Experimental Investigation of Solar Hot Case Based on Photovoltaic Panel

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Abstract*: In the present work design and experimental investigation of a solar hot case for food warming are briefly summarized. Solar hot case is a sustainable device designed to lessen poor nations' dependency on traditional energy sources aiming at advantages such as improved healthy food, and environmental protection. A 100-watt solar panel and Ni-Cr resistance heating alloy are used in the experiment to keep the food in a safe temperature range. The present study investigates multi-wire combinations and identifies the best configuration to get the optimum temperature. The findings show that the solar hot case efficiently keeps food warm and germs-free, making it a practical option for homes, community kitchens, and workplaces in underdeveloped countries.*

Keywords: Solar Hot Case, sustainable device, environmental protection, safe temperature range, underdeveloped countries

1. INTRODUCTION:

Solar hot case is a proper sustainable appliance for food warming and can be used in household community kitchens and offices in various developing countries which depend upon conventional energy sources. The solar hot case has many merits in terms of health recovery, the environment and the economy of the nation. The use of solar hot case to warm up the food will reduce the use of traditional fuel items (i.e., wood and cow dung) as well as costly camp fuels(i.e., LPG, kerosene) in rural and urban areas. Having good food with proper nutrition is essential for human beings because if it is not handled properly it may result in food-borne disease. There exist approximately 600 million instances of foodborne maladies on a global scale. Among these cases, children under the age of 5 bear a substantial 40% of the overall load of foodborne afflictions, culminating in an annual toll of 125,000 fatalities among this demographic.[1] The exacerbation of extreme meteorological occurrences and environment-related stressors due to climate dynamics adversely impacts the integrity of water and soil safety, thereby augmenting the vulnerabilities associated with waterborne and foodborne maladies these may go higher because trusted data from least developed countries and developing countries is not available due to lack of track record of such disease.

Unhealthy food consumption may not only impact the health of people but also negatively affects a nation's GDP, economic growth, and productivity as a whole. According to a world bank report in 2018 low- and medium-income countries lost $110 bn USD due to unsafe healthy food practices.[2]This financial burden encompasses both direct expenses, such as medical treatments and hospitalizations, as well as indirect costs like lost productivity and reduced economic output and it is avertible if measures related to food safety are not taken seriously. Food safety measures can categorically contribute to many sustainable development goals like as hunger prohibiting(SDG-2),poverty deduction(SDG-1) and development of wellbeing(SDG-3).[3]

According to global food security index 2022, in India 16.3% undernutrition,30.9% stunted children,33.4% underweight and 3.8% are fighting with obesity. food safety not only help to get healthy food but also help the country to utilize its demographic dividend in a better way.

Pathogenic microbial growth is the major cause of food borne disease. This pathogenic microbe growth happens happened when food is not stored at an adequate temperature.[4] The temperature range at which microorganism growth faster is known as temperature danger zone. The range is described between 50 C to 600 C by the food safety information council(FSIC),Australia 2016.[5]

Many international food safety organizations recommend keeping cold food cold at temperatures below 5 C and hot food hot at temperatures of 60 C or above. There is also 2 hr. /4 hr. rule which says that if food is kept more than 4 hours in temperature danger zone than chances of microbial growth had increased.[6]so food must be kept between safe temperature zone i.e., either it kept below 40 C or kept above 610 People carry food in their lunch boxes and consume it after four to five hours. Electrical appliances such as microwave oven etc. are used for heating food and refrigerators for cooling. These facilities are not available in offices and institutions in developing countries because of high energy consumption. Most of the developing and least developed countries are geographically located at optimal absorption area of sun rays with high solar potential.[11]so a solution based on warming through solar thermal energy seems feasible. Keeping such aspect in mind, present work is focused on experimental investigation of solar thermal food warmer which can be used at offices institution and household for keeping food warm and germ free(out of temperature danger zone)

2. DESIGN AND DEVELOPMENT OF SOLAR HOT CASE

2.1. Energy calculation of food warming up

The energy requirement of the water is calculated by following formula

$$Q = m_s c_s \Delta t + m_f c_w \Delta t$$

Here;

Table 1. Nomenclature

Parameters	**Symbol**	**Unit**
Energy need to warm food	Q	J
Mass of stainless-steel	m_s	kg
Specific heat of stainless-steel	c_s	J/kg-K
Mass of food	m_f	kg
Specific heat of water	c_w	J/kg-K
Rise in temperature	Δt	^{0}C

In this experiment, one glass of water was used and it was kept warm inside the case. Empty glass weight is 38.87 gram and glass weight with water is 150 grams. The specific heat of stainless-steel glass is taken 500 J/kg-K as and specific heat of water is taken as 4186 J/kg-K. Generally, food item contain water as one of its constituents that is why the calculations incorporate the specific heat of water. As the specific heat of water is highest so the energy outcome is on higher side. The main objective to warm the food within the safe zone limits thus 600 C was taken as a reference temperature in this experiment.[7]

Solar hot case is made up of plywood. With total area of 929.03 cm2 .the hot case is a cuboid with dimensions equal to 30.48 cm.

System is consisting of aluminium sheet on the inner side of the case on all the sides. Aluminium sheets are used to work as a reflector or contain the energy within the box. Plywood used have both side mica which works as an insulator to reduce heat loss and trap the radiation within the box to warm up the food as well as box temperature. The inner length of experimental setup box is 27.88 cm and inner length is also 27.88 cm with inner height of 24 cm. solar hot case schematic diagram presented in fig.1

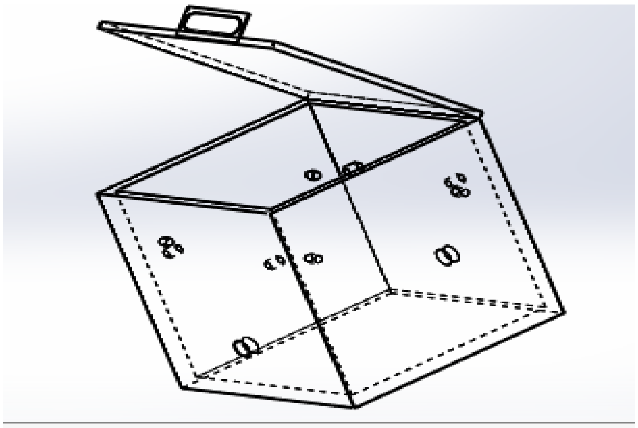

Fig.1: Schematic diagram of solar hot case

Table 2. Specification of Solar Hot Case

Parameters	Solar hot case
Weight(kg)	6.3 kg
Shape	Box type
External dimension	30.48x30.48x30.48 cm^3
Volume	28316.847 cm^3
Internal dimension	27.88x27.88x24 cm^3
Insulation	Aluminium foil

2.2. Characteristics of solar Photovoltaic Panel and heating elements

In this experiment a 100-watt Photovoltaic Panel is used. A detailed review of temperature effect on photovoltaic panel was studied[8,9,10].by changing the temperature the voltage output automatically changes and vice versa in case of output current. The effect of temperature over solar photovoltaic is a major problem. The site where the research is being conducted has an average summertime temperature of 30 C, which is 50 C higher than the standard condition (STC) temperature as defined by IEC-61215 and IEC-61646.STC test condition are

Table 3. Standard Condition Parameter

Parameters	Values
Irradiation	1000W/m^2
Cell temp	25 C
Air mass	1.5 AM

Higher irradiance-absorbing cells can generate more heat in addition to more electricity. A cell temperature rise of 180 C might result in a loss of around 2V.[8] In this module output Photovoltaic Panel specification given below:

Table 4. Specification of Photovoltaic Panel

Parameters	Specification
Maximum Power	100W
Open circuit voltage	21.9V

Short circuit current	6.12A
Maximum Power Voltage	17.96V
Maximum Power Current	5.57A
Maximum system voltage	600V

Ni-Cr, a kind of resistance heating alloy, is an alloy made of 80% Ni and 20% Cr. The joule heating of resistive (ohmic) materials is what heats the Ni-Cr the most. Heating, or the production of heat when current flows through the Ni-Cr. The rate of heating for Ni-Cr wire is quite high. Ni-Cr is too inexpensive for this experiment's work when compared to other heating sources like thermoelectric devices and other heating wires.

Fig.2: Photovoltaic Panel

The properties and specification of Ni-Cr wire is given below in the table 5.

Table 5: Properties of Ni-Cr wire

Parameters	**Specification**
Electrical resistance at room temperature	2.4 Ω
Specific heat	450 Jkg−1°C−1.
Thermal conductivity	11.3 Wm−1°C−1
Wire gauge	32 gauge
Wire length	30.48 cm
Resistance at room temperature	(1.0 to 1.5) × 10−6 Ω
Cross sectional area	0.032429 m^2

The Ni-Cr wire is placed inside the box through clamping both ends with the help of copper clip and extend through a ceramic tube in order to connect with the cable powered by 100 w solar photovoltaic panel.

3. EXPERIMENTAL PROCEDURE

All the test were carried out inside the manufacturing lab of Mechanical Engineering department of HBTU,Kanpur during 6,7,10,11 July of 2023.

From 10:00 am until 4:00 pm, all of the experiment readings are taken on an hourly basis. 32-gauge Ni-Cr wire was used for this experiment. Ni-Cr wire with 3 combination-single wire ,double wire, triple wire was used. The data revealed a pattern of temperature fluctuations in both the cabin and water over the course of the day. The recorded temperatures demonstrate a gradual rise in the morning hours, with both cabin and water temperatures consistently increasing until around midday. Following this period, there was a transition towards slightly lower temperatures, which become more pronounced in the afternoon.

The cabin temperature, initially starting at 59.00 degrees Celsius, steadily climbs to its peak of 82.60 degrees Celsius at 13:00, after which it experiences a gradual decline to 67.50 degrees Celsius by 16:00. Similarly, the water temperature exhibits a parallel trend, reaching its highest point of 63.00 degrees Celsius at 13:30 before diminishing to 52.60 degrees Celsius by 16:00.

The temperature fluctuations could be attributed to various factors, including the external environment, time of day, and potential heating or cooling mechanisms in place. The fluctuations might also reflect the cyclical nature of temperature changes over the course of a day.

Overall, the data underscores the dynamic nature of temperature regulation within the cabin and water systems, illustrating the impact of time on temperature variations and offering insights into potential patterns that could inform further investigations or adjustments in temperature control strategies. By using the output power to input power ratio, the efficiency of the solar hot case was estimated, and the results are shown in the Table 6.

Table 6: Data Table

Time	T_{cabin}	T_{water}	P_0	**Pi**	**η(%)**
10:00	59.00	28.30	55.56	1453.70	0.04
10:30	68.60	48.00	57.74	975.45	0.03
11:00	73.90	50.00	61.05	1131.71	0.05
11:30	75.00	54.80	62.33	956.51	0.02
12:00	77.60	55.00	65.00	1070.15	0.06
12:30	82.50	62.00	64.48	970.71	0.07
13:00	82.60	62.50	60.88	951.77	0.06
13:30	82.40	63.00	60.76	918.63	0.07
14:00	82.20	62.00	54.56	956.51	0.00
14:30	82.30	61.90	46.74	965.98	0.05
15:00	80.00	61.90	37.00	857.07	0.01
15:30	76.20	55.90	26.10	961.24	0.03
16:00	67.50	52.60	27.00	705.54	0.04

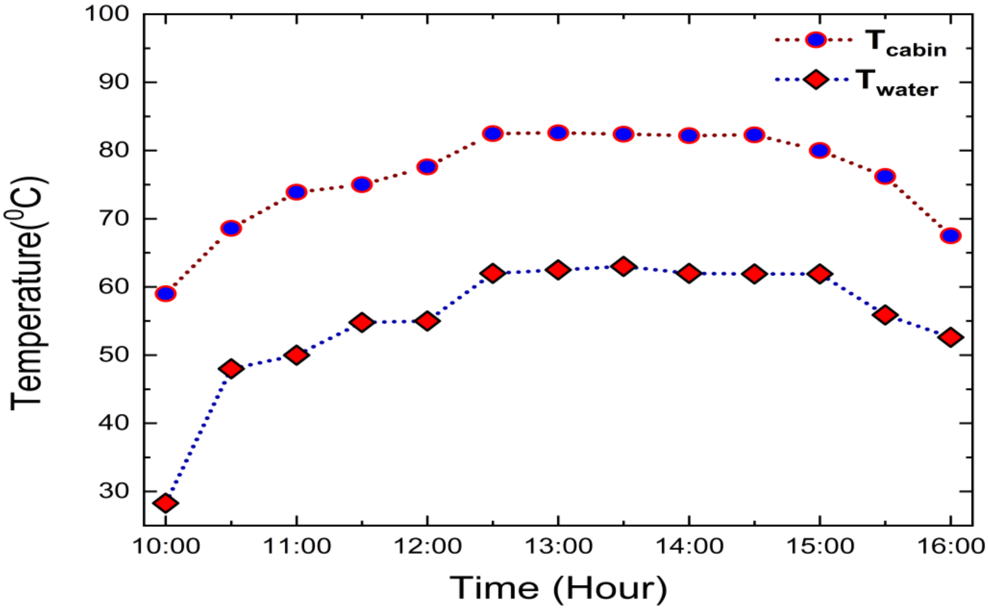

Fig.3(a): Time-dependent Temperature Variation of Water and Cabin

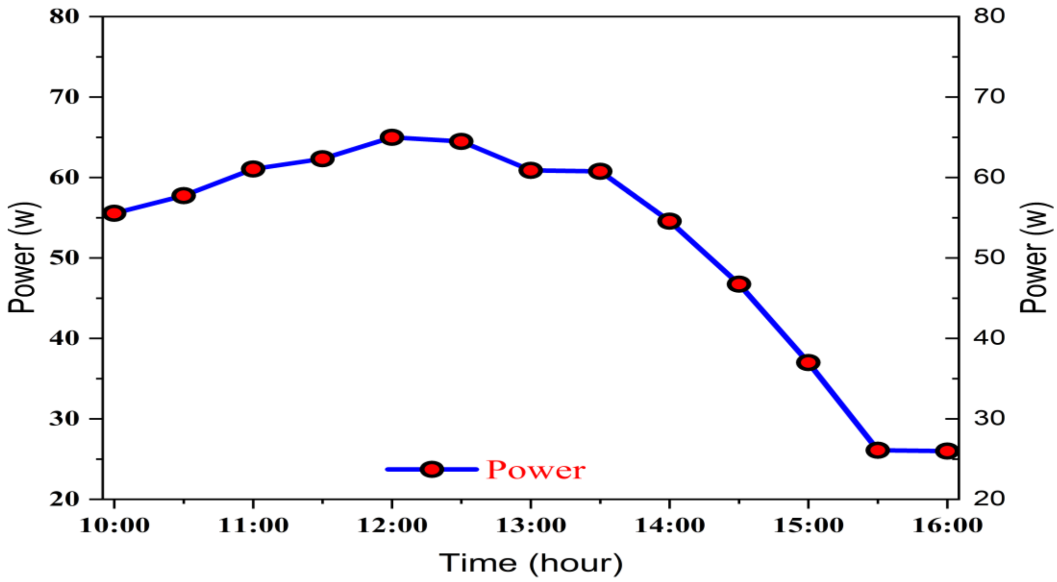

Fig.3(b): Power output variation w.r.t. Time

Equations 2 and 3 provide the formulas to determine the input power and output power of a solar hot case, respectively. The temperature of the cabin was measured over a period of 60 minutes at the beginning, when it increased quite quickly. The above calculations can be used to determine the efficiency of a solar hot case.

$P_i = mc_p\Delta T/\Delta t$ ....(2)

$P_o = VI$ ....(3)

$\eta = P_o/P_i$

4. RESULT

The experiments were conducted with 32-gauge Ni-Cr heating element single wire in order to produce heat via radiation but due to high temperature rise at junction point where wire and photovoltaic cable meet it gets melt. wire gauge is too small for the current passing through it, it will have higher electrical resistance. Higher resistance means more heat is generated, leading to overheating and potential melting of the wire but the maximum temperature of 450 C which is not desirable to keep food out of temperature danger zone so try for two - wire combination.

In two wire combination, wrapping the 32-gauge Ni-Cr heating wire in such a way that it generates maximum energy output through radiation. Again, same issue occurs melting at junction point. But in this experiment the maximum temperature of cabin achieved is 550C which is again less than the safe temperature zone(more than 600C).

After that three-wire combination used for further experiment which was quiet promising to our desirable temperature. In` this arrangement three continuous wires used without wrapping it in order to reduce the bending losses.

Having this arrangement, achieved temperature of the cabin is 820 C. In order to achieve more heat, combination of four wire were used together but the difference was very low so it is clear that three wire combination is optimum for this prototype arrangement as shown in following graph.

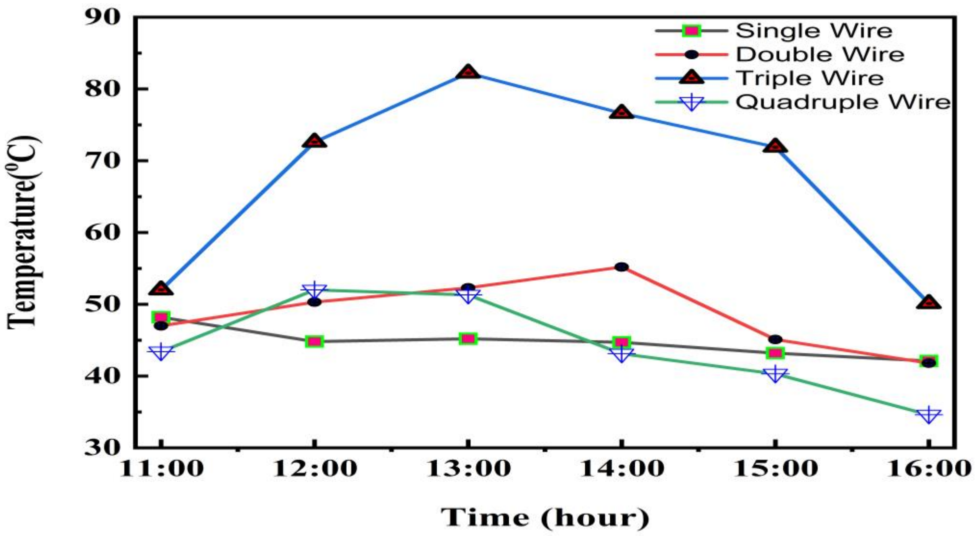

Fig.4: Temperature profile between four wire combinations w.r.t. Time

5. CONCLUSIONS:

The experimental study of the solar hot case has demonstrated promising results in reheating and maintaining food within the recommended temperature range, thereby reducing foodborne illnesses. This sustainable appliance, constructed from plywood, aluminium sheets, and Ni-Cr resistant heating alloy, offers an eco-friendly alternative for homes and businesses in impoverished nations. It promotes sustainable habits and environmental preservation by utilizing solar thermal energy, reducing reliance on costly camp fuels and traditional energy sources. The study recommends using the Ni-Cr heating alloy in a three-wire configuration to achieve the target temperature of 82°C. As a development prototype experiment, the solar hot box design has ample room for refinement and improvement. Overall, the solar hot case holds significant potential as a viable solution for food warming in developing countries.

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