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# Experimental Study on the Performance of Solar Air Heaters with the Absorber Plate Made of Discarded Beverage Cans

1st **Nabil Elsharif**
*Mechanical Engineering Department*
*University of Benghazi*
Benghazi, Libya
nabil.elsharif@uob.edu.ly

2nd **Gamal Hashem**
*Mechanical Engineering Department*
*University of Benghazi*
Benghazi, Libya
gamal.hashem@uob.edu.ly

3rd **Saleh Etaig**
*Mechanical Engineering Department*
*University of Benghazi*
Benghazi, Libya
saleh.etaig@uob.edu.ly

4th **Khaled Hossin**
*Mechanical and Industrial Engineering Department*
*American University of Ras Al Khaimah*
Ras Al Khaimah, UAE
khaled.hossin@aurak.ac.ae

5th **Abderrahmane Khechekhouche**
Applied Mathematical and Energies Unit
*University of El Oued*
El Oued, Algeria
abder03@hotmail.com

6th **Lotfe Elfrgane**
*Mechanical Engineering Department*
*University of Benghazi*
Benghazi, Libya
looofy23saan@gmail.com

## الملخص:

يعد استخدام الطاقة الشمسية إحدى الاستراتيجيات الممكنة للتخفيف من المشكلات البيئية الناجمة عن حرق الوقود الأحفوري وتلبية الارتفاع الكبير في الطلب العالمي على الطاقة. وغالبية الطاقة التي تستهلك في المباني تكون لغرض التدفئة، ولهذا يعتبر تسخين الهواء بالطاقة الشمسية البديل الصديق للبيئة والفعال من حيث التكلفة مقارنة بالتدفئة باستخدام الوقود الأحفوري.

الغرض من البحث الحالي هو توضيح كيف يمكن استخدام العلب المعدنية (علب المشروبات) القابلة لإعادة التدوير لالتقاط الطاقة الشمسية وتسخين الهواء لغرض تدفئة المنازل او لتجفيف المواد الزراعية والصناعية. تمثل علب الصودا المصنوعة من الألومنيوم لوحة الامتصاص لمسخني الهواء الشمسي (SAHs) اللذين تم بناؤهما، لوحة الامتصاص لكل سخان هواء تتكون من ثمانية أعمدة وستة صفوف تم ربطها معًا في سلسلة شمسي ومطلية باللون الأسود الغامق.

تم استخدام المسخن الشمسي الأول (SAH1) بدون تعديل، وتمت إضافة مادة متغيرة الطور (PCM) - شمع البرافين - إلى المسخن الثاني (SAH2). بالإضافة إلى ذلك، من أجل تقييم أداء النظامين تم استخدام زاويتي ميل مختلفتين لكلا المسخنين الشمسيين.

أظهرت النتائج أن درجة حرارة الهواء عند فتحة خروج المسخنين الشمسيين ارتفعت بشكل كبير، وهو ما يكفي لتدفئة المنازل وتجفيف المحاصيل والاستخدامات الصناعية الأخرى، كما أظهرت نتائج التحقيق في أداء المسخن الحراري المعدل بإضافة شمع البرافين أن إضافة الشمع لها تأثير ضئيل، ويمكن تفسير ذلك إما بنقص الشمع أو رداءة نوعية الشمع نفسه.

**الكلمات المفتاحية:** الطاقة الشمسية ، سخان الهواء الشمسي ، مواد متغيرة الطور ، التجربة.

# Abstract

Utilizing solar energy is one potential strategy for mitigating the environmental issues brought on by the burning of fossil fuels and meeting the significant rise in global demand for energy. Buildings consume the majority of the energy for heating. Solar air heating is a cost-effective and green alternative to heating with fossil fuels. The purpose of the current research is to demonstrate how recyclable soda cans can be used to capture solar energy for heating homes and heating air for drying agricultural and industrial materials. Aluminum soda cans served as the absorption plate for the two solar air heaters (SAHs) that were built. The absorption plate for each solar air heater is painted a deep black and consists of eight columns and six rows that have been bonded together in series. One system—SAH—was utilized unmodified, and a phase-changing material—paraffin wax—was added to the second collector. Additionally, two distinct passive system angles were utilized in order to evaluate the performance of the two systems. The results show that the temperature of the air at the SAH's outlet has gone up significantly, which is enough for heating homes, drying crops, and other industrial uses. The results of an investigation into the performance of SAH in conjunction with paraffin wax demonstrate that the addition of the wax has little effect. This can be explained by either a lack of wax or a poor quality of the wax itself.

**Keywords:** Solar Energy, Solar air Heater, PCM, Experiment.

# I. Introduction

In this region of the world near the equator, no research has been conducted on beverage can solar air heaters. Solar drying, space heating, and air pre-heating are all possible applications for beverage can heaters. They could be very useful in industries where it is necessary to pre-heat the air before fuel is burned in boilers because they are air pre-heaters. The total thermal efficiency of the power plants is improved, and fuel consumption is decreased by preheating the air prior to entering the combustion chamber.

A number of solar air heaters were built to see what would happen if the main parts of the SAH were changed to make them work better.

(Alvarez et al., 2004) looked at the thermal performance of a single glass air solar collector with an aluminum can absorber plate, both theoretically and experimentally. They stated that the maximum efficiency achieved was 74% and that there was a good agreement between the predicted theoretical temperatures and the ones that were measured. (Fathi, 1995) also presented a thermosyphon solar air heater with built-in latent heat thermal energy storage system that used a variety of phase change materials (PCM) with varying melting temperatures of 61 °C, 51 °C, 43 °C, and 32 °C, and they also compared the results to those of a system that did not use any storage material. Solar air heaters with PCM melting temperatures of 51°C and 43°C were found to perform best. A natural circulation solar air heater using phase change material (paraffin wax) as energy storage was the subject of theoretical and experimental research presented by (Enibe, 2003). For each major heater component, energy balance equations were developed and linked to heat and mass balance equations for the heated air that flows through the system. The experimental data and the system's predicted performance were compared. Predicted temperatures at specific locations on the absorber plate, heat exchanger plate, glazing, and heated air were found to be within 10, 6, and 10 °C of the experimental data. The predicted efficiencies' correlations were also presented.

(Kabeel et al., 2017) examined the design configurations, enhancement strategies, and applications of solar air heaters in depth. The v-corrugated

SAH was found to be the most effective, while the flat plate SAH was found to be the least effective. The v-corrugated SAH outperforms flat plate SAHs by 5-11% and 10-15%, respectively, in double-pass and single-pass modes, according to the findings.

(Ozgen et al., 2009) experimented with a double-pass channel solar air heater under a variety of operating conditions. According to their findings, SAHs of the double-flow type, in which air flows simultaneously over and under the absorbing plate, performed better than those with only one flow channel. In addition, the findings demonstrated that solar air heaters with cans that were not arranged in any particular order were more effective than those without cans. (Sahu & Bhagoria, 2005) looked into how SAH's thermal performance improved with different pitches of 90 broken wire rib roughness. Using finned and v-corrugated air heaters, (Karim & Hawlader, 2006) investigated the theoretical and experimental enhancement of conventional air heater performance. An experimental investigation of heat transfer and air flow friction in rectangular ducts with multiple V-shaped ribs and gap roughness on one broad wall was carried out by (Kumar et al., 2013). (Gil et al., 2017) looked into how well the staggered piece in the broken arc rib improved SAH performance. (Ghritlahre et al., 2020) looked at the heat transfer and thermal performance of an arc-shaped roughened solar air heater (SAH) with apex up and apex down air flow. They found that the wire rib roughness absorber plate with apex up air flow was more effective than the roughness absorber plate with apex down air flow. An experimental study on heat transfer and thermal performance of solar air heaters that have been artificially roughened for fully developed turbulent flow was presented by (Prasad, 2013).

(Parker et al., 1993) presented a study on solar air heaters with six collector units and V-corrugated absorber plates. The findings demonstrated that the thermal efficiency of the V-corrugated absorber plates was very high. For a brand-new flat plate solar air heater (SAH), (Esen, 2008) conducted an experimental study on energy and exercise analysis with and without obstacles. Solar air heaters with quarter-circular ribs on the absorber plate (Mahanand & Senapati, 2021) a staggered C-shape finned absorber plate

(Saravanan et al., 2021) a discrete roughened plate (Agrawal et al., 2022) and a finned absorber plate that forms multiple rectangular air flow passages (Karwa, 2023) were also examined for their performance. The objective of the current experimental investigation is to undertake a comparative study of the performance of a solar air heater, and a modified solar air heater with Paraffin wax. Lastly, the results obtained from the experimental research are compared and presented.

# II. Experimental setup

## Test rig construction

Fig. 1 demonstrates the schematic diagram with dimensions of the used device. The dimensions are 155 cm in length and 50 cm in width, while the surface area of the heat is 89 cm x 50 cm, and through the device 8 circular holes are made from the bottom and top for entry and exit of air, and each one has a diameter of 5 cm.

An empty space was created at the top of the device and adjacent to the heat absorber surface with dimensions of 50 cm from the bottom of the space and 32 cm from the top, while the height is 24 cm. So that hot air escapes from it.

The SAH used in this experiment was handcrafted using treated wood, which is resistant to environmental conditions and has a high workability and low thermal conductivity. In the experiment, Aluminum cans (soda cans) were used as a heat absorber surface, as they are widely available to be used by recycling.

The SAH consists of 8 columns and 6 rows of these cans, which are connected to each other using heat-resistant silicone glue to form 8 air channels, each of which is 89 cm long as shown in Fig. 2 and Fig. 3. Aluminum cans are completely perforated from the top and from the bottom in the form of a star with four fins spaced evenly to create turbulence to the incoming air, which helps in increasing the transfer of heat to the working fluid. These channels were placed inside the device and were connected from the top and bottom using heat-resistant silicone glue to ensure that no air leakage occurred through the collector.

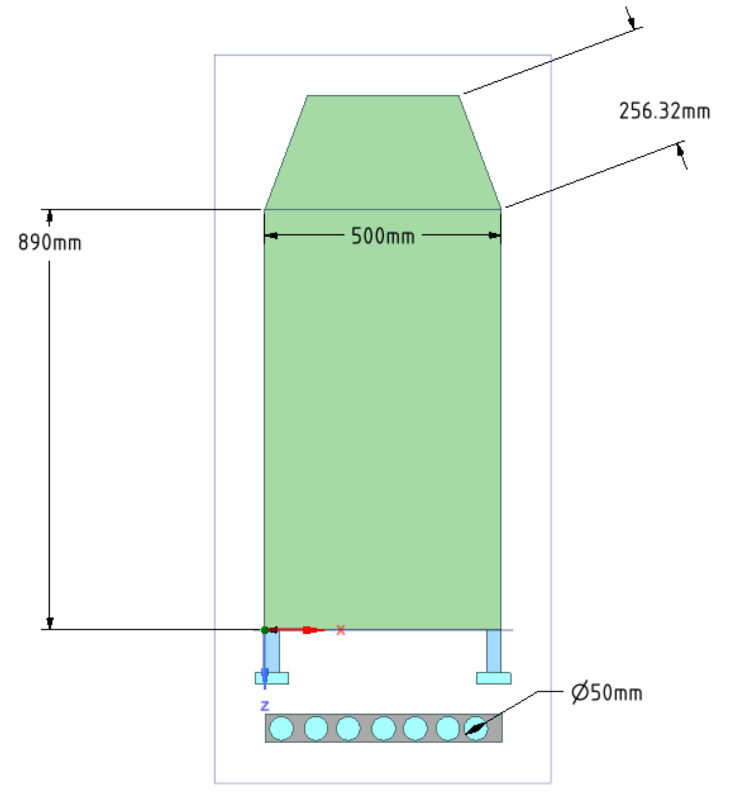


**Fig. 1. Experimental set-up**

**Fig. 2. SAH collectors at angle 90̊**

**Fig. 3. SAH collectors at angle 32o**

The surface of the aluminum cans used as a heat absorber plate was painted an opaque dark black color to improve heat absorption. In order to reduce heat load losses to the environment, the collector is covered with a transparent glass cover that is 4 millimeters thick and has a high permeability.

The temperature of the collector's glass cover, ambient air temperature, and the air temperature at the solar heater's entrance and exit were all measured with a digital thermometer during the experiment. This digital meter can also determine the air's relative humidity.

## Experimental procedure

In this study two SAHs were constructed to investigate the performance of SAH in different conditions:

- First SAH is a conventional solar air heater, which is denoted by SAH1 in this study. SAH1 consists of the main components of the complex without any additives.

- Second SAH, SAH2 is a conventional solar air heater with the addition of a phase-change material (PCM), which is a material capable of absorbing and releasing a quantity of potential thermal energy by changing its state from one phase to another (solid - liquid) and the material used in this experiment is Paraffin wax, which is a substance whose melting temperature ranges from 20-70 °C. Paraffin wax is considered a safe material and has a low thermal conductivity, especially in its solid state, as it was placed inside a rubber balloon and the goal is to take advantage of the latent heat that the paraffin wax releases during its freezing during the cold weather at night. The amount of the Paraffin wax used in the experiment is 300g.

In this experiment, two different angles of solar collectors were tested and studied to find out and obtain the best possible results.

- First position: the solar air heaters were placed at an angle of 90° to the south.
- Second position: the solar air heaters were placed at an angle of 32° to the south, and this angle was chosen based on the same latitude as the city of Benghazi.

The tests were conducted in the winter climatic conditions of Benghazi, with coordinates 32.11o North and 20.07o East, and about 3 meters above sea level. The experiments were conducted in the passive mode of two solar collectors with two different angles. At the beginning of the experiment, the temperatures of the entry, exit and glass cover were measured and recorded. Repeat the measurement and recording of temperatures at a 30-minute interval for different periods of the day. The experiments were conducted during two days, each day at a different angle, over a period of 14 hours (from 8:00 AM to 22:00 PM). In the complex in which paraffin wax was added, temperatures were measured from 8:00 am to 11:00 pm in order to study the effect of the latent heat released by the wax during its freezing and to compare it with the rest of the other configurations.

## III. Results

The performance of the two solar air heaters were studied over a period of two days, the 24th and the 25th of January 2021 under the climate conditions of Benghazi, Libya. During the experiments, the average values of ambient air temperature ranged from 10-20 °C, and the relative humidity ranged from 20-98%. Fig. 4 shows that the ambient temperature reached its highest values between 12 and 1:30 pm.

The study relied on choosing a better angle for solar collectors, and on the other hand, studying some modifications to solar heaters (adding paraffin wax) and their effect on the efficiency of the solar air heater. All experiments were conducted by passive system.

Fig. 5 shows the variation of the air temperature at the ambient and outlet of the solar air heater SAH1, and the glass cover temperature for an inclination angle of 90°. Fig. 6 shows the variation of the air temperature at the ambient and outlet of the solar air heater SAH1, and the glass cover temperature for inclination angle 32°.

It can be noticed that, in general, the temperature increased gradually till it reached a maximum value at around 1:30 pm and then began to decrease gradually due to the progressive decline in the incoming solar radiation during the last daylight hours.

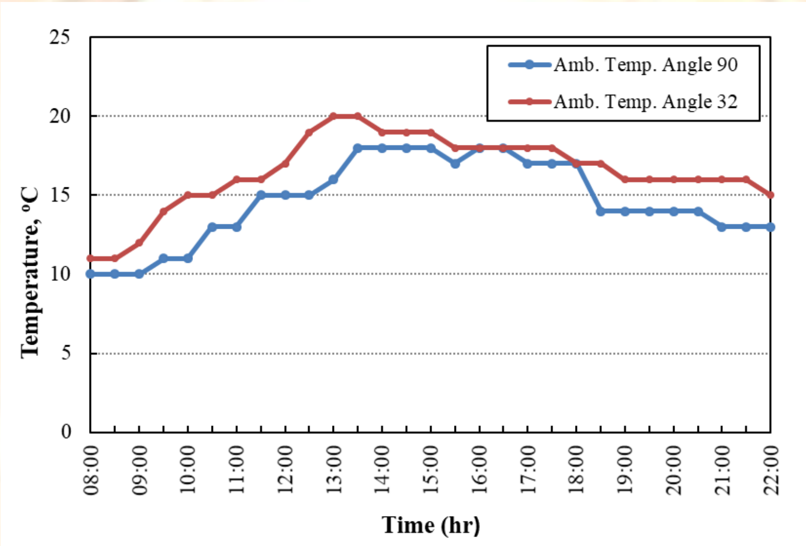


**Fig. 4. Variation of ambient temperature during the experiment's days.**

Moreover, the temperature difference between the ambient and the exit temperature of the air $\Delta T_{max}$ was 23.3°C at the angle of 90° while $\Delta T_{max}$ was 27.9°C at the angle of 32° at midday and then began to decrease until the end of the experiment period.

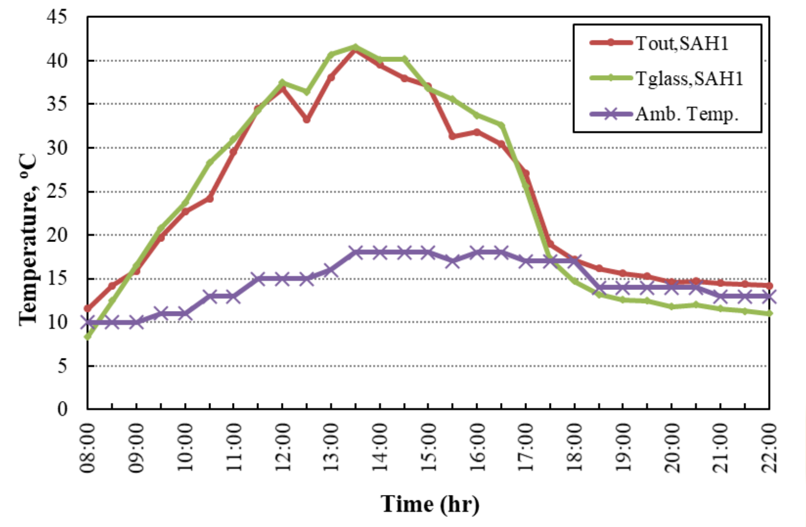


**FIG. 5. VARIATION OF TEMPERATURES OF SAH1 AT ANGLE 90$^{o}$.**

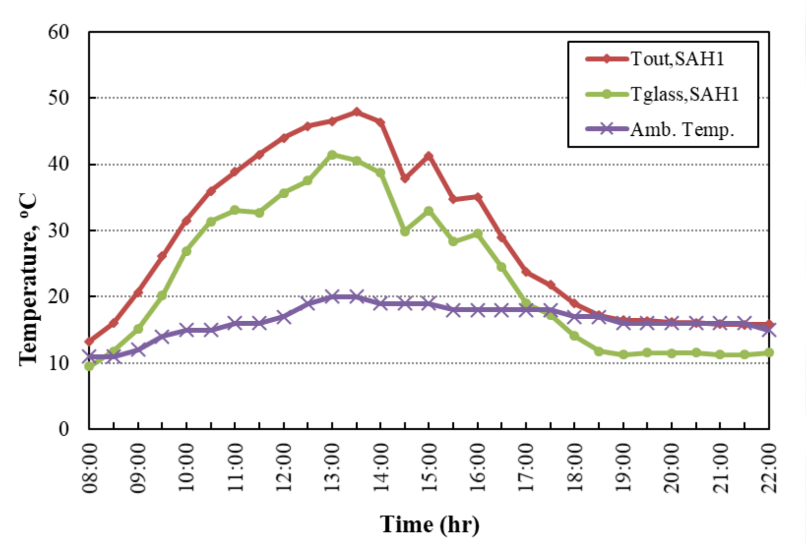


**FIG. 6. VARIATION OF TEMPERATURES OF SAH1 AT ANGLE 32$^{o}$.**

The variation of outlet temperature of the two inclination angles is presented in Fig. 7. It can be seen that the solar air heater that is positioned at an angle of 32$^{o}$ produces higher temperature and better efficiency than that at an angle of 90$^{o}$.

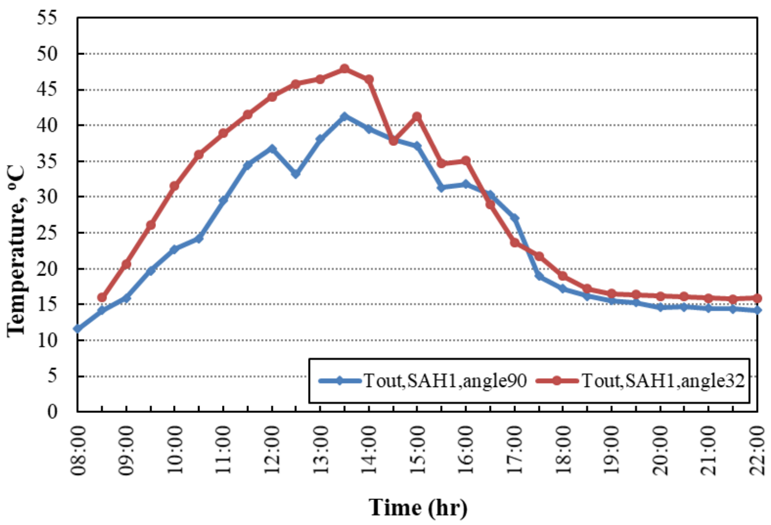


**Fig. 7. Variation of outlet temperatures of SAH1 for both angles.**

The performance of the second solar air heater, SAH2, which contains a phase-changing substance (paraffin wax) is shown the Fig. 8 and 9 for inclination angles 90° and 32°, respectively. It is clear that the temperature of the air at the exit is lower than the glass temperature, this is can be explained by that the paraffin wax at the start of the experiment began to gain and store heat because the thermal conductivity of the wax, which caused a delay in gaining heat of the outlet air , the temperature of the wax increased until it reached the melting point where the increase in the temperature of the wax stops temporarily until all the wax melts and then the temperature continues to rise.

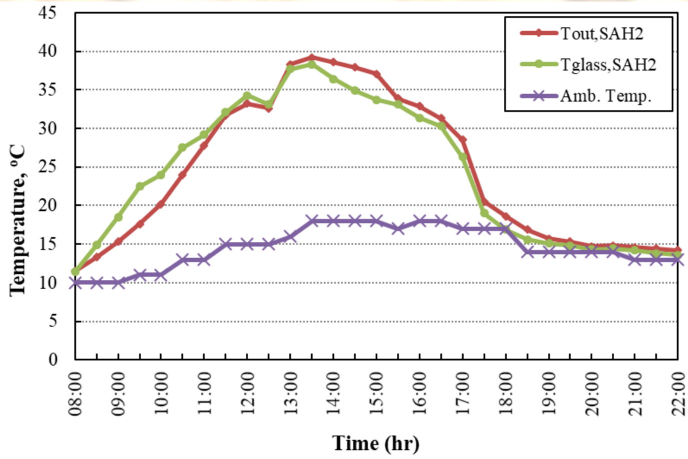


**FIG. 8. VARIATION OF TEMPERATURES OF SAH2 AT ANGLE 90°.**

It is noticeable from the use of paraffin wax that its effect is weak in terms of retaining heat, as it loses its temperature quickly with the coolness of the air and its negative effect in that it consumes a large part of the heat in melting the wax.

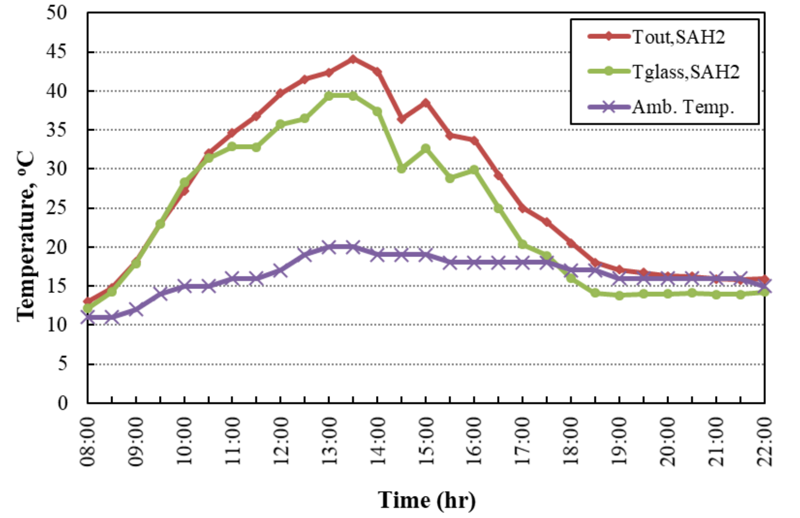


**Fig. 9. Variation of temperatures of SAH2 at angle 32º.**

In addition, the temperature difference is $\Delta T_{max}$ 21.2°C at 90̊, while$\Delta T_{max}$ is 24.1°C at 32̊ at midday and then begins to decrease until the end of the day.

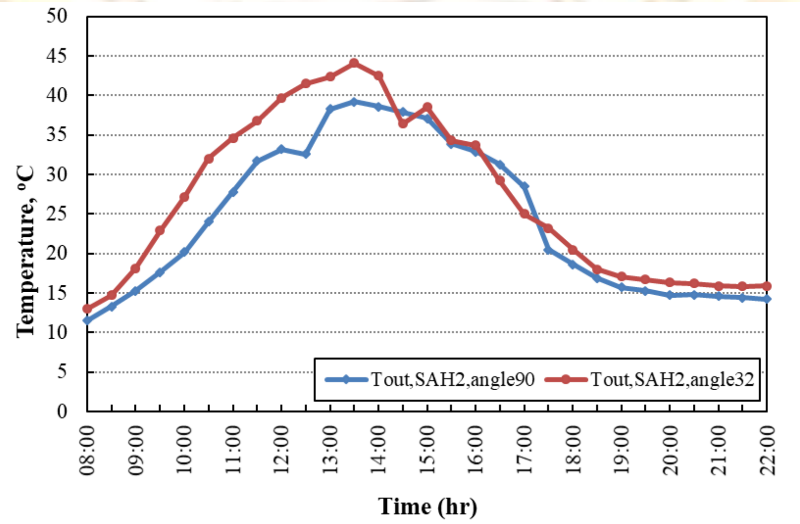


**FIG. 10. VARIATION OF OUTLET TEMPERATURES OF SAH2 FOR BOTH angles.**

Fig. 10 presents the variation of air temperature at the outlet of the SAH2 for the two inclination angles. It can be seen that the SAH2 that positioned at an angle of 32o produced higher temperature and has better efficiency than that at an angle of 90o, which is similar to the behavior of SAH1.

## Conclusion

Solar air heaters can be considered as one of the promising alternatives to provide heat for low-temperature applications such as domestic heating or food drying. The performance of the solar air heaters was investigated in terms of the air temperature at the outlet of the SAHs, and some modifications were done to the complexes to improve the performance of SAHs. The inclination angle of the solar heater plays an important role in the performance of the SAH.

The performance of SAH with paraffin wax was investigated and the results show that the addition of the wax add weak effect. This can be explained by that the amount of the wax was not enough or the wax itself had poor quality. A significant increase in the air temperature at the outlet of the SAH was observed and the maximum temperature of the air at the outlet of the SAH was 47.9$^{o}$C.

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