A REVIEW ON SOLAR AIR HEATER TECHNOLOGY

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ABSTRACT

In this paper, a review of the available literature on solar air heaters is presented. The review is performed to allow a discussion and evaluation of the findings obtained by researchers. The review covers the overview of solar air heater technology, detail description of various types of solar air heaters, solar air heaters with different absorber plate surface geometry to enhance the rate of heat transfer. Different designs of solar air heater with and without heat storage materials especially phase change materials are reported. Use of fins on the absorber plate and different surface geometry of absorber plate enhances the rate of heat transfer during the sunshine hours and use of PCM (thermal energy storage medium) supply heat energy during off sunshine hours. As a result, solar air heaters gain popularity in a wide range of its applications.


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1. INTRODUCTION

Solar energy is the origin of all forms of energy. The essence of energy to our society is growing to ensure the quality of life and to smoothly run the other elements of our economy. Several renewable energy technologies are in practice in the 21st century, but many of these are still under development. In solar energy applications, the solar air heaters (SAHs) were commonly used as heat exchanger [1]. Air heating is one of the major solar thermal applications, used for space heating and process heating like laundry, desalination, crop drying and other drying processes. Utilizing of conventional energy for this process will increase the process cost as well as pollute the environment. Using solar energy for air heating will reduce the operational cost of the system and the consumption of conventional energy [2]. This review aims to merge the efforts of the researchers working on SAH and find the pathways to present it by means of robust applications to use, and thus to enhance the performance for consideration in the design and development in present context. It is very complex to classify solar air heater due to the many numbers of shapes and empirical constructions. Ekechukwu and Norton [3] conducted a detailed review on different designs, construction and principles of operation of a wide variety of SAHs for drying. SAHs can be classified; based on mode; into active, hybrid and passive. Tyagi et al. [4] classified the solar air heaters according to their tracking axis, energy storage,
extended surface and numbers of covers as indicated in Fig 1. In passive solar air heating systems, hot air is generated at different places and directed to end use. Heat storage materials are commonly utilized in active SAH to generate hot air during off day time. On other hand passive SAHs are generally utilized during daytime. From another perspective, SAHs may be classified according to the number of air passes into single-pass and double-pass with or without heat storage [5–6]. In single-pass air solar heater, air flows in one way either above the absorber plate or below it from the air inlet to outlet as presented in Fig 2. While in double-pass air solar heater, air flows in two passages, which may be either counter or parallel as illustrated in Fig 3. SAHs consist mainly of air flow duct and absorber plate. To reduce heat losses from both bottom and sidewalls, thermal insulation with low thermal conductivity is used. Many researchers have fabricated their experimental test-rigs to study the effect of modifications which may be done in the main components of the SAH. Therefore, the main objective of the present paper is to find the scope and to study the different design configurations of SAHs.

2. CLASSIFICATION OF AIR HEATERS

Solar air heater is a device in which energy transfer is from a distant source of radiant energy to air. Solar air heaters can be used for many purposes such as crop drying, space heating, marine products, heating a building to maintain a comfortable environment especially in the winter season. A comprehensive review on numerous designs, construction and working of solar air heater for drying is presented by Ekechukwu and Norton [3]. Here an attempt is made to classify the solar heater on the basis of with and without energy storage, numbers of covers, extended surface and their tracking axis is presented in Fig 1.

![Figure 1](image1.png)

**Figure 1** Classification of the SAHs based on [4].

3. SOLAR AIR HEATERS WITH DIFFERENT SURFACE GEOMETRY

Solar air heaters have many attractive advantages over liquid heaters regarding the problems of corrosion, boiling, freezing and leaks [7]. Solar air heater without thermal storage is extensively used for drying agriculture products. In fact most of the agriculture products are getting dried at low temperature (50–60 °C) and this can be easily achieved in flat plate type solar air heater. Further hot air generated by air heater can be delivered by natural convection or by forced convection mode. It depends upon the type of fabrication and climate condition.
Fig. 2. Single-pass air solar heater [5]  Fig. 3. Double-pass SAH (a-counter flow b-parallel flow) [7]

Chabane et al. [8] have fabricated a single pass solar air heater test rig Fig 4, studying their performance. Two collectors were fabricated and two modes of the absorber plates were utilized. The test rig performed under forced convection mode.

Figure 4 Schematic view of test rig used [8]

Akpinar and Koçyiğit [9] have investigated the performance of SAH using four types of absorber plates in the shape of triangular, leaf shaped, rectangular obstacles and flat plate Fig 5. Bayrak et al. [10] investigated the performance of five collectors using baffles made of Closed-cell aluminum foams. The baffles were positioned in both staggered and sequence arrangements above the absorber plate. The experimental apparatus is appeared in Fig 6.

Figure 5 Types of absorbers used in [9] Figure 6 Experimental apparatus of collectors [10]

El-Sebaii et al. [11] constructed an experimental test rig for double pass SAH Fig 7. The finned plate SAH was compared to v-corrugated plate SAH with the same design configurations. Gao et al. [12] constructed a baffled double-pass SAH with external recycle Fig 8. Baffles were welded to five fins made of stainless steel for both under and above the absorber plate. For achieving recycle process, the air flow from the lower channel was mixed with the regulated air flow before entering the upper channel using of an adjustable valve existing at the upper channel end Plate.
Bouadila et al. [13] constructed an experimental test-rig to study the performance of a SAH with latent storage collector. The setup consisted of a packed bed absorber formed of spherical capsules with a black coating. Krishnananth and Kalidasa [14] fabricated a counter flow double pass SAH. The inlet and outlet sections of the SAH were made of conical shape to maintain a uniform distributed flow inside the collector. The heater was integrated with Paraffin waxes in the six aluminum capsules painted with black color. The photo of the experimental test rig is shown in Fig 10.

Yamali and Solmus [15] fabricated the double-pass solar air heater shown in Fig 11. The solar air heater mainly consists of duct made of iron sheets coated with a matt black dye. The absorber plate was made of a matte black painted copper absorber plate and placed horizontally on the center-line of the duct. The SAH was covered using two glass covers.

**Figure 11** A photograph of the double-pass flat plate SAH [15].

**4. SOLAR AIR HEATERS WITH ENERGY STORAGE**

Solar air heater with PCM based thermal storage is based on the solar energy collection for it’s off sunshine hours use. A phase change material is a solid and melted which stores energy. The melting temperature may be fixed or may vary over a small range. The stored energy is recovered upon solidification of the liquid. In this system, solar energy stored in thermal energy storage system (TESS), during sunny days and recovered later at night or during cloudy days. Different phase change materials (PCMs) are available for their temperature range, usually hydrated salts such as calcium chloride hexa hydrate, paraffin’s, non-paraffin and fatty acids [16-19] are very popular materials. A comprehensive review has been made with thermal energy storage is presented in this section.
Jurinak and Abdel-Khalik [20] have made a study to determine the optimum physical properties of phase-change energy storage materials for solar air-heating systems. They used simulation techniques to determine the system performance over the entire heating season for different space heating load. They have investigated the transient behavior of phase-change energy storage (PCES) units and presented simulation techniques to use in conjunction with these models to determine the performance of solar heating systems utilizing PCES. They used sodium sulfate decabhydrate and paraffin wax as a storage medium for air heating system and calculated optimum ranges of storage sizes, the variation of the solar supplied fraction of load with storage size and collector area for systems.

Hammou and Lacroix [21] proposed a hybrid thermal energy storage system (HTESS), using phase change materials for managing simultaneously the storage of heat from solar and electric energy as shown in Fig 13. They stored solar heat during sunny days and released later at night or during cloudy days and, to smooth power demands, electric energy is stored during off-peak periods and later used during peak periods. The results of this study indicate that, by using a HTESS, the electricity consumption for space heating is reduced by 32%. Also, more than 90% of the electricity is consumed during off-peak hours. For electricity markets where time-of-use rate schemes are in effect, the return on the investment in such a storage system is very attractive. Qi et al. [22] have studied on solar heat pump heating system with seasonal latent heat thermal storage (SHPH–SLHTS). They develop a mathematical model for the system and the simulated operating performances of the system. The simulation results suggested that the temperature of the PCM in a storage tank was much lower than that of water in a central solar heating system with hot-water heat storage, and could be maintained at around the melting point of the PCM.

Kaygusuz [23] have investigated experimentally and theoretically the performance studies of a solar heating system with a heat pump. Experimental studies show that the parallel heat pump system saved more energy than the series heat pump system, because it uses both air and solar as a heat source for the evaporator while the series system uses only solar energy stored in the storage tank. In this experimental study, they used CaCl$_2$·6H$_2$O as a PCM and concluded that it is technically preferable as a storage material in this region. The experimental results of this study indicate that high collector efficiencies ranging from 62 to 70% can be realized with 30 m$^2$ flat-plate water cooled collectors over the heating period for the solar assisted series heat pump with energy storage as illustrated in Fig 14, while the collector efficiency of the parallel heat pump system ranged from 54 to 60%. However, energy storage efficiencies were less than the collector efficiencies. The average net storage efficiency is 63% for both systems. In this study, a thermodynamic model has been developed for a solar assisted series heat pump system with latent heat energy storage. The system parameters were determined from experimental data. It was found that the model agreed well with the experimental results.

Fig 13. Schematic of the hybrid thermal energy storage system. [21] Fig. 14. Schematic of solar flat plate collector with PCM capsules based heating system.[22]

Nallusamy et al.[24] have experimentally investigate the thermal behavior of a packed bed of combined sensible and latent heat thermal energy storage (TES) unit. A TES unit is designed, constructed and integrated with constant temperature bath/solar collector to study the
A Review On Solar Air Heater Technology

performance of the storage unit. The TES unit contains paraffin as phase change material filled in spherical capsules, which are packed in an insulated cylindrical storage tank. Charging experiments are carried out at constant and varying (solar energy) inlet fluid temperatures to examine the effects of inlet fluid temperature and flow rate of HTF on the performance of the storage unit. They concluded that in the case of constant inlet HTF temperature, the mass flow rate has only a small effect on the rate of charging, as the surface resistance is not significant compared to the varying resistance offered inside.

Alkilani et al. [25] achieved indoor prediction for output air temperature due to the discharge process in a solar air heater integrated with a PCM unit, for eight different values of mass flow as shown in Fig 15. This system consists of a single glazed solar air collector integrated with a PCM unit which is divided into cylinders as an absorber container installed in the collector in a cross flow of pumped air. An indoor simulation supposed that the PCM initially at liquid phase (50 °C) heated by solar simulator while the pumped air over the cylinders at room temperature (28 °C), the mass flow rate, output air temperature, and the freezing time of PCM, represent important factors, eight steps of mass flow rate were started by 0.05–0.19 kg/s. The PCM consists of paraffin wax with mass fraction 0.5% aluminum powder to enhance the heat transfer, the freezing time for the PCM unit has been predicted for each mass flow rate, the freezing time of the PCM cylinders was related inversely to the mass flow rate, and took longer time approximately (8 h) with flow rate of 0.05 kg/s.

Tyagi et al. [19] have experimentally studied the solar air heating system with and without thermal energy storage (TES) material for energy and exergy analysis Fig 16. The paraffin wax as latent heat storage and hytherm oil for sensible heat storage were used in this study. They calculated the first law and the second law efficiencies on basis of the experimental observations with respect to the available solar radiation for three different arrangements, viz. one arrangement without heat storage material and two arrangements with THES, viz. hytherm oil and paraffin wax, respectively. They found fruitful observation in case of air heater with out and with heat storage material/fluid some are given below: they noted that the fluctuation in both the efficiencies which is mainly due to the fact that solar radiation also fluctuates throughout the day. In addition, as time increases, both the efficiencies first increase and then decrease in case without temporary storage material and the similar trend is found for solar radiation. In case of without THES material, the efficiency increases with time, attains its peak in the first half in general and then decreases after that. However, in cases where temporary heat storage material is used, both the efficiencies increase with time, attain their peaks at approximately 16:30 h with a small fluctuation with flow rate and then decrease smoothly.

Saman et al. [26] studied the thermal performance of a phase change thermal storage unit based solar roof integrated heating system. The storage unit was a component of a roof integrated solar heating system being developed for space heating of a home as shown in Fig 17. The storage unit consists of several layers of phase change material (PCM) slabs with a melting temperature of 29 °C. The warm air was circulated in a roof integrated collector and passed through the spaces between the PCM layers to charge the storage unit. The stored energy
in form of heat was utilized to heat ambient air before being admitted to a living space. They concluded some useful remarks for this study.

Figure 17 Solar roof integrated heating system with storage unit. [26]

5. HYBRID PHOTOVOLTAIC/ THERMAL (PV/T) SOLAR AIR HEATER

Photovoltaic (PV) solar panels generally produce electricity in the 5–20% efficiency range, depending on the type of solar cell and the rest being dissipated in thermal losses [27]. To recover the thermal losses hybrid photovoltaic thermal systems (PV/T) are recommended. Hybrid photovoltaic/thermal (or simply PV/T) solar collector produces both thermal energy and electricity simultaneously. A PV/T collector typically consists of a PV module on the back of which an absorber plate (a heat extraction device) is attached. The purpose of the absorber plate is twofold. Firstly, to cool the PV module and thus improve its electrical performance (electrical efficiency losses amount to 0.4% for each degree of increase of cell temperature with reference to standard test conditions $25^\circ C$, $q = 1000$ W/m$^2$) and secondly to collect the thermal energy produced, which would have otherwise been lost as heat to the environment.

Fig. 18

Shahsavari and Ameri [28] in this system panels were connected in parallel and mounted on the air channel and above a thin metal (aluminum) sheet (TMS). This aluminum sheet was suspended at the middle of air channel as a secondary absorber plate and used to improve heat extraction from the panels (by increasing heat exchange surface) and consequently achieving higher thermal and electrical outputs. The air channel casing built from Medium Density Fiberboard (MDF) wood as illustrated in Fig 19. This PV/T system was tested in natural convection and forced convection (with two, four and eight fans operating). During the experiments it found that in the case of forced convection, air mass flow rate decreases by setting glass cover on photovoltaic panels. On the other hand, in free convection mode, setting glass cover leads to air mass flow rate increases. Thermal efficiency increases with increasing the air mass flow rate due to increased heat transfer coefficient. Setting glass cover on photovoltaic panels leads to an increase in thermal efficiency and a decrease in electrical efficiency of the system.
Huang et al.[29] made an attempt to evaluate the performance of the integration of solar photovoltaic and thermal systems (IPVTS). The experimental results comprehensively compared with the conventional solar water heater. Schematic of IPVTS is shown in Fig. 20, the polycrystalline PV module has been integrated with the thermal collector made from a corrugated polycarbonate panel with sheet and tube heat collecting plate made of copper. They concluded that the solar PV/T collector made from corrugated polycarbonate panel produced good thermal efficiency. They suggested that further improvement can be achieved by proper insulation for the PV/T design.

6. CONCLUSION
Solar air heater is a simple device which captures the solar energy. Producing hot air by using solar air heater is a renewable energy heating technology used to process heat generation for space heating. Such systems produce heat at zero cost. Minimum maintenance like cleaning of collectors only is required. Energy storage not only plays an important role in conservation of the energy but also improves the performance and reliability in wide range of energy systems and becomes more important where the energy source is intermittent in nature such as solar. Energy storage process reduces the rate of mismatch between energy supply and its demand. The thermal energy storage can be used in such places where the variation between the day and night temperature is much more. In this comprehensive review, a detailed research work is accumulated for air heating system with and without thermal energy storage. Obstacle, Fin, baffles based air heating system, latent heat storage based air heating system and PV/T hybrid air heating systems are covered. It can also be concluded that from these comprehensive reviews lot of works have been carried out globally to evaluate the performance of different types of solar air heaters. Mostly flat plate air heater produces hot air at low temperature and found suitable for drying agricultural products. Hybrid PV/T type solar air heater shows their viability in force convection type air heating with electricity production. Various investigators have developed thermal energy storage type air heater for effective and efficient utilization of hot air for space heating. Many investigations reported that PCM based thermal energy storage solar heater is suitable for crop drying applications.
REFERENCES


A Review On Solar Air Heater Technology


