# HYBRID SOLAR/ HEAT PIPE/ WATER HEATER

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**A project report submitted in partial fulfilment of the**

**requirements for the award of the degree of**

**Bachelor of Engineering (Hons) Industrial Engineering**

**Faculty of Engineering and Green Technology**

**Universiti Tunku Abdul Rahman**

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# DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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# APPROVAL FOR SUBMISSION

I certify that this project report entitled **"HYBRID SOLAR/HEAT PIPE/ WATER HEATER"** was prepared by **LAU JIN YIK** has met the required standard for submission in partial fulfilments of the requirements for the award of Bachelor of Engineering (Hons) Industrial Engineering at Universiti Tunku Abdul Rahman.

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Specially dedicated to

My beloved mother and father

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# HYBRID SOLAR/ HEAT PIPE/ WATER HEATER

## ABSTRACT

The performance of a hybrid solar/ heat pipe/ water heater were investigated the system conversion of an array individual evacuated tube heat pipe solar collector (ETHPSC) exposed to sunlight, four thermoelectric (TE) modules are placed on the outer surfaces of the aluminum block and four units of water cooled jackets are placed over the TE modules. The jackets are thin aluminum composite slabs with parallel internal water flow channels connected by inlet and outlet headers inside the slabs. The experiment result showed that water can be heated with a temperature difference of around 0.3 $^{o}$C – 7.6 $^{o}$C.

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# LIST OF SYMBOLS

| | |
|---|---|
| $q$ | heat removal rate, W |
| $\eta_w$ | thermal efficiency % |
| $Cpw$ | specific heat capacity of water, J/kg.K |
| $T$ | temperature, $^oC$ |
| $\Delta T$ | temperature difference |
| $Ta$ | ambient temperature, $^oC$ |
| $T_{e1} – T_{e3}$ | temperature points on heat pipe evacuated tube, $^oC$ |
| $T_{adb}$ | temperature points on heat adiabatic, $^oC$ |
| $T_{atm}$ | temperature pints on atmosphere, $^oC$ |
| $T_{cond1}$- $T_{cond4}$ | temperature points on condenser, $^oC$ |
| $T_{al1}$- $T_{al12}$ | temperature points on aluminum block, $^oC$ |
| $T_{hs1} – T_{hs12}$ | temperature points on heat sink, $^oC$ |
| H | solar radiation, $^oC$ |
| $T_{wi}$ | water inlet temperature, $^oC$ |
| $T_{wo}$ | water outlet temperature, $KW/m^2$ |
| $T_{h1} – T_{h4}$ | TE hot side temperatures, $^oC$ |
| $T_{c1} – T_{c4}$ | TE cold side temperatures, $^oC$ |
| $A_{sc}$ | area of evaporator,$m^2$ |

# Chapter 1

# Introduction

## 1.1 Background

### 1.1.1 Solar energy

Nowadays, with the reducing of fossil fuels consisting of petroleum, coal, natural gas and heavy crude oil, which contribute about ¾ of all carbon, methane, nitrogen oxide and other greenhouse gases emission into atmosphere when fossil fuel use to generate energy from combustion. The effect of those sources will lead to climax change, environmental pollution and acid rain known as global warming. Greenhouse gases is trapping the heat from sun to keep our earth suitable for living, however, when the greenhouse gases too many may cause our earth temperature rises rapidly and out of control would be issue as global warming.

Therefore, much effort has been directed to finding a new renewable energy source and developing green technologies to reduce dependency on fossil fuel combustion environment issues. Solar energy consider as sustainability without affect ecosystem and this kind of renewable energy generally comes from the directly exposed to sunlight. In addition,  solar energy has been started to adopt as renewable energy because it is the sources without compromising the future generation and unlike nonrenewable energy such as fossil fuel can release many hazardous gases to atmosphere and unlimited. Other than that, Solar energy can be consider as green environment friendly, because it release low carbon to atmosphere also widely use on today. Solar energy can be converted into useful energy in various technologies such as transfer solar energy into heat energy implement by solar water heater and photovoltaic system transfer solar energy to electric energy.

The solar energy is the ultimate sources to provide solar radiation that can be changed over into energy specifically utilizing different advances for some techniques to harness the solar thermal and solar photovoltaic energy. In such cases, the efficient heat transfer device is concerns of energy utilization and environmental pollution work on clean energy simultaneously. Therefore, usage of solar energy brought to accomplish a safe and comfortable environment for sustainable of human life. Solar energy has been development of renewable energy because it can be replenish the sources continuously on specific natural process also very valuable to develop in Malaysia because located on equator. Solar energy can be changed over into helpful in different innovation, for example, transfer solar energy into heat energy implement by solar water heater and photovoltaic system transfer solar energy to electric energy.

Solar energy has proven to be a viable source of renewable energy for water heating system. The review indicated that the application of heat pipe system can significantly increase heat transfer rates thus increase the thermal efficiency. Furthermore, the idea of heat pipe is that solar energy will be collected by solar tube collector when exposed to sunlight and transferred to the evaporator section of the heat pipe inside the solar tube collector. The energy absorbed then is used for thermal heating application such as water heating in order to prevent any waste energy from occurring thus increasing the overall performance of the system.

### 1.1.2 Heat pipes

In the recent past decades, research aimed at the development of thermal absorption has intensified to increase the efficiency or performance solar system. However, the efficiency of power source can be improved with help of heat pipes heat exchanges. Heat pipe performed as utilizing the evaporation and condensation heat transfer process while the solar energy as a heat source obtained from exposure to sunlight. The heat pipe was first invented by Angier March Perkins in 1839 which the time he called it as hermetic boiler tube. In 1963, George Grover and his co-workers further created the prototype and named it as heat pipe then widely apply in industries. The first heat pipe application was in satellites to accomplish the thermal equilibrium between side presented to the sun's radiation and the other presented to the deep cool space.

Heat pipe comprises of three sections to be specific in three section which is evaporation section that the evaporator liquid function through adiabatic section and carry those heat energy through condensation section, its function as given in Figure 1.

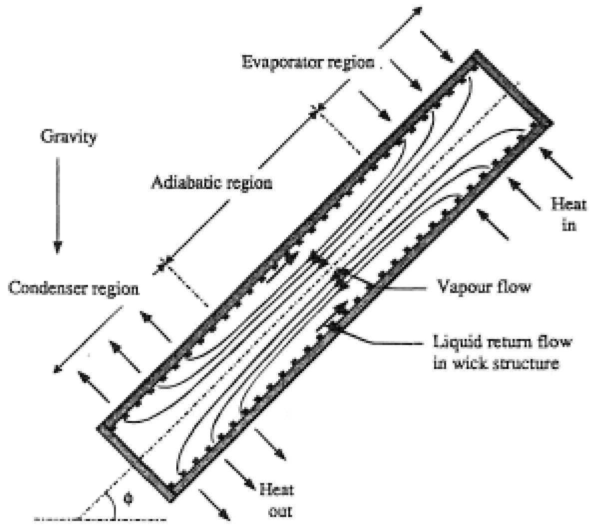



Figure 1: Schematic of the condenser and evaporator section of a heat pipe.

The concept of heat pipe is based on working fluid absorbing amount of heat energy thus turns into evaporation of vapor. The vapor flow into inverse end of the condenser zone where it loses its heat to cold interface will be condensates into liquid. Liquid flow back to the evaporation zone and the principle of both processes of cycle repeats.

Heat pipe device is perform heat transfer in very high performance also large quantity of heat effectively and efficiently by utilizing the evaporation and condensation heat transfer process. Meanwhile, there are many investigation about heat pipe thus to determine by variety operational parameter such as select the pipe material. Material that generally used to construct a heat pipe would be nickel, aluminum, copper and stainless steel. Beside on that, other investigation of working fluid at certain temperature ranges by measure surface of heat flux. Many research has been indicate the liquid ammonia heat pipe are favorite be used in industrial because it is lightweight. However, experiments show that condition of water heat pipe has most effective combine with copper vessels for generate temperature range between 5 to 230 $^{o}$C.

## 1.2 Problem statements

Thermal performance characteristics of Hybrid solar/heat pipe/ water heating system are to find out a solution to improve the reliability operation. As there are many configurations could be applied on this performance characteristics and relationships would prove a great step towards the development of viable environmental friendly heating application. Therefore, in this study will concentrate about heat transfer from both side of TE module to provide thermal heating efficiently as well as prevent any waste heat from occurring thus increasing the overall efficiency of the system. This is an attractive saving system would be developed and studied in this research.

## 1.3 Aims and objective

The studied was carried out investigation the thermal performance characteristics of a hybrid solar heat pipe collector coupled to a thermoelectric module and water cooled jacket for hot water production.

## 1.4 Outline of report

Chapter 1 presents the background of solar energy as renewable energy and heat pipe heat exchanger. This chapter likewise discuss about the problem statement and objective of this research. A chapter 2 talk about the writing literature review from explores that with respect to this research which is regarding of characteristics of a hybrid solar heat pipe. Methodologies and discoveries from the analysts will be talked about in this section. Chapter 3 describes depicts about hypothetical model of Hybrid solar/heat pipe/water heater. Some theoretical calculation about heat transfer rate and thermal efficiency for this experiment will be examined in this section. In Chapter 4 will explain about experimental apparatus consists on Hybrid solar/heat pipe/ water heater also the experimental setup on this system. Other than that, this part additionally talks about the results finding for this experimental research. Results will be plot out to indicate various performance conditions without further explanation. Chapter 5 will continuous explain about the test results for each runs also some comparison of consequences of the impact of performance of project that will be discuss. Other than that, this part additionally talks about the impact of thermal efficiency performance. Chapter 6 has provided some of the recommendation for future studies and methods required for future examination. Chapter 7 discuss the finish of this undertaking and some discoveries on performance of hybrid solar/ heat pipe/ water heater will be determined

# Chapter 2

# Literature review

## 2.1 Application and performance of heat pipe

Yan, et al. [1] experimentally investigated the affecting elements of heat transfer exchange using of Heat pipe heat exchanger and he demonstrated the several factors which will lead to performances like distance across of heat pipe which is heat carry through the evaporator process located at length of heat pipe. Next the heat pipe consists of aluminum heat fin which heat up the working liquid inside the heat pipe spacing have an unprecedented lead on the heat exchange process and will affected pressure drop. In this study, The choice of fin he suggested is the thickness as small as possible to ensure the heat energy balance transfer more effectively and efficiently

## 2.2 Hybrid solar heat pipe thermoelectric modules heat generation.

Chen, Wei-Hsin et al. [2] conducted a research of characteristic of TEM at different operating condition by investigates the power and heat generated simultaneously by low temperature heat exposure sunlight. He suggested that 0.4 L/min water flow rate has been use for this experiment research also TE modules place along surface of condenser to analysis the thermal performance. Results have indicated the growing of TE heat and power performance relay to raising heat source. However, the efficient for system was found the efficiency has about linear dependence on the temperature different.

Date, Ashwin et al. [3] presented experimental on the behavior of a proposed combined solar water heating application together with power generation of thermoelectric system. They proposed construction comprises of concentrated solar collector thermal device that gives a high thermal flux source for thermoelectric generators. An experimental investigated a flux of 50,000 W/m2 a temperature difference of 75 C across the thermoelectric generator can be achieved and 80 C of hot water was heated up through this experiment. This might helpful be used for domestic or industrial applications. According to this experiment has show that 3.02 V of open circuit voltage can be generated for each thermoelectric generator with dimensions of 40 mm 40 mm.

He et al [4] conducted a trial study on heat pipe solar collectors combine with the fuse of TE module. This hybrid can be utilized for joined water heating and electrical power generation, this model configuration comprises of a TE module combining between the condenser of the heat pipe and a water channel. Solar energy is received will converted through the heat pipe to provide the TE module while the water channel absorbs heat from the other end of the module thus creating a temperature different required for power generation. An analytical model was displayed to find out the average performance of thermal and electrical simultaneously with the ambient temperature. Beside on that, solar irradiation and water temperature also become a reference in this experiment together with other geometrical specification of the system. This simulation demonstrated that 45 degree of water temperature and 600W/m$^2$ solar radiation has results a thermal efficiency of 55 percent and electrical of 1 percent. This experiment also compared the electrical efficiency to that of an organic rankine cycle with 3 until 4 percent efficiency. Although this system has an electrical efficiency of 1-2 percent but the design and non-existing move components make the application more accessible and applicable.

Figure 2 shows the result of thermal effectiveness and electrical proficiency for diverse solar irradiation. Experimental shows increase of solar irradiation influence the performance of the SHP-TE unit increment and both thermal productivity and electrical effectiveness decrease with expanding water temperature. Based on figure below shows that there is about 25 percent of thermal energy has been reducing within TE this is change into electrical power. Meanwhile, the increasing the number of thermo element lead the better performance of thermal efficiency because it will increase heat conduct through the thermoelectric module.

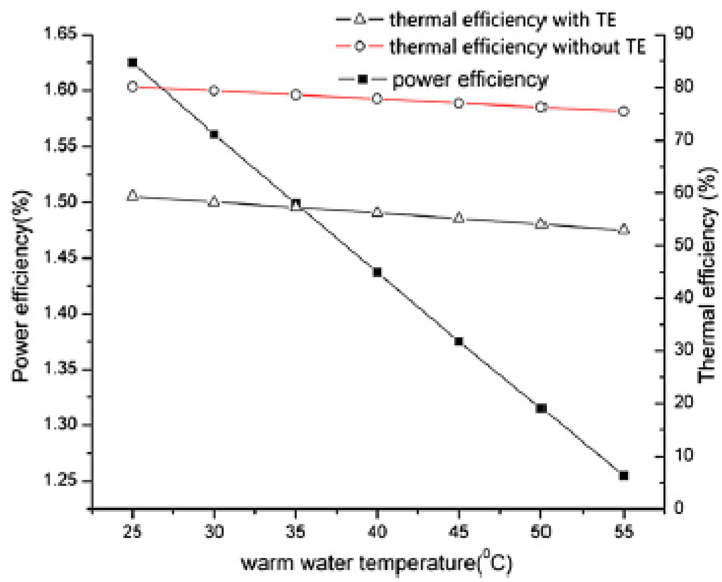



Figure2: Thermal and electrical efficiencies vary with water temperature.

Zhang, Ming et al. [5] outlined a solar thermoelectric co-generator (STECG), which can created electrical power and heat energy simultaneously, he setup a system whereby consists of evacuated heat pipe and TE modules . It consists of an array of 36 evacuated tube heat pipe solar collectors with resistances energy of 1.24 K/W per TEM and a module $ZT_M$ of about 0.59. The STECG successfully warm up water as it experienced the heat pipes and normal evaporator tube gatherer capability was 46.72%can be created 0.19 kW h of electrical power and around 300L of heated water at temperature from 25 C to 55 C in a day.

Gang, Pei et al. [6] investigated a system of heat pipe thermal systems utilizing a piece of aluminum plate. First, he was started with the constant flow rate of 0.1kg/s, four units of water cooled jackets are placed over the TE modules and each of the water flow rate was 0.025 kg/s. The decrease in the valuable thermal energy fluctuates somewhere around 23% and 38%, which of the electrical energy shifts somewhere around 1.5% and 4.3%.

Lee et al [7] conducted an experiment study on TE refrigeration system by employs two phase loop thermosyphons. Based on the research there are 5.4Kw/km² heat transfer rate with loop heat pipe heat sink. Beside on that, an analytical occurred for the system and were able reasonable results of the involving parameters. However requires that the temperature distribution along the loop be verified by experiment.

Vian and Astrain [8] developed a thermosyphon type heat exchanger for the cold side of thermoelectric module. This device improved the thermal resistance between the cold side of the TE module and the refrigerated ambient by 37 percent and it was experimentally proven that the COP of refrigerators can be improved up to 32 percent. A functional of energy generated in 8 hour increased marginally and comprises around 383Wh/m² and the coefficient of the generator efficiency amount to around 1.1 percent.

Zhang, Xinyu et al. [9] investigated the higher coefficient of thermal performance for water-in-glass evacuated tube sun oriented water heaters in China. Test results demonstrated that the sun oriented collector limit (or heat pick up from the sun) and heat loss from the capacity tank affected the thermal execution of SWHs. RAV affected the collector capacity; the recommended RAV was 57–72 L/m2. In this situation, the system efficiency ranges from 0.49 to 0.57 and the final temperature of the SWH will be above 45 C after a whole day of heat collection with relatively good solar irradiation. The thickness of polyurethane insulation should be 50 mm thick, and it should have a free foaming density of about 35 kg/m3 for production process quality control. We found that a shorter evacuated tube exhibited better thermal performance than a longer tube. A shorter tube is also less likely to be damaged during transportation, so we recommend the shorter tube. The tilt angle of the system did not affect thermal performance, so it should be designed to acquire maximum solar energy at the installation site. These results reveal how to maximize the performance of SWHs and minimize cost. The experimental results showed that the distance between the centers of the tubes will have an effect on the thermal execution of a water-in-glass evacuated solar water heater without diffuse reflectors, and the external distance across of the evacuated tube is another factor, both of which need further research.

Liu, Zhen-Hua et al. [10] studied a novel evacuated tubular solar air incorporated with simplified CPC and open thermosyphon. This system was designed to provide air temperature for utilize the water based CuO nano liquid as working fluid. This experimental apparatus used in the system which is consists of two link panel whereby each panel consists of one evacuated tube. Meanwhile it is also consist of a simplified CPC together with open thermosyphon. The comparison of examination includes air outlet temperature of the system whereby the system total effectiveness has been investigated. Likewise, there are two different experimental system was done by investigated both performances. The experiment study the influences of different structure show that thermosyphone is better than collector with concentric tube. Further result also show that nanofluids have better performances working with thermosyphone.

Wei He et al [11] exhibited a test study on parametrical examination of the outline and execution of a solar heat pipe thermoelectric generator unit. The analysis was compared the complex influence with different solar irradiation, ambient temperature, water temperature and other geometrical specifications of the system. This analysis is presented based on different characteristics performance and ideal configuration parameters contrasted and the state of a consistent temperature. The simulation indicated that peak point of three most extreme force transformation effectiveness is 3.346 percent when solar irradiation was $1000Wm^2$.

Sateikis et al [12] carried out investigation of a micro-power TE generator operating at a low temperature different. This experiment was studied energy evaluation of the TE generator utilizing two lines of three TE modules associated in between water flows in a counter-flow arrangement which is connected in series. Next, the experimental result show amount of the energy generated in 8 hours increased marginally when the comparative cold water flow rate was 0.347-0.376 liter per second and the coefficient of the generator efficiency amount to around 1.1 percent.

Gaowei Liang et al [13] presented the performance of a parallel TE generator by hypothetical investigation and experimental result. Based on the theoretical model was takes into account for example heat sink, temperature of heat source, contact resistance and thermal contact resistance of every TE module in parallel and an exploratory system was then constructed to confirm the theoretic model. Results demonstrate that just when all TE modules have the same inalienable parameter and working conditions, the parallel properties imitate that of a common DC power source. It was additionally demonstrated that increment in thermal contact resistance act simply like an increment of the TE module's interior resistance which prompt diminishing to decrease in power generated. The analytical result derived was consistent with the experimental results despite some discrepancies due to assumptions made to ignore heat conduction between thermocouple.

Khattab et al [14] studied the ideal operation of thermoelectric cooler driven by solar thermoelectric generator. This experiment included the theory of both TE generation and TE cooling as well as the requirements for the TE cooling system to achieve best performance from the TE power generator all year around. Performance tests was led to focus both the physical properties and the execution bends of the accessible TE modules and a theoretical model was developed to simulate the TEG-TEC system to anticipate its execution throughout the entire year under specific climate conditions. The results indicated that due to low conversion efficiencies of the TEG system, 10 TE power generator modules were obliged to control the TEC at ideal execution at most times of the year. Despite the required number of TE modules needed to power a TE cooling system, this indicated that solar power generation is able to provide electrical power reliably throughout the year.

Chavez et al [15] investigated the possibility of using thermoelectric generators in solar hybrid systems. This experiment was examined for those four systems which is one of the traditional photovoltaic thermal geometries with TE modules allocated between solar cells and the heat extractor, working without radiation concentration, and other three was using concentrators in various set up. The efficiency for each system was investigated and it was found that the TEG efficiency has almost linear dependence on the temperature different between junctions, reaching about 4 percent at a temperature different of 155 degree and indicated that regardless of the setup, TEG works as long as a constant temperature difference can be supplied. Therefore, the addition of a TEG generator to a photovoltaic solar cell will allow an increase in electrical power generated by the system. However the low conversion efficiency of about 5 percent are still not a reliable and viable power generator.

Lertsatitthanakorn et al [16] performed a hybrid thermoelectric solar air collector which generates both thermal and electric power generation simultaneously. This experiment has double-pass TE solar air collector and developed where the occurrence solar radiation warms up a heat absorber plate so that a temperature contrasts made between the TE modules. Results demonstrate that the warm proficiency increments as the air flow rate increase at the point when the surrounding wind current through the warmth sink situated at the lower channel to pick up heat while cooling the TE modules hence provide heat to the air flow. Other than that, the electrical proficiency rely on upon the temperature difference obtained and this experiment results at a temperature different was 22.8 degree, the system was generated 2.13W of power output and the change productivity of 6.17 percent. This concept of solar collector concept for supplied heat source has widely anticipated increasing the output of TE power generate system due to its abundance.

Rahbar et al [17] also studied of a novel portable solar still by still by using the heat pipe and thermoelectric modules. This design function while water is evaporated due to exposure to solar energy and condensed by the cooling provided by a TE modules act as a heat-pump. Heat is then rejected at the other end of thermoelectric modules using a fan and a heat pipe system. The experiment results indicated that the surrounding temperature and sun based radiation have an immediate impact on the framework execution however there is a lessening in water profitability by increase the wind speed. This study display of the efficiency and applicability of incorporated heat pipe technology and solar energy into the function of thermoelectricity and the application was flexible of TE modules and heat pipes work well together to provide a stable TE system.

Maneewan et al [18] constructed and carried out a lab-scaled investigation on the generating power of thermoelectric roof solar collector. The design consists of a straightforward acrylic sheet and air hole. Next, this experiment also employs a copper plate in other to absorb heat with combination to thermoelectric modules and a rectangular balance heat sink. The halogen lamp also employ for generate the solar radiation energy thus to heat up somewhere around 400 and 1000W/m2. Solar radiation will expose carrier the heat energy to the copper plate so that create temperature different in between TE modules in that way to convert the heat energy. The cooling system of fan was used by current power generated along the experiment. Ten TE modules were used in this design and it was found that the system could generated around 1.2W under sun based radiation power of 800W/m2 at a surrounding temperature shift between 30 degree and 35 degree. Despite the innovation design and demonstration of the flexibility of TE modules, the system was possesses a low electrical conversion efficient of 1-4 percent.

Miljkovic et al [19] were displayed and improvement of a hybrid solar thermoelectric system which utilizes a thermosyphon as a method of heat transfer to convey warmth to a base cycle for different applications. An illustrative trough concentrates sunlight based energy onto a specific surface coated thermoelectric modules as the hot junction while a thermosyphon adjoining to the back side of the thermoelectric device which keeps up the temperature of the cold junction thus producing electric power. An energy-based model of the system with a thermal resistance network system was produced to focus the overall performance of the system. In addition, the system proficiency for temperature of 300 until 1200 liter, solar centralizations of 1-100 aggregates, and diverse thermosyphon and thermoelectric materials were investigated and the geometry of the thermosyphon was also investigated. Result show the optimization of the system that the efficiency as high as 52.8 percent can be accomplished at ideal detail. The solar concentration convergences of 100 suns and a base cycle temperature of 776K result obtained that TE system can be used at higher temperatures while keep up the electrical change efficiencies this is unlike the conversion efficiencies of photovoltaic technologies which starts to deteriorate as the mean working temperature increases. This simulated level of solar irradiation is far on the high side and will be hard to obtain in reality. However this indicated the potential of a solar generator.

Zhang et al [20] outlined a sun powered thermoelectric and hot generator which can heat as well as electrical power generation simultaneously, within thermoelectric module to the heat pipe in an evacuated tube solar collector. A ring shaped TE module is applied around the condenser of the heat pipes was sandwich which was combine in between heat spreader and heat sink . A theoretical model for accurately prediction the thermal losses based on energy balance and heat exchange mathematical statement was figure out and based on the theoretical model for TE modules can produce an electrical efficiency of 1.59 percent when solar irradiation is 1000W/m$^2$, wind velocity is 1.3 m/s, ambient temperature and water temperature of 25 degree. This shows that the TE modules incorporated evacuated tube solar collectors are economical and practical.

# Chapter 3

## Theoretical calculation

### 3.1 water heating

The heat energy absorbed by the water channel will be used to heat up the water in the water tank of this experiment. Heat transfer to the water tank is measured by the change in temperature and can be determine by equation below.

$$\dot{q}_w = \dot{m}_w \, c_{pw} \, (T_{wo} - T_{wi}) \quad (1)$$

Where the

$q_w$ = heat transfer rate w

$m_w$= mass of object heated g/s

$C_{pw}$ = specific heat capacity for water is 4.183 J/g °C

$\Delta$T= changing in temperature $\Delta T = T_2 - T_1$ T

The total instantaneous thermal efficiency of the hybrid water heater is determined from

$$\eta_w = \frac{4\,\dot{q}_w}{(H\ A_{SC})}\ x\,100\,\% \qquad (2)$$

Whereby

$q_w$ = heat transfer rate w

H= solar radiation Kw/m²

Asc= area of evaporator m²

# Chapter 4

## Experimental investigation

An experimental SHPTE hybrid system with a single ETHPSC was set-up as shown in Figure 3 which is solid work diagram show the framework was setup. Major dimensions are listed in figure 5 and. Isometric views of the aluminum block and water cooling jacket are shown in Figure 4 (b). The aluminum block measured 70 x 105 mm with a 24 mm diameter hole bored into it to fit over the condenser of the heat pipe. Each cooling jacket measured 0.04m x 0.04m x 0.02 mm thick with six 2 mm diameter channels machined inside and connected to two 5 mm diameter common manifolds for water flow into and out of the jacket. Water mass flow rate is assumed equal in all the water channels in the jackets. The ETHPSC was inclined at about 30 degrees to the horizontal. Solar radiation was measured utilizing a Kipp and Zonen solarimeter which is place at flat surface 0 degree. Coolant water mass flow rates supplied from an overhead cold water supply tank were adjusted to produce roughly equal flow rates to each jacket. Type T copper-constantan thermocouples were employed to measure the temperatures at the locations shown in Fig. 7. Resistance loads to the TE modules were applied using common resistors of about 5.3 ohms each. Solar radiation, temperatures and TE voltages were recorded on a data logger at 1 minute’s intervals

## 4.1 Experimental Apparatus

Figure 3 demonstrate a schematic graph of hybrid solar/ heat pipe/ water heater system experimental setup. Based on this experimental setup comprises of the part including a hybrid heat pipe solar collector, an aluminum condenser, four piece of thermoelectric modules and four water cooled jacket was used in this experiment study. The configuration and development of the framework are portrayed the assessment of its execution by combination of theoretical modeling and experimental testing. Heat energy presented to daylight and heat transfer to the evaporator section of the heat pipe which would transfer heat to water supply as creating a temperature different to generate power and heat simultaneously.

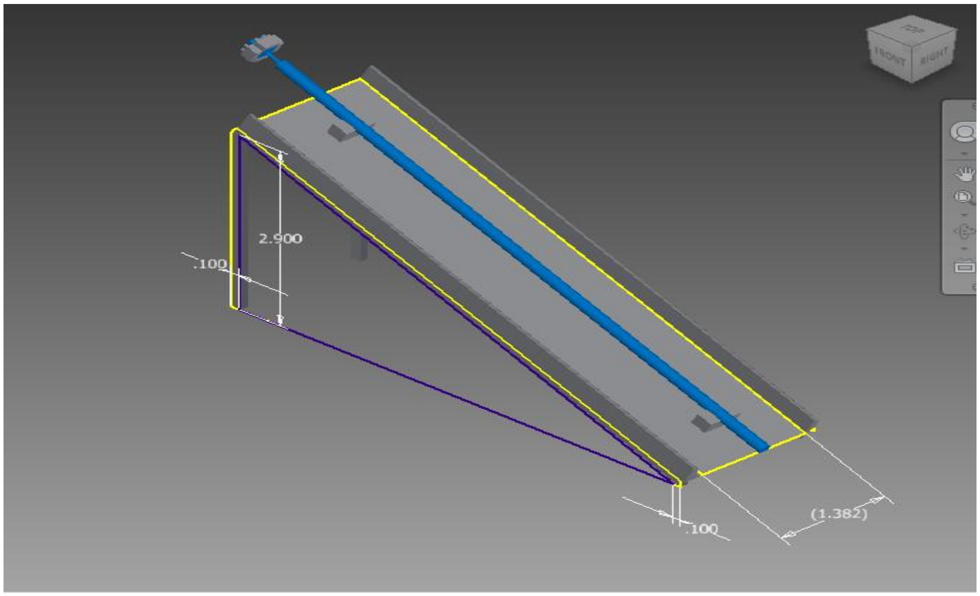
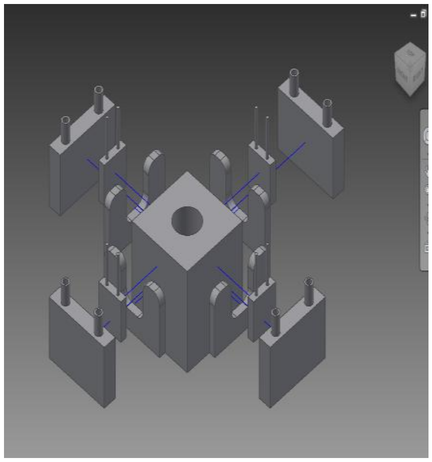
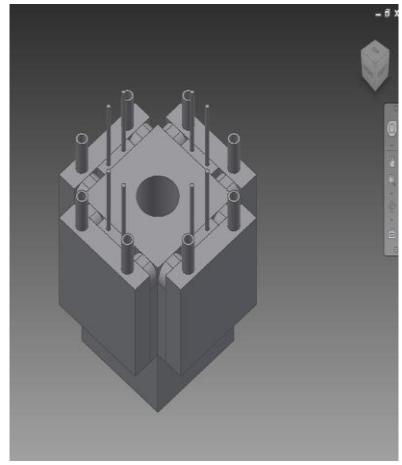



Figure3: Schematic Diagram of Experimental Setup





a) Exploration view b) Assembly view

Figure 4: a) Exploration view and b) Assembly view combine with aluminum block, water jacket and TE modules.

The solid work of system was presented as figure 4 shown the exploration view in section (a) used in this experiment. The cooled jacket, TEs, cock board and aluminum block acts as thermal loading as that the condenser across to provide thermal conductivity along the process. Section (b) was the combination of those apparatus applied between aluminum block surface and aluminum water jacket.

**Thermocouple Calibration**

The thermocouple wire used in this experiment is type T thermocouple that can operate at temperature range between -250 $^{o}$C to 350 $^{o}$C. Thermocouples were exact to inside ±0.5oC. 45 thermocouples were utilized as a part of this venture. There are some hardware and device used to adjust thermocouples. The equipments was used in this experiment is stopwatch, bottle shower, terminal augmentation, information lumberjack, refined water, and thermometer. Most importantly, refined water was filled into bottle shower and guarantees volume of refined water to be inside of the satisfactory level. At that point, one of the closures of thermocouples was associated with terminal augmentation and information lumberjack. Another end was drenched into bottle shower. After that, refined water was warmed up to 30 degree by turning the handle of bottle shower and sit tight for couple of minutes to achieve unfaltering state. The perusing indicated on bottle shower and thermometer was noted down. Thermocouple alignment was rehashed by expanding the temperature of refined water by 10 degree like clockwork from 30 degree to 90 degree

**Thermoelectric modules**

The prototype of this experiment was used Laird Technologies Thermoelectric Modules HT8 12 F2 4040 TA 40mm x 40mm x 3.3mm as manufactured by Bismuth Telluride semiconductor. This experiments study required 4 TE modules which allocated above and below an aluminum block, hot junction will be connected with the aluminum block outer surface that spreads heat from condenser. Next, the other junction will be in contact with the water cooling jacket to provide cooling surface applied on TE modules.

**Aluminum block**

Component diagram has shown in figure 5 sections (a) aluminum block was used in this experiment study with 0.105m x 0.105m x 0.07m with a 0.024m diameter cylinder hole in the center was fabricated and used as heat condenser spreader to direct the heat from the heat pipe toward TE module. For this stage of experiment, 2 mm holes were drilled through the center of aluminum block because it was used to measure the condenser section.

**Aluminum Cooling Water jacket**

Figure 5 section (b) was presented the dimension of the water cooled jacket utilized as 0.04m x 0.04m x 0.02 mm and outlined in H-kind of cooling water channel to provide cooling to the surface area for optimized the sink effect in term of performance.

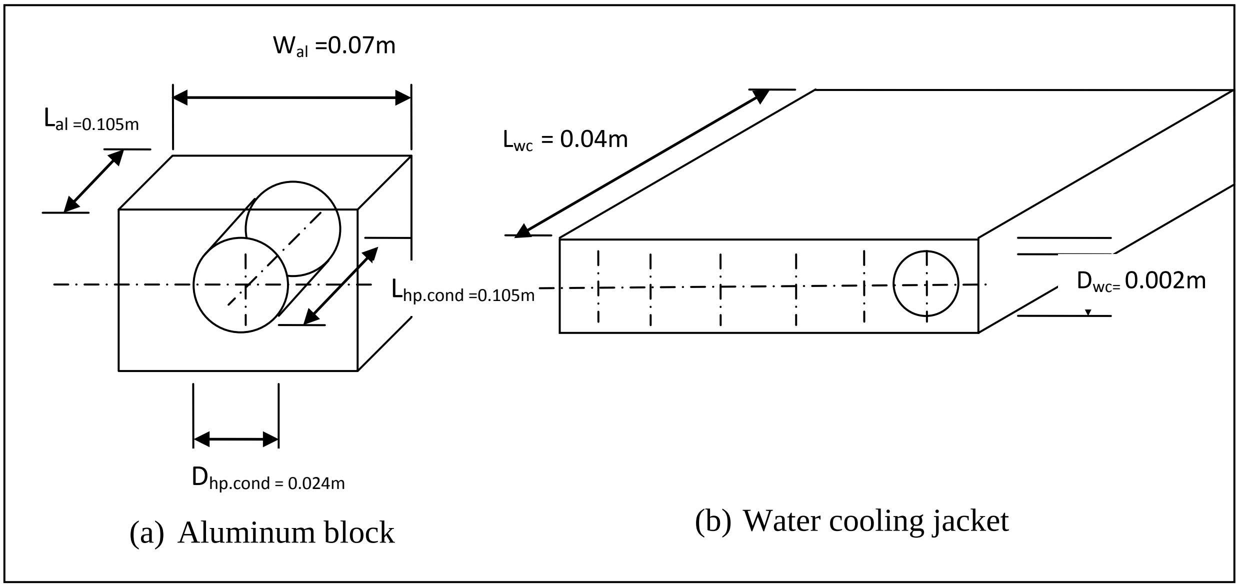



Figure 5: (a) aluminum block and (b) Water cooling jacket

**Insulation material**

The insulation material used in this experiment which is gasket paper, silicon rubber sheet and cock board was used as primary insulation around the experiment block. This insulation material used to ensure that all the heat transferred through the aluminum block is transfer to the system and prevent or reduce heat loss occurred during the experiment.

**Installation metal frame with heat pipe**

The metal frame can be seen in figure 6 is to hold the evacuated tube solar collector was fabricated which was made from steel slotted angle bars of dimension 0.04m x0.03m and were cut in length separately to build up the frame. The frame is designed so that the evacuated tube solar collector would be at angle of 30 degree.

Figure 6: Photograph of installation heat pipe with metal frame

**Installation water input and output pipes**

The connecting pipe would be used is 4mm diameter length pipes, those water pipes is connected to an aluminum water jacket consisting of water input and output. Other than that, thermocouple was joints into water output pipes to investigate the outlet water temperature of the experiment. The connection stage is shown in figure 7.

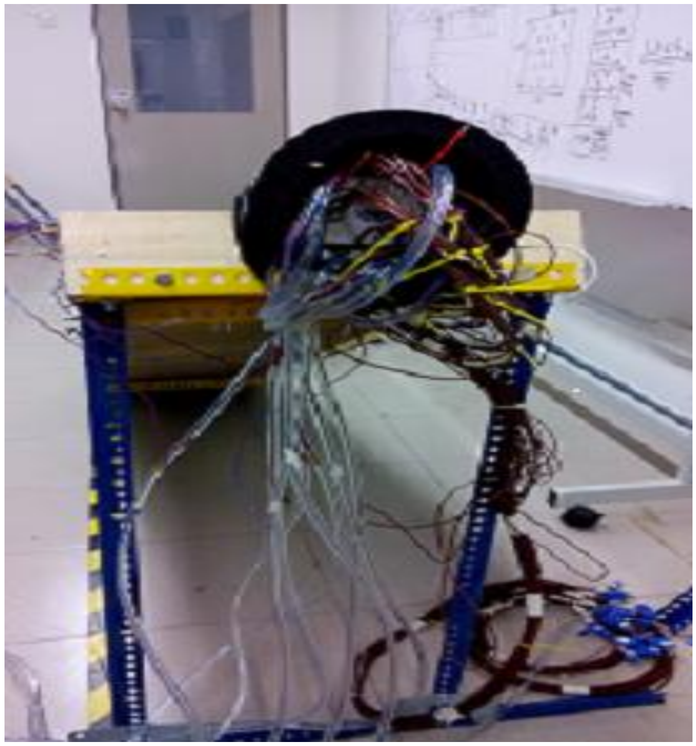


Figure 7: Photograph of installation water input pipes together with Thermocouple

**Installation aluminum cover**

The prototype design comprise of aluminum cover which is covered the aluminum block, condenser section, water jacket and TEs to prevent any solar radiation directly explore that affect the results of ambient temperature, water temperature would influence characteristic of performance. It can be seen in figure 8.

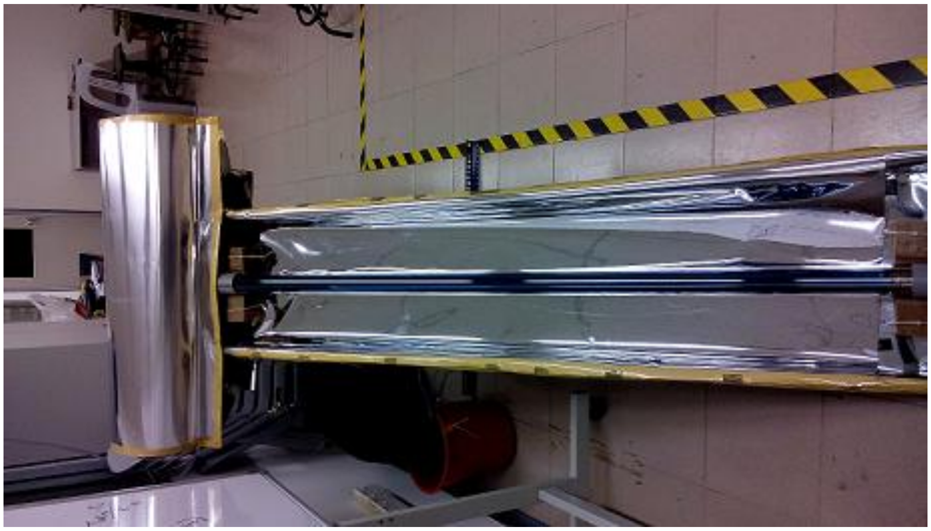


Figure 8: Photograph of installation cover

**4.6: Experiment procedure**

A commercial evacuated tube solar water heating system consists of individual evacuated tube solar collector to collect of three parts which is the solar tube collector, the heat pipe and the thermoelectric model. This system consists of an aluminum block which is work as a heat spreader, TE modules and water cooled heat sink. The schematic of the system can be seen in figure 10.

The development of solar hybrid system that includes solar radiation concentration and thermoelectric generator with the heat extracting water-based inside water channel system, furthermore to provide a good thermal contact between the elements of energy generation stages, thermal paste was used as an interface between heat sink and heat source that can easily be implemented as heat transfer system. Besides that, thermoelectric is the direct conversion of a temperature different imposed between the junctions of two types different materials to generated electricity as known as the See-back effect. See-back effect also can determined as when an electric current flow through a circuit composed of two different conductor, heat will be liberated at one junction and absorbed at the other which is depending on the current flow direction ( Peltier effect).

In order to obtain both effects, combined heat pipes in a thermoelectric (TE) device used for hybrid system could provide both power generation and heat simultaneously. Typically, the cold side of the thermoelectric cooler is in contact with the thermoelectric chip to maintain the chip temperatures below its design temperature with natural or forced convection at the hot side of the TE modules to carrier the heat from the thermoelectric chip and the applied power to the TE modules to the ambient.

The performance of the system relay upon the design and geometric dimensions of the collector, insulation, connecting pipe size, relative angle (30 degree) also environmental factors such as weather and wind conditions to justify the temperature that can be achieved. Next, insulation inside the tank would determine the heat losses will lead to performance drop during the experiments. Such as this case, the solar tank will insulate with thermal resistance rubber that could reduce emissivity heat losses during analyze in this work.

The idea of this design is that solar energy will be collected by the solar tube collector when exposed to sunlight and transferred to the evaporator section of the heat pipe inside the solar tube collector and the heat pipe will then transferred this energy to the condenser section thus heat up the aluminum block. Meanwhile the aluminum block works as heat spreader as transfers and spreads the energy toward the TE module which are placed along and in contact with the condenser section and other surface of the TE module is cooled with water jacket and water from water tank would flow through the water cooled heat sink to absorb heat energy through the TE module thus create a temperature different between both sides to gain in TE power generation and water heating simultaneously. A diagram depicting the flow of the heat transfer through a commercial solar heater of the hybrid system is shown in figure 9.

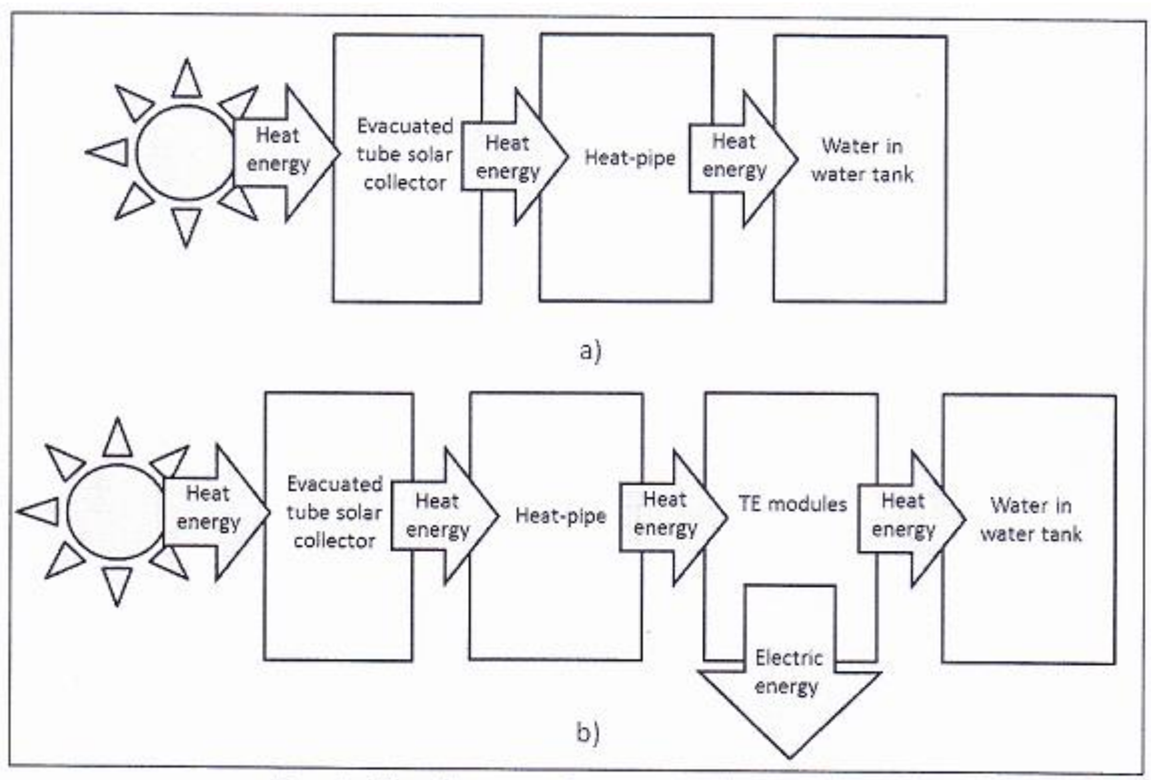



Figure 9: Flow of heat energy in a solar water heater and Flow of energy in the solar / heat pipe / TE hybrid system

Procedure:

1. Evacuated tube solar collector exposed to sunlight.

2. Water from water tank flow through the aluminum cooling water channel.

3. Thermocouple wire connected with terminal channels.

4. AC power supply used to supply to Graphtec GL820 data logger.

5. Three terminal channels directly connected with Graphtec GL820 data logger.

6. Data record started, temperature and voltage measurements were recording on per mine basic to ascertain the steady-state system.

7. Data logger will record the temperature data and the performance of thermoelectric will be determined via tabulated results.

8. kipp & onen Solarimeter were placed with an angle same as experiment rig at an open area to detect the solar radiation absorb by the rig.

9. kipp & onen Solarimeter measured and recorded through the day of solar radiation performance.

10. Data record started solar radiation measurements were recording on per mine basic to ascertain the steady-state system.

11. Solar radiation data direct connected onto a computer will be determined via performance results.

The schematic diagram of temperature point in figure 10 shown the connection of temperature point which is measured by thermocouple wires in this experiment. For this stage of the experiment, the allocations of temperature points are presented as shown

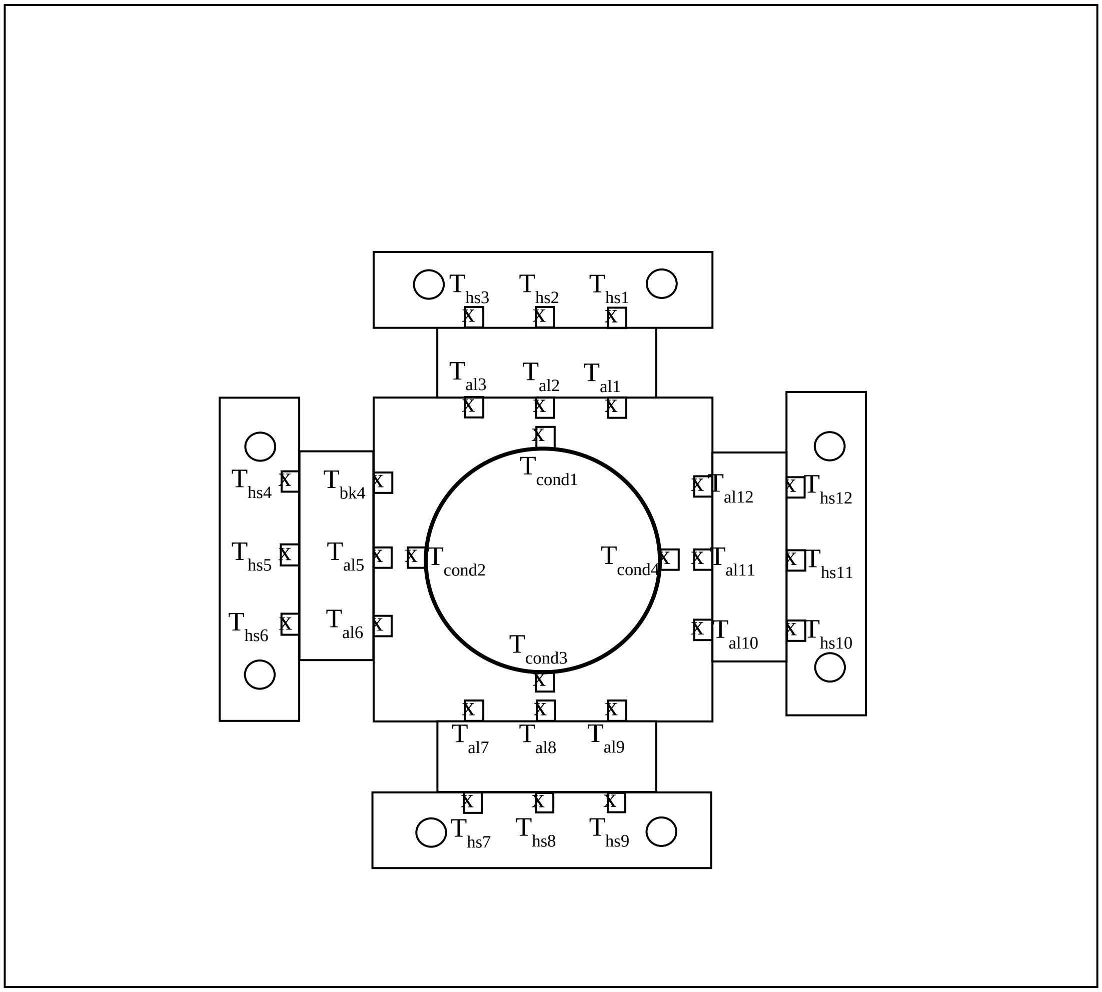



Figure 10: Temperature points on TEG system.

Figure 10 shown cross section location of the temperature points was fabricated aluminum block and a 2mm holes was drilled through the center of the aluminum block in order to measure the temperature of condenser section. $T_{cond1}$ , $T_{cond2,}$ $T_{cond3}$, $T_{cond4}$ ( Temperature points on condenser).

Meanwhile $T_{al1}$, $T_{al2}$, $T_{al3}$, $T_{al4}$, $T_{al5}$, $T_{al6}$, $T_{al7}$, $T_{al8}$, $T_{al9}$, $T_{al10}$, $T_{al11}$, $T_{al12}$ (Temperature points on aluminum block) those temperature points was located at the outer surface of each side of the aluminum block where 12 temperature points are measured to measure the temperature of the surface that can be provides even for the large surface area for optimized heat performance.

Other than that, $T_{hs1}$, $T_{hs2}$, $T_{hs3}$, $T_{hs4}$, $T_{hs5}$, $T_{hs6}$, $T_{hs7}$, $T_{hs8}$, $T_{hs9}$, $T_{hs10}$, $T_{hs11}$, $T_{hs12}$ (Temperature points on heat sink) is measure aluminum H-type cooling water jacket for the surface area of cold junction

The proposed hybrid system would undergo an outdoor performance test at UTAR top roof which the solar energy as a heat source for system will be evaluated and analyzed. Moreover, the system is set 30 degree angle on top of a fabricated metal stand.

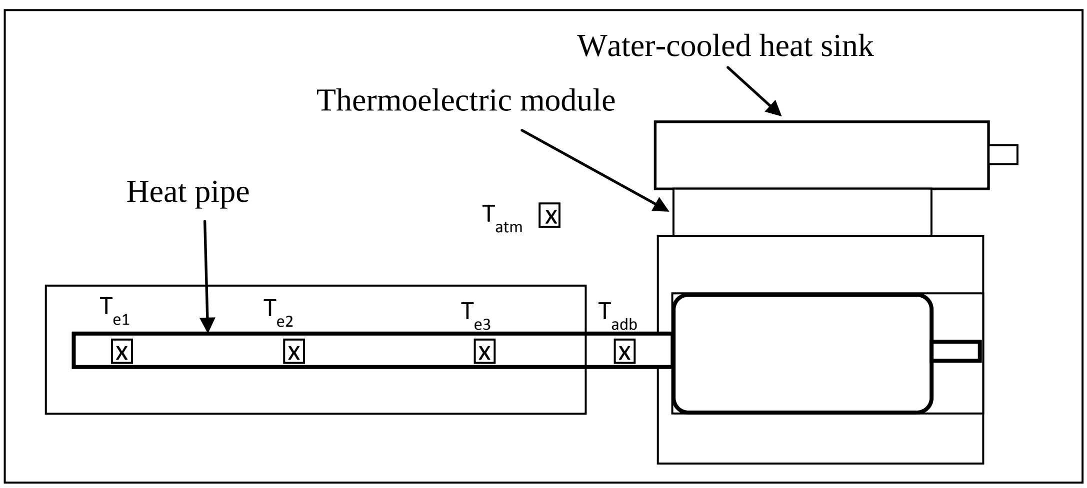



Figure 11: Temperature points on evacuated tube solar water heating system

The temperature pints measured for this system shown in Figure 11 provides a large heat input as heating section in the evaporator area of heat pipes $T_{e1}$, $T_{e2}$, $T_{e3}$ (Temperature points on heat pipe evacuated tube ) used to represent the solar energy that obtained from exposure to sunlight converted in to heat energy. The system also investigated $T_{adb}$ (Temperature points on heat Adiabatic ) that will be evaluated and analyzed. Next is $T_{atm}$ (Temperature points on atmosphere ) measured by thermocouple wires in this experiment.

## 4.3 Experimental Results

Figures 12 to figure 27 demonstrate every one of the charts of experimental results from Runs 1 to 4 with diverse with different flow rate and temperature condition. Figure 12to figure 27 shows the repeatability test run 1 to run 4. Besides that, figure 12, figure 13, figure 14 and figure 15 was typical experimental results which is indicated the solar radiation and ambient temperature in different coolant flow rate 0.9 g/s, 1.5 g/s , and good weather condition 0.9 g/s. Next, the figure 16 to figure 19 was the typical experimental results of heat pipe and condenser temperature in different coolant flow rate conditions results the different values. In additional, figure 20, figure 21, figure 22 and figure 23 also results the different TE both side temperature condition was show in run1, run 2, run 3 and run 4. Lastly, the figure 24 to figure 27 was indicated the experimental results of temperature efficiency performed by different coolant flow rate and temperature different in run1, run2, run3 and run 4.

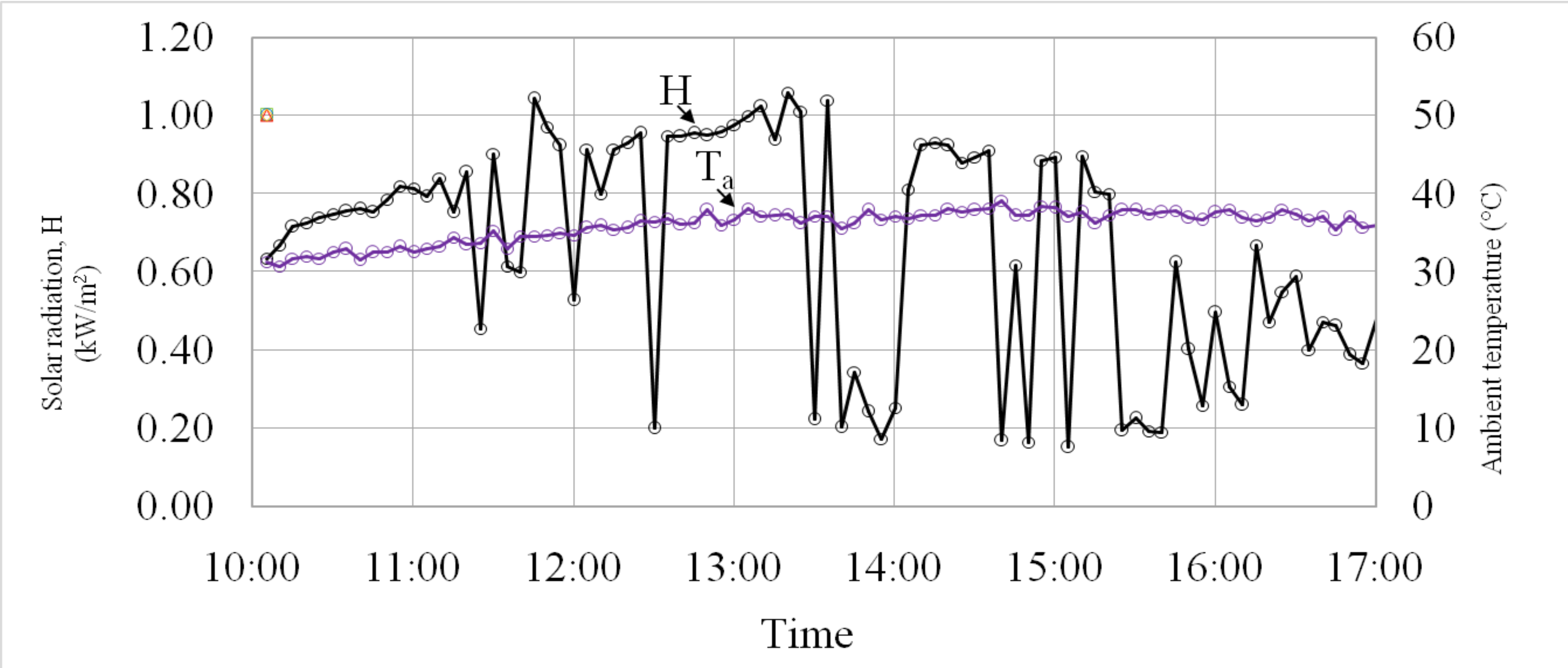



Figure 12 Typical experimental results showing solar radiation, ambient temperature (coolant flow rate = 0.9 g/s)(run 1)

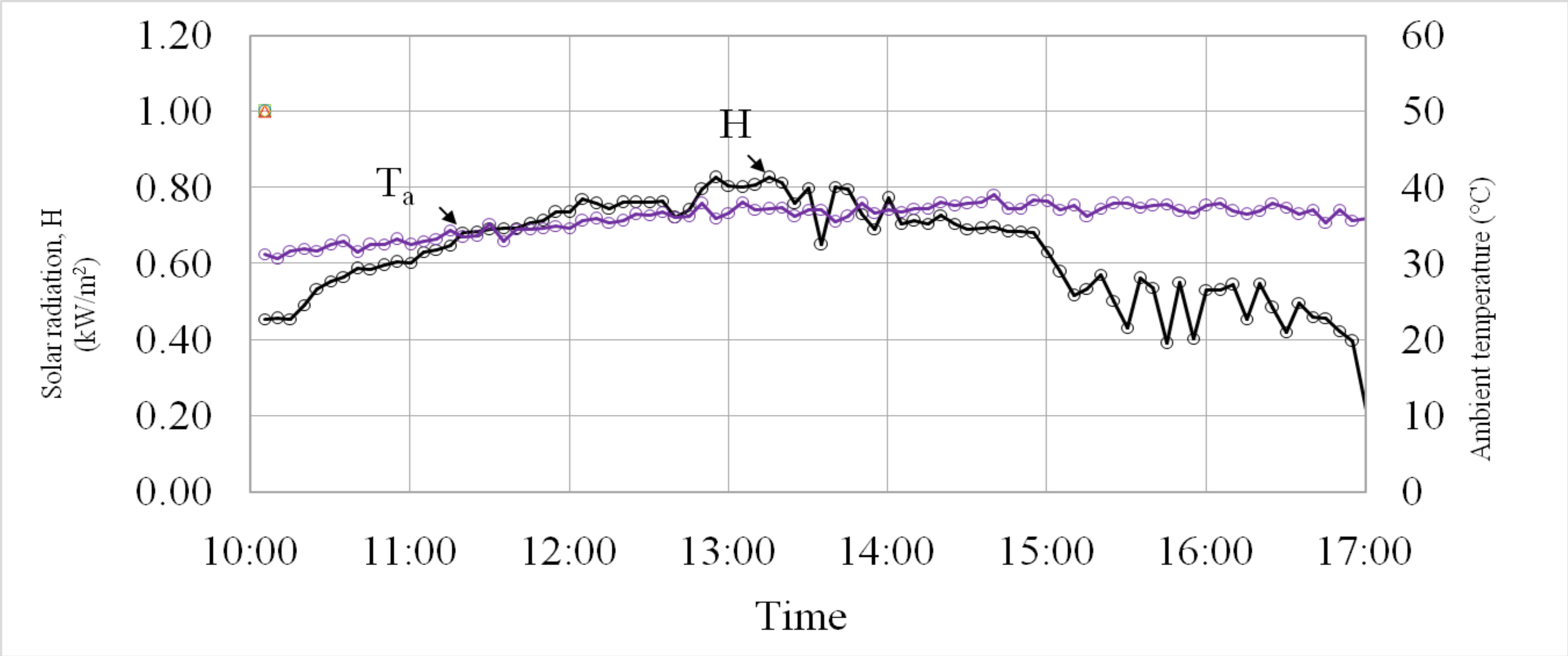



Figure 13 Typical experimental results showing solar radiation, ambient temperature (coolant flow rate = 1.5 g/s)(run 2)

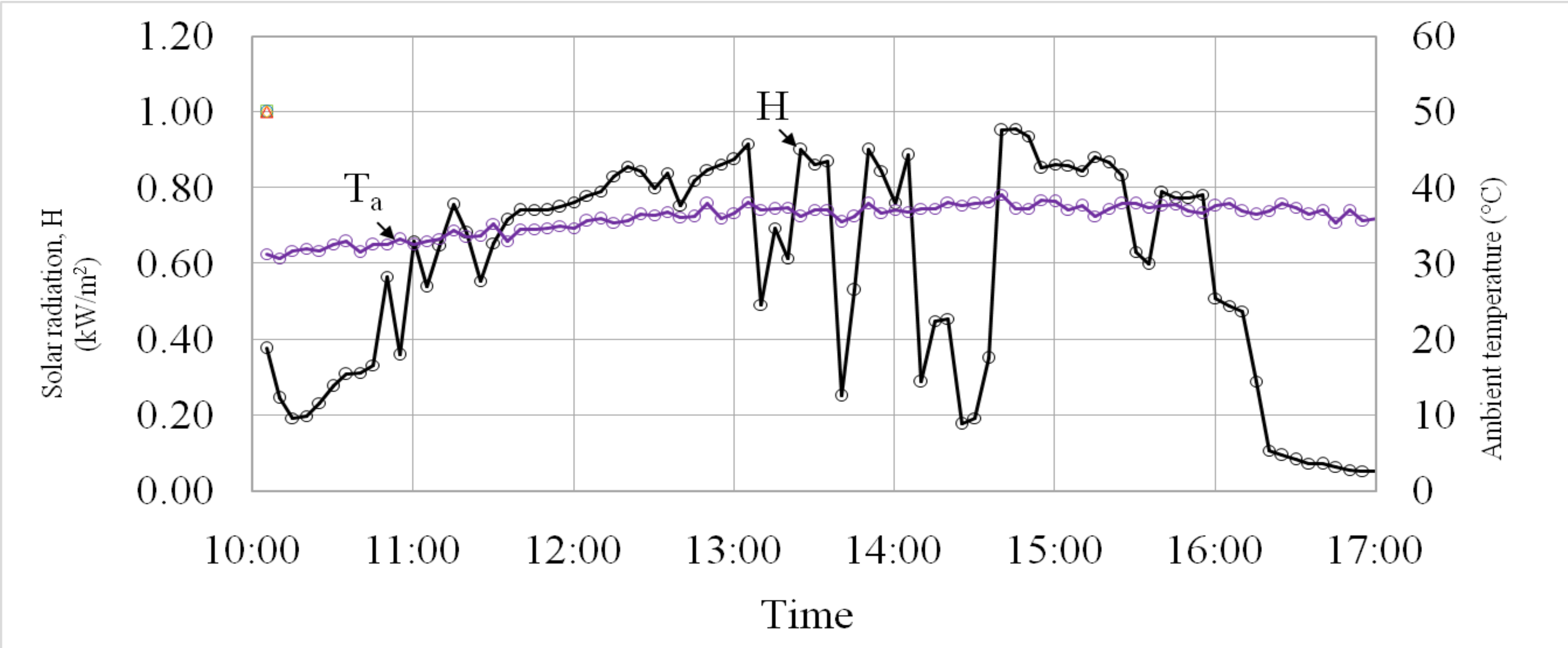



Figure 14 Typical experimental results showing solar radiation, ambient temperature (coolant flow rate = 8.33 g/s)(run 3)

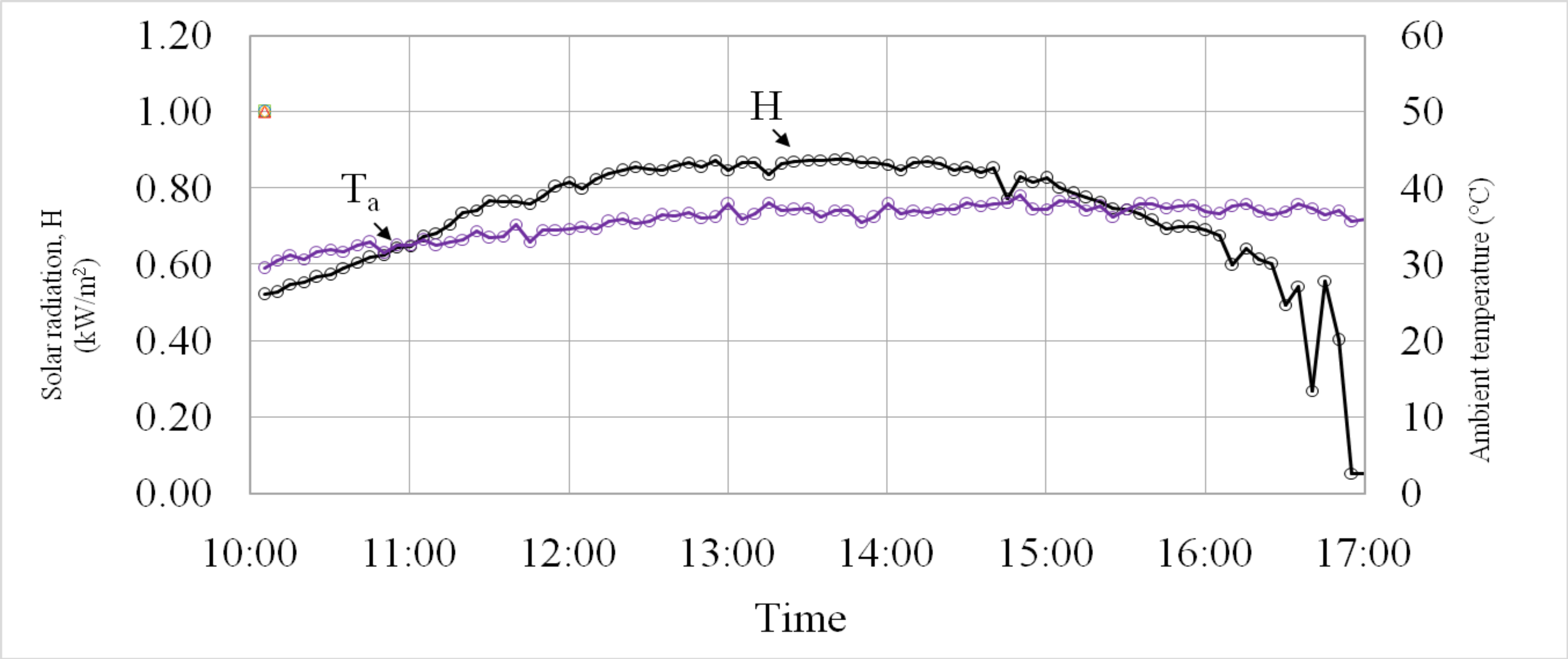



Figure 15 Typical experimental results showing solar radiation, ambient temperature (coolant flow rate = 0.9 g/s)(run 4)

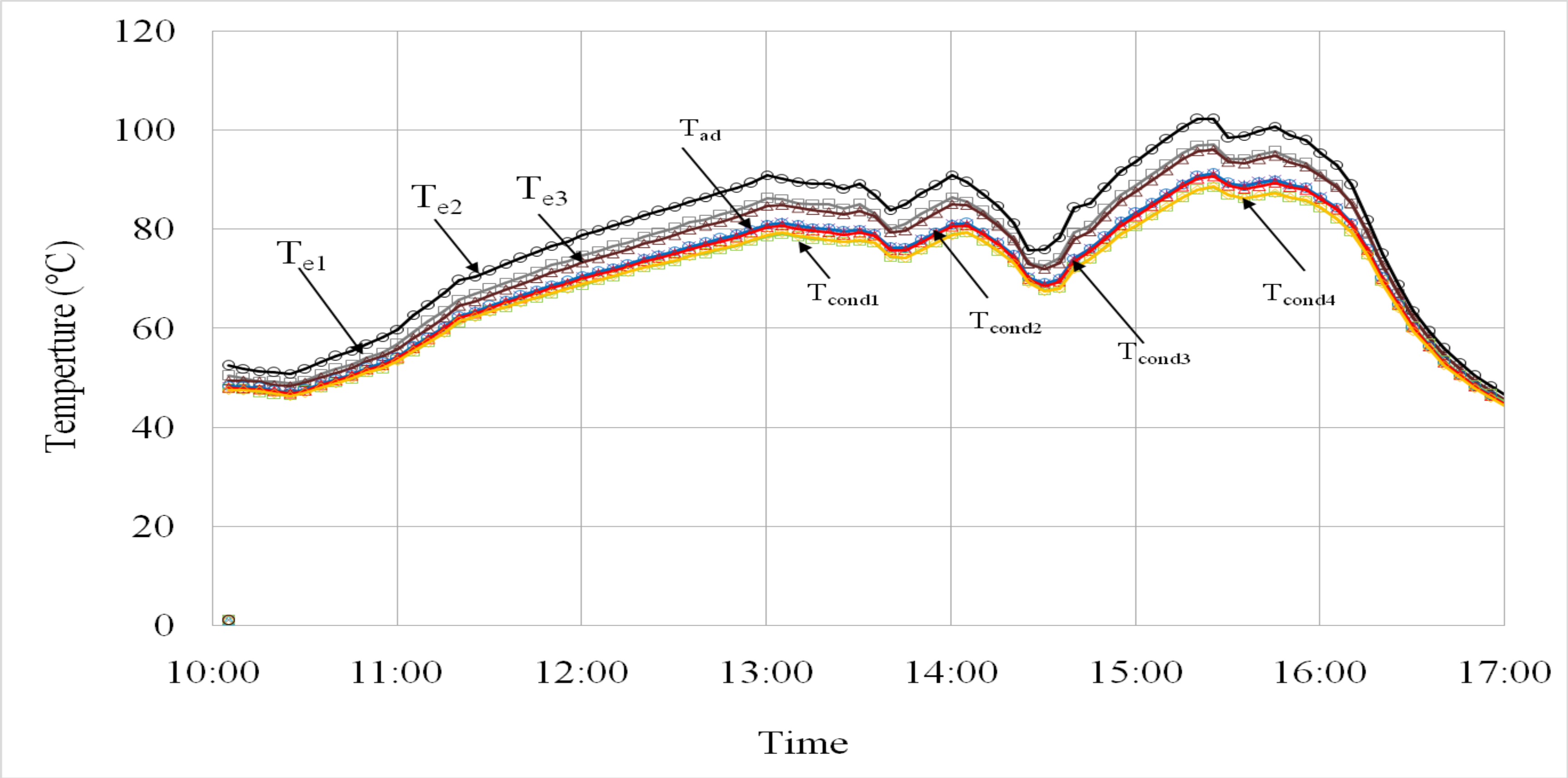



Figure 16 Typical experimental results showing heat pipe and condensor temperature (coolent flow rate = 0.9)(run 1)

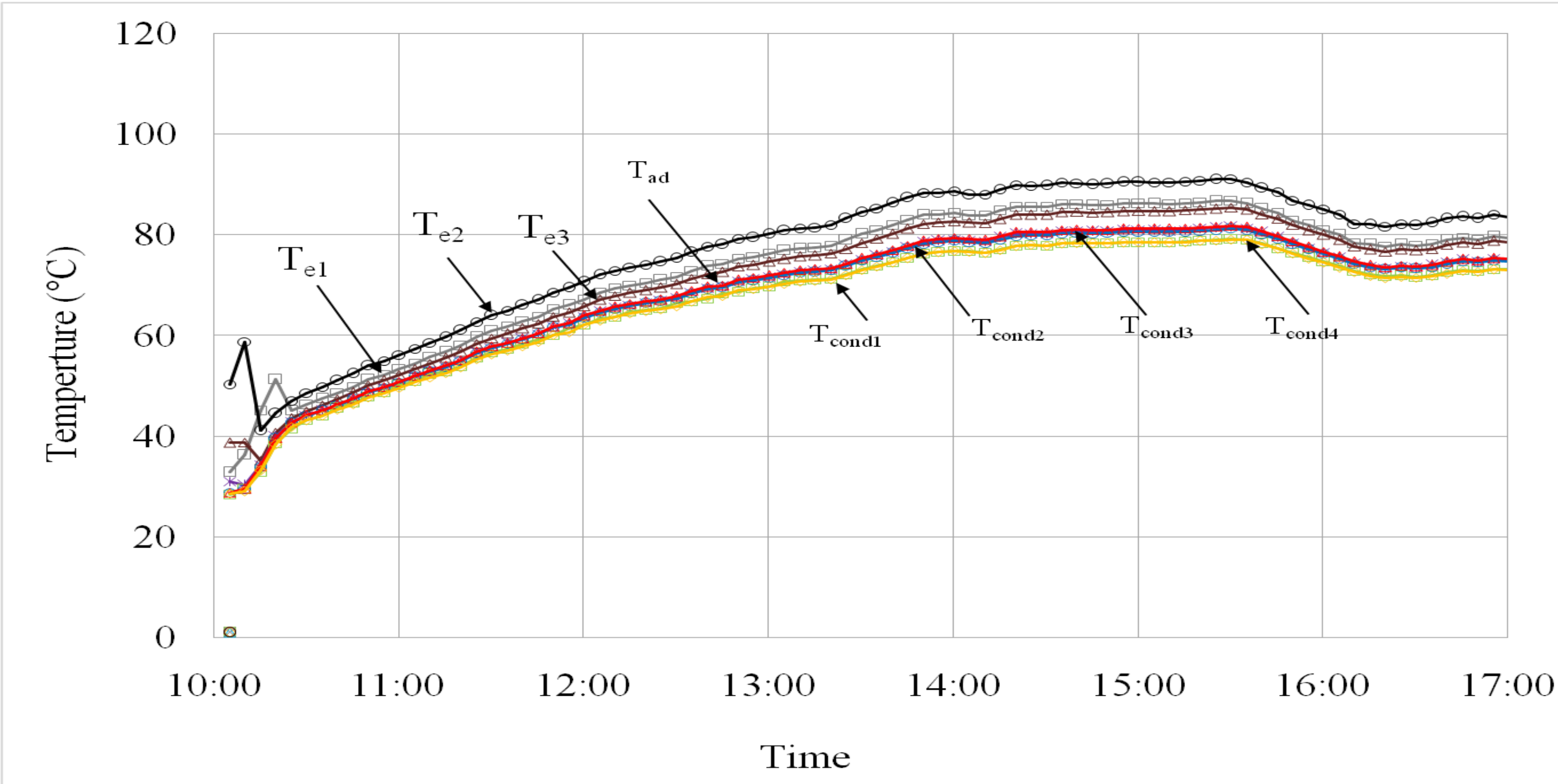



Figure 17 Typical experimental results showing heat pipe and condensor temperature (coolent flow rate = 1.5)(run 2)

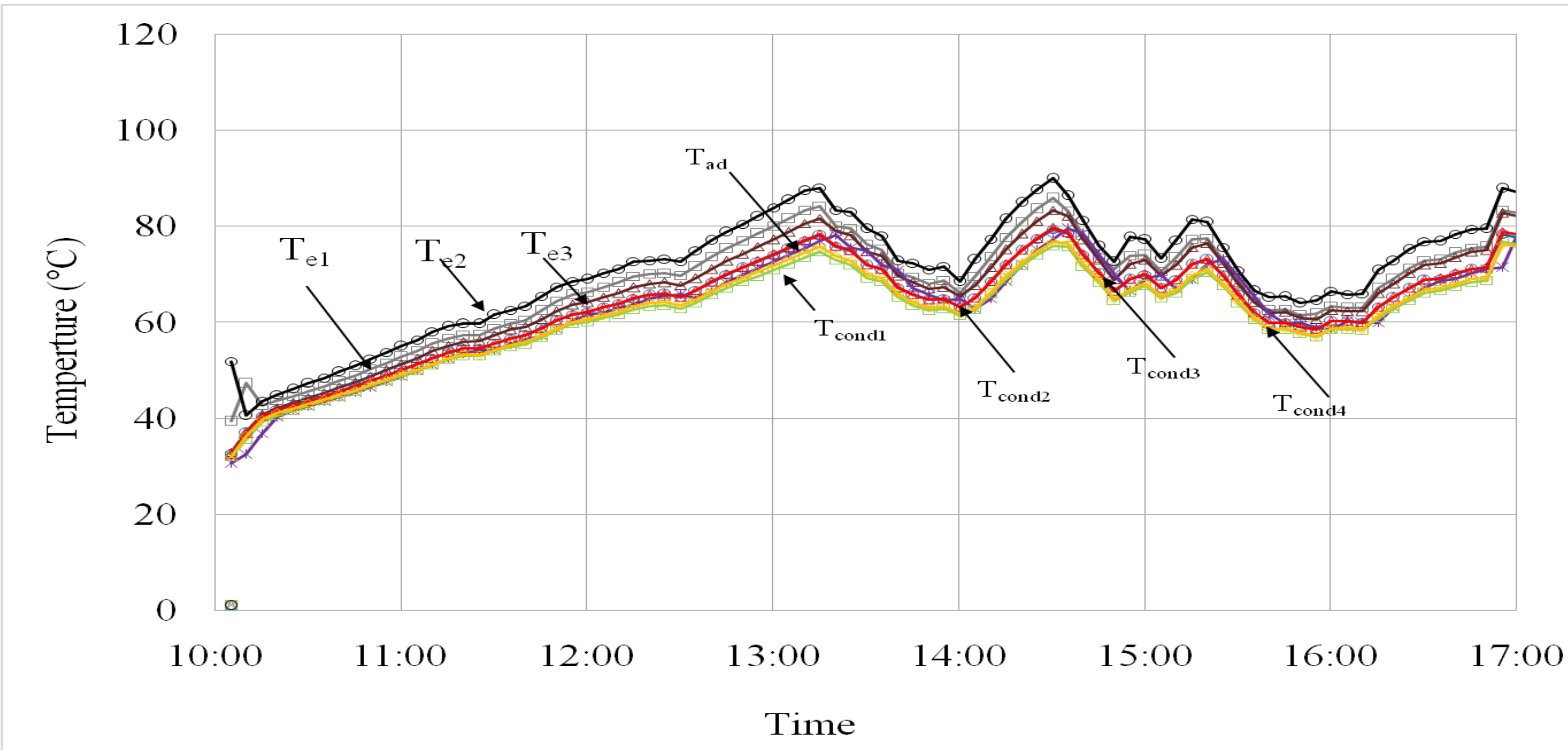



Figure 18 Typical experimental results showing heat pipe and condensor temperature (coolent flow rate = 8.33)(run 3)

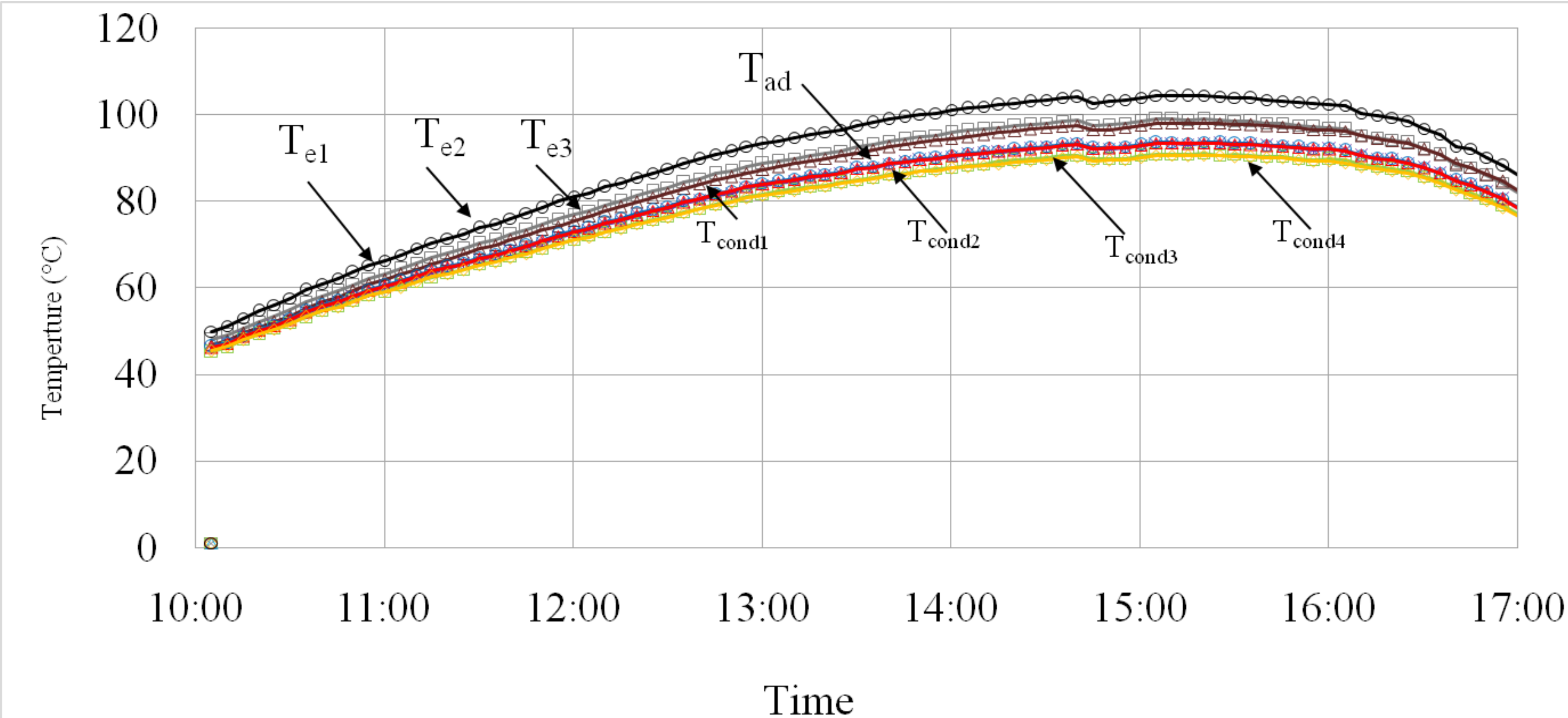



Figure 19 Typical experimental results showing heat pipe and condensor temperature (coolent flow rate = 0.9)(run 4)

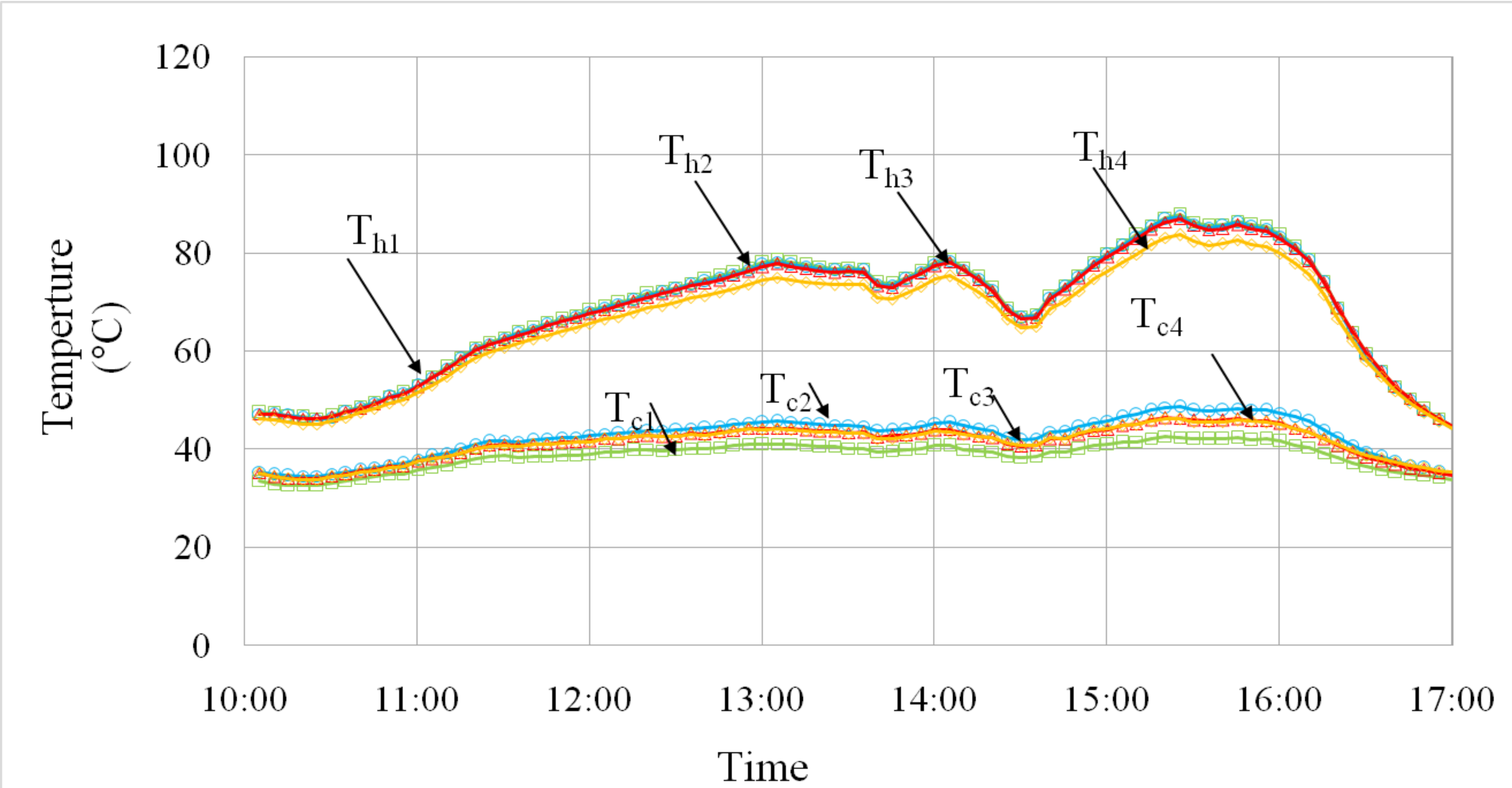



Figure 20 Typical experimental results showing TE hot side and cold side temperature (coolent flow rate = 0.9 g/s)(run 1)

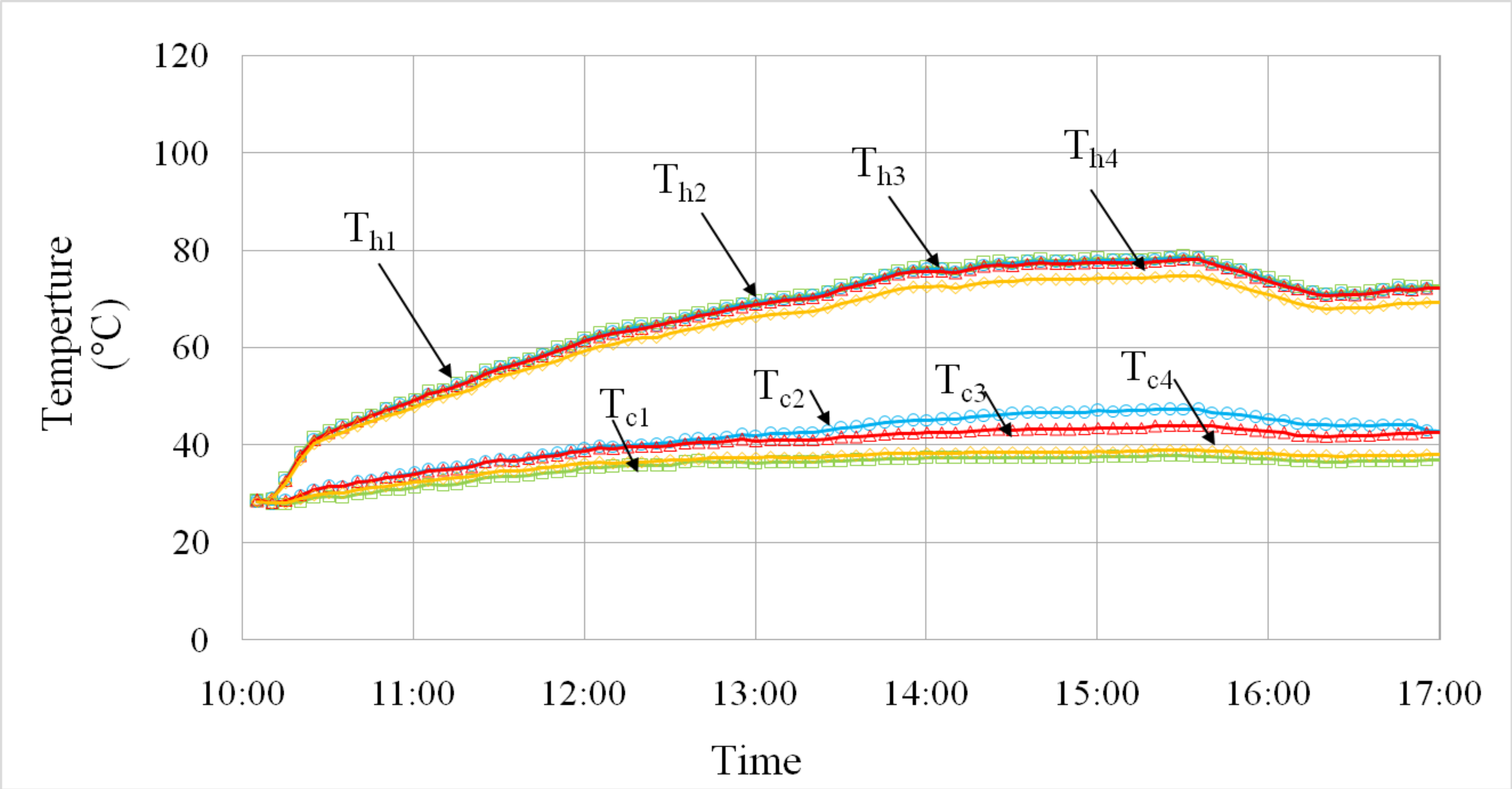



Figure 21 Typical experimental results showing TE hot side and cold side  temperature (coolent flow rate = 1.5 g/s)(run 2)

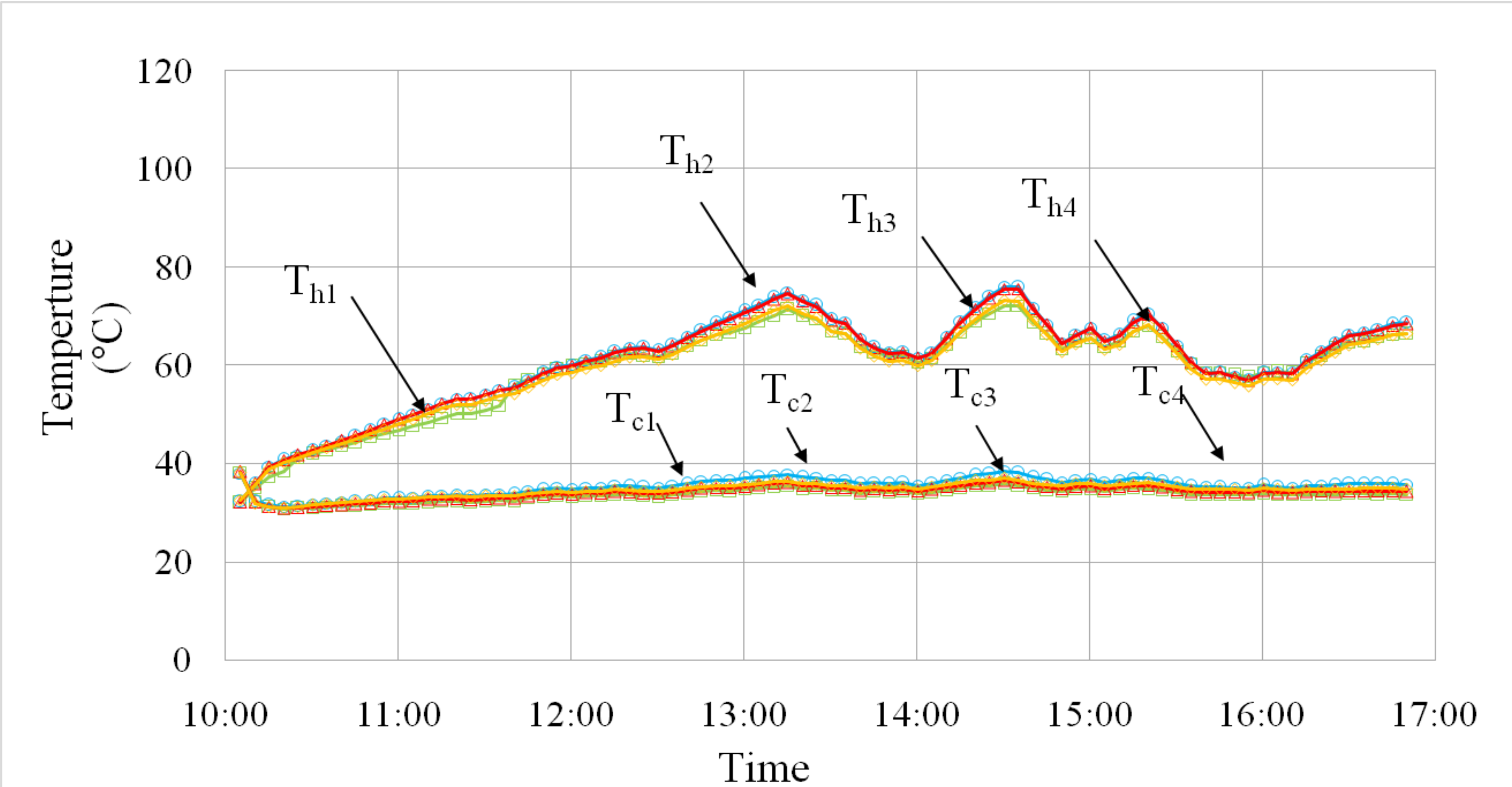



Figure 22 Typical experimental results showing TE hot side and cold side temperature (coolent flow rate = 8.33 g/s)(run 3)

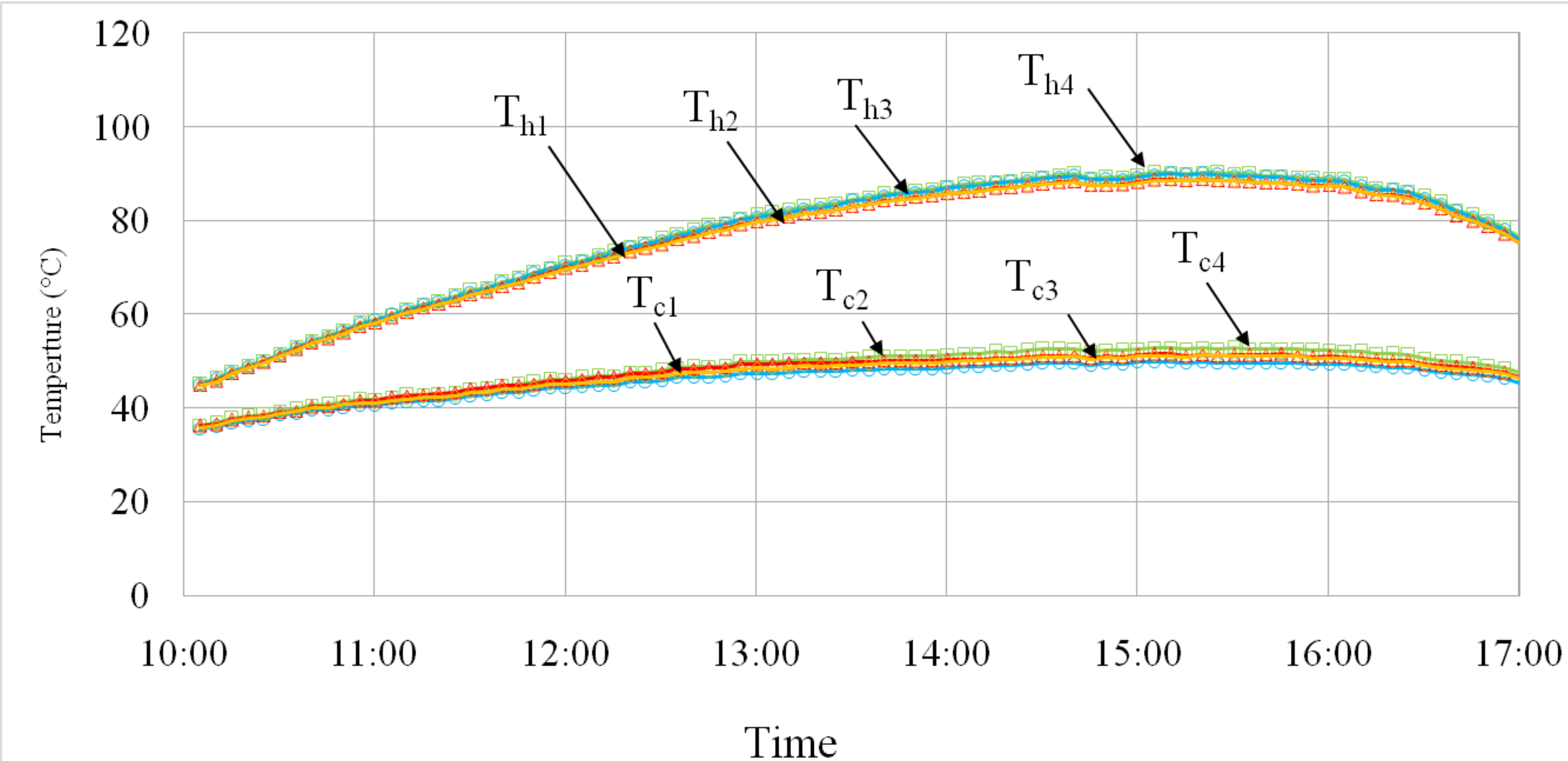



Figure 23 Typical experimental results showing TE hot side and cold side temperature (coolent flow rate = 0.9 g/s)(run 4)

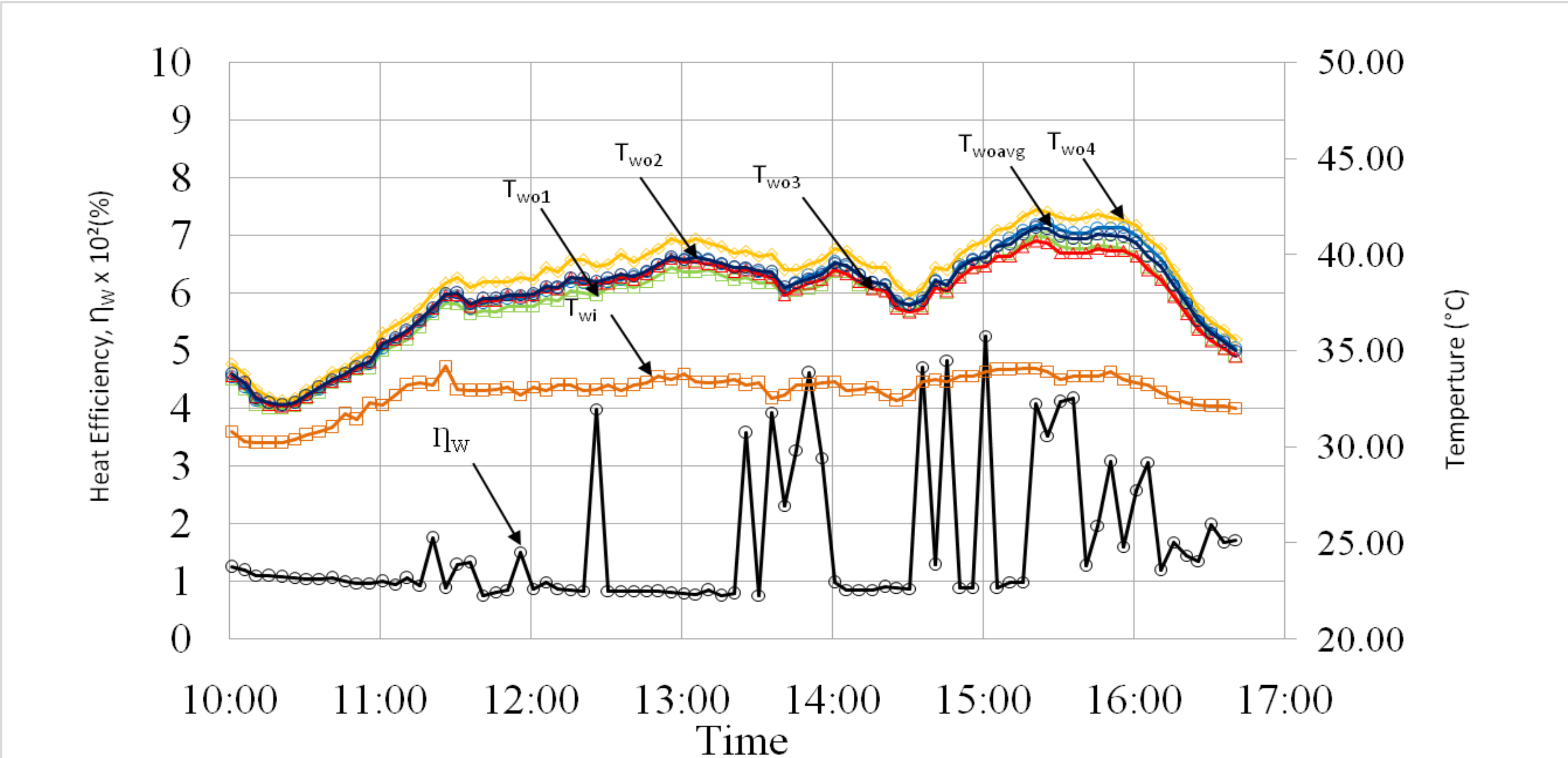



Figure 24 Typical experimental results showing thermal efficiency and water input and output temperature (coolent flow rate = 0.9 g/s)(run 1)

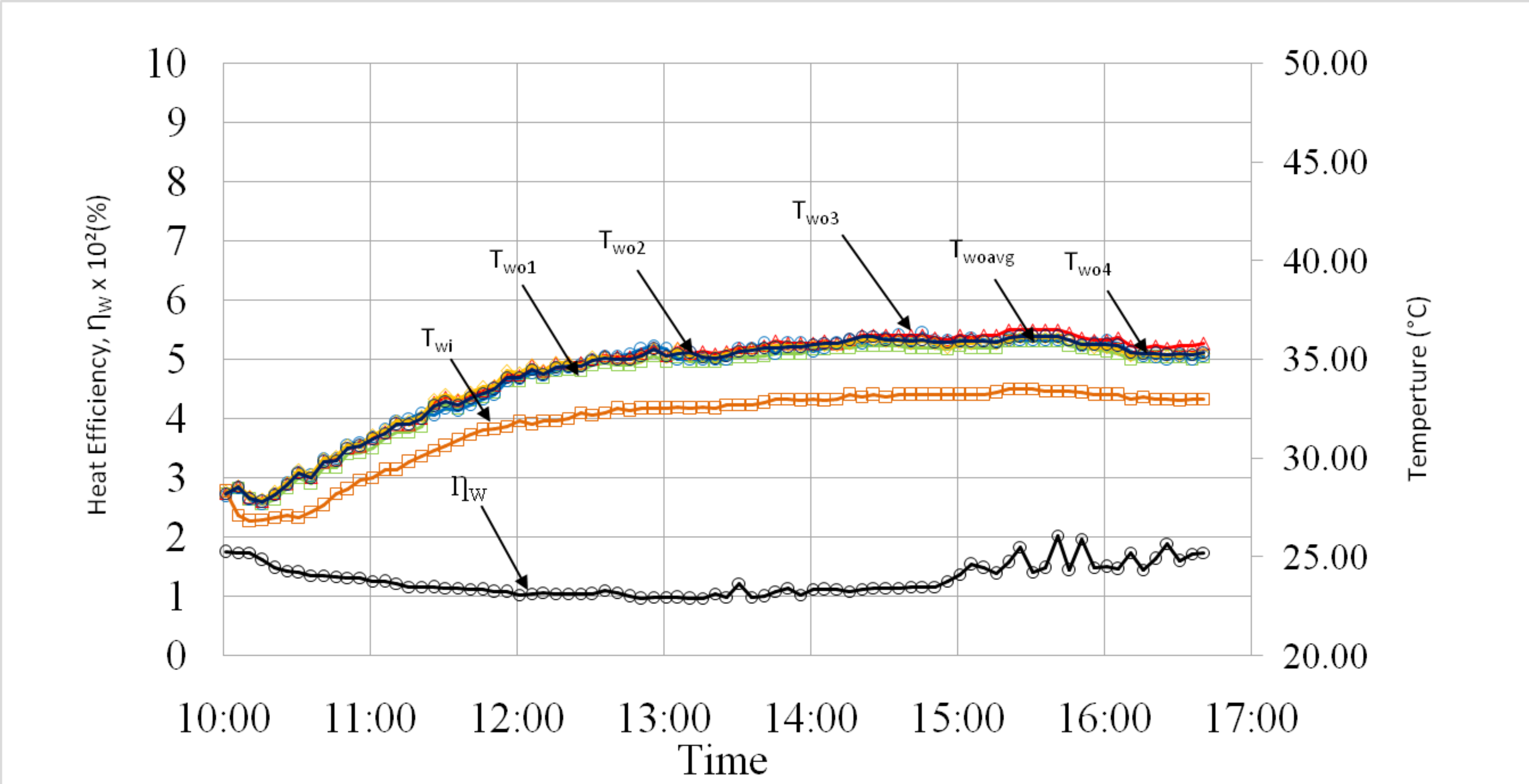



Figure 25 Typical experimental results showing thermal efficiency and water input and output temperature (coolent flow rate = 1.5 g/s)(run 2)

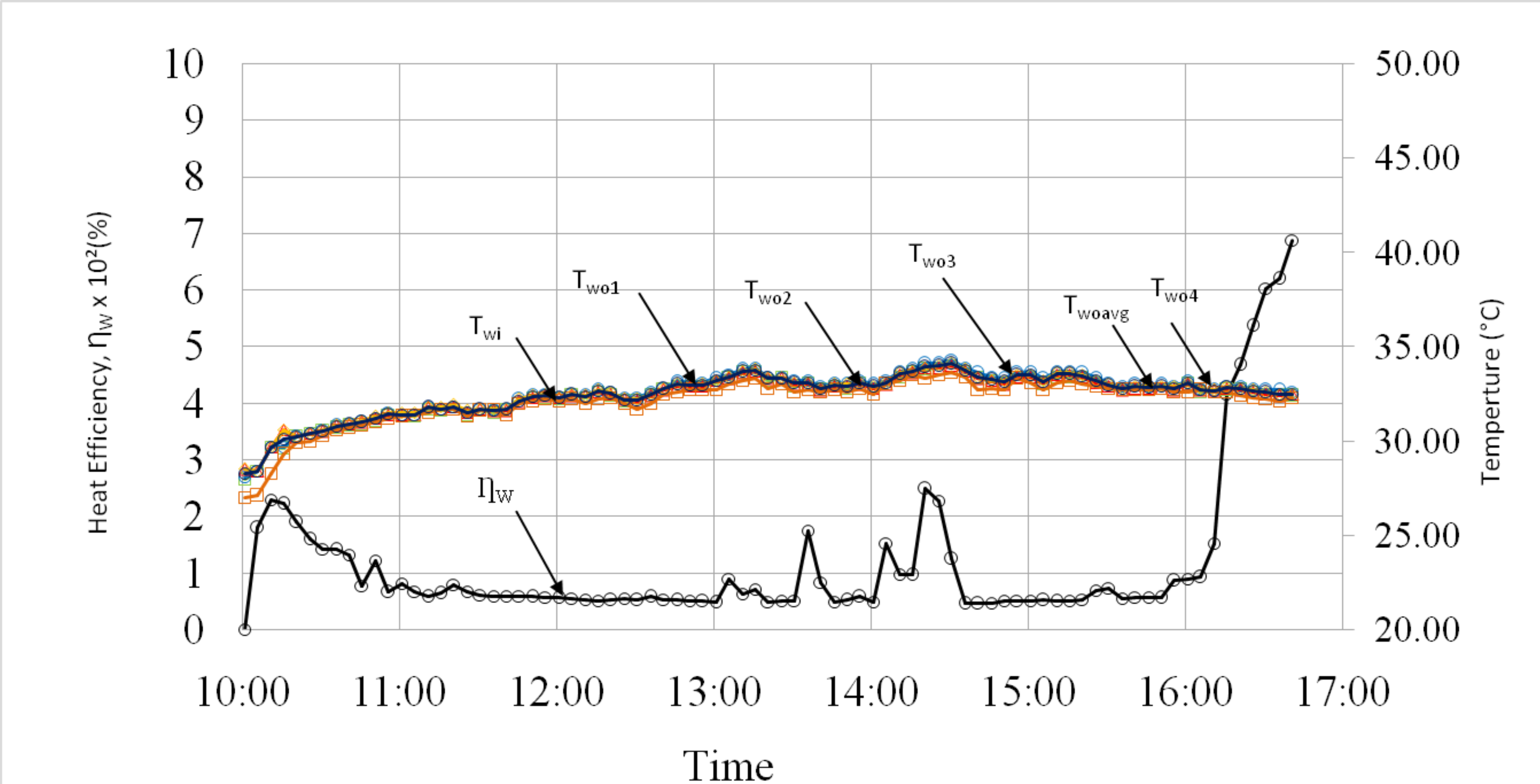



Figure 26 Typical experimental results showing thermal efficiency and water input and output temperature (coolent flow rate = 8.33 g/s)(run 3)

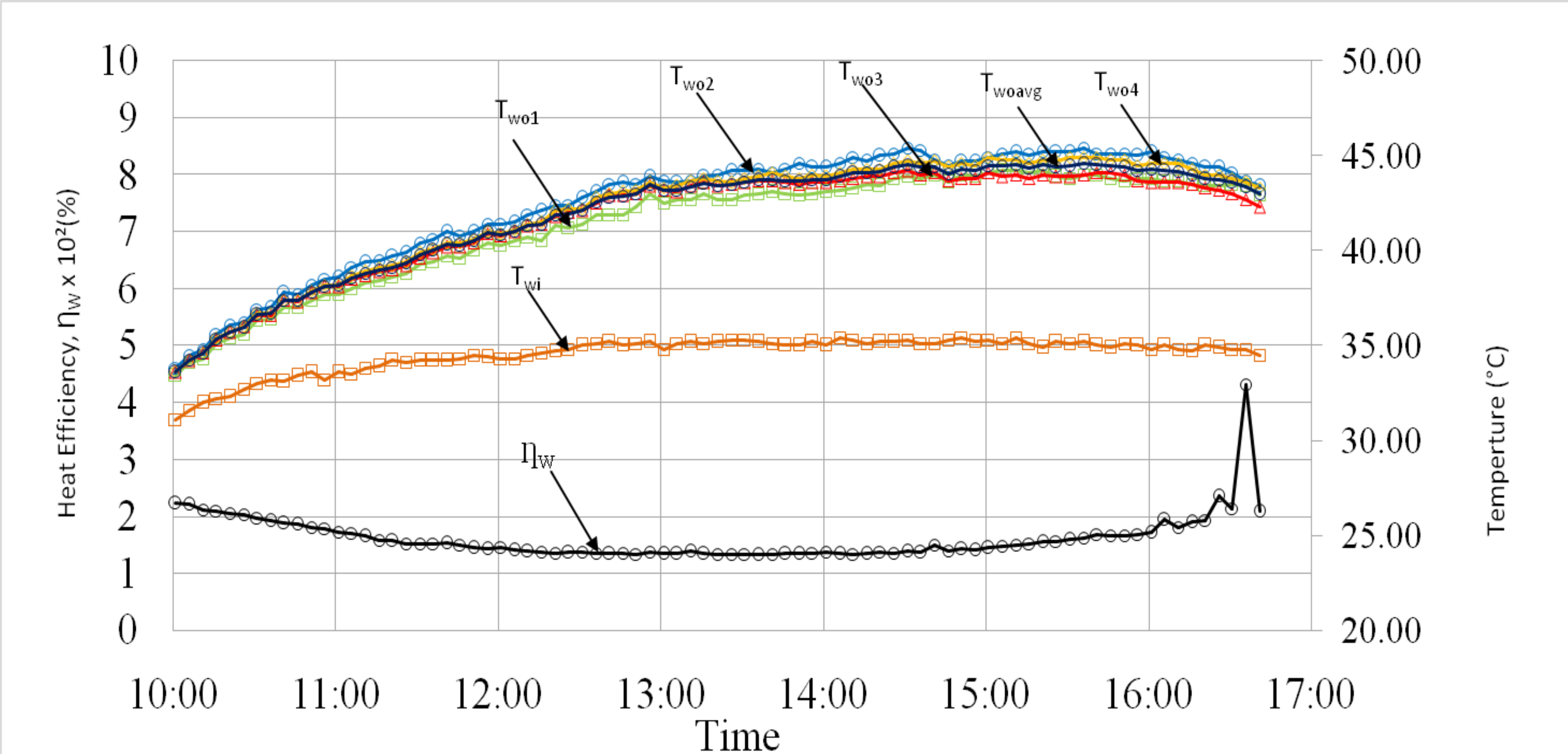



Figure 27 Typical experimental results showing thermal efficiency and water input and output temperature (coolent flow rate = 0.9 g/s)(run 4)

# Chapter 5

## Discussion of Results

Experiments were conducted from throughout the day from 10.00 - 17.00 hrs at various coolant water mass flow rates.

Weather conditions fluctuate widely in the tropics. Typical results obtained are plotted every 5 mins which is started form 10.00 – 17.00 hrs. The following observations were made:

1. Except for some fluctuation in the morning around 10.00 – 11.00 hrs, the radiation pattern was quite smooth, peaking around 13.00 hr to about 900 $W/m^2$.
2. All temperatures increased throughout the day and peaked around 15.00 hr.
3. Maximum ambient temperature was about $36^oC$.
4. Variations in fin temperatures ($T_{hp1}$ – $T_{hp3}$) at the evaporator section were observed with maximum values from about 90 – $96^oC$.
5. Maximum adiabatic temperature ($T_{ad}$) was about $85^oC$.

6. Maximum condenser temperatures ($T_{cond1}$ – $T_{cond4}$) varied from about 82 – 84$^o$C.
7. Water outlet temperature ($T_{wo}$) varied by about 1- 8$^o$C.

## 5.1 Solar radiation and ambient temperature variation

The effectiveness of this experiment relies on upon a few climatic factors, for example, the efficiency obtained by solar radiation hence affecting the ambient temperature also the performance respectively. The simulated result obtained shown temperature do not stay steady throughout the day, however change impressively. It is then worth examination the impact the optimized system. For several temperature data 10.00 to 17.00 hour which resulted around 13.30 hour was presented the peak values of solar radiation and for a maximum ambient temperature was achieved 36 degree. However it is decrease towards the evening in term of temperature regulation. Figure 12 to figure 15 displayed the collected data have been analyzed as an element of solar radiation for run 1 to run 4 when the ambient temperature found in the day, due to the transition of cloud and wind characteristics during the system performed. This experiment was carried out an investigation on both 0.9g/s flow rate with different weather condition. The temperature different for figure 24 was 5 degree and figure 27 shows the temperature different obtain throughout the day was 8 degree. Therefore, the efficiency of heating can be determined by weather condition.

5.2 Heat pipe evaporator condenser temperature

Figure 16,figure 17, figure 18, and figure 19 was conducted to investigate the performance of heating temperature performed where the flow rate of water was fixed at 0.9g/s, 1.5g/s and 8.33g/s. The amount of radiation received of day thus to provide heat transfer to rise up the aluminum block. This show that there is temperature build up from 23 degree to 97 degree whereas the maximum condenser temperature of 90 degree to 96 degree.

5.3 Influence of flow rate of water

The efficiency of the system was shown in this experiment and flow rate of water on the performance of water heating stated at the flow rate at 0.9g/s, 1.5g/s and 8.33g/s. It was presented in figure 24, figure 25, figure 25 and figure 26 where the heating temperature was in various conditions. The results has shown that the flow rate influencing the temperature different over the module is between 1- 8 percents. These results obtained during 8 hour throughout the day. Consequently, the higher the heating temperature, the bigger the temperature difference between water inlet 27 degree to 32 degree and water outlet was 29 to 35 degree somewhere. Due to the temperature different, provided at the condenser section of the heat pipe with the TE modules cold side temperature, heat energy dissipates through the interaction whereby water cooled jacket to ovartake the heat input from the TE surface. These are demonstrated in run 1, run 2 and run 3, heat flow by conduction through few components, for example, aluminum condenser, TE modules and heat transfer happens from different surface by convection and radiation. Heat is additionally added to the space between the human setup errors and used of equipments. It can be seen that the output performances of water heating temperature was 5, 3 and 0.3 degree of average simultaneously. The simulated thermal efficiency demonstrates the impact of heat conductivity and the maximum condition of solar irradiation 1000w/m$^2$. Refer to equation 1 stated in theoretical calculation, the heat transfer rate was calculated as 18.82W, 18.82W and 10.45W. Meanwhile, the performance of the system show the thermal efficiency from equation 2 was 163.8%, 132% and 152.8% of average simultaneously. The overall efficiency obtained based on measured the heat transfer rate, solar radiation and are of evaporator. The results shown were greater than 100% of thermal efficiency because of internal heat energy store in aluminum spreader. It can be explain that the temperature keep at thermal equilibrium while solar radiation energy exposed fluctuations hence increase in thermal efficiency.

## 5.4 TE modules temperature

Based on the information at the previously stated of different flow-rate was fixed which is 0.9g/s, 1.5g/s and 8.33g/s shown in figure 20, figure 21, figure 22 and figure 23. The temperature different at the hot and cold sides TE modules at different flow rates are plotted whereby variation of both TE modules side temperature was 26.711 degree, 26.7 degree, 30.4 degree and 30.5 degree consequently. The successful heat transfer between the TE module‘s ceramic plate cold side and the water jacket and it may be set to be a proportionate steady value. In additional, a good thermal insulation prompts a better prevention of heat lose. It can additionally be seen that the effect of thermal protection gets to be littler with expanded the amount of TE modules. Next, the heat conduction between the hot side and cold side of the TE module additions may generate a littler temperature different and thus created 1-8 degree water heating.

An analysis model was created by MatCad software based on thermodynamic hypothesis and law of conservation of energy studied. The model was considered number of TE module, for example, temperature of heat source and heat sink or water cooled jacket, contact resistance, geometry of the system also the environment condition was counted into model. The results demonstrate that all TE modules and equipments have the same characteristic parameters and work in the same conditions.

During the experimental test, the parameters of four TE modules are fixed in more and likely parameters. In addition, the run was conducted in experiments have slightly different in related of water jacket structure hence affecting the temperature of the water channel which will then affect the temperature different across the TE module. Other than that, the internal resistances of TE module are not inherent parameter thus a significant amount of different reflects the different thermal performances in system. Beside on that, the analysis model value is slight greater than the test results as a consequence of the supposition which miss conduct with the heat conduction between the thermocouples. Other than that, the place the thermocouple wires, surface not completion , equity of water jacket and improper installation may lead the decrease of thermal contact thus to created mistake during experimental was performed.

# Chapter 6

## Suggestion for future studies

Two proposals for future studies are suggested as below:

1. Increase the number of heat pipe to enhance the thermal performance
2. Water cooling jacket connected in series

# Chapter 7

## Conclusion

The performance of the solar/ heat-pipe/ water heating system was investigated and the thermal efficiency of the system performance was found to be more than 100 percent efficiency. This is obtained by a decrease in solar radiation exposed with internal heat energy come from an aluminum block. However, it is being halved due to semi-exposure to the sunlight throughout the solar evacuated tube.

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APPENDICS

Table 1. Raw data for run1 (0.9g/s) solar radiation,

Ambiant temperature, heat loss W and thermal efficiency

| Hour | Solar radiation KW/m2 | Ta°C | Qw | Efficiency ῃW | Average Efficiency ῃW |
|---|---|---|---|---|---|
| 10:00:52 AM | 0.634 | 32.1 | 18.8235 | 125.011 | 163.8094247 |
| 10:05:52 AM | 0.668 | 29.4 | 18.8235 | 118.648 | |
| 10:10:52 AM | 0.716 | 30.4 | 18.8235 | 110.694 | |
| 10:15:52 AM | 0.726 | 29.3 | 18.8235 | 109.169 | |
| 10:20:52 AM | 0.74 | 29.5 | 18.8235 | 107.104 | |
| 10:25:52 AM | 0.748 | 29.9 | 18.8235 | 105.958 | |
| 10:30:52 AM | 0.755 | 30.2 | 18.8235 | 104.976 | |
| 10:35:52 AM | 0.761 | 30.4 | 18.8235 | 104.148 | |
| 10:40:52 AM | 0.752 | 30.5 | 18.8235 | 105.395 | |
| 10:45:52 AM | 0.785 | 31 | 18.8235 | 100.964 | |
| 10:50:52 AM | 0.819 | 30.7 | 18.8235 | 96.7727 | |
| 10:55:52 AM | 0.814 | 32.3 | 18.8235 | 97.3671 | |
| 11:00:52 AM | 0.792 | 30.9 | 18.8235 | 100.072 | |
| 11:05:52 AM | 0.839 | 32.2 | 18.8235 | 94.4658 | |
| 11:10:52 AM | 0.752 | 32.8 | 18.8235 | 105.395 | |
| 11:15:52 AM | 0.855 | 33.2 | 18.8235 | 92.6981 | |
| 11:20:52 AM | 0.454 | 32.6 | 18.8235 | 174.575 | |
| 11:25:52 AM | 0.902 | 33.3 | 18.8235 | 87.8679 | |
| 11:30:52 AM | 0.615 | 33.1 | 18.8235 | 128.873 | |
| 11:35:52 AM | 0.6 | 32.8 | 18.8235 | 132.095 | |
| 11:40:52 AM | 1.043 | 34.3 | 18.8235 | 75.9893 | |
| 11:45:52 AM | 0.97 | 34.4 | 18.8235 | 81.7081 | |
| 11:50:52 AM | 0.923 | 33.5 | 18.8235 | 85.8687 | |
| 11:55:52 AM | 0.527 | 34.2 | 18.8235 | 150.392 | |
| 12:00:52 PM | 0.913 | 34.1 | 18.8235 | 86.8092 | |
| 12:05:52 PM | 0.799 | 34.5 | 18.8235 | 99.195 | |
| 12:10:52 PM | 0.914 | 36.2 | 18.8235 | 86.7143 | |
| 12:15:52 PM | 0.929 | 35 | 18.8235 | 85.3141 | |
| 12:20:52 PM | 0.955 | 34.7 | 18.8235 | 82.9915 | |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 12:25:52 PM | | 0.199 | | 35 | 18.8235 | | 398.276 | | | | |
| 12:30:52 PM | | 0.947 | | 35.6 | 18.8235 | | 83.6925 | | | | |
| 12:35:52 PM | | 0.946 | | 34.5 | 18.8235 | | 83.781 | | | | |
| 12:40:52 PM | | 0.955 | | 34.3 | 18.8235 | | 82.9915 | | | | |
| 12:45:52 PM | | 0.949 | | 35.8 | 18.8235 | | 83.5162 | | | | |
| 12:50:52 PM | | 0.959 | | 36.3 | 18.8235 | | 82.6453 | | | | |
| 12:55:52 PM | | 0.977 | | 35.3 | 18.8235 | | 81.1227 | | | | |
| 1:00:52 PM | | 0.999 | | 36.4 | 18.8235 | | 79.3362 | | | | |
| 1:05:52 PM | | 1.023 | | 35.5 | 18.8235 | | 77.4749 | | | | |
| 1:10:52 PM | | 0.938 | | 35.2 | 18.8235 | | 84.4956 | | | | |
| 1:15:52 PM | | 1.059 | | 35.4 | 18.8235 | | 74.8412 | | | | |
| 1:20:52 PM | | 1.011 | | 35.9 | 18.8235 | | 78.3945 | | | | |
| 1:25:52 PM | | 0.222 | | 35.6 | 18.8235 | | 357.013 | | | | |
| 1:30:52 PM | | 1.039 | | 34.9 | 18.8235 | | 76.2818 | | | | |
| 1:35:52 PM | | 0.202 | | 34.1 | 18.8235 | | 392.361 | | | | |
| 1:40:52 PM | | 0.343 | | 33.9 | 18.8235 | | 231.07 | | | | |
| 1:45:52 PM | | 0.242 | | 34.9 | 18.8235 | | 327.508 | | | | |
| 1:50:52 PM | | 0.172 | | 35.7 | 18.8235 | | 460.796 | | | | |
| 1:55:52 PM | | 0.252 | | 35.5 | 18.8235 | | 314.511 | | | | |
| 2:00:52 PM | | 0.811 | | 35.1 | 18.8235 | | 97.7273 | | | | |
| 2:05:52 PM | | 0.924 | | 35.1 | 18.8235 | | 85.7758 | | | | |
| 2:10:52 PM | | 0.93 | | 34.6 | 18.8235 | | 85.2224 | | | | |
| 2:15:52 PM | | 0.924 | | 35.7 | 18.8235 | | 85.7758 | | | | |
| 2:20:52 PM | | 0.88 | | 34.1 | 18.8235 | | 90.0646 | | | | |
| 2:25:52 PM | | 0.894 | | 33.7 | 18.8235 | | 88.6542 | | | | |
| 2:30:52 PM | | 0.91 | | 34.6 | 18.8235 | | 87.0954 | | | | |
| 2:35:52 PM | | 0.168 | | 36 | 18.8235 | | 471.767 | | | | |
| 2:40:52 PM | | 0.617 | | 35.2 | 18.8235 | | 128.455 | | | | |
| 2:45:52 PM | | 0.164 | | 34.6 | 18.8235 | | 483.273 | | | | |
| 2:50:52 PM | | 0.885 | | 36.1 | 18.8235 | | 89.5558 | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 2:55:52 PM | | 0.893 | | 35.9 | 18.8235 | | 88.7535 | | | | |
| 3:00:52 PM | | 0.151 | | 37.9 | 18.8235 | | 524.88 | | | | |
| 3:05:52 PM | | 0.897 | | 35.3 | 18.8235 | | 88.3577 | | | | |
| 3:10:52 PM | | 0.806 | | 37.1 | 18.8235 | | 98.3336 | | | | |
| 3:15:52 PM | | 0.799 | | 37.4 | 18.8235 | | 99.195 | | | | |
| 3:20:52 PM | | 0.194 | | 36.1 | 18.8235 | | 408.54 | | | | |
| 3:25:52 PM | | 0.225 | | 36.3 | 18.8235 | | 352.253 | | | | |
| 3:30:52 PM | | 0.193 | | 36.1 | 18.8235 | | 410.657 | | | | |
| 3:35:52 PM | | 0.19 | | 36.9 | 18.8235 | | 417.141 | | | | |
| 3:40:52 PM | | 0.624 | | 36.7 | 18.8235 | | 127.014 | | | | |
| 3:45:52 PM | | 0.402 | | 35.8 | 18.8235 | | 197.156 | | | | |
| 3:50:52 PM | | 0.258 | | 36.1 | 18.8235 | | 307.197 | | | | |
| 3:55:52 PM | | 0.496 | | 35.5 | 18.8235 | | 159.792 | | | | |
| 4:00:52 PM | | 0.307 | | 36.6 | 18.8235 | | 258.166 | | | | |
| 4:05:52 PM | | 0.259 | | 34.9 | 18.8235 | | 306.011 | | | | |
| 4:10:52 PM | | 0.668 | | 34.1 | 18.8235 | | 118.648 | | | | |
| 4:15:52 PM | | 0.471 | | 34.2 | 18.8235 | | 168.274 | | | | |
| 4:20:52 PM | | 0.549 | | 33.8 | 18.8235 | | 144.366 | | | | |
| 4:25:52 PM | | 0.587 | | 33.8 | 18.8235 | | 135.02 | | | | |
| 4:30:52 PM | | 0.401 | | 34.2 | 18.8235 | | 197.648 | | | | |
| 4:35:52 PM | | 0.472 | | 33.7 | 18.8235 | | 167.917 | | | | |
| 4:40:52 PM | | 0.462 | | 34.1 | 18.8235 | | 171.552 | | | | |
| 4:45:52 PM | | 0.387 | | 33.9 | 18.8235 | | 204.798 | | | | |
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Table 2. Raw data for run2 (1.5g/s) solar radiation,
Ambiant temperature, heat loss W and thermal efficiency

| Hour | Solar radiation KW/m2 | Ta˚C | Qw | Efficiency ηW | Average Efficiency ηW |
|---|---|---|---|---|---|
| 10:00:52 AM | 0.454 | 27.8 | 18.8235 | 174.575 | 132.683 |
| 10:05:52 AM | 0.456 | 27.9 | 18.8235 | 173.809 | |
| 10:10:52 AM | 0.455 | 28.4 | 18.8235 | 174.191 | |
| 10:15:52 AM | 0.492 | 28.3 | 18.8235 | 161.091 | |
| 10:20:52 AM | 0.535 | 28.9 | 18.8235 | 148.144 | |
| 10:25:52 AM | 0.554 | 29.5 | 18.8235 | 143.063 | |
| 10:30:52 AM | 0.565 | 29.3 | 18.8235 | 140.278 | |
| 10:35:52 AM | 0.587 | 30.5 | 18.8235 | 135.02 | |
| 10:40:52 AM | 0.586 | 29.2 | 18.8235 | 135.251 | |
| 10:45:52 AM | 0.596 | 29.6 | 18.8235 | 132.981 | |
| 10:50:52 AM | 0.604 | 30.2 | 18.8235 | 131.22 | |
| 10:55:52 AM | 0.603 | 29.9 | 18.8235 | 131.438 | |
| 11:00:52 AM | 0.632 | 29.8 | 18.8235 | 125.406 | |
| 11:05:52 AM | 0.637 | 30 | 18.8235 | 124.422 | |
| 11:10:52 AM | 0.648 | 31.5 | 18.8235 | 122.31 | |
| 11:15:52 AM | 0.682 | 31.4 | 18.8235 | 116.212 | |
| 11:20:52 AM | 0.686 | 31 | 18.8235 | 115.535 | |
| 11:25:52 AM | 0.69 | 30.6 | 18.8235 | 114.865 | |
| 11:30:52 AM | 0.694 | 31.6 | 18.8235 | 114.203 | |
| 11:35:52 AM | 0.694 | 32.2 | 18.8235 | 114.203 | |
| 11:40:52 AM | 0.709 | 32.2 | 18.8235 | 111.787 | |
| 11:45:52 AM | 0.712 | 32 | 18.8235 | 111.316 | |
| 11:50:52 AM | 0.735 | 32.6 | 18.8235 | 107.832 | |
| 11:55:52 AM | 0.735 | 33.1 | 18.8235 | 107.832 | |
| 12:00:52 PM | 0.771 | 32.5 | 18.8235 | 102.797 | |
| 12:05:52 PM | 0.758 | 31 | 18.8235 | 104.56 | |
| 12:10:52 PM | 0.746 | 31.4 | 18.8235 | 106.242 | |
| 12:15:52 PM | 0.761 | 33.3 | 18.8235 | 104.148 | |
| 12:20:52 PM | 0.761 | 34 | 18.8235 | 104.148 | |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 12:25:52 PM | | 0.762 | | 33.6 | 18.8235 | | 104.012 | | | | |
| 12:30:52 PM | | 0.766 | | 33.9 | 18.8235 | | 103.468 | | | | |
| 12:35:52 PM | | 0.721 | | 33.5 | 18.8235 | | 109.926 | | | | |
| 12:40:52 PM | | 0.741 | | 34 | 18.8235 | | 106.959 | | | | |
| 12:45:52 PM | | 0.795 | | 34.3 | 18.8235 | | 99.6941 | | | | |
| 12:50:52 PM | | 0.827 | | 34.7 | 18.8235 | | 95.8366 | | | | |
| 12:55:52 PM | | 0.806 | | 33 | 18.8235 | | 98.3336 | | | | |
| 1:00:52 PM | | 0.801 | | 34.1 | 18.8235 | | 98.9474 | | | | |
| 1:05:52 PM | | 0.807 | | 33.3 | 18.8235 | | 98.2117 | | | | |
| 1:10:52 PM | | 0.827 | | 34.2 | 18.8235 | | 95.8366 | | | | |
| 1:15:52 PM | | 0.814 | | 33.4 | 18.8235 | | 97.3671 | | | | |
| 1:20:52 PM | | 0.76 | | 33.8 | 18.8235 | | 104.285 | | | | |
| 1:25:52 PM | | 0.8 | | 34.1 | 18.8235 | | 99.0711 | | | | |
| 1:30:52 PM | | 0.65 | | 33.5 | 18.8235 | | 121.934 | | | | |
| 1:35:52 PM | | 0.803 | | 34.3 | 18.8235 | | 98.7009 | | | | |
| 1:40:52 PM | | 0.797 | | 34.4 | 18.8235 | | 99.444 | | | | |
| 1:45:52 PM | | 0.731 | | 34 | 18.8235 | | 108.422 | | | | |
| 1:50:52 PM | | 0.692 | | 33.7 | 18.8235 | | 114.533 | | | | |
| 1:55:52 PM | | 0.772 | | 34.2 | 18.8235 | | 102.664 | | | | |
| 2:00:52 PM | | 0.706 | | 34.9 | 18.8235 | | 112.262 | | | | |
| 2:05:52 PM | | 0.713 | | 35.4 | 18.8235 | | 111.16 | | | | |
| 2:10:52 PM | | 0.705 | | 34.9 | 18.8235 | | 112.421 | | | | |
| 2:15:52 PM | | 0.729 | | 34.4 | 18.8235 | | 108.72 | | | | |
| 2:20:52 PM | | 0.706 | | 34.5 | 18.8235 | | 112.262 | | | | |
| 2:25:52 PM | | 0.691 | | 34.1 | 18.8235 | | 114.699 | | | | |
| 2:30:52 PM | | 0.693 | | 35 | 18.8235 | | 114.368 | | | | |
| 2:35:52 PM | | 0.696 | | 34.7 | 18.8235 | | 113.875 | | | | |
| 2:40:52 PM | | 0.684 | | 35 | 18.8235 | | 115.873 | | | | |
| 2:45:52 PM | | 0.686 | | 34.7 | 18.8235 | | 115.535 | | | | |
| 2:50:52 PM | | 0.683 | | 35.6 | 18.8235 | | 116.042 | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 2:55:52 PM | | 0.631 | | 34.5 | 18.8235 | | 125.605 | | | | |
| 3:00:52 PM | | 0.579 | | 33.7 | 18.8235 | | 136.886 | | | | |
| 3:05:52 PM | | 0.516 | | 34.2 | 18.8235 | | 153.599 | | | | |
| 3:10:52 PM | | 0.535 | | 34.4 | 18.8235 | | 148.144 | | | | |
| 3:15:52 PM | | 0.572 | | 35 | 18.8235 | | 138.561 | | | | |
| 3:20:52 PM | | 0.503 | | 35.6 | 18.8235 | | 157.568 | | | | |
| 3:25:52 PM | | 0.432 | | 35.5 | 18.8235 | | 183.465 | | | | |
| 3:30:52 PM | | 0.561 | | 34.6 | 18.8235 | | 141.278 | | | | |
| 3:35:52 PM | | 0.537 | | 34.6 | 18.8235 | | 147.592 | | | | |
| 3:40:52 PM | | 0.391 | | 34.4 | 18.8235 | | 202.703 | | | | |
| 3:45:52 PM | | 0.551 | | 33.9 | 18.8235 | | 143.842 | | | | |
| 3:50:52 PM | | 0.403 | | 34.2 | 18.8235 | | 196.667 | | | | |
| 3:55:52 PM | | 0.531 | | 33.6 | 18.8235 | | 149.26 | | | | |
| 4:00:52 PM | | 0.53 | | 34 | 18.8235 | | 149.541 | | | | |
| 4:05:52 PM | | 0.544 | | 34.1 | 18.8235 | | 145.693 | | | | |
| 4:10:52 PM | | 0.455 | | 34.2 | 18.8235 | | 174.191 | | | | |
| 4:15:52 PM | | 0.549 | | 33.7 | 18.8235 | | 144.366 | | | | |
| 4:20:52 PM | | 0.485 | | 35.4 | 18.8235 | | 163.416 | | | | |
| 4:25:52 PM | | 0.42 | | 34.6 | 18.8235 | | 188.707 | | | | |
| 4:30:52 PM | | 0.498 | | 35.1 | 18.8235 | | 159.15 | | | | |
| 4:35:52 PM | | 0.46 | | 34.5 | 18.8235 | | 172.297 | | | | |
| 4:40:52 PM | | 0.457 | | 34.2 | 18.8235 | | 173.429 | | | | |
| 4:45:52 PM | | 0.424 | | 34.7 | 18.8235 | | 186.927 | | | | |
| 4:55:52 PM | | 0.396 | | 34.6 | 18.8235 | | 200.144 | | | | |
| 5:00:52 PM | | 0.215 | | 34.8 | 18.8235 | | 368.636 | | | | |
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Table 3. Raw data for run1 (8.33g/s) solar radiation,

Ambiant temperature, heat loss W and thermal efficiency

| HOUR | Solar radiation KW/m2 | Ta°C | Qw | Efficiency ηW | Average Efficiency ηW |
|---|---|---|---|---|---|
| 10:00:52 AM | 0.376 | 30.1 | 10.4533 | 117.058 | 152.379 |
| 10:05:52 AM | 0.245 | 31.4 | 10.4533 | 179.649 | |
| 10:10:52 AM | 0.192 | 31.1 | 10.4533 | 229.239 | |
| 10:15:52 AM | 0.198 | 31.7 | 10.4533 | 222.293 | |
| 10:20:52 AM | 0.232 | 30.7 | 10.4533 | 189.715 | |
| 10:25:52 AM | 0.276 | 30.9 | 10.4533 | 159.471 | |
| 10:30:52 AM | 0.308 | 31.3 | 10.4533 | 142.902 | |
| 10:35:52 AM | 0.312 | 31.8 | 10.4533 | 141.07 | |
| 10:40:52 AM | 0.332 | 31.3 | 10.4533 | 132.572 | |
| 10:45:52 AM | 0.566 | 31.6 | 10.4533 | 77.7632 | |
| 10:50:52 AM | 0.359 | 32.2 | 10.4533 | 122.602 | |
| 10:55:52 AM | 0.659 | 32 | 10.4533 | 66.789 | |
| 11:00:52 AM | 0.539 | 32.6 | 10.4533 | 81.6586 | |
| 11:05:52 AM | 0.648 | 32.8 | 10.4533 | 67.9228 | |
| 11:10:52 AM | 0.755 | 32.8 | 10.4533 | 58.2966 | |
| 11:15:52 AM | 0.681 | 31.8 | 10.4533 | 64.6314 | |
| 11:20:52 AM | 0.555 | 31.8 | 10.4533 | 79.3044 | |
| 11:25:52 AM | 0.654 | 33.2 | 10.4533 | 67.2996 | |
| 11:30:52 AM | 0.715 | 32.9 | 10.4533 | 61.558 | |
| 11:35:52 AM | 0.741 | 32.8 | 10.4533 | 59.3981 | |
| 11:40:52 AM | 0.742 | 33.7 | 10.4533 | 59.318 | |
| 11:45:52 AM | 0.741 | 33.8 | 10.4533 | 59.3981 | |
| 11:50:52 AM | 0.75 | 34.4 | 10.4533 | 58.6853 | |
| 11:55:52 AM | 0.763 | 32.3 | 10.4533 | 57.6854 | |
| 12:00:52 PM | 0.779 | 32.6 | 10.4533 | 56.5006 | |
| 12:05:52 PM | 0.791 | 34.3 | 10.4533 | 55.6434 | |
| 12:10:52 PM | 0.831 | 33.5 | 10.4533 | 52.9651 | |
| 12:15:52 PM | 0.857 | 33.5 | 10.4533 | 51.3582 | |
| 12:20:52 PM | 0.845 | 33.3 | 10.4533 | 52.0875 | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12:25:52 PM | | 0.8 | | 33 | 10.4533 | | 55.0175 | | | | | |
| 12:30:52 PM | | 0.839 | | 33.5 | 10.4533 | | 52.46 | | | | | |
| 12:35:52 PM | | 0.754 | | 33 | 10.4533 | | 58.374 | | | | | |
| 12:40:52 PM | | 0.819 | | 33.6 | 10.4533 | | 53.7411 | | | | | |
| 12:45:52 PM | | 0.848 | | 34.2 | 10.4533 | | 51.9033 | | | | | |
| 12:50:52 PM | | 0.863 | | 34.7 | 10.4533 | | 51.0011 | | | | | |
| 12:55:52 PM | | 0.875 | | 34.6 | 10.4533 | | 50.3017 | | | | | |
| 1:00:52 PM | | 0.916 | | 33.7 | 10.4533 | | 48.0502 | | | | | |
| 1:05:52 PM | | 0.491 | | 35.1 | 10.4533 | | 89.6415 | | | | | |
| 1:10:52 PM | | 0.694 | | 35.8 | 10.4533 | | 63.4207 | | | | | |
| 1:15:52 PM | | 0.614 | | 34.7 | 10.4533 | | 71.684 | | | | | |
| 1:20:52 PM | | 0.901 | | 33.6 | 10.4533 | | 48.8501 | | | | | |
| 1:25:52 PM | | 0.862 | | 33.8 | 10.4533 | | 51.0603 | | | | | |
| 1:30:52 PM | | 0.869 | | 35.3 | 10.4533 | | 50.649 | | | | | |
| 1:35:52 PM | | 0.251 | | 33.5 | 10.4533 | | 175.354 | | | | | |
| 1:40:52 PM | | 0.53 | | 33.6 | 10.4533 | | 83.0452 | | | | | |
| 1:45:52 PM | | 0.901 | | 35.7 | 10.4533 | | 48.8501 | | | | | |
| 1:50:52 PM | | 0.845 | | 34.4 | 10.4533 | | 52.0875 | | | | | |
| 1:55:52 PM | | 0.758 | | 34.6 | 10.4533 | | 58.0659 | | | | | |
| 2:00:52 PM | | 0.886 | | 33.8 | 10.4533 | | 49.6772 | | | | | |
| 2:05:52 PM | | 0.288 | | 35.9 | 10.4533 | | 152.826 | | | | | |
| 2:10:52 PM | | 0.449 | | 35.9 | 10.4533 | | 98.0267 | | | | | |
| 2:15:52 PM | | 0.455 | | 36.2 | 10.4533 | | 96.734 | | | | | |
| 2:20:52 PM | | 0.177 | | 36.3 | 10.4533 | | 248.666 | | | | | |
| 2:25:52 PM | | 0.193 | | 35.7 | 10.4533 | | 228.052 | | | | | |
| 2:30:52 PM | | 0.351 | | 37.2 | 10.4533 | | 125.396 | | | | | |
| 2:35:52 PM | | 0.952 | | 35 | 10.4533 | | 46.2332 | | | | | |
| 2:40:52 PM | | 0.956 | | 34.8 | 10.4533 | | 46.0397 | | | | | |
| 2:45:52 PM | | 0.937 | | 34.6 | 10.4533 | | 46.9733 | | | | | |
| 2:50:52 PM | | 0.852 | | 35.5 | 10.4533 | | 51.6596 | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2:55:52 PM | | 0.862 | | 35.8 | 10.4533 | | 51.0603 | | | | | |
| 3:00:52 PM | | 0.86 | | 34.8 | 10.4533 | | 51.179 | | | | | |
| 3:05:52 PM | | 0.845 | | 34.7 | 10.4533 | | 52.0875 | | | | | |
| 3:10:52 PM | | 0.883 | | 36.2 | 10.4533 | | 49.8459 | | | | | |
| 3:15:52 PM | | 0.867 | | 36.6 | 10.4533 | | 50.7658 | | | | | |
| 3:20:52 PM | | 0.832 | | 34.8 | 10.4533 | | 52.9014 | | | | | |
| 3:25:52 PM | | 0.631 | | 34.4 | 10.4533 | | 69.7527 | | | | | |
| 3:30:52 PM | | 0.599 | | 34.7 | 10.4533 | | 73.4791 | | | | | |
| 3:35:52 PM | | 0.791 | | 34.6 | 10.4533 | | 55.6434 | | | | | |
| 3:40:52 PM | | 0.772 | | 35.3 | 10.4533 | | 57.0129 | | | | | |
| 3:45:52 PM | | 0.772 | | 34.4 | 10.4533 | | 57.0129 | | | | | |
| 3:50:52 PM | | 0.782 | | 34.2 | 10.4533 | | 56.2838 | | | | | |
| 3:55:52 PM | | 0.509 | | 35.7 | 10.4533 | | 86.4714 | | | | | |
| 4:00:52 PM | | 0.488 | | 34.4 | 10.4533 | | 90.1926 | | | | | |
| 4:05:52 PM | | 0.474 | | 34.2 | 10.4533 | | 92.8565 | | | | | |
| 4:10:52 PM | | 0.289 | | 34.1 | 10.4533 | | 152.297 | | | | | |
| 4:15:52 PM | | 0.106 | | 35.8 | 10.4533 | | 415.226 | | | | | |
| 4:20:52 PM | | 0.094 | | 34.8 | 10.4533 | | 468.234 | | | | | |
| 4:25:52 PM | | 0.082 | | 35.2 | 10.4533 | | 536.756 | | | | | |
| 4:30:52 PM | | 0.073 | | 35.1 | 10.4533 | | 602.931 | | | | | |
| 4:35:52 PM | | 0.071 | | 34.4 | 10.4533 | | 619.915 | | | | | |
| 4:40:52 PM | | 0.064 | | 34.6 | 10.4533 | | 687.718 | | | | | |
| 4:45:52 PM | | 0.056 | | 34.7 | 10.4533 | | 785.964 | | | | | |
| 4:50:52 PM | | 0.052 | | 33.6 | 10.4533 | | 846.422 | | | | | |
| 4:55:52 PM | | 0.052 | | 33.5 | 10.4533 | | 846.422 | | | | | |
| 5:00:52 PM | | 0.054 | | 33.2 | 10.4533 | | 815.073 | | | | | |
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Table 4. Raw data for run4 (0.9g/s) solar radiation,

Ambiant temperature, heat loss W and thermal efficiency

| Hour | Solar radiation KW/m2 | Ta°C | Qw | Efficiency ηW | Average Efficiency ηW |
|---|---|---|---|---|---|
| 10:00:52 AM | 0.521 | 29.5 | 28.4589 | 222.954 | 163.089 |
| 10:05:52 AM | 0.527 | 30.6 | 28.4589 | 220.415 | |
| 10:10:52 AM | 0.548 | 31.3 | 28.4589 | 211.969 | |
| 10:15:52 AM | 0.554 | 30.7 | 28.4589 | 209.673 | |
| 10:20:52 AM | 0.567 | 31.7 | 28.4589 | 204.866 | |
| 10:25:52 AM | 0.573 | 32 | 28.4589 | 202.721 | |
| 10:30:52 AM | 0.591 | 31.7 | 28.4589 | 196.546 | |
| 10:35:52 AM | 0.606 | 32.6 | 28.4589 | 191.681 | |
| 10:40:52 AM | 0.619 | 32.9 | 28.4589 | 187.656 | |
| 10:45:52 AM | 0.625 | 31.5 | 28.4589 | 185.854 | |
| 10:50:52 AM | 0.645 | 32.5 | 28.4589 | 180.091 | |
| 10:55:52 AM | 0.649 | 32.6 | 28.4589 | 178.981 | |
| 11:00:52 AM | 0.673 | 33.2 | 28.4589 | 172.599 | |
| 11:05:52 AM | 0.683 | 32.5 | 28.4589 | 170.072 | |
| 11:10:52 AM | 0.705 | 33 | 28.4589 | 164.764 | |
| 11:15:52 AM | 0.736 | 33.3 | 28.4589 | 157.825 | |
| 11:20:52 AM | 0.742 | 34.4 | 28.4589 | 156.548 | |
| 11:25:52 AM | 0.768 | 33.5 | 28.4589 | 151.249 | |
| 11:30:52 AM | 0.764 | 33.7 | 28.4589 | 152.04 | |
| 11:35:52 AM | 0.764 | 35.3 | 28.4589 | 152.04 | |
| 11:40:52 AM | 0.76 | 33 | 28.4589 | 152.841 | |
| 11:45:52 AM | 0.778 | 34.6 | 28.4589 | 149.304 | |
| 11:50:52 AM | 0.804 | 34.6 | 28.4589 | 144.476 | |
| 11:55:52 AM | 0.817 | 34.7 | 28.4589 | 142.177 | |
| 12:00:52 PM | 0.8 | 35 | 28.4589 | 145.199 | |
| 12:05:52 PM | 0.825 | 34.7 | 28.4589 | 140.799 | |
| 12:10:52 PM | 0.84 | 35.6 | 28.4589 | 138.284 | |
| 12:15:52 PM | 0.846 | 35.9 | 28.4589 | 137.304 | |
| 12:20:52 PM | 0.856 | 35.4 | 28.4589 | 135.7 | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12:25:52 PM | | 0.85 | | 35.6 | 28.4589 | | 136.657 | | | | | |
| 12:30:52 PM | | 0.848 | | 36.5 | 28.4589 | | 136.98 | | | | | |
| 12:35:52 PM | | 0.859 | | 36.4 | 28.4589 | | 135.226 | | | | | |
| 12:40:52 PM | | 0.868 | | 36.8 | 28.4589 | | 133.824 | | | | | |
| 12:45:52 PM | | 0.855 | | 36.1 | 28.4589 | | 135.858 | | | | | |
| 12:50:52 PM | | 0.873 | | 36.2 | 28.4589 | | 133.057 | | | | | |
| 12:55:52 PM | | 0.848 | | 37.9 | 28.4589 | | 136.98 | | | | | |
| 1:00:52 PM | | 0.866 | | 36 | 28.4589 | | 134.133 | | | | | |
| 1:05:52 PM | | 0.868 | | 36.7 | 28.4589 | | 133.824 | | | | | |
| 1:10:52 PM | | 0.837 | | 38.1 | 28.4589 | | 138.78 | | | | | |
| 1:15:52 PM | | 0.864 | | 37.1 | 28.4589 | | 134.443 | | | | | |
| 1:20:52 PM | | 0.871 | | 37.2 | 28.4589 | | 133.363 | | | | | |
| 1:25:52 PM | | 0.874 | | 37.4 | 28.4589 | | 132.905 | | | | | |
| 1:30:52 PM | | 0.873 | | 36.2 | 28.4589 | | 133.057 | | | | | |
| 1:35:52 PM | | 0.876 | | 37.1 | 28.4589 | | 132.601 | | | | | |
| 1:40:52 PM | | 0.875 | | 37.1 | 28.4589 | | 132.753 | | | | | |
| 1:45:52 PM | | 0.867 | | 35.5 | 28.4589 | | 133.978 | | | | | |
| 1:50:52 PM | | 0.868 | | 36.2 | 28.4589 | | 133.824 | | | | | |
| 1:55:52 PM | | 0.862 | | 37.9 | 28.4589 | | 134.755 | | | | | |
| 2:00:52 PM | | 0.848 | | 36.7 | 28.4589 | | 136.98 | | | | | |
| 2:05:52 PM | | 0.868 | | 37.1 | 28.4589 | | 133.824 | | | | | |
| 2:10:52 PM | | 0.871 | | 36.8 | 28.4589 | | 133.363 | | | | | |
| 2:15:52 PM | | 0.864 | | 37.3 | 28.4589 | | 134.443 | | | | | |
| 2:20:52 PM | | 0.847 | | 37.3 | 28.4589 | | 137.141 | | | | | |
| 2:25:52 PM | | 0.856 | | 38.1 | 28.4589 | | 135.7 | | | | | |
| 2:30:52 PM | | 0.842 | | 37.7 | 28.4589 | | 137.956 | | | | | |
| 2:35:52 PM | | 0.852 | | 37.9 | 28.4589 | | 136.337 | | | | | |
| 2:40:52 PM | | 0.774 | | 38.1 | 28.4589 | | 150.076 | | | | | |
| 2:45:52 PM | | 0.831 | | 39.1 | 28.4589 | | 139.782 | | | | | |
| 2:50:52 PM | | 0.816 | | 37.2 | 28.4589 | | 142.352 | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2:55:52 PM | | 0.827 | | 37.3 | 28.4589 | | 140.458 | | | | | |
| 3:00:52 PM | | 0.803 | | 38.4 | 28.4589 | | 144.656 | | | | | |
| 3:05:52 PM | | 0.787 | | 38.2 | 28.4589 | | 147.597 | | | | | |
| 3:10:52 PM | | 0.775 | | 37.1 | 28.4589 | | 149.882 | | | | | |
| 3:15:52 PM | | 0.765 | | 37.6 | 28.4589 | | 151.842 | | | | | |
| 3:20:52 PM | | 0.749 | | 36.3 | 28.4589 | | 155.085 | | | | | |
| 3:25:52 PM | | 0.746 | | 37.3 | 28.4589 | | 155.709 | | | | | |
| 3:30:52 PM | | 0.732 | | 37.9 | 28.4589 | | 158.687 | | | | | |
| 3:35:52 PM | | 0.716 | | 37.9 | 28.4589 | | 162.233 | | | | | |
| 3:40:52 PM | | 0.693 | | 37.4 | 28.4589 | | 167.617 | | | | | |
| 3:45:52 PM | | 0.698 | | 37.6 | 28.4589 | | 166.417 | | | | | |
| 3:50:52 PM | | 0.699 | | 37.8 | 28.4589 | | 166.179 | | | | | |
| 3:55:52 PM | | 0.69 | | 36.9 | 28.4589 | | 168.346 | | | | | |
| 4:00:52 PM | | 0.677 | | 36.6 | 28.4589 | | 171.579 | | | | | |
| 4:05:52 PM | | 0.598 | | 37.6 | 28.4589 | | 194.246 | | | | | |
| 4:10:52 PM | | 0.642 | | 38 | 28.4589 | | 180.933 | | | | | |
| 4:15:52 PM | | 0.613 | | 36.9 | 28.4589 | | 189.492 | | | | | |
| 4:20:52 PM | | 0.601 | | 36.5 | 28.4589 | | 193.276 | | | | | |
| 4:25:52 PM | | 0.495 | | 37 | 28.4589 | | 234.664 | | | | | |
| 4:30:52 PM | | 0.543 | | 38 | 28.4589 | | 213.921 | | | | | |
| 4:35:52 PM | | 0.269 | | 37.4 | 28.4589 | | 431.817 | | | | | |
| 4:40:52 PM | | 0.558 | | 36.5 | 28.4589 | | 208.17 | | | | | |
| 4:45:52 PM | | 0.402 | | 37.1 | 28.4589 | | 288.952 | | | | | |
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