

Design and Performance Analysis of a Solar Air Heater With High Heat Storage

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ABSTRACT

The aims of this work is to enhance the efficiency of a simple designed solar air heater for crop drying and space heating. 'Desert sand', has been introduced as a heat absorbing media inside the solar heater. The experimental testing has been carried out on four different configurations by operating it on natural and forced convection in the climatic conditions of Moradabad, India. The thermal behavior of the system is evaluated by operating it on auxiliary power by placing a halogen lamp tube (300W) inside the inlet and outlet ducts. Because of using halogen lights the system is feasible to perform in poor ambient conditions. The thermal performance of all new configurations of the modified system was found better over a similarly designed conventional solar air heater.

Keywords: air heater, desert sand, heat storage, solar energy, performance, thermal energy storage

INTRODUCTION

Since solar radiation is inherently time-of-day dependent, storage of energy is essential if solar is to meet energy needs at night or during daytime periods of cloud cover and make a significant contribution to total energy needs. Since radiant energy can be converted into a variety of forms, energy may be stored as thermal, chemical, kinetic, and potential energy. Generally, the choice of the storage media is related to the end use of the energy and the process, storage as thermal energy is often cost effective. The optimum capacity of the storage device for a given solar process depends on the time dependence of the solar availability,

the nature of the load, the cost of auxiliary energy, and the prices of the process components. These factors must all be weighed carefully for a particular application to arrive at the system design which minimizes the final cost of delivering energy [1-3]. The system basically consists of a flat plate collector (FPC) tilted at some angle from the horizontal with a blower to transfer heat from the collector to storage. All the solar energy provides goes through the storage unit, may be a tank of water or a bin of dry crushed rock. The stored energy could be used for either building heating or water heating [4].

All materials absorb, store heat and release heat as they become heat up or cool down. Materials like water or stone will absorb more heat for a fixed temperature rise than straw or wood. Heavy materials can store large quantities of heat without becoming too hot. When temperatures around them drop, the stored heat is released and the materials themselves cool down. This heat storage capacity of various materials can be used to store the sun's heat for later use. Solar energy (a

Nomenclature

TES - thermal heat storage	T_p - temperature of absorber plate ($^{\circ}\text{C}$)
LHS - latent heat storage	T_1, T_{as}, T_{amb} - ambient temperature ($^{\circ}\text{C}$)
SAH - solar air heater	T_2, T_{ps1} - temperature of absorber plate of model s1 ($^{\circ}\text{C}$)
SAHS- solar air heating systems	T_4, T_{ps2} - temperature of absorber plate of model s2 ($^{\circ}\text{C}$)
PCM- phase change material	T_3, T_{os1} - temperature of exhaust air of model s1 ($^{\circ}\text{C}$)
FP- flat plate	T_5, T_{os2} - temperature of exhaust air of model s2 ($^{\circ}\text{C}$)
HHTS - high heat thermal storage	T_{ci}, T_i - fluid inlet temperature to the collector ($^{\circ}\text{C}$)
f - friction factor	T_o - outlet temperature ($^{\circ}\text{C}$)

viable source for cooking, drying and heating) penetrates through walls or glazing to the interior of a body or system.

This solar heat is absorbed in the air and inside surrounding materials. The air in the system is likely to heat up first. It then distributes this heat to the surrounding materials via convection [5]. Most collectors employ a black-painted, flat absorber plate with heat-transfer passages built within, above or below it and with one or more glass covers on the top. The heat transfer in solar collector takes place by simultaneous radiation, convection, and conduction [6].

In view of rising energy prices and an increasing share of power generated by renewable energy sources, the importance of energy storage is growing. In the framework of this work, a thermal energy storage concept for solar air heater is being developed, in which desert sand

serves as a storage medium. The desert is suitable due to its properties such as high thermal stability, specific heat capacity, and low-cost availability. Compared with storages based on ceramic bodies, the use of sand promises to reduce costs of energy storage and thus to reduce the costs of heating.

A solar air heater (SAH) is a specific type of heat exchanger which transfers heat to the air, which is obtained from absorbing solar radiation by an absorber. During solar air heating heat transfer occurs from an energy source which spreads radiation in the air. It consists of an absorber plate (an *Aluminium* made sheet that converts the solar energy into heat energy, fixed in such a way as to form an air duct through which the air is circulated and heated), supportive walls, ducts or channels for fluid flow (*G.I* or *Al* sheets of which one 'end' is used to carry the fresh air from the outside to the heat collector. The other 'end' is of large area carrying hot air from the heat collector to the required place), glazing (a transparent float glass that minimizes convective and radiative losses to the atmosphere and obtains solar radiation to stay between absorber and glazing, and to be absorbed by blackened absorber), air blower or fans (to supply air at high velocity for forced convection), and insulation (to minimize heat losses to the environment). Almost parts of solar air heaters are thermally well insulated to reduce thermal heat losses. These air ducts (with two open ends) are made for *SAHS* are generally used to dry agricultural products, to dry fabrics and space heating. Drying grains, fruits, vegetables, tea, and building heating are a few examples of this [7-8]. Since solar radiant energy can be converted into a variety of forms of energy storage as thermal, chemical, kinetic or potential energy. Commonly, the choice of the storage media is related to the end use of the energy and the process employed to meet that application. In the thermal conversion process, stored as thermal energy, it is often most cost effective [9].

Thermal Energy Storage (TES) can be classified as sensible heat in hot liquids and solids, as latent heat in melts and vapor, as thermochemical heat appearing in chemical reactions, and as sorption heat in adsorption processes. Thermal energy is stored by raising the temperature of a solid or a liquid medium by using its heat capacity. Apart of this, *LHS* uses the latent heat of the material to store thermal energy. Latent heat is the amount of heat absorbed or released during the change of the material from one phase to another. The amount of thermal energy stored in the form of sensible heat or latent heat in the

Table 1. Improvements in the performance of solar air heaters by using different heat storing materials

Reference	Heat storing media	Results
Abbud et al. [11]	rock bed storage	efficiency improved from 2% to 12%.
Chauhan et al. [12]	rock bed storage	efficiency improved with decreasing drying rate
A.-Enein et al. [13]	sand, granite and water	$T_{o,p}$ was found maximum in the sand
S.O. Enibe [14]	paraffin type PCM	η_{system} was reaching up to 50%
Thakur et al. [15]	low porosity packed bed	heat transfer rate was improved
P. Naphon [16]	porous media	η_{therm} was improved 25.9% than a system without porous media
Prasad et al. [17]	packed bed storage	An improvement was observed in η_{therm} from 53.3% to 68.5%.
Saravanakumar and Mayilsamy [18]	gravel with iron scraps	η_{therm} was improved from 10% to 20%.
Alkilani et al. [19]	paraffin wax with Al powder	$T_{o,p}$ was observed 42 °C maximum
Karthekeyan and Velraj [20]	commercial grade paraffin	$T_{o,p}$ was found suitable for solar drying and space heating
V. V. Tyagi et al. [21]	paraffin wax with hytherm oil	an improvement was observed in η_{therm} from 20% to 53%.
W.Aissa et al. [22]	granite stone storage material	$T_{o,p}$ was observed 10-25 °C more than T_{amb}
Krishnananth and Murugavel [23]	paraffin wax in Al capsules	$T_{o,p}$ was observed 58 °C maximum

material can be calculated by reference [10]. In *SAHS*, it is essential to provide a suitable thermal storage in adding together to the solar collector to enhance the heat transfer and storage capacity. Both latent and sensible heat storages use as a heat transfer enhancing media to solar energy collectors. Phase change materials are used widely as a TES in many solar applications. It has been originated by studying the available literature that the rock bed, pecked bed and paraffin wax are commonly used in solar air heaters as TES. In several previous works, a few good improvements are found in the thermal behavior of *SAHS* by using of these heat storing materials (table 1). An attempt is made here for an optimal design of *SAH* that is simple in design, user friendly, easy to maintain, can be performed in poor ambient conditions, inexpensive and have improved efficiency over than other designs.

All the works and experiments have been carried out previously [11-23] are typical in design and costly in comparison of our model especially in the case of *SAH* with heat storages. Besides this almost available materials used as thermal heat storage used in solar energy equipments are much costlier to purchase and higher production cost [10]. In the present model, the desert sand is used as a *TES*, which is purchased from the local market @ of 0.1 \$/kg. Near about 3 kg of the desert sand was used in the system and the cost was 0.3 \$- approximately, which is very less than the cost of any of other thermal heat storage materials used for solar air heaters.

EXPERIMENTAL SET UP

Two solar air heaters (H1 and H2) of same specific dimensions (Figure 1a) have been designed and fabricated to supply the hot air for crop drying and space heating purposely. Both the air heaters were experimentally tested individually for their thermal performance on the 4 different configurations. Plywood of 1 cm thickness was used for the fabrication of both the heaters. The precise area of absorber tray was 151 x 53 cm² and made of 0.5 mm thick 22 SWG *Al* sheet. The absorber plate was painted dull black to store the maximum amount of solar energy for H1. To reduce the heat losses, a 2 cm thick layer of glass-wool (insulator) was inserted between the absorber tray and outer cabinet. A single pane transparent float glass of 0.3 cm thickness and 151 x 70 cm² was used as glazing to allow the solar radiation inside the solar heaters. The single

glazing was considered especially for the maintenance of the SAHS. The efficiency effecting elements of SAH such as; halogen lights, inside wall of ducts (for good reflection), and principally the absorber plate are required to be very clean while performing (a float glass, beneath which the desert sand is spread to be high SHS) as well for efficient working in poor ambient conditions. Dusty transparent glass over storage media and dusty reflective walls will be resulted in lower efficiency of the solar energy systems [24]. Double glazing makes the system a little bit complicated in comparison of discussing system and more maintenance and attention will be requisite.

The distance between glazing and absorber plate was 10 cm for both the heaters. A layer of desert (Figure 1 b) of 1 mm was spread on the absorber plate and sealed by 2 mm float glass for H2 (Figure 2). The side walls of SAH were tilted at 115° angle because of receiving good amount of solar radiation through its exposed area. For the supply of

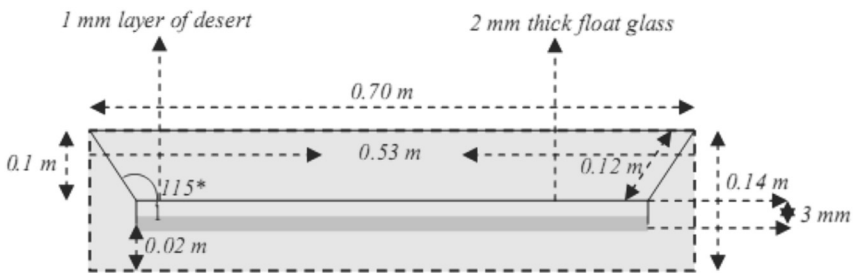


Figure 1a. Desert spread on the absorber plate and sealed by float glass

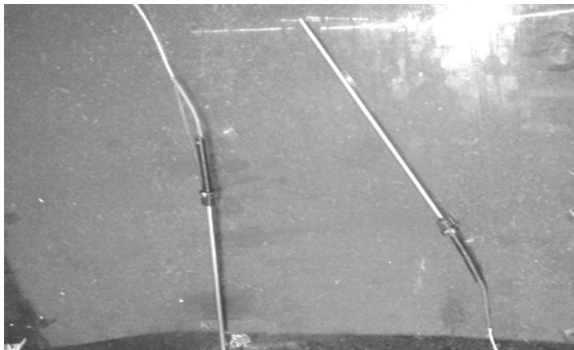


Figure 1b. Desert spread on the absorber plate

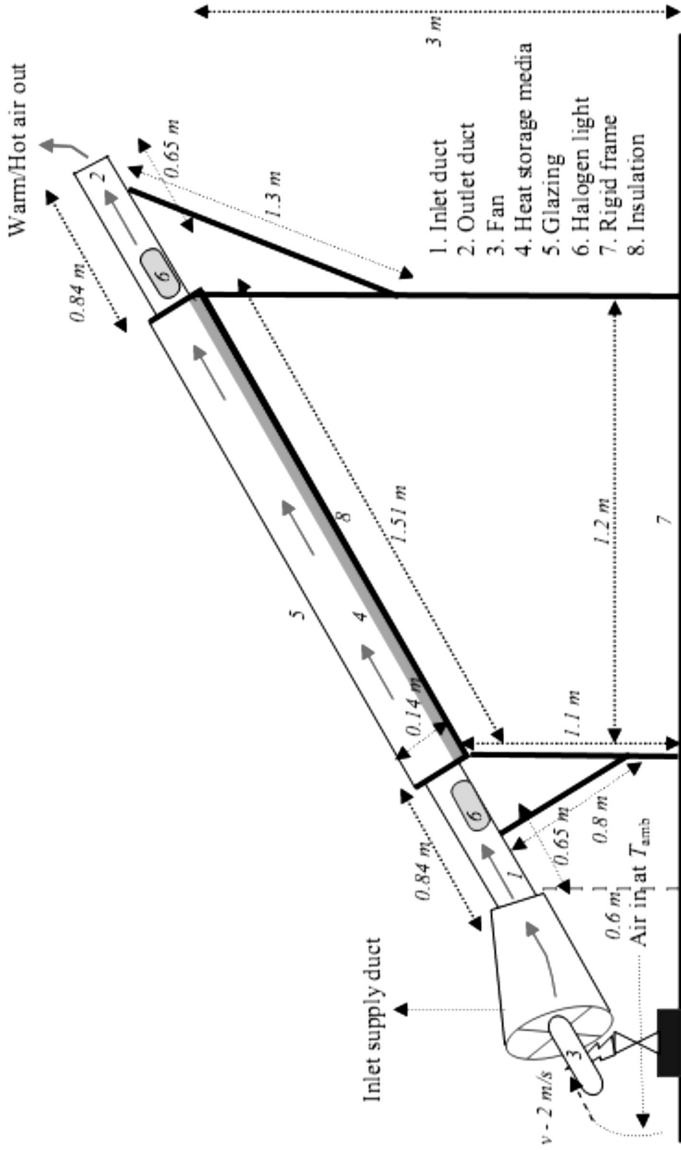


Figure 2. Schematic view of experimental set-up of solar air heater

the air, similar table fans (40W) of 'CINNI- 20 CR' trademark were used to supply the air to the system. The flow rate air supplying was set at 2 m/s for forced convection. The speed of the fan can be controlled by a knob which was fixed on 3 inbuilt controls viz; low speed -1750 rpm, mid speed-1980 rpm, and high speed-2200 rpm. Even this speed can also be varied up to 2500 rpm through a high voltage of current supply.

A cylindrical tapered shaped vessel was used to connect the fan directly to the inlet duct of SAH to pass the fresh air {thermal conductivity- 0.26 (W/mK), specific heat-1005 (J/kgK), density-1.2 (kg/m³)} inside the SAH. This vessel was fabricated of an Al bucket (0.5 mm thick) with two 'Ends' in which the round shaped end was fixed with the fan while rectangular end was fixed to the inlet duct of SAH. The other two ducts (inlet and outlet) of same dimensions were fitted to the SAH (fabricated with the same grade of Al and 0.5 mm thick) for the air supply and for exhaust. Both the ducts were also painted dull black from outside. The ducts were remained as it is (with no painted walls) inside which results in increasing the temperature of the duct because of the high reflectivity produced by using halogen lights (placed inside the ducts) while operating. A rigid frame of galvanized iron was used to support the SAH at the ground level. The system was placed towards the southward at an angle of 43° from horizontal. For a HHTS a thin layer of 1 mm desert was spread above on the blackened surface i.e. absorber tray. The desert sand is taken because of good thermal heat storage {Density (kg/m³)→ 1450, thermal conductivity (W/m-K)→ 0.26, specific heat (kJ/kg-K)→ 0.80, thermal diffusivity (m²/s/10⁶)→ 0.35, heat capacity (J/m³k x10⁻⁶)→ 1.28, emissivity→ 0.91 and absorbitivity→ 0.95, porosity→ 26%} for high heat absorber and performs as SHS [25].

The test desert sand was sieved to 20 x 50 (US Sieve) mesh, yielding a particle size range from 0.25 to 0.60 mm. It has been observed the desert gets the surface temperature up to 50 to 60°C in 30 to 35°C of T_{amb} [26]. In the experimental set up the desert was fully sealed with a transparent float glass with an adhesive of 'M-Seal', trademark. To enhance the η_{ther} of new designed SAH, 2 halogen lights of 'Phillips' trademark (300 W each- MFG Model #: 415711) were placed in the inlet and outlet ducts of SAH at the distance of 65 cm from the open channels and the halogens can be performed on auxiliary power. The key advantage of the system was that it can be performed well in poor ambient conditions.

All the experiments have been conducted at the M.I.T, Moradabad-244001, (latitude-28°58'N and Longitude-78°47'E). There were 4

different configurations for which the H1 and H2 have experimentally tested on both natural and forced convection. The variation in temperature of both the SAHS and the T_{amb} was measured by using a 6 wire K-type thermocouple meter with an accuracy of $\pm 1^\circ\text{C}$. The solar insolation (W/m^2) on the horizontal surface was directly measured by a standard solarimeter 'Surya-maapi' (CEL-201) with an accuracy of $1 \text{ W}/\text{m}^2$. The velocity of the air was monitored using an anemometer with 1% accuracy located nearby the experimental set up while the air temperature was measured using mercury in-glass type thermometer. The measured variables were recorded at time intervals of 15 min (and discussed on an hourly basis with an average value of 04 actual reading values) included; solar radiation, the inlet and outlet temperatures of the air circulating through the systems, ambient temperature, absorber plate temperatures at three selected points, and wind speed. The experiments were repeated for different mass air flow rates ($0.019 \text{ kg}/\text{s}$ for natural convection and $0.12 \text{ kg}/\text{s}$ on forced convection). All the experiments have been started at 10:00 AM and ended at 19:00 PM to observe the behavior of heat storage media.

RESULT AND DISCUSSION

The thermal efficiency of a solar collector is the major requirement to predict the thermal performance of the complete solar system of which the solar air collector is a part. It is, therefore, important that the η_{therm} information is in a form which is useful for existing and projected future solar energy system design methods. To evaluate the thermal performance of solar air heaters different methods are developed earlier [27]. Among them steady-state procedure is the most common, the procedure involves simultaneous and accurate measurements of \dot{m} , the inlet and outlet temperatures of the collector fluid, and the ambient conditions. Here, after a change of flow rate, both the solar heaters 'H1' and 'H2', was allowed to attain a steady state before experimentation. Following are the parameters, used to evaluate the thermal performance of both solar heaters 'H1' and 'H2' and enhancement by using TES.

$$\text{Mass flow rate } \dot{m} = \rho.A.V \quad [1]$$

$$\text{Equivalent hydraulic diameter } d_e = 2LH/L+H \quad [2]$$

$$\text{Reynolds number } \text{Re} = \frac{V \rho \cdot 2LH}{\mu(L+H)} \quad [3]$$

$$\text{Friction factor } f = \frac{0.0791}{(\text{Re})^{0.25}} \quad [4]$$

$$\text{Pressure drop } \Delta P = 2f(\rho \cdot V^2) L/d_e \quad [5]$$

$$\text{Overall heat transfer coefficient } h = \frac{Q_u}{A_p(T_p - T_f)} \quad [6]$$

$$\text{Overall heat loss coefficient} \quad [7]$$

$$U_t = \left[\frac{N}{\frac{C_t}{T_p} \left(\frac{T_p - T_a}{N + f_t} \right)^{0.33} + \frac{1}{h_w}} \right] + \left[\frac{\sigma(T_p^2 - T_a^2)(T_p - T_a)}{\frac{1}{\{\epsilon_p + 0.05 \times N(1 - \epsilon_p)\}} + \frac{2N + f_t - 1}{\epsilon_g} - 1} \right]$$

Equation 7 can be solved by using following relations;

$$h_w = 5.7 + 3.8v_w \quad [8]$$

$$C_t = 520 \cdot [1 - 0.0000513 \cdot \beta^2] \quad [9]$$

$$f_t = (1 + 0.089 \cdot h_w + 0.1166 \cdot h_w \epsilon_p)(1 + 0.0786N) \quad [10]$$

$$U_b = k_i/t_i \quad [11]$$

$$U_L = U_t + (k_i/t) \quad [12]$$

$$\eta \equiv \frac{Q_u}{I \cdot A_c} = \frac{\dot{m} \cdot C_p (T_o - T_i)}{I \cdot A_c} \quad [13]$$

The value obtained for h_w is 9.5 W/m²K, for C_t is 473.25 W/m²K, for f_t is 3.37, for U_b is 1.75, for U_t is 10.09, for UL is 11.84 W/m²k, $N = 1$ because of single glazing, $\sigma = 5.67 \times 10^{-8}$ W/m²K⁴ and the emissivity of the absorbing plate and glass cover are $\epsilon_p = 0.91$ and $\epsilon_g = 0.81$ respectively.

Pressure drop was observed 0.271 (at velocity of the air = 0.30 m/s and $f = 0.01$) and 0.163 (at velocity of the air = 0.95 m/s and $f = 0.006$) for natural and forced convection respectively for full length 3.19 m, $d_e = 0.254$, $\rho = 1.1 \text{ kg/m}^3$.

To evaluate the thermal performance of both the models 'H1' and 'H2' at different 4 configurations on natural and forced convection, all the experiments have been conducted in the month of April 2012 (10.04.2012 to 17.04.2012) from 10:00AM to 19:00 PM because of a drawn out sunshine hours. Both the systems were placed at southward direction at an angle of 43° from horizontal, exposed to the Sun and both the systems were operated on natural convection by supplying of the air to the inlet duct. It is notable that the cylindrical-conical duct was not used in any of the natural convection process. While in the forced convection it is considered as an important element to supply the forced air to the inlet rectangular duct of the SAH by an additional circular duct at constant velocity. The velocity speed at the inlet rectangular duct from circular duct was measured 2 m/s and kept constant for all forced convection experiments. The experiments were conducted in a subsequent manner from point 1 to 8, for both the models simultaneously to observe the variations in performance (For heat transfer mechanism see Figure 3).

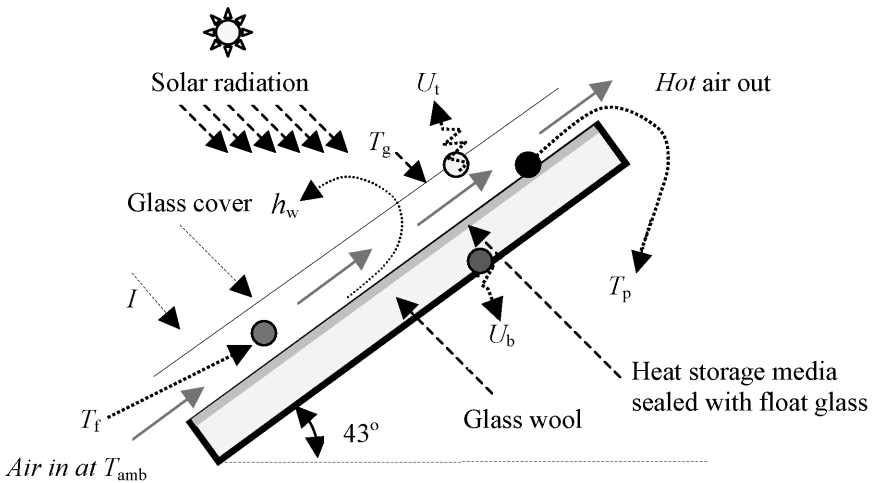


Figure 3. Heat transfer mechanism of SAH

- i). On 10.04.2012, both the models 'H1' and 'H2' were operated on natural convection.
- ii). On 11.04.2012, both the models 'H1' and 'H2' were operated on forced convection.
- iii). On 12.04.2012, both the models 'H1' and 'H2' were operated on natural convection by placing a 300 W halogen light inside the inlet duct at 65 cm from opening end.
- iv). On 13.04.2012, both the models were 'H1' and 'H2' operated on forced convection by placing a 300 W halogen light inside the inlet duct at 65 cm from opening end.
- v). On 14.04.2012, both the models were 'H1' and 'H2' operated on natural convection by placing a 300 W halogen light inside the outlet duct at 65 cm from opening end.
- vi). On 15.04.2012, both the models were 'H1' and 'H2' operated on forced convection by placing a 300 W halogen light inside the outlet duct at 65 cm from opening end.
- vii). On 16.04.2012, both the models were 'H1' and 'H2' operated on natural convection by placing two separate 300 W halogen lights inside the inlet and outlet duct at 65 cm from opening ends.
- viii). On 17.04.2012, both the models were 'H1' and 'H2' operated on forced convection by placing two separate 300 W halogen lights inside the inlet and outlet duct at 65 cm from opening ends.

On the first day (10.04.2012), both the solar heaters 'H1' and 'H2' were operated on natural convection simultaneously. At the starting (10:00 Hrs) of experiments the T_{amb} was observed 29°C with 580 W/m² of solar radiation and ended with 29°C with 490 W/m² at 19:00 hrs. The T_p was observed maximum 59°C and 62°C at 15:00 Hrs at noon respectively for 'H1' and 'H2' during the performance testing. The maximum η_{therm} was found 14.1% and 15.98% at 15:00 Hrs and 17:00 Hrs, while the minimum η_{therm} was measured 8.38% and 10.18% at 10:00 Hrs respectively for 'H1' and 'H2' (Figure 4). The average output hot air velocities were measured 0.31 m/s and 0.33 m/s with average output temperatures 44.50°C and 47.30°C, respectively for 'H1' and 'H2'. On the next day (11.04.12) both the SAHS were operated on forced convection at a constant air velocity (2 m/s), and in this testing both the systems were

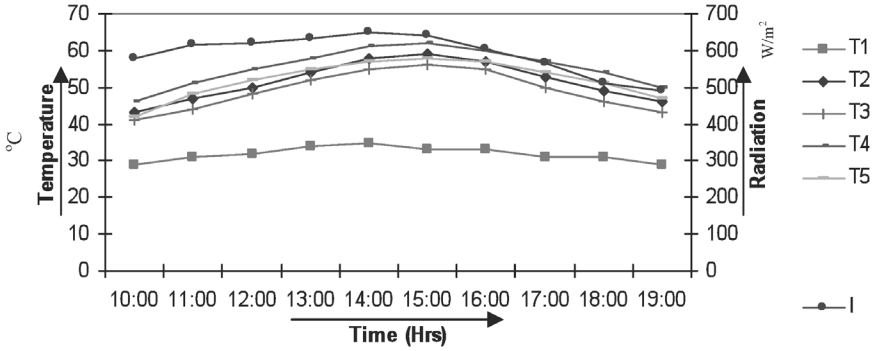


Figure 4. Performance of H1 and H2 on plain absorber plates on natural convection

found to be taken much time to get hot in comparison of natural convection. At the starting (10:00 Hrs) of experiments the T_{amb} was observed 30°C with 590 W/m² of solar radiation and ended with 29°C with 485 W/m² at 19:00 hrs. The T_p was noticed maximum 47°C and 49°C at 14:55 Hrs and 14:05 Hrs respectively for 'H1' and 'H2' at noon while testing. The maximum η_{therm} was found 41.44% and 47.97% at 14:50 Hrs and 13:00 Hrs, while the minimum η_{therm} was observed 33.45% and 29.73% at 10:00 Hrs respectively for 'H1' and 'H2' (Figure 5). The average output hot air velocities were 0.93 m/s and 0.95 m/s while the average output temperatures were measured 35°C and 36.7°C respectively for 'H1' and 'H2'.

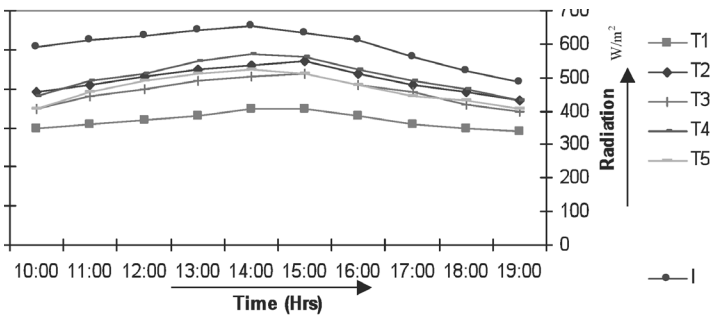


Figure 5. Performance of H1 and H2 on plain absorber plates on forced convection

On 12.04.12, the experiments were conducted on natural convection by placing a halogen light of 300 W at the inlet ducts of both the solar heaters at the distance of 65 cm from the ends open for intake of the fresh air, of the ducts. After the performance evaluation on this configuration of both the systems, the results were found satisfactorily with an improvement in the output air velocity, outlet temperature and η_{therm} . Readings were taken in the same way with an interval of 15 minutes during 10:00 hrs to 19:00 hrs. T_p was noticed maximum 62°C and 66°C at Hrs and 14:55 Hrs at noon for 'H1' and 'H2' respectively during the performance evaluation. The maximum η_{therm} was observed 15.19% and 17.36% at 15:00 Hrs respectively while the minimum η_{therm} was evaluated 8.98% and 9.58% at 9:55 Hrs respectively for 'H1' and 'H2'. The average output hot air velocities respectively for 'H1' and 'H2' were observed 0.32 m/s and 0.35 m/s with an average output temperatures 46°C and 48.5°C, while testing (Figure 6). On 13.04.12, both the SAHS were operated on forced convection (as previous). This time T_p was noticed maximum 47°C and 50°C at 14:55 Hrs and 14:05 Hrs at noon for 'H1' and 'H2', respectively. The maximum η_{therm} was found 46.73% and 54.39% at 15:50 Hrs and 14:10 Hrs respectively, while the minimum η_{therm} was found 33.73% and 29.99% at 10:00 Hrs respectively for 'H1' and 'H2' (Figure 7) during the experiments. The average output hot air velocities were 0.93 m/s and 0.94 m/s for both 'H1' and 'H2', while the average output temperatures were measured 36.9°C and 37.7°C, respectively for 'H1' and 'H2'.

On the next day 14.04.2012, the experiments were conducted by placing halogen lights of 300 W inside outlet ducts of both the solar heaters at the distance of 65 cm from the opening ends of ducts (open to the environment for heating). In this configuration a good improvement was observed in output air's temperature while η_{therm} was found for an agreed improvement for both the air heaters. The maximum value of the T_p was noticed 66°C and 68°C at 13:55 Hrs at noon for 'H1' and 'H2' respectively. The maximum η_{therm} was observed 16.56% and 17.63% at 14:00 Hrs, while the minimum η_{therm} was observed 10.18% and 10.77% at 10:00 Hrs respectively for 'H1' and 'H2' during the testing. The average output hot air velocities were 0.32 m/s and 0.34 m/s and the average output temperatures were measured 48.1°C and 50°C respectively, for 'H1' and 'H2' (Figure 8). On 15.04.12, both the SAHS were operated on forced convection. In this case, the T_p was notified maximum 49°C and 51°C at 13:05 Hrs and 13.50 Hrs at noon for 'H1' and 'H2', respectively.

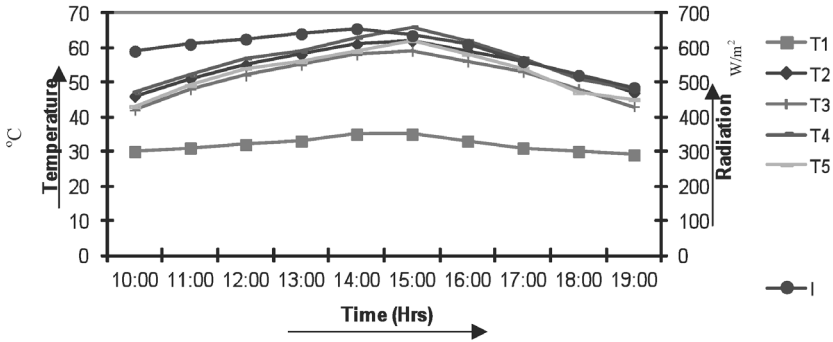


Figure 6. Performance of H1 and H2 by placing halogen light inside the inlet duct on natural convection

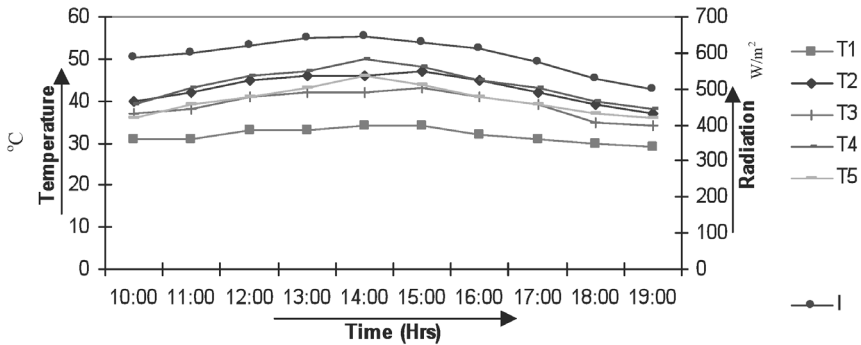


Figure 7. Performance of H1 and H2 by placing halogen light inside the inlet duct on forced convection

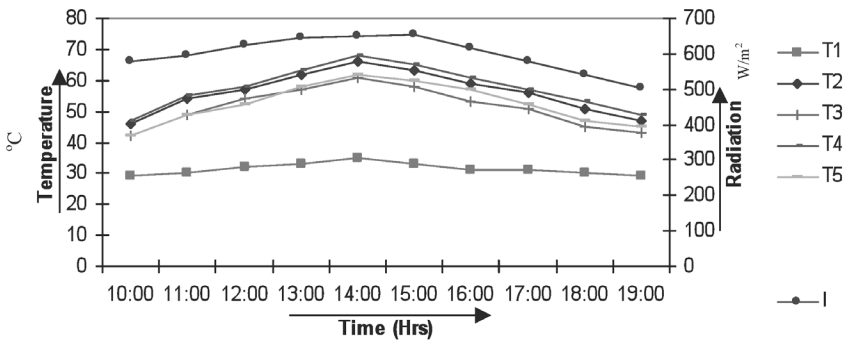


Figure 8. Performance of H1 and H2 by placing halogen light inside the outlet duct on natural convection

The maximum η_{therm} was noticed 51.39% and 54.82% at 14:00 Hrs, respectively for 'H1' and 'H2' and the minimum η_{therm} was found 36.85% and 33.17% at 10:00 Hrs respectively for 'H1' and 'H2' (Figure 9) while conducting the experiments. The average output hot air velocities were 0.93 m/s and 0.95 m/s for 'H1' and 'H2' respectively while the average output temperatures were measured 38°C and 39.10°C respectively, for 'H1' and 'H2'.

On 16.04.2012, the performance evaluation of both solar heaters was carried out by placing halogen lights of 300 W inside both the ducts (inlet and outlet) of both SAHS at same position as in previous configurations. This configuration was found to provide a better output in terms of air's temperature and η_{therm} of both the heaters on both natural and forced convection heat transfer with respect of all previous configurations. The T_p was noticed maximum 65°C and 67°C at 14:55 Hrs at noon for 'H1' and 'H2', respectively. During the testing, the maximum η_{therm} was observed 17.50% and 18.74% at 14:50 Hrs and 14:05, while the minimum η_{therm} was evaluated 11.87% and 12.46% at 10:00 Hrs respectively for 'H1' and 'H2' (Figure 10). The average output hot air velocities were 0.32 m/s and 0.34 m/s with an average output temperatures were measured 49.3°C and 51.3°C respectively for 'H1' and 'H2'. On the next day while operating both the air heaters T_p was notified maximum 51°C and 54°C at 13.55 Hrs, at noon. The maximum η_{therm} was found 60.12% and 69.06 % at 13:00 Hrs and at 13:55 Hrs while the minimum η_{therm} was found 37.31% and 41.59% at 10:10 Hrs, respectively for 'H1' and 'H2' (Figure 11). The average output hot air velocities were 0.93 m/s and 0.95 m/s for 'H1' and 'H2', while the average output temperatures were measured 39.9°C and 41.95°C respectively for 'H1' and 'H2'.

After the completion of all the experiment testing for the thermal performance evaluation of both the solar heaters successfully, the heat transfer rate was observed moderately improved while operating both the systems on forced convection in comparison of operating on natural convection. The Q_u ranges from 242.51 W to 372.5 W for H1 model while 295 W to 372.35 W for model H2 respectively in the case of natural convection. In the case of forced convection Q_u ranges from 373.49 W to 1036.13 W for H1 model while 578.30 W to 1373.47 W for model H2 respectively. Apart this, the heat transfer coefficient was found to be increased for each new configuration (from configuration 1 to 4) on both operating conditions (i.e., natural and forced convection) for both the models. The value of " h " was observed in a range from 42.69 W/m²K

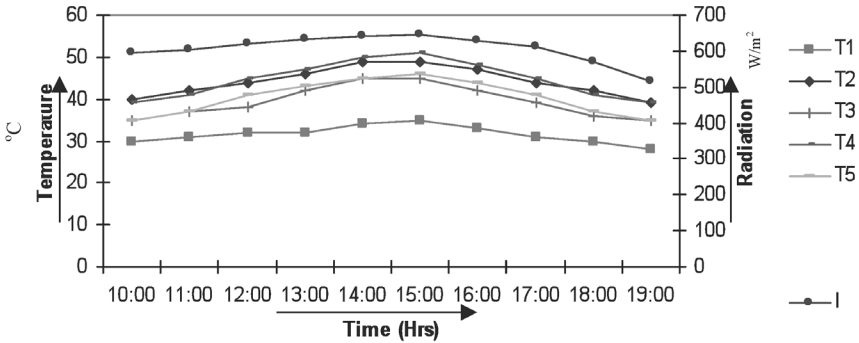


Figure 9. Performance of H1 and H2 by placing halogen light inside the outlet duct on forced convection

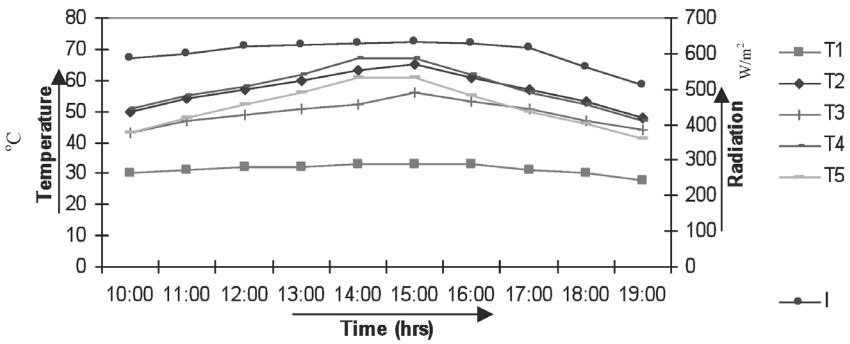


Figure 10. Performance of H1 and H2 by placing halogen lights inside the inlet and the outlet ducts on natural convection

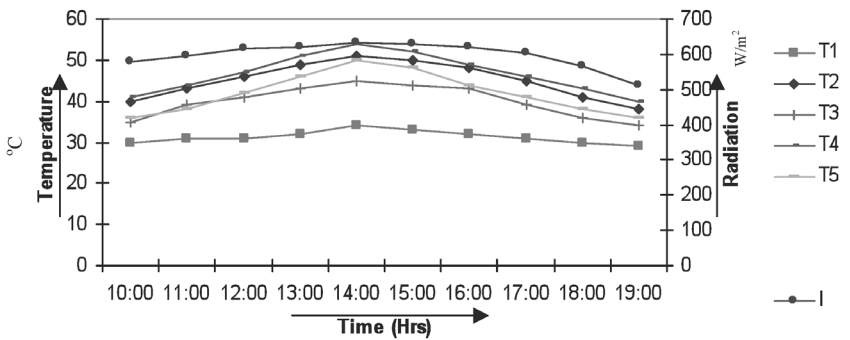


Figure 11. Performance of H1 and H2 by placing halogen lights inside the inlet and the outlet ducts on forced convection

to 57.29 W/m²K and 45.67 W/m²K to 72.73 W/m²K for 'H1' and 'H2' respectively on natural convection while 64.84 W/m²K to 392.47 W/m²K and 86.06 W/m²K to 429.21 W/m²K for 'H1' and 'H2' respectively on forced convection, respectively.

In both the solar heaters model "H2" was found better than model "H1" in temperature of the exhaust air, while the output air velocities range from 0.31 m/s to 0.34 m/s for natural convection and 0.91 m/s to 0.93 m/s for both the solar heaters. The minimum and maximum value of T_{os1} was 26.7°C and 33.2°C while 30.1°C and 37.4°C for T_{os2} . This temperature "37.4°C" of the model H2 is good enough for heating or drying in poor ambient conditions and makes the models H2 better in comparison of the model H1. It is also notable that all the modifications made to both the air heaters in a similar manner but model H2 is found better for thermal performance than H2. In order to perform the uncertainty, analysis of experiments conducted from 10.04.2012 to 17.04.2012, all the experiments have been repeated in the same sequence from 20.04.2012 to 27.04.2012. The uncertainty of each parameter is shown in table 2. It can be concluded that the uncertainty at 96% confidence level is $\pm 0.98.5\%$ for thermal efficiency.

Table 2. Uncertainty analysis of performance parameters

S. No.	Parameters	Uncertainty
1.	Solar radiation	$\pm 0.25\%$
2.	Ambient temperature	$\pm 0.18^\circ\text{C}$
3.	Humidity	$\pm 2.75\%$
4.	Wind velocity	$\pm 2.60\%$
5.	T_{ps1}	$\pm 2.1^\circ\text{C}$
6.	T_{ps2}	$\pm 2.5^\circ\text{C}$

CONCLUSION

A SAH "H2" has been designed, fabricated and evaluated for thermal performance on 4 different configurations. The results were compared with a similarly designed SAH (H1) consisting an Al made dull blackened absorber tray. All the experiments were carried out on both 'H1' and 'H2' in the same ambient conditions simultaneously. It was observed that the "H2" got the maximum temperature in very short

span of time in comparison of "H1." A good improvement was found in the thermal performance of both the heaters while performing on all new configurations on both natural and forced convection. The results show that there was a significant effect on "H1" and "H2" with ambient conditions.

The maximum η_{therm} 14.1%, 15.19%, 16.56%, and 17.5% were observed for "H1" on natural convection for four different configurations while for "H2," the maximum η_{therm} were obtained as; 15.73%, 17.36%, 17.63%, and 18.74% on same configurations on natural convection. There was a good improvement by operating both heaters on forced convection and the maximum η_{therm} were obtained as; 41.44%, 46.73%, 51.39%, and 60.12% for "H1," while the maximum η_{therm} for "H2" were calculated as; 47.97%, 54.39%, 54.82%, and 69.06%. Beside this a good stability in the T_p , the output air velocity, the outlet temperature, and η_{therm} were found in "H2" in comparison of "H1," while performing. The model "H2" was also found as well high heat storage SAH and suitable for drying and space heating than conventional SAHS. The model "H2" was also found economical by eliminating a blower of high power consumption [28], which minimizes the system's operating and maintaining cost. The use of halogen lights makes systems feasible to perform in bad climatic conditions. This model "H2" has the feasibility to increase the exhaust temperature by increasing the number of halogen lights or accordingly (in the case of requiring high heat temperature of the air) in poor ambient conditions.

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