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A COMPARATIVE THEORETICAL AND EXPERIMENTAL STUDY OF HOT BOX SOLAR COOKERS OF TWO DIFFERENT SHAPES AND SAME APERTURE AREAS

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Abstract: This paper presents a comparative study of solar hot box cookers of two different box shapes - cuboid and trapezoidal with same aperture area. The study involves theoretical estimation of energy absorbed by the systems for global solar radiation and assessment of energy distribution between the walls and base plate of the respective absorber trays of the cookers. The on-field studies for observation of the temperature profiles of the base plate and load water have been carried out at Kota (25.11^{o}N, 75.85^{o}E) Rajasthan. The study indicates that the performance of trapezoidal shaped hot box is equivalent to cuboid shaped hot box in summers and slightly better in winters.
Keywords: Hot box solar cookers, shapes, energy distribution, global solar radiation, temperature profiles.

1. INTRODUCTION

With about 300 clear sunny days in a year, the average solar radiation over India is around 5 kWh$m^{-2} day^{-1}$. Thus India is rich in solar but still the solar potential is largely untapped. In rural areas people still depend largely on biomass for cooking. Solar cooking is a simple, safe and convenient way to cook food. Box type solar cookers provide a very cost-efficient and environment-friendly solution to developing countries [1].

There have been several studies on box type solar cookers [2-7] but a direct comparison of solar hot boxes of different shapes to study the energy distribution between base plate and walls is not to be found. Therefore in this paper a comparative theoretical and experimental study of solar hot box cookers of two different box shapes such as cuboid and trapezoidal with same aperture area has been presented.

The rate of heat absorbed by a collector plays a significant role in deciding the performance of the collector. The absorbing surface of a solar hot box is in the form of a tray and the energy collected by the aperture area is distributed between the absorber base plate and walls.

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The wall height and wall inclination play a major role in determining the shading effects on the base plate which maybe further visualized as non-uniform heating of load. On the basis of the formalism [8] a computer program was developed to compare theoretically the energy absorption for the developed cookers of different shapes and energy distribution between base plate and walls. Further the experimental results related to temperature profiles have also been reported.

Fig. 1. Cuboid and trapezoidal hot box solar cookers with thermocouples and digital temperature indicators.

2. DESIGN DETAILS

Two hot box solar cookers have been developed with same aperture area of 0.21 sq.m. The outer and inner boxes are of plywood. The glaze consists of two acrylic sheets with gap spacing of 1.5cm. and aperture area 46cm x 46cm. The insulation is ceramic wool (around1.25cm thickness) and the absorber tray is of 0.5mm thick aluminium sheet. The absorber tray and cooking pots are painted black. The cuboid cooker has inner box of 46cm x 46cm at bottom and top. The absorber tray is 10 cm deep. The walls are straight with wall inclination 0^o. The trapezoidal system has inner box 40cm x 40cm at bottom and 46cm x 46cm at the top. The depth of the tray is 10 cm. The walls are inclined outwards at 20^o (Fig. 1).

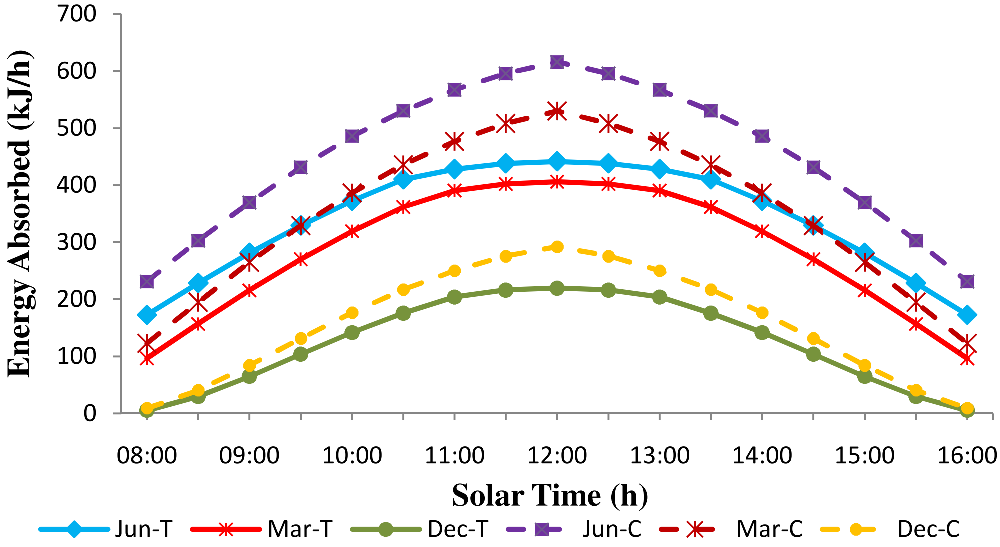

Fig. 2: Variation in theoretical hourly energy absorbed by the base plate of the solar hot boxes (Trapezoidal-T, Cuboid-C) for global radiation on Dec-21, Mar-21 and Jun-21.

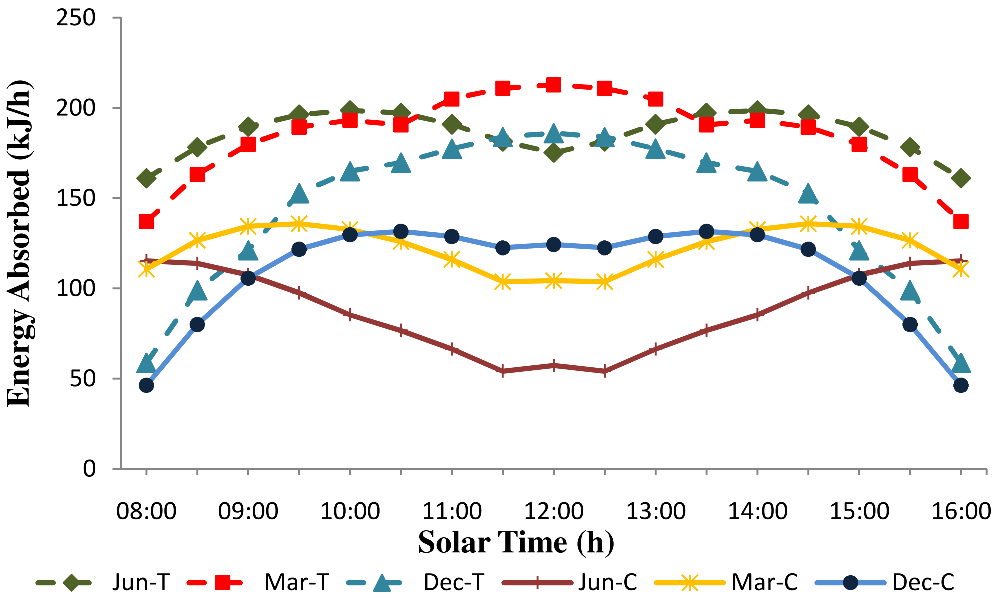

Fig. 3 Variation in theoretical hourly energy absorbed by the walls of the solar hot boxes for global radiation on Dec-21, Mar-21 and Jun-21.

3. THEORETICAL STUDY

The mathematical model [8] used to estimate the energy absorption by the base plate and walls of the solar hot boxes is based on a number of parameters such as wall height and the wall inclination, tilt of the collector, transmissivity-absorptivity, aperture area, base plate area, hour angle, angle of incidence, solar and surface azimuth angles, solar insolation etc. for the estimation of rate of heat absorbed by the collector considering the global solar radiation.

The values of beam and diffuse radiation I_b and I_d have been obtained through ASHRAE method, where the values of A, B and C used in the calculations are the revised values given by Iqbal [9]. The energy absorption by the base plate and walls of the three solar hot boxes has been estimated for Dec-21 (δ= - 23.45°), Mar -21 (δ = 0°) and June -21 (δ = 23.45°) and the comparative results have been shown in figures 2-3. The calculations have been made assuming the systems as non-tracked and horizontally placed

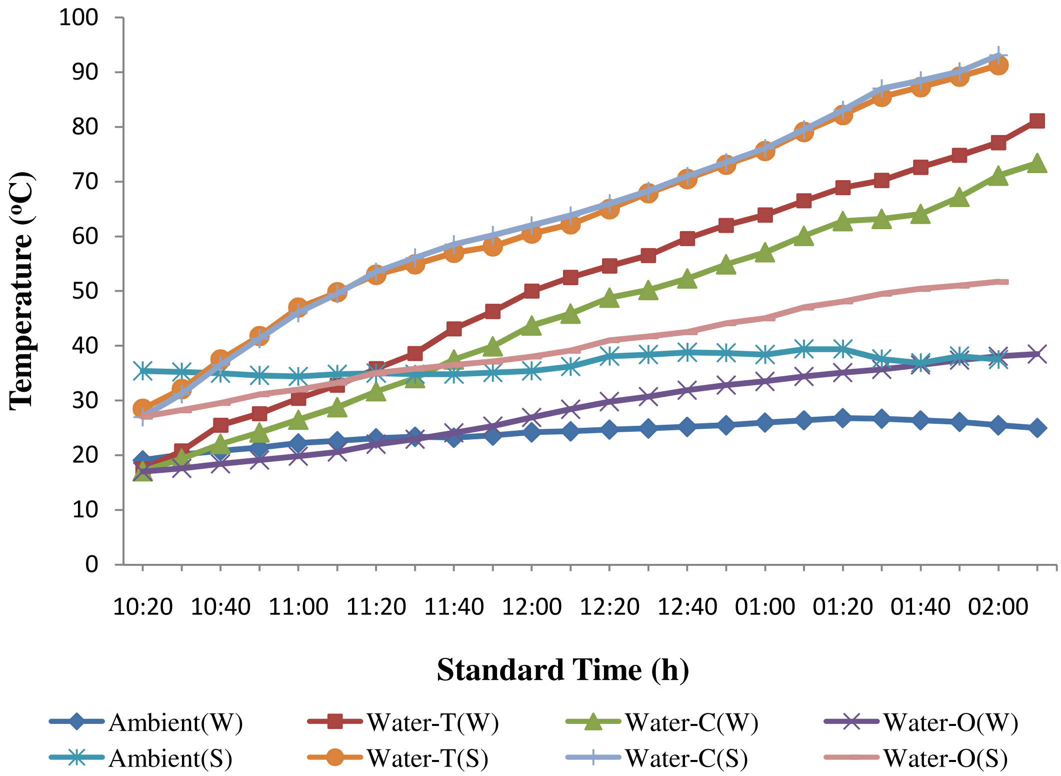

Fig. 4. On-field temperature profiles of the water in containers in solar hot boxes with ambient temperature and outside water. Water-T means for trapezoidal, water-C means for cuboid cooker and water-O means water kept in outside container. (W) and (S) indicate winter and summer day.

4. ON-FIELD STUDIES

For studying the thermal performance of the cookers experimentally field testing has been adopted, which is more reliable and informative. The cookers were placed in Sun and observations have been taken for various days throughout the year. During the experiment, the cookers were loaded with water in containers. The diameter of a container is 16.5 cm. The containers are filled with 850 ml of water in one container with 1700 ml of water in total as per the bureau of standards during the experiment. The temperature profiles of the base plate and the water loaded in the containers have been recorded through the K-type thermocouples and CIE 305 digital temperature indicator. The ambient temperatures have also been noted down. One similar container is kept outside with 850 ml of water. Though the observations have been taken for various days, here representative observation for one summer and winter day has been presented. The temperature profiles for the water corresponding to the cookers have been shown in Fig 4.

5. RESULTS AND DISCUSSION

From the comparative study of the Fig.2-3 it can be clearly seen that the energy absorption by the base plate of the cuboid box cooker is more than the trapezoidal for the three days of December, March and June though the total energy incident is same as the aperture area is same. The lesser value of energy absorption by the base plate of trapezoidal is due to the lesser base plate area of the trapezoidal box as compared to the cuboid box. The energy absorption by the walls of the trapezoidal system is higher as compared to the energy absorption by the cuboid as presented in Fig.3. This is obvious as the total energy received by the systems is same for same aperture area and therefore the system which has higher base plate energy absorption will have lesser distribution of energy on walls.

It is interesting to observe the thermal performance of the systems in Fig. 4. It can be seen that the temperature of the water kept in the cuboid and trapezoidal systems is almost equal but the water temperatures are higher for trapezoidal system as compared to the cuboid one in winters. This shows that though the base plate area is less for the trapezoidal system (around 75% of cuboid) but the thermal performance is better as shading of containers is less in it due to inclined walls.

From Fig. 2 it can be seen that the difference in energy absorption in base plate is more pronounced in summers as compared to winters for the two cookers. This is due to the fact that in summers the solar angle of incidence is lower and shading of base plate is less. As trapezoidal system has lesser base plate area the energy absorption is also less than cuboid. In winters the sunrays are slant, solar incident angles are higher leading to more shadowing of base plate and containers. Thus in winters the trapezoidal system which has inclined walls causes lesser shadowing of base plate and containers and the result is reflected in form of better thermal performance in winters as evident from Fig.4.

6. CONCLUSIONS

From the study of the two solar hot boxes with same aperture area but different shapes; cuboid and trapezoidal, it can be concluded that for improving the thermal performance of the solar hot box cookers in winter, system with inclined walls are preferable. While designing efficient hot box solar cooker energy distribution on base plate and walls should be considered along with the minimum shadowing of the base plate by walls.

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