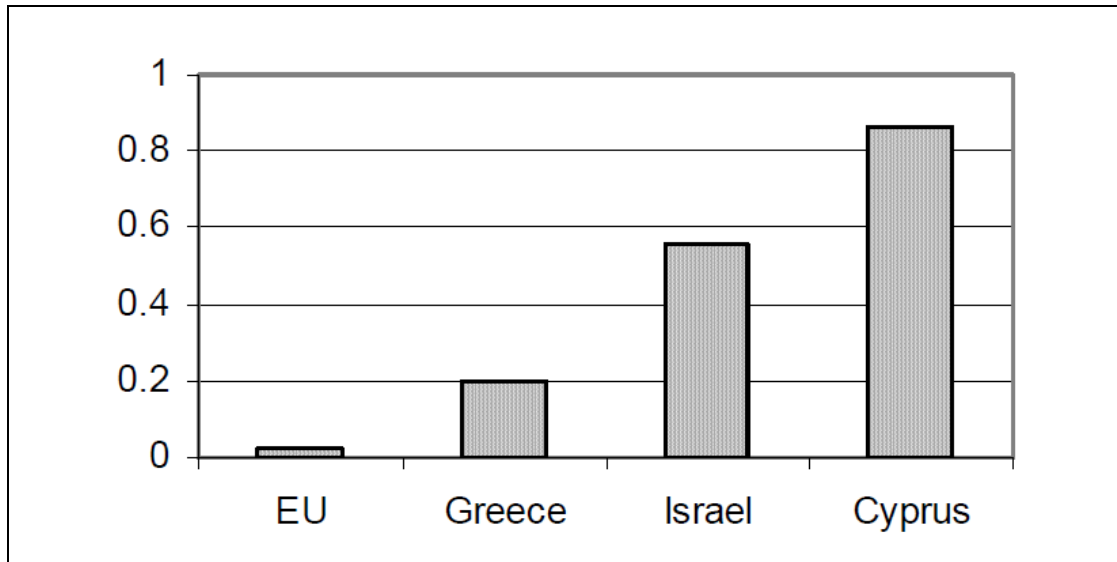


**Figure 2.6:** Typical Application of Tower-Type Solar Water Heater Installed on Flat Roof

Hotels, hotel apartments, hospitals and clinics are using either thermosyphon systems in array of several units or active systems equipped with central storage systems, which employ pumps, heat exchangers and oil-fired boilers as back-up source of energy. A study conducted in the past showed that central solar hot water systems for hotels and hotel apartments are technically and economically feasible (Kalogirou, 2004). In particular a payback time of 7 years for a solar hot

water system for a 4-star hotel in Cyprus was obtained from this study (at a much lower fuel price than the present value).

Compared to other Mediterranean countries and the European Union, Cyprus is in a very good position with respect to the exploitation of solar energy (Chwieduk, 2014). The estimated park of solar collectors in working order is 560,000 m<sup>2</sup>, which corresponds to approximately 0.86 m<sup>2</sup> per inhabitant as compared to 0.56 and 0.2 for Israel and Greece respectively (see Figure 2.8).



**Figure 2.7:** Installed Solar Collector Area per Inhabitant, 1994.

It is assessed that the quantity of sunlight based water radiators introduced in Cyprus surpasses 190,000 units. This compares to one sunlight based water radiator for each 3.7 persons in the island, which is a world record.

The assessed authority zone introduced up today incorporating focal frameworks in lodgings and inn lofts, is around 560,000 m<sup>2</sup> out of which 540,000 m<sup>2</sup> are introduced in houses and pads at the southern part of the island. In the traveler business, it is evaluated that around 44% of the current lodgings and 80% of the current inn condo are outfitted with sun powered helped water warming frameworks and the commitment of sun based vitality to the aggregate vitality utilization in the inn business is around 2%. A critical business sector potential exists for the improvement of sunlight based water radiators in the business and modern divisions (Blanco and Rodriguez, 2009).

But from not very many imported authorities of the vacuum tube sort, level plate gatherers are constantly utilized as a part of all sun based water radiators in the nation. The normal quality is worthy and the sun based water radiator in Cyprus appreciates a decent notoriety by people in general. The normal existence of the frameworks is 20 years in spite of the fact that frameworks over 25 years of age are still operational.

Imports of sunlight based water warmers are few made for the most part from Greece, Israel, Australia and Turkey. Around 700 frameworks are foreign made every year (2000 m<sup>2</sup> of sun based gatherer zone every year).

#### **2.4. General description about thermosyphonic solar systems type**

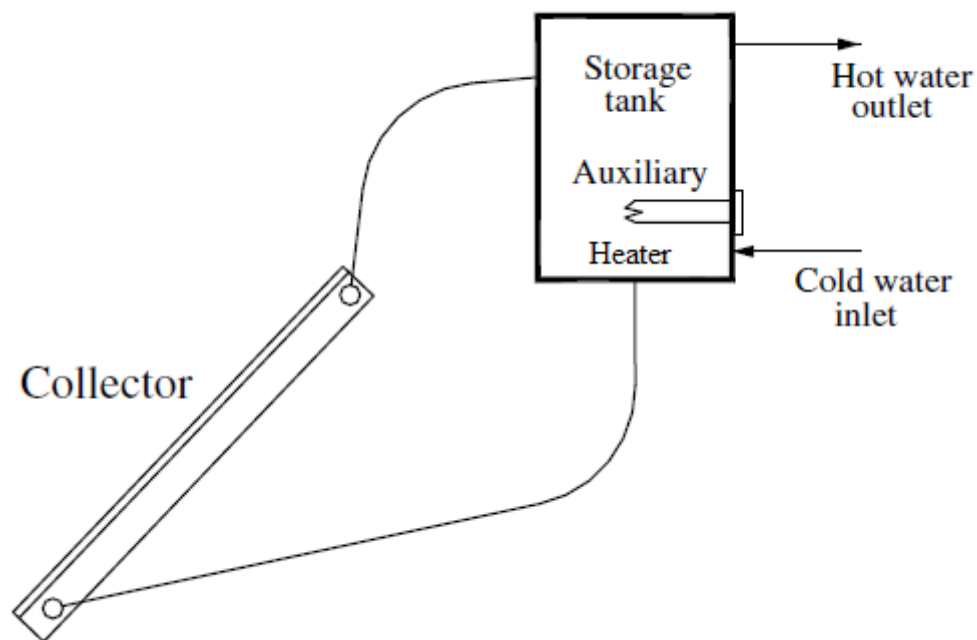
Thermosyphon, or common dissemination, sun based water warming frameworks (likewise called aloof frameworks) are the least difficult and most generally utilized sun oriented vitality gathering and use gadgets. They are proposed to supply heated water for local utilize, and depend on regular dissemination or thermosyphon guideline. They supply heated water at a temperature of around 60 °C and comprise of a gatherer, stockpiling tank, and associating funnels (Sayigh, 1977)..

A schematic graph of the thermosyphon frameworks is appeared in Figure 2.9 (Ananth and Jaisankar, 2013). Thermosyphoning happens when the water in the authority extends turning out to be less thick as warmth is included by sun based vitality and ascends through the gatherer header into the highest point of the capacity tank. There it is supplanted by the cooler water that has sunk to the base of the tank from which it streams down the gatherer.

Dissemination proceeds the length of the sun is sparkling. Since the main impetus is just a little thickness distinction between the hot and frosty water, bigger channel sizes must be utilized to minimize funnel grating. In the capacity tank, boiling hot water gathers close to the top when water is warmed amid the day by sun powered radiation. To consider times of low sunlight based radiation levels, stockpiling tanks are typically measured to hold around two days supply of boiling point water. It ought to be noticed that the water coursing through the gatherers is consumable water that goes to the client and any amount of high temp water utilized is

supplanted through the freshwater gulf (from the frosty water stockpiling tank or mains supply) which enters the capacity tank close to the base so as not to break the stratification.

Interfacing lines must be all around protected to anticipate heat misfortunes and slanted to avert arrangement of air stashes which would stop flow. During the evening, or at whatever point the gatherer is cooler than the water in the tank the bearing of the thermosyphon stream will turn around, subsequently cooling the put away water, unless the highest point of the authority is put well beneath (around 30 cm) the base of the capacity tank (Kalogirou, 2004a).



**Figure 2.8:** Schematic Diagram of a Thermosyphon Solar Water Heater

The measure of a thermosyphon close planetary system relies on upon the overall climate conditions and the high temp water necessities. The authority range is resolved essentially by the day by day heated water request, which changes from spot to put contingent upon nearby traditions and ways of life and is typically around 30 lt/individual/day. A run of the mill unit working in a decent situation (Mediterranean range) for the most part comprises of two level plate sun powered gatherers having a safeguard territory somewhere around 2.5 and 4 m<sup>2</sup>, and a capacity tank with limit somewhere around 150 and 180 lt. A helper electric inundation warmer and/or a warmth exchanger, for focal warming helped heated water creation, are utilized

as a part of winter amid times of low sun powered insolation. Such a framework covers around 80% of the high temp water necessities of a four-man gang. The level plate gatherer is for the most part altered forever in position, and in this way the tilt of the authority is resolved basically by thought of the dominating season of high temp water use. For year-round utilize, the gatherer tilt is kept equivalent to the scope of the area in addition to 5°. In the northern half of the globe, the gatherer confronts coordinate south (azimuth point = 0°), in spite of the fact that a movement of a couple of degrees towards east or west does not significantly impact its execution (Kalogirou, 2004a). The day by day general framework productivity of a residential sunlight based high temp water framework is around 30–40%, and the temperature contrast between the gatherer outlet and channel is around 10 °C. The capacity tank is put on a level plane or vertically. In spite of the fact that the shallow profundity of the flat tanks corrupts stratification, for level tanks with widths more noteworthy than 500 mm there is just a little execution misfortune in correlation with vertical tanks.

The essential damage of thermosyphon structures is the way that they are correspondingly tall units, which makes them not amazingly appealing gorgeously. Ordinarily, a nippy water stockpiling tank is presented on top of the sun fueled power, supplying both the bubbling boiling hot water chamber and the chilly water needs of the house, therefore making the gatherer unit taller and even less charming (see Figure 2.7). Moreover, to an incredible degree hard or acidic water can realize scale stores that may block or dissolve the protection fluid segments. For direct structures, weight reducing valves are required when the city water is used clearly and weight is more important than the working weight of the gatherers.



## CHAPTER 3

### METHODOLOGY

#### 3.1. Radiation on horizontal surface

Daily variation of horizontal surface solar radiation ( $Q_{\text{met}}$ ) in Nicosia was taken for the year 2007 from meteorological office of Northern Cyprus (Appendix A). The data given was in  $\text{cal/cm}^2 \text{ h}$  and converted to  $\text{kJ/m}^2 \text{ h}$  to be used in the study.

Daily total radiation can be calculated by adding up the hourly values. Plotting daily radiation values throughout the year will show the variation of radiation. However, generally monthly average values are used for SDHWS and can be calculated by averaging the total daily radiation per month of the year.

#### 3.2. Estimation of solar radiation on a titled surface ( $Q_t$ )

A Microsoft Excel worksheet was prepared to find the solar radiation on any tilted surface on any day of a year. A sample view is given in Appendix B. The radiation data of 2007 for Nicosia was used in the worksheet as the input data. It is possible to input different data set from different years and from different locations. The input variables can be listed as follows:

- Date (year, month and day)
- Latitude ( $36^\circ$  for Nicosia)
- Surface tilt angle
- Surface azimuth angle
- Solar noon (10:00 GMT for Cyprus)

The day of the year,  $n$ , was calculated by adding up the days from the beginning of the year to the date in consideration. Declination angle,  $\delta$ , was calculated for a day of the year using Equation 2.1. Hour angles during the day were calculated using Equation 2.2. Cosine of zenith angle ( $\cos \theta_z$ ) and cosine of incidence angle ( $\cos \theta_i$ ) were calculated by the Equation 2.3 and 2.6, respectively. Their ratio,  $R$ , was calculated using Equation 2.7 and multiplied by  $Q_{\text{met}}$  to give radiation on a tilted surface,  $Q_t$ , as given in Equation 2.8.

### **3.2.1 Variation of solar energy on solar collectors according to tilt angle**

The variation of solar radiation on solar collectors with different tilt angles on the days of solstices and equinoxes were observed and plotted according to GMT (Cyprus is GMT+2) to see the effect of tilt angle on the seasonal performance of SDHWS. The azimuth angle of the collectors were kept as 0°.

### **3.2.2 Variation of solar energy on solar collectors according to azimuth angle**

The solar radiation on the panel surface was observed for different collector azimuth angles from west to east for the days of solstices and equinoxes. The collector tilt angle was kept as 36°.

### **3.2.3 Efficiency**

Different efficiencies of the SDHWS were considered and plotted on a single graph to observe the effect of efficiencies on the performance. The collector azimuth angle was taken as 0° and tilt angle as 36°. The analysis was conducted for date.

## **3.5. Thermocouples and data acquisition system**

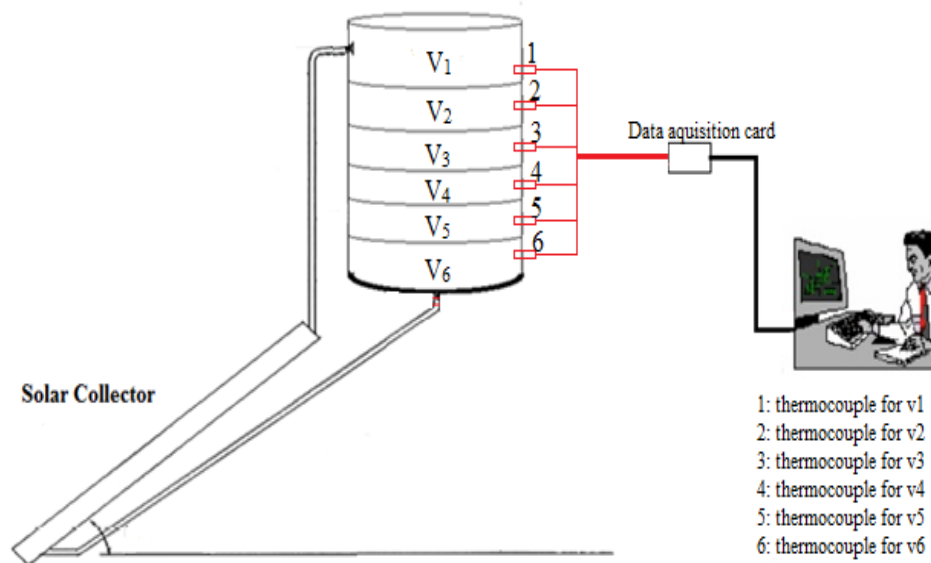
Calibration of the thermocouples used done by taking the temperature inside a boiled water and by using two different types of thermometers mercury and alcohol were used to take the variation between the thermocouples and the thermometers. The thermocouples reading were determined to be the same with the thermometers with a deviation of 0.2°C between thermocouples.

T-type thermocouples were used to read the temperatures inside the HWC during the experiments. They are connected to the data acquisition system (ORDEL UDL100) to convert analog signals into digital ones. The data is then transferred through USB port into a laptop computer to be recorded by the related software DALI 08.

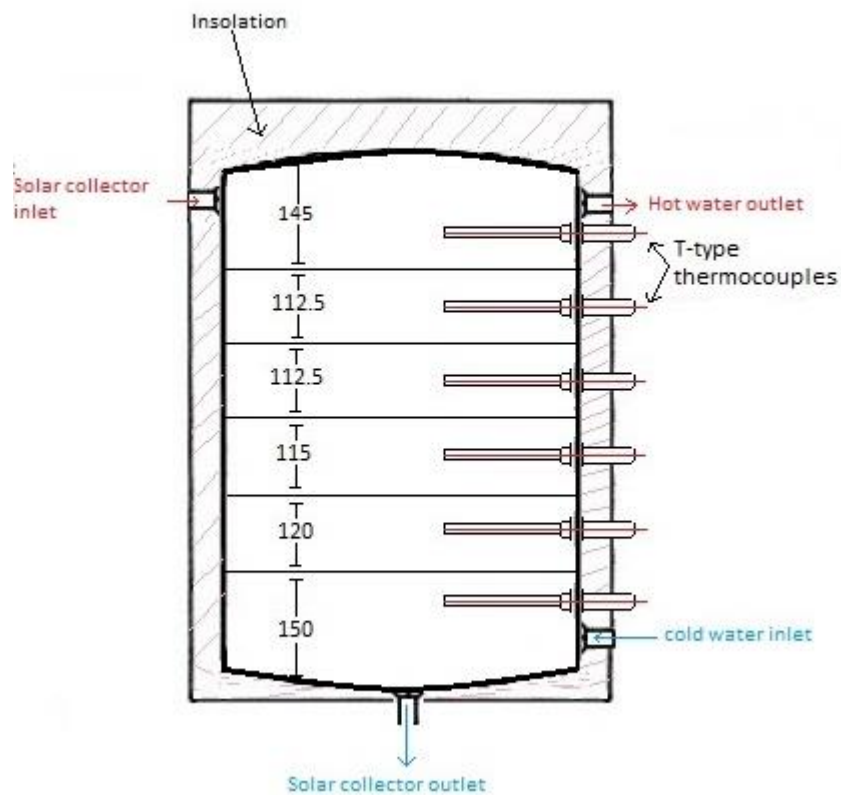
### 3.3 Laboratory Tests

The set-up shown schematically in the Figure 3.1 below is used to conduct SDHWS experiments with different tilt and azimuth angles in the laboratory. The HWC was divided into 6 sections. It was assumed that the temperature change within each section is negligible. The six T-type thermocouples placed into each section of the HWC is used to measure the average temperature of each section. The energy absorbed by each section could then be calculated from Equation 2.9 for any time interval. For this purpose the change of temperature during the experiments were recorded by using a data acquisition system (ORDEL UDL100) and transferred to a computer to be recorded by the related software (DALI 08). Equation 2.9 was applied to each section separately with the data obtained from the experiments and using the volumes given in Table 3.2. The density and specific heat of water were obtained from Table 3.2 and Table 3.3, respectively. The procedure can be given as follows:

- 1) Adjust the tilt and collector azimuth angles.
- 2) Refill the system with cold water.
- 3) Start the measurements removing the cover of solar panels.
- 4) Stop the experiment after enough data is collected.
- 5) Plot temperature vs time graphs to observe change of temperature during the day.
- 6) Plot height vs temperature graphs to see the variation of temperature within the HWC in the vertical direction using Table 3.1.
- 7) Calculate the energy absorbed by the water on HWC and plot against time.



**Figure 3.1:** Thermosyphonic Type Laboratory SDHWS Setup



**Figure 3.2:** Cross Section of Laboratory Thermosyphonic Type SDHWS Setup

**Table 3.1:** Relative density of water

S. No.	Temperature (°C)	Relative density	S. No.	Temperature (°C)	Relative density
1	4	1.000000	22	25	0.997074
2	5	0.999992	23	26	0.996813
3	6	0.999968	24	27	0.996542
4	7	0.999930	25	28	0.996262
5	8	0.999876	26	29	0.995974
6	9	0.999809	27	30	0.995676
7	10	0.999728	28	31	0.995369
8	11	0.999633	29	32	0.995054
9	12	0.999525	30	33	0.994731
10	13	0.999404	31	34	0.994399
11	14	0.999271	32	35	0.994059
12	15	0.999127	33	36	0.993712
13	16	0.998970	34	37	0.993357
14	17	0.998802	35	38	0.992994
15	18	0.998623	36	39	0.992623
16	19	0.998433	37	40	0.992246
17	20	0.998232	38	41	0.99186
18	21	0.998021	39	42	0.99147
19	22	0.997799	40	43	0.99107
20	23	0.997567	41	44	0.99066
21	24	0.997326	42	45	0.99024

**Table 3.2:** Specific heat for water

Temp. °C	Heat capacity kJ K.kg	kcal K.kg	Temp. °C	Heat capacity kJ K.kg	kcal K.kg	Temp. °C	Heat capacity kJ K.kg	kcal K.kg
0 (ice)	1.960	0.468	34	4.178	0.999	68	4.189	1.001
1	4.217	1.008	35	4.178	0.999	69	4.189	1.001
2	4.213	1.007	36	4.178	0.999	70	4.190	1.001
3	4.210	1.006	37	4.178	0.999	71	4.190	1.001
4	4.207	1.005	38	4.178	0.999	72	4.191	1.002
5	4.205	1.005	39	4.179	0.999	73	4.192	1.002
6	4.202	1.004	40	4.179	0.999	74	4.192	1.002
7	4.200	1.004	41	4.179	0.999	75	4.193	1.002
8	4.198	1.003	42	4.179	0.999	76	4.194	1.002
9	4.196	1.003	43	4.179	0.999	77	4.194	1.002
10	4.194	1.002	44	4.179	0.999	78	4.195	1.003
11	4.192	1.002	45	4.180	0.999	79	4.195	1.003
12	4.191	1.002	46	4.180	0.999	80	4.195	1.003
13	4.189	1.001	47	4.180	0.999	81	4.197	1.003
14	4.188	1.001	48	4.180	0.999	82	4.198	1.003
15	4.187	1.001	49	4.181	0.999	83	4.199	1.004
16	4.185	1.000	50	4.181	0.999	84	4.200	1.004
17	4.184	1.000	51	4.181	0.999	85	4.200	1.004
18	4.183	1.000	52	4.182	1.000	86	4.201	1.004
19	4.182	1.000	53	4.182	1.000	87	4.202	1.004
20	4.182	1.000	54	4.182	1.000	88	4.203	1.005
21	4.181	0.999	55	4.183	1.000	89	4.204	1.005
22	4.181	0.999	56	4.183	1.000	90	4.205	1.005
23	4.180	0.999	57	4.183	1.000	91	4.206	1.005
24	4.180	0.999	58	4.184	1.000	92	4.207	1.005
25	4.180	0.999	59	4.184	1.000	93	4.208	1.006
26	4.179	0.999	60	4.185	1.000	94	4.209	1.006
27	4.179	0.999	61	4.185	1.000	95	4.210	1.006
28	4.179	0.999	62	4.186	1.000	96	4.211	1.006
29	4.179	0.999	63	4.186	1.000	97	4.212	1.007
30	4.178	0.999	64	4.187	1.001	98	4.213	1.007
31	4.178	0.999	65	4.187	1.001	99	4.214	1.007
32	4.178	0.999	66	4.188	1.001	100	4.215	1.008
33	4.178	0.999	67	4.188	1.001	100 (gas)	2.080	0.497

**Table 3.3:** Laboratory hot water cylinder sections

<b>Thermocouple-No</b>	<b>Section-Height (mm)</b>	<b>Section-Volume (lt)</b>
<b>1</b>	<b>145.0</b>	<b>29.7</b>
<b>2</b>	<b>112.5</b>	<b>23.1</b>
<b>3</b>	<b>112.5</b>	<b>23.1</b>
<b>4</b>	<b>115.0</b>	<b>23.6</b>
<b>5</b>	<b>120.0</b>	<b>24.63</b>
<b>6</b>	<b>150.0</b>	<b>30.8</b>

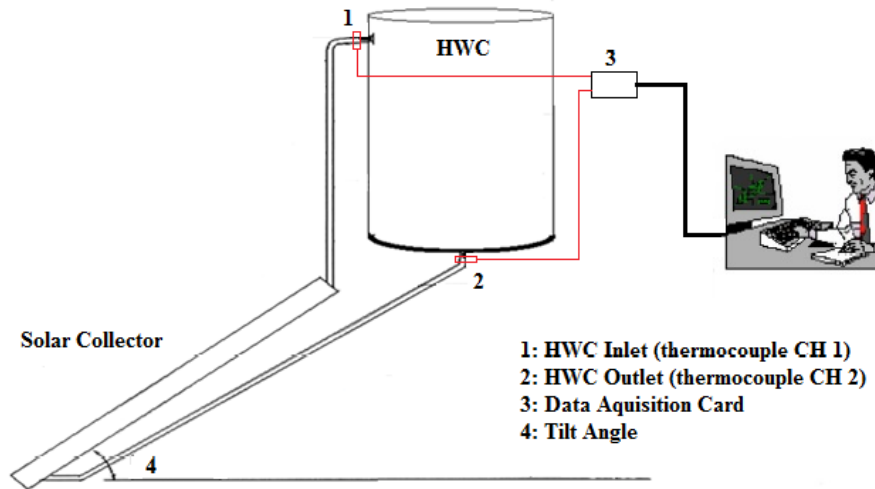
### **3.4. On-Site Tests**

On-site tests were conducted similar to laboratory tests however only 2 T-type thermocouples were used to measure the change in temperature of HWC placed on the pipes close to the inlet and outlet, the thermocouples were stickled on the pipes and then insulated as shown schematically in Figure 3.2. The variation of temperature in the vertical direction within the HWC is assumed to be linear since only 2 thermocouples could be used without damaging the systems on-site.

The procedure can be given as follows:

- 1) Record the variables on the case study paper (Appendix C):
  - a) Date
  - b) Tilt angle
  - c) Collector azimuth
  - d) Area of collector
  - e) Volume of cylinder
- 2) Make the connections before sun rise.
- 3) Record temperature variations from sunrise to sunset.

- 4) Calculate energy absorbed by assuming linear variation of temperature ( $T = \frac{T_1 + T_2}{2}$ ) in the vertical direction within the HWC and plot the results against time.



**Figure 3.3:** Schematic Representation of Thermosyphonic Type on-site SDHWS

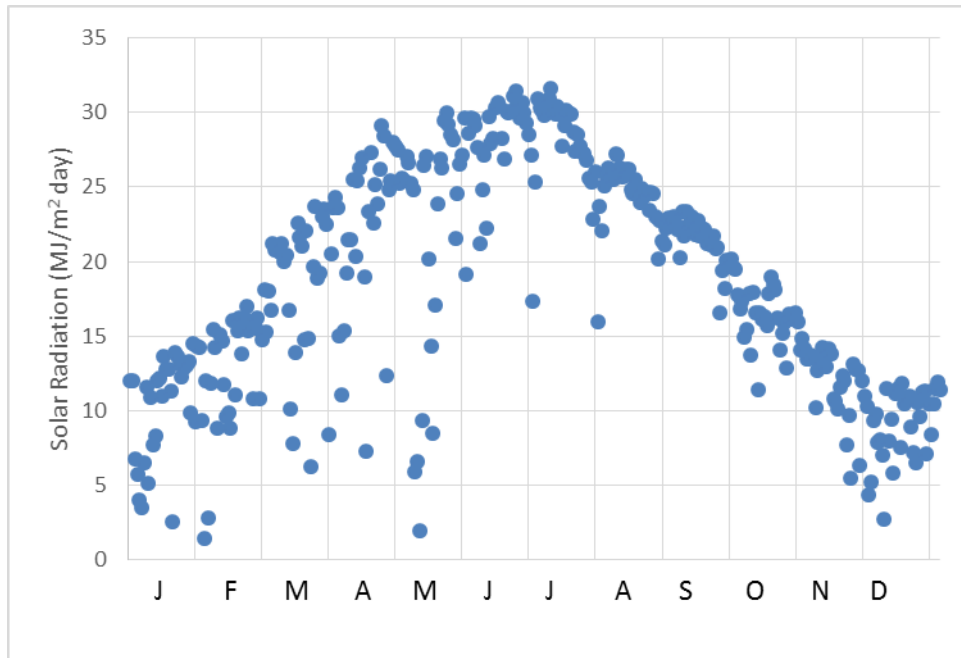
## CHAPTER 4

### RESULTS AND DISCUSSIONS

The results of theoretical calculations the radiation data obtained from meteorological office (Nicosia, 2007; appendix A) and the experiments performed in laboratory and also on-site will be presented and discussed in this chapter.

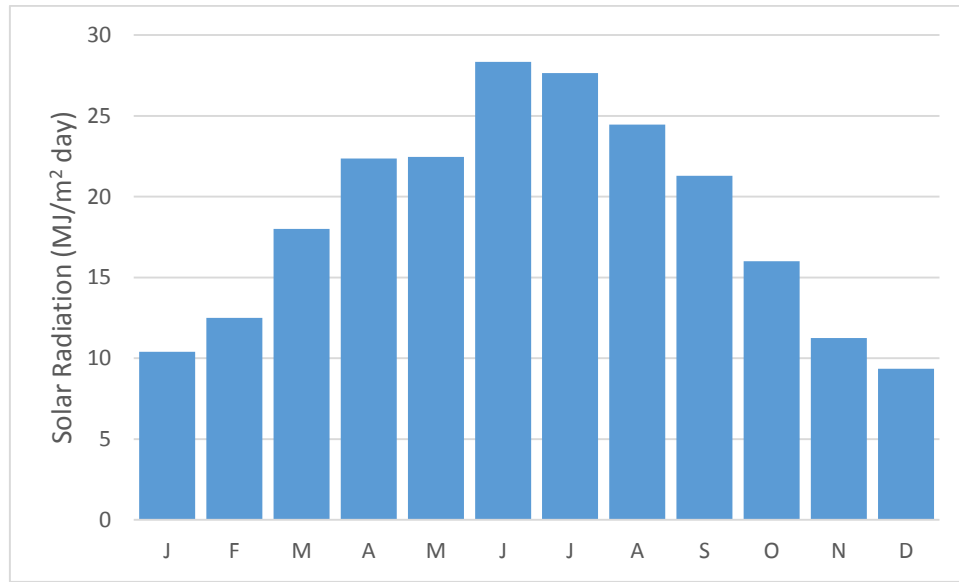
#### 4.1. Radiation data for Nicosia, 2007

Daily variation of solar radiation on horizontal surface in Nicosia, 2007 obtained from meteorological office of TRNC is given in Appendix A. Figure 4.1 shows variation of total daily solar radiation throughout the year. The average of daily total solar radiations for each month is also shown in Figure 4.2. The daily solar radiation changes from about 10 MJ/m<sup>2</sup> during winter and up to 28 MJ/m<sup>2</sup> during summer.



**Figure 4.1:** Variation of Daily Solar Radiation in Nicosia, 2007





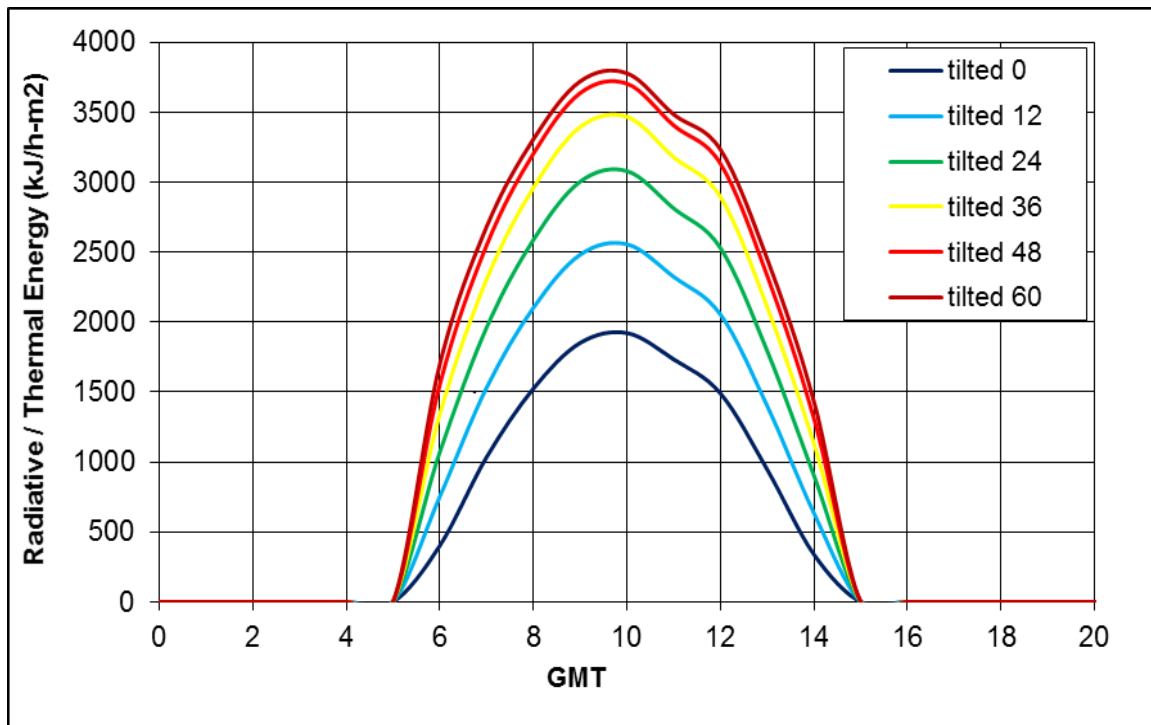
**Figure 4.2:** Variation of Monthly Average Daily Solar Radiation in Nicosia, 2007

## 4.2. Investigations about the radiation on solar panels

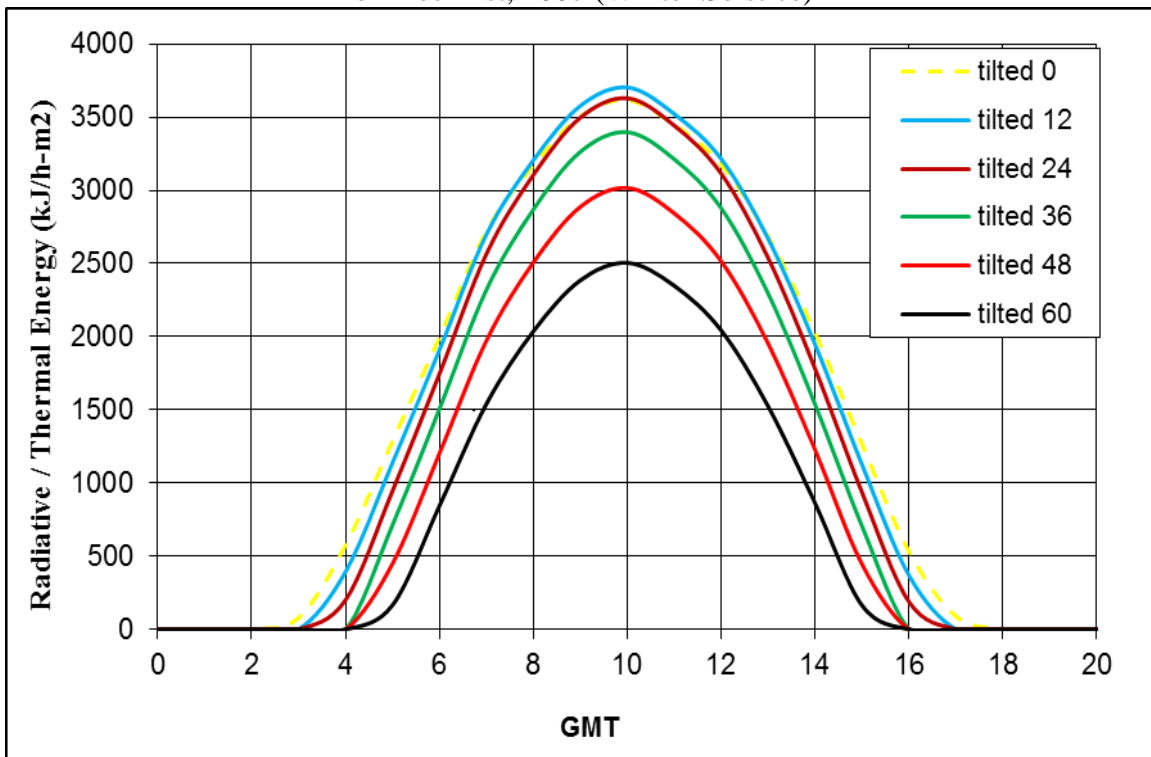
Using the radiation data for Nicosia, 2007 the effect of collector tilt and azimuth angles were examined, the energy available for different SDHWS efficiency were considered and will be discussed in this section. The radiation data for solstices and equinoxes were used.

### 4.2.1 Variation of solar energy on solar collectors according to tilt angle

In Figure 4.3 the variation of solar radiation with respect to tilt angle of a surface facing south (azimuth angle = 0 °C) on Dec 21<sup>st</sup>, 2007 (winter solstice) is given. As the tilt angle decreases below 36° (Latitude of Northern Cyprus) the radiation on the surface of the solar collector increases, and as the tilt angle is increased above 36° the energy on the surface decreases. This is an expected result since the angle of sun (solar altitude) is lower in winter than in summer.



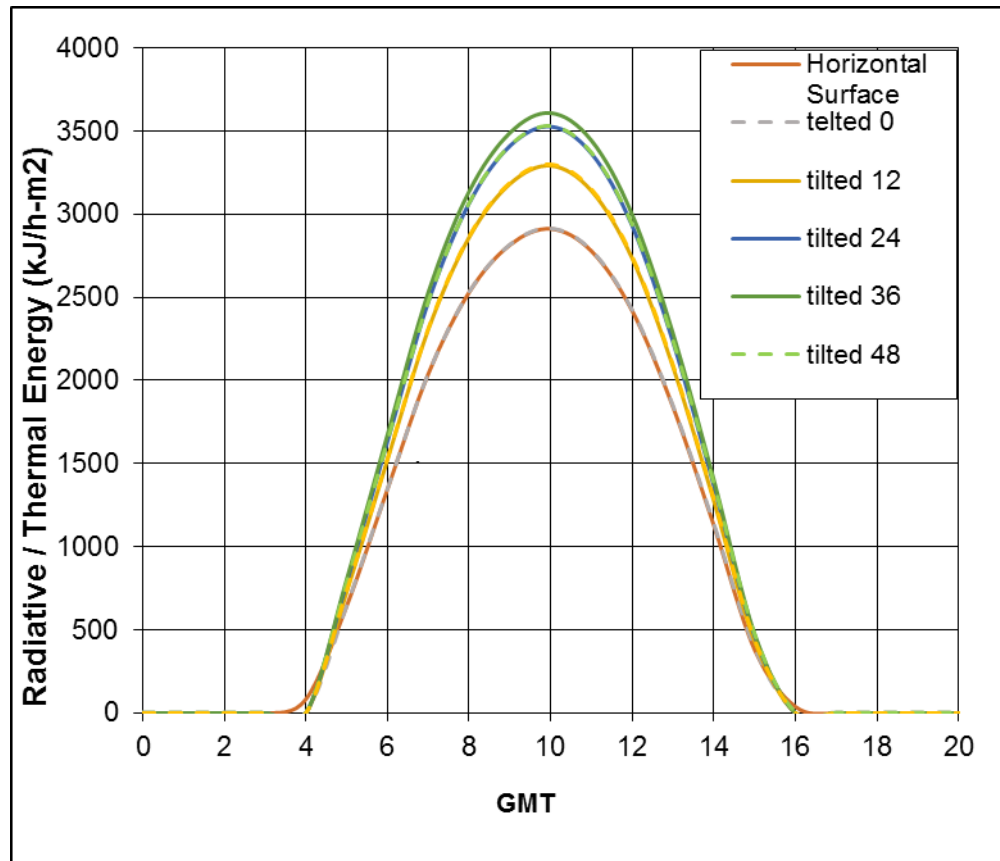
**Figure 4.3:** Variation of Solar Radiation with respect to Tilt Angle on a Surface Facing South on Dec 21st, 2007 (Winter Solstice)



**Figure 4.4:** Variation of Solar Radiation with respect to Tilt Angle on a Surface Facing South on June 21st, 2007 (Summer Solstice)

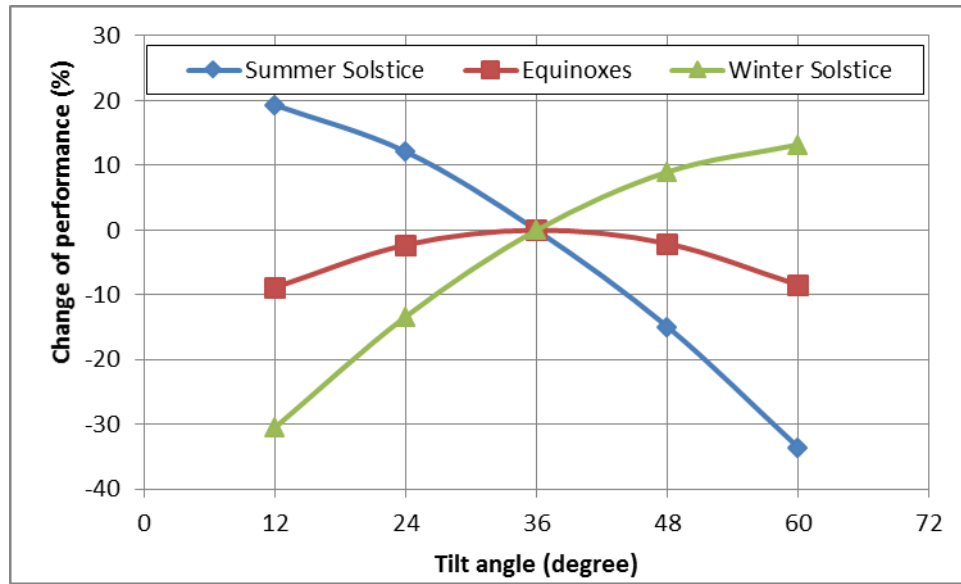
In Figure 4.4 the variation of solar radiation with respect to tilt angle on a surface facing south on June 21<sup>st</sup>, 2007 (summer solstice) is shown. Unlike Figure 4.3 as the tilt angles is decreased below 36° the radiation on the surface of the solar collector increases as expected, this is because in summer the sun angle (solar altitude) is higher. Increasing the tilt angle decreases the radiation on the solar panels.

36° being the average for the whole year gives less energy than could be obtained in winter and summer times. However, in spring and autumn (equinoxes) it is expected to get about the maximum available as it is presented in Figure 4.5 below for a surface facing south.



**Figure 4.5:** Variation of Solar Radiation with respect to tilt Angle on a Surface Facing South on Sep 23rd, 2007 (Autumn Equinox)

The change of daily performance according to tilt angle with respect to 36° tilt angle for a surface facing south can be seen in Figure 4.6 for Equinoxes, summer and winter solstices.

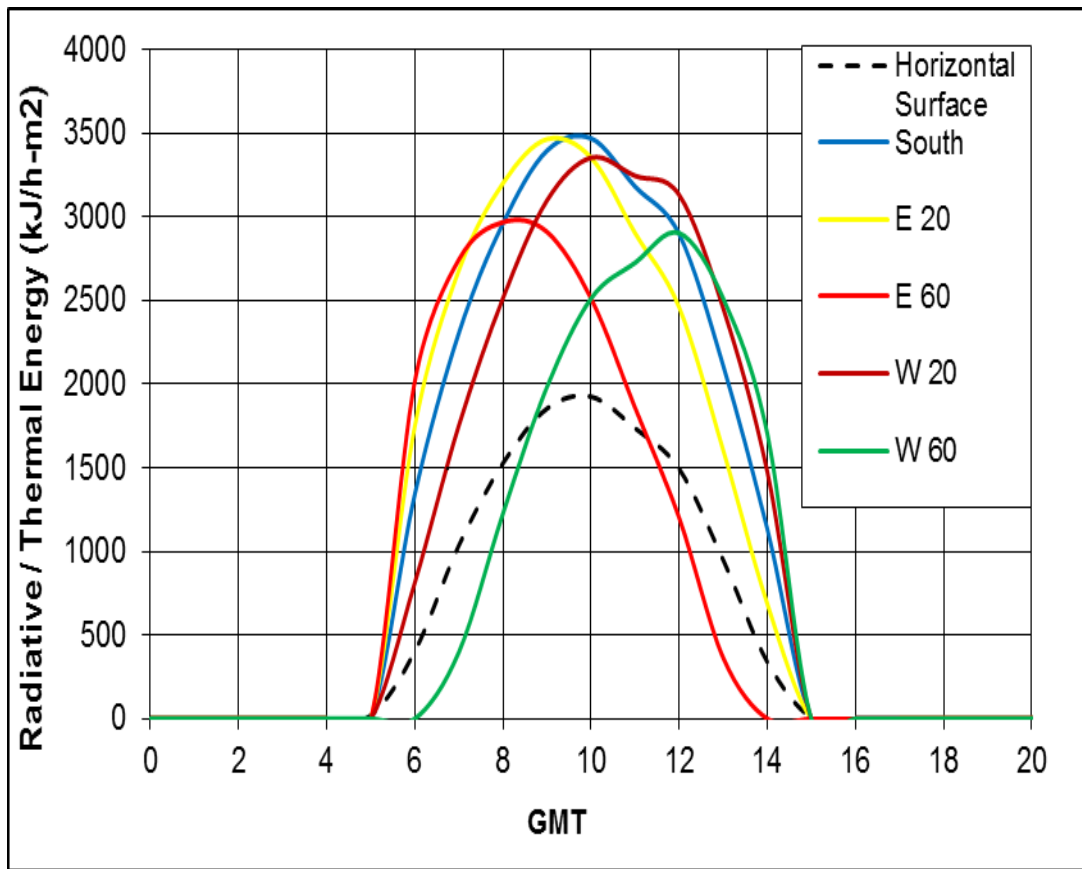


**Figure 4.6:** Change of Daily Performance with Respect to 36° Tilt Angle (Azimuth South)

#### 4.2.2 Variation of solar energy on solar collectors according to azimuth angle

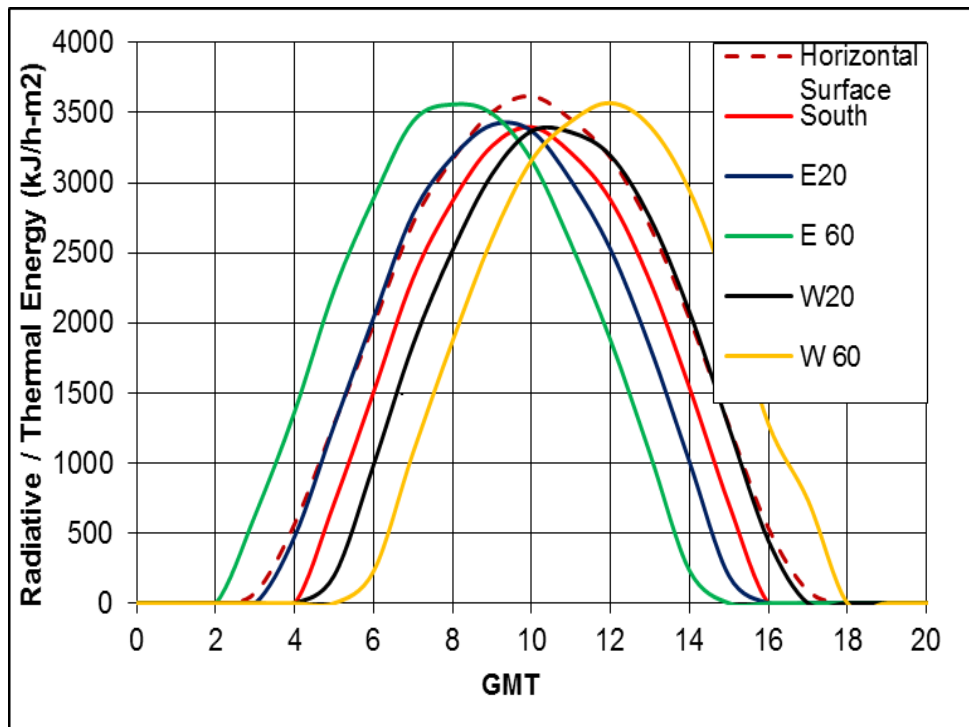
Figure 4.6, Figure 4.7, Figure 4.8 shows the variation of radiation on the tilted surface with a tilt angle of 36° as a function of azimuth angle for Sep 23<sup>rd</sup>, June 21<sup>st</sup>, and Dec 21<sup>st</sup> respectively.

In all of the figures changing the azimuth angle towards east and west will cause more energy gain in the morning and afternoon, respectively. However in winter and spring since the radiation period is less when compared with the summer, the total energy gained during the day will be less. During summer the total energy gained daily will not be effected that much since daily radiation period is longer. The data presented can be used for solar system design according to the hot water usage time.

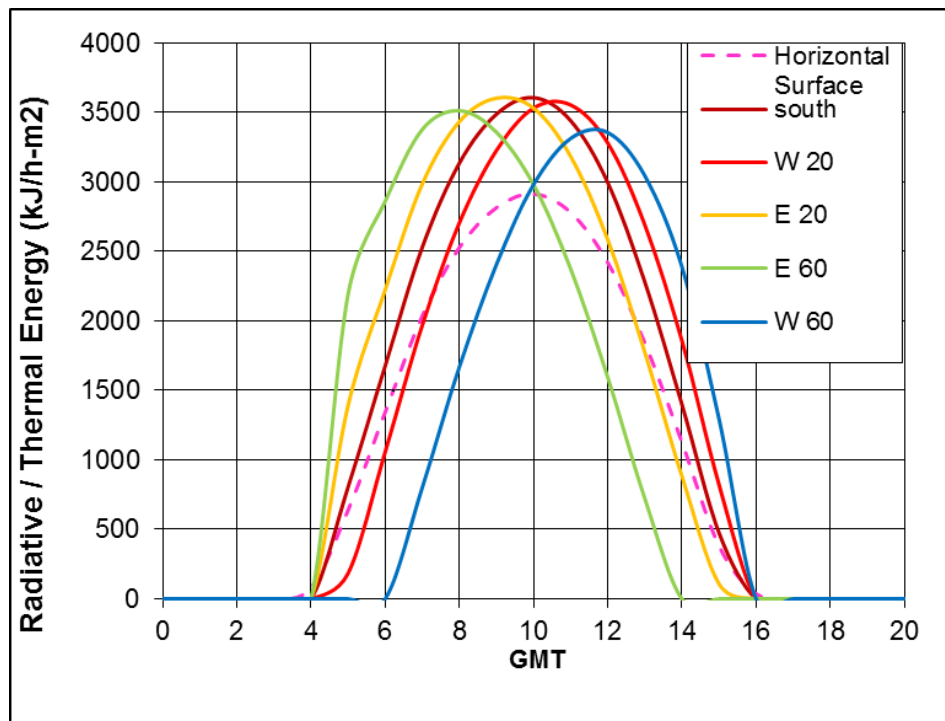


**Figure 4.7:** Variation of Solar Radiation with respect to Azimuth Angle on Sep 23rd (Autumn Equinox, Tilt Angle 36°)

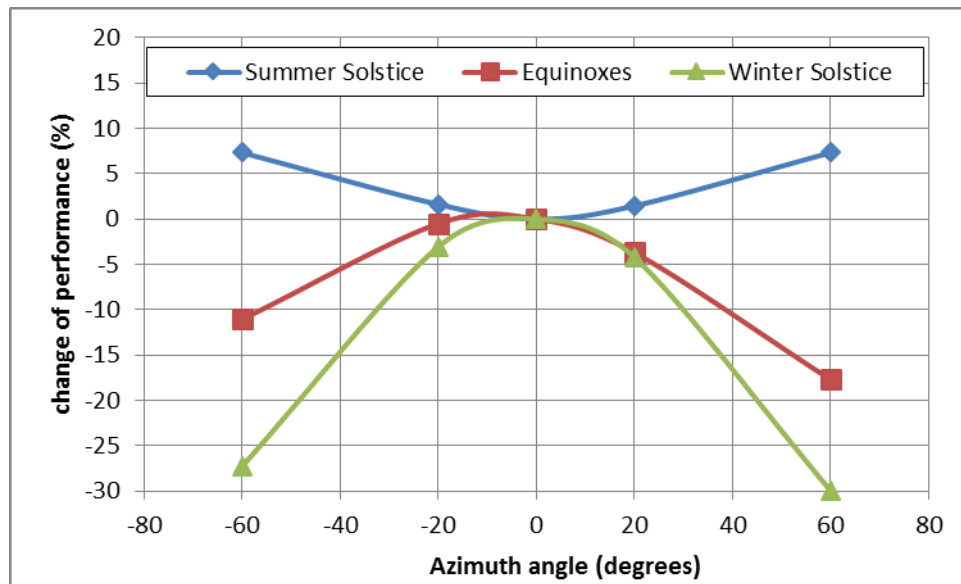
The change of daily performance according to azimuth angle with respect to 0° azimuth for surface having a tilt angle of 36° can be seen in Figure 4.10 for Equinoxes, summer and winter solstices.



**Figure 4.8:** Variation of Solar Radiation with respect to Azimuth Angle on June 21st (Summer Solstice, Tilt Angle 36°)



**Figure 4.9:** Variation of Solar Radiation with respect to Azimuth Angle on Dec 21st (Winter Solstice, Tilt Angle 36°)

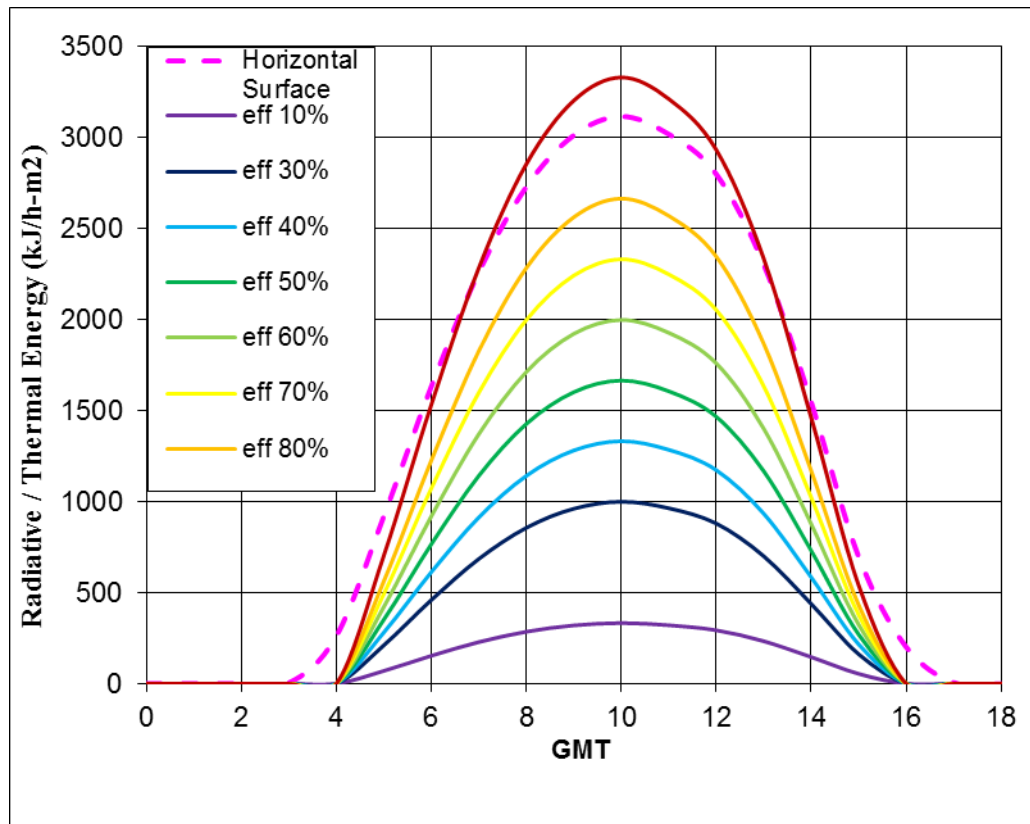


**Figure 4.10:** Change of Daily Performance with respect to 0° Azimuth Angle (Tilt= 36°)

### 4.2.3 Efficiency

Efficiencies of flat plate solar collectors changes from 30% up to 75% according to the material used and designs considered.

Figure 4.9 below states the energy that could be gained by a solar hot water system according to its efficiency. The installation of the system may cause efficiency drops well below the lowest efficiency value of 30% down to 10%, and therefore also indicated in the figure.



**Figure 4.11:** Effect of Efficiency of Solar Hot Water System. (Azimuth = 0°, Tilt = 36°)



### 4.3 The results of laboratory tests

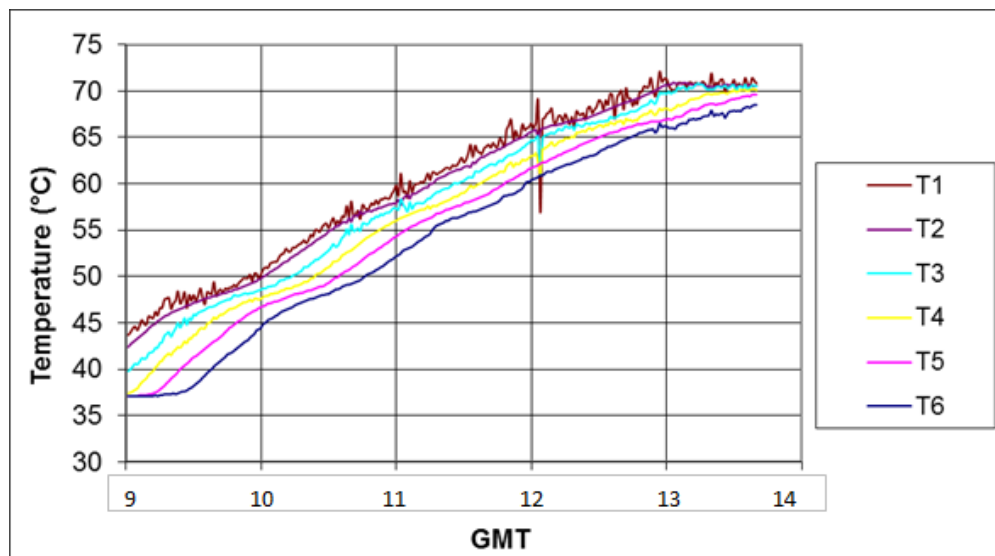
A total of 10 laboratory experiments were conducted to observe the change of water temperature within the HWC by time as it was heated due to solar radiation and also to investigate the performance of SDHWS with respect to collector azimuth and tilt angles. Two different collector tilt angles of  $36^\circ$  and  $48^\circ$  (Case 7 and 8 were performed with  $43^\circ$  erroneously) were used with a collector azimuth angle of  $0^\circ$  (facing south) and,  $20^\circ$  and  $40^\circ$  towards east and west. Table 4.1 summarizes the information about the experiments conducted.

**Table 4.1:** Laboratory Experiment Details

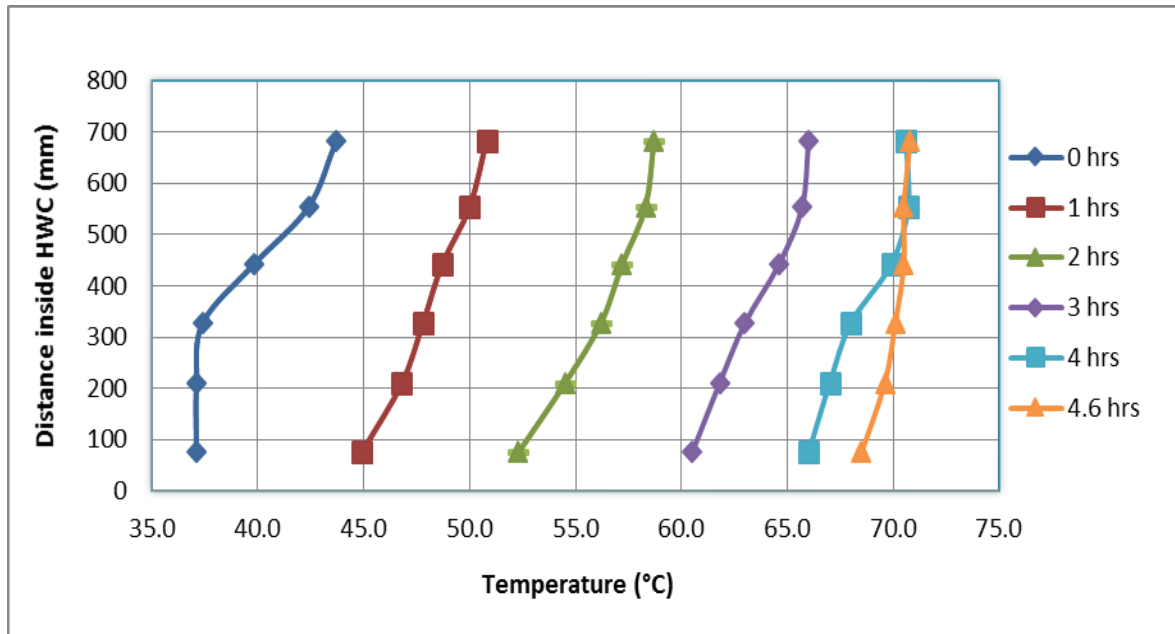
Test	Date	Tilt Angle	Azimuth Angle	Figure	Location	Water usage
L01	18/8/2015	$36^\circ$	South	4.10, 4.11, 4.12	Nicosia	Restricted
L02	19/8/2015	$36^\circ$	$20^\circ\text{E}$	4.14	Nicosia	Restricted
L03	20/8/2015	$36^\circ$	$20^\circ\text{W}$	4.15	Nicosia	Restricted
L04	21/8/2015	$36^\circ$	$40^\circ\text{W}$	4.17	Nicosia	Restricted
L05	24/8/2015	$36^\circ$	$40^\circ\text{E}$	4.16	Nicosia	Restricted
L06	27/8/2015	$43^\circ$	$40^\circ\text{E}$	4.20	Nicosia	Restricted
L07	28/8/2015	$43^\circ$	$20^\circ\text{E}$	4.18	Nicosia	Restricted
L08	15/9/2015	$48^\circ$	$40^\circ\text{W}$	4.21	Nicosia	Restricted
L09	16/9/2015	$48^\circ$	$20^\circ\text{W}$	4.19	Nicosia	Restricted
L10	17/9/2015	$48^\circ$	South	4.13	Nicosia	Restricted

Figure 4.10 shows the change of temperature levels recorded from six thermocouples during the experiment conducted for Test L01. A gradual increase of temperatures was observed. It is worth to note that the temperatures recorded by thermocouples T4, T5 and T6 located at the lower part of the HWC were the same (35°C) at the beginning of the experiment. Towards the end of the experiment the temperatures recorded by thermocouples T1, T2 and T3 located at the upper part of the HWC showing differences at the beginning are equalized at about 70 to 71°C. The temperature difference between upper and lower parts of the HWC (between T1 and T6) being about 6 to 7°C at the beginning of the experiment remained the same all through the experiment decreasing towards the end of experiment after 4 hours. At the end of experiment (after 4.6 hours) the difference dropped down to about 2 to 3°C. Decrease in the temperature difference between the upper and lower parts of the HWC shows that the SDHWS has nearly reached to its maximum capacity of heating.

Similar observations can be done by looking at the curves given in Figure 4.11 where the variation of temperature across the HWC in the vertical direction with 1 hour of intervals is given. It is significant to note that this variation across the HWC is almost linear except the data set given at the beginning of the experiment. This result verifies the linearity assumption explained in Section 3.4 for on-site experiments exceptionally at the beginning of the experiment and also after a possible hot water usage.



**Figure 4.12:** Variation of Temperature with respect to time in HWC for Test L01



**Figure 4.13:** Hourly Variation of Vertical Temperature Distribution in HWC for Test L01

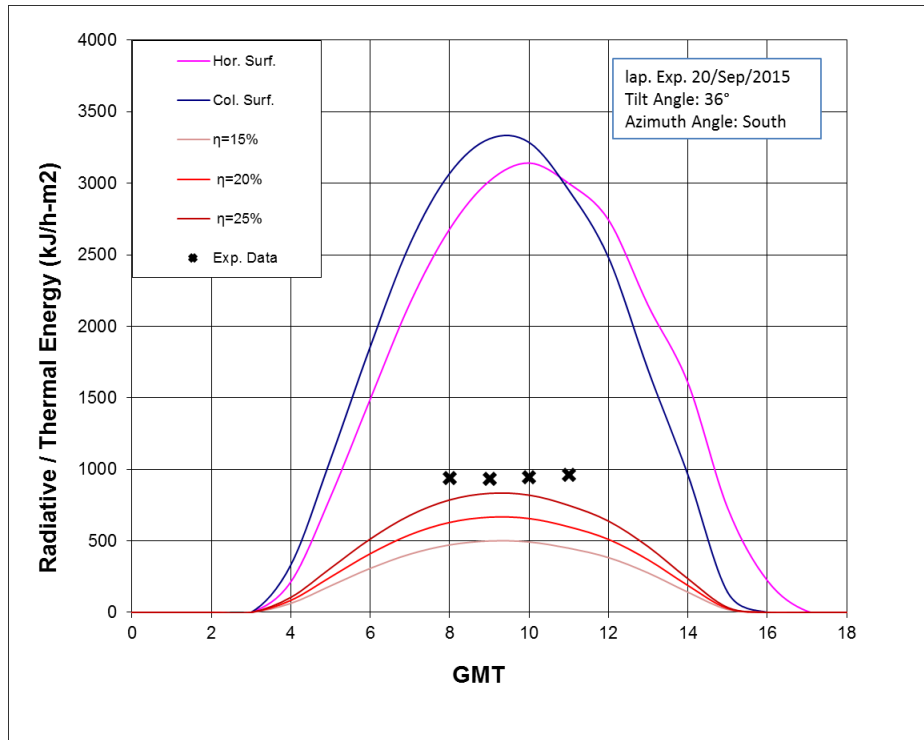
Figures 4.12 to 4.21 shows the hourly thermal energy absorption of the water in the HWC during the experiment together with the measured radiation on horizontal surface and expected radiation on the collector surface. In these figures, expected energy absorption levels are also given for different SDHWS efficiencies (15%, 20%, 25%) for comparison. Variation of energy absorption of the water in HWC collectors facing south with tilt angles  $36^\circ$  and  $48^\circ$  are given in Figures 4.12 and 4.13, respectively.  $36^\circ$  tilt angle has higher efficiency (about 30%) when compared with  $48^\circ$  (about 25%) as expected for spring time as described in Figure 4.5.

Variation of energy absorption of the water in HWC with collectors tilt angle  $36^\circ$  facing  $20^\circ\text{E}$  and  $20^\circ\text{W}$  are given in Figures 4.14 and 4.15, respectively. As described earlier in Figure 4.6 a lower efficiency was expected and the results are showing that efficiency has dropped from 30% to 25%, approximately. However, energy absorption values during before and after noon cannot be compared since the duration of the experiment was not all through the day. Conducting the experiment from sun rise to sun set might cause the energy abortion to stop towards the end of the day as described also in Figure 4.11 and may lead to wrong discussions.

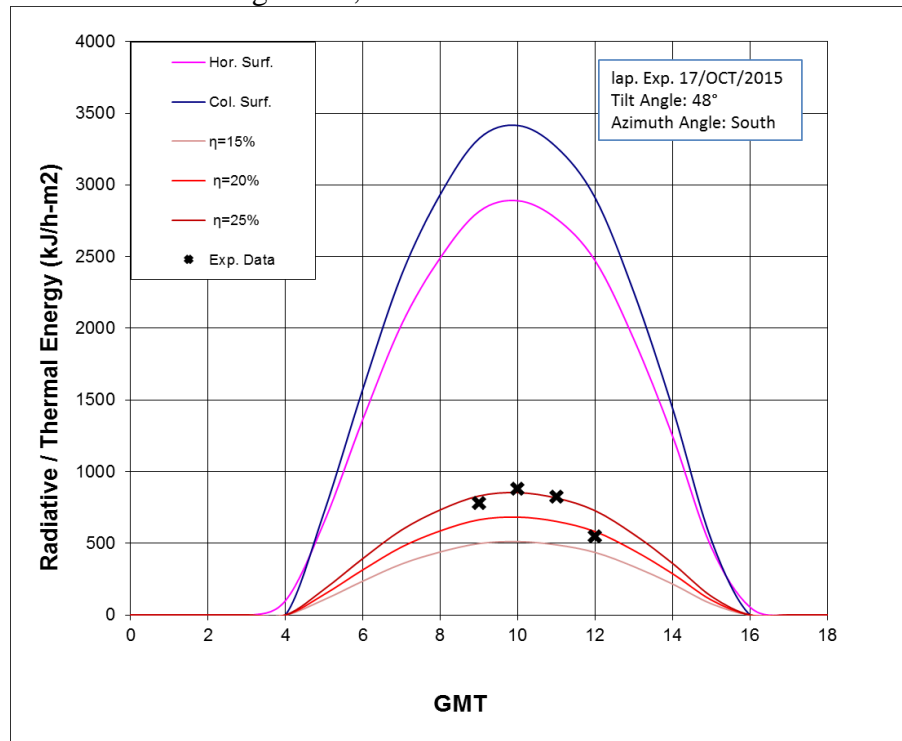
Variation of energy absorption of the water in HWC with collectors tilt angle  $36^\circ$  facing  $40^\circ\text{E}$  and  $40^\circ\text{W}$  are also given in Figures 4.16 and 4.17, respectively. It can be seen that the efficiency

of the SDHWS setup decreased further generally. In Figure 4.16 higher absorption values in the morning hours and lower energy values after noon are quite remarkable. However, the reverse case can not be seen in Figure 4.17.

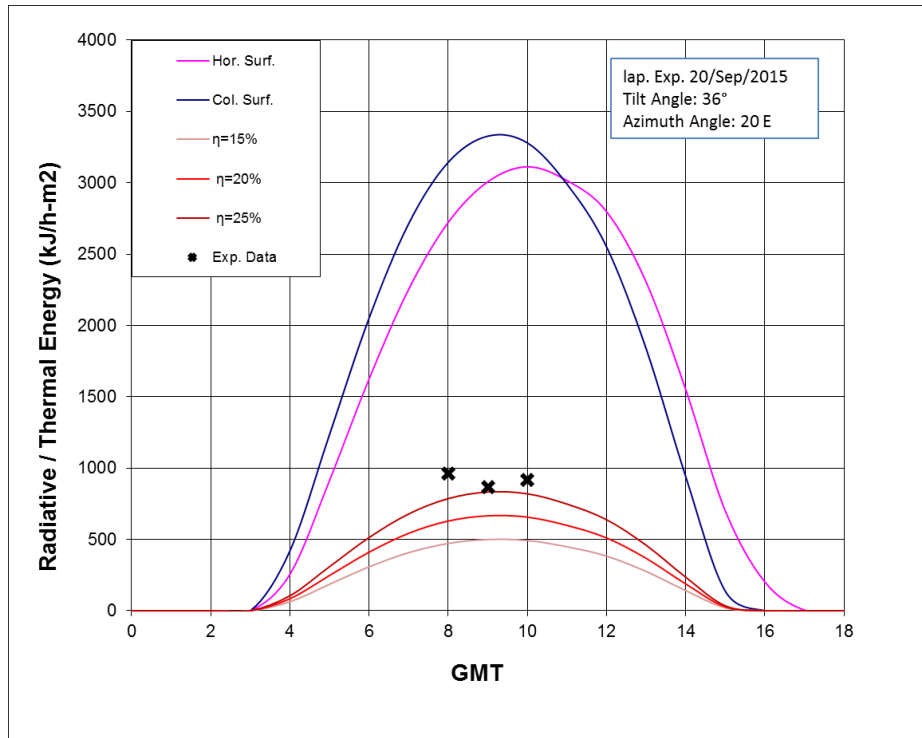
Figures 4.18 to 4.21 shows the variation of energy absorption of the water in HWC with collectors tilt angle  $43^\circ$  and  $48^\circ$  facing  $20^\circ\text{E}$ ,  $20^\circ\text{W}$ ,  $40^\circ\text{E}$  and  $40^\circ\text{W}$ , respectively. Decrease in efficiency values down to 20% can be observed for these cases.



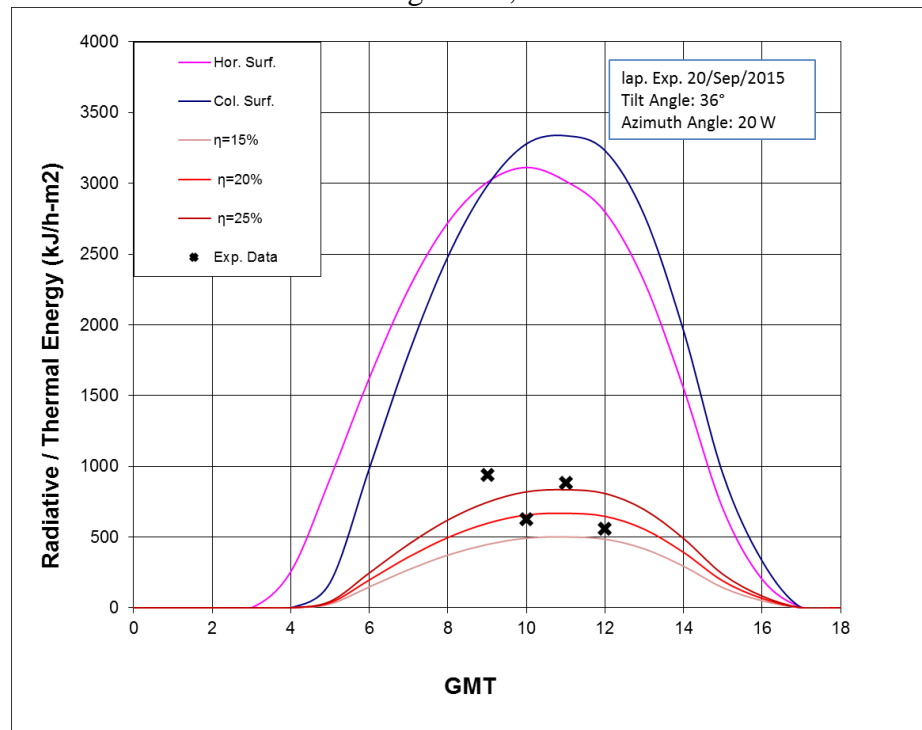
**Figure 4.14:** Variation of Energy Absorption of the Water in HWC (Test L01) Collector Tilt angle: 36°, Collector Azimuth: South



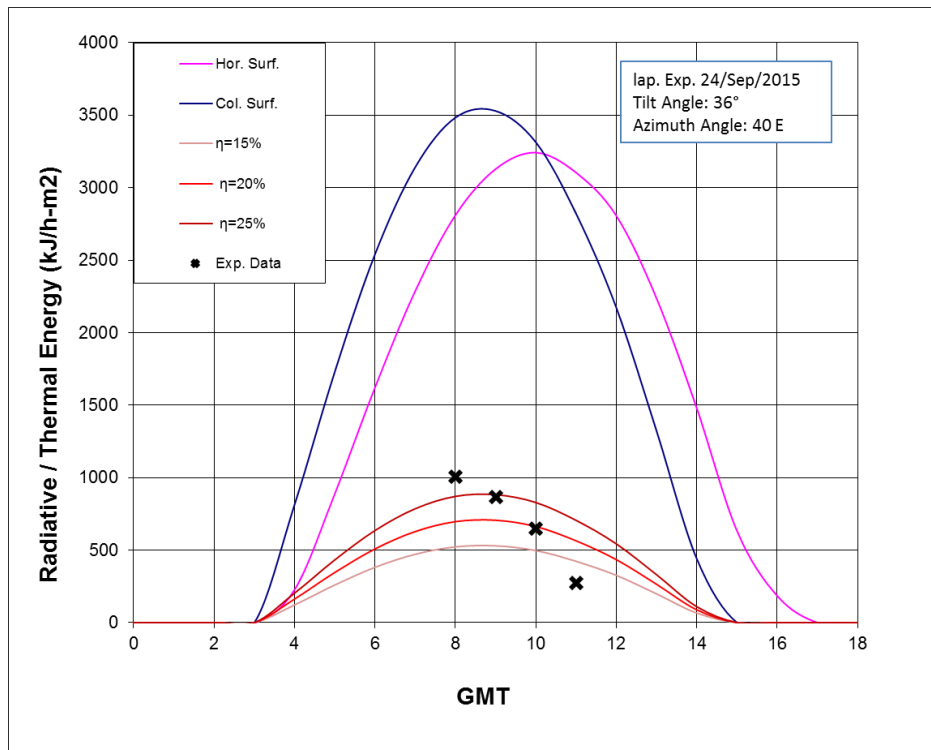
**Figure 4.15:** Variation of Energy Absorption of the Water in HWC (Test L10) Collector Tilt Angle: 48°, Collector Azimuth: South



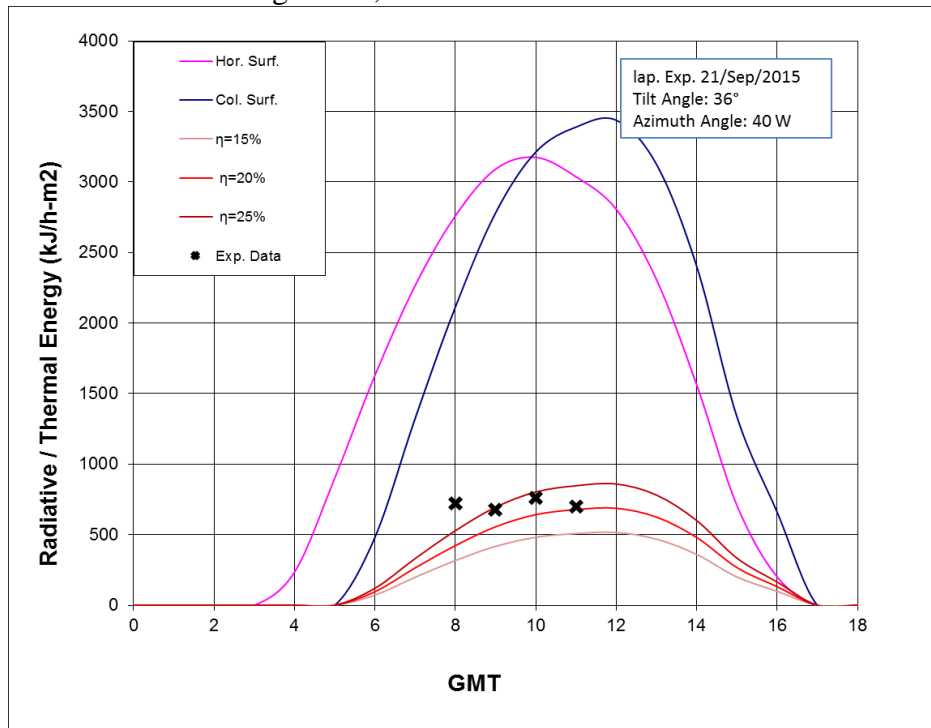
**Figure 4.16:** Variation of Energy Absorption of the Water in HWC (Test L02)  
Collector Tilt Angle: 36°, Collector Azimuth: 20°E



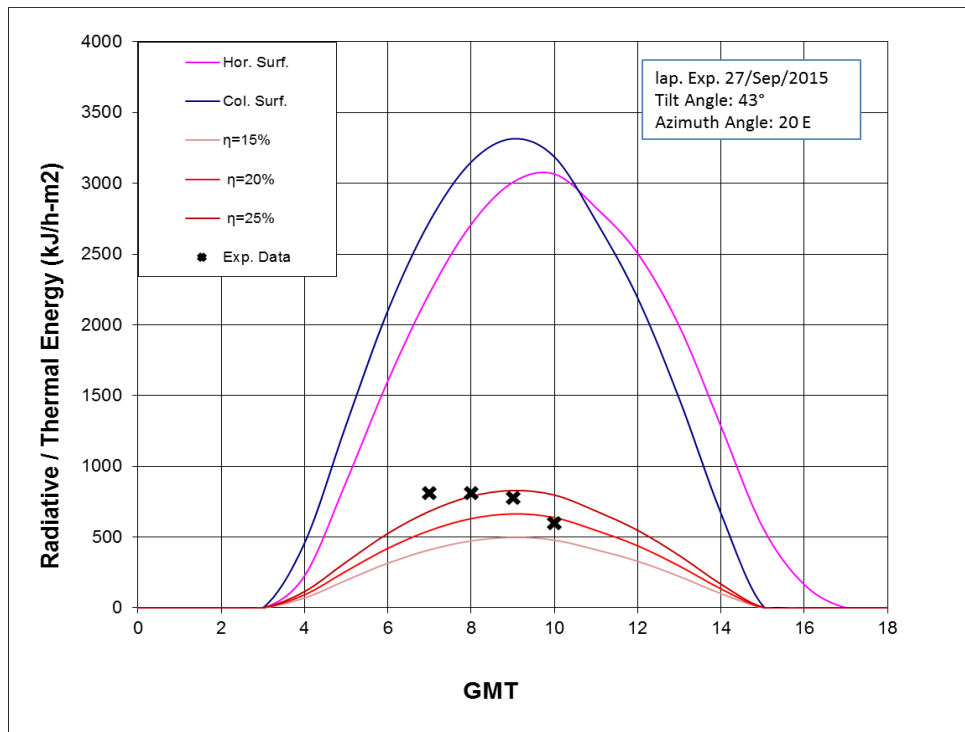
**Figure 4.17:** Variation of Energy Absorption of the Water in HWC (Test L03)  
Collector Tilt Angle: 36°, Collector Azimuth: 20°W



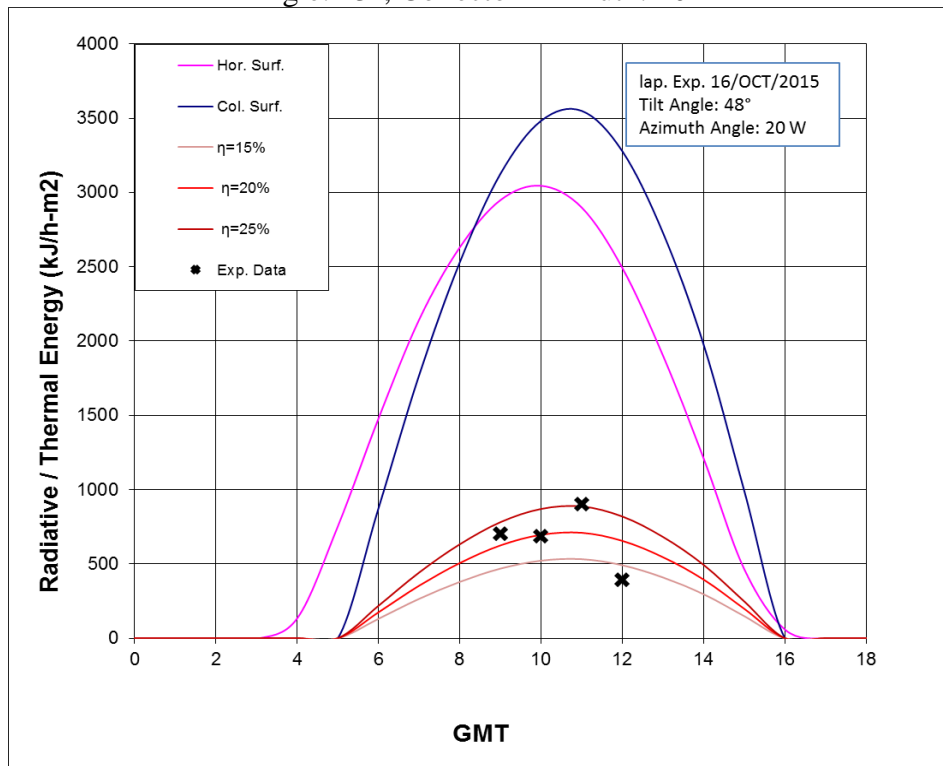
**Figure 4.18:** Variation of Energy Absorption of the Water in HWC (Test L04) Collector Tilt Angle: 36°, Collector Azimuth: 40°W



**Figure 4.19:** Variation of Energy Absorption of the Water in HWC (Test L05) Collector Tilt Angle: 36°, Collector Azimuth: 40°E

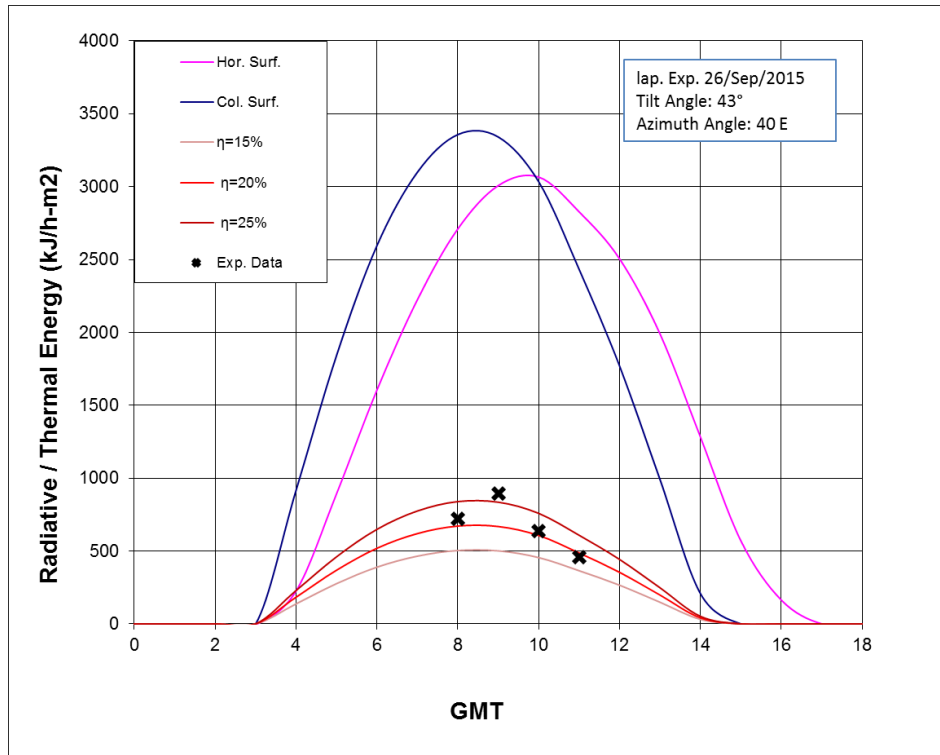


**Figure 4.20:** Variation of Energy Absorption of the Water in HWC (Test L06) Collector Tilt Angle: 43°, Collector Azimuth: 40°E

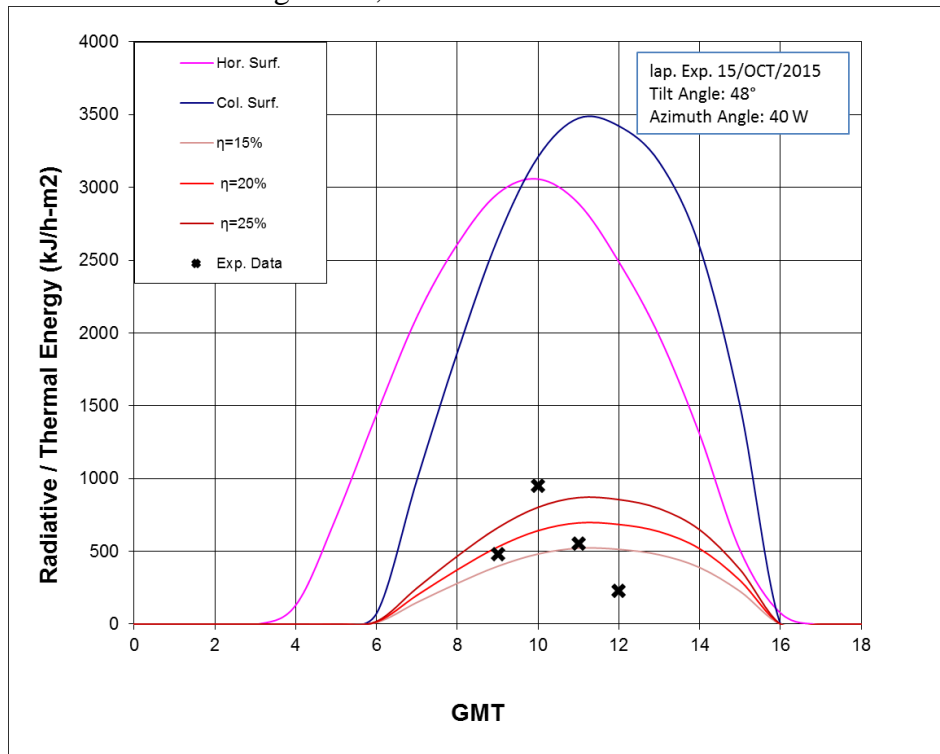


**Figure 4.21:** Variation of Energy Absorption of the Water in HWC (Test L07) Collector Tilt Angle: 43°, Collector Azimuth: 20°E





**Figure 4.22:** Variation of Energy Absorption of the Water in HWC (Test L08) Collector Tilt Angle: 48°, Collector Azimuth: 40°W



**Figure 4.23:** Variation of Energy Absorption of the Water in HWC (Test L09) Collector Tilt Angle: 48°, Collector Azimuth: 20°W

#### **4.4 On-site experiments**

A total of 10 on-site experiments were conducted to observe the performance of SDHWS located on the northern part of Cyprus. Table 4.2 summarizes the information about the experiments conducted and the case study papers can be seen in Appendix D. The results are shown in Figures 4.22-4.31. In these Figures the temperature variation between the top and bottom of the hot water cylinder together with the energy absorbed by the water is presented.

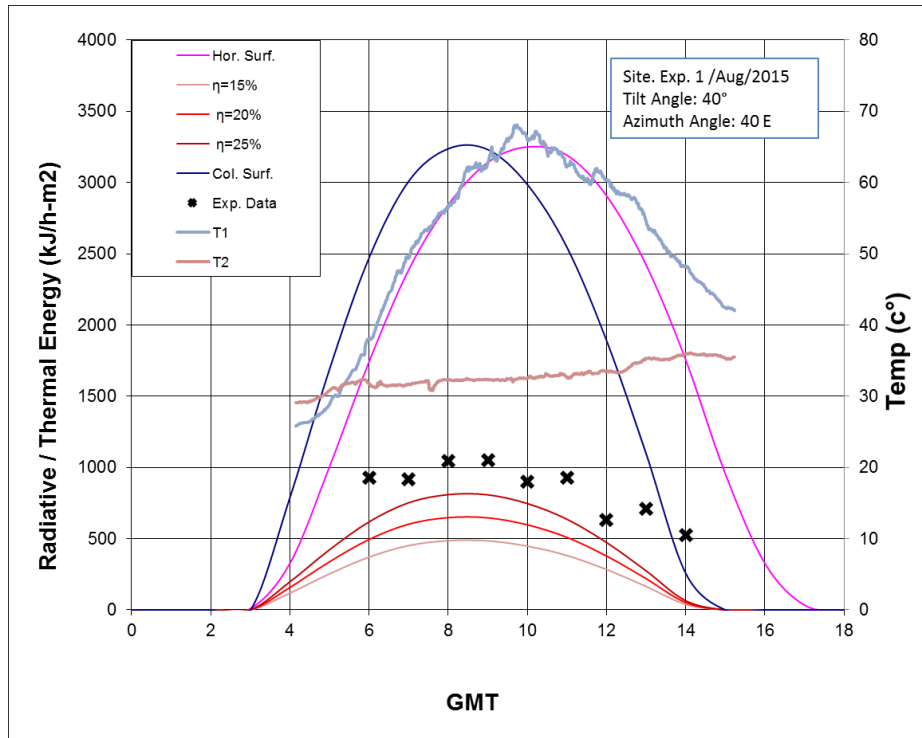
Additionally, the total radiation on the horizontal surface and collector surface for the date of experiment are given. The expected energy absorption for different efficiencies are also plotted (15%, 20%, 25%) during the day to compare with the experimentally obtained energy absorption data.

In Figure 4.22 of Test S01, T1 increased up to about 70°C at noon and started to decrease afterwards, T2 remaining almost constant throughout the day at about 30-35°C. This behavior is unexpected and shows no similarity with the results of laboratory tests (Figure 4.10). The behavior may be due to improper natural circulation or due to a circulation between the cold water tank and the lower part of HWC. Calculated absorption values are considered as misleading. Similar observations can be made for the Test S04 (Figure 4.25) and S07 (Figure 4.28).

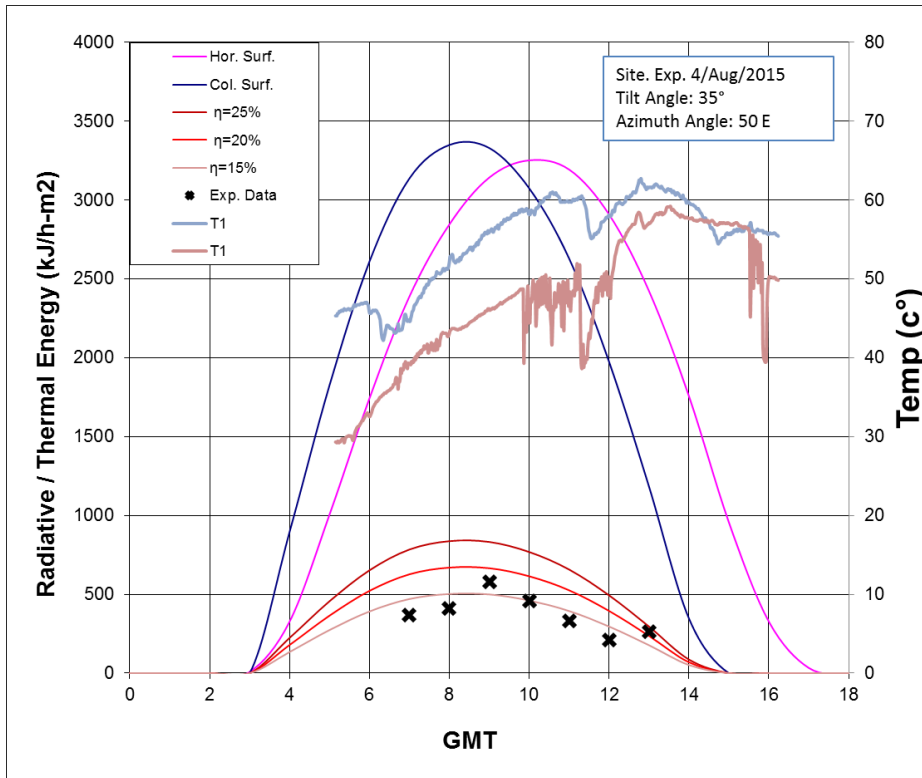
In the remaining tests efficiencies of the SDHWS were determined to be changing between 15 to 25%. The usage of hot water also effects the energy absorption values in a misleading manner and results in oscillations of these values during the tests. Trustable values are retained after some time from hot water usage when the change of temperature in the HWC in vertical direction becomes close to linear variation again.

**Table 4.2:** On-Site Experiment Details

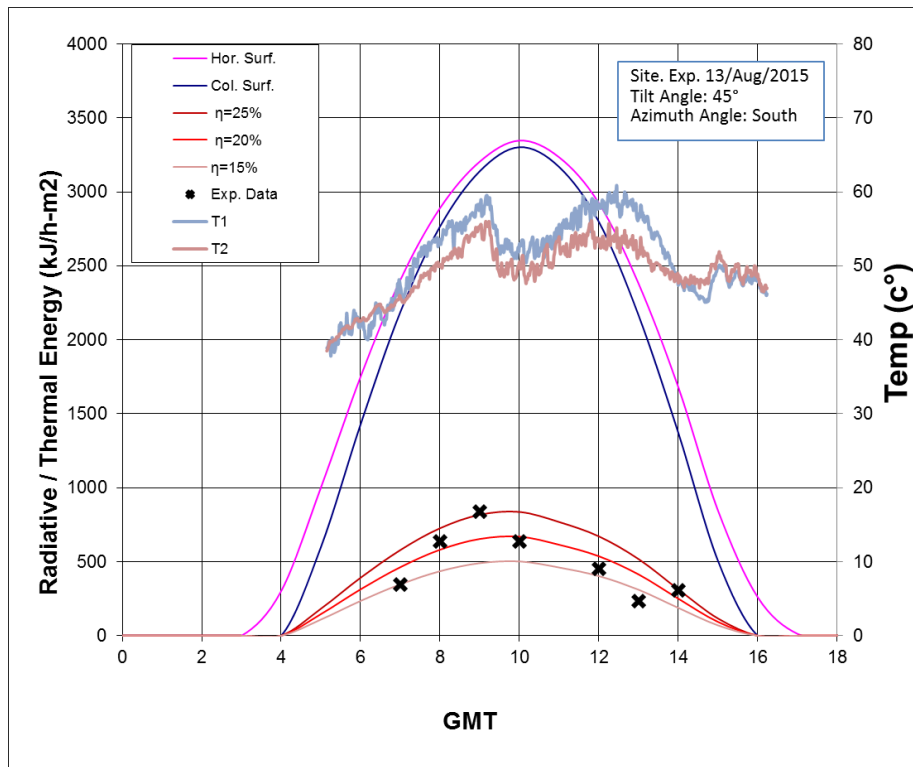
Test	Date	Tilt Angle	Azimuth Angle	Figure	Location	Water usage
S01	1/8/2015	43°	40 E	4.22	Girne	Restricted
S02	4/8/2015	35°	50 E	4.23	Nicosia	Non-Restricted
S03	13/8/2015	45°	South	4.24	Nicosia	Non-restricted
S04	14/8/2015	40°	9 E	4.25	Nicosia	Non-restricted
S05	23/8/2015	44°	2 E	4.26	Nicosia	Non-restricted
S06	26/8/2015	42°	5 E	4.27	Nicosia	Non-restricted
S07	29/8/2015	45°	South	4.28	Nicosia	Non-restricted
S08	30/8/2015	42°	South	4.29	Nicosia	Non-restricted
S09	31/8/2015	45°	South	4.30	Nicosia	Non-restricted
S10	1/9/2015	43°	South	4.31	Nicosia	Non-restricted



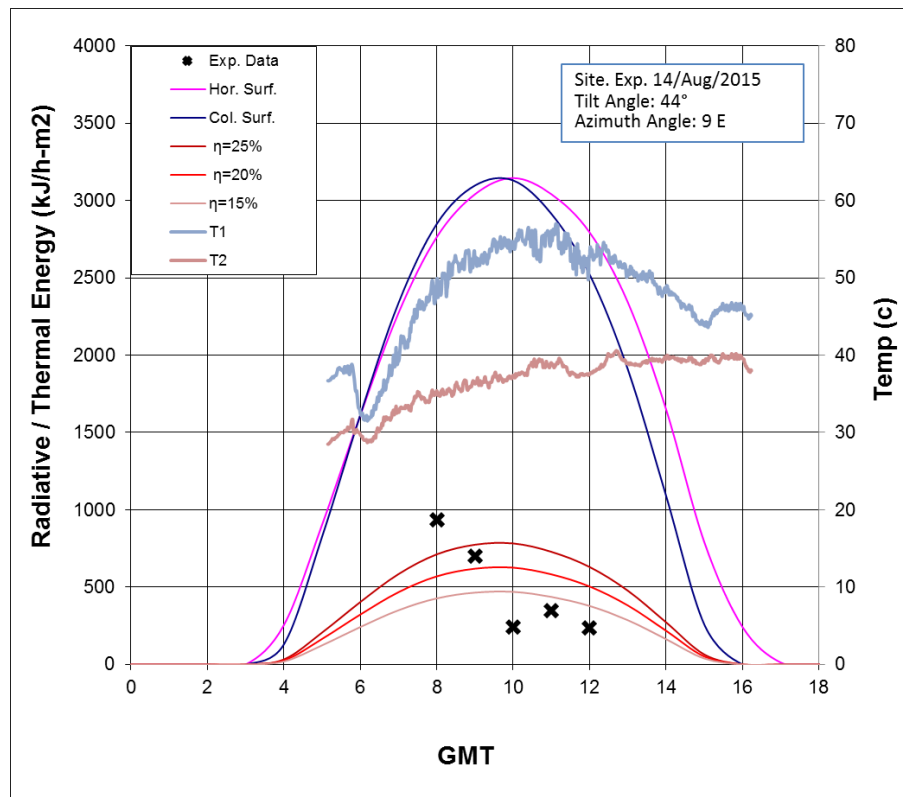
**Figure 4.24:** Thermal Energy Absorbed During On-Site Experiment; (Test S01)



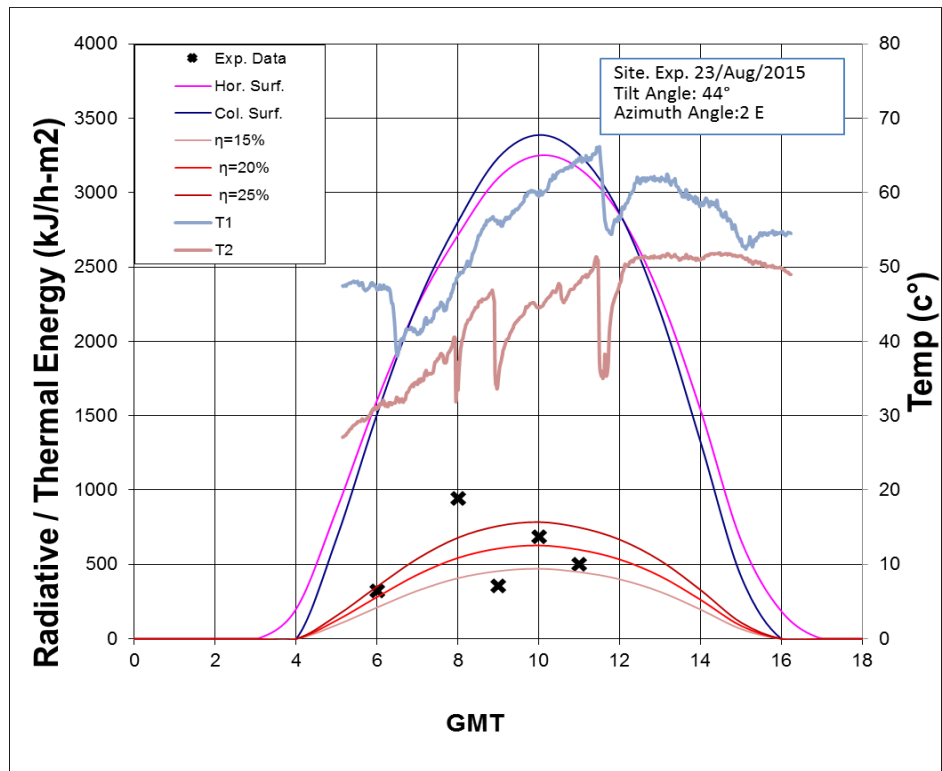
**Figure 4.25:** Thermal Energy Absorbed During On-Site Experiment; (Test S02 )



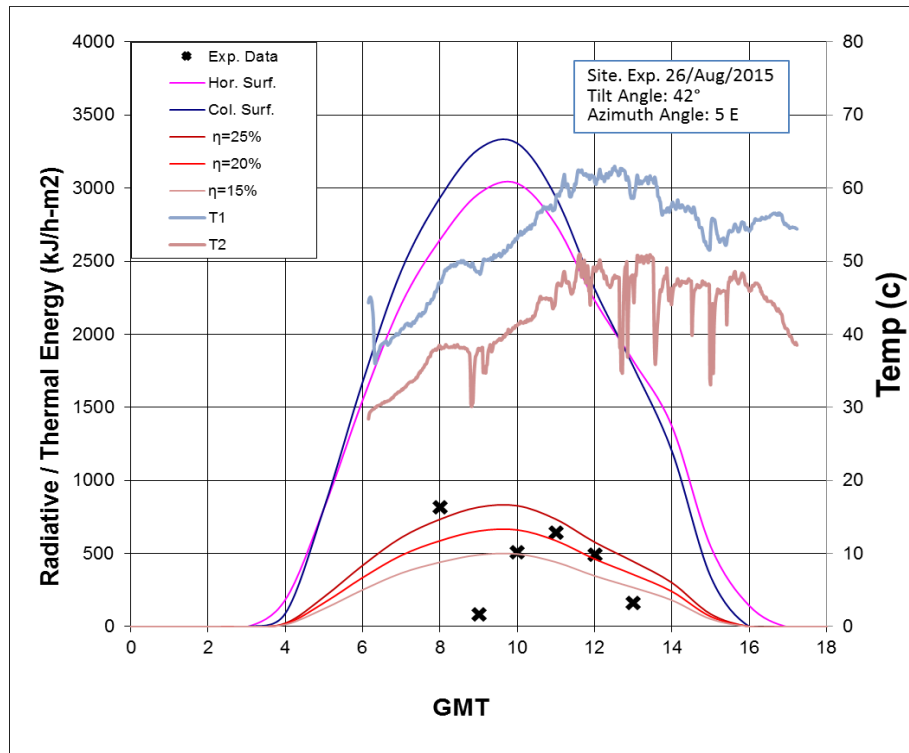
**Figure 4.26:** Thermal Energy Absorbed During On-Site Experiment; (Test S03 )



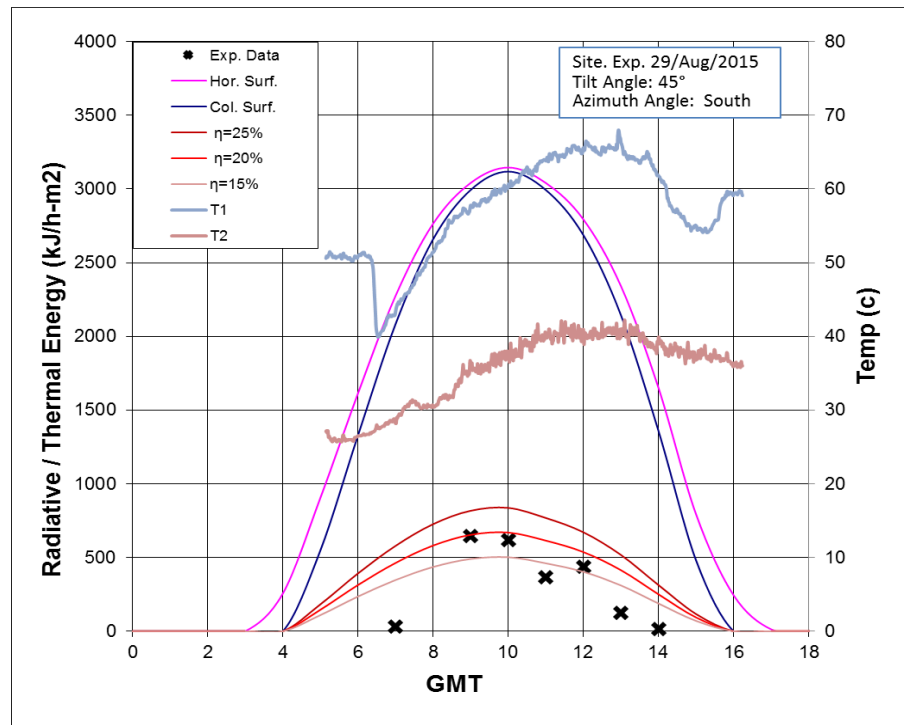
**Figure 4.27:** Thermal Energy Absorbed During On-Site Experiment; (Test S04 )



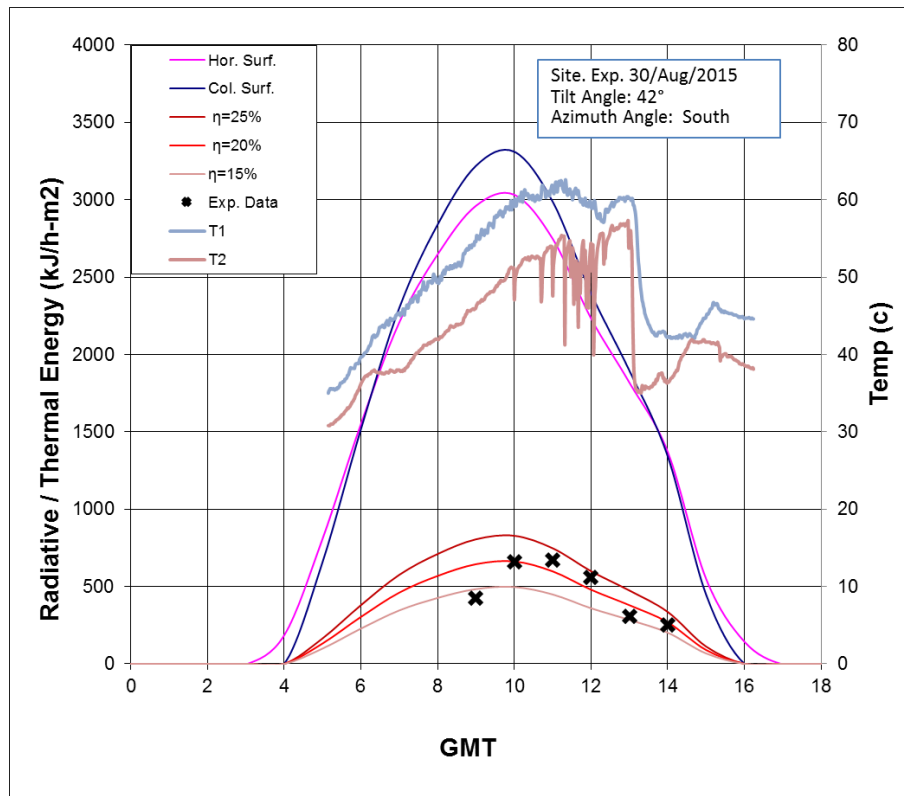
**Figure 4.28:** Thermal Energy Absorbed During On-Site Experiment; (Test S05)



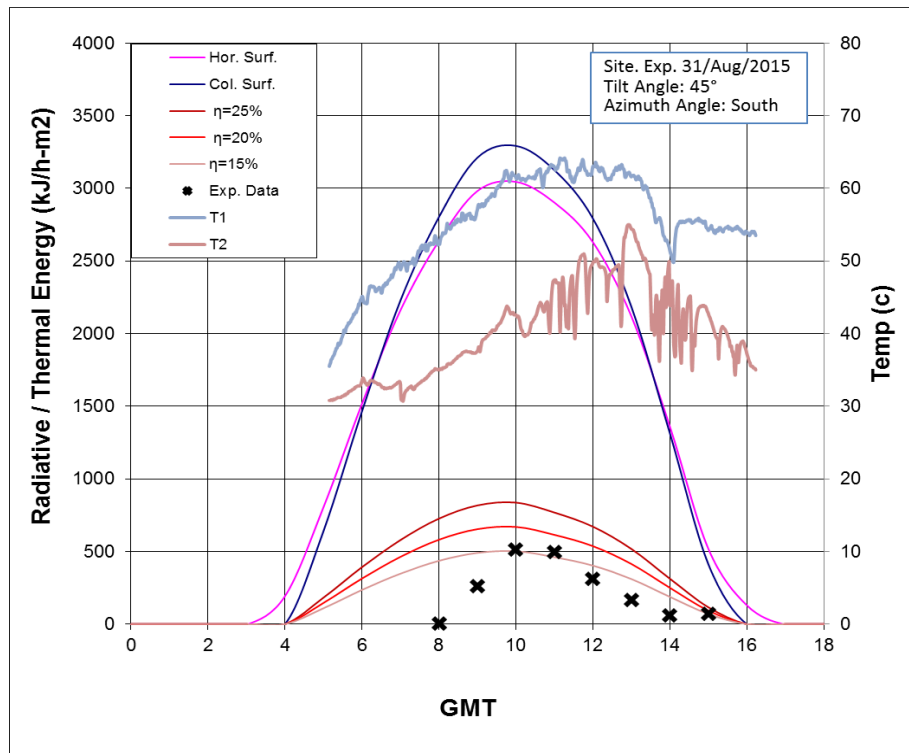
**Figure 4.29:** Thermal Energy Absorbed During On-Site Experiment; (Test S06)



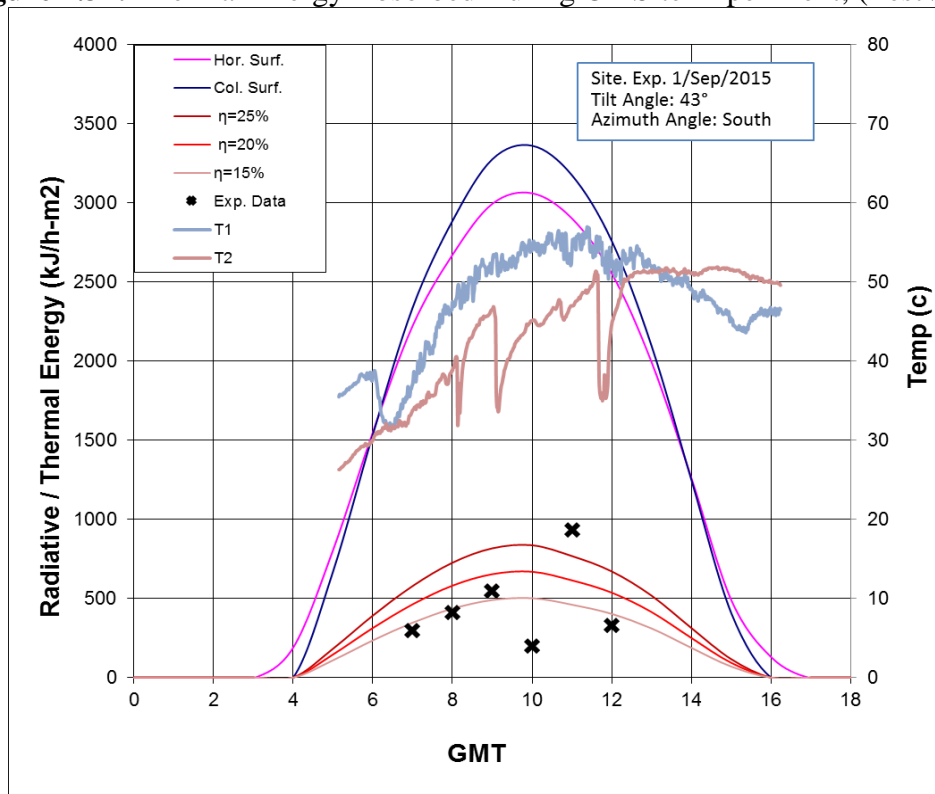
**Figure 4.30:** Thermal Energy Absorbed During On-Site Experiment; (Test S07)



**Figure 4.31:** Thermal Energy Absorbed During On-Site Experiment; (Test S08)



**Figure 4.32:** Thermal Energy Absorbed During On-Site Experiment; (Test S09)



**Figure 4.33:** Thermal Energy Absorbed During On-Site Experiment; (Test S10)



## **CHAPTER 5**

### **CONCLUSION**

The increasing demand on energy and decreasing fossil fuel reserves lead to usage of renewable energy resources and effective usage of energy in the whole world. Usage of solar energy for domestic hot water preparation is a widely used application. Cyprus, being the world leading country in this area, the study aims to determine the usage effectiveness of solar domestic hot water systems in Turkish Republic of Northern Cyprus.

The study was conducted in three section. In the first section the meteorological hourly radiation data for 2007 was studied together with theoretical formulations. It was observed that monthly average daily total solar radiation varied from  $10 \text{ MJ/m}^2$  up to  $28 \text{ MJ/m}^2$  in 2007 in Nicosia.

The effects of collector tilt and azimuth angles were investigated at the days of solstices and equinoxes. In winter, as the tilt angle decreases below  $36^\circ$  the radiation on the surface of the solar collector increases, and as the tilt angle is increased above  $36^\circ$  the energy on the surface decreases. Inversely in summer, as the tilt angle is decreased below  $36^\circ$  the radiation on the surface of the solar collector increases. In spring and autumn tilt angles equal to the latitude give the maximum performance.

The azimuth angle towards east and west will cause more energy gain in the morning and afternoon, respectively. However in winter and spring since the radiation period is less when compared with the summer, the total energy gained during the day will be less. During summer the total energy gained daily will not be effected that much since daily radiation period is longer.

The tests conducted in the laboratory showed that the temperature of the water inside the HWC increases gradually at all levels, the maximum temperature different between the top and bottom being about  $6$  to  $7^\circ\text{C}$  at the beginning of the experiment and decreasing to about  $2$  to  $3^\circ\text{C}$  at the end. It was concluded that as the temperature difference becomes less the energy absorption also becomes less. The temperature profile in the vertical direction was almost linear except at the beginning of heating and after hot water usage at which new cold water enters to the system.

A total of 10 laboratory tests conducted with collector azimuth angles of 40°E, 20°E, 0 20°W and 40°W and tilt angles of 36° and 48°. In two experiment tilt angle was adjusted wrongly as 43° instead of 48°. The energy absorption results calculated from the data obtained were compared with the estimated theoretical results and the efficiencies were found to be between 25 to 30%. The maximum efficiency was obtained in the test where the solar collector was facing south with a tilt angle of 36° as expected according to the period of the tests (Spring time). Change of tilt and azimuth angles decreased the performance of the system.

The performance of SDHWS in use in TRNC were tested by additional 10 on-site experiments. A total of 2 thermocouples were used in these test and only the temperature change at the upper and lower parts of the HWC could be measured. The energy absorption was calculated by assuming a linear temperature variation within the HWC. The efficiencies of SDHWS were determined to be as low as 15% to 25%, and 30% of the collectors tested were not working properly at all.

The most common SDHWS used in TRNC, being thermosiphonic type with black painted solar collectors made of galvanized steel, has a maximum efficiency of about 30%. However, the low performance levels obtained from on-site experiments show that much more care must be taken during the installation of the systems and also for maintenance to obtain the most out of solar energy.

Seasonal domestic hot water requirements together with the seasonal performances of the SDHWS can be used to obtain a most effective collector tilt angle according to different applications as a future work.

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## **APPENDICES**

### Hourly radiation data (cal/cm<sup>2</sup>)

[illegible]







91	-0.1	-0.1	-0.1	-0.1	-0.1	1.3	15.6	35.5	48.4	50.4	43.8	57.4	54.3	68.1	54.1	38.8	19.9	3.7	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
92	-0.1	-0.1	-0.1	-0.1	-0.1	2.1	17.1	36.5	53.7	67.3	75.7	79.3	76.9	68.7	46.1	24.4	12.5	5	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
93	-0.1	-0.1	-0.1	-0.1	-0.1	2.6	17.6	36.8	53.8	67.6	76.7	74	76.2	70.1	47.2	34.7	19	4.8	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
94	-0.1	-0.1	-0.1	0	2.7	22.2	24.5	53.5	67.6	75.5	78.8	73.9	59.5	53.9	32.4	15.6	3.8	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
95	-0.1	-0.1	-0.1	-0.1	-0.1	2.8	16	12.1	27.5	26.1	21.7	36.5	40.4	59.1	55.5	38.2	19.5	4.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
96	-0.1	-0.1	-0.1	-0.1	-0.1	1.7	16.6	30.5	27.8	20.3	26.8	26.3	35.3	19.1	28.5	16.1	13.1	2.8	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
97	-0.1	-0.1	-0.1	-0.1	-0.1	1	4.9	15.5	34.4	29.3	30.6	68.9	60.7	32.7	33.7	32.6	19.6	3.9	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
98	-0.1	-0.1	-0.1	-0.1	-0.1	2.3	17.7	37	54	66.3	72.6	78.1	28.8	33	28	22.2	16.2	3.3	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
99	-0.1	-0.1	-0.1	-0.1	-0.1	2.9	17.4	43.3	54.3	67.5	77.5	83.7	70.1	34.5	28.3	20	10.7	2.9	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
100	-0.1	-0.1	-0.1	-0.1	-0.1	2.6	17.7	37.2	51.3	67.9	76.4	80.4	77.8	46	23.3	16.1	13.2	4.4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
101	-0.1	-0.1	-0.1	-0.1	-0.1	3.5	19.3	38.9	54.9	67.8	77.8	81.8	78.7	71.2	45.8	44.4	21.2	4.8	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
102	-0.1	-0.1	-0.1	1	7.1	17.2	27.7	41.1	44.5	66.4	76	75.2	58.2	52.9	8.8	8.8	8.8	2.6	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
103	-0.1	-0.1	-0.1	-0.1	-0.1	4.3	19.7	37.8	54.3	68.5	68.4	81.4	78.2	71.2	58.4	40.9	20.7	5.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
104	-0.1	-0.1	-0.1	-0.1	-0.1	3.1	19.7	39.3	55.2	69.5	79.5	82.9	79.1	72.1	59.1	41.6	21.5	5.4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
105	-0.1	-0.1	-0.1	-0.1	-0.1	5.4	22.4	41.3	57.5	70.5	80	83.1	80.2	73.2	61	43.5	22.2	5.7	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
106	-0.1	-0.1	-0.1	-0.1	-0.1	5	21.5	40.8	56.8	70.4	69.1	46.2	24.4	26.6	36.2	28.4	24.3	4.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
107	-0.1	-0.1	-0.1	-0.1	-0.1	3	3.6	8.5	15.7	16	8.9	17.1	29.5	39.3	14.9	7.1	8.6	2.1	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
108	-0.1	-0.1	-0.1	-0.1	-0.1	5.8	22.6	42.1	56.8	57.7	58.3	64	74.6	71.2	43.9	31.3	26.2	5	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
109	-0.1	-0.1	-0.1	0	4.5	23.9	32.1	54	73.1	82.8	86.4	83.4	75.7	63.1	44.8	23.4	6.7	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
110	-0.1	-0.1	-0.1	0	6.6	23.2	41.8	58.3	70.2	79.7	67.6	73	55	36.6	13.2	8.6	5.3	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	0
111	0	0	0	0.1	3.4	16.8	38.4	49.1	62.3	73.2	84.3	79.1	71.6	57.9	40.1	21.1	4.3	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
112	-0.1	-0.1	-0.1	0	7.1	15.3	39.9	56	69.6	78.3	80.4	74.8	57.1	56.5	24.1	10.3	2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
113	-0.1	-0.1	-0.1	-0.1	-0.1	2.6	10.4	40.8	58.7	71.2	79.9	83.3	79.2	71.7	58.7	41	22.5	6.3	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
114	-0.1	-0.1	-0.1	0	8.2	27.7	47.4	64.3	76.8	84.3	88.3	83.1	76.1	62.4	44.6	25.4	7.8	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
115	-0.1	-0.1	-0.1	0.1	8.7	26.7	46	62.5	74.8	83.1	86.6	81.6	74.2	60.7	43.1	24.3	6.9	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
116	-0.1	-0.1	-0.1	0.2	9.8	23.4	27.2	29.4	32.5	38.8	52.5	26.4	15.4	10.7	15.8	9.1	3.8	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
117	-0.1	-0.1	-0.1	0	5.7	21.1	39.2	55.8	68.5	75.9	78.4	73.8	67.1	52.2	34.4	14	6.9	0.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
118	-0.1	-0.1	-0.1	0.2	7.5	24.1	42.8	58.7	70.3	78.2	79.5	75.4	67	38.3	40.8	19.6	5.9	0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
119	-0.1	-0.1	-0.1	0.1	8.4	26.1	44.9	60.4	72.3	79.8	84.4	81.5	76.4	55.1	47.5	23.8	7.9	0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
120	-0.1	-0.1	-0.1	0.2	9.4	27.1	46.1	61.2	73	80.9	83.8	80.1	73.3	58.7	41.5	21.6	7.2	0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1

121	-0.1	-0.1	-0.1	-0.1	0.3	8.8	25.9	44.7	61.4	73.6	81.8	84.6	80.9	70.4	55.7	41.5	21.8	5.6	0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
122	-0.1	-0.1	-0.1	-0.1	0.3	7.5	25	42.8	57.6	67.7	74.5	76.1	70.6	64.4	53.6	36.7	20.1	6.2	0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
123	-0.1	-0.1	-0.1	-0.1	0.2	7.8	24	41	56.3	67.8	74.7	78.7	73.9	67.5	54.7	38.6	21.2	6.4	0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
124	-0.1	-0.1	-0.1	-0.1	0.3	8.5	25.3	43.6	58.8	69.9	78.2	80.7	76.4	61.9	48.9	30.1	19.8	5.5	0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
125	-0.1	-0.1	-0.1	-0.1	0.4	8.6	26.1	44.1	59.1	71.5	79.5	81.9	77.6	70.1	57.6	41	22.4	7	0.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
126	-0.1	-0.1	-0.1	-0.1	0.4	9	25.6	43.4	58.7	70.9	78.1	80.4	76.6	68.9	56.6	39.6	21.4	6.2	0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
127	-0.1	-0.1	-0.1	-0.1	0.4	7.7	23.2	40.6	55.5	67.5	74.6	76.4	73.2	65.8	54.1	37.8	20.4	6.6	0.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
128	-0.1	-0.1	-0.1	-0.1	0.2	7.4	25.4	40.9	57.8	66.8	75.8	76.1	74.3	67.7	55.3	25.9	13.2	6.3	0.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
129	-0.1	-0.1	-0.1	-0.1	0	1.5	2.6	9.5	17.8	11.8	14.2	10.4	15.2	18.8	9.7	11	12.5	7.2	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
130	-0.1	-0.1	-0.1	-0.1	0.1	3	3.3	7.1	8.4	34.2	27.4	15.3	9.4	20.6	13.9	3.2	5.9	5.4	0.4	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
131	-0.1	-0.1	-0.1	0	0	0.1	0.1	0.7	0.8	2.3	5	4.7	13.9	6.2	2.9	5.3	3.1	1.2	0	0	-0.1	-0.1	0	0	0	0
132	0	0	0	-0.1	0.3	2.3	5.1	15.1	23.9	19.3	8.8	20.2	31.7	31.9	30.7	14	12.5	6.6	0.5	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
133	-0.1	-0.1	-0.1	-0.1	0.3	6.7	13.8	43.2	49.4	73.4	80.8	82.5	78.2	72.1	58.4	41.7	24.9	6.5	0.6	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
134	-0.1	-0.1	-0.1	-0.1	0.7	8.9	27.6	46.9	62.7	74	80.5	81.5	77.6	62.1	55.2	41	19.1	8	0.5	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
135	-0.1	-0.1	-0.1	-0.1	0.5	7	12.9	27.6	48	74	76.4	63.3	53.3	33	26.8	30.7	21.8	6.3	0.3	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
136	-0.1	-0.1	-0.1	-0.1	0.2	4.7	23.9	41.3	31.7	16.7	20.6	24.8	60.8	42.9	31.8	22.8	15	5.4	0.5	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
137	-0.1	-0.1	-0.1	-0.1	0.2	1.9	3.9	9.3	5	20.4	32.8	30	40.5	31.2	13.4	9.4	5.1	1	0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
138	-0.1	-0.1	-0.1	-0.1	0.6	6.4	21.5	29.8	50.9	58	46.4	52	39.9	44.3	25.6	17	10.8	6	0.5	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
139	-0.1	-0.1	-0.1	-0.1	0.5	6.1	10.2	18.9	29.6	60.1	81.2	82.8	78.9	71.3	58	42.2	19.4	10.1	0.7	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
140	-0.1	-0.1	-0.1	-0.1	0.9	9	25.6	40.1	59.7	69.6	75.5	82.4	78.5	70.2	58.5	33.3	27.8	11.2	1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
141	-0.1	-0.1	-0.1	-0.1	1	12.9	32.2	51.5	69.3	71.2	84.8	85.4	87.4	74.5	30.5	12.7	8.1	5.6	0.8	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
142	-0.1	-0.1	-0.1	-0.1	1.7	14	32.6	50.6	66.1	77.2	86.3	88.1	82.9	62.2	58.6	45.2	27.2	10.2	1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
143	-0.1	-0.1	-0.1	-0.1	4.4	12.4	40.1	50.2	65.6	76.9	83.5	85.2	81.7	73.6	61.3	44.6	26.1	9.7	1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
144	-0.1	-0.1	-0.1	-0.1	1.7	13.6	32.1	49.8	65.1	76.6	83.7	84.8	80.4	72.9	60.1	43.4	24.7	9.1	0.9	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
145	-0.1	-0.1	-0.1	-0.1	1.3	11.1	29.4	47.5	63.7	74.4	81.6	82.9	78.8	71.8	59.4	43.4	25.6	9.7	1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
146	-0.1	-0.1	-0.1	-0.1	1.7	13.6	31.2	49.4	64.5	76.3	83.6	60.5	78.5	75.6	58.5	44.4	25.7	8.7	0.8	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
147	-0.1	-0.1	-0.1	-0.1	1.4	12.7	30.4	45.2	63.1	73.6	78.6	78	14.2	24	32.9	44.1	9.7	7.1	0.8	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
148	-0.1	-0.1	-0.1	-0.1	1.7	13.4	30.2	45.6	49.8	70.4	70.3	65.9	72.1	60.7	23.7	44.8	28.2	9.8	0.9	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
149	-0.1	-0.1	-0.1	-0.1	0.8	6.3	15.1	42.7	59.3	70.4	76.9	78.6	75.8	69	58.1	43.2	26.5	10.2	1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
150	-0.1	-0.1	-0.1	-0.1	1.3	11.1	27.6	45.4	59.9	71.2	76.9	78.9	74.7	68.4	56.2	41.5	24.9	10.3	1.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
151	-0.1	-0.1	-0.1	-0.1	1.5	13	31	49.3	64.1	75	82.2	84.6	84.4	76	61.8	45.6	27.8	11.1	1.3	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1

152	-0.1	-0.1	-0.1	-0.1	1.8	14.4	32.3	50.1	45.2	23.9	64.3	57.4	57.8	40.2	23.5	21.5	12.5	11.2	1.4	-0.1	-0.1	-0.1	-0.1	-0.1
153	-0.1	-0.1	-0.1	-0.1	2	14.1	31.9	50.1	65.5	76.9	83.4	84.9	78.4	73.4	33.1	48.8	28.7	11.1	1.5	-0.1	-0.1	-0.1	-0.1	-0.1
154	-0.1	-0.1	-0.1	-0.1	1.8	13.7	30.6	49.3	64.6	75.7	82.7	84.9	81.5	75.9	63.4	45	27.3	11.2	1.5	-0.1	-0.1	-0.1	-0.1	-0.1
155	-0.1	-0.1	-0.1	-0.1	1.9	13.9	30.6	47.9	62.9	74.9	82.4	85.3	81.7	77.1	61.6	44	27.5	12.1	1.6	-0.1	-0.1	-0.1	-0.1	-0.1
156	-0.1	-0.1	-0.1	-0.1	1.9	14.4	31.7	48.7	63	74.6	79.5	85	76.9	74.5	61.1	45.6	27.8	10.8	1	-0.1	-0.1	-0.1	-0.1	-0.1
157	-0.1	-0.1	-0.1	-0.1	1.3	12.3	27.4	44.4	59.9	71.6	78.5	80.1	76.9	69.1	58.4	42.8	26.1	10.8	1.6	-0.1	-0.1	-0.1	-0.1	-0.1
158	-0.1	-0.1	-0.1	-0.1	2.1	14.9	32.1	40.9	55.6	67	61.9	27.9	24.9	38.4	52.9	47.5	28.5	11.1	1.9	-0.1	-0.1	-0.1	-0.1	-0.1
159	-0.1	-0.1	-0.1	-0.1	1.9	13.8	30.8	48.4	63	73.5	72	87.3	83.1	53.1	21.4	26	12.5	6.3	1.3	-0.1	-0.1	-0.1	-0.1	-0.1
160	-0.1	-0.1	-0.1	-0.1	1.7	13.4	30.3	48	63.9	74.6	82.4	85.1	33.8	69.6	63.7	45.8	26	10	1.4	-0.1	-0.1	-0.1	-0.1	-0.1
161	-0.1	-0.1	-0.1	-0.1	0.4	9	17.5	12.7	28.3	33.1	46.4	85.8	80.2	71.8	59.9	45	28.7	11.6	1.6	-0.1	-0.1	-0.1	-0.1	-0.1
162	-0.1	-0.1	-0.1	-0.1	1.6	12.6	29.8	47.7	63	74.8	82.7	84.9	81	74.8	62.4	48.5	31.1	13.4	2.4	-0.1	-0.1	-0.1	-0.1	-0.1
163	-0.1	-0.1	-0.1	-0.1	2.1	15.1	32.5	49.6	64.3	75.1	82.2	84	81.4	62	40.8	28.7	32.1	14.4	2.3	-0.1	-0.1	-0.1	-0.1	-0.1
164	-0.1	-0.1	-0.1	-0.1	2.1	15.1	32.5	49.6	64.3	75.1	82.2	84	81.4	62	40.8	28.7	32.1	14.4	2.3	-0.1	-0.1	-0.1	-0.1	-0.1
165	-0.1	-0.1	-0.1	-0.1	2.1	14.8	32.4	49.9	65.3	76.9	83.4	85.7	82.5	75.5	63.1	48.2	30.2	13	2.1	-0.1	-0.1	-0.1	-0.1	-0.1
166	-0.1	-0.1	-0.1	-0.1	2.3	15.4	32.9	50.4	66	77.5	84	86.5	83.6	76.2	63.7	48.7	30.7	13	2.1	-0.1	-0.1	-0.1	-0.1	-0.1
167	-0.1	-0.1	-0.1	-0.1	2.3	15.2	33	50.4	65.8	77.2	84	86.7	83.9	76.3	62.9	46.9	28.9	12	2	-0.1	-0.1	-0.1	-0.1	-0.1
168	-0.1	-0.1	-0.1	-0.1	0.9	10.7	19.3	40.7	64.1	75	82	84.1	80.8	72.9	61.1	46.1	24.1	11.6	1.8	-0.1	-0.1	-0.1	-0.1	-0.1
169	-0.1	-0.1	-0.1	-0.1	1.4	4.8	9.3	32.2	61.4	75.3	82.2	83	78.2	73.9	51.2	46.6	29.4	11.5	1.9	-0.1	-0.1	-0.1	-0.1	-0.1
170	-0.1	-0.1	-0.1	-0.1	1.9	13.9	31.3	49	64.7	76.6	84	85.7	81.2	74.8	63.3	47.8	29.5	12.5	2.1	-0.1	-0.1	-0.1	-0.1	-0.1
171	-0.1	-0.1	-0.1	-0.1	2	13.7	31.6	50.1	64.7	76.1	83.6	85.9	81.7	74.4	62.9	47.4	29.1	12.2	2	-0.1	-0.1	-0.1	-0.1	-0.1
172	-0.1	-0.1	-0.1	-0.1	1.8	13.6	30.6	47.5	64.8	75.6	83.6	86.3	82.3	75.8	64.1	48.4	30.2	12.7	2.1	-0.1	-0.1	-0.1	-0.1	-0.1
173	-0.1	-0.1	-0.1	-0.1	1.9	14.8	32.8	51.2	66.5	78	85.4	87.9	84.3	77	65.6	50	31.6	13.5	2.2	-0.1	-0.1	-0.1	-0.1	-0.1
174	-0.1	-0.1	-0.1	-0.1	2.2	15.7	33.5	51.9	67.5	78.8	85.8	88.1	84.8	78	66.6	51.2	32.2	13.8	2.2	-0.1	-0.1	-0.1	-0.1	-0.1
175	-0.1	-0.1	-0.1	-0.1	2.1	15.4	33	51.3	66.3	77.3	84.6	86.5	82.7	75.8	63.9	48.1	30.1	12.6	1.9	-0.1	-0.1	-0.1	-0.1	-0.1
176	-0.1	-0.1	-0.1	-0.1	1.5	12.6	29.4	47.2	63.1	75.6	82.9	85.4	81.9	75.1	62.8	47	29.8	12.8	2	-0.1	-0.1	-0.1	-0.1	-0.1
177	-0.1	-0.1	-0.1	-0.1	1.8	14.4	32	50.4	65.8	77.5	84.4	86.4	83.2	76.8	64.9	48.9	30.4	13.2	2	-0.1	-0.1	-0.1	-0.1	-0.1
178	-0.1	-0.1	-0.1	-0.1	1.6	13.7	30.6	48.9	65	76.6	83.6	85.5	81.8	75.2	63.4	47	29	12.3	1.8	-0.1	-0.1	-0.1	-0.1	-0.1
179	-0.1	-0.1	-0.1	-0.1	1.5	12.7	29.6	47.1	61.7	73.2	81.7	84.3	81.2	74.2	62.1	46.8	29.1	12.3	1.8	-0.1	-0.1	-0.1	-0.1	-0.1
180	-0.1	-0.1	-0.1	-0.1	1.3	12.1	28.7	46.5	62	72.4	80	82.9	80.2	72.3	61.7	44.9	22.7	11.7	2.3	-0.1	-0.1	-0.1	-0.1	-0.1
181	-0.1	-0.1	-0.1	-0.1	1.4	11.9	28.2	45.5	60.8	71.8	78.4	80.9	76.5	66.1	60.1	25.3	27.6	11.9	1.8	-0.1	-0.1	-0.1	-0.1	-0.1

182	-0.1	-0.1	-0.1	-0.1	1.1	11.5	28.2	45.6	60.3	69.7	80	31	12.1	21.9	34.3	11	2.9	5.1	1.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
183	-0.1	-0.1	-0.1	-0.1	1.3	10.6	28.8	47	62.5	74.9	82.5	72.8	21.6	41.3	66.4	49.2	30.9	14.2	2.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
184	-0.1	-0.1	-0.1	-0.1	1.7	14.5	31.9	50	66.3	78.1	85.1	87.3	83.8	77	64.9	50.3	31.8	14.7	2.5	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
185	-0.1	-0.1	-0.1	-0.1	1.6	14.1	31.4	49.2	64.3	75.7	82.8	85.7	82.6	75.9	64.5	49.3	31.5	14.5	2.4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
186	-0.1	-0.1	-0.1	-0.1	1.5	13.5	30.8	49	64.5	75.7	82.6	84.3	81.9	75.6	64.3	49.3	31.7	14.3	2.4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
187	-0.1	-0.1	-0.1	-0.1	1.4	12.7	29.8	48.1	63.5	74.5	80.8	83.2	81.2	75.6	64.6	49.1	31.4	14.1	2.3	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
188	-0.1	-0.1	-0.1	-0.1	1.4	13.8	31.5	49.8	64.9	75.2	82.4	85.1	82.2	75.6	62.8	47.3	30.1	13.3	2.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
189	-0.1	-0.1	-0.1	-0.1	1.4	13.6	31.3	49.8	65.9	78.1	85.1	87.3	85.1	78.5	66.1	50.3	31.2	13.8	2.4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
190	-0.1	-0.1	-0.1	-0.1	1.4	14.3	32.6	51.2	67.7	79.3	86.4	88.8	86	79.3	67.4	51.5	32.7	14.7	2.4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
191	-0.1	-0.1	-0.1	-0.1	1.2	12.7	32.3	49.9	64.4	75	81.4	84.5	82.3	76.1	64.4	48.7	31.7	13.7	2.4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
192	-0.1	-0.1	-0.1	-0.1	1.3	13.5	30.6	48.6	63.7	75.4	82.2	84.4	82.5	76.2	64	48.2	29.8	12.8	2.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
193	-0.1	-0.1	-0.1	-0.1	2.9	19.1	37.8	48.7	63.8	75.3	82.5	84.3	81.8	75	62.9	47.9	29.5	12.4	2.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
194	-0.1	-0.1	-0.1	-0.1	1.3	13.6	31.2	49.3	64.5	76.3	83.5	85.1	81.6	74.6	63.1	47.4	29	12.1	2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
195	-0.1	-0.1	-0.1	-0.1	0.9	9.9	25.7	43	58.9	70.9	79.8	82.8	80	72.9	52.7	45.9	27.1	11.2	1.8	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
196	-0.1	-0.1	-0.1	-0.1	0.9	11.4	28.5	46.3	61.4	73.4	80.9	84.2	81.6	74.8	62.9	47.9	29.5	11.5	1.9	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
197	-0.1	-0.1	-0.1	-0.1	1.1	13.2	30.6	48.9	64.8	76.4	84.1	86.9	83.5	76.9	64.3	47.8	28.9	11.5	1.6	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
198	-0.1	-0.1	-0.1	-0.1	1	12.8	30.4	48.1	64	76.1	83.6	86.2	83	76.5	64.9	48.1	29	11.4	1.7	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
199	-0.1	-0.1	-0.1	-0.1	0.9	12	29.8	48.4	64	75.6	82.9	85.7	82.8	76.2	64.7	48.5	29.5	11.4	1.8	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
200	-0.1	-0.1	-0.1	-0.1	0.8	10.9	27.5	45.1	61.4	73.5	80.7	83.2	80.1	73.3	61.8	46.9	28.3	11.1	1.6	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
201	-0.1	-0.1	-0.1	-0.1	0.8	11.1	27.6	45.2	61.2	72.8	80.3	81.9	78.6	62.8	47.7	44.9	27.7	11.1	1.6	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
202	-0.1	-0.1	-0.1	-0.1	0.7	10.8	27.8	45.4	61.3	72.9	80.3	82.6	79.9	73.4	61.7	45.8	27.4	10.6	1.4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
203	-0.1	-0.1	-0.1	-0.1	0.6	9.7	25.9	43.8	59.7	71	78.5	81.3	78.3	71.8	60.5	44.7	26.6	10.2	1.4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
204	-0.1	-0.1	-0.1	-0.1	0.3	9.1	24.4	43.2	59.1	70.8	78	81.4	77.6	70.1	58.3	43.3	25.6	10	1.5	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
205	-0.1	-0.1	-0.1	-0.1	0.4	8.3	22.5	43.4	59.1	70.9	77.7	80.7	78.6	71.7	58.4	42.6	25.2	9.5	1.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
206	-0.1	-0.1	-0.1	0	0.3	4.8	25.2	43.9	59.6	70.6	77.4	80	76.7	69.8	56.6	40.7	23.9	9	1.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
207	-0.1	-0.1	-0.1	-0.1	0.3	5.7	24.7	42	57.5	68.8	75.9	78	62.9	61	58.3	41.7	24.3	9	1.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
208	-0.1	-0.1	-0.1	-0.1	0.2	6.4	23.9	40.3	57.4	67.4	75.4	77.8	75.3	65.5	57.6	28.7	19.7	9	1.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
209	-0.1	-0.1	-0.1	-0.1	0.5	8.7	17.1	23.1	57.7	65.8	66.1	42.8	60.9	71.2	58.2	41.6	24.2	8.4	1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
210	-0.1	-0.1	-0.1	-0.1	0.3	8.2	24.3	41.7	57	68	75.3	78.5	75.6	68.1	55.7	40.1	20.4	8.3	1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
211	-0.1	-0.1	-0.1	-0.1	0.2	6.8	15.8	25.1	49.2	29.2	31.8	39.9	66.7	38.2	30.4	20.5	19.6	7.7	0.7	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
212	-0.1	-0.1	-0.1	-0.1	0.1	5.2	11.7	35.5	55.1	66.8	76	79.2	50.2	67.2	53.5	38.2	20.8	7.5	0.8	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1



213	-0.1	-0.1	-0.1	-0.1	0.1	2.6	14.2	28.8	51.7	60.9	65.9	74.2	57.7	51	39.8	44.1	26.5	9.4	0.9	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
214	-0.1	-0.1	-0.1	-0.1	0.2	6	18.3	38.9	59.7	64	71.7	75.4	72.7	67.5	55.3	39.5	21.8	8	0.9	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
215	-0.1	-0.1	-0.1	-0.1	0.2	7	22.4	40	54.8	66.2	73.7	76.2	74.8	59.9	62.5	41.8	23.3	8.2	0.9	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
216	-0.1	-0.1	-0.1	-0.1	0.2	7.8	24	41.6	57	67.9	75	77.6	76.2	69.4	57.8	41.9	22.8	7.8	0.8	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
217	-0.1	-0.1	-0.1	0	0.2	7.2	20.4	37.6	57.1	69.6	76.6	78.9	75.9	69.1	56.9	41.1	22.5	7.7	0.8	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
218	-0.1	-0.1	-0.1	-0.1	0.1	7.7	24.1	43.3	59.5	71	78.1	79.7	79.1	44.1	49.5	39.8	24.7	8.2	0.8	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
219	-0.1	-0.1	-0.1	-0.1	0.1	8.6	25.8	43.7	59.8	71.2	80	80.7	77.9	70.6	58.1	42.5	22.9	7.6	0.7	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
220	-0.1	-0.1	-0.1	-0.1	0.2	8.7	25.7	42.2	59.6	70.6	78	81.2	78.9	71.9	59.4	42.4	22.3	7.2	0.6	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
221	-0.1	-0.1	-0.1	-0.1	0.1	8.3	24.4	42	57.7	69.3	75.9	78.5	75.8	69.1	56.7	40.8	21.5	7	0.5	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
222	-0.1	-0.1	-0.1	-0.1	0.1	7.3	23.2	40.8	56.2	66.8	74.4	77	74.9	68.3	56.5	40.5	21	6.7	0.5	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
223	-0.1	-0.1	-0.1	-0.1	0.1	5.4	21.4	39.5	55.3	66.9	74.2	78.6	77	70.7	58.2	41.3	21	6.6	0.4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
224	-0.1	-0.1	-0.1	-0.1	0	3.9	23.1	42.4	57.9	69.6	77	79.9	76.8	70.3	57.4	40.3	20.4	6.4	0.4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
225	-0.1	-0.1	-0.1	-0.1	0	7.2	23.9	41.8	57.4	69	76.5	79.9	77.2	69.8	56.8	40.1	20.2	6.2	0.3	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
226	-0.1	-0.1	-0.1	-0.1	0	6.1	21.6	38.5	54.3	66	72.6	75.1	72.6	66.7	55.9	39.4	18.9	5.8	0.3	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
227	-0.1	-0.1	-0.1	-0.1	0	6.1	21.3	38.9	55.2	66.6	74.1	77.1	73.7	66.4	50.6	33.1	18.6	5.7	0.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
228	-0.1	-0.1	-0.1	-0.1	1.8	8.5	27.7	39.3	55.1	66	73.4	76	75.5	69.8	55.3	37.8	18.3	5.7	0.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
229	-0.1	-0.1	-0.1	-0.1	0	5.3	20.2	38	53.8	64.9	72.4	75.3	73.2	66.5	53.8	37.8	18.2	5.5	0.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
230	-0.1	-0.1	-0.1	-0.1	0	5.1	19.3	35.6	51.6	64	72	75	71.6	65.5	51.2	38.3	17.4	5.3	0.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
231	-0.1	-0.1	-0.1	-0.1	0	5.2	21	38.6	54.3	65.8	73.3	75.9	74.9	68.8	55.9	38.3	17.7	5.2	0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
232	-0.1	-0.1	-0.1	-0.1	0	6.1	21.8	38.8	53.8	65	71.8	74.3	72	66.8	55	37	16.7	4.8	0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
233	-0.1	-0.1	-0.1	-0.1	0	5.6	21.5	38.9	54.1	65.9	73.8	75.8	72.5	67	55.1	37.3	16.9	4.8	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
234	-0.1	-0.1	-0.1	-0.1	0	5.2	20.1	36.8	52	63.7	70.9	73.6	70.6	62.8	50.7	34.2	15.5	4.2	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
235	-0.1	-0.1	-0.1	-0.1	-0.1	4.8	20.7	38.3	53.5	64.8	74	77.6	75.5	68.1	55	36.7	15.8	4.4	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
236	-0.1	-0.1	-0.1	-0.1	-0.1	5.4	21.2	38.7	54.6	67.1	74.7	77.4	74.1	67	53.4	35.3	15.1	4.4	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
237	-0.1	-0.1	-0.1	-0.1	-0.1	5.4	21.3	38.3	53.1	64.7	71.8	73.2	67.5	59.8	47.5	30.6	13.6	3.9	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
238	-0.1	-0.1	-0.1	-0.1	-0.1	5.2	20.6	37.2	52.3	63.8	71.2	73.8	54.3	22.7	44.7	21.1	11.4	4.1	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
239	-0.1	-0.1	-0.1	-0.1	-0.1	5.1	20.7	37.2	52.3	63.7	71.5	66.8	71.8	65.6	38.6	34.2	14.1	3.8	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
240	-0.1	-0.1	-0.1	-0.1	-0.1	4.6	19.3	36.1	51.7	63.5	71.1	73	70.5	26.2	46.5	31.3	14.1	3.8	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
241	-0.1	-0.1	-0.1	-0.1	-0.1	4.2	19	36.3	51.9	63.6	71	73.2	71.6	39.5	26.9	31.7	13.3	3.3	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
242	-0.1	-0.1	-0.1	-0.1	-0.1	4.4	19.3	37	52.7	63.2	70.7	72.4	65.6	53.3	43.4	32.7	13.1	3.4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
243	-0.1	-0.1	-0.1	-0.1	-0.1	4.6	19.2	36.2	51.6	63	71.2	72.7	69.3	62.8	50.6	32.5	12.4	3.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1

244	-0.1	-0.1	-0.1	-0.1	-0.1	4.5	19.2	37	53.1	63.8	71.5	73.1	69.3	61	47.6	30.1	11.7	3.1	-0.1	-0.1	-0.1	-0.1	-0.1
245	-0.1	-0.1	-0.1	-0.1	-0.1	4.1	19.9	35.5	51	63.1	71.4	73.4	68.5	61.8	49.3	34.1	16.3	2.9	-0.1	-0.1	-0.1	-0.1	-0.1
246	-0.1	-0.1	-0.1	-0.1	0	2.1	16.6	34.5	50.2	61.7	69	72.3	70.9	62.1	49.2	34	16.1	2.7	-0.1	-0.1	-0.1	-0.1	-0.1
247	-0.1	-0.1	-0.1	-0.1	-0.1	3.6	17	34.7	50.8	62.4	70	71.5	66.5	58.8	46.3	31.7	14.6	2.6	-0.1	-0.1	-0.1	-0.1	-0.1
248	-0.1	-0.1	-0.1	-0.1	-0.1	2.4	18.3	35.7	44.1	59.9	72.8	70.7	49.3	42.5	39.8	32.4	14.9	2.5	-0.1	-0.1	-0.1	-0.1	-0.1
249	-0.1	-0.1	-0.1	-0.1	-0.1	4.3	19.6	36.7	53.3	64.2	71.7	73.8	70.1	62.7	50.1	34.4	15.6	2.6	-0.1	-0.1	-0.1	-0.1	-0.1
250	-0.1	-0.1	-0.1	-0.1	-0.1	3.8	18.1	34.6	50.1	59.5	64	68.6	67.4	59.4	46.5	31.4	14.2	2.6	-0.1	-0.1	-0.1	-0.1	-0.1
251	-0.1	-0.1	-0.1	-0.1	-0.1	4.6	19.8	37.1	53	64.8	72.7	74.7	69.9	61.9	49	33.1	14.6	2.6	-0.1	-0.1	-0.1	-0.1	-0.1
252	-0.1	-0.1	-0.1	-0.1	-0.1	3.9	18.6	36.4	48.7	52.2	73.1	74.2	70.6	62.5	48.9	32.9	14.4	2.5	-0.1	-0.1	-0.1	-0.1	-0.1
253	-0.1	-0.1	-0.1	-0.1	-0.1	4.4	19.1	36.4	52.5	63.9	71.4	73.8	70	61.9	49.5	31.2	13.6	2	-0.1	-0.1	-0.1	-0.1	-0.1
254	-0.1	-0.1	-0.1	-0.1	-0.1	4	18.7	35.9	52.2	64.1	73.5	74.7	54.5	60.7	48.5	31.9	13.1	1.9	-0.1	-0.1	-0.1	-0.1	-0.1
255	-0.1	-0.1	-0.1	-0.1	-0.1	3.7	18	34.9	50.3	61.2	68.7	72	70.1	50.4	47	30.8	12.8	2	-0.1	-0.1	-0.1	-0.1	-0.1
256	-0.1	-0.1	-0.1	-0.1	-0.1	3.3	17.5	34.7	52.1	63.6	72.1	74.3	70.5	61.9	49.3	31.3	12.9	1.9	-0.1	-0.1	-0.1	-0.1	-0.1
257	-0.1	-0.1	-0.1	-0.1	-0.1	2.5	15.8	32.7	49.2	61.4	69.5	71.5	67.6	59.6	46.3	29.5	12.3	1.8	-0.1	-0.1	-0.1	-0.1	-0.1
258	-0.1	-0.1	-0.1	-0.1	-0.1	3.1	17.5	34.4	50.4	62.3	70.6	73	69	59.4	47.2	31.1	12.1	1.8	-0.1	-0.1	-0.1	-0.1	-0.1
259	-0.1	-0.1	-0.1	-0.1	-0.1	3.2	18	35.3	51.2	62.8	70.4	72.7	69.2	59.5	45.4	28.9	11.1	1.4	-0.1	-0.1	-0.1	-0.1	-0.1
260	-0.1	-0.1	-0.1	-0.1	-0.1	2.4	15.5	32.6	48.4	59.5	67.2	69	66	59	45.9	29.8	11.3	1.3	-0.1	-0.1	-0.1	-0.1	-0.1
261	-0.1	-0.1	-0.1	-0.1	-0.1	2.8	16.4	33.1	48.9	60.2	69	70.6	67	59.3	45.1	27.8	10.5	1.1	-0.1	-0.1	-0.1	-0.1	-0.1
262	-0.1	-0.1	-0.1	-0.1	-0.1	2.6	16.6	33.6	49.3	60.5	67.9	69.1	65.2	57	44.1	27.2	10.2	1.2	-0.1	-0.1	-0.1	-0.1	-0.1
263	-0.1	-0.1	-0.1	-0.1	-0.1	2.3	21.6	34.2	50.1	62.5	70.3	71.7	66.9	58.5	44.3	26.3	9.4	1	-0.1	-0.1	-0.1	-0.1	-0.1
264	-0.1	-0.1	-0.1	-0.1	-0.1	2	15.4	32.2	48.7	60.4	67.2	69.5	66.3	57.7	43.9	26.9	9.1	0.9	-0.1	-0.1	-0.1	-0.1	-0.1
265	-0.1	-0.1	-0.1	-0.1	-0.1	2	15.7	32.9	48.4	61.1	69.8	71	66.3	56.7	43	26.2	8.5	0.7	-0.1	-0.1	-0.1	-0.1	-0.1
266	-0.1	-0.1	-0.1	-0.1	-0.1	1.9	14	30.9	46	58.6	64.3	47.6	46	16.8	37.6	26	6.9	0.9	-0.1	-0.1	-0.1	-0.1	-0.1
267	-0.1	-0.1	-0.1	-0.1	-0.1	1.9	14.9	28.8	42.6	59.3	71.3	62.4	55.5	48.2	45.9	24.2	8.4	0.6	-0.1	-0.1	-0.1	-0.1	-0.1
268	-0.1	-0.1	-0.1	-0.1	-0.1	1.8	10.2	30.5	45.9	58	73.5	45.4	66.7	51.2	14.5	27	9.6	0.6	-0.1	-0.1	-0.1	-0.1	-0.1
269	-0.1	-0.1	-0.1	-0.1	-0.1	1.8	14.4	31.6	47.3	58.9	67.2	69.5	66	55.2	40.8	19.9	6.8	0.4	-0.1	-0.1	-0.1	-0.1	-0.1
270	-0.1	-0.1	-0.1	-0.1	-0.1	1.9	14.7	31.9	47.9	59.6	66.3	67	62.5	53.3	41.2	24.5	7.3	0.5	-0.1	-0.1	-0.1	-0.1	-0.1
271	-0.1	-0.1	-0.1	-0.1	-0.1	1.9	14.9	32.5	48.3	60	67.2	67.9	63.8	54.4	41.2	24.2	7.1	0.4	-0.1	-0.1	-0.1	-0.1	-0.1
272	-0.1	-0.1	-0.1	-0.1	-0.1	1.6	14.1	31.2	46.8	58.4	65.8	66.9	62.9	53	38.6	22	6.5	0.3	-0.1	-0.1	-0.1	-0.1	-0.1
273	-0.1	-0.1	-0.1	-0.1	-0.1	1.5	13.5	30.9	46.4	57.9	64.9	66.2	62.4	53.5	40.2	20.8	7.2	0.2	-0.1	-0.1	-0.1	-0.1	-0.1

274	-0.1	-0.1	-0.1	-0.1	-0.1	1	12.2	28.9	44.7	56.6	63.7	63.7	63.7	59.5	51.1	18.2	16.3	9.3	0.5	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
275	-0.1	-0.1	-0.1	-0.1	-0.1	0.3	6	23.3	40.7	49.7	59	60	54.9	46.5	35.5	20.6	6	0.1	0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
276	-0.1	-0.1	-0.1	-0.1	-0.1	0.6	5.6	22.3	39.1	53.4	62.2	62.8	62.8	57.4	50.4	36.4	19.4	5.5	0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
277	-0.1	-0.1	-0.1	-0.1	0	0.8	8.3	25.6	41.7	58.1	64	50.2	50.6	21.9	20	14.2	1.6	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
278	-0.1	-0.1	-0.1	-0.1	-0.1	0.7	11.9	28.9	44.8	59.3	63.5	61.2	42.1	13.2	26.2	13.5	4.2	0	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
279	-0.1	-0.1	-0.1	-0.1	-0.1	0.9	11.9	28.9	43.9	55.4	62.8	57.7	44.2	54.9	40	22.3	5.3	0	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
280	-0.1	-0.1	-0.1	-0.1	-0.1	0.8	10.7	26.8	41.5	52.6	61.1	42.6	30.4	11.6	19.8	25.1	5.9	0	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
281	-0.1	-0.1	-0.1	-0.1	-0.1	0.8	11.8	28.8	43.7	54.8	61.3	60.6	60.6	50.8	31.2	20	4.8	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
282	-0.1	-0.1	-0.1	-0.1	-0.1	0.7	9.5	27.1	39.3	50.3	57.2	58.7	54.3	45.9	33	16.9	3.7	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
283	-0.1	-0.1	-0.1	-0.1	-0.1	2.8	13.2	25	37.7	48	55.3	57.3	11.8	3.1	5.3	7.5	5.6	0	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
284	-0.1	-0.1	-0.1	-0.1	-0.1	0.6	9.3	24.9	40.8	53.9	63.2	64.9	59.1	49.5	20.5	7.1	3.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
285	-0.1	-0.1	-0.1	-0.1	-0.1	0.6	8.8	25.7	41.2	53.1	59.7	58.8	55	44.6	26.1	9.2	3.4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
286	-0.1	-0.1	-0.1	-0.1	-0.1	0.5	9.7	26.2	41.6	53.4	63.2	51.3	52.4	37.6	32.4	18.2	3.4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
287	-0.1	-0.1	-0.1	-0.1	-0.1	0.8	11.5	24.9	40.8	51.7	62.1	62.2	45.8	35.8	24.1	14.5	1.8	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
288	-0.1	-0.1	-0.1	-0.1	-0.1	0.6	11.6	27.9	43	55	61.2	61.8	58.3	49.5	36	18.8	3.9	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
289	-0.1	-0.1	-0.1	-0.1	-0.1	0.7	12.5	30.2	45.8	57.8	63.9	64.7	61.1	52.8	39.1	20.7	4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
290	-0.1	-0.1	-0.1	-0.1	-0.1	0.6	12.3	29.4	44.4	56.5	63	63.4	59.9	51.5	37.8	20	3.9	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
291	-0.1	-0.1	-0.1	-0.1	-0.1	0.5	11.4	29	44.4	55.9	61.8	61.9	58.3	50.2	36.8	19.1	3.5	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
292	-0.1	-0.1	-0.1	-0.1	-0.1	0.2	8.7	25	39.7	50.5	56.3	57.4	53.6	45.2	32.1	17.3	2.6	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
293	-0.1	-0.1	-0.1	-0.1	-0.1	0.4	6.8	26	39.2	50.5	48.9	56.6	47.3	19.1	24.8	14.5	2.3	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
294	-0.1	-0.1	-0.1	-0.1	-0.1	0.35	7.2	17.2	40.4	50.9	57.3	57.7	54	40.9	22	14.1	1.6	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
295	-0.1	-0.1	-0.1	-0.1	-0.1	0.3	9.7	24.4	39.8	50.3	57	56.4	53.1	43.1	31.5	14.3	1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
296	-0.1	-0.1	-0.1	-0.1	-0.1	0	4.1	18.9	37.9	43.3	49.2	55.2	39.6	36.2	15.9	6.1	2.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
297	-0.1	-0.1	-0.1	-0.1	-0.1	0.1	7.9	24.8	40.9	53.9	60	59.4	53.8	44.6	31.4	15	2.3	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
298	-0.1	-0.1	-0.1	-0.1	-0.1	0.4	11	24.8	40.7	49.9	57.8	59.8	53.7	43.6	29.7	12.3	2.6	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
299	-0.1	-0.1	-0.1	-0.1	-0.1	0.1	8.3	24.6	39.3	51.2	57.9	57.4	53.4	45.7	31.9	14.6	2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
300	-0.1	-0.1	-0.1	-0.1	-0.1	0.3	8.5	22.6	41.5	54.8	59.5	60.2	55.3	46.7	31.9	13.5	1.7	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
301	-0.1	-0.1	-0.1	-0.1	-0.1	0.1	8	24.2	38.6	51.1	58.9	59.2	54.1	44.7	29.9	12.8	1.4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
302	-0.1	-0.1	-0.1	-0.1	-0.1	0.1	6.3	22.3	36.1	44.8	53.9	54.3	50.6	35.7	19.9	10.8	1.5	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
303	-0.1	-0.1	-0.1	-0.1	-0.1	0	6.4	21.1	35.5	48.8	59.9	45.2	52.6	44.6	28.7	12.3	1.5	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
304	-0.1	-0.1	-0.1	-0.1	-0.1	0.1	6.8	21.7	36.3	48.2	54.4	54.8	47	34.5	22.5	11.9	1.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1







## Appendix B: MICROSOFT-EXCEL WORKSHEET

Month	8
Day	18

Latitude (L):	36	deg	0.628	rad
Surface tilted angle (s):	36	deg	0.628	rad
Surface azimuth angle (ψ):	0	deg	0	rad
Solar Noon	10	hours	600	min.
Day of the year (n):			230	day
Solar declination(δ):	12.79	deg	0.223	rad

Period (GMT)	00:00-01:00	01:00-02:00	02:00-03:00	03:00-04:00	04:00-05:00	05:00-06:00	06:00-07:00	07:00-08:00	08:00-09:00	09:00-10:00	10:00-11:00	11:00-12:00	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00	17:00-18:00	18:00-19:00	19:00-20:00	20:00-21:00	21:00-22:00	22:00-23:00	23:00-00:00
GMT	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Local Time	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	0	1	2
Hour angle (H)	-150	-135	-120	-105	-90	-75	-60	-45	-30	-15	0	15	30	45	60	75	90	105	120	135	150	165	180	195
cos θi	-0.84	-0.69	-0.49	-0.25	0.00	0.25	0.49	0.69	0.84	0.94	0.98	0.94	0.84	0.69	0.49	0.25	0.00	-0.25	-0.49	-0.69	-0.84	-0.94	-0.98	-0.94
cos θz	-0.55	-0.43	-0.26	-0.07	0.13	0.33	0.52	0.69	0.81	0.89	0.92	0.89	0.81	0.69	0.52	0.33	0.13	-0.07	-0.26	-0.43	-0.55	-0.63	-0.66	-0.63
R	0.00	0.00	0.00	0.00	0.00	0.76	0.93	1.00	1.04	1.06	1.06	1.06	1.04	1.00	0.93	0.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Qmet (cal/cm <sup>2</sup> h)	0.0	0.0	0.0	0.0	5.1	19.3	35.6	51.6	64.0	72.0	75.0	71.6	65.5	51.2	38.3	17.4	5.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Qmet (kJ/m <sup>2</sup> h)	0.0	0.0	0.0	0.0	213.6	808.4	1491.2	2161.4	2680.8	3015.9	3141.6	2999.2	2743.7	2144.7	1604.3	728.9	222.0	8.4	0.0	0.0	0.0	0.0	0.0	0.0
Qt (cal/cm <sup>2</sup> h)	0.0	0.0	0.0	0.0	0.0	14.6	33.1	51.7	66.5	76.0	79.6	75.6	68.0	51.3	35.6	13.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Qt (kJ/m <sup>2</sup> h)	0.0	0.0	0.0	0.0	0.0	610.4	1386.1	2166.5	2783.7	3184.4	3333.6	3166.7	2849.0	2149.7	1491.3	550.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

## Appendix C: CASE STUDY SAMPLE

### Near East University

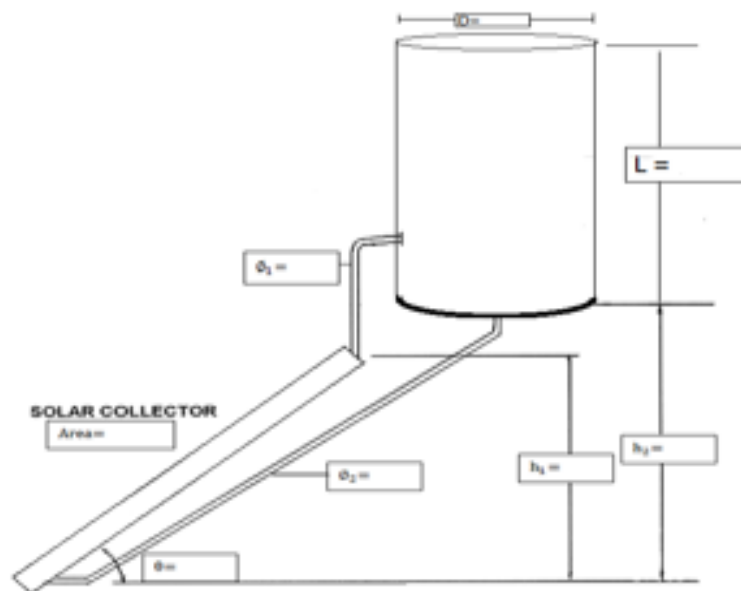
### Case study

Date:

Study no:

City:

owner:



Collectors Area:

Galvanized pipes:

Tank volume:

tilted angle:

Azimuth Angle:

Done by:

supervised by:

Eng. Youssef OSMAN

Assist. Prof. Dr. Ali EVCIL

Appendix D: ON-SITE CASE STUDY  
**Near East University**

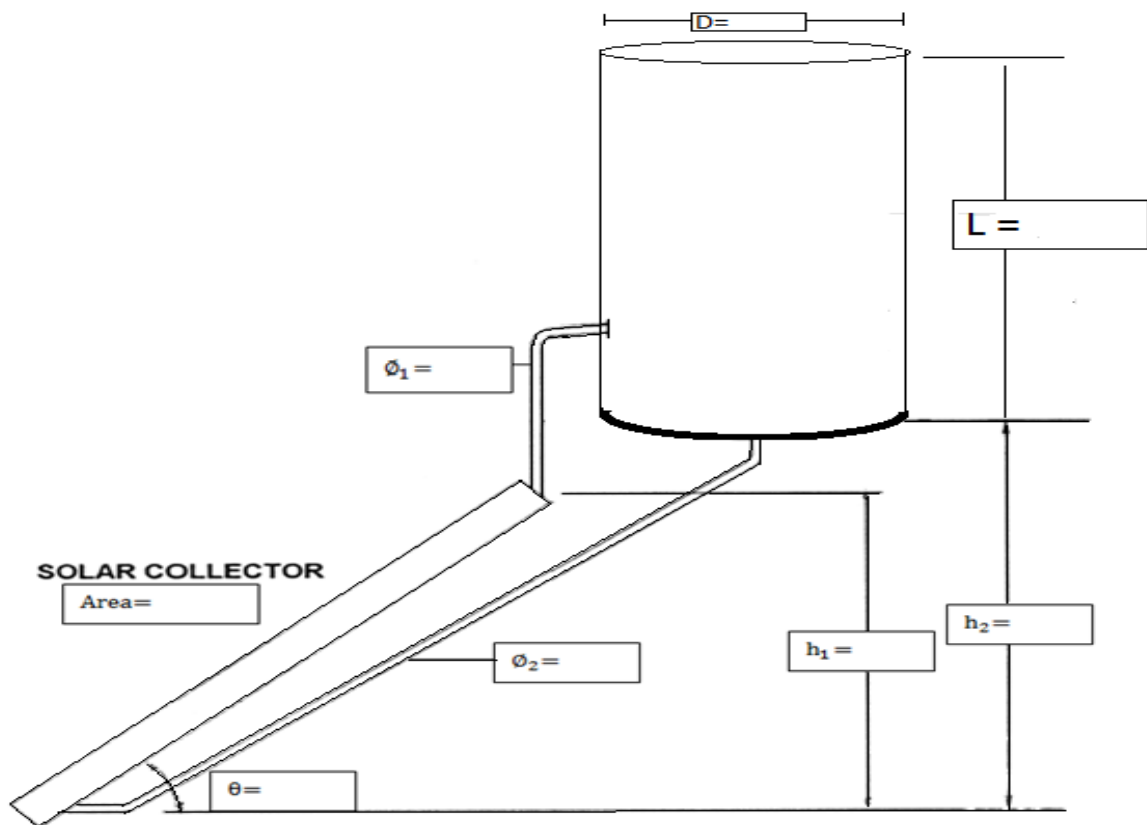
**Case study**

**Date:** 1/8/2015

**Study no:** S01

**City:** Girne

**owner:** Ali Evcil



**Collectors Area:** 3.64 m<sup>2</sup>

**Galvanized pipes:** 24

**Tank volume:** 155 lt

**tilted angle:** 43°

**Azimuth Angle:** 40° East

Done by:

supervised by:

Eng. Youssef OSMAN

Assist. Prof. Dr. Ali EVCIL

# Near East University

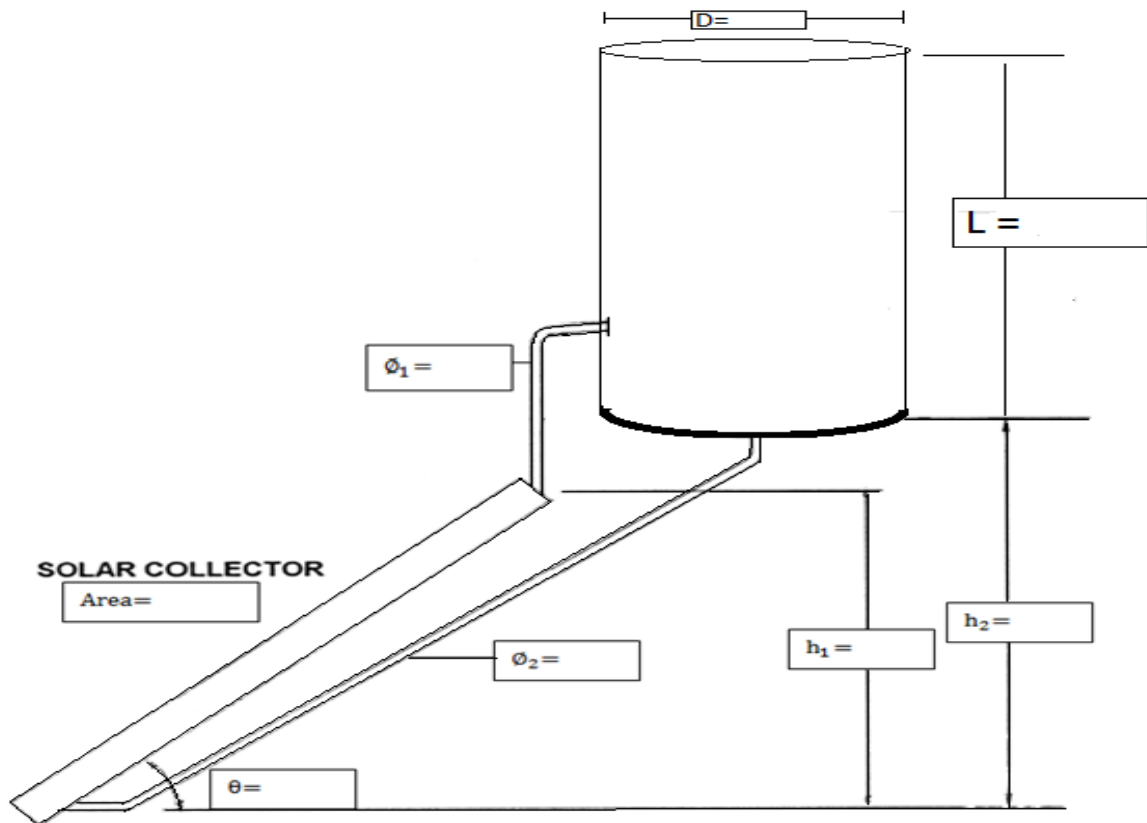
## Case study

**Date:** 4/8/2015

**Study no:** S02

**City:** NICOSIA

**owner:** Ridvan Albayrak



**Collectors Area:**  $3.64 \text{ m}^2$

**Galvanized pipes:** 24

**Tank volume:** 155 lt

**tilted angle:**  $35^\circ$

**Azimuth Angle:**  $50^\circ$  East

Done by:

supervised by:

Eng. Youssef OSMAN

Assist. Prof. Dr. Ali EVCIL

# Near East University

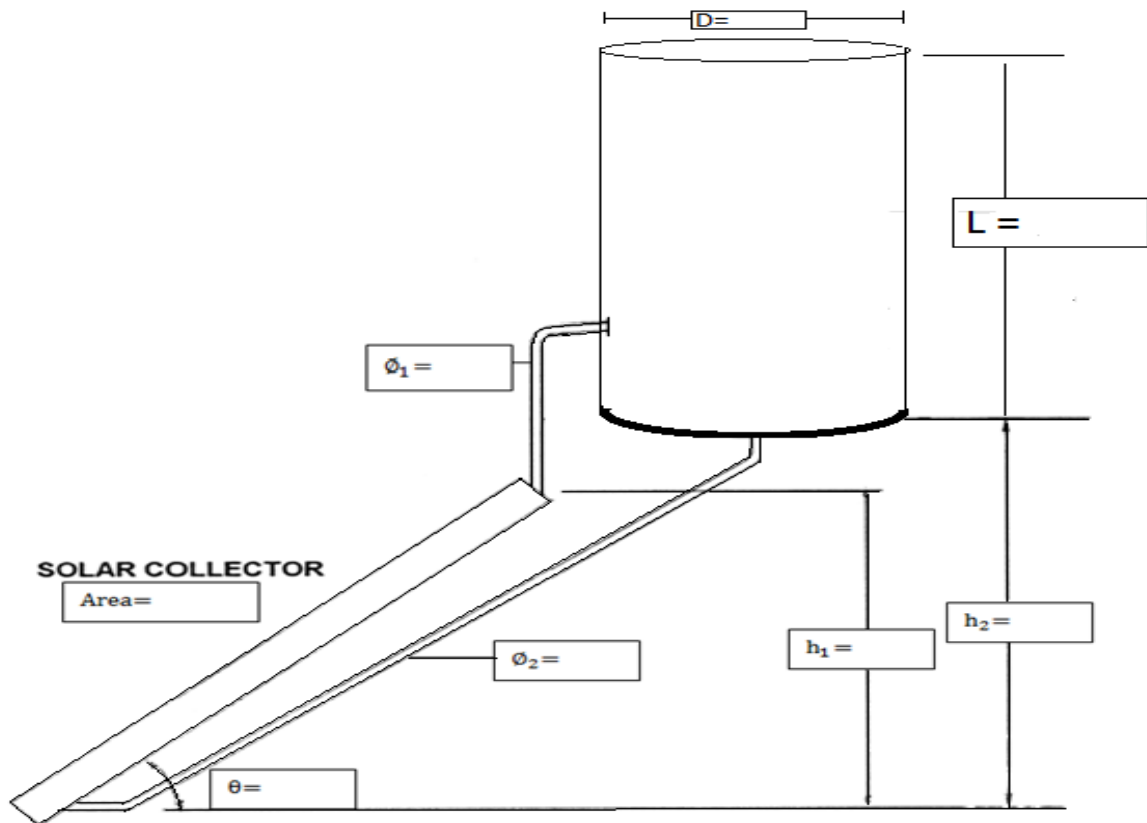
## Case study

**Date:** 13/8/2015

**Study no:** S03

**City:** Nicosia

**owner:** Abdulkarim ghariba



**Collectors Area:**  $3.64 \text{ m}^2$

**Galvanized pipes:** 24

**Tank volume:** 155 lt

**tilted angle:**  $45^\circ$

**Azimuth Angle:** South

Done by:

supervised by:

Eng. Youssef OSMAN

Assist. Prof. Dr. Ali EVCIL

# Near East University

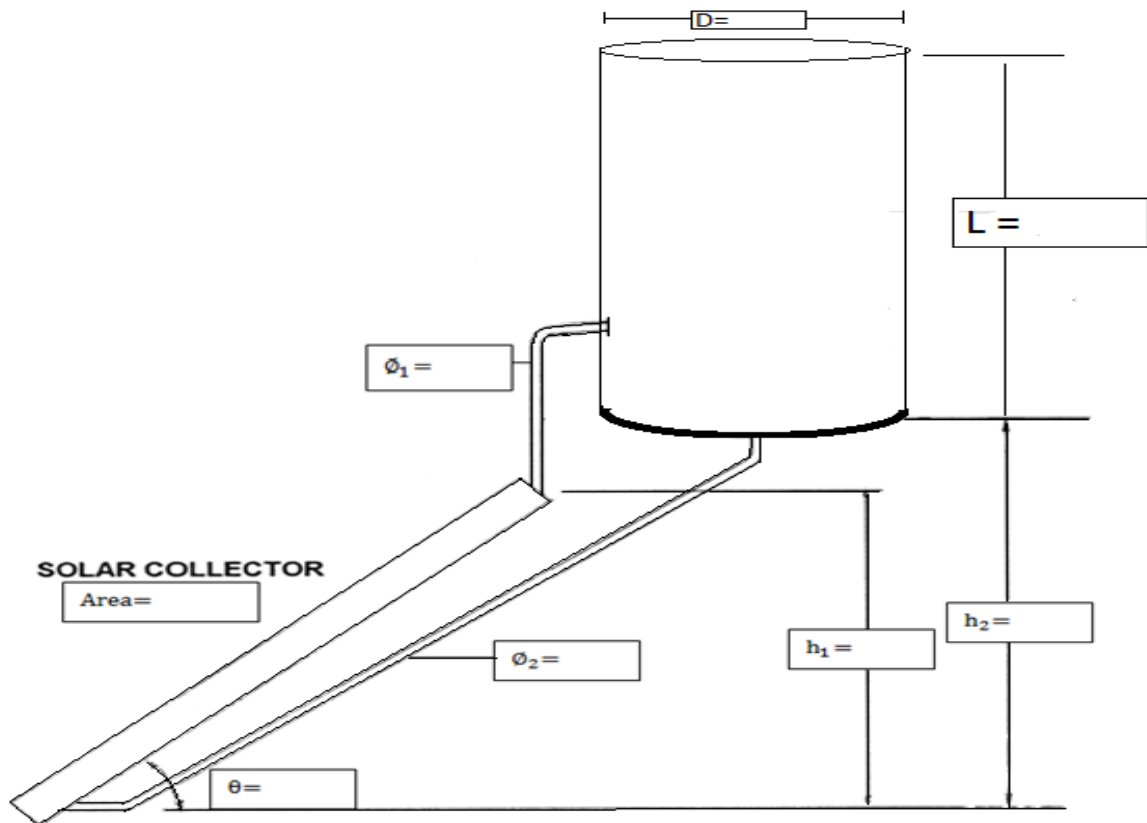
## Case study

**Date:** 14/8/2015

**Study no:** S04

**City:** Nicosia

**owner:** Kamal Bikaii



**Collectors Area:** 3.64 m<sup>2</sup>

**Galvanized pipes:** 24

**Tank volume:** 155 lt

**tilted angle:** 40°

**Azimuth Angle:** 9° East

done by:

supervised by:

Eng. Youssef OSMAN

Assist. Prof. Dr. Ali EVCIL

# Near East University

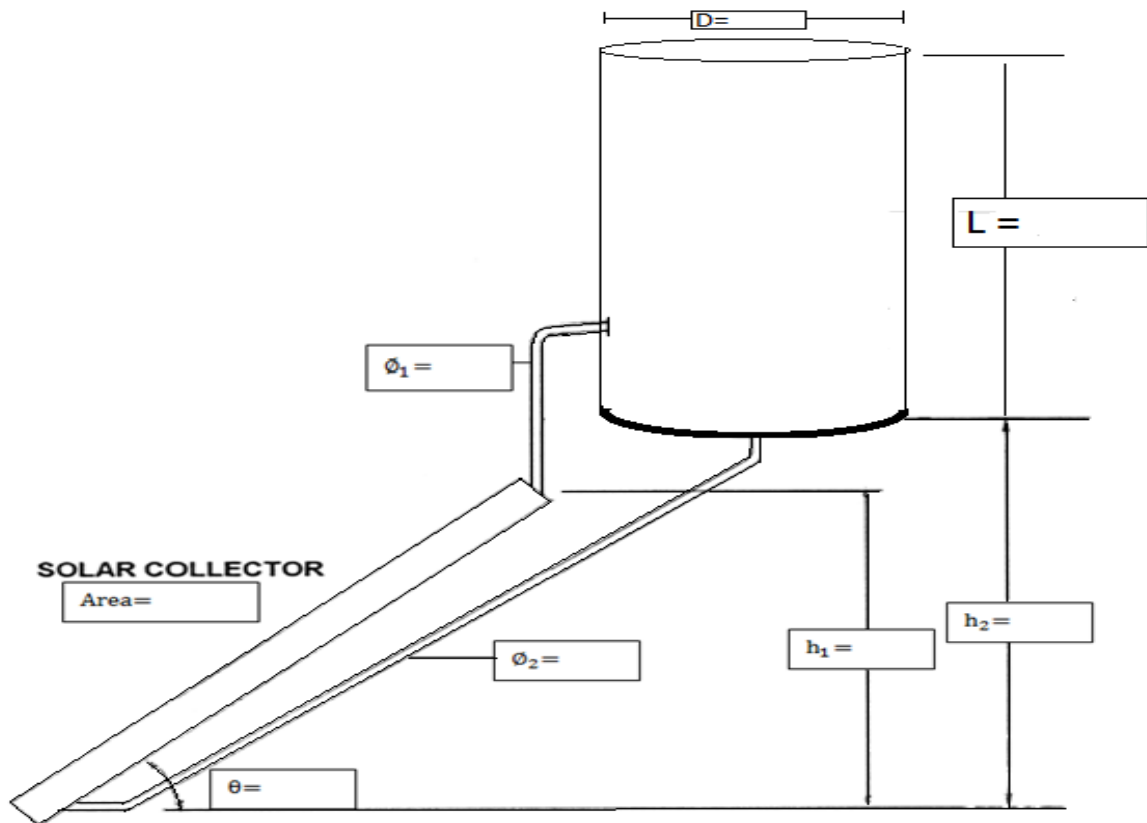
## Case study

**Date:** 23/8/2015

**Study no:** S05

**City:** Nicosia

**owner:** Mehmet Doksal



**Collectors Area:**  $3.64 \text{ m}^2$

**Galvanized pipes:** 24

**Tank volume:** 155 lt

**tilted angle:**  $44^\circ$

**Azimuth Angle:**  $2^\circ$  East

Done by:

supervised by:

Eng. Youssef OSMAN

Assist. Prof. Dr. Ali EVCIL



# Near East University

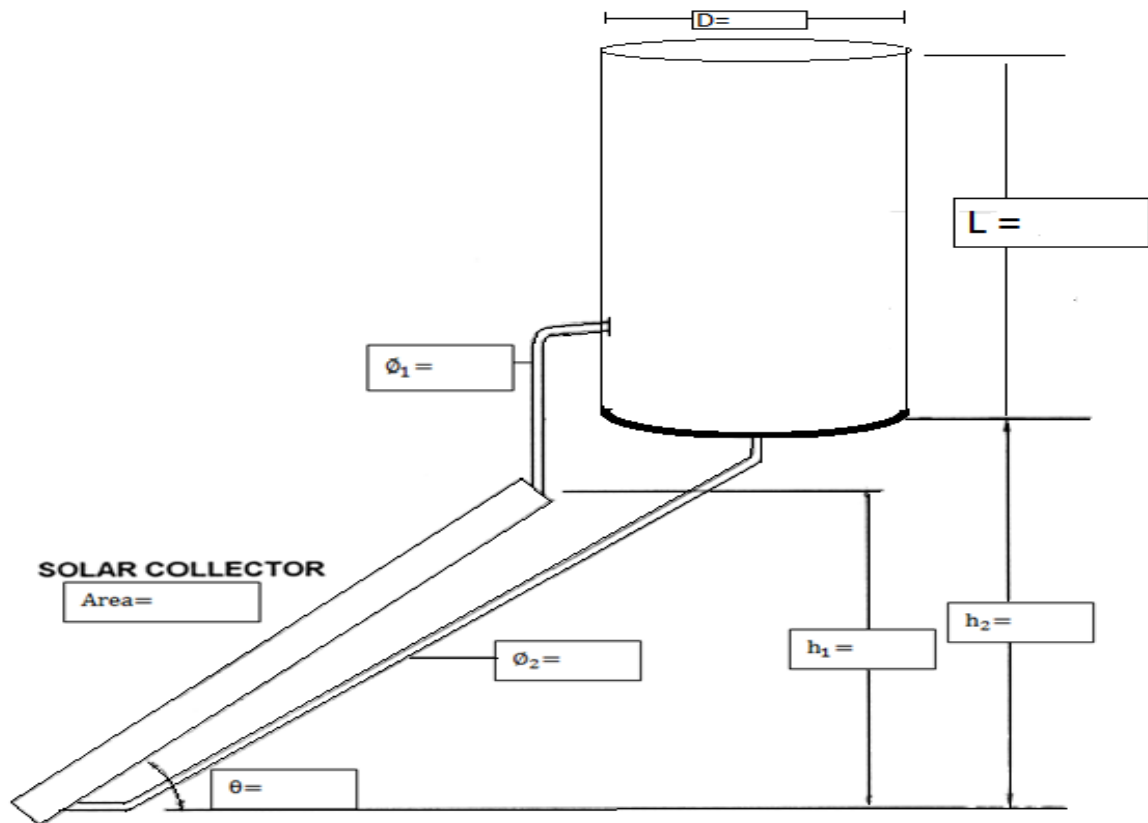
## Case study

**Date:** 26/8/2015

**Study no:** S06

**City:** Nicosia

**owner:** Youssef Kasem



**Collectors Area:**  $3.64 \text{ m}^2$

**Galvanized pipes:** 24

**Tank volume:** 155 lt

**tilted angle:**  $42^\circ$

**Azimuth Angle:**  $5^\circ$  East

Done by:

supervised by:

Eng. Youssef OSMAN

Assist. Prof. Dr. Ali EVCIL

# Near East University

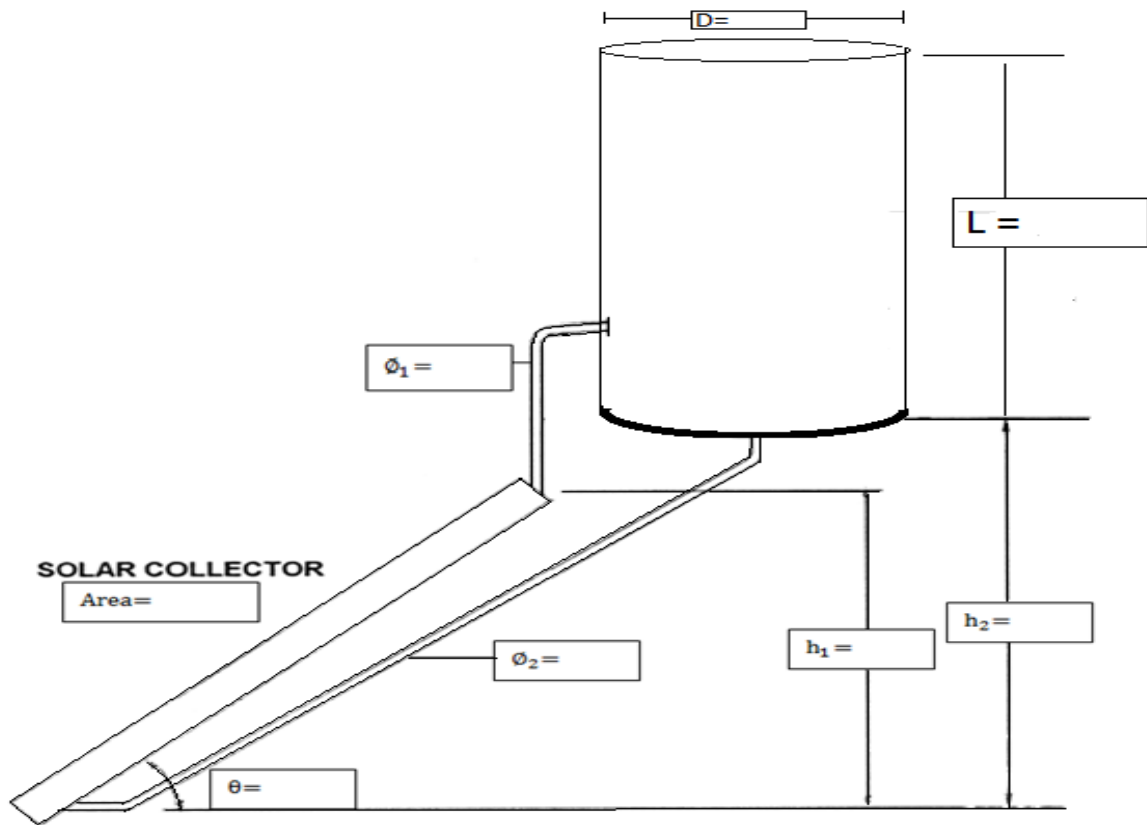
## Case study

**Date:** 29/8/2015

**Study no:** S07

**City:** Nicosia

**owner:** Ferhat Kotan



**Collectors Area:**  $3.64 \text{ m}^2$

**Galvanized pipes:** 24

**Tank volume:** 155 lt

**tilted angle:**  $45^\circ$

**Azimuth Angle:** South

Done by:

supervised by:

Eng. Youssef OSMAN

Assist. Prof. Dr. Ali EVCIL

# Near East University

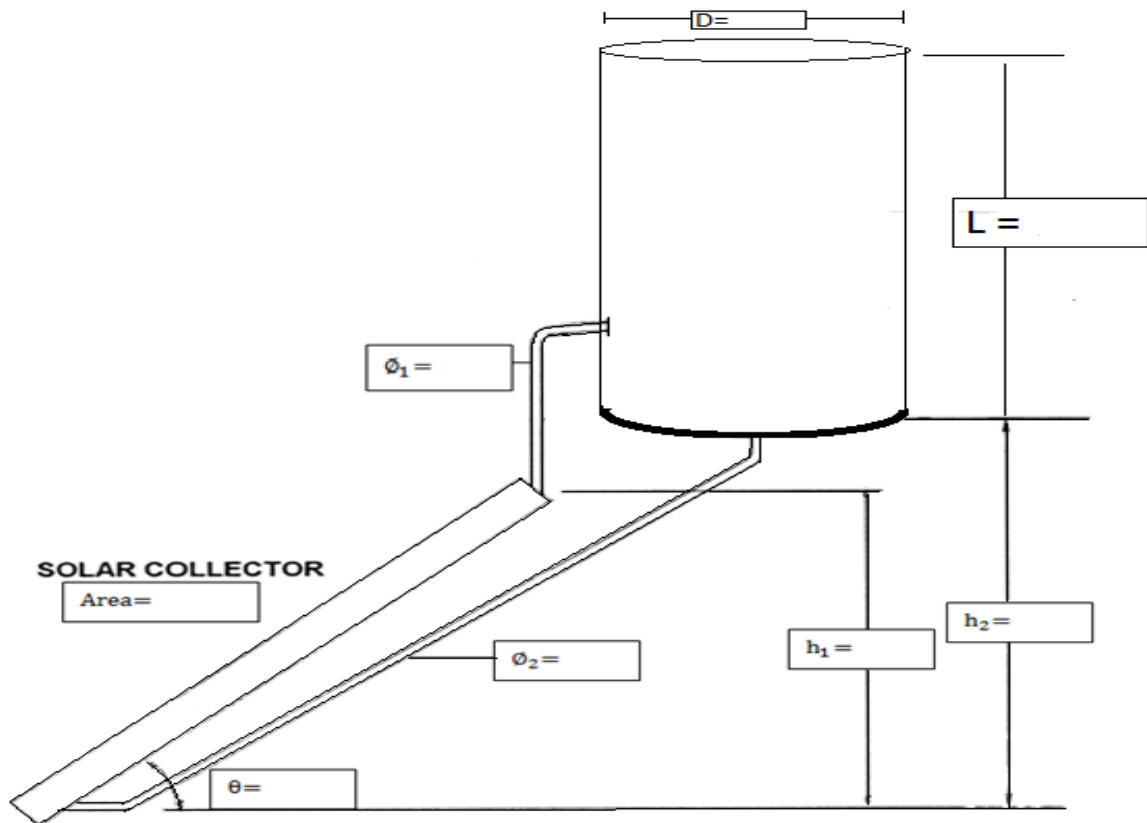
## Case study

**Date:** 30/8/2015

**Study no:** S08

**City:** Nicosia

**owner:** Ahmet Aldic



**Collectors Area:**  $3.64 \text{ m}^2$

**Galvanized pipes:** 24

**Tank volume:** 155 lt

**tilted angle:**  $42^\circ$

**Azimuth Angle:** South

Done by:

supervised by:

Eng. Youssef OSMAN

Assist. Prof. Dr. Ali EVCIL

# Near East University

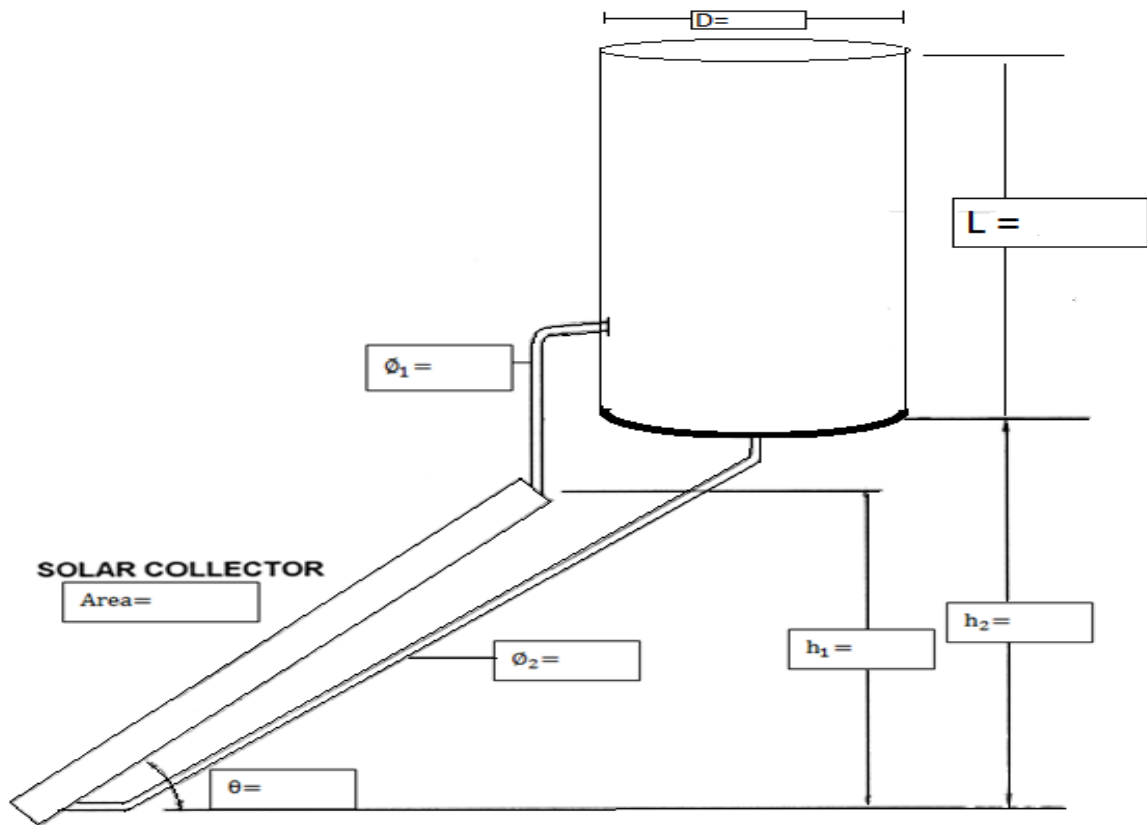
## Case study

**Date:** 31/8/2015

**Study no:** S09

**City:** Nicosia

**owner:** Osman Adli



**Collectors Area:**  $3.64 \text{ m}^2$

**Galvanized pipes:** 24

**Tank volume:** 155 lt

**tilted angle:**  $45^\circ$

**Azimuth Angle:** South

Done by:

supervised by:

Eng. Youssef OSMAN

Assist. Prof. Dr. Ali EVCIL

# Near East University

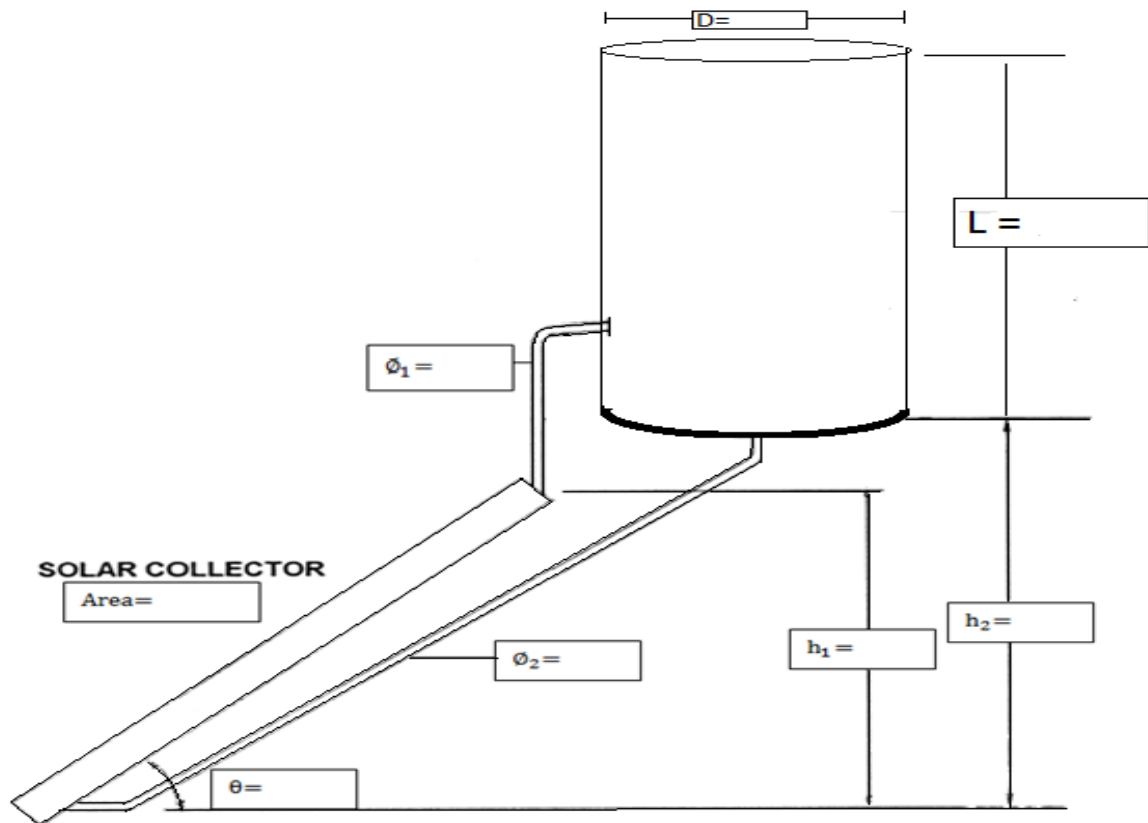
## Case study

**Date:** 1/9/2015

**Study no:** S10

**City:** Nicosia

**owner:** Mahmod Sefrani



**Collectors Area:**  $3.64 \text{ m}^2$

**Galvanized pipes:** 24

**Tank volume:** 155 lt

**tilted angle:**  $43^\circ$

**Azimuth Angle:** South

Done by:

supervised by:

Eng. Youssef OSMAN

Assist. Prof. Dr. Ali EVCIL