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Design and Experimental Studies of a Funnel Solar Cooker with Phase Change Material

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Abstract: Solar cookers can greatly reduce the overall carbon footprint of the cooking done in India. In the present work a funnel-type solar cooker is designed using cardboard. After making the solar cooker it is then analyzed on the various performance metrics namely the figures of merit, efficiency value and Cooker Opto–thermal Ratio (*COR*) which are dependent parameters. Paraffin wax which is a phase change material (PCM) is also incorporated in the testing process to evaluate the overall improvement in the thermal efficiency of the solar cooker. The time taken to break is also calculated. The experimental results show that the solar cooker is capable of reaching a temperature of 125 °C. From the results it can also be seen that using paraffin wax also offers significant improvement in the overall thermal efficiency. The results are tested on various parts of India considering the major cities such as Chennai, Trivandrum, Kanpur and Delhi with the ANN model, which is a deep learning model. The advantage of this model is that it can forecast and estimate the temperature of the absorber plate and water from weather forecasting data which is used to calculate F1 and F2 metrics for the performance of the solar cooker. For all the cities, the model's R2 value is greater than 99% and RMSE values are small.

Keywords: *COR*; figures of merit; phase change material; break even

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1. Introduction

Cooking is an activity that is done by almost all of the people. Gas stove is the workhorse of millions of kitchens. The fuels used in cooking are natural gas, LPG, electricity, wood etc. Though LPG and electricity are clean sources for cooking food, most people in India do not have access to LPG and electricity due to various reasons.

About two-thirds of India still uses wood and dung-based fuel for cooking. This creates a huge amount of carbon dioxide and other greenhouse gases into the atmosphere. This is not only harmful to the environment but also to the person who is working in the kitchen and is inhaling these harmful gases.

People living in cities have access to LPG and electricity, but the constant increase in prices of LPG and electricity has put large stress on the financial stability of the people. On paper, LPG may appear to be a clean source of energy for cooking but in reality it is not because recent research shows that large amounts of methane leaks into the environment during the process of extracting and making it available in the homes of people [1]. Methane can cause serious damage to the climate as it is a more potent greenhouse gas than carbon dioxide. Gas stoves have a huge impact on the indoor air quality too. There are various guidelines for maintaining the outdoor air quality, but there are none for indoor air quality. It has been seen that gas combustion produces about twice as much PM2.5 particles than the electric option. It also produces nitrogen oxides, carbon monoxide and formaldehyde, which are all major health risks if not managed properly [2]. Using ventilation may help, but it is not enough.

Therefore, electricity seems to be a good alternative to LPG, but it has its own disadvantages too. In India, most of electricity is produced using coal, 44% to be precise [3]. This puts a huge question mark on the environmental impact of electricity as a source of cooking. Large numbers of the regions in India are prone to load shedding. With an increase in electric vehicles in India the demand for electricity has increased, thus putting more strain on the current electricity supply. To meet this demand, more coal needs to be burned thus making electricity equivalent to burning coal for cooking. The other disadvantage of using electricity as a source of energy for cooking is the constant increase in price which further increases the burden on the earnings of a common man.

One cannot phase out the current methods of cooking overnight. It is not only impossible but also not a very efficient way to deal with the problem. Better way to deal with the problem is to find alternative sources of energy for cooking. These alternative sources can work with the current methods and thus reduce the burden on the LPG and simultaneously have no impact on the environment. Solar cookers provide a good alternative for this problem. Using solar cookers for cooking is a good option in India, as India receives large amounts of solar energy for the majority of the year. Using a solar cooker, one can not only reduce the greenhouse gas emissions but can also reduce the load on the fossil fuel reserves such as natural gas, which are widely used for cooking and coal, which is used to produce the electricity used for cooking. Solar cookers can provide us with some time to find better or alternative sources for cooking, which can help us to phase out the conventional methods of cooking which are damaging the climate.

There are three basic types of solar cookers, viz., box-type, panel-type and the concentrator-type [4]. Box-type solar cooker is just a simple box which has been painted black on the inside with few mirror reflectors on top to direct sunlight inside the box, which also has space for a vessel in which the food will be kept. Box-type solar cookers are easy to use and maintain and are inexpensive too. However, box-type solar cookers have a long cooking time. Panel-type cooker is in which the sunlight is reflected on the vessel using an array of reflecting panels thus increasing the solar irradiance incident onto the vessel. These are not compact as compared to box-type solar cookers but are able to reduce the cooking time since the area on which sun rays fall is increased. Funnel-type solar cookers fall under this category of solar cooker. Lastly we have the concentrator-type solar cooker. These are most efficient and also expensive. These can also attain very high temperatures. The basic principle is that sunlight is concentrated on a small area using a highly polished parabolic mirror or using Fresnel lens. This makes the small area extremely hot, thus providing the energy required for cooking. The cooking time is reduced a lot. The main problem with these types of solar cookers is that they are expensive and cannot be affordable for people in developing countries who don't have access to the conventional methods of cooking.

All the above solar cooker designs can be used to cook food directly or indirectly. In direct method cooking, the food is kept in a vessel and the solar irradiation is used to heat the vessel which cooks the food. Though the direct cooking method is simple and not different from the conventional cooking methods, it is not that efficient. In an indirect cooking method, a substance called Phase Change Material is heated using solar irradiation. Then, the heat stored in this material is used to cook food. This method provides the capability of storing heat in the form of latent heat and can help in decreasing the cooking time of the solar cooker. Though indirect cooking methods increase the overall cost of the solar cooker, the improvements in the efficiency are more worthy than the increase in cost.

Therefore, this study aims to design a funnel-type solar cooker. The reason to choose a funnel-type solar cooker is because these are cheap to make and are capable of performing close to box-type solar cookers.

In a study conducted by Jonah Chepkurui, the funnel-type solar cooker which is a panel-type solar cooker is evaluated with various funnel lengths [5]. Various funnel lengths are made and then tested on the same test load. It was observed that the longer the funnel length, higher temperature is observed. The maximum temperatures of 93 °C, 84 °C, 68 °C and 58 °C for the funnel lengths of 50 cm, 42.6 cm, 32 cm and 23.3 cm, respectively, were achieved at average solar intensity of 684 W/m^2. As the funnel lengths increased from 23.3 cm to 50 cm, the thermal efficiency of the cooker increased from to 29.2% to 33.2% due to increased solar collecting surface.

Hassan [6] tried to optimize the reflector position by changing the shape of the reflector depending on the position of the sun during the day. With this concept the efficiency of the solar cooker is improved as compared to a static funnel reflector. Maximum temperature of 93 °C was obtained. Solar cooker efficiency improved as compared to a static funnel-type solar cooker.

In the study done for the development of solar cooker using fresnel lens as a concentrator by Yunsheng Zhao [7], we can see that the temperature up to 360 °C can be achieved thus shortening the cooking time and also providing frying and baking capabilities. The fresnel lens needs to be adjusted relative to the position of the sun to maximize the cooking time and temperature. Thus, an adjusting mechanism is provided in the stand. The collector used is an evacuated tube as used in the solar water heaters. The shortest time of 34 min was obtained for lean cooked pork at average solar intensity of 714 W/m^2. This solution is efficient, but the components such as Fresnel lens and evacuated tubes are expensive, thus making it not feasible in developing countries.

In a study on the performance of solar funnel cookers by Pagoaga et al. [8], two identical solar cookers are tested One cooker has a normal cooking pot, the other has a pot which is inside the glass enclosure. The other objective is to reach a temperature above the boiling point of water, and this is tested using glycerine as a test load. Using glycerine as test load temperatures above boiling point of water were obtained. Using a glass enclosure around the cooking pot higher temperatures were obtained as compared to the other without the glass enclosure. The temperature when using the glass enclosure was 154.5 °C when not using it was 124.5 °C. The glass enclosure also improved the efficiency of the cooker from 10.2% to 11.8%. The study also shows that funnel-type cookers can also reach temperatures above the boiling point of water.

In the study carried out by Gupta et al. [9] to develop solar cooker with cheap materials such as polypropylene sheets, it can be seen that the performance of the panel cooker is comparable to the standard box-type solar cooker, but the decrease in cost is what makes it attractive.

Mawire et al. [10] conducted tests using a concentrator-type solar cooker using two vessels. One of the vessels had sunflower oil for sensible heat storage. The other had a Phase change material. Both the vessels were tested under identical conditions. The findings showed that the vessel with phase change material (PCM) outperformed the other during off sunshine periods because of lower temperature drops. This shows that to increase the cooking time after the sunset PCM is better for storing heat.

Macmanus Chinenye Ndukwu et al. [11] reviewed the exergy analysis of solar thermal systems such as hybrid solar water heaters, solar still and space heating systems, solar dryers/heaters and solar cooking systems integrated with phase change materials based on the exergy equations and reported that, when paraffin wax was used as a phase change material for solar cooker, there was an increase in exergy efficiency

In the various literature discussed above, it was evident that the funnel-type solar cooker is viable for use as a cooking alternative. In the above studies, we saw that, by carrying out various modifications in the normal funnel solar cooker design, one can achieve a higher temperature by using fresnel lens and shorten the cooking time. One can change the shape of the reflector according to the position of the sun to optimize the collection of solar irradiation. We have also seen improvement in the overall efficiency of the solar cooker when using the longer funnel and when using the vessel inside the glass enclosure. However, there is a lack of study on using PCM with funnel-type solar cookers. PCM can offer significant performance advantages with the cheap design of funnel-type solar cookers. Therefore, we aim to study this aspect in the present work and evaluate the performance benefits utilizing deep learning models.

2. Models and Methods

In this study, we have to design and construct the funnel solar cooker. Then, experimental data need to be collected to perform the analysis and to find the performance metrics such as Figures of Merits, thermal efficiency and *COR*-dependent parameters.

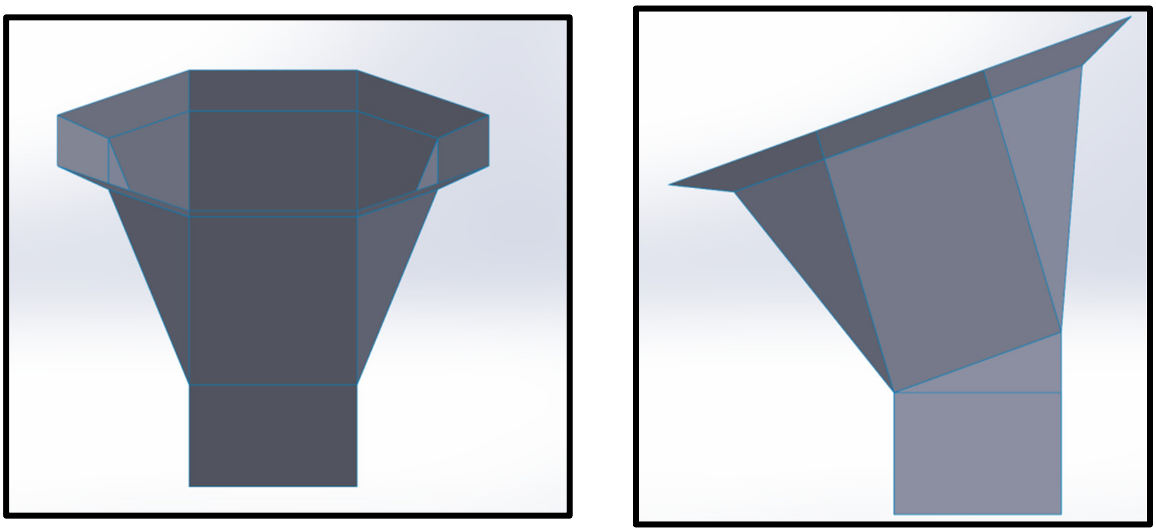
2.1. Design and Construction of the Funnel Solar Cooker

2.1.1. Design Process

Funnel-type solar cookers as the name suggests are in the shape of funnel. The funnel-type solar cooker falls under the category of panel-type solar cooker. Therefore, the funnel acts as an array of panels which direct the sunlight to the vessel. This funnel is placed on top of the box inside of which the vessel to be heated is kept. The funnel is generally kept at angle with respect to the box. This angle depends on the solar altitude of the sun.

Therefore, the design was initiated with making four panels which will be tilted at 45° to each other. The angle 45° is chosen, as it allows the light to reach the vessel after a single bounce thus less loss of energy [12]. In a study done at Birmingham University, 45° was found to be the optimum opening angle for the funnel-type solar cooker. However, the panels in the funnel are at an angle which makes the funnel not closed. Therefore, to do this, the small triangular sections are placed in between the four panels.

After designing the funnel with CAD software, the box on top of which the funnel is kept is designed too. The box needs to be big enough to be able to accommodate all the vessels in the house. After following the above design methodology, a funnel-type solar cooker was designed, and the images are shown in Figure 1.



(**a**) (**b**)

Figure 1. (**a**) Front view of the funnel-type solar cooker. (**b**) Side view of the funnel-type solar cooker.

Before making the above design into a prototype, a check was made if the funnel is able to direct light on to the box of the solar cooker. To test this, a ray diagram of the solar cooker made from the side view for a solar angle of 62°. An online tool is used to make the ray diagram of the solar cooker from the side view [13]. The light rays from the sun are taken to be parallel to each other, because light rays coming from infinity are taken to be parallel and the sun is a large distance from the Earth. The ray diagram is shown in Figure 2.

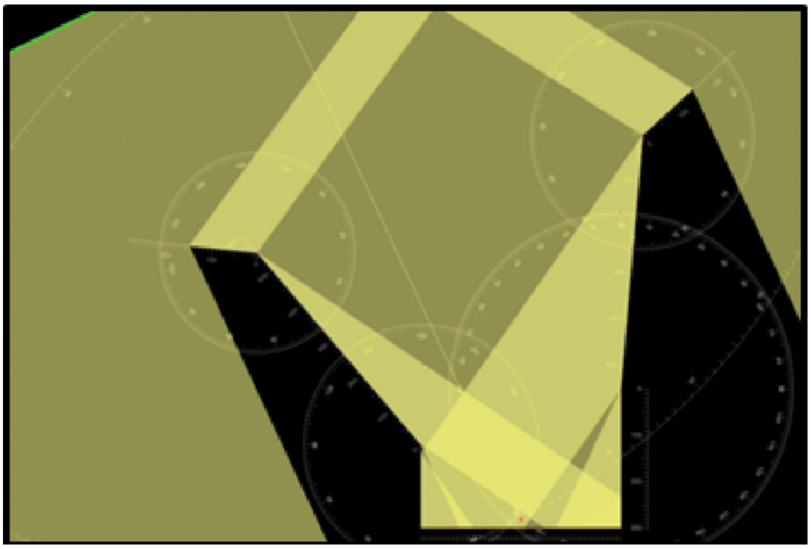
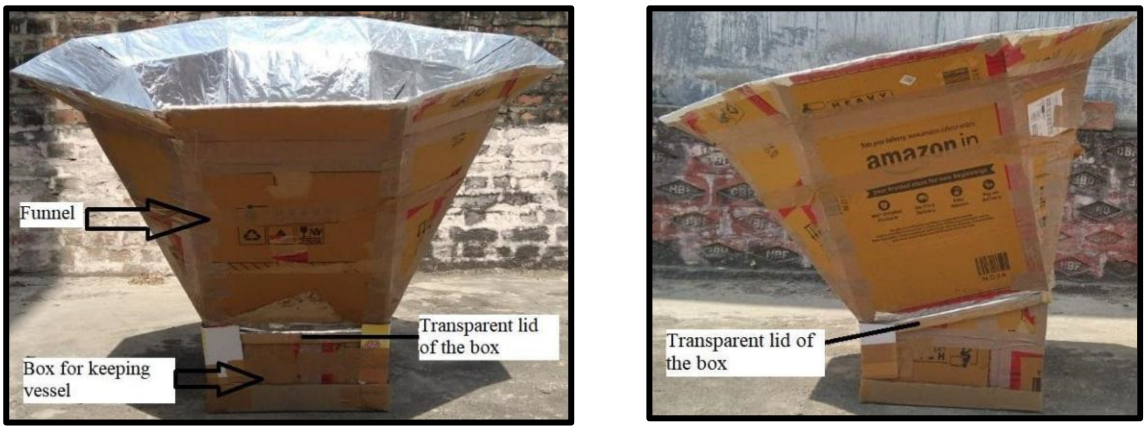


Figure 2. Ray diagram showing the light rays directed to the box where the vessel is kept.

We can see in the above image that at the bottom of the solar cooker the light from the sun is getting concentrated where the vessel is going to be kept. Thus, according to the ray diagram, the cooker seems to concentrate the solar irradiation onto the vessel. Thus, the design of the funnel is capable of directing the solar irradiation to the box where the vessel is kept.

2.1.2. Construction of Funnel-Type Solar Cooker

The solar cooker was made out of cardboard boxes. By using cardboard, the cost of the solar cooker is kept low. The funnel and the box of the solar cooker contains various panels. The size of the panels was taken from the design of the solar cooker. The panels were cut and then pasted to form the shape as shown in the design process. The internal surface of the funnel and the box is made reflective to direct sunlight onto the vessel which is kept inside the box of the solar cooker. Aluminum foil is used to make the surface reflective. The box of the solar cooker also has a transparent lid to prevent any convective or radiative losses. After the entire construction of the funnel, the solar cooker looks as shown in Figure 3.



(**a**) (**b**)

Figure 3. (**a**) Front view of the funnel-type solar cooker when put together. (**b**) Side view of the funnel-type solar cooker.

2.2. Materials and Equipments Required for Experimentation

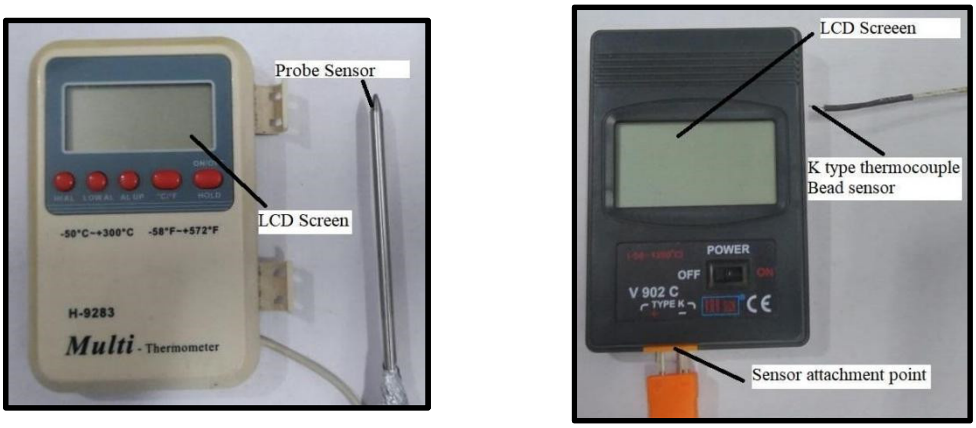
A vessel was used to contain the liquids which will act as test loads. The vessel is an aluminum pot of mass 0.8 kg. The total volume of the pot is 2 L. The inside and the outside of the pot has been painted black using enamel paint. The pot also has a transparent glass lid.

The test liquids used were water and glycerine. Water was used as a test load to collect data to find the second figure of merit.

To improve the overall efficiency of the solar cooker PCM material was used. Paraffin wax was chosen as the PCM material. Paraffin wax has a good latent heat of fusion and has more specific heat capacity than most of the PCM materials.

To contain the PCM while experimentation, a plate is used. The plate is made out of stainless steel. The plate is painted black so that it can absorb the incoming solar radiation

To measure the temperature of the test liquids during the experiment two thermometers were used. One of the temperature-measuring devices was the Multi-Thermometer H-9283. It has a sensor inside the stainless steel probe. It has a temperature range from −50 °C to 300 °C. It has an LCD screen to display the temperature. It has temperature accuracy of 1 °C from −50 °C to 200 °C. The other temperature measuring device was a V902C digital thermometer which uses a K type thermocouple to measure the temperature. It has a temperature range from −50 °C to 1200 °C. The images of both the temperature-measuring devices are shown in Figure 4.



(**a**) (**b**)

Figure 4. (**a**) Temperature measuring device up to single decimal place. (**b**) Temperature measuring device.

The temperature was recorded manually at intervals of 1 min.

To obtain the solar irradiation values, an online website called 'Solar Global atlas' was used [14] The website provides the average direct solar irradiation values of the month on hourly basis.

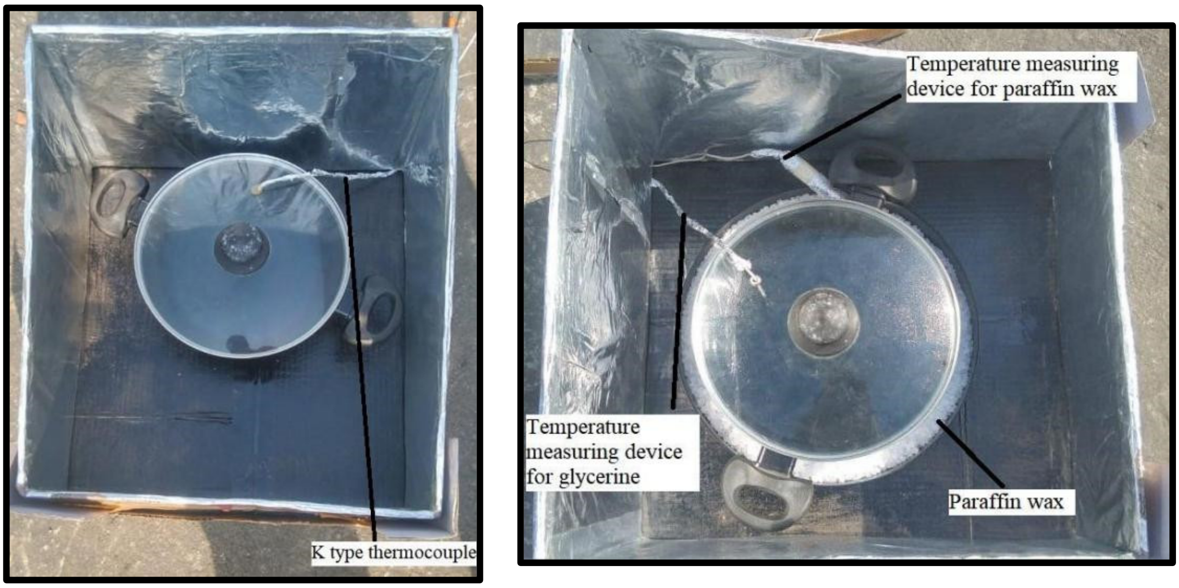
To plot the graph of temperature and direct solar irradiation values vs. time Google sheets was used [15]. To get the solar altitude angle, an online website was used called 'pveducation.org' [16]. To obtain the ambient temperature value, an online website time and date was used [17].

The website gives the solar angle at a place during the particular time of the day using the input parameters.

2.3. Experimentation Process

The experiments were conducted over a period of five days. Data was collected to find performance parameters such as the thermal efficiency and figure of merits and *COR* (cooker opto–thermal ratio)-dependent parameters such as the maximum achievable temperature reference time to reach that temperature and break even period of the solar cooker. Glycerine was used as a test load to collect the values to calculate the thermal efficiency, and water was used to collect data to calculate the figure of merit.

The experimental setup was quite similar most of the days and differed only when the paraffin wax was used. The experimental setup photos are shown in Figure 5.



(a) (b)

Figure 5. (**a**) Experimental setup on day 1 without the paraffin wax. (**b**) Experimental setup on day 3 when paraffin wax is used to collect data to find improvement in the thermal efficiency.

The transparent lid of the solar cooker is placed on the top of the box, and then, the funnel of the solar cooker is placed on top of the box, as shown in Figure 6.

Figure 6. Funnel placed on top of the box.

The temperature from various sensors were recorded every minute. The funnel of the solar cooker was adjusted every 30 min according to the position of the sun. The data collected on various days was tabulated and plotted using google sheets. The temperature curve vs. time of various days is shown in Figures 7–11.

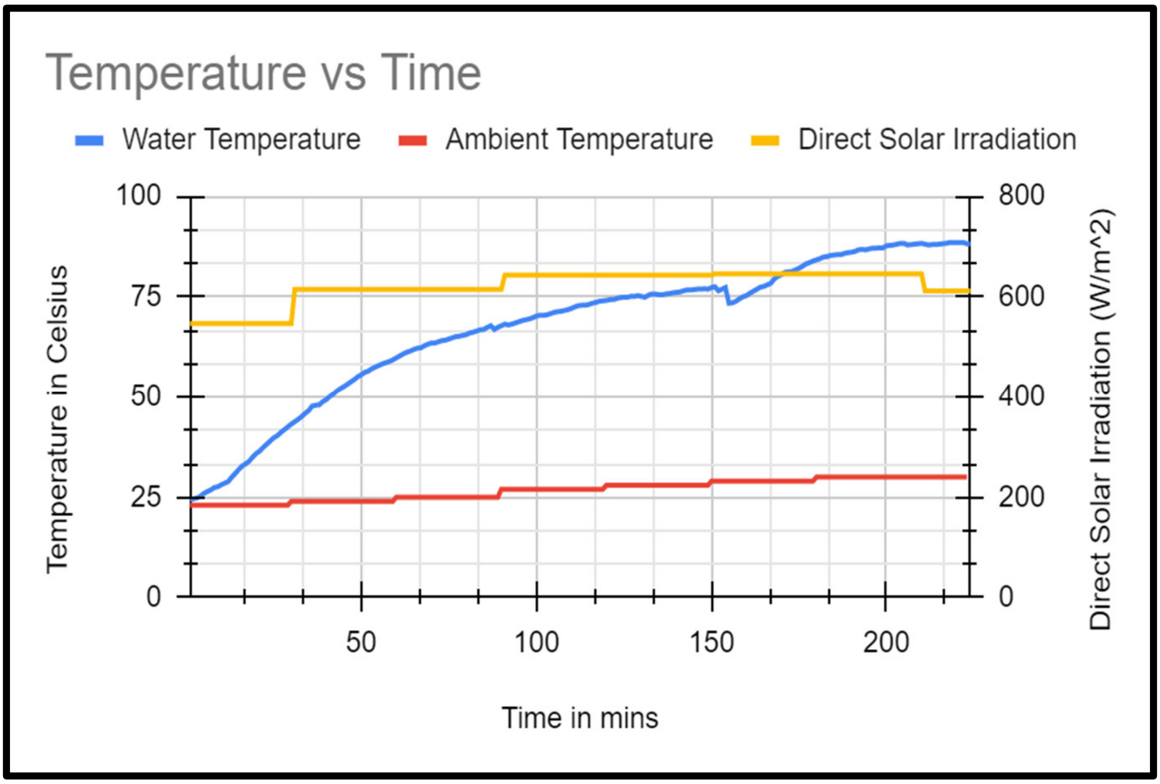


Figure 7. Temperature and irradiation values from day 1 using water as test load.

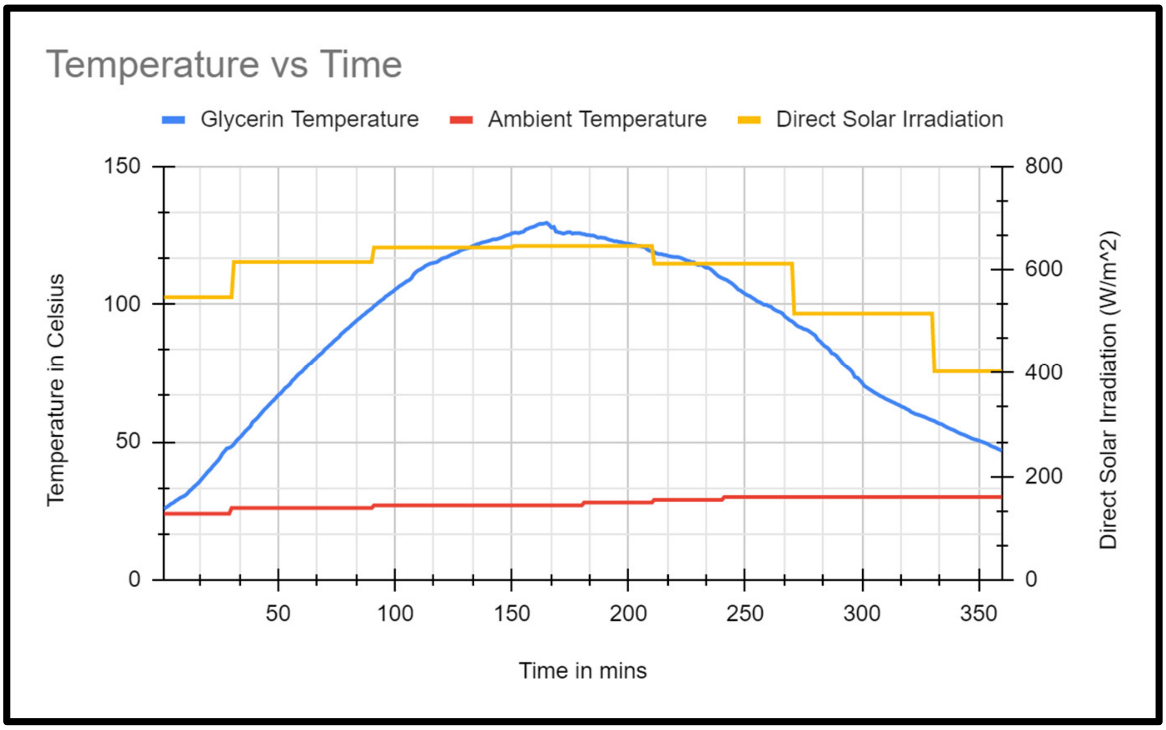


Figure 8. Temperature and irradiation values from day 2 using glycerine as test load.

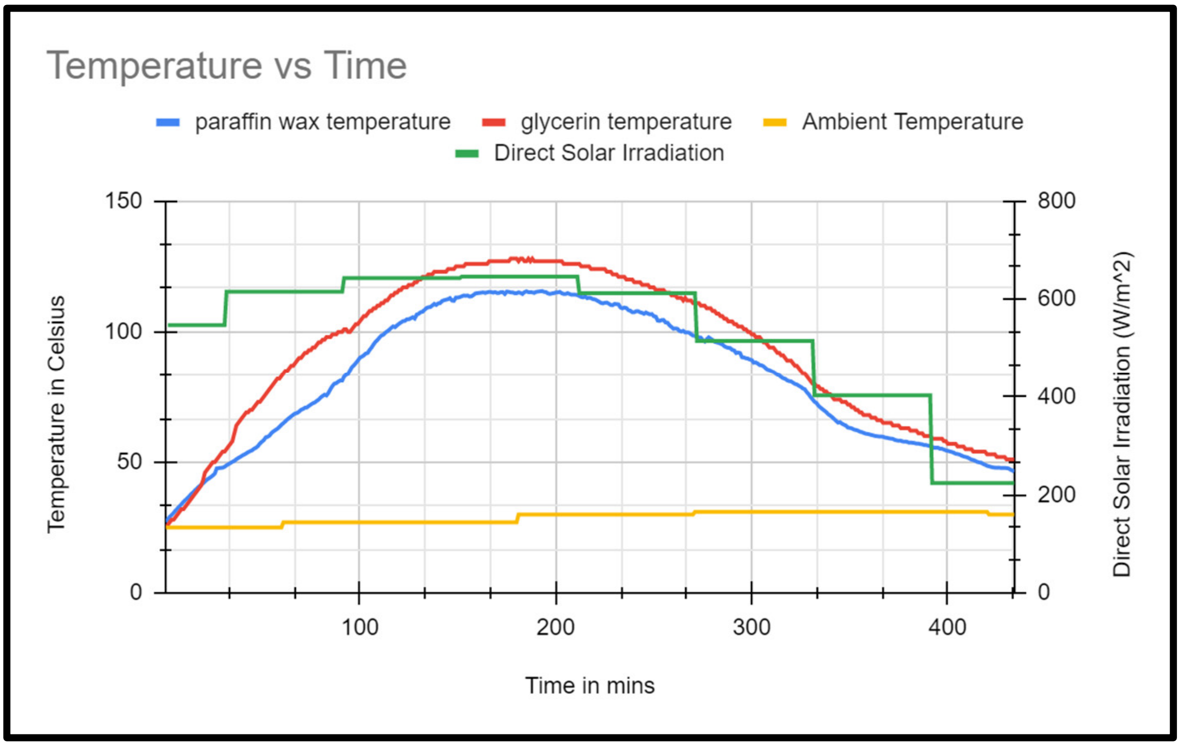


Figure 9. Temperature and irradiation values from day 3 using glycerine as test load and paraffin wax as heat storage material.

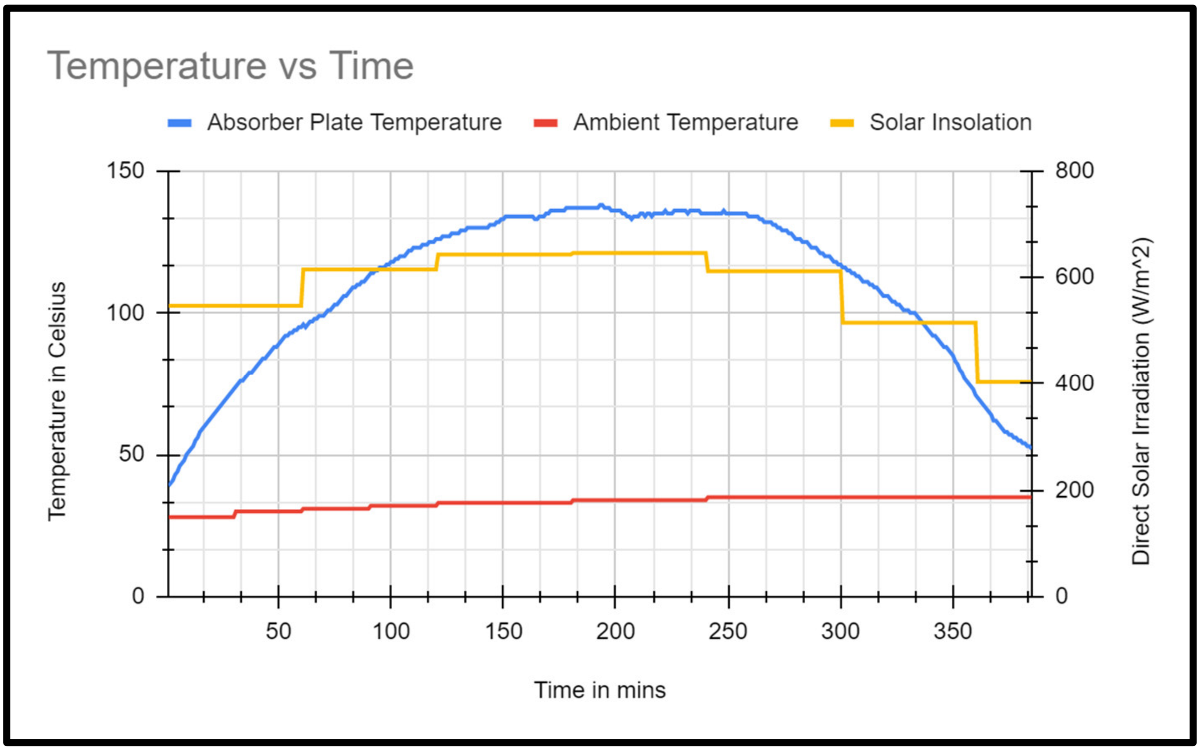


Figure 10. Temperature and irradiation values from day 4 with no test load for first figure of merit.

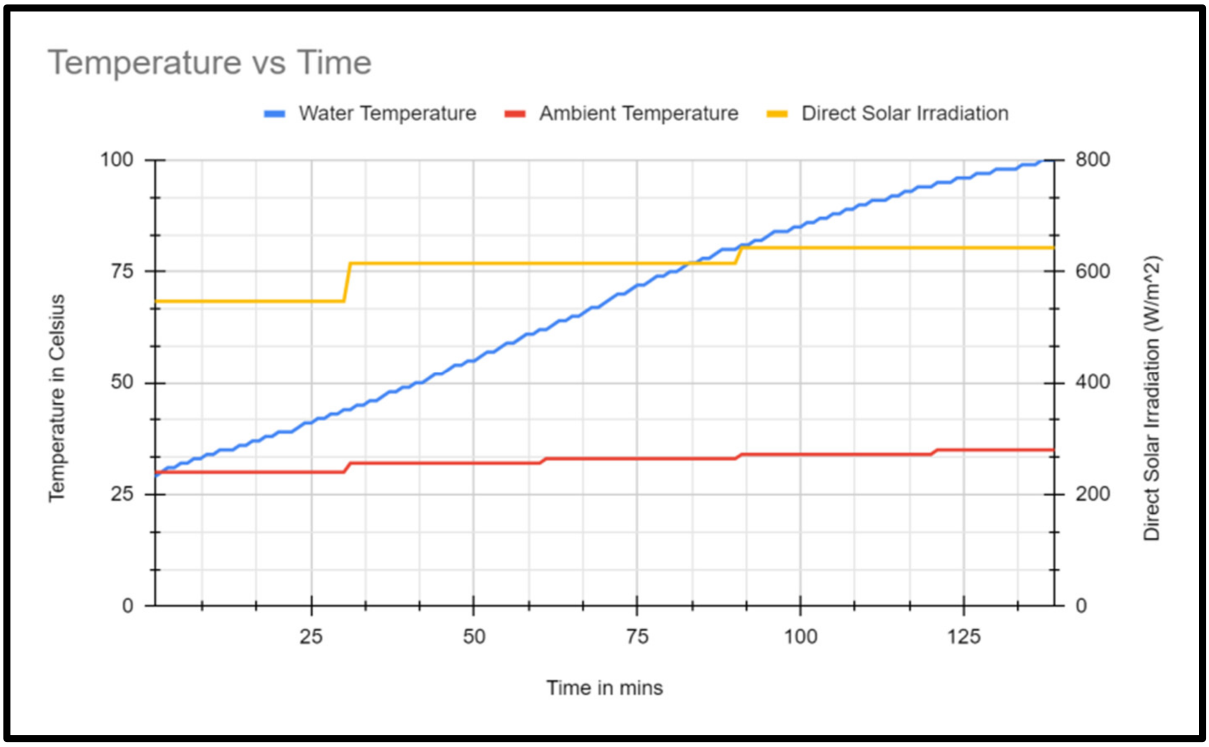


Figure 11. Temperature and irradiation values from day 5 using water as the test load for the second figure of merit.

2.4. Calculation of the Performance Metrics

Using the data collected from the experimentation process various performance parameters of the funnel solar cooker can be calculated and also the improvements in the thermal efficiency when using the paraffin wax as phase change material.

2.4.1. First Figure of Merit (F1)

The first figure of merit of the solar cooker is the ratio of the optical efficiency of the solar cooker and overall heat loss coefficient of the solar cooker. A high value of the F1 indicates good optical efficiency and low heat loss coefficient.

$$\mathrm{F1} = \frac{T_{ps} - T_a}{\underline{G_T}}, \tag{1}$$

where F1 is the first figure of merit, Tps is the maximum absorber plate temperature under no load condition, T_a is the ambient temperature and $\underline{G_T}$ is average solar irradiation. On substituting the values from day 4 of the experiment in Equation (1), we get F1 is 0.14.

2.4.2. Second Figure of Merit (F2)

Second figure of merit of a solar cooker is evaluated under full load conditions and is equal to the product of exchanger efficiency factor and optical efficiency.

High values of F2 indicate good optical efficiency, good heat exchange efficiency factor and low heat capacity of the cooker interiors in comparison with full load of water [18]

$$\mathrm{F2} = \mathrm{F1} \times \frac{M_W A_p C_W}{t} \times ln\left(\frac{(1 - (1/F1)(Tw1 - T_a)/\underline{G_T})}{(1 - (1/F1)(Tw2 - T_a)/\underline{G_T})}\right), \tag{2}$$

where F2 is the second figure of merit, F1 is the first figure of merit, M_W is the mass of water used, A_p is the aperture area of the funnel solar cooker, C_W is the specific heat capacity of water used, $Tw1$ is initial temperature, $Tw2$ is the final temperature, t is the time between $Tw1$ and $Tw2$, T_a is ambient temperature and $\underline{G_T}$ is average solar irradiation. On substituting the values from day 5 of experiment in Equation (2), we get $F2$ is 0.0577.

2.4.3. Thermal Efficiency without the Use of Phase Change Material

Efficiency of the solar cooker is the ratio of the energy used to heat the contents of the pot and the solar energy collected by the solar cooker [8].

$$\eta = \text{Total energy stored in pot and glycerine/Solar energy being collected by the cooker}, \tag{3}$$

Using the data collected on day 2, the thermal efficiency of the solar cooker is found to be 0.121.

2.4.4. Thermal Efficiency with the Use of Phase Change Material

The efficiency of the solar cooker is the ratio of the energy used to heat the contents of the pot and pot and the solar energy collected by the solar cooker [8].

$$\eta = \frac{\text{Total energy stored in pot, glycerine and paraffin wax}}{\text{Solar energy being collected by the cooker}} \tag{4}$$

Using the data collected on day 4, the thermal efficiency of the solar cooker is found to be 0.152.

2.4.5. Cooker Opto–Thermal Ratio (*COR*)

COR or cooker opto–thermal ratio is a parameter determined using the experimental data. Using this parameter, one can calculate the maximum achievable temperature by the solar cooker and the reference time taken to achieve that temperature [8].

To find *COR* one has to first calculate the heat flux and the difference between mean of fitted temperature values and the ambient temperature. After doing that, a graph of heat flux over average value of solar irradiation and the difference in mean of fitted value and the ambient temperature over average value of solar irradiation are plotted. Then a line of best fit is drawn through these values. The *COR* is then the ratio of the intercept values and the symmetric slope of the line. Using the data collected on day 2 of testing, the graph is plotted as shown in Figure 12.

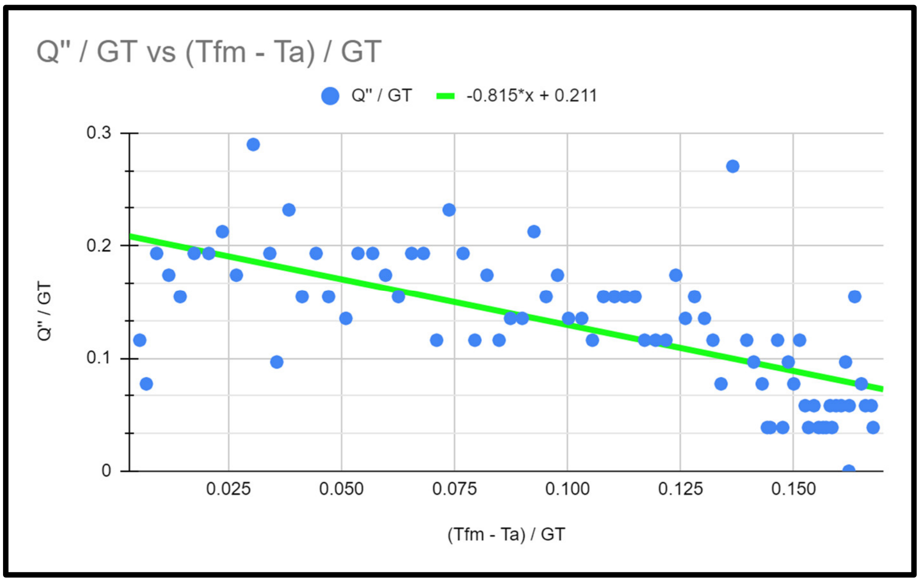


Figure 12. The plot of Q″/GT vs. (Tfm-Ta)/GT and the line of best fit of the plotted points.

$$COR = \frac{\text{Intercept Value}}{\text{Symmetric value of the slope of line of best fit}} \quad (5)$$

On substituting the values from the graph, the COR is equal to 0.22.

2.4.6. Maximum Achievable Temperature

The theoretical maximum achievable temperature using the funnel solar cooker used in this project is found using the COR parameter [8]:

$$T_{fmax} = T_a + COR(\underline{G_T}), \quad (6)$$

On substituting the values from the day 2 of testing we obtain a theoretical value of maximum achievable temperature of 166 °C.

2.4.7. Theoretical Value of Reference Time to Reach the Maximum Achievable Temperature

The theoretical maximum achievable temperature using the funnel solar cooker used in this project is found using the COR parameter [8].

$$\tau_R = \frac{M_f C_f}{A_p F' \eta_0} \times COR \times ln\left[\frac{G_T - \frac{(T_{f1} - T_a)}{COR}}{G_T - \frac{(T_{f2} - T_a)}{COR}}\right], \quad (7)$$

where M_f C_f is the sum of thermal capacities of pot and paraffin wax, A_p is the aperture area of the solar cooker in m^2, $F'\eta_0$ is the intercept value, T_{f1} = lower limit of temperature and T_{f2} = upper limit of temperature.

On taking the upper limit and lower limit of temperature as 129 and 30 °C respectively the reference time is 144 min. In the actual experiment the time taken to reach the temperature of 129 °C is 166 min.

2.4.8. Break Even Analysis of the Funnel Solar Cooker

Break even analysis is a procedure through which we calculate the break even time or break even point. Break even time is the time it takes for a product or service to make enough profit to cover the entire initial cost. In industries this is calculated to find the number of units that need to be sold to cover the entire capital investment that is used to make that product.

In our case of the funnel solar cooker, we are trying to find the time after which we have made enough savings on the cost of the domestic LPG or cooking gas to cover the entire cost of making the funnel solar cooker.

Taking the ambient temperature to be 30 °C degree Celsius, and the water needs to be heated to 100 °C steam, as the energy required per day to cook all the meals is equal to the sensible heat and the latent heat energy. Total energy required to cook the food per day is 12,475 kJ for a family size of five [19,20] for cooking three meals approximately five kilograms of water is required.

The amount of LPG gas inside a domestic cylinder in India is 14.2 kg. The calorific value of LPG is 46.10 MJ/kg [21]. Thus, the total energy content inside the cylinder is 654,620 kJ.

However, the total energy inside the cylinder is not used to heat the water since some amount of energy is lost to the air and some is used up in heating the utensils. So approximately only 80% of the energy inside the cylinder is used to heat or cook the food. Thus, actual usable energy inside the cylinder is 523,696 kJ per cylinder.

Amount of energy collected by the funnel solar cooker, which can be used to heat the water can be calculated by the equation given below.

$$Q_{produced} = M_G X C_G X \left(T_f - T_i\right) \times No\ of\ Operating\ hours \quad (8)$$

where M_G = mass of glycerine is 1 kg, C_G is the specific heat capacity of glycerine is =2.490 kJ/kg K T_f = the final temperature of glycerine = 129.5 °C, T_i = the initial temperature of glycerine = 30 °C and number of operational hours = 8 h.

The total energy produced by the funnel solar cooker with eight hours as the operational time is 1982 kJ.

Using the total energy used for cooking per day and the total energy available in the cylinder the number of days a cylinder will last can be found, which is around 41 days. Taking the current cost of the LPG cylinder, which is 965 INR, we can find the cost of cooking per day without the use of a solar cooker is around 23 INR. However, when using the solar cooker this cost of cooking per day is 20.104 INR. Thus, we are saving around 3 INR when using a solar cooker to cook food.

The cost of making the cooker was 400 INR and we are saving around 3 rupees each day. Thus, the breakeven time of the solar cooker is 133 days after that the solar cooker will provide net gain.

2.4.9. Prediction Model Based on Artificial Neural Networks (ANN)

A comprehensive review of such solar cooker models is reported in the literature [22] In this work, a comprehensive ANN model is developed to predict the temperature of the absorber plate and the temperature of water, which are they key parameters that dictates the figures of merit F1 and F2. Direct solar radiation and Average Ambient temperature are extracted from Photovoltaic Geographical Information Systems (PVGIS) [23] given with the latitude and longitude. The dataset consists of temperature and direct solar irradiation for four cities in India namely Kanpur, Trivandrum, Chennai and Delhi. The time period of the data collected is for four months. An input data set sample for the city of Kanpur is given in Table 1

Table 1. Input data set (Kanpur).

Time in Mins	Ambient Temperature, °C	Direct Solar Radiation (W/m^2)
1	28	547
2	28	547
3	28	547
4	28	547
5	28	547
6	28	547

In the Artificial Neural Network (ANN) Model, the Multi-Layer Perceptron (MLP) is implemented by using a feed-forward backpropagation algorithm. The MultiLayer Perceptron (MLP) is used as the dataset has more features so the model can also learn non-linear functions which offers great forecasting. ReLu function is used activation function in deep learning models. ReLu function will return zero from the input if it has any values that are not positive, however, it returns the exact value for any positive inputs. It can be written as (x) = $(0,x)$. It also converges quickly, and model performance is improved significantly.

The artificial neural network models can be separated into two stages. First is the learning stage and second is the testing stage. The network in the learning stage makes errors and learns from them by adjusting the weights and biases to properly predict the correct or actual class label of the input tuples. For example, Input data has three features: Time in mins, Ambient Temperature in Celsius and direct solar radiance in W/m^2, during the training phase data features are presented to the network one at a time and the biases and weights associated with the input values are adjusted each time. For most regression problems, the Mean Squared Error (MSE) is the loss function used for this model. For a single example, MSE is calculated by determining the difference in error between the calculated output by the model and the output prediction that is provided. Then, square the obtained error. The optimizer used is Adam, which also has a backpropagation parameter.

The model architecture and model summary are shown in Figure 13 and Table 2, it consists of three layers namely input layer, hidden layer and output layer, inside hidden layer there is a 30% dropout. Dropout is used for the model since the amount of dataset is limited. This will prevent the model from overfitting.

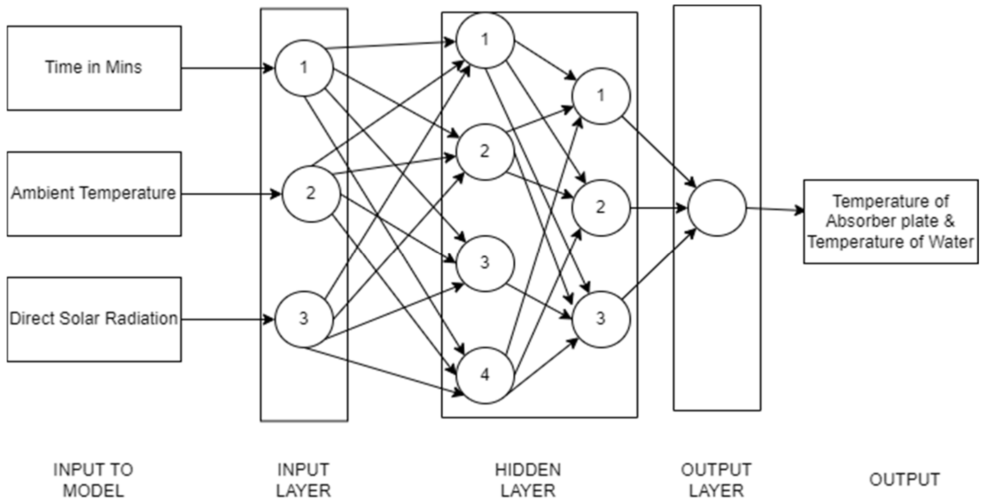


Figure 13. ANN architecture and model summary.

Table 2. Model Summary.

Layer (Type)	Output Shape	Number of Parameters
Dense (Dense)	(None, 32)	128
Dropout (Dropout)	(None, 32)	0
Dense_1 (Dense)	(None, 64)	2112
Dropout_1 (Dropout)	(None, 64)	0
Dense_2 (Dense)	(None, 1)	65
Total Parameters	2305	

The dataset is split into 90% for training and 10% for testing. As the amount of dataset is very limited, the training set with 70% or 80% ratio doesn't improve the accuracy as model saturated to 89%. Therefore, 90% from the dataset is used in the training set and the remaining in the training set. The model is trained for 500 epochs with a batch size of 32. 500 epochs are the saturation point of this model as the accuracy reached 99% and Increasing the epochs above 500 doesn't improving accuracy as seen in Figure 14.

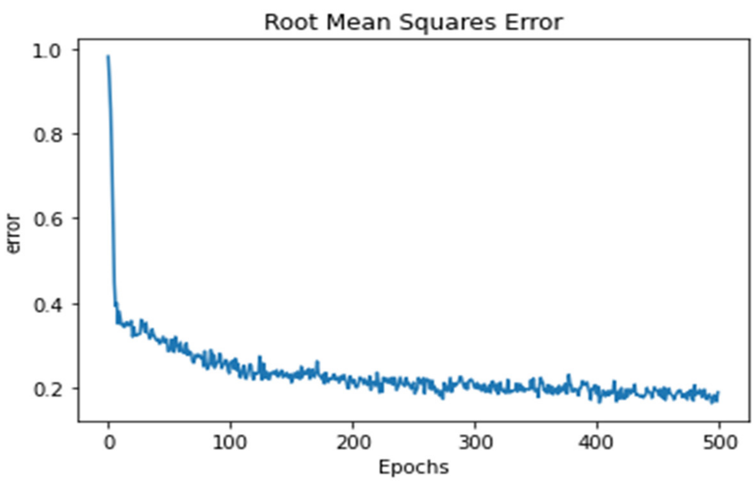


Figure 14. Training MSE plot.

As a result, after combining the Adam optimizer with learning rate decay, with a Training Loss of around 0.0796. The model accuracy is 0.9933 on the training set and 0.99 on the testing set. The consolidated results are shown in Table 3

Table 3. Model evaluation results.

	Value
R2 Score of Whole Data Frame	0.987604
R2 Score of Training set	0.993325
R2 Score of Test set	0.990816
Mean of Test set	101.826241
Standard Deviation of Test set	28.7214199
Relative standard deviation	0.282090

From the model prediction, outputs are the temperature of the absorber plate for calculating the F1 metric of the solar cooker and the temperature of the water for calculating the F2 metric of the solar cooker along with the F1 metric. From the model, the prediction was obtained for four cities: Chennai, Delhi and Trivandrum. From the experimental data tested at Kanpur, 1 metric is 0.14 and F2 is 0.0577 were obtained. The following Table 4 is a prediction of the temperature of the absorber plate and the temperature of the water. These values are used to calculate F1 and F2 metrics, which is depicted in Table 4

Table 4. Predicted F1 and F2 values.

	Dec 21		**Mar 22**		**Jul 22**		**Oct 22**	
	F1	**F2**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**
Kanpur	0.2551	0.0159	0.1748	0.0129	0.4974	0.0342	0.1932	0.0153
Chennai	0.248	0.0166	0.17613	0.0106	0.393	0.0265	0.2497	0.0186
Trivandrum	0.2253	0.0146	0.2107	0.0122	0.5034	0.0265	0.2677	0.0181
Delhi	0.2523	0.0135	0.189	0.012	0.4726	0.028	0.1927	0.0116

3. Discussion

After making the funnel solar cooker, experiments were conducted, and the data was collected. On the data collected, calculations were done to obtain performance metrics which will inform about the performance of the funnel solar cooker.

The figures of merit were the first parameter that were calculated. The minimum value for the first figure of merit is 0.12 [24] The calculated value for the funnel solar cooker is 0.14. This indicates that the designed solar cooker has good optical efficiency and low heat loss factor. Low heat loss factor shows that the heat loss due to convection and radiation is less. The second figure of merit calculated was 0.0577 which is less than the standard value of 0.40 [25]. This lower second figure of merit indicates that the solar cooker has a low heat exchange factor. and the heat capacity of the funnel solar cooker interior is high. This can be improved by using a vessel with low specific heat capacity.

The next parameter calculated was the efficiency value. The efficiency of the funnel solar cooker without using paraffin wax was calculated to be 0.121 and with paraffin wax was calculated to be 0.152. These efficiency values are higher than what was obtained in few of the studies discussed in the literature survey [8]. This may be attributed to the fact that the funnel solar cooker in the other studies did not incorporate a box to contain the vessel which led to more convective heat loss. The box used in our case with the solar cooker helps in reducing the heat loss to the environment thus improving the efficiency of the funnel solar cooker. We can also see improvement in the value of efficiency when using paraffin wax to store heat. The percentage improvement in the value of efficiency is about 25%. This shows that using paraffin wax helps to improve the efficiency of the funnel solar cooker. Using paraffin wax we can also sustain peak temperature for a longer period when compared to not using paraffin wax. This can be seen in the plot in Figure 15. It can be seen in the plot that the peak temperature of glycerin is maintained for approximately 40 min longer when using paraffin wax as compared to when not using paraffin wax.

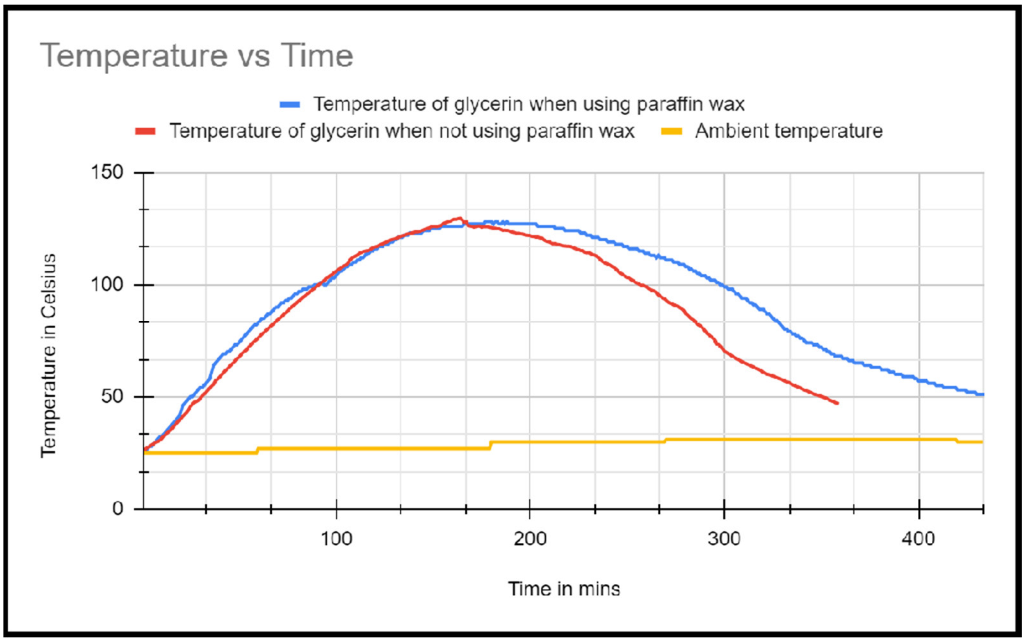


Figure 15. Time vs. temperature plot of glycerin when using paraffin wax and not using paraffin wax.

Cooker opto–thermal ratio of the funnel solar cooker was calculated to find the maximum theoretical temperature that can be achieved. The calculated value of maximum theoretical temperature that can be achieved is 166 °C. The maximum temperature achieved in reality is 129 °C which is lower than the theoretical. This can be due to various reasons such as the heat losses that happened during the experimentation, the heat absorbed by the air, the vessel inside the box. The value of the reference time is also calculated using the *COR* value. The theoretical value of time which is required to reach an upper limit of temperature is called reference time. The reference time required to achieve a temperature of 129 °C when the initial temperature is 30 °C is 144 min. The actual time it took to reach 129 °C is 166 min. The higher value of actual time is due to the heat loss to the atmosphere during experimentation.

The break even analysis of the funnel solar cooker was also done in the calculations. Break-even analysis gives us the approximate idea of the time it will take for the funnel solar cooker to repay its own total cost after which the running cost of the funnel solar cooker will be zero. The total cost to make the funnel solar cooker in our case was about 400 INR. To do the break even analysis, a family of five people was assumed, and the total cooking bill of this family was calculated using the current domestic gas prices. The daily cooking price for the family of five people when not using the funnel solar cooker was 23 INR and, when using the funnel solar cooker, was 20 INR. Thus, using the funnel solar cooker, the family is able to save 3 INR per day. Thus, the break even point of the funnel solar cooker is about four and half months. If the price of domestic gas increases, which is a constant trend in current time this break even point will also reduce. After a period of four and half months the cost of using the funnel solar cooker will be zero, and it will provide us net gain on each usage. The values obtained with the use of deep learning and an artificial neural network trained with data values are accurate. The advantage of this model is that it can forecast and estimate the temperature of the absorber plate and water correctly from weather forecasting data which can be used to calculate the F1 and F2 metrics for the performance of the solar cooker. For all cities, the model's R2 value is greater than 99%, and the RMSE values are small. From the experimental data of Kanpur, the model was able to estimate metrics for various cities, and the performance of the model is best in all cities for different months.

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