Analysis on electrical power requirement of a hybrid solar-electric oven.

by

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CERTIFICATION OF APPROVAL

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Approved by,

(Azman B Zainuddin)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

July 2008

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMMAD ZULHILMI BIN SAIFUL AZNAN

ABSTRACT

The energy cost is rising rapidly and some work has been done using solar energy as the source of heat for cooking in an oven. There are limitations to the performance of solar oven due to limited access to sunlight at night and cloudy weather. To overcome this problem, a further study is made in utilizing electrical power to enhance the performance. The objective of this project is to analyze the electrical power requirement in a hybrid solar-electric oven. This study will analyse how much additional power is required to bring the performance of the oven up to several defined acceptable levels.

ACKNOWLEDGEMENTS

Bismillahirrahmanirrahim

In the name of Allah, The Most Gracious and The Most Merciful

First and foremost, I would like to extend my heartiest gratitude towards Allah for giving me the opportunity to complete this Final Year Project. Throughout this two-semester project, lots of efforts and inputs have been put to yield the output which is achieving the goal.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

A solar oven is a device which uses only sunlight to cook. Because they use no fuel and they cost nothing to run. Humanitarian organizations and conservationists are promoting their use worldwide to help slow deforestation and desertification, caused by the need for firewood used to cook. Solar cookers are also sometimes used in outdoor cooking, especially in situations where minimal fuel consumption or fire risk is considered highly important.

A hybrid solar oven is a type of solar oven that uses both the regular elements of a solar box cooker as well as a conventional electrical heating element for cloudy days or nighttime cooking. Hybrid solar ovens are therefore more independent of the weather. However, they lack the cost advantages of some other types of solar cookers, and so they have not caught on as much in third world countries.

Considering the fact that Malaysia is blessed with good sunshine, high and a reliable electric network, a hybrid solar oven is thought to be useful. This oven can be used for cooking and baking at any time during the year employing solar and electrical energy and consuming the minimum quantity of electric energy when it is required to heat foods.

1.2 Problem Statement

The cost of energy is increasing all the time and a lot of energy used everyday in cooking. As the price of oil per barrel, gas and electricity is increasing rapidly in the international market, cooking by using the petroleum gas is a burden and can be costly to the people in the third world country such as Malaysia. Therefore it is necessary to use solar energy is as it is free of charge. In spite of various efforts made, the widespread use of solar oven has not become possible due to different reasons, including the impossibility of using during the period lacking sufficient sunshine for cooking. It cannot be operated at night and during the cloudy climate. Therefore, this project will study on how to improve the usage of solar oven during cloudy climate and nighttime. This project will enhance the performance of solar oven. One potential way if enhancing the solar oven is to use electricity in order to overcome this problem.

1.3 Significance of Study

Solar oven nowadays are very popular since people are searching alternatives for fuel consumption. However, this technology is still not up to an acceptable level. The output of this research should be a very useful for solar oven designer in order to enhance the performance. Therefore, this project will study on how to increase the performance of the solar oven so that people will consider using the solar oven in their daily life. Moreover, the cost of energy shows an increasing trend as the fossil fuel is depleting.

1.4 Objective and Scope of Study

The main objectives of this research are:

- To analyse the viability of having an electrical heater to boost the performance of a solar oven
- To analyse the electrical power requirement in a hybrid solar-electric oven

The analysis of the power requirement is specific for the particular oven available for research in Universiti Teknologi Petronas. Different oven may have different efficiency in transferring the solar energy to the food. The output of this project will determine the required electrical power for the existing solar oven. It will provide the information of the solar strength trend in a day, the performance of the specific solar oven and the required electrical power in order to raise the water temperature in a specified time with important ratio of solar-electric power. These informations are important in the future for others who is intended to make a hybrid solar electric oven. Several experiments were done to evaluate the performance of the existing solar oven. These data will be used to calculate the required electrical power.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Hybrid solar electrical oven is an oven that uses sunlight as the main heating source and electrical power as the secondary heating source. Several research and development works have been done on this oven.

2.2 Tulsi-Hybrid Solar Oven [1]

Figure 2.1 Tulsi-Hybrid Solar Oven

Figure 2.2 Tulsi-Hybrid Solar Oven Cooking Panel

Currently there is a product available that uses the same concept. The manufacturer of the product, Sun BD Corporation named the product as Tulsi-Hybrid Solar Oven. It is capable by making solar cooking more practical, with its electrical back-up and switches automatically between solar and electric power, depending on sunshine availability. It claimed to use 75% less energy than a conventional oven which is a power saving product. Several features are introduced with this product. First, it is high performance solar oven with "energy miser" back up AC 120 volts electric elements, ultimate in solar oven technology up to 400^{o}F in hybrid mode. This is an advantage for as it has energy miser as a back up. Then, it has 95% reflective scratch resistant reflector panel for longer wear and higher cooking temps, higher reflectivity than a standard glass mirror. This feature is important because the reflector is the main tool to focus the sunlight into the oven chamber and this reduces in heat or light energy. Third, it has double paned oven window instead of single pane so that it traps heat longer for superior heating. Moreover, it is double rubber oven sealed which mean it has better long term retention to keep the food hot. Next, it has attachable temperature booster reflector panels that will boost the temperature higher for high temperature cooking. It has larger internal cooking chambers which allow the cooking of several types of food at a time or a large size food i.e pizza. Other feature is it has electric back-up system and portable in a suitcase design. Overall, the product is considered as a five star product. However, the author personally thinks that there is still a space for improvement especially considering its weight which is very heavy and price up to $300.

2.3 Design, construction and experimental study of electric cum solar oven [2]

Another project that is still running right now is the design, construction and experimental study of electric cum solar oven (ECSO) by Shyam S. Nandwani in 2003. This oven can be used for cooking and baking almost all types of meals at any time during the year employing solar and/or electric energy and consuming the minimum quantity of electric energy when it is required. However, this project is still under construction and therefore, the study about improving the solar oven can be extended further.

2.4 Design, construction and study of a hybrid solar food processor in the climate of Costa Rica [3]

Figure 2.3 Hybrid Solar Food Processor

In 2006, the author, Shyam S. Nandwani [3] has designed, constructed, studied and promoted solar oven, hybrid solar/electric oven, solar oven cum drier, solar cooker cum water heater and solar still during the last 25 years,. In different parts of the world, solar cookers have been made, studied, patented, however, their real uses are very limited due to many reasons—unstable climate, economic, cultural, social and single use, etc. In order to overcome part of the problems mainly the last one, author has recently designed one hybrid food processor (multi-purposes device) and studied various technical and practical aspects. It has been used for cooking, heating/pasteurizing water (to inactivate microbes) and distillation of small quantity of water (to remove different minerals) and drying domestic products (fruits, vegetables and condiments/herbs, etc.). For more than three years of use, author has found this to be a useful device, mainly from convenience, fuel saving, economic and also from ecological point of view. This device can be used at any time and for different uses but with the reduced consumption of conventional fuel. This device is good in term of saving fuel consumption but however this device is not recommended to use for cooking and heating water or drying simultaneously, unless used in a very sunny climate. The built of the solar cooker are as below. Some typical data of the usage of this solar cooker are:

a. *To use the device as a solar cooker*
b. *To pasteurize water*
c. *To use device as a solar dryer*
d. To use the food processor as a solar still

2.5 Design of Solar Cooker by Group 26, ETP, UTP. [4]

During July 2007, group 26 from Engineering Team Project of Universiti Teknologi Petronas has made a solar cooker which is meant to be affordable, economical, user-friendly, safe-to-handle and able to cook effectively. They had conducted 2 tests to show the performance of the solar oven. For the first experiment (Figure 2.4), the temperature increases as the time and angle of reflection increase. The highest temperature is 60°C and it is achieved at 1300 hours when the angle of reflection is set to 110 ° and the temperature drops towards the last 90 minutes of the experiment as the angle of reflection is reduced. For the second experiment (Figure 2.5), the temperature shows an increment for the first 60 minutes. The highest temperature is reached at 86°C and it achieved at 1045 hours when the angle of reflection is set to 88°. The temperature suddenly decreases for the next 60 minutes. The temperature decreases in the last 30 minutes of the experiment although the angle of reflection is increased throughout this experiment. However, the solar cooker that is used has to be further studies since the experiment done at different temperature and different angle which makes the result is hardly seen the affection whether by the angle of reflection or by angle of the sun. The insulator that is used also has no function since the heat is not trapped by the container, but trapped inside the cooking pot.

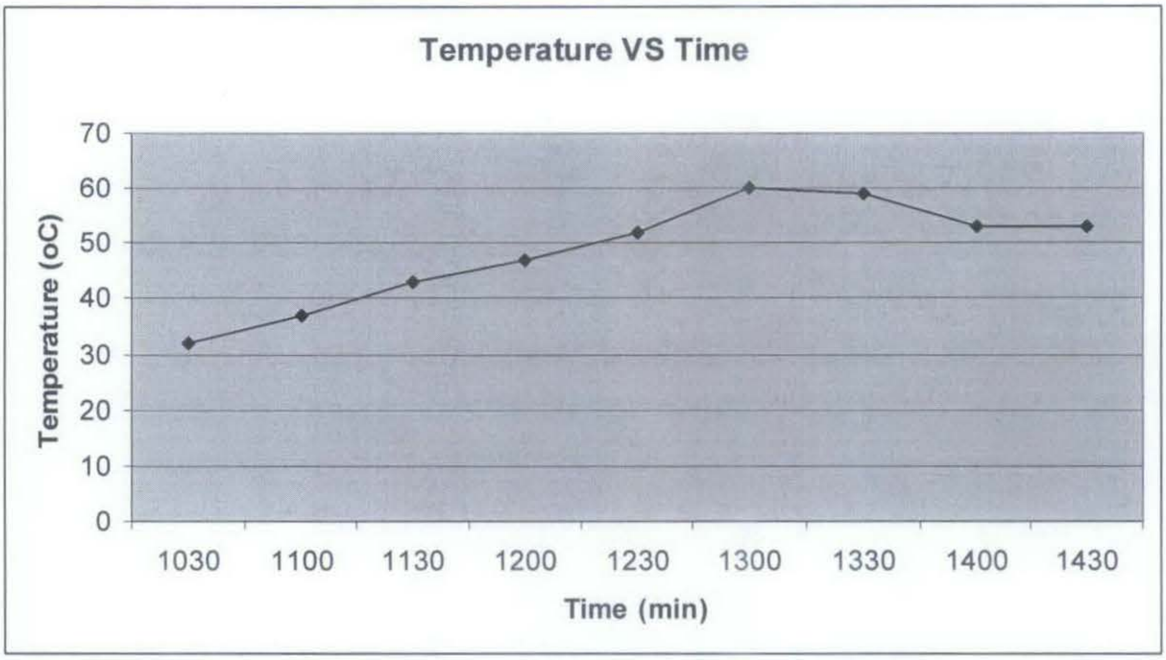

Figure 2.4 Temperature Distributions for Experiment 1

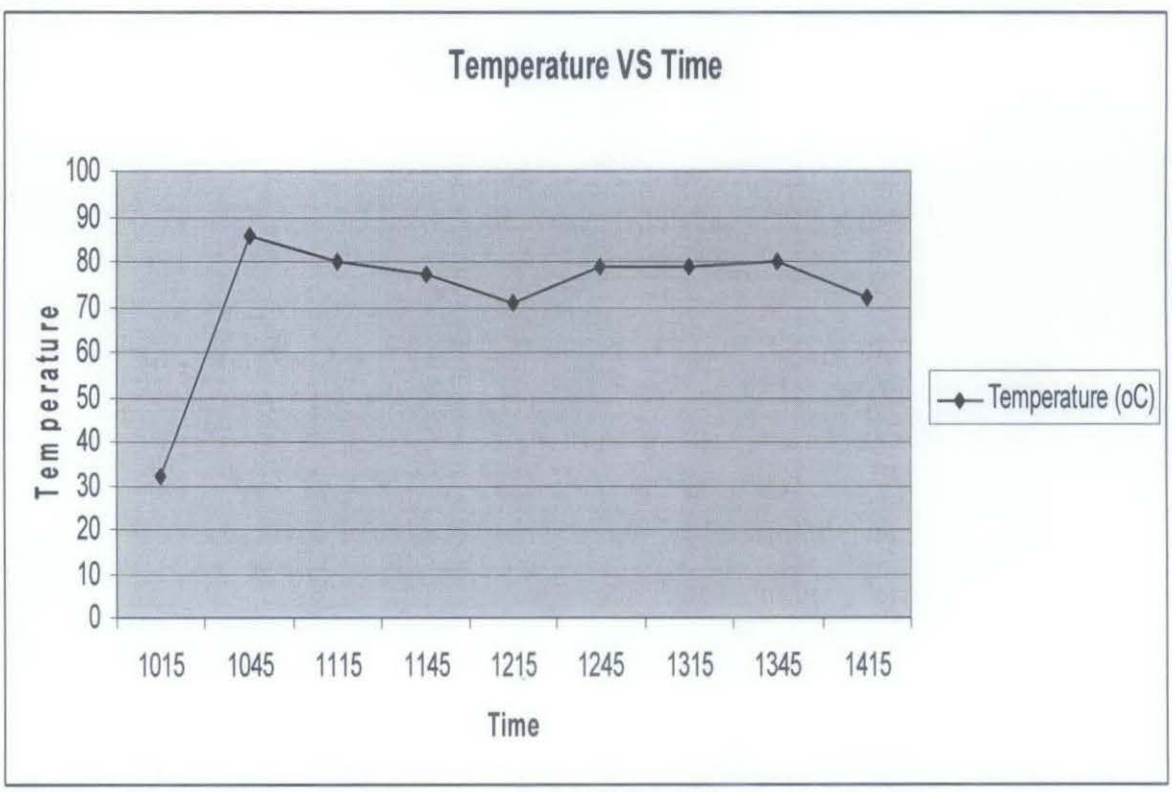

Figure 2.5 Temperature Distribution for Experiment 2

2.6 Design of Portable Solar Oven by Group 54, ETP, UTP. [6]

Another undergraduate project group, Group 54 also designed a solar cooker with a slightly different design as shown in Figure 2.6. The difference is it has a proper solar cooking room covered with Perspex to allow the solar ray and trap it inside. The results obtained in the experiment are shown in Figure 2.7 and Figure 2.8. According to the result that is obtained, we can see that the highest temperature achieved inside the solar oven is about the same time with the distribution of surrounding. This means that at the peak time where solar strength is brightest, it transfers the heat through radiation to the solar oven. Sizing about 35cm x 35cm x 25cm however, the solar oven can be improved by making it lighter and by adding the capability of working at the time where there is not much or none solar power.

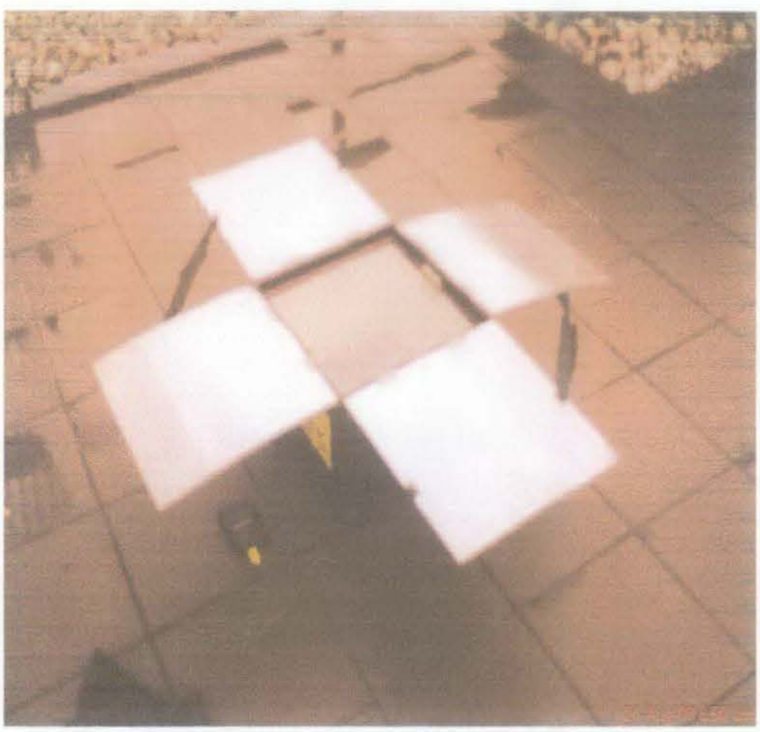

Figure 2.6 Solar oven fabricated by Group 54 ETP of UTP

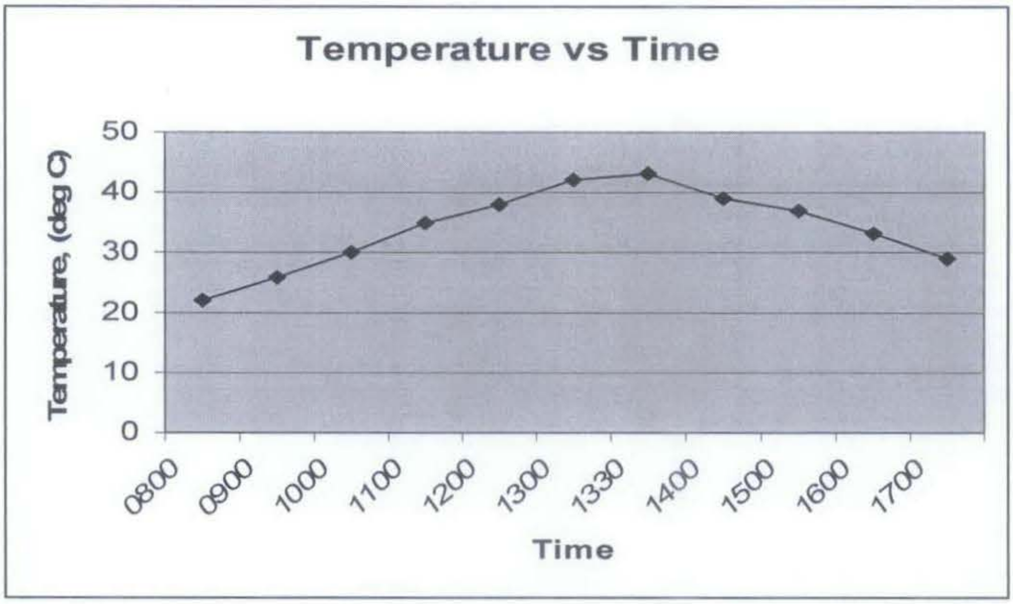

Figure 2.7 Temperature vs Time of Temperature Distribution of Surrounding

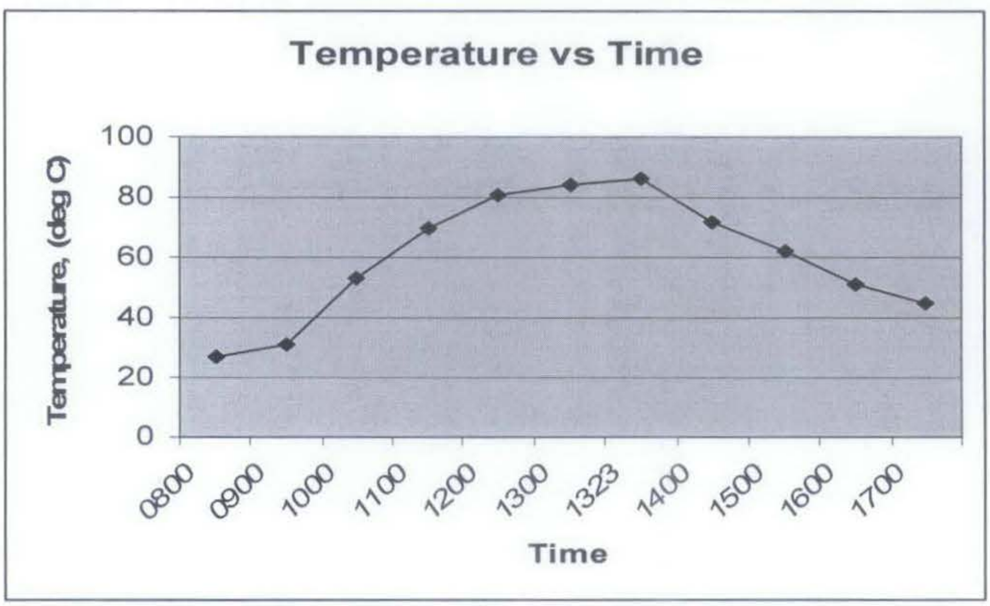

Figure 2.8 Air Temperatures Inside the Solar Oven versus Time

CHAPTER 3
METHODOLOGY

3.1 Methodology

The methodology of this project will be as Figure 3.1. At first, the problem is identified and defined to get a clear picture of this project. Next, the objective will be set to make an aim of this project. The cooking performance criteria are then studied in order to specify what the hybrid solar oven requirement is. The type of food, amount which is size and weight, cooking time and maximum temperature of food is studied at this stage. After that, the hybrid solar-electric oven design criteria are set in order to identify what is the criteria required. The design criteria that have been specified are the capital cost, running cost, maintenance cost, heating power capacity, portability which is size and weight, ease of manufacture and assembly, ergonomics and safety. These design criteria have to be fulfilled in order to design the hybrid solar electric oven. Then, the experiments were set up. In order to set up the experiment, it involves in choosing a solar oven from 2 available solar ovens, the food to be cooked, the input parameters, the variables to be measured and the location for the experiment. After that, calculations of the theoretical energy required to perform certain cooking were done. Only then, the experiments were conduct to obtain the data and collected to be analyzed. Next, the data were analyzed and the solar energy used in cooking was estimated to perform certain cooking task. Then, the electrical power required for a variety of cooking task is calculated and specified for the hybrid solar-electric oven. Finally, the author will propose the conceptual design of Health, Safety and Environment (HSE) oven.

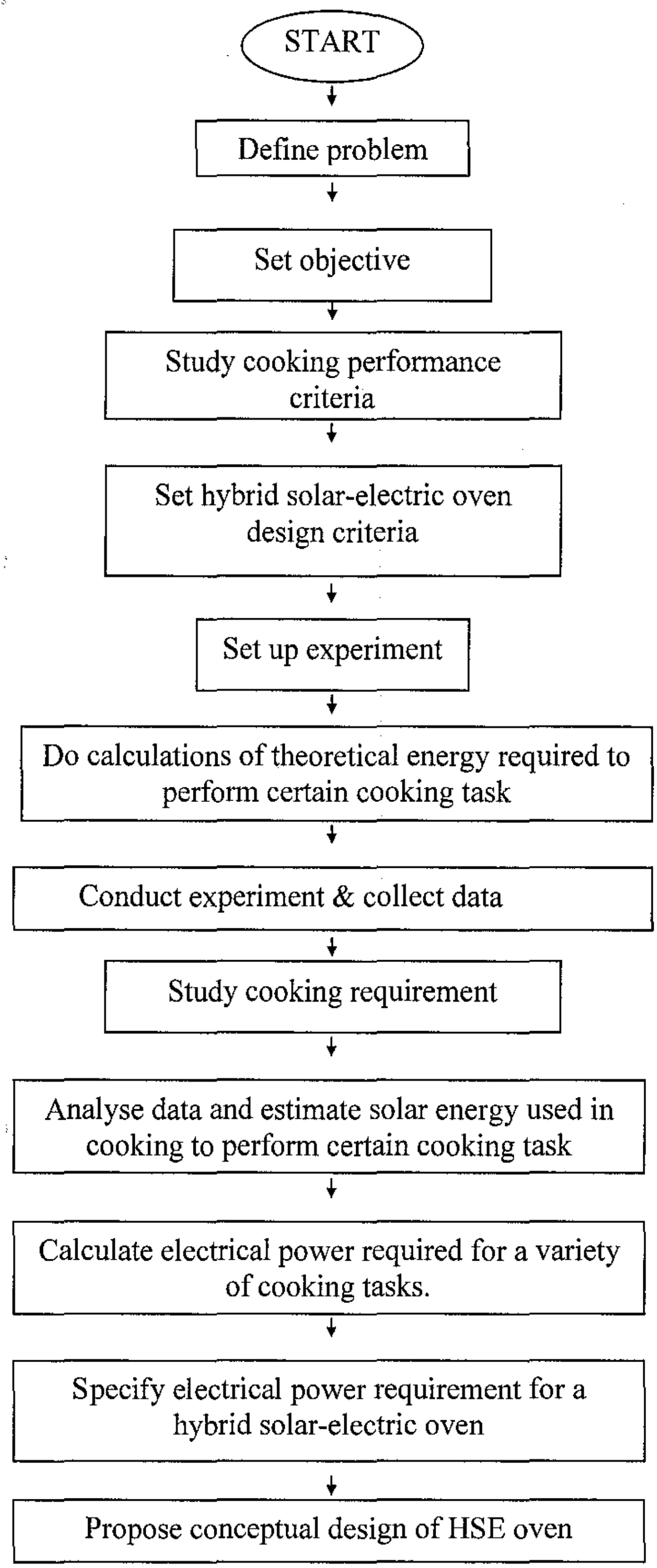

Figure 3.1 Methodology

3.2 Products Comparison

Table 3.1 Comparison between Products

PRODUCT	SOLAR OVEN BY GROUP 54, JULY 2007 ETP, UTP	SOLAR COOKER BY GROUP 26, JULY 2007 ETP, UTP
COOKER SIZE (CM)	35 x 35 x 25	45 x 45 x 15
MATERIAL	Plywood	Wood
WEIGHT (KG)	unknown	3.5
TRAY MATERIAL & COATING	Stainless steel	Aluminium sheet, black painted
ELECTRICAL CONSUMPTION	N/A	N/A
POWER SOURCE	Solar Source only	Solar source only
COST	RM173.30	RM184.60

Since the only available solar oven is from group 26 and 54 of July 2007 ETP, the author had decided to use the Solar Cooker by group 54 ETP UTP. This is due to the objective is to improve the existing solar oven system performance by adding capability of utilizing electrical power. It also can be directly use without doing the adjustment. The solar oven will be equipped with electrical power source in order to overcome the solar problem.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Cooking Requirement

After studying several types of solar cooker, the author has decided to choose standard 200 gram water as the constant for the testing and data collection.

4.2 Design Criteria

After several consultation and research, several factors have been decided will be taken into account for the hybrid solar-electric oven:

1. Cost
    a. Capital

        Capital costs are costs incurred on the purchase of land, buildings, construction and equipment to be used in the production of goods or the rendering of services. In other words, the total cost needed to bring a project to a commercially operable status

    b. Maintenance

        Maintenance cost is the cost required to maintain the solar cooker once it is used. The maintenance cost includes the cost to replace any damaged parts.

2. Heating power required

    Heating power required is the amount of heat required to cook a 200 grams of water within 20 minutes.

3. Size and weight

   Size means the suitable size to be used to cook the food and to be used in daily cooking as an alternative cooker. Weight means the suitable weight for this solar for daily cooking usage and easy to move. Both of these criteria relates to the portability of the solar cooker.

4. Ease of Manufacture and Assembly

   Ease of manufacture is an aspect where the author considers the easiness to manufacture or fabricate the product. This includes the material used, shape and process required in order to yield a working prototype.

5. Ergonomics

   Ergonomics is an aspect that is concerned with designing according to the human needs, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance. This includes the ease to install the food and to cleaning the solar cooker itself.

6. Safety

   Safety means that the solar cooker is safe enough to be used for cooking. There are no hazardous materials that will affect the quality of food or neither gives side effect to the user.

4.3 Estimating Power Required to Heat Food

4.3.1 Experimental Data

Several experiments were done to estimate the performance of the solar oven. The objective of this experiment is to study the relation between the powers that the sun had produced with the power absorbed by 200ml water placed inside the solar oven. Another objective is to calculate how much the electrical power needed to speed up the heating process to a suitable time period. The variables involved are solar meter reading and water temperature reading. Graph in Figure 4.1 shows that the temperature is low in the morning and increase in the afternoon. The temperature will drop a little bit in the evening since the solar intensity is lower. For the solar strength, we can see in Figure 4.2 that it does not show a uniform trend. However, for an ideal case, solar intensity will rise by 11am to 12 pm and it will reduce in the evening as the time goes by.

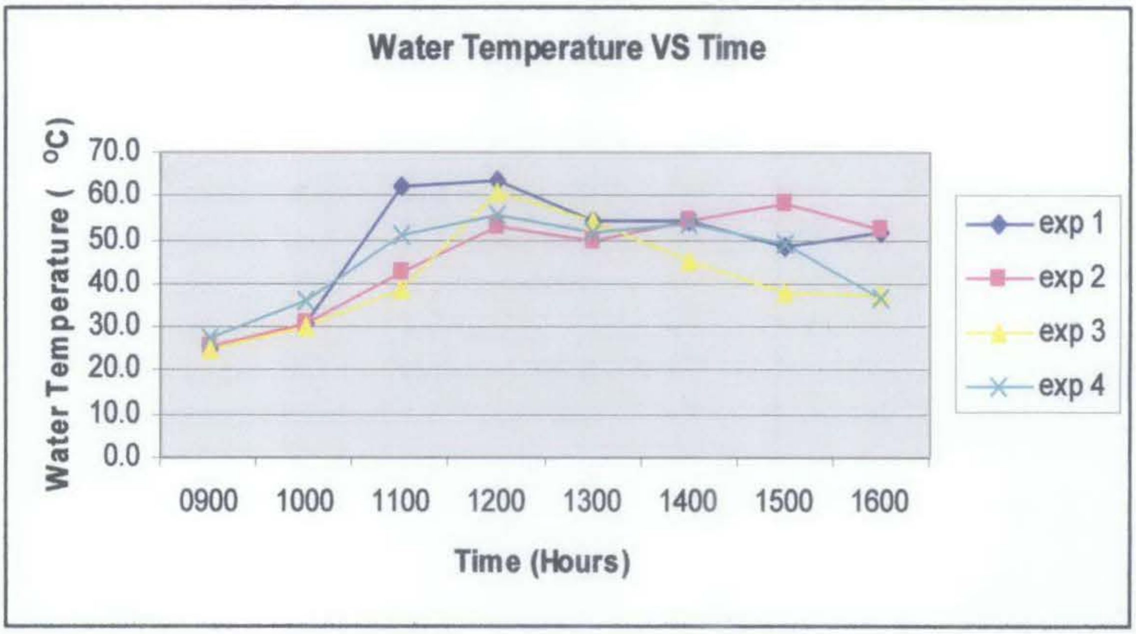

Figure 4.1 Graph of Water Temperature Versus Time

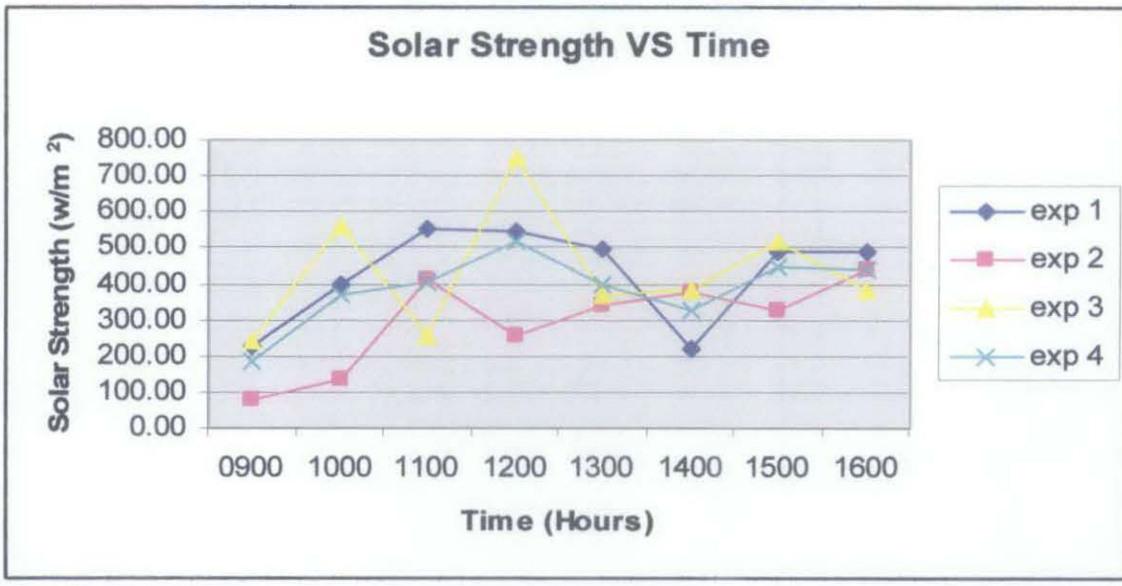

Figure 4.2 Graph of Solar Strength Versus Time

In order to estimate the electrical power required, it is assumed that:

1. The 200 ml beaker is in contact with the inner surface of the cooker and hence their temperatures are the same
2. The physical properties of the material to be cooked are the same as that of water
3. The solar oven is well insulated.
4. Initial water temperature is 27 ^{O}C and rise up to 60 ^{O}C.

From the temperature changes, the power required to increase the 200 ml water by 33 ^{O}C is

$$E = mC_p\Delta T$$
$$E = (0.2kg)(4200J / kg°C)(33°C)$$
$$= 27720J$$

From the data that is collected, it takes the minimum about 1 hour to bring the temperature from 27^{O}C to 60^{O}C. The power that is transferred to the water within this time period is

$$Power, P = \frac{27720J}{3600s}$$
$$= 7.7W$$

Therefore, the solar power that strike the Perspex surface of the solar oven is

$$Area, A = 0.35m \times 0.35m$$
$$= 0.1225m^2$$

It is assumed that 500 W/m^2 is constantly strike the surface of the solar oven in 1 hour. The amount of solar power striking the surface of solar oven is

$$Energy, E = 500W / m^2 \times 0.1225m^2$$
$$= 61.25W$$

From the calculation, only 7.7W is transferred to the water instead of 61.25W that strike the solar oven. Only 12.57 percent is transferred to the water. This maybe because of the solar power that strike the solar oven is used to heat and maintain

1. the air particle inside the oven
2. the oven walls
3. the Perspex
4. the beaker's glass

as well as the water. These causes had influenced the heat transferred to the water.

4.3.2 Estimating Electrical Power Required

From the experimental data, we can see the efficiency of the particular solar oven. Only 12.57 percent energy is transferred to the water inside the solar oven. Therefore, if a 1000W electric kettle is used and the heat transferred through conduction, the time required is

$$
\begin{aligned}
t &= \frac{E}{P} \\
&= \frac{27720J}{1000W} \\
&= 27.72s
\end{aligned}
$$

Instead, using the solar oven, the time taken to heat the water by the same increment is 1 hour or 3600s. Based on experiment 1, this is relatively large compared using a 1000W electric kettle. However, the objective is to improve the existing solar oven system performance by adding capability of utilizing electrical power. Several heating time is chosen in order to estimate the viable time for the solar oven:

1) 5 minutes

   If the time taken to raise the water temperature for 33°C is 5 minutes, then the total power required is

$$
\begin{aligned}
Power, P &= \frac{E}{t} \\
&= \frac{27720J}{(5 \times 60)s} \\
&= 92.4W
\end{aligned}
$$

2) 10 minutes

   If the time taken to raise the water temperature for 33°C is 10 minutes, then the total power required is

$$
\begin{aligned}
Power, P &= \frac{E}{t} \\
&= \frac{27720J}{(10 \times 60)s} \\
&= 46.2W
\end{aligned}
$$

3) 20 minutes

If the time taken to raise the water temperature for 33°C is 20 minutes, then the total power required is

$$
\begin{aligned}
Power, P &= \frac{E}{t} \\
&= \frac{27720J}{(20 \times 60)s} \\
&= 23.1W
\end{aligned}
$$

From these periods of cooking, we can see that the power required is decreasing as the time is increasing. In order to heat the water, the estimated power is

$$\text{Total Power, } P_T = P_{solar} + P_{electric}$$

From the calculation earlier, the power provided by the solar energy to the oven is 7.7W. In order to have a hybrid solar oven that works mainly on solar power and backup by electrical power, the feasibility of using electrical power can be calculated.

1) 5 minutes

$$
\begin{aligned}
\text{Total Power, } P_T &= P_{solar} + P_{electric} \\
92.4W &= 7.7W + P_{electric} \\
P_{electric} &= 92.4W - 7.7W \\
&= 84.7W
\end{aligned}
$$

The contribution of using the solar power is 8.3 percent which is very small and not significant for a solar oven.

2) 10 minutes

$$
\begin{aligned}
\text{Total Power, } P_T &= P_{solar} + P_{electric} \\
46.2W &= 7.7W + P_{electric} \\
P_{electric} &= 46.2W - 7.7W \\
&= 38.5W
\end{aligned}
$$

For this time period, the solar power contribution is 16.7 percent. It is more significant compared to 5 minutes period of heating.

3) 20 minutes

$$\text{Total Power}, P_T = P_{solar} + P_{electric}$$
$$23.1W = 7.7W + P_{electric}$$
$$P_{electric} = 23.1W - 7.7W$$
$$= 15.4W$$

The solar power contribution is 33.3 percent which is the highest of the three. Further time period than 20 minutes is not considerable since it is relatively a long period to cook a 200g food.

From the above values, 20 minutes is likely feasible to be taken into consideration as the targeted time to heat the 200g water for the solar power contribution that it used which is 33.3 percent for about 20 minutes.

Table 4.1 Summarized Calculation of Solar Power Percentage

EXPECTED TIME TO COOK (MIN)	SOLAR POWER (W)	ELECTRICAL POWER (W)	TOTAL POWER (W)	SOLAR PERCENTAGE (%)	ELECTRICAL PERCENTAGE (%)
5	7.70	84.70	92.40	8.33	91.67
10	7.70	38.50	46.20	16.67	83.33
15	7.70	23.10	30.80	25.00	75.00
20	7.70	15.40	23.10	33.33	66.67
25	7.70	10.78	18.48	41.67	58.33
30	7.70	7.70	15.40	50.00	50.00
35	7.70	5.50	13.20	58.33	41.67
40	7.70	3.85	11.55	66.67	33.33
45	7.70	2.57	10.27	75.00	25.00
50	7.70	1.54	9.24	83.33	16.67

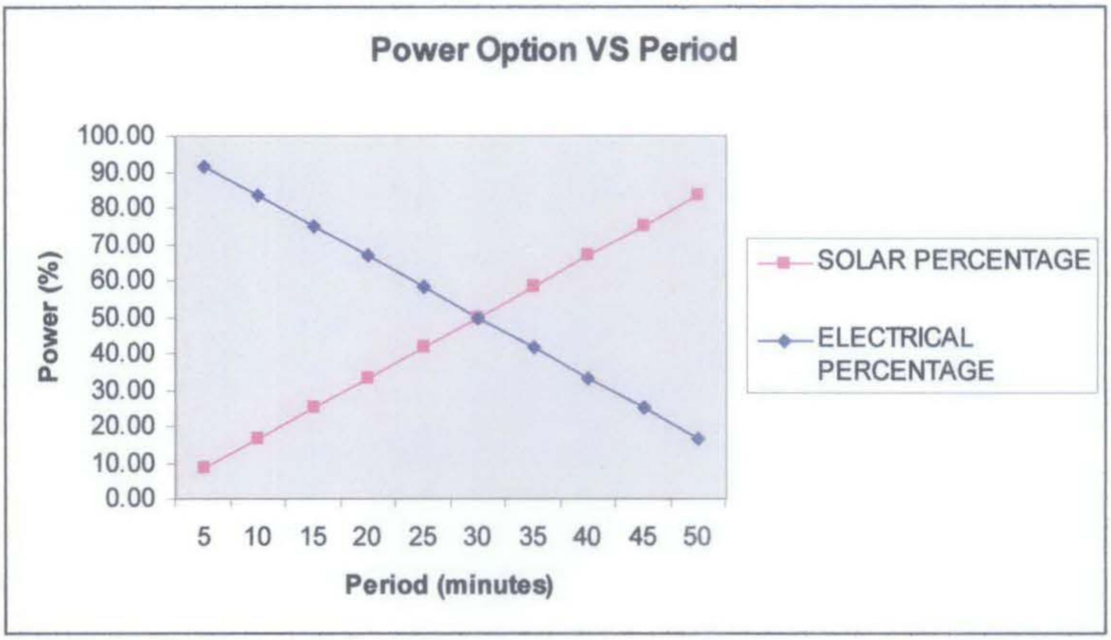

Figure 4.3 Power Option versus Time Period

The summary of percentage solar power used in each case is summarized in Table 4.1. From the above calculation, we can conclude in Figure 4.5. It shows that at one point, 30 minutes, the ratio of the power is 1:1 for solar and electrical power. However, the time can vary according to the electrical power consumed. The consumption of solar and electrical energy depends on the time and condition. It is surely a reasonable decision to wait for 30 minutes in order to save the world.

The IEA assumes that the projection of crude oil import price averages $100 per barrel (in real year-2007 dollars) over the period 2008 to 2015, rising to over $120 in 2030. Therefore, as the oil and gas production is decreasing and the price is increasing, the usage of the renewable energy is relevant in the mean time and future. Waiting for last minute action is certainly not a wise solution. We have to act now in order to save our future.

CHAPTER 5
CONCLUSION

Hybrid solar electrical oven is a new concept that is still not widely used all around the world. Therefore the author has done the analysis of electrical power requirement in a hybrid solar-electric oven in a climate such as Malaysia where the sunlight is easy to obtain and rain is just around the corner. The hybrid solar-electrical oven is hopefully can be a good alternative in these days and the future. This project can be further studied in order to reduce the non-renewable energy usage.

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APPENDICES

Appendix 1 : Suggested Milestone for the Second Semester of 2-Semester Final Year Project

Suggested Milestone for the Second Semester of 2-Semester Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7	Mid-Semester Break	8	9	10	11	12	13	14
1	Project Work Continue															
2	Submission of Progress Report 1				●											
3	Project Work Continue															
4	Submission of Progress Report 2									●						
5	Seminar (compulsory)									●						
5	Project work continue															
6	Poster Exhibition											●				
7	Submission of Dissertation (soft bound)													●		
8	Oral Presentation														●	
9	Submission of Project Dissertation (Hard Bound)															●