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Design and Performance Analysis of a Solar Air (SA) Heater with Phase Change Material (PCM) Heat Storage for Residential Applications

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ABSTRACT- Outlet air temperature can be seen as one of the main determinants of the functioning of the solar air heaters and this is one of the main features of the PCM. Variations in solar radiation can be considered a key determinant of the functioning of solar air heaters used in residential applications. Weather conditions can influence the presentation of the air heaters operated by solar energy to a great extent. Structuring of collector plates needs to be done in an effective manner by designers of air heaters used in residential applications. The contact surface of the collector plates is the other determinant of the presentation of the air heaters. A blower is one of the most vital components used in air heaters and the efficiency of the blower can improve the execution of this device. Transport fluid has been identified as a vital factor that can have a huge impact on the functioning of air heaters operated by solar energy. Air thermal capacity can be considered as the other determinant of the functioning of this device. The high cost of fluid circulation has been found as one of the negative factors in the structure and functioning of the air heaters used in residential applications.

KEYWORDS- Solar air heaters, Phase change materials, Environmental factors, Thermal capacity, Solar energy.

I. INTRODUCTION

In order to boost the competence of solar air (SA) heaters, execution analysis and evaluation of the designs can be carried out in order to advance their presentation. SA heaters used in residential applications have to rely heavily on phase change materials in order to function effectively and efficiently [36]. Several studies have found that thermal heat storage can play a huge role in the presentation of solar air heaters that are used for residential applications due to its ability to keep thermal heat for a long time. The purpose of this study was to determine whether paraffin wax can be utilized as a unit of latent storage space in solar-powered air heaters.

The phase change materials (PCMs) can increase the temperature of outlet air at night. Solar heaters powered by solar energy can be affected greatly by variations in solar radiation, according to the study [29].

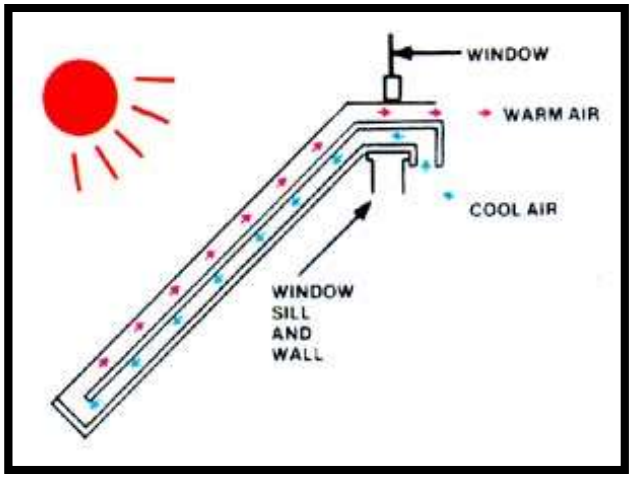

Figure 1: Functioning of solar air heater [1]

The studies from [56-71] Patel Anand et al. for solar heater [72] Anand Patel et al. for solar cooker and [73] Patel Anand et al. for heat exchanger involves thermal performance analysis by variation of geometries of the solar collector to enhance heat transfer which helps to perform the review for the current topic of the paper.

II. OBJECTIVES

- To critically analyse the presentation and designs of SA heaters.
- To analyse the role of PCM in enhancing the performances of solar air heaters.
- To identify the advantages of using PCM in air heaters operated by solar energy in residential applications.
- To identify the drawbacks of using PCM in air heaters operated by solar energy used for residential purposes.

III. METHODOLOGY

In order to analyse the execution of the air heaters operated by solar energy, the study has reviewed the previous literature. Secondary and qualitative type of information was collected relevant to the research topic. Journals and articles of reputed authors have been used for the data collection of this research [12]. Along with these, the study

has used the process of thematic analysis in order to obtain findings in an easier manner. Moreover, the study has focused on descriptive design in order to collect and analyse data regarding the research topic.

Choosing the right PCM is critical for effective heat storage and release. This stage entails taking into account elements such as melting and freezing temperatures, latent heat capacity, thermal conductivity, cost-effectiveness, and system compatibility [17]. To assess alternative PCM choices, it may be necessary to perform tests or use thermos physical property databases.

Numerical modelling and simulation utilising computational fluid dynamics (CFD) techniques are used to evaluate the performance of the SA heater system with PCM heat storage. This stage entails generating a virtual model of the system geometry, imposing boundary conditions, and solving the governing equations for fluid flow and heat transfer (e.g., Navier-Stokes equations). Temperature distributions, heat transfer rates, and overall system efficiency may all be predicted using simulation.

IV. STRUCTURE AND EXECUTION OF SA HEATER

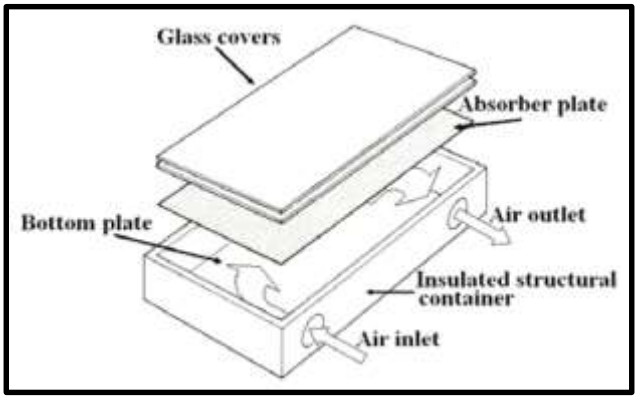

Figure 2: Structure of SA heater [1]

The heating of the air stream is done by the collector plate and the back side of the plate is used in this method. In order to boost the contact surface, fins are attached to the collector plate [1]. The usage of mineral wool can be seen in the collector plate for the purpose of insulation. Usage of a blower can be found in some cases for drawing air within the collector and the hot air is transmitted into the dryer.

Elimination of freezing is done in the device by using transport fluid. Along with these, the usage of transport fluid prevents issues due to corrosion. It has been found that larger air volume than liquids can lead to issues in the functioning of air heaters operated by solar energy [2]. At the same time, the low thermal capacity of air can have an adverse impact on the functioning of air heaters. The cost of fluid circulation has been found high in the functioning of air heaters operated by solar energy. Moreover, the study has identified a high level of noise in the functioning of the device [3].

V. ROLE OF PHASE ALTER MATERIAL (PCM) IN IMPROVING THE EXECUTION OF SA HEATER

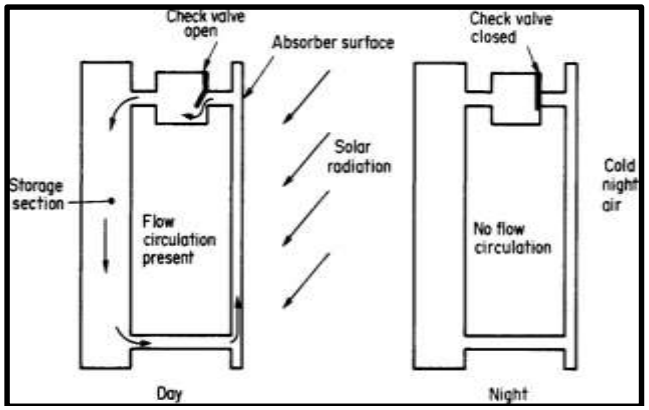

Figure 3: Design of solar air heater [2]

In SA heaters, salt hydrates are used as phase change materials to heat air as they undergo phase changes over time [4]. There have been some delays in heat penetration in PCM as a result of low thermal conductivity levels. Aside from these, it has been found that discharge lag in the storage units can also depressingly impact the execution of the storage units as a consequence of the discharge lag in this system. There is increasing evidence that the use of tubular containers can significantly improve the execution of solar-powered air heaters that operate on solar energy [5].

Moreover, using naked encapsulates for the air heaters powered by solar energy is another factor that can lead to a noteworthy increase in the competence of the air heaters powered by solar energy. As a way of improving the execution of SAheaters, the use of Rabitz wire meshes has been identified as an Effective method.

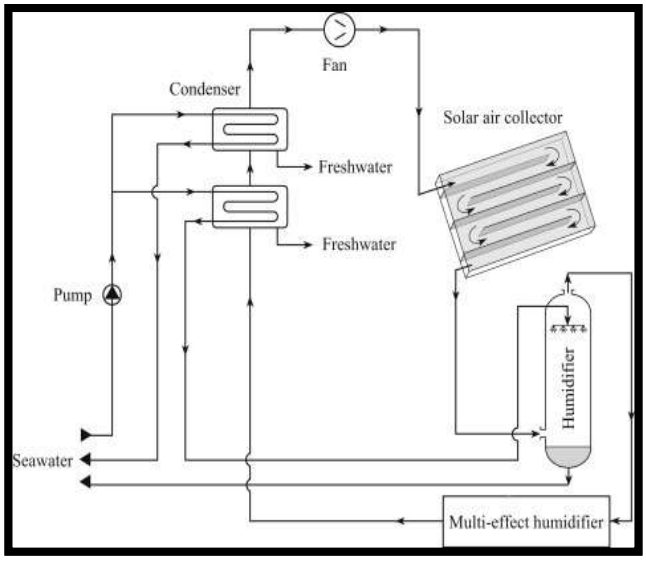

Figure 4: Procedure of solar air heating [3]

Among the many positive aspects of this technology, one of the most important can be considered to be its affordability [6]. Solar air heaters have been found to have a number of

advantages that have been identified in their working, including the truth that they are non-flammable. Due to the chemical stability of PCMs, the execution of SA heaters has been enhanced due to a high level of chemical stability.
A sure sign of the quality of PCMs can be found in the fact that they are capable of conformal melting, which is one of their main characteristics, which makes an air heater powered by solar energy more efficient [36] [45]. Despite this, it has been found that one of the negative aspects of these materials has been the formation of harmful gasses as a part of their operation

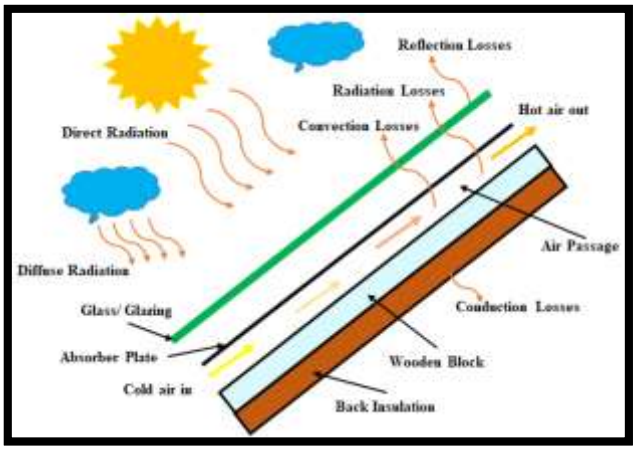

Figure 5: Impacts of environmental factors on solar air heater [7]

VI. THEORETICAL UNDERPINNING

A. Social Presence Theory

It has been shown that the social presence theory is highly effective in restoring the competence of SA heaters through the advancement of technology [8]. As stated in this theory, an advancement in technology can have a major impact on a country's social condition as a result of the advancement in technology. Using this theory as a guideline, it is believed that interpersonal relations can play an important role in the advancement of technology as one of the most crucial factors.

B. Technology adoption model (TAM)

The model of technology adoption can be followed by the development process of air heaters operated by solar energy. Following the measures suggested by this theory, the developers will be able to design the structure by adopting advancements in technologies [9]. Perceived usefulness is one of the major factors which have been taken into account by the TAM model which can play an important role in adopting advanced technology.
The TAM model defines perceived usefulness as the degree to which individuals feel that a certain technology may improve their performance, productivity, or overall effectiveness [19] [35]. The perceived utility element becomes extremely important in the situation of solar air heaters. It is concerned with how people perceive the benefits and drawbacks of using solar energy for air heating.
Developers can increase the adoption of these technologies by developing air heaters that emphasise the perceived value of solar energy. This may be accomplished by emphasising possible advantages such as decreased energy prices, lower carbon emissions, and improved energy independence. Highlighting the environmental benefits and potential cost savings can be effective in persuading people to use solar air heaters.

VII. DESIGN CONSIDERATIONS

PCM heat storage is used to design solar air heaters with several considerations:
PCMs must be selected depending on their melting and freezing temperatures, heat storage capacity, thermal conductivity, and stability.Heat is transferred between the air and the PCM through the heat exchanger in the solar air heater. Maximizing the contact area, ensuring proper airflow, and optimizing heat transfer efficiency are all important design considerations. In the air ducts or absorber plates, PCM containers or panels are used to integrate them into the system. Heat transfer and system performance are affected by the location and arrangement of PCM containers [55].

VIII. PCM HEAT STORAGE PERFORMANCE ANALYSIS OF SOLAR AIR HEATERS

Solar air heaters with PCM heat storage are evaluated for their thermal efficiency and energy storage capabilities. Parameters to consider include:
Integrating PCM containers affects heat transfer efficiency. Heat transfer from the air to the PCM is considered in the performance analysis during the charging phase and vice versa during the discharging phase.
Comparatively to conventional storage materials, PCMs offer a greater thermal storage capacity. An analysis of the PCM's performance focuses on its ability to store and release thermal energy.
An analysis of the dynamic behaviour of the system, including the charging and discharging times of the PCM, is helpful in optimizing performance and energy consumption.

IX. PROBLEM STATEMENT

Low air density is one of the main issues which need to be given high importance by the designers engaged in developing thermal air heaters. Along with these, low level of air thermal capacity has been found as the other factor which has led to issues in the air thermal heaters. Moreover, lack of thermal storage is another factor that has affected the functioning of air heaters operated by solar power.
Several obstacles face the design and performance analysis of a solar air heater with phase change material (PCM) heat storage for residential use [37] [38] [33]. Optimising PCM selection, constructing efficient heat exchangers, integrating and distributing PCMs throughout the system, conducting accurate performance analysis and optimisation, and resolving practical implementation and scalability challenges are all part of the process. To maximise the thermal performance, energy efficiency, and practicality of solar air heaters with PCM heat storage in residential contexts, several problems must be overcome.

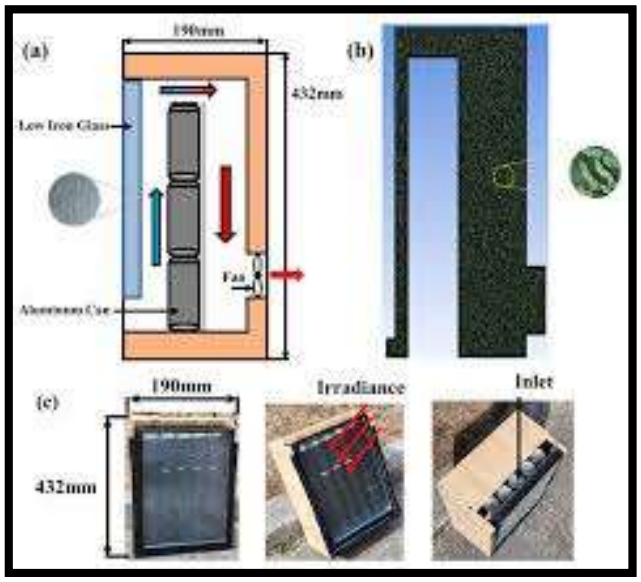

Figure 6: Structure of economical on solar air heater [7]

X. RESULT

A leakage test of the empty stem was performed in a few selected articles. Place plates had been removed from the casing. The trial had done at the three rates of flow 100, 250, and 400m^3/h. The difference between pressure values at the outlet and inlet in this system was small [13]. Based on the article, the entire static pressure was done at the eight different rates of flow from 100 m^3/h to 800 m^3/h for the 1.5mm as well as 3mm gap in the system.

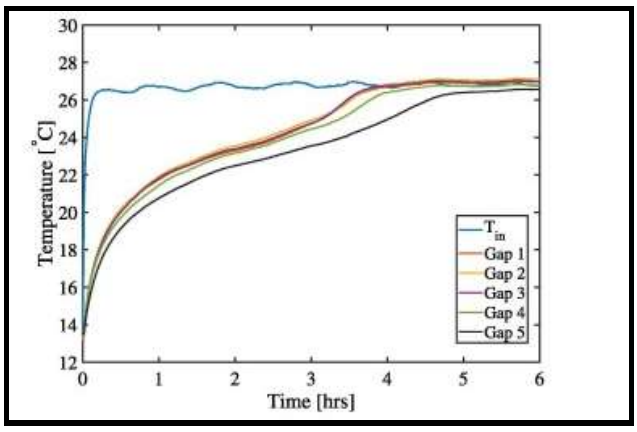

Figure7: 1.5mm gap system [14]

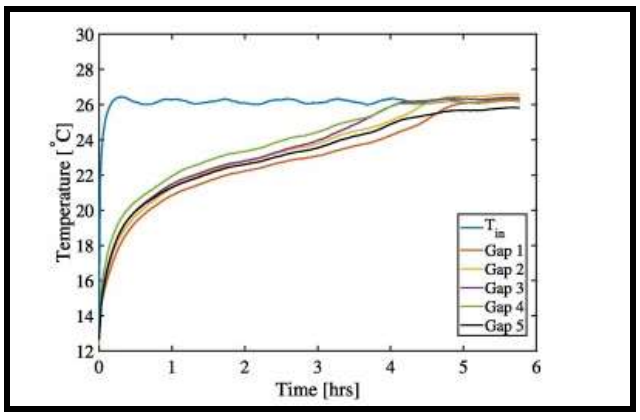

Figure 8: "3mm gap system" [14]

On the other hand, the above figures present the result of the solar heating cycle at 800 m^3/h in the case of both the 3 mm system and 1.5mm systems have been presented in the above figures. The distribution of the temperature and its results were the same for both systems [14]. This happened as the paths of airflow from the inlet to the outlet had the same in both configuration designs. From the above figures can be seen that there is only a specific difference which was the effect of the rate of flow upon the melting of the storage of PCM with the increasing flow rate from the "400m3/h to 800m3/h". Therefore, the absorption of heat to PCM increased and its result led to a faster rate of melting of the storage of PCM [20].

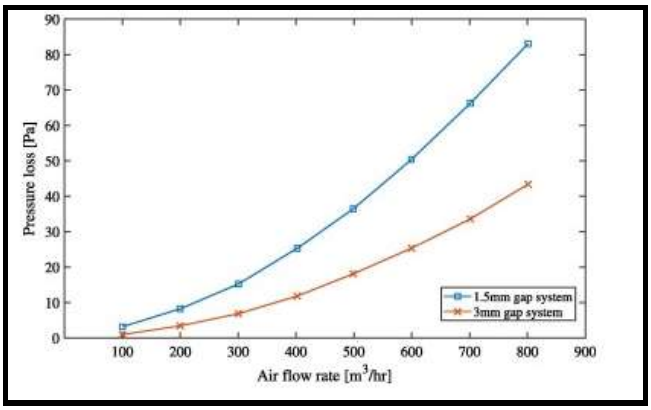

Figure 9: Loss of overall pressure by 3mm and 1.5mm gap system [30]

The above figure depicts the obtained results from the overall static pressure of the loss system for both 3mm and 1.5mm. From the figure, it can be seen that maximum pressure drops from both 3mm and 1.5 mm occur at 800m^3/h which is 43.3 Pa and 83 Pa respectively. Testing for the discharging cycle of two systems had done at the temperature of 27^{o}C and the flow rate was 400 m^3/h and 800 m^3/h [30]. In order to investigate the melting of the PCM model in the CSM plate there can be six thermocouple sensors. For every CSM plate, thermocouples were installed at the upper surface as well as three on the bottom; the surface of every sensor placed was divided into three different locations [50]. These locations are the last region, the edge of the plate as well as the middle region. These three plates with the measurement of the surface temperature had been placed at the top, middle and last region of the storage of the PCM. Three plates had been kept at 13^{o}C, which was below the temperature of the solidification of PCM [34]. This was before starting the melting cycle for ensuring the PCM had completely solid.

XI. DISCUSSION

In the case of this current study, "phase change material" have discussed with the solar air heater. Among the various energy sources that are renewable, solar energy is available to generate electricity. The model of PCM and its materials storage is considered as the large amount of energy that is constant temperature through the undergoing phase of transition. Here are different researches accounting for the structural characterization and the long-term performance carefully assessed [50]. When the range of the temperature gets wider then its low sensible capacity of heat

reduces stored energy. Storage of PCM based is important during the energy crisis researcher studied this model as the heating residential application.

Based on the result of some studies suggest that PCMs can be used in various commercial applications with the "Solar Air Heater" where the storage of energy, as well as stable temperatures, will need, including, within others cooling for the stitching boxes of telephone, heating pads and others. On the other hand, a few articles highlighted that the solar fraction is a crucial parameter in the case of solar thermal energy storage is needed to consider. The effect of the electro hydrodynamics in melting of the PCM system can melt at 36ºC whereas the melting time can be reduced by 50 % by the "electro hydrodynamics" [51] [52]. The analysis of the SAH and its impact on the PCM can be different in the case of melting temperatures. The melting temperature of PCMs needs to have the same difference in fluid temperature with its path to the higher efficiency of energy.

XII. CONCLUSION

Based on the consequences of this study, it can be completed that the utilization of transport fluids in solar air heaters should be done in an efficient manner in order to get better the efficiency and the effectiveness of the devices [41] [44] [52]. It is important to note that the fins that are used in the collector plates play a major role in the device's operation. It has been identified that high fluid circulation costs are one of the issues faced by this device, and it is a problem that needs to be addressed.

The efficiency and efficacy of solar air heaters may be considerably enhanced by addressing the issues associated with fluid circulation expenses and adopting design adjustments based on research findings [41 [43] [52]. This makes these devices more cost-effective, ecologically benign, and useful for household heating applications.

Finally, the study emphasises the significance of effective transport fluid utilisation and the relevance of fin design in solar air heaters [23] [29] [32]. It emphasizes the need of addressing the issue of high fluid circulation costs and presents novel alternatives such as enhanced flow control systems and alternate heat transfer fluids. Solar air heaters may be optimised for greater efficiency and effectiveness by overcoming these hurdles, contributing to a more sustainable and energy-efficient household heating solution [32] [42] [39].

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