Development of Solar Thermal Appliances Using Building Materials

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Abstract

Solar thermal appliances (STAs) can be made as an integrated part of the building/housing using building material housings (BMH), which ultimately make these appliances more user friendly, durable and weather resistance. This paper presents fabrication and testing of three different solar thermal appliances. Appliances are developed for water heating and cooking purposes, these are: Building material housing solar water heater (BMSWH), Fixed structure solar concentrator (FSSC), Community size solar cooker (CSSC). According to the test results, the thermal performances of CSSC and BMSWH are found satisfactory even after 2 and 10 years, respectively. Two meals cooking for 8 to 10 persons can be done in CSSC on a sunny day and in BMSWH (62 liter) water can be stored near 60 ºC. Due to building material housing, systems have good durability and high weather resistance. For FSSC thermal profile and cooking test show it's cooking ability (100-200 gm rice within 45 minutes to 1.5h) in peak sunny hours in lesser time than box type solar cooking. Fix structure makes the system user friendly and building material structure decreases payback period of the system.

Keywords: solar water heater, solar cooker, solar concentrator, building material

1. Introduction

Human civilization has been witnessing a gradual shift towards cleaner fuels- from wood to coal, from coal to oil, from oil to natural gas; renewable is the present demand. It is quite obvious that solar energy is the most promising current and future option among all non-renewable and renewable energy resources used currently across the globe. Energy form the sun can be utilized in two ways: (i) in the form of heat or thermal energy called solar thermal applications and (ii) in the form of electrical energy called solar photovoltaic applications. In all nations, a major share of total energy consumption is utilized by the household sector for water heating and cooking purpose. Solar thermal applications have immense potential especially in domestic and industrial sector to meet thermal energy demand of the world (Dzioubinski and Chipman, 1999; Sen, 2004; Thirugnanasambandam et al., 2010; Mahavar et al., 2012a, 2012b; Mahavar, 2015).Therefore, in the present research work our interest have been to provide cost effective, user friendly and durable solar thermal appliances for the domestic or small industries.

Solar thermal appliances (STAs) e.g. water heater, solar concentrator, box–type solar cookers, solar stills and dryers work on direct application of solar power. These all appliances have some common components: (i) absorber/receiver, (ii) glaze, (iii) insulation, (iv) casing and (v) reflector. In the present piece of work we have focused our attention on building materials (bricks, cement and their composite) to use as casing material of different solar thermal appliances (Sukhatme, 2007).

With building material housing (BMH) STAs can be made as an integrated part of the building, which ultimately make this appliances more user friendly and durable. BMH casing is highly weather resistant hence increase the life time of the appliance and decreases payback period of the appliance. This casing also favorable to increase thermal performance of appliances as it has low thermal conductivity. In order to test building material as casing in STAs we have fabricated different solar thermal appliances viz. community size solar cooker, fixed structure solar concentrator and solar water heater. The experimental studies of fabricated appliances have been done as per Indian and international standard (Nayak, 2000; BIS, 2000; Belusko, 2004; Sukhatme, 2007; Hossainb, 2011). The thermal performances of appliances are found quite satisfactory even for long time duration of 2 to 10 years. It reveals that building material casing can makes STAs more convenient to use (due to fix structure), increase durability and weather resistance.

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2. Literature review

In a small capacity domestic solar water heater (SWH) a closed shallow rectangular box made of metal sheet (absorber) is contained in a housing which supports a glass cover on the top and, insulation material that surrounds the bottom and sides of the absorber tray. In a close-coupled SWH system the storage tank is horizontally mounted above the solar collectors on the roof and the hot water naturally rises into the tank through thermosyphon flow (Sukhatme, 2007; Mahavar , 2015). Different type of solar water heaters have been developed and tested by several researchers (Hossainb, 2011; 5, Mahavar, 2015). This literature also reveals that a few researches have been done to make solar water heaters as integrated part of housing by use of building material casing (Sengar, 2007; Marwal, 2012). As far as solar concentrators concern, these are the most effective for collecting solar radiations. This is due to high concentration ratio and high thermal energy collection ability (Mahavar et al., 2016). Five main solar concentrator technologies can be identified: (i) compound parabolic concentrator (CPC) (ii) parabolic trough concentrator (PTC) (iii) linear fresnel reflector (LFR) (iv) parabolic dish with fixed focus (e.g. Scheffler) (v) parabolic dish with moving focus. A number of solar concentrator has been developed from very large to small scale for a wide range of applications viz. power generation, thermochemical reactions that involve production of synthetic gas and hydrogen, production of hybrid solar-fossil fuel and solar thermal detoxification and recycling of waste materials (Kaushika and Reddy, 2000; Sonune and Philip, 2003; Lovegrove, 2011; Reddy, 2013). Besides these applications these systems are also used for solar cooking. Considering above aspects a parabolidal dish solar concentrator has been fabricated for cooking in peak sunny hours. A parabolidal dish solar concentrator is a point focal collector that requires dual axes sun tracking to concentrate solar energy onto a receiver located at the focal point. Instead for tracking keeping the structure fix cooking can also be performed in short duration at local noon. This cooking time is lesser than the box type solar cookers and as system does not require tracking so it is also easy to handle by users. Use of building material housing for structure of concentrator makes the system more durable and weather resistance. Concentrating on this, fixed structure solar concentrator (FSSC) is consisted of building material.

The other solar thermal appliance i.e. box type solar cooker consists of a rectangular enclosure insulated on the bottom and sides, and having one or two transparent covers on the top called glazes. Solar radiation enters through the upper glaze and heats up the absorber and container containing food stuff. Different types of solar cookers (box type , focusing type and advanced or indirect type) have been developed by many researchers (Panwara, 2012; Mahavar et al., 2012a, 2012b, 2013, 2015, 2017; Cuce and Cuce, 2013; Punia, 2013) using different kind of materials for different components. A considerable work has also been done for development of community size solar cooker (Nahar, 1993; Piroschka, 2014) i.e. a cooker which serve cooking for 8 to 20 persons. Senger.et al. (2011) have developed a building material housing solar cooker for cooking need of 2 to 4 persons. Fabrication of community size solar cooker using building material has not been done yet (Punia, 2013).

Hence, building material casing has been used for fabrication of various solar thermal appliances and its long term effect has also been tested for these appliances.

3. Fabrication of appliances

All the systems are installed (facing south) at open rooftop of Department of Physics, University of Rajasthan, Jaipur (26.92ºN, 75.87ºE). Building material housing solar water heater (BMSWH): This system is shown in Fig. 1. Mainly system consists of a solar collector and a storage tank. The details of these components are given in Table 1. Fixed structure solar concentrator (FSSC): This system is shown in Fig. 2. The dimensions of system are: 0.7 m diameter, 0.2 m height and 0.15 m focal length. An aluminum sheet of diameter 0.09 m, 0.3 mm thick and 0.013 kg mass is used as receiver for measurement of thermal profile. A steel pot (coated with thin black coat) of diameter 0.1 m is used for cooking placing at focal length distance. Community size solar cooker (CSSC): The cooker has been designed in such a way that length to width ratio is about four, so maximum radiation reflected from the reflector falls on the glass cover. Since aperture of the system is very large, the glaze has been designed in two pieces, each of dimension 100×60 cm^2. The lid is hinged at the top of the cooker and is used to reflect the solar radiation onto the cooker aperture. The cooker size is sufficient to cook two meals per day for 8 to 10 persons. System is shown in figure 3 and 4, and the component details are given in Table 2.

Table 1: Design details of building material housing solar water heater (BMSWH)

S. No	Parameters	Details
	Solar collector	
1.	Casing (i)Dimension (ii) Material (iii) Thickness (iv) Inclination (tilt angle)	 144×140×37 cm^3(outer), 122×112×23 cm^3 (inner) RCC, tile bricks and cement 11 cm (upper and lower walls),14 cm (side walls) 45° (facing due south)
2.	Absorber tray (i)Dimension (ii) Shape Collector tube (i) Shape (ii) Diameter (iii) Length (iv) Material (iv) Coating	 110×100× 6 cm^3(aperture) Trapezoidal Spiral 1.15 cm 15.24 m Copper (both) Black matt paint (both)
3.	Glaze (i) No. of glaze (ii) Material (iii) Thickness (iv) Spacing between glaze	 2 Transparent acrylic (PMMA) 2.75 mm 10 mm
4.	Insulation (i) Material (ii) Thickness	 Mineral wool 6 cm (bottom and all sides)
	Storage tank	
1.	(i) Shape (ii)Dimension(outer) (iii) Material (iv) Insulation thickness (v) Storage capacity	Cylindrical 0.45 m (diameter), 0.66 m height Stainless Steel 0.04 m 62 liter

Fig. 1: Building material housing solar water heater (BMSWH)

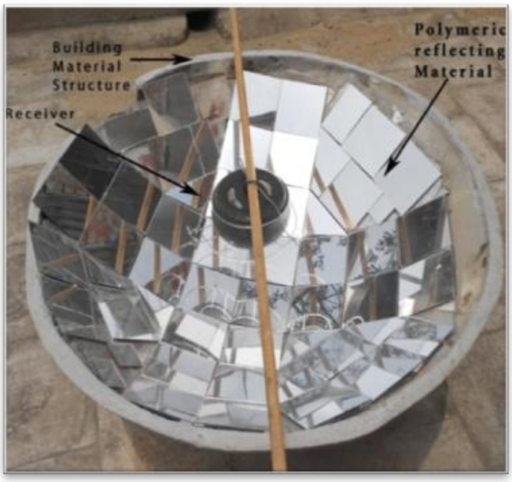

Fig. 2: Fixed structure solar concentrator (FSSC)

Table 2: Design details of community size solar cooker (CSSC)

S. No.	Parameters	Details
1.	Casing (i)Dimension (ii) Material (iii) Thickness (iv) Orientation	 210×67.5×17cm^3 Bricks and cement 15 cm Facing due south
2.	Absorber tray (i)Dimension (ii) Shape (iii) Material (iv) Thickness (v) Coating (vi) Absorptivity	 185×47 cm^2(Bottom) Trapezoidal Aluminum 0.35mm Black board paint 0.9
3.	Glaze (i) No. of glaze (ii) Material (iii) Thickness (iv) Spacing between glaze	 2 Glass Lower 5 mm and upper 4 mm 13 mm
4.	Insulation (i) Material (ii) Thickness	 Glass wool 5 cm (all sides)
5.	Containers (i) Shape (ii) Dimension (iii) Material (iv) No. of pots (v) Coating	 Cylindrical Diameter 19 cm, height 7 cm Stainless steel 16 Black matt paint
6.	Reflector (i) Number (ii)Dimension (iii) Thickness (iv) Material	 1(Three parts) 70×74cm^2(each) 4 mm Silicate glass

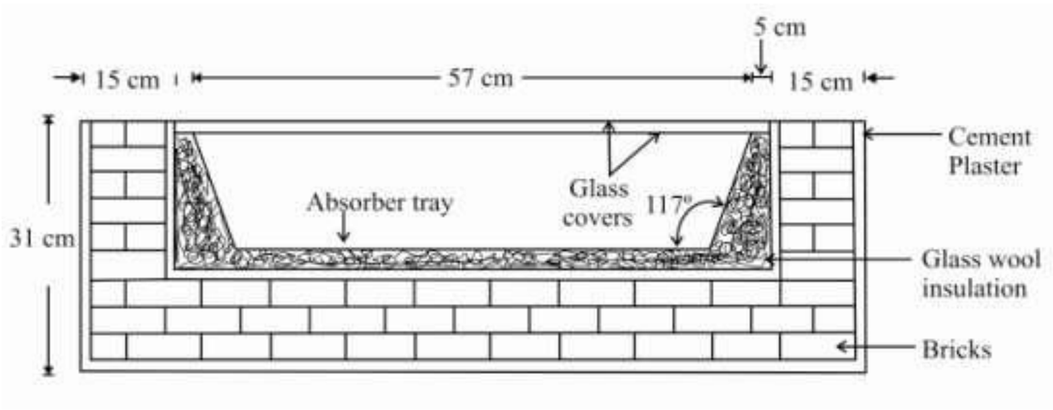

Fig. 3: Schematic view of developed community size solar cooker (CSSC)

Fig. 4: Community size solar cooker (CSSC)

4. Experimental study of appliances

4.1. Experimental set-up

On a number of days the experimental studies of all the systems have been conducted at the University of Rajasthan, Jaipur (26.92˚N, 75.87˚E). In these experiments, the solar radiation intensity (I_s) on a horizontal surface was measured using a pyranometer (Nation Instruments Ltd. Calcutta, instrument no. 0068). CIE-305 thermometer with point contact thermocouples (accuracy 0.1 ºC) was used to measure the temperatures at different locations of the CSSC and FSSC; viz. the water load (T_w), and the absorber plate (T_P). For BMSWH eight channel MS 1208 Multispan thermometer (accuracy 1 ºC) is used with J-type thermocouple to measure temperature of inlet (T_{in}), outlet (T_{out}) and storage tank (T_s) temperature. Ambient temperature (T_a) was measured using a mercury thermometer (accuracy 0.1ºC) placed in an ambient chamber. The measurements of temperatures of different regions were carried out on clear sunny days at every 10 minutes interval for the duration of 10:00 to 16:00 Indian Standard Time (IST) for CSSC and BMSWH. For FSSC this time interval is 5 minute and experimental time period is around local noon. The experimental arrangement of temperature measurements is shown in Fig. 4 for CSSC. Other instruments namely pyranometer and mercury thermometer were situated within 5 meter distance of this arrangement during testing.

4.2. Thermal Profiles

For solar water heater temperature of inlet (T_{in}), outlet (T_{out}) and storage tank temperature (T_s) are measured and reported in Fig. 5. Sengar, (2007) and Marwal, (2012) have also studied the system with different other components. For the reference thermal profiles of system measured in 2006 is also shown in Fig. 6 and 7 (Sengar, 2007). Fig. 8 shows the temperature profile of FSSC. The thermal performance of CSSC has been measured without load and with load. These are depicted in Fig. 9 and 10.

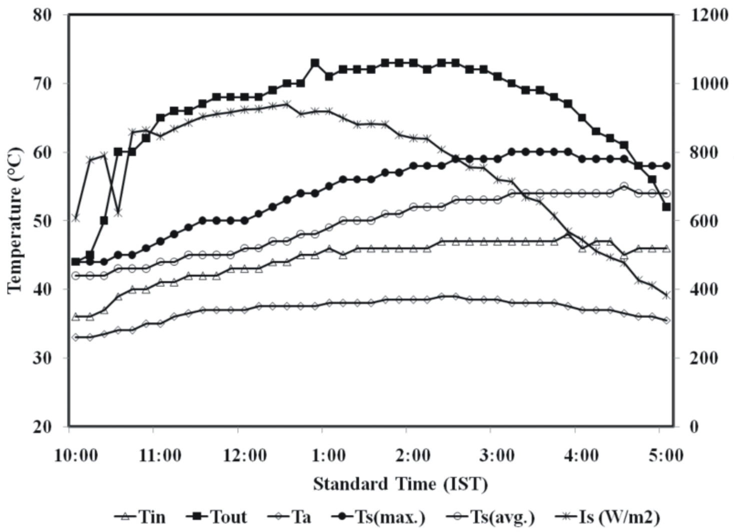

Fig. 5: Thermal profile of BMSWH (close loop) on 21 June 2017 with PMMA double glaze (T_a, T_{in}, T_{out} and T_s are ambient, inlet water, output water and storage tank water temperatures, I_S is solar insolation).

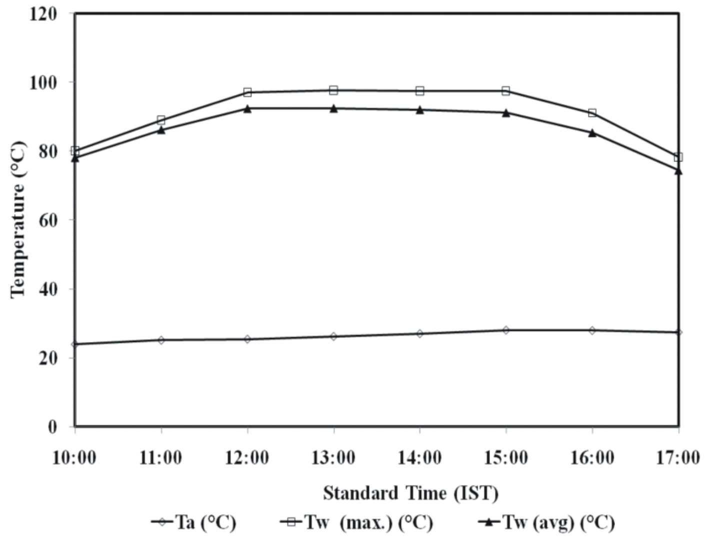

Fig. 6: Thermal profile of BMSWH (open loop) on 25th Nov. 2006 with single glass glaze (T_a and T_w are ambient and output water temperatures) (Sengar, 2007).

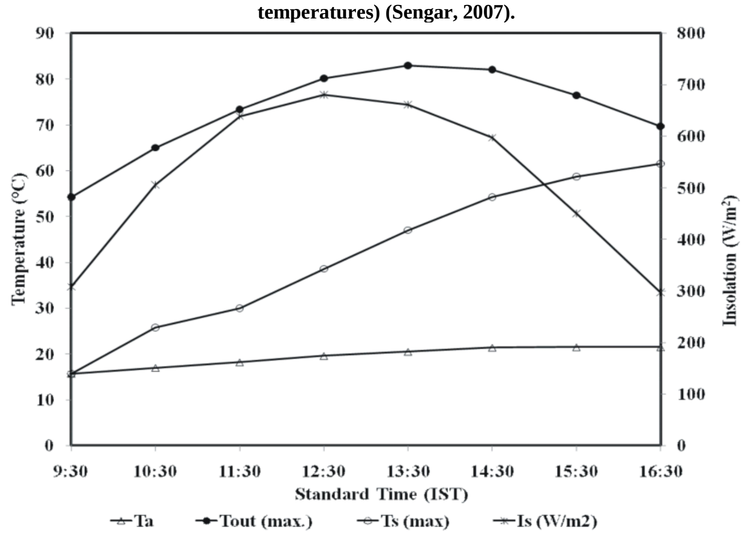

Fig. 7: Thermal profile of BMSWH (close loop) on 21 Dec. 2006 with single glass glaze (T_a, T_{out} and T_s are ambient, output water and storage tank water temperatures, I_S is solar insolation) (Sengar, 2007).

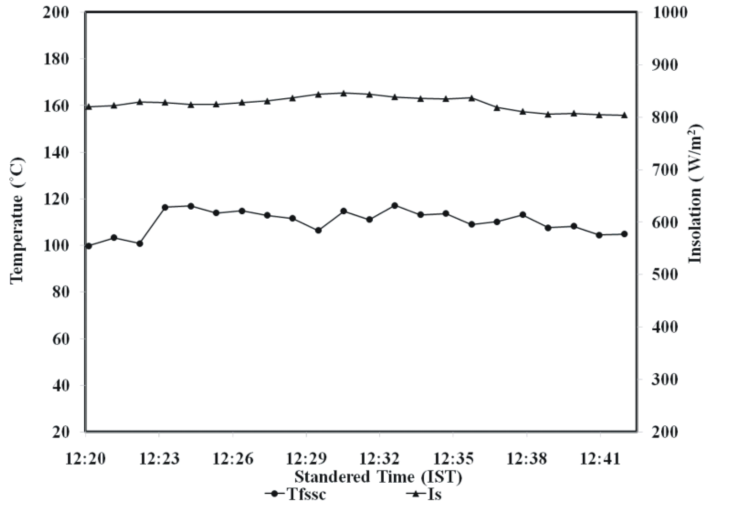

Fig. 8: Temperature profile of FSSC on 20 Jun 2015 (T_{fssc} is receiver temperature and I_S is solar insolation).

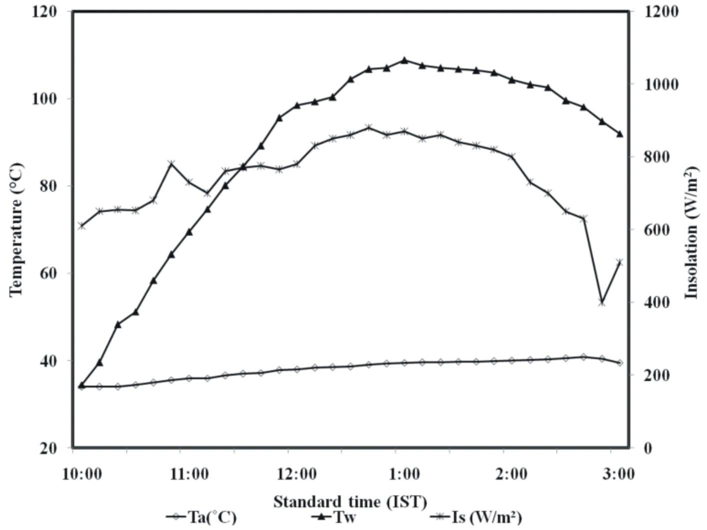

Fig.9: Measured temperature profiles and radiation intensity during sensible heating test of CSSC (8 kg water load) on 08 April 2012 (T_a and T_w are ambient and load water temperatures, I_S is solar insolation).

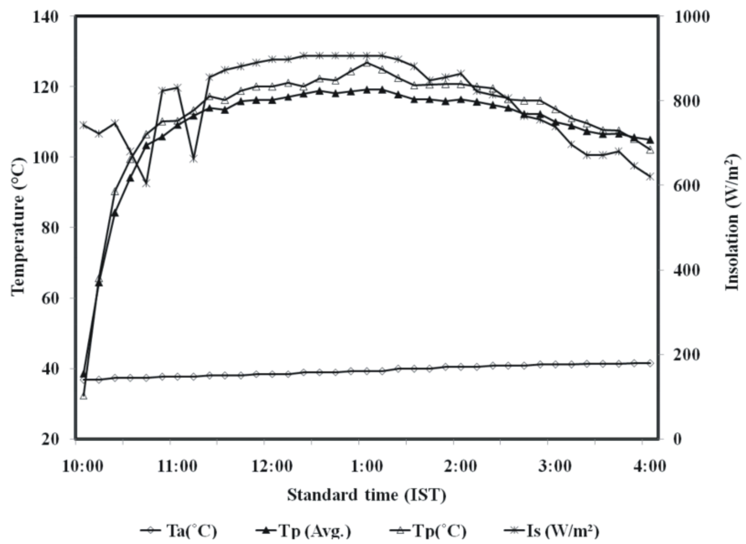

Fig. 10: Temperature profile of the different components (T_p- base plate, T_a-ambient, T_p (avg.)- average plate) of CSSC and variation of solar insoltion (I_s) with the standard time on 12 July 2014.

5. Results and discussion

Building material housing solar water heater: Initial experimental studies (in year 2017) are performed with PMMA glaze for BMSWH. The representative experimental observations for close loop cycle are plotted in Fig. 5. The maximum outlet water temperature is about 74 ºC and storage tank temperature reaches around 60 ºC. System thermal performance has also studied by Sengar; (2007) and Marwal; (2012). This is shown in Fig. 6 and 7. For slow mass flow rate in open loop cycle the maximum outlet temperature was recorded about 90 ºC in 2006 (Fig. 6). These tests were conducted with single glass glaze and hybrid insulation. A comparison of Fig. 5 with reference thermal profile Fig. 7 reveals that system thermal performance is quite good (storage temperature 60 ºC) even after more than 10 years. Although components of system (glaze, insulation, storage tank etc.) have been changed yet the casing is same. It indicates building material casing makes the system good weather resistance and increases the durability. System is still under the testing for determination of different characteristic parameters of a solar water heater.

Fixed structure solar concentrator: Fig. 8 shows that FSSC receiver attained a maximum temperature of 117 ºC at local noon and remains above 100ºC for about 20 minutes for insolation around 800 W/m^2. In FSSC cooking of rice is also done in a pot of diameter 10 cm and height 6 cm. The observed cooking time is 45 min. for 100 gm rice cooking which required 200 gm of water to cook. Hence, FSSC is suitable for cooking of boiling type food in peak sunny hours.

Community size solar cooker: The diurnal variation of water load temperature, solar insulation and ambient temperature for 8kg water load are depicted in Fig. 9.The results of these figures are used to calculate the second figure of merit. Figure shows that in 1 h 30 min water load attained temperature about 80 ºC and it is sustained for more than 3 h. This reveals that two meals cooking for 8 to 10 persons can be done in this cooker as per ref. (Mahavar et al., 2015). The value of second figure of merit (F_2) (using T_{w1}=63.8ºC,T_{w2}=95.1ºC, τ=5400 sec. , average values for the ambient temperature 39.2ºC insulation is 806 W/m^2) calculated as per ref. (Mahavar et al., 2012a) is found to be 0.416 . Fig. 10 represents the diurnal variation of solar insolation, absorber plate and ambient temperature of CSSC under no lad condition. The temperature of the absorber plate increases with time until it achieves the maximum values around 1:00 p.m. The maximum temperature of the absorber plate T_p is recorded to be 126.9ºC. The absorber plate temperature remains above 100ºC for most of the time. This stagnation test as per ref. (BIS, 2000) assures the satisfactory thermal performance of community size solar cooker. This test is conducted after more than two years in 2014 with same components and still the thermal performance of the system is found satisfactory, it indicates the good weather resistance and durability of the system due to the building material casing.

Hence, building material housing can serve as good casing material for solar thermal appliances and using this casing these appliances can be made an integrated part of the building/housing.

6. Conclusion

Solar thermal applications (STAs) have immense potential especially in domestic and industrial sector to meet thermal energy demand of the world. Beside all the development of STAs, there is still need of user friendly, more durable and weather resistant appliances with good thermal performance. Paper concludes that the appliances (water heater, solar concentrator and solar cooker) developed using building material housing have good thermal performance for long duration of 2 to 10 years or even more years. Hence, with building material casing STAs can be developed as integrated part of the housing or small industries and can be more popularized for hot water and cooking need of individual houses in effective way.

7. Acknowledgment

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