Solar Cooking Device for Remote Areas

A final year project report

Presented to

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

Department of Mechanical Engineering

NUST

ISLAMABAD, PAKISTAN

In partial Fulfillment

Of the Requirements for the Degree of

Bachelors in Mechanical Engineering

By

Nosherwan Adil

Masroor Khalid

Muhammad Huzaifa

June, 2017

EXAMINATION COMMITTEE

We hereby recommend that the final year project report prepared under our supervision by: Nosherwan Adil – 05128, Masroor Khalid – 06049 & Muhammad Huzaifa – 05548. Titled: "SOLAR COOKING DEVICE FOR REMOTE AREAS" be accepted in partial fulfillment of the requirements for the award of Bachelors in Mechanical Engineering degree.

Supervisor: Hafiz Abd-ur-Rehman (Lecturer) SMME,NUST	______________ Dated:
Committee Member: Abdul Naeem Khan (Assistant Professor) SMME,NUST	______________ Dated:
Committee Member: Jamal Saeed (Assistant Professor) SMME, NUST	______________ Dated:

____________________ ________________

(Head of Department) (Date)

COUNTERSIGNED

Dated: ________________ ___________________________

(Dean / Principal)

ABSTRACT

In this report, a solar cooker was designed, developed and tested. The main objective of this project is to optimize the design of box type solar cooking device for better and more efficient performance. The operating parameters for the optimum performance of the solar cooker are evaluated by performing the parametric and necessary CFD analysis. Keeping in view the overall portability of the cooker, a suitable dimensional and heat analysis was also performed for the phase change material and its storage compartment. Based on the optimum design values, a prototype is developed and tested under the climatic conditions of Islamabad, Pakistan.

After the successful execution of experimental analysis, it was concluded that the cooking device will work best during the noon time when the incident radiations are at a maximum value. Moreover, a detailed cost and environmental analysis provided a clear picture of Solar Cooker's impact on carbon emissions and its contribution to the greener atmosphere with a decrease in global warming.

PREFACE

This report is a result of progress made while working on our Final Year Project for the degree of bachelors in Mechanical Engineering. A group of 3 students is responsible for delivering the working prototype of the said project. Every effort was made to complete this report according to the expectations and quality desirable. Theoretical and parametric analysis were used to find out the optimum dimensions and working conditions of the portable device.

The purpose of this report is to provide a sound knowledge about the solar cooker and the progress made including the overall results made in its design and manufacturing.

ACKNOWLEDGEMENTS

We would like to thank Lecturer Hafiz Abd ur Rehman for his kind guidance, necessary support and invaluable supervision for this project without whom this report wouldn’t have been possible. His cooperation and timely suggestions built the very foundation of this report.

We would also like to appreciate the facilities and efforts provided by Dr. Abdul Ghafoor (Principal SMME), Dr. Khalid Akhtar (HoD Mech) and Dr. Aamir Mubashar (Asst. Professor).

In the end, we express our sincerest thanks to our friends and family members who have supported us for this impactful and environmentally friendly project.

ORIGINALITY REPORT

%13	%10	%8	%7
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	solarcooking.wikia.com Internet Source	%4
2	Cuce, Erdem, and Pinar Mert Cuce. "A comprehensive review on solar cookers", Applied Energy, 2013. Publication	%3
3	ijlct.oxfordjournals.org Internet Source	%1
4	Submitted to North Point High School Student Paper	%1
5	Submitted to Cheshire High School Student Paper	%1
6	www.ijera.com Internet Source	%1
7	www.appropedia.org Internet Source	%1
8	mickiesplace.com Internet Source	%1

9	Submitted to Universiti Teknologi MARA Student Paper	%1

EXCLUDE QUOTES	OFF	EXCLUDE MATCHES	< 1%
EXCLUDE BIBLIOGRAPHY	ON		

COPYRIGHT

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF GRAPHS

ABBREVIATIONS

PCM	Phase Change Material
SCD	Solar Cooking Device
SS	Stainless Steel
SA	Stearic Acid

NOMENCLATURE

$Q_{loss} = Heat\ Loss$

$Q_{input} = Heat\ Input$

$R = Resistance$

$L = Length$

$W = Width$

$H = Height$

$d_{ins} = Insulation\ Thickness$

$K = Thermal\ Conductivity$

$T = Temperature$

$T_{max} = Maximum\ Temperature$

$T_{envm} = Environmental\ Temperture$

$I = Intensity$

$A = Area$

$C = Heat\ Capacity$

$t = Time$

CHAPTER 1

INTRODUCTION

Energy is one of the most important part of our life and is defined as the ability of any physical system to do work. Energy has different types that can be broadly categorized as renewable and non-renewable. Non-renewable energy is produced by burning of fossil fuels and wood. Although, wood is easily available and is cheaper to use for cooking purposes and water heating, burning of wood causes different diseases such as lung diseases, eye disorders etc. which are mostly dangerous for human health. These specific reasons among many made clear our preference to use solar energy for cooking, baking and water heating.

Solar energy utilization is an exciting domain and central focus of many researchers. There are many applications of solar energy utilization and solar cooker is one of them. Solar cooker is a device which can cook food without burning the fossil fuels or disrupting the greener environment. Solar cookers provide many advantages that include non-recurring costs, high nutritional value of food, potential to reduce drudgery, and high durability.

Solar cooker/Solar oven has three main categories listed as parabolic, box, and panel type solar cooker. Factors that can improve their performance and reduce the time of cooking are shape, size and type of solar cooker. In remote areas, solar cooker can be widely used for cooking purposes and even in winter it can be used for heating, drying or pasteurizing food instead of cooking. One of the main benefit of solar cooking is to fight against deforestation and global warming.

Difference between box type and parabolic solar cooker was studied which showed that parabolic part is more effective to utilize solar energy more efficiently as compared to box type solar cooker. Performance/efficiency of solar cookers can be improved by using Fresnel lenses or booster mirrors and by providing proper insulation. The mounted mirrors on the parabolic part affect about 25% on the performance of the solar cookers and flat mirrors in the box-type of the solar cooker affect about 18.5%.

One of the most important theoretical aspect behind the performance and working of solar cooker is the law of conservation of energy. Among the three options for design of cookers listed as solar panel cooker, box type solar cooker and parabolic solar cooker, we chose box type solar cooker because solar panel cooker is not very useful due to providing less cooking power. Other one is parabolic solar cooker which is the most expensive design.

The solar cooker that we manufactured used booster mirror instead of Fresnel lenses so that the high temperature can be controlled without burning the food. Double glazing is employed for insulation purposes and enhancement of greenhouse effect whereas side walls were insulated to prevent heat loss. Absorber Plate is painted with black color to absorb more solar radiations. Cooking vessel of cylindrical shape made of aluminum and painted black is used for maximum absorption and higher cooking efficiency. Phase change material used as a facilitator made cooking possible in evening and cloudy days on this device.

The overall objective of this work was to develop a multipurpose solar cooking device. The specific objectives of the proposed work were:

- Thermodynamic analysis of the proposed solar cooking design.
- Design, manufacturing, and testing of the proposed design.
- Experimental investigation of the proposed design.
- Techno-economic feasibility of the proposed solar cooking design for its possible installation in remote areas.

CHAPTER 2

LITERATURE REVIEW

According to the several research papers and materials available throwing light on the solar cookers working and their performance, difference between box solar cooker and parabolic type solar cooker is studied which shows that parabolic part is more effective to utilize solar energy more efficiently as compared to solar cooker so parabolic type solar cooker is more efficient as compared to box solar cooker. Performances/efficiency of solar cookers can be improved by using Fresnel lenses or booster mirrors and by providing proper insulation. The mounted mirrors on the parabolic part affect about 25% on the performance of the solar cooker and flat mirrors in the box-type of the solar cooker affect about 18.5%. If we install some thermal fins on the vessel in a double-exposure solar cooker, then it will decrease its boiling time and also utilization of some simple fins on absorber plate in a box-type solar cooker increases its temperature. [6] [10]

Effective Parameters on Performance of Solar Cookers

Significant Parameters to enhance performance of solar cooker are shown below:

1. Booster Mirror:

   It is very important for a solar cooking device since it has an ability to allow high intensity of sunlight falling on the top surface of the cooker. Due to this, high temperatures are achieved which increases the efficiency. Cooker position and the tilt angle of the mirror were adjusted so due to this, the sunlight concentration is maximized. Fresnel lens is not good to concentrate intensity of light because it concentrates large quantity of heat on fixed point as a result thing under consideration can be burned. So, Booster mirror is good choice to increase amount of heat.

2. Glazing:

   In order to transfer the solar energy to the absorber plate, one or more sheets of glass was used. Due to the presence of air layer between the absorber plate and the glass, the transparent cover minimizes convection losses from the absorber plate. It is also helpful in order to reduce radiation losses from the collector because the glass is transparent to the short-wave radiation received from the sun but it is nearly opaque to long-wave thermal radiation emitted by the absorber plate. To absorb the considerable amount of sunlight rays, we must make one surface of the box to be transparent and so we can face the sun to provide heating via the "greenhouse effect." The most commonly used glazing materials are glass and high temperature plastics. Double glazing using either glass or plastic affects both the heat gain and the heat loss. [5] [9]

3. Absorber Plate:

In order to maximize the solar intensity falling on the absorber tray and enhance the heat transfer from the absorber tray to the food in cooking vessels, absorber tray is a key item which allows various modifications.

4. Cooking Equipment:

Cooking pots are used along with the absorber tray to receive the absorbed energy and transfer it to the food. Cooking vessel has different types which can be used in solar cooking device but in general, cylindrical & rectangular shaped cooking vessels made of copper or aluminum are recommended.

5. Heat Storage Material:

Solar cooker has most challenging point that is when the sun goes down, it is not able to work. In order to allow late evening cooking, some researchers performed huge efforts on solar cookers. Phase Change Materials were utilized to resolve this problem.

6. Insulation:

In literature, it is well written that insulation is one of most significant item for a box type solar cooker so it is able to enhance the performance of solar cooker. Materials having low thermal conductivity can be used to reduce the heat losses in solar cookers. However, the main objective to do this should be reducing heat loss from the solar cooker to the environment with minimum cost. In order to enhance interior temperatures in box for cooking, the insulation material with less thermal conductivity and low cost are used to coat side walls and the bottom of the box. There are number of good insulation materials such as feathers, spun fiberglass, Rockwool, cellulose, rice hulls, wool and sawdust. Insulating materials should be utilized in this way so that they allow minimum conduction of heat from the inner box to the outer box structural materials. Cooking temperature can be enhanced by lowering the amount of heat loss with the help of insulation materials.

7. Structural Material:

Structural materials are important so that the box will remain in a given shape and form, and have durability over time. There are large number of examples of structural material, some of which are written such as Cardboard, wood, plywood, bamboo, metal, cement, bricks, stone, glass, fiberglass, woven reeds, rattan, plastic, clay, rammed earth, metals and tree bark.

Methods to Enhance Performance of Solar Cooking Device

There are number of methods/ways to increase the performance of solar cooker. Some methods are listed below:

a. Solar energy absorbed by the solar cooker may be enhanced with the help of a concentrating system such as mirror etc.
b. Absorber trays with high thermal conductivity or coated with black paint should be used in order to increase the efficiency of solar cooker.
c. In order to increase heat transfer from absorber tray to food present in the cooking vessel, absorber plate with extended surfaces can be used.
d. An efficient insulation with low cost should be used to prevent loss of heat from walls of the cooker to the surrounding.
e. Phase change materials should be used in solar box cooker to cook food in case of overcast cloudy weather and late cooking when sunlight is no available.
f. Double Glazed Glass can enhance the performance of solar box cooker.
g. One or more reflectors are used to enhance amount of light into the solar box which is significant increase cooking temperatures. Reflectors increase cooking performance in temperate regions of the world. [5] [7] [8]

8. Heat Principles:

The basic objective of a solar box cooker is to cook food, purify water, and sterilize instruments. Energy coming from the sun is responsible to heat the inside of cooker and so it results in cooking of food. Sunlight enters the solar box through the glass. It turns to heat energy when it is absorbed by the dark absorber plate and cooking pots. This heat input enhances the inside temperature of the solar box cooker to rise until the heat loss of the cooker is equal to the solar heat gain. Temperatures sufficient for cooking food and purifying water are easily achieved.

The following heating principles will be considered first:

a. Heat gain

b. Heat loss

c. Heat storage

a. Heat gain:

Greenhouse effect:

Green House Effect results in the heating of enclosed spaces into which the sun shines through a transparent material such as glass or plastic. Visible light has ability to pass easily through the glass and hence it is absorbed and reflected by materials within the enclosed space. The reflected light is either absorbed by other materials within the space or, because it doesn't change wavelength, passes back out through the glass. Critical to solar cooker performance, the heat that is collected by the dark metal absorber plate and pots is conducted through those materials to heat and cook the food.

Glass Orientation:

Glass orientation is most important factor in enhancing the energy coming from sun and as a result it will increase the cooking temperature of solar box cooker. The more directly the glass faces the sun, the greater the solar heat gain.

Reflectors, Additional Gain:

One or more reflectors are used to enhance amount of light into the solar box which is significant increase cooking temperatures. Reflectors increase cooking performance in temperate regions of the world.

b. Heat Loss:

The Second Law of Thermodynamics states that heat always travels from high to low energy. Heat within a solar box cooker is lost in three fundamental ways:

i. Conduction

ii. Convection

iii. Radiation

c. Heat Storage:

By increasing the density and weight of the materials within the insulated shell of a solar box cooker, the capacity of the box to hold heat will be enhanced. Things with heavy materials present in solar box cooker such as rocks, heavy pans, water, or heavy foods will take long duration to heat up because of this additional heat storage capacity. The incoming energy is stored as heat in these heavy materials which is responsible to slow down the heating of the air in the box. [1]

Rule to Handle Solar Cooker

A good rule of thumb that indicates when the sun is high enough in the sky to allow for efficient cooking is when the length of one's shadow on the ground is shorter than that individual's height. [2]

CHAPTER 3

METHODOLOGY

The inception of this final year project started at least a year ago with the primary purpose to build something innovative, workable and easy to use. The solar cooker was designed, manufactured and tested by keeping in mind the overall requirements according to the needs of market and commercial sector. This section of the report will be divided into several parts covering the span of completion and experimental analysis done as part of the final year project.

Project Plan

The project was executed with an extensive plan formulated on MS Project to distribute resources and workload across the available timeframe. Work Breakdown structure also helped a lot in achieving the milestones within the deadline and use of software enabled us to execute the tasks accordingly within suitable time. Gantt chart and Network diagram provided a detailed image of the project plan and completion of tasks before the deadlines. A proper flow of activities enabled us to perform each and every task within acceptable limits and of proper quality.

Theoretical Analysis

A theoretical analysis based on several governing parameters of the solar cooker was performed keeping in view the several practical constraints involved. A detailed inspection was done using various theories and laws of thermodynamics and heat transfer. The total heat loss from the system was calculated at maximum temperature in order to have an insight of the insulation's type and dimension required.

The internal atmosphere of the device will lose most of the heat through conduction and convection only, because the remaining portion of reflected radiations will get conducted through the small layer of air insulation in between the double glass top. Heat equations were utilized to find out the optimum design dimensions keeping in view the ultimate objective of portability.

1. Calculations:

In order to calculate the total heat loss from the solar cooker, it was assumed that the solar cooker achieved a maximum temperature of 140°C. Each side of the cooker was considered separately and the top was designed with double glass glazing in order to capture the sunlight. Following are some of the governing equations used for the calculation of heat loss:

$$Q_{loss} = \frac{\Delta T}{R}$$

$$\Delta T = T_{in} - T_{out}$$

$$A = L \times W$$

$$R_{conv} = \frac{1}{h \times A}$$

$$R_{cond} = \frac{L}{k \times A}$$

$$R_{total} = \sum R_{cond} + \sum R_{conv}$$

$$Q_{req} = \frac{m \times C \times \Delta T}{t}$$

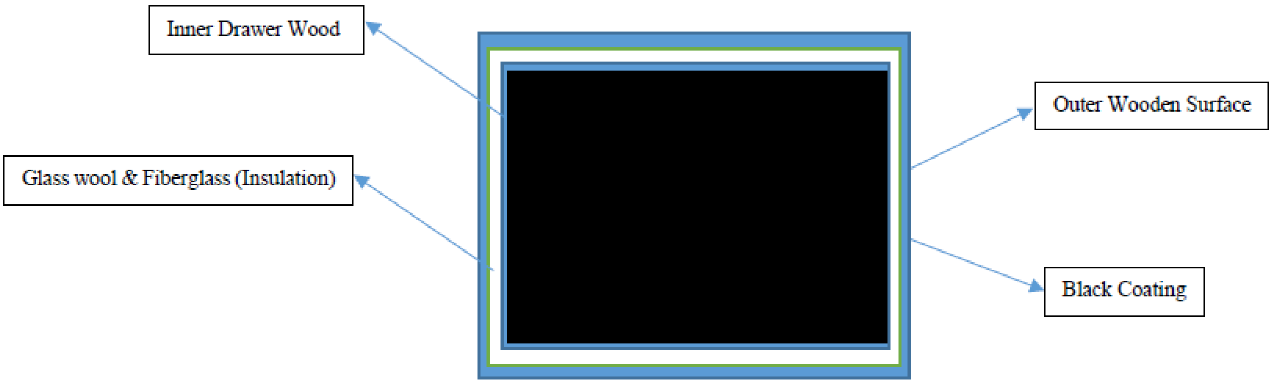


Figure 1: Schematic Diagram

Table 1: Values of Governing Parameters

Parameter (Units)	Numerical Value
$\boldsymbol{h_{air}}\ (\frac{W}{m^2.°C})$	11.086
$\boldsymbol{k}_{\ air}\ (\frac{W}{m.°C})$	0.026
$\boldsymbol{k}_{\ ins}\ (\frac{W}{m.°C})$	0.04
$\boldsymbol{k}_{\ stainless\ steel}\ (\frac{W}{m.°C})$	16.0
$\boldsymbol{k}_{\ wood}\ (\frac{W}{m.°C})$	0.15
$\boldsymbol{k}_{\ glass}\ (\frac{W}{m.°C})$	1.05
$\boldsymbol{d_{ins}}$	0.0127
$\boldsymbol{L}\ (\boldsymbol{m})$	0.3048
$\boldsymbol{W}\ (\boldsymbol{m})$	0.3556
$\boldsymbol{H}\ (\boldsymbol{m})$	0.1397
$\boldsymbol{T_{in}}\ (°\boldsymbol{C})$	140
$\boldsymbol{T_{out}}\ (°\boldsymbol{C})$	25

The total heat loss from all the surfaces of Solar Cooker is:

$$Q_{loss} = 65.17\ W$$

Now, the heat input from sunlight through the double glass glazing can be found out by:

$$Q_{input} = I \times A \times \alpha$$

Table 2: Solar Radiation Data for Islamabad, Pakistan

Month	Air Temperature (°C)	Daily Solar Radiation ($kWh/m^2/d$)	Sunshine hours	Solar Irradiance (W/m^2)	Wind Speed (km/h)
January	6.9	3.18	8	397.5	9
February	9	3.87	8	483.75	8
March	13.9	4.95	10	495	9
April	20.1	6.31	11	573.64	12
May	24.9	7.27	13	559.23	12
June	27.6	7.54	13	580	9
July	25.7	6.44	12	536.67	9
August	24.2	5.72	11	520	8
September	22.4	5.69	11	517.27	6
October	18.6	5.07	11	460.91	8
November	14	3.89	9	432.22	6
December	9.3	2.99	8	373.75	8
Average	18.05	5.24	10.42	494.16	8.67

From given assumed data for Solar Cooker and the average value of solar irradiance in Islamabad, the value of heat input with emissivity of 0.9 comes out to be:

$$Q_{input} = 75.16\ W$$

The above values are a good indication of achieving the required optimum temperature. However, the several environmental factors will also impact the overall performance of the solar cooker. Keeping this in mind, a solar reflector will also be installed on the upper portion of cooker.

During the analysis, the amount of heat required to raise the temperature of 1 liter of water up to 100°C in 60 minutes was calculated to be approximately;

$$Q_{req} = \frac{m \times C \times \Delta T}{t}$$

$$Q_{req} = 5.23\ W$$

After calculating the required dimensions and constraints for the portability, a reverse engineering approach was used for the dimensions of PCM compartment underneath the lower portion. The total allowable value for the compartment volume came out to be approximately 0.00207.

After considerable literature review and consulting the research of the past, it was decided that Stearic acid will be used as a phase change material for the role of facilitator. Following are some of the important properties of this white solid:

Table 3: Stearic Acid Properties

Material Properties (Units)	**Numerical Values**
Melting Temperature (°C)	60-61
Heat of fusion (kJ/kg)	186.5
Thermal Conductivity (W/m.K)	0.172
Density (kg/m^3)	848 (liquid, 70°C)

Using this value, the total mass of the required PCM was calculated by using its density as:

$$m = \rho \times V$$

$$m \cong 1.76\ kg$$

The amount of heat required to raise the temperature of PCM up to its melting point was calculated to be:

$$Q_{req/PCM} = 111.7\ kJ$$

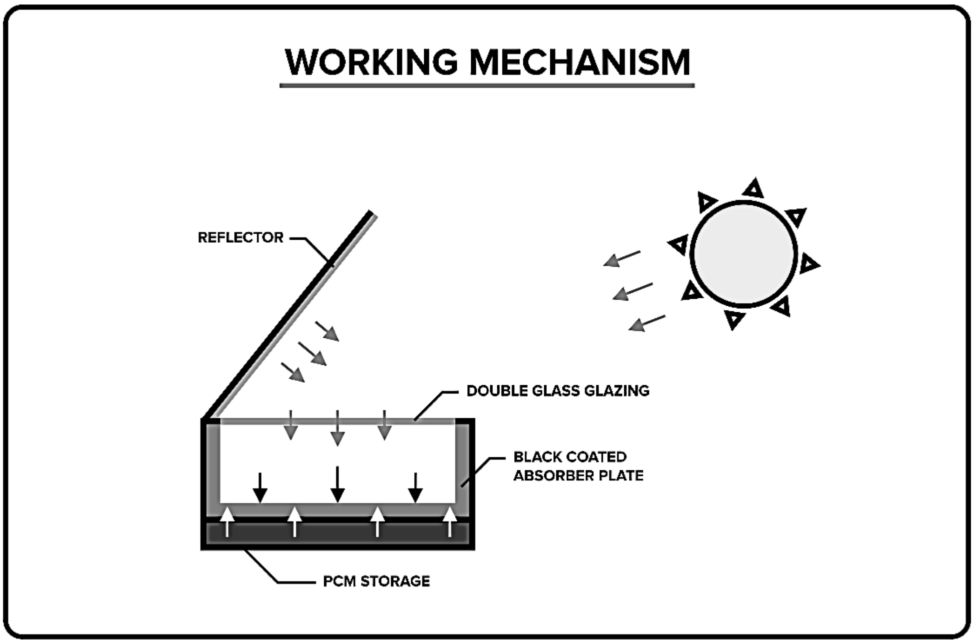


Figure 2: Working Mechanism

2. Parametric Analysis:

A comprehensive parametric analysis was done using Microsoft Excel in order to have a clear picture of certain prime parameters affecting the performance and efficiency of Solar Cooker. Several parameters were kept constant and the impact of certain dimensions was analyzed one by one with the total heat loss. The units involved in this analysis were American for the ease of market research in Pakistan. Following are some of the graphical depiction of our final result which lead to the construction of Solar Cooker with the best possible dimensions and materials:

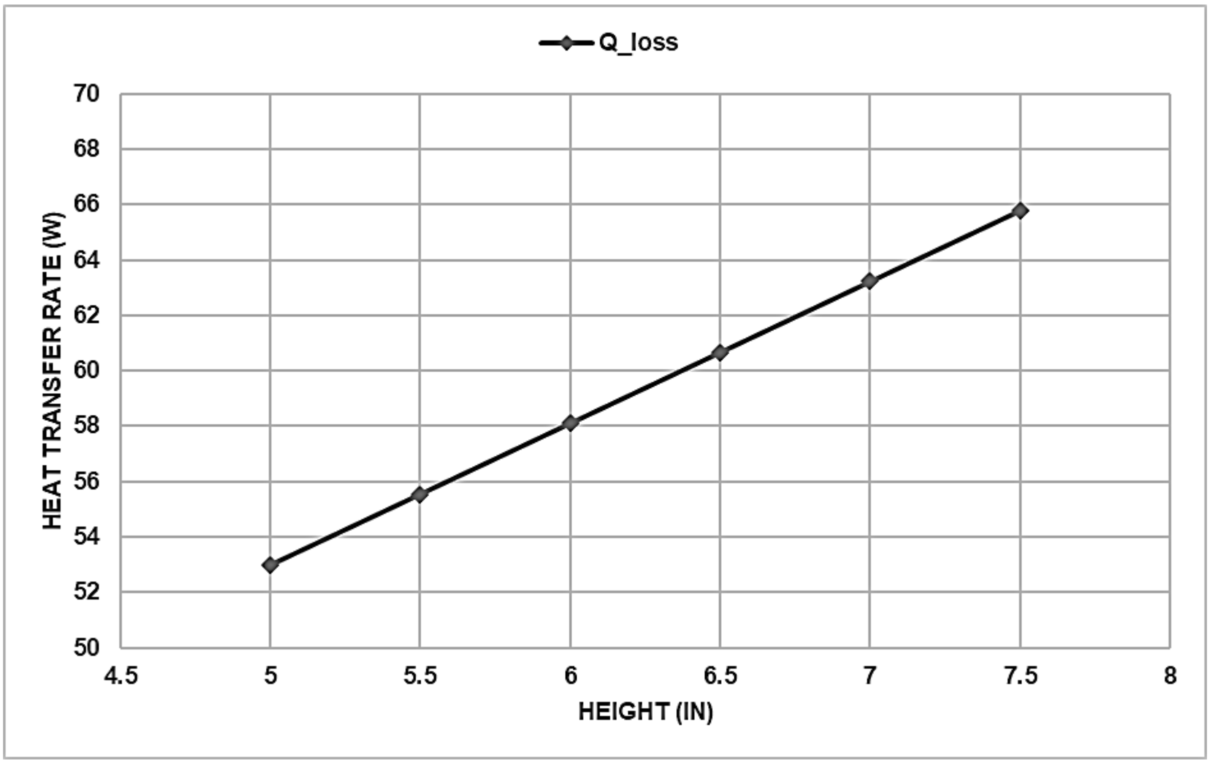
d. Variation in internal height:

The analysis for height involved several parameters which were kept constant and the overall result was obtained:

- **Insulation Material:** Fiberglass/Glass wool
- **Variable Parameter:** Height (5-7.5 in)

Table 4: Constant Parameters

Constant Parameter (Units)	Numerical Value
Length (in)	12
Width (in)	14
Insulation Thickness	0.75
Insulation Conductivity (W/m.°C)	0.04
Assumed Temperature Difference	115



Graph 1: Heat Loss vs. Height

e. *Variation in internal length:*

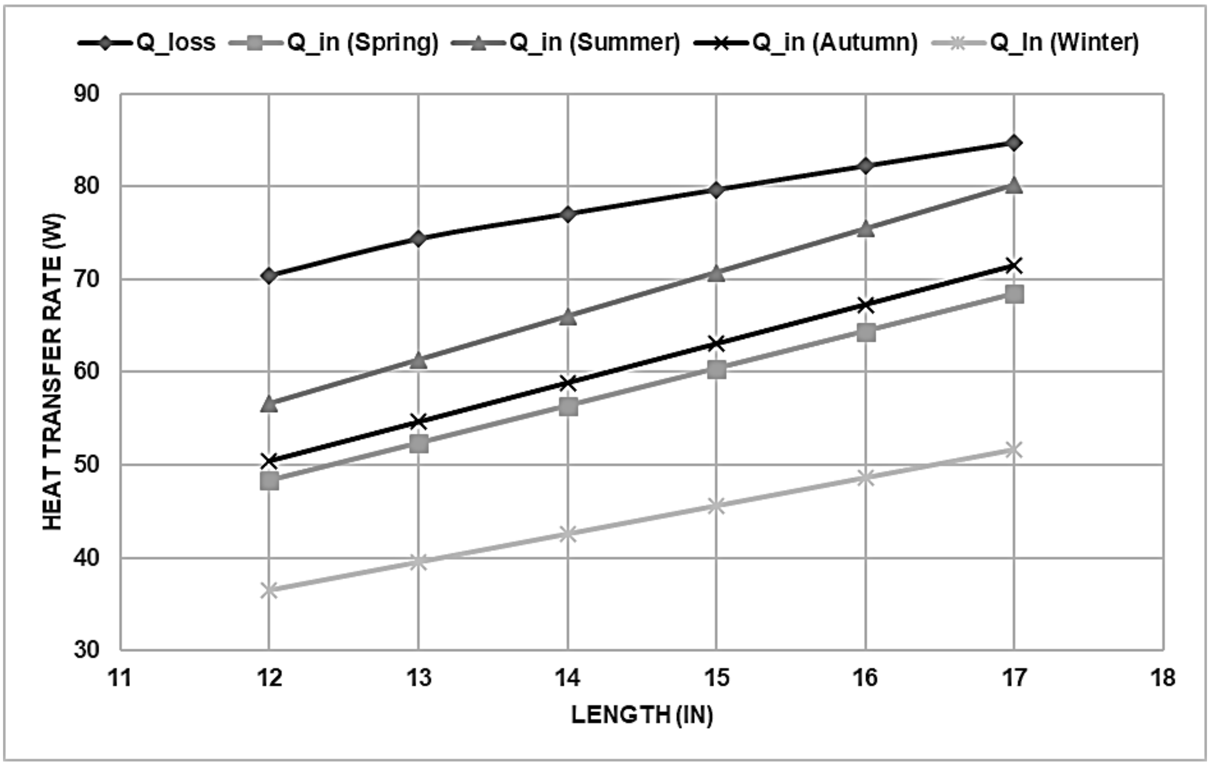
The analysis for length also involved several parameters which were kept constant and the overall result was obtained for different seasons throughout a year:

- **Insulation Material:** Fiberglass/Glass wool

- **Variable Parameter:** Length (12-17 in)

Table 5: Constant Parameters

Constant Parameter (Units)	Numerical Value
Height (in)	5.5
Width (in)	14
Insulation Thickness	0.75
Insulation Conductivity (W/m.°C)	0.04
Assumed Temperature Difference	115



Graph 2: Heat Loss vs. Length

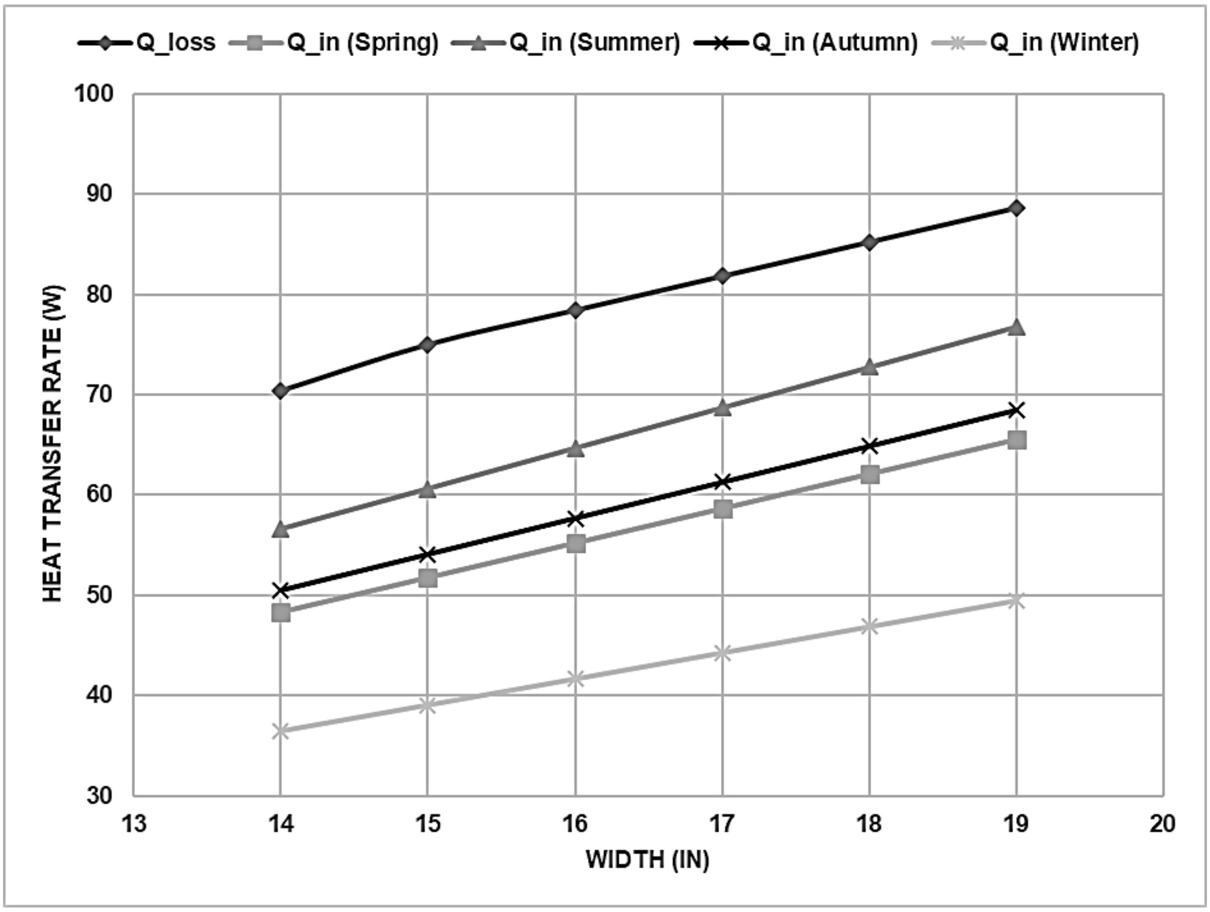
f. Variation in internal width:

The analysis for length also involved several parameters which were kept constant and the overall result was obtained for different seasons throughout a year:

- **Insulation Material:** Fiberglass/Glass wool
- **Variable Parameter:** Width (14-19 in)

Table 6: Constant Parameters

Constant Parameter (Units)	Numerical Value
Height (in)	5.5
Length (in)	12
Insulation Thickness	0.75
Insulation Conductivity (W/m.°C)	0.04
Assumed Temperature Difference	115



Graph 3: Heat Loss vs. Width

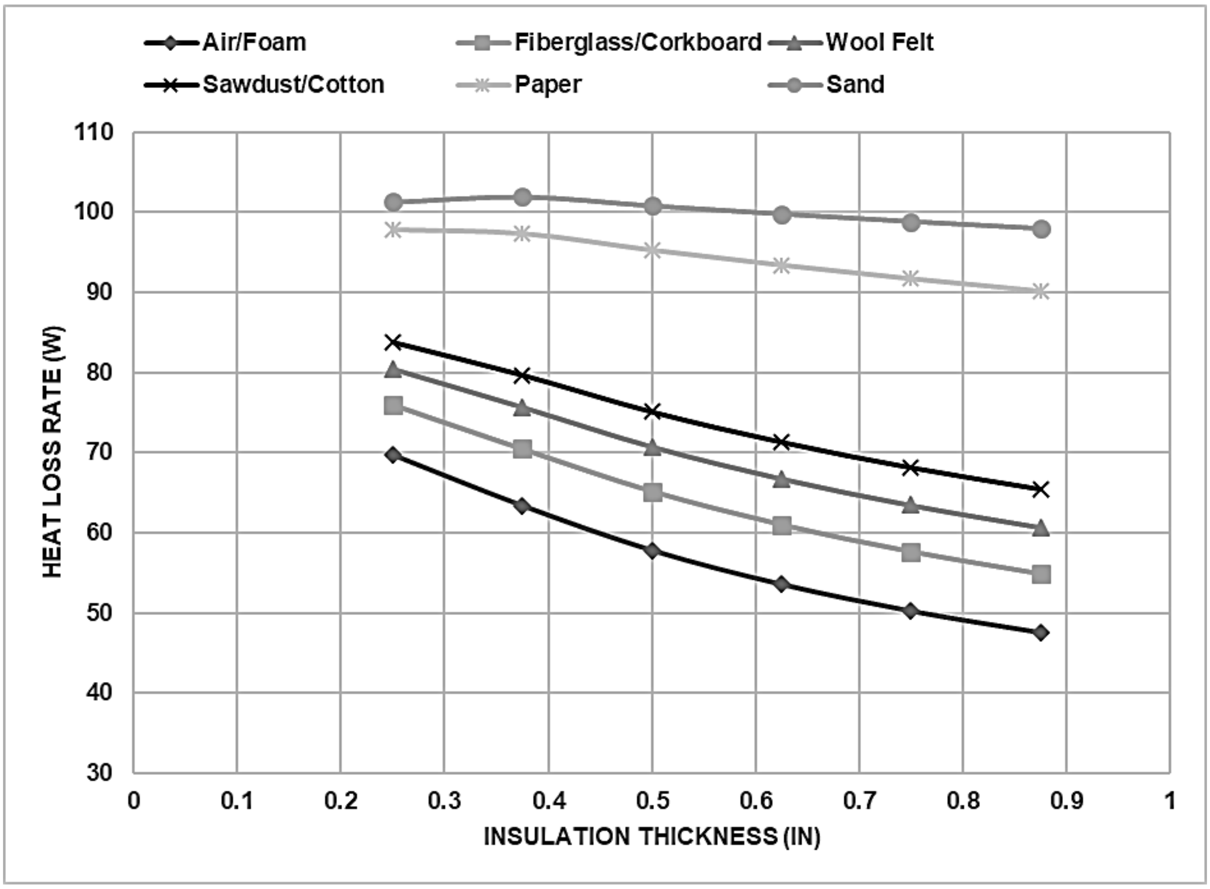
g. Variation in internal width:

The analysis for length also involved several parameters which were kept constant and the overall result was obtained for different seasons throughout a year:

- **Insulation Material:** Several
- **Variable Parameter:** Insulation Thickness (0.25-0.875 in)

Table 7: Constant Parameters

Constant Parameter (Units)	Numerical Value
Height (in)	5.5
Length (in)	12
Width (in)	14
Insulation Conductivity (W/m.°C)	0.04
Assumed Temperature Difference	115



Graph 4: Heat Loss vs. Insulation Thickness

Discussion:

Based on the above theoretical and parametric analysis, it is evident that heat loss depends considerably upon the internal height, insulation thickness and insulation material. These calculations were followed by the final design using the best possible dimensions. The total heat lost was reduced to a minimum while keeping the constraint of portability in mind.

3. Design:

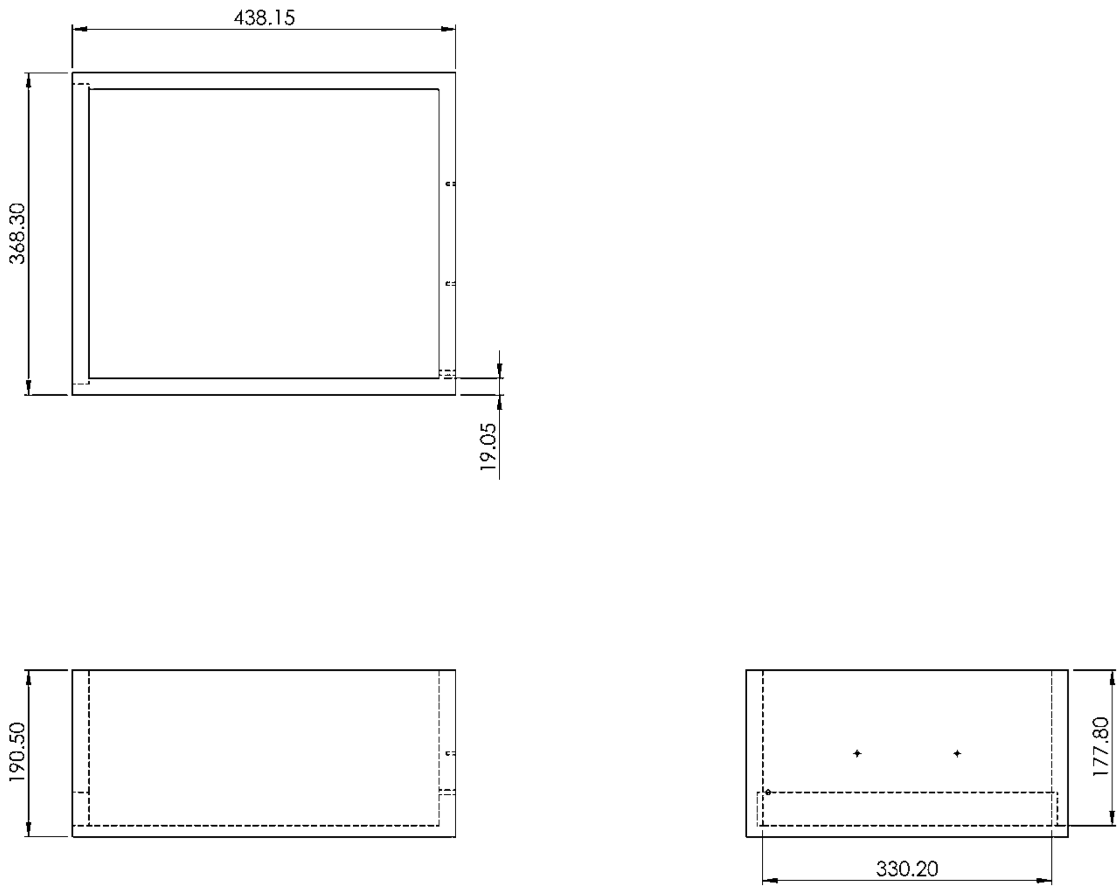
A CAD model was generated using Solid works with the most favorable dimensions. This model formed the basis of our final prototype. The different parts/compartments of the solar cooker are explained/described below with the final dimensions and pictorial views:

a. Internal Box Compartment:

The internal box was constructed with Lasani-Laminated wood, Insulation material and stainless-steel box-type structure. The insulation material was sandwiched between the outer wood and internal SS compartment with a thickness of 0.75 in.

The internal surface of the stainless steel was coated with black spray paint in order to have maximum absorption of radiation with an emissivity value of one. The box is also equipped with a railing system for sliding purposes in connection with the outer box compartment.

A rubber sealing layer was also installed along the edges of the compartment to provide an enclosed system for capturing heat. This box is also equipped with an analog temperature sensor for live indication of PCM storage compartment temperature.



-

Figure 3: Orthographic Views

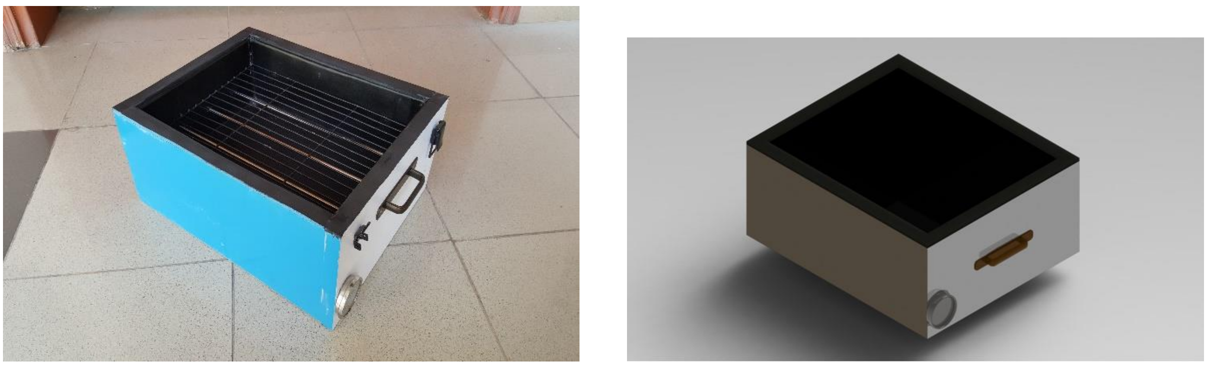


Figure 4: Original and CAD Model

b. Outer Box Compartment:

The inner box casing is designed to slide inside an outer box compartment also built using Lasani-Laminated wood structure. This compartment is designed to have a double glass glazing installed on the upper portion in order to capture the sunlight through greenhouse effect. The double glass glazing has two 3mm simple glass with a thin layer of air sandwiched in between acting as an insulation for heat rays. A mirror reflector is also attached to the compartment through a wooden base structure for directing additional sunlight towards the glass glazing. The box is also equipped with 4 wheels installed at the bottom with an ash wood base (For reducing overall weight) for moving it easily.

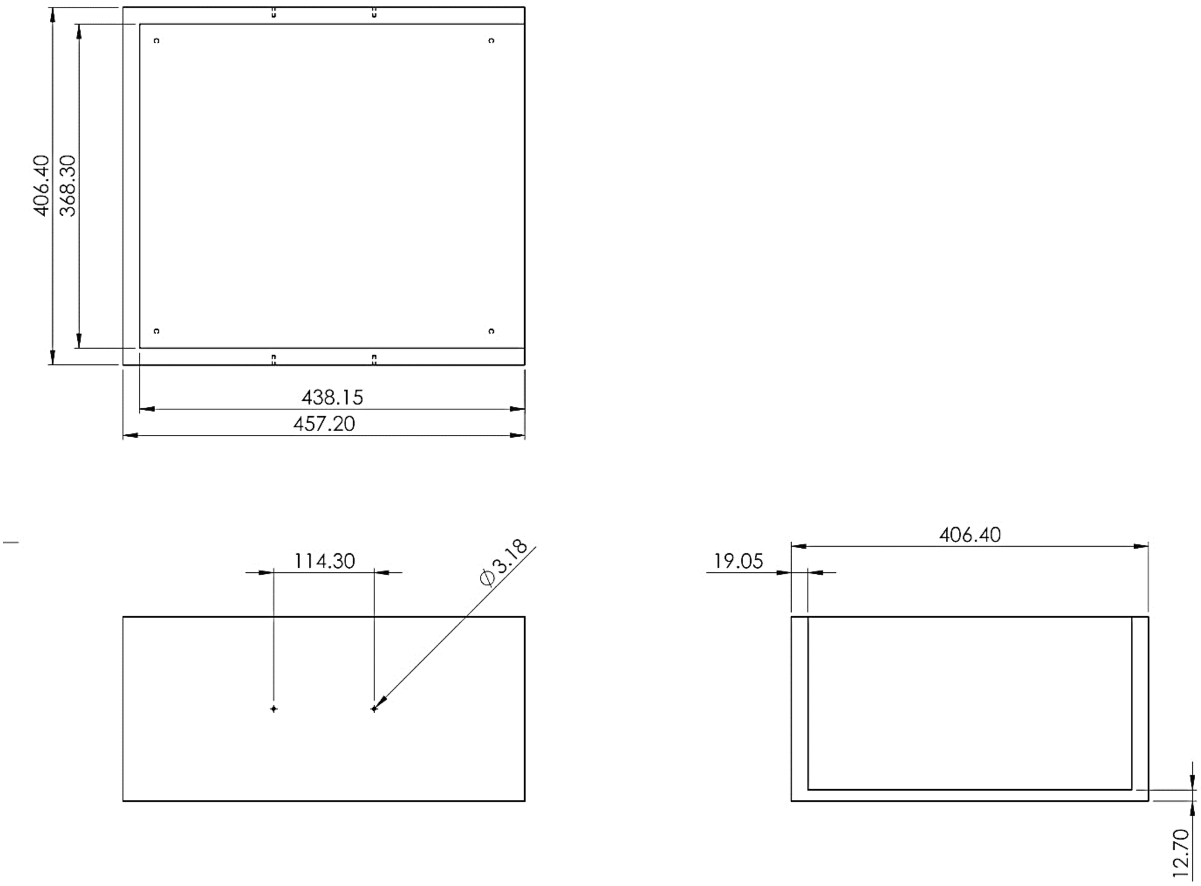


Figure 5: Orthographic View

Figure 6: Original and CAD Model

c. PCM storage compartment:

A stainless-steel compartment merged with a wooden structure filled with insulation is used for storing the stearic acid. The selection was based on low reactivity of SA with stainless steel. This compartment is divided into 4 sections for containing the acid in proportionate amount and allowing the flexibility to have different materials within one storage compartment. A hinge system is used for opening and closing the upper portion of the compartment. Several screws are used for keeping it shut and tight to avoid any spillage of liquid outside the container.

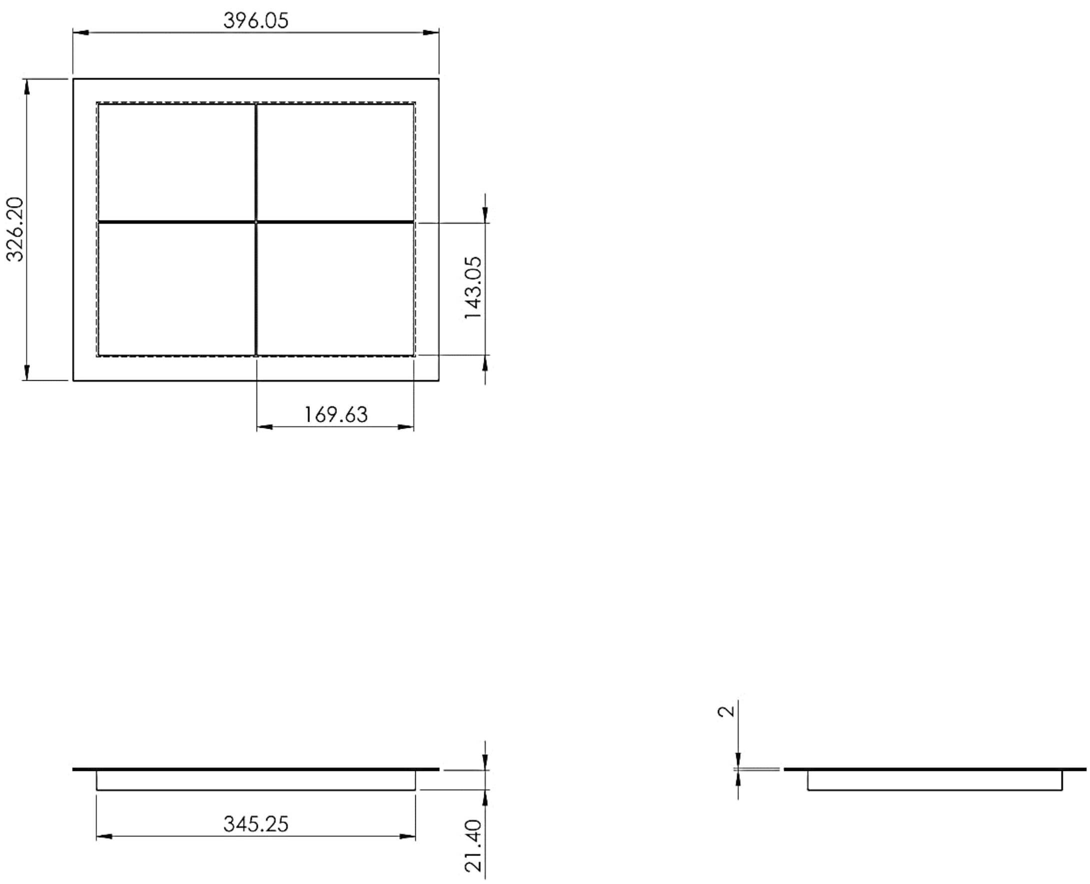


Figure 7: Orthographic Views

Figure 8: Original and CAD Model

d. Phase Change Material:

Phase change material is a kind of material used for storage of heat due to its high heat of fusion. There are numerous materials available throughout the market that can be used to serve this purpose. In our project, the purpose of PCM is to act as a facilitator in case, there is a shortage of heat input. The material will release its stored heat while transitioning from its liquid state.

The choice of stearic acid was made based on several reviews throughout the literature and advantages of fatty acids upon other different materials available.

Figure 9: Stearic Acid

CHAPTER 4

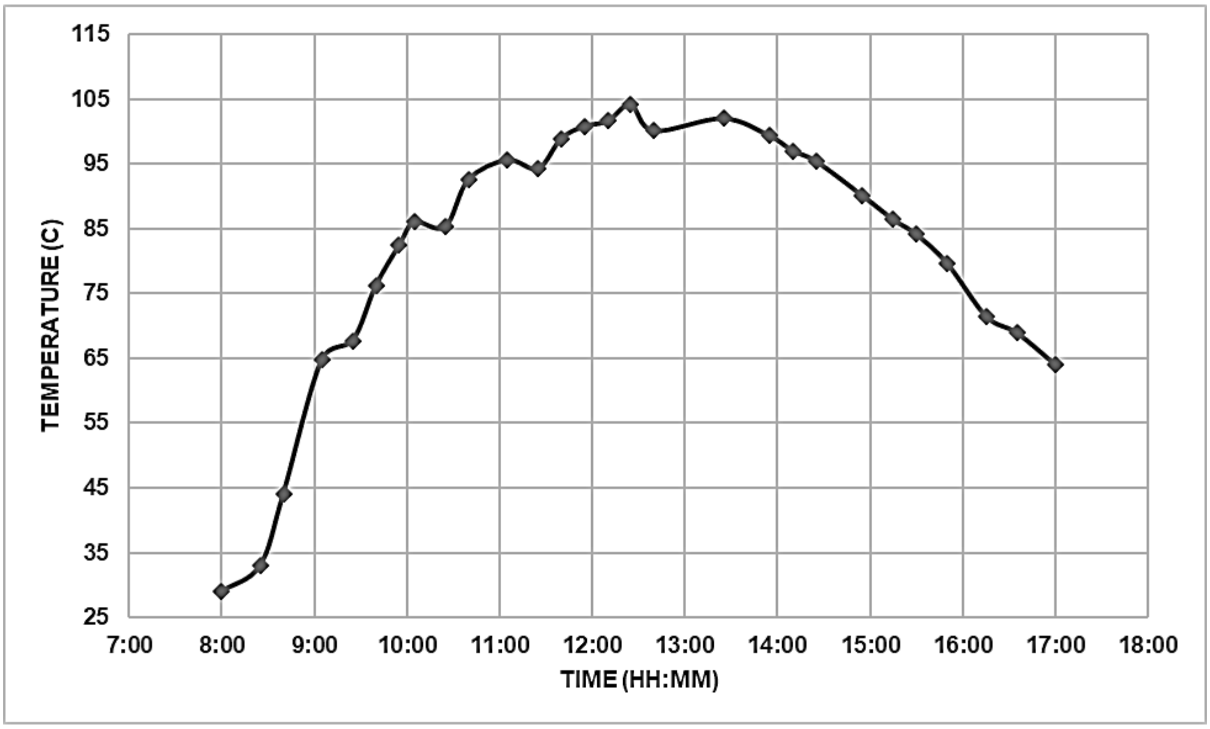
RESULTS

After the completion of project, a detailed experimental analysis was done to have an in-depth picture of several governing parameters. The overall testing was based on internal environmental temperature (air) and water boiling. Most of the testing was done in the month of April and May within the premises of Islamabad, Pakistan.

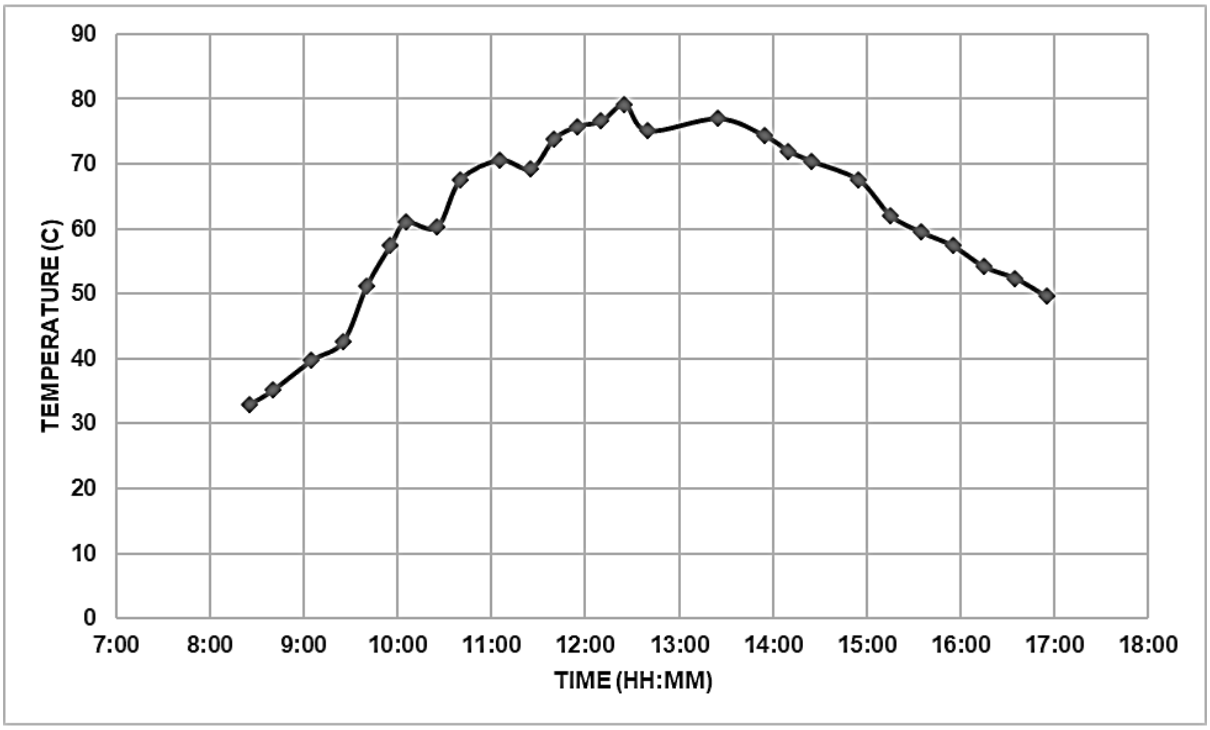
1. **Test-A:**

This test was performed on 26-April-2017 from 8 AM in the morning to 5 PM in the evening and the temperature variation was measured at 20 minute intervals. The PCM compartment was kept empty and the reflector of SC was covered with a sheet in order to have an indication of performance change with its exclusion.

- PCM Compartment: Empty
- Reflector: Covered (Excluded)
- $\mathbf{T_{envm}} = 28 - 33°\text{C}$
- $\mathbf{T_{max/int}} = 104.1°\text{C}$
- $\mathbf{T_{max/PCM}} = 79.1°\text{C}$



Graph 5: Temperature vs. time (Internal Compartment)

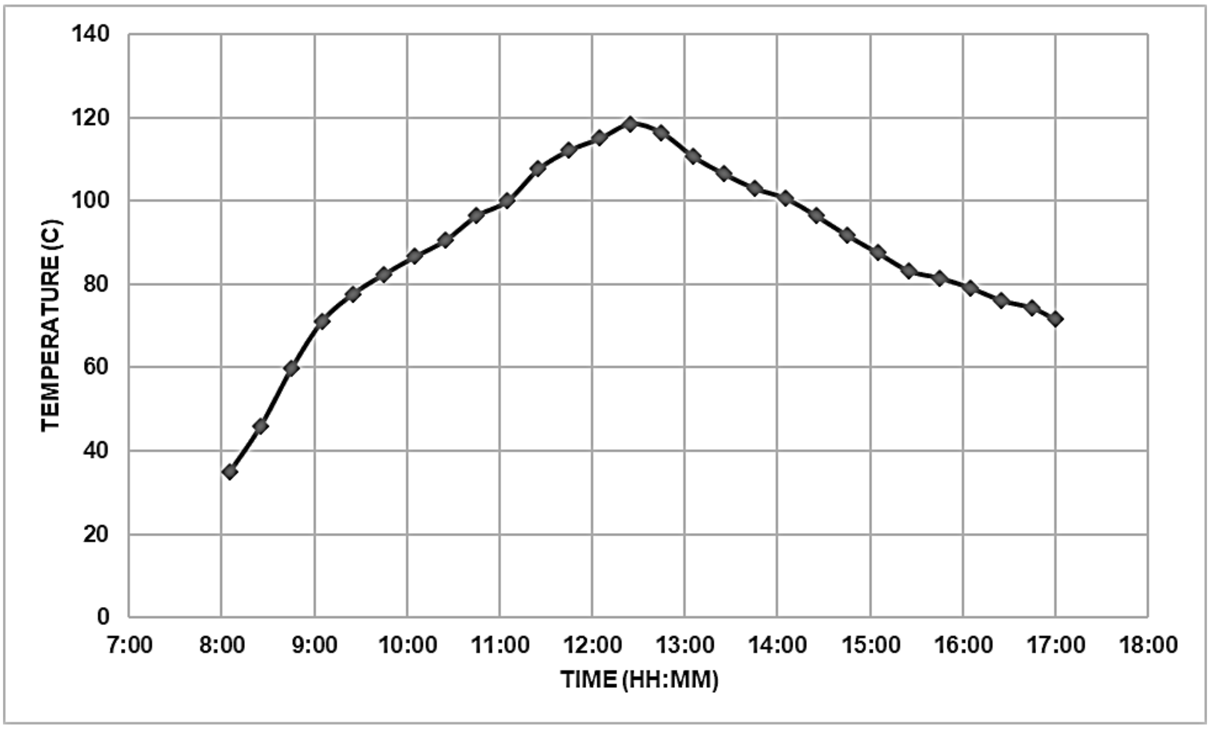


Graph 6: Temperature vs. time (PCM Compartment)

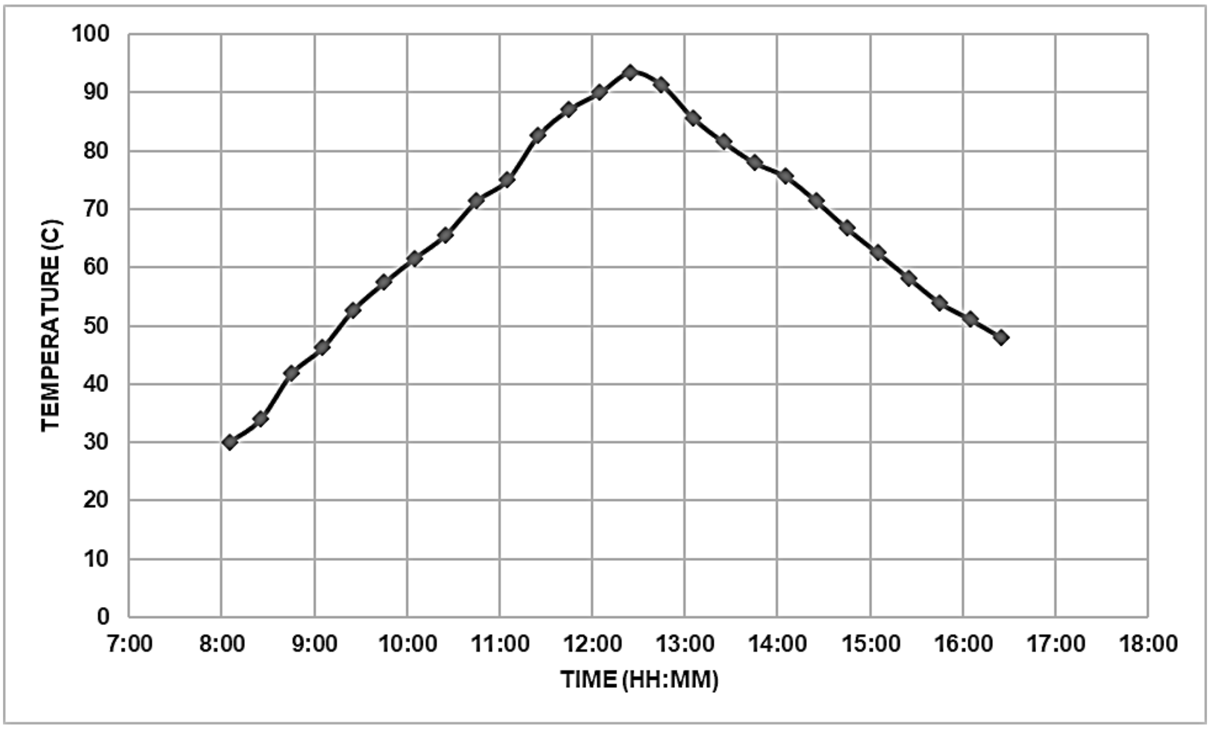
2. Test-B:

This test was performed on 05-May-2017 from 8 AM in the morning to 5 PM in the evening and the temperature variation was measured at 20 minute intervals. The PCM compartment was kept empty and the reflector of SC was exposed to the sunlight in order to have an indication of performance change with its inclusion.

- **PCM Compartment:** Empty
- **Reflector:** Exposed (Included)
- $\mathbf{T_{envm}} = 28 - 35°C$
- $\mathbf{T_{max/int}} = 118.5°C$
- $\mathbf{T_{max/PCM}} = 93.5°C$



Graph 7: Temperature vs. time (Internal Compartment)

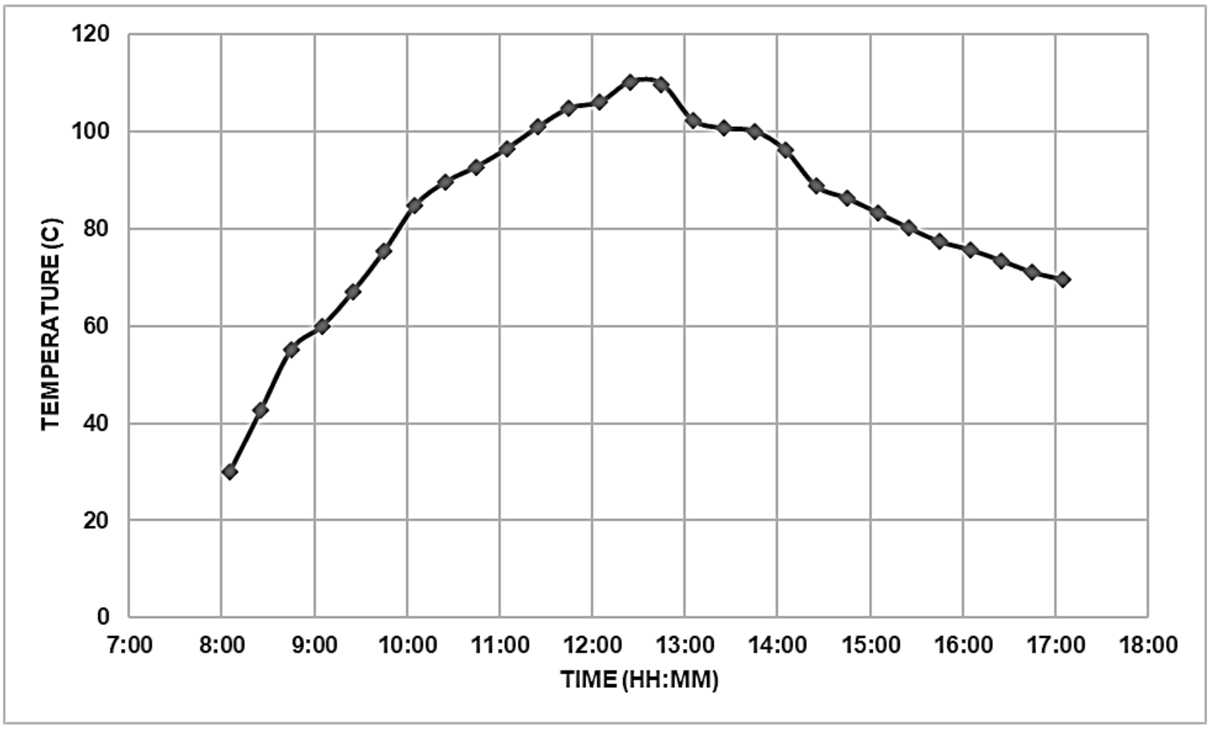


Graph 8: Temperature vs. time (PCM Compartment)

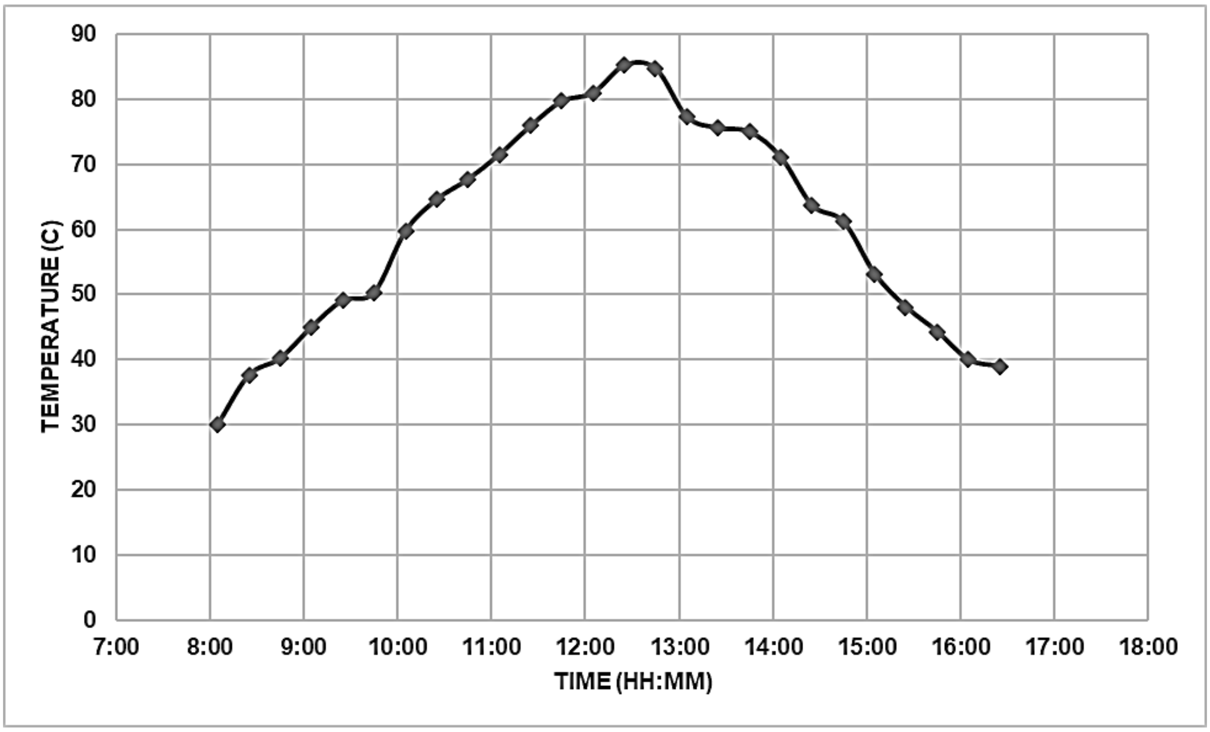
3. Test-C:

This test was performed on 11-May-2017 from 8 AM in the morning to 5 PM in the evening and the temperature variation was measured at 20 minute intervals. The PCM compartment was filled with SA and the reflector of SC was covered with a sheet in order to have an indication of performance change with its exclusion. The effect of PCM addition was analyzed.

- **PCM Compartment:** Filled (Stearic Acid)
- **Reflector:** Covered (Excluded)
- $\mathbf{T_{envm}} = 28 - 36°\text{C}$
- $\mathbf{T_{max/int}} = 110.2°\text{C}$
- $\mathbf{T_{max/PCM}} = 85.2°\text{C}$



Graph 9: Temperature vs. time (Internal Compartment)

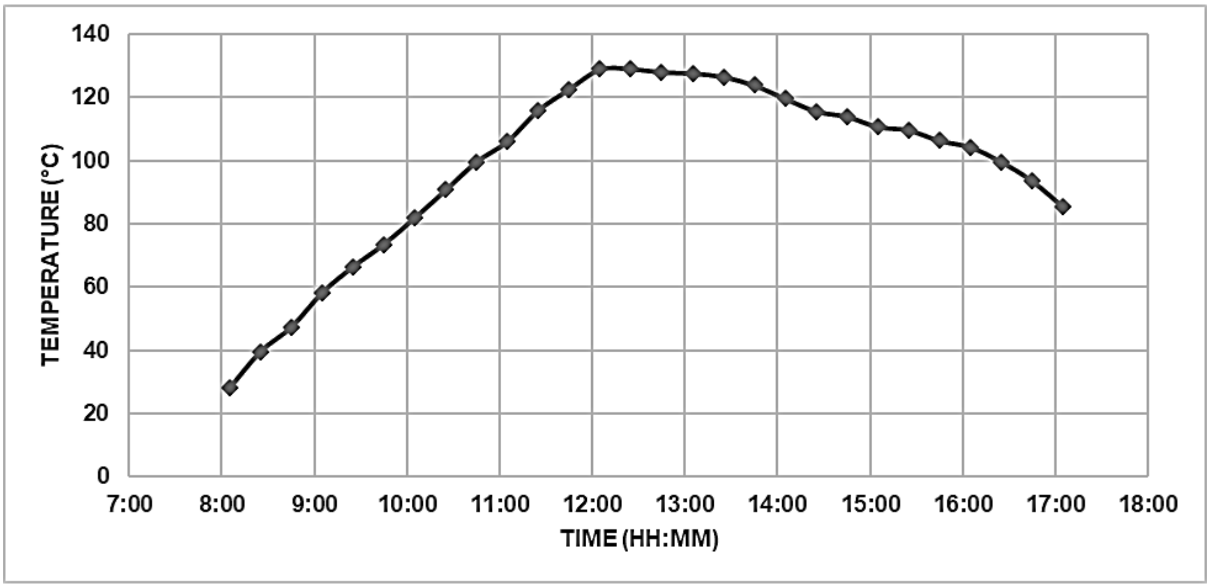


Graph 10: Temperature vs. time (PCM Compartment)

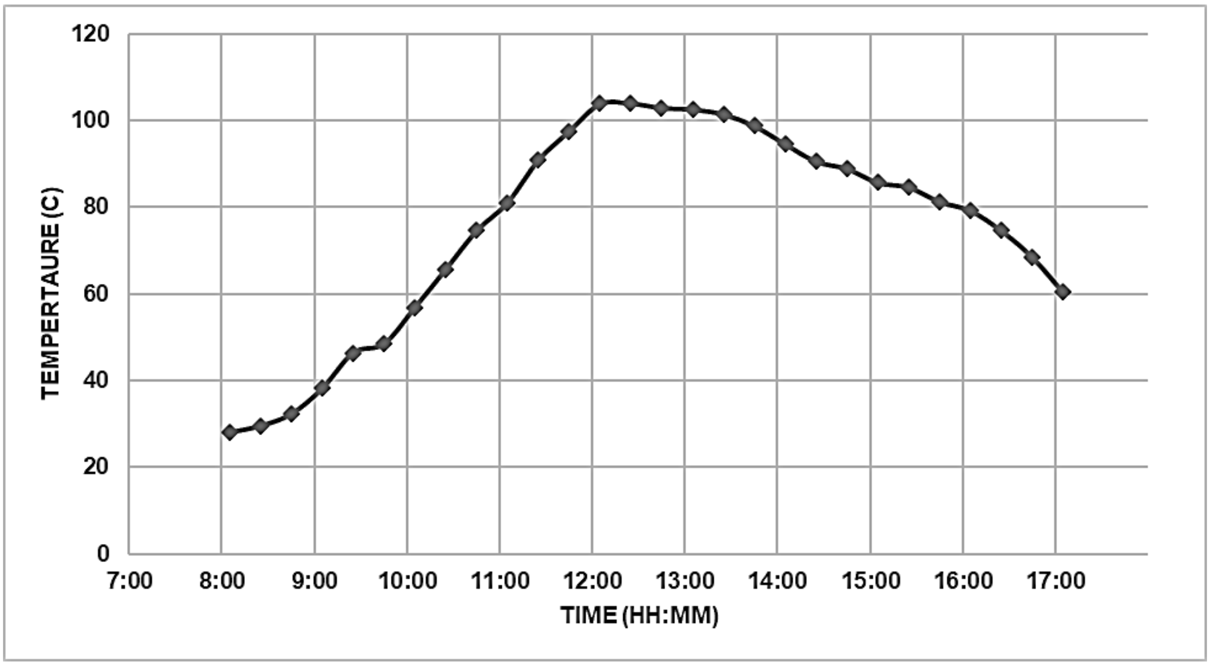
4. **Test-D:**

This test was performed on 15-May-2017 from 8 AM in the morning to 5 PM in the evening and the temperature variation was measured at 20 minute intervals. The PCM compartment was filled with SA and the reflector of SC was exposed to the sunlight in order to have an indication of performance change with its inclusion. The effect of PCM addition was also analyzed.

- **PCM Compartment:** Filled (Stearic Acid)
- **Reflector:** Covered (Excluded)
- $\mathbf{T_{envm}} = 28 - 36°C$
- $\mathbf{T_{max/int}} = 129.0°C$
- $\mathbf{T_{max/PCM}} = 104.0°C$



Graph 11: Temperature vs. time (Internal Compartment)



Graph 12: Temperature vs. time (PCM Compartment)

CHAPTER 5

CONCLUSION

From above calculations and graph drawn, we conclude that major factors that are affecting the value of heat loss are height of solar box cooker, thickness and conductivity of insulation. In order to get the optimum performance out of this device, it is suggested that by decreasing the height and increasing the thickness of insulation, we will get considerable reduction in heat loss.

It is also concluded that changing the insulation material will also affect the heat loss and operation of Solar Cooking Device. Using fiber glass & glass wool as an insulation material can be very beneficial for making a significant reduction in heat loss. Hence, by making use of these important points, we will be able to decrease the value of heat loss significantly. Heat input throughout the day will also vary according to the intensity of solar radiation. Solar reflector will be used to capture additional sunlight thus adding more heat to the system.

According to the four tests taken with the solar cooker, we conclude that the without reflector and phase change material solar cooker give us less temperature and it takes much amount of time to rise but with the addition of reflector we get high temperature and also rise in temperature takes short time. Now with the addition of Phase change material in solar cooker but without reflector, the temperature is also increased and this rise takes long time as compared to other tests done before it. Then after these tests we have a final test where we use both reflector and phase change materials, this gives us an optimum condition means we get maximum temperature rise and it requires lesser time to increase.

According to the cost analysis done by us, it is known that payback period of the solar cooking device is 6 months in case of electrical oven which consumes 2400 kW of energy for an hour and also in case of Liquefied Petroleum Gas (LPG) which consumes almost 3300 kJ of energy for an hour, it is almost one year and three months.

Now finally we discuss about carbon emission produced by cooking in domestic sector. The amount of carbon dioxide released from cooking is equal to 0.202 $CO2$ / MWh * 20.000Mwh = 4.040 which is 2.2% of total annual emissions. Plants are necessary to remove carbon dioxide emissions. Almost 675,000 trees are required to absorb carbon dioxide emitted from cooking.

CHAPTER 6

RECOMMENDATIONS

Solar cooking device will reduce the overall emission of carbon contents in the environment as a result of fossil fuel burning. Moreover, it will also save the energy consumed by electrical and gas cookers. The designed and complete manufactured box type solar cooking device will have lots of modifications in the future. An addition of automatically controlled solar reflector with the incident radiations of sun will also increase the efficiency by an appropriate amount. Temperature achieved by this device will not be high enough for burning the food and hence will omit the requirement of a controller to maintain temperature within normal range. In the future, the effect of different phase change materials on cooking will be tested and from these tests, a performance analysis of PCMs will be obtained. It should also be noted that the addition of rotating barbecue rods will have no impact on the cooking performance as the overall environmental heat will be same throughout the cooker.

WORKS CITED

[1] Aalfs, M. (2010). Principles of Solar Box Cooker Design. *Solar Cookers International Network (SCInet)*.

[2] Akoy, E. O., & Ahmed, A. I. (2015). Design, Construction and Performance Evaluation of Solar Cookers. *Journal of Agricultural Science and Engineering*, 75-82.

[3] Chaudhari, V. N., Rathod, M. K., & Chaudhari, K. A. (2013). Stearic Acid as Phase Change Material: Thermal Reliability Test and Compatibility with some Construction Materials. *International Journal of Engineering Research and Technology*.

[4] Chuah, T. G., Rozanna, D., Salmiah, A., Thomas Choong, S. Y., & Sa'ari, M. (2006). Fatty acids used as phase change materials (PCMs) for thermal energy storage in building material applications. *Applied Energy*, 123-137.

[5] Cuce, E., & Cuce, P. M. (2013). A comprehensive review on solar cookers. *Applied Energy*, 1399-1421.

[6] Cuce, E., & Cuce, P. M. (2015). Theoretical investigation of hot box solar cookers having conventional and finned absorber plates. *International Journal of Low-Carbon Technologies*, 238-245.

[7] El-Sebaii, A. A., & Ibrahim, A. (2005). Experimental testing of a box-type solar cooker using the standard procedure of cooking power. *Renewable Energy*, 1861-1871.

[8] Folaranmi, J. (2013). Performance Evaluation of a Double-Glazed Box-Type Solar.

[9] Saxena, A., Varun, Pandey, S. P., & Srivastav, G. (2011). A thermodynamic review on solar box type cookers. *Renewable and Sustainable Energy Reviews*, 3301-3318.

[10] Zamani, H., Kianifar, A., Moghiman, M., & Mamourian, M. (2015). Experimental Study of a Double-Exposure Solar Cooker based on the Parabolic and Flat Reflected Surfaces. *International Journal of Advanced Renewable Energy Researches (IJARER)*.

APPENDIX I: PROPERTIES OF STEARIC ACID

Properties of Stearic Acid	
Chemical formula	$C_{18}H_{36}O_2$
Molar mass	284.48 g·mol^{-1}
Appearance	White solid
Odor	Pungent, oily
Density	0.9408 g/cm^3 (20 °C) 0.847 g/cm^3 (70 °C)
Melting point	69.3 °C (156.7 °F; 342.4 K)
Boiling point	361 °C (682 °F; 634 K)
Solubility in acetone	4.96 g/100 g
Solubility in chloroform	18.4 g/100 g
Solubility in toluene	15.75 g/100 g
Vapor pressure	0.01 kPa (158 °C) 0.46 kPa (200 °C) 16.9 kPa (300 °C)
Thermal conductivity	0.173 W/m·K (70 °C) 0.166 W/m·K (100 °C)
Refractive index (n_D)	1.4299 (80 °C)
Specific heat capacity (C)	501.5 J/mol·K
Standard molar entropy (S^o_{298})	435.6 J/mol·K
Standard enthalpy of formation ($\Delta_f H^o_{298}$)	−947.7 kJ/mol
Standard enthalpy of combustion ($\Delta_c H^o_{298}$)	1129

APPENDIX II: THERMAL CONDUCTIVITIES OF MATERIALS

Material	Thermal Conductivity (W/m.K)
Air	0.024
Cotton	0.04
Wool Felt	0.04
Fiberglass	0.04
Glass	1.05
Glass Wool	0.04
Paper	0.05
Sand	0.25
Sawdust	0.08
Stainless Steel	16
Styrofoam	0.033
Ash Wood	0.16