

Experimental evaluation of the thermal performance of a solar air collector

ABSTRACT

This article analyses the performance of a solar air collector which is used to supply hot air to a food dryer. After the realization, the collector was connected to the dryer and a campaign of measurements was carried out in order to evaluate the thermal performances of this one. The measured parameters are sunshine, temperature and speed. These parameters allowed to evaluate the thermal efficiency of the collector. The results obtained show that with an air speed of 0.3 m/s and an irradiation that varies between 142 W/m² and 837 W/m², the difference in air temperature between the outlet and inlet of the collector varies between 0.1°C and 74.4 °C; this corresponds to a variation in thermal efficiency between 0.94% and 50.68%. In the dryer, the air temperature varies between 27.2 °C and 69.2 °C:

This temperature range is favorable for the drying of most food products.

Key words: Solar energy, heat transfer, forced convection, drying.

1. INTRODUCTION

As in other developing countries, agricultural producers in Burkina Faso most often exploit solar energy to conserve surplus production or to reduce post-harvest losses through drying. The drying technique using solar dryers has the advantage of ensuring the drying process at low cost, reducing the drying time, protecting and having good quality dried products. The solar dryers are generally made up of solar air collector(s) for the heating of the air, and a compartment to arrange the different products to be dried.

The use of solar air collectors has been gaining interest in recent years because heating drying air with them is simple and less expensive [1]. Also, their maintenance and technology do not require specialized manpower; moreover, they can be constructed from locally available materials and are also environmentally friendly. In view of the many advantages of their use in solar dryers, several types of solar air collectors have been developed in the research field to improve their ability to heat the heat transfer fluid ([2], [3]). Generally, the thermal performance of a solar air collector depends on the materials used in its construction, its shape, size and arrangement. The overall heat transfer coefficients in solar air collectors are low due to the unfavorable thermophysical properties of the heat transfer medium (air)[4]. These coefficients can be improved by proper selection of the absorber or by increasing the turbulence of the heat transfer medium.

In this study, we evaluate the thermal performance of an air-source solar collector constructed from locally available materials to supply heat to an indirect dryer.

2. MATERIAL AND METHODS

2.1 Material

Solar energy is one of the most abundant sources of energy in Burkina Faso, with an estimated average daily sunshine of 5.5 kWh/m² and an insolation of 8.3 hours per day ([5], [6]). It is therefore interesting to develop technologies to exploit this available and less expensive resource.

The flat plate solar air collector whose thermal performance is evaluated in this work is made largely from locally available materials. It is used to heat the drying air which is then sent to a drying chamber of an indirect dryer. **Fig. 1 and 2** show respectively a schematic and a picture of the realized solar collector. Its frame is made of 10 mm thick wooden plywood with a length of 210 cm and a width of 185 cm. The frame rests on an iron support forming an angle of 12° with respect to the horizontal and the whole is connected to the drying chamber as shown in **fig. 3**. In addition to the frame, the solar air collector consists of a 5 mm thick glass pane on its solar radiation collecting surface, two absorbers painted in matte black, one of which is a sheet of steel plate, and the other is a set of 26 tubes (air duct). Each tube is obtained by an arrangement of 17 cans, each of which has a length of 13.4 cm, a diameter of 5 cm and a thickness of 2mm. The cans are perforated and arranged to increase the air turbulence in the tubes. The collector is insulated on its back side with 5 cm thick glass wool. The collector works thermally as follows:

The solar rays falling on the collection surface, reach the two absorbers (sheet metal absorber and can tubes) where they are converted into heat. The long-wave rays, such as infrared rays, emitted by the absorbers are trapped by the glass, creating a greenhouse effect and increasing the absorption of solar rays. The air circulating thanks to fans placed at the entrance of each tube, receives heat by convective exchange with the hot internal wall of the tubes. After heating, the air enters directly into the dryer where the products to be dried are exposed.

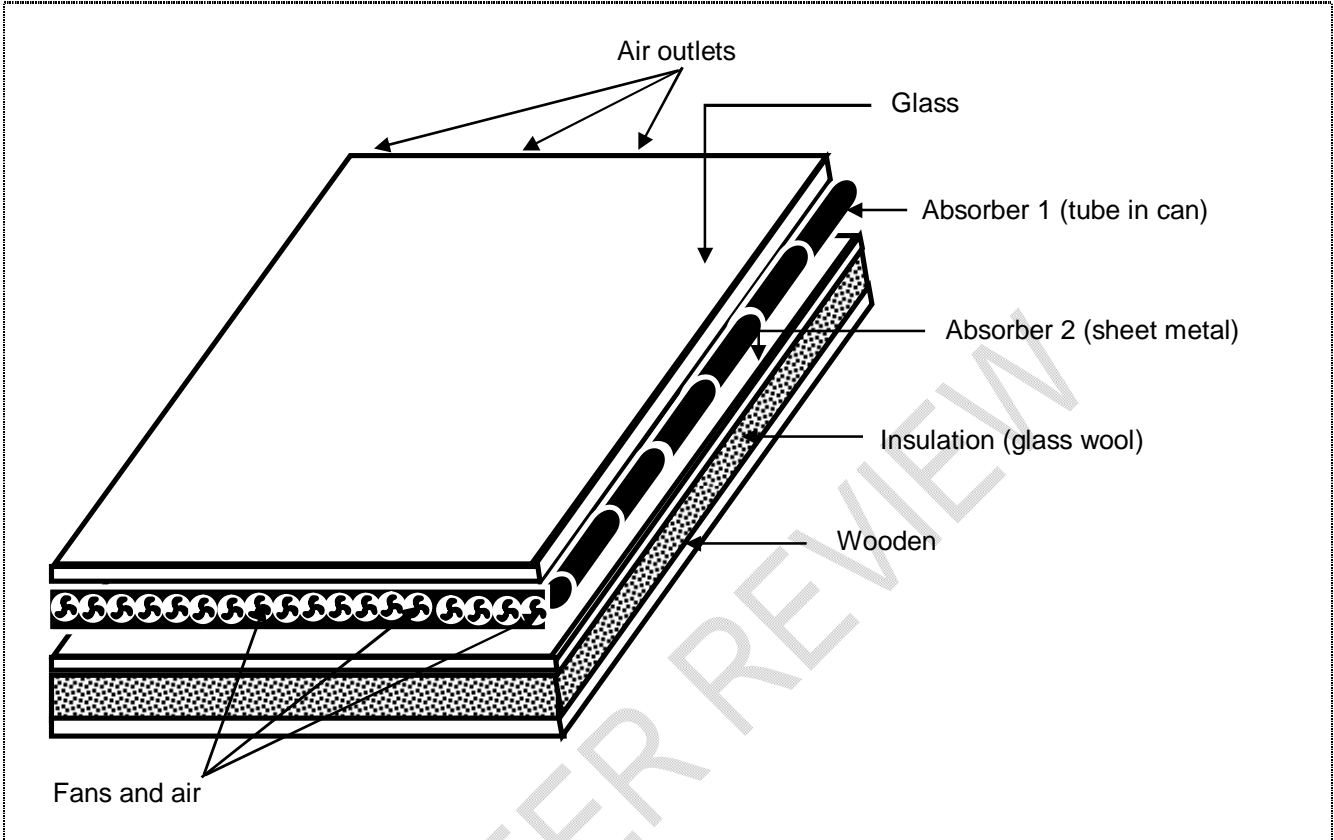


Fig. 1: Diagram of the solar air collector



Fig. 2: Pictures of the components of the solar collector

*(a)-Inlet of a perforated can ;(b)-Outlet of a perforated can;
(c)-Arrangement of perforated cans; (d)-Fan at the inlet of each tube ;
(e)-Collector containing tubes made of cans*



Fig. 3: Solar collector connected to the drying chamber

2.2 Methods

The solar dryer is positioned on the site of the Institute of Research in Applied Sciences and Technologies (IRSAT) in Ouagadougou along the North-South direction. In order to evaluate the thermal performance of the solar air collector, tests are carried out during the months of December 2020 and February 2021. Each test is performed between 8:00 am and 5:00 pm. The parameters measured are sunshine, temperature and air speed. The measurement of sunshine is provided by a solarimeter connected to a data logger type GL 220. The solarimeter is placed in the same position as the collection surface. The sunshine is obtained by weighting the voltage measured from the solarimeter. The air speed in the solar collector is determined by a Testo 425 anemometer of precision $\pm(0.03+5\% \times \text{Reading})$. The temperature is measured using K-type thermocouples connected to the GL 220 midi logger. The thermocouples are placed in the following locations :

- 01 thermocouple placed 15 cm below the sensor to measure the temperature of the environment;
 - 03 thermocouples placed respectively at the inlet, in the middle and at the outlet of one of the canister tubes (air duct) for the temperature of the heat transfer fluid (air);
 - 01 thermocouple placed on the glass ;
 - 01 thermocouple placed in the middle of the drying chamber;
- 01 thermocouple placed at the entrance of the chimney of the drying chamber

2. THERMAL STUDY

The evaluation of the thermal performance of the solar air collector is made from the calculation of its thermal efficiency by exploiting the measured data of the sunshine, the temperature and the speed. The efficiency is defined by the ratio of the heat recovered by the air at the collector outlet and the solar energy received on the collector. It is determined by the relation (1) :

$$\eta = \frac{Q_u}{Q_r} \quad (1)$$

With :

$$Q_u = Se(\rho V)_{air} c_p (T_{as} - T_{ae}) \text{ et } Q_r = A_c G$$

3. RESULTS AND DISCUSSION

Fig. 4-a, 5-a, 6-a show the evolution of the sunshine and the measured temperatures of the different elements of the solar air collector respectively on 14/12/2020, 15/12/2020 and 17/02/2021. The evolution of the solar irradiance during these tests varies between 142 W/m^2 and 837 W/m^2 . The peak of 837 W/m^2 is close to that obtained by Compaoré[7] during his measurements on 29/05/2017. The analysis of the temperature evolution shows that the temperatures vary in the same direction as the sunshine on the sensor. The maximum values of the air temperature at the outlet of the collector and the glass were 117.5°C and 76.7°C , respectively. The difference in air temperature between the outlet and the inlet of the collector presented in **fig. 4-b, 5-b, 6-b** varies between $0,1^\circ\text{C}$ and $74,4^\circ\text{C}$. This important difference would be explained by the turbulence undergone by the air in the tubes, thus improving the heat transfer by convection between the air and the wall. The deviation values are in the same temperature range as those obtained by Karsli [1] which was 37°C to 79°C . As for the air temperature in the dryer, it ranges from 27.2°C to 69.2°C .

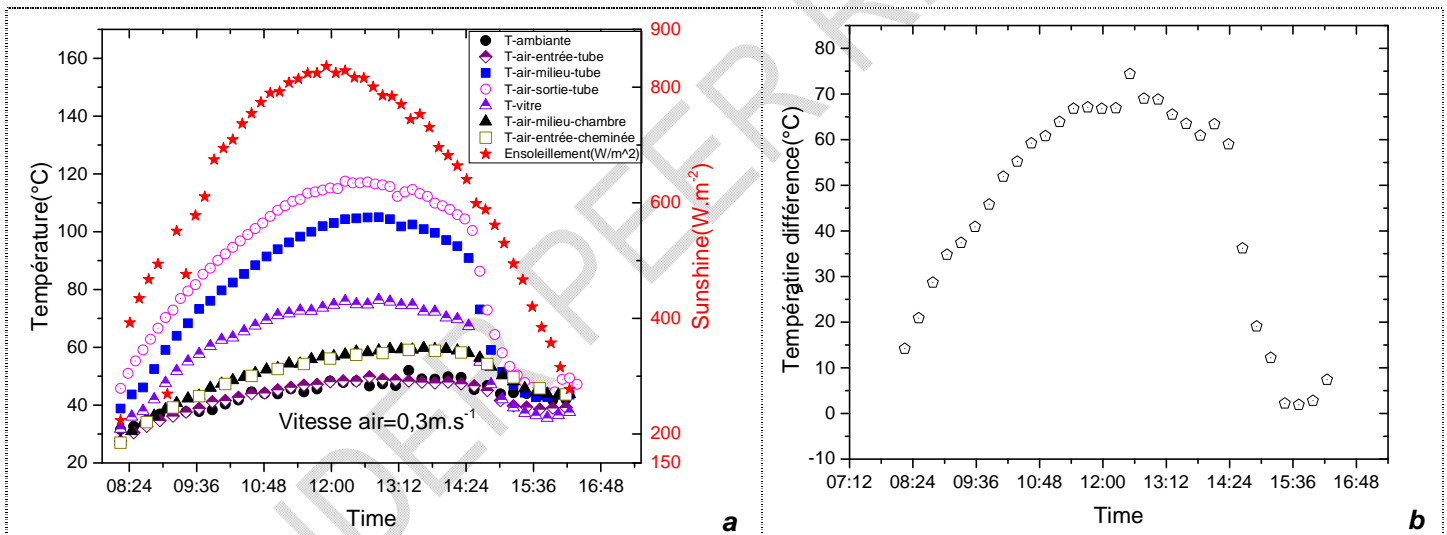


Figure 4: Sunshine and temperature variation for the different elements of the sensor on 14/12/2020

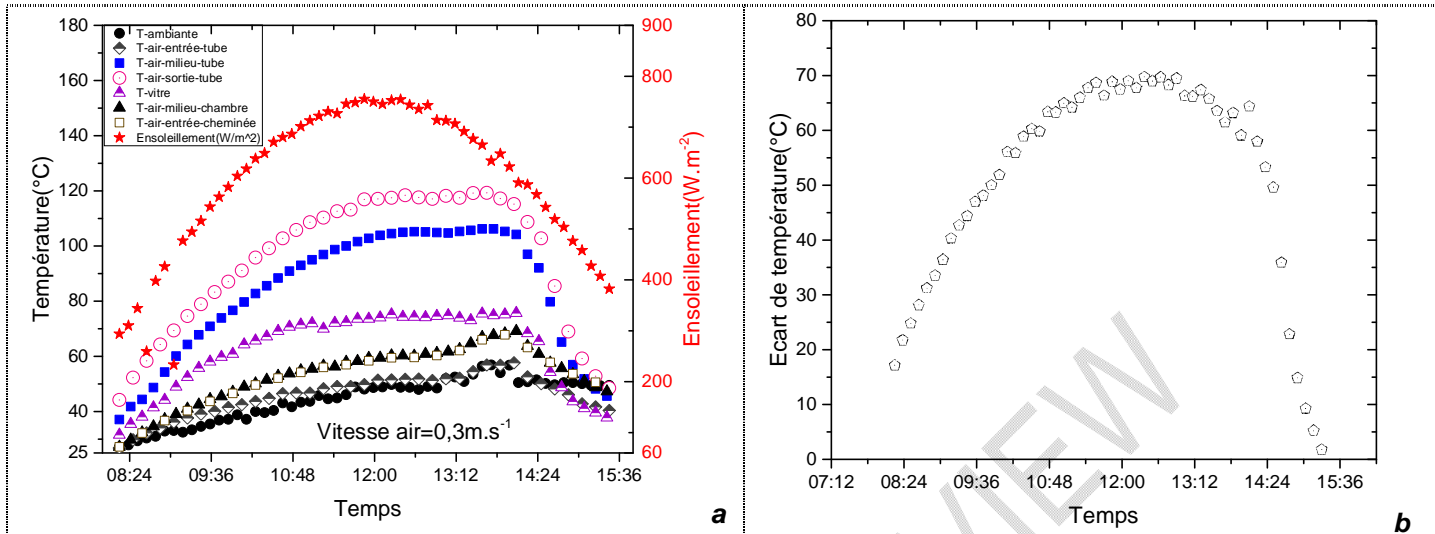


Fig. 5: Sunshine and temperature variation for the different elements of the sensor on 15/12/2020

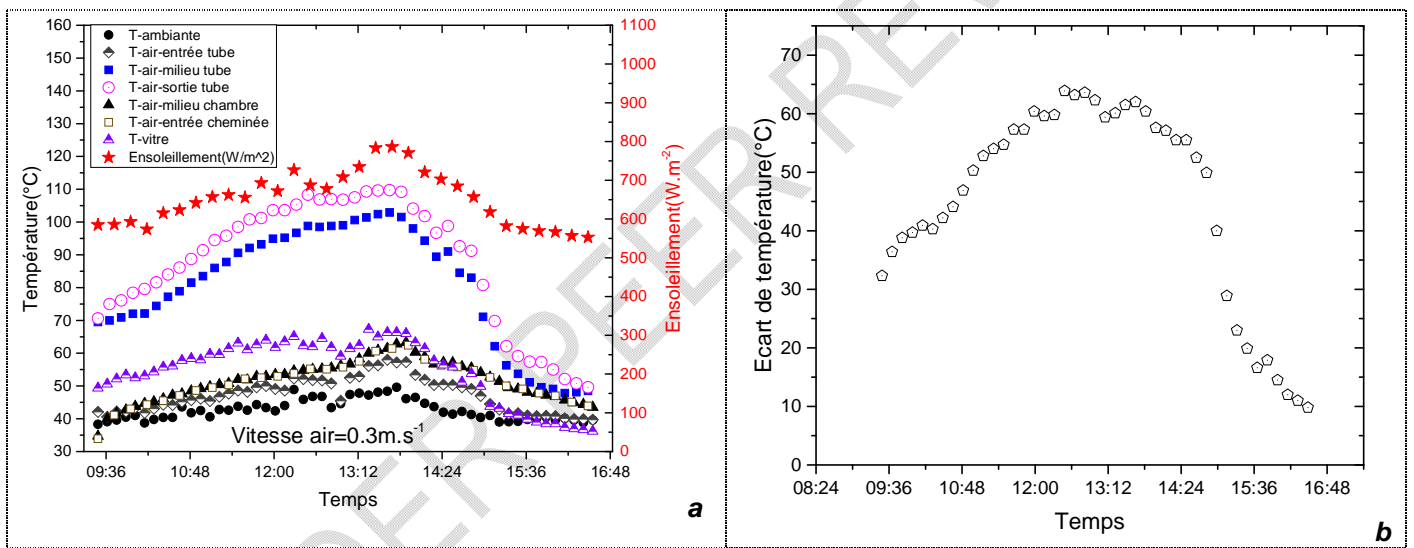


Fig. 6: Sunshine and temperature variation for the different elements of the sensor on 17/02/2021

The measurement of sunshine and air temperature allowed the evaluation of the thermal efficiency of the collector. **Fig. 7, 8** and **9** show the evolution of the efficiency as a function of time during the different tests. The maximum efficiency is 50.68% with an air speed of 0.3m/s and a sunshine of 588.33 w/m². The high efficiency values would be due to the improved capacity of conversion of solar rays into heat by the collector, thanks to its two absorbers, and also to the turbulences created by the configuration of the tubes in which the air circulates, which increases the heat transfer between the wall and the air. The maximum efficiency of the present study is higher than the 35% obtained by Dissa et al.[8] with an air flow rate of 0.022kg/s and an irradiance of 850W/m². Therefore, the realized collector can satisfy the drying heat requirement of different fruits and vegetables. Each figure should have a caption. The caption should be concise and typed separately, not on the figure area. Figures should be self-explanatory. Information presented in the figure should not be repeated in the table. All symbols and abbreviations used in the illustrations should be defined clearly. Figure legends should be given below the figures.] A sample figure is given in **fig. 1**.

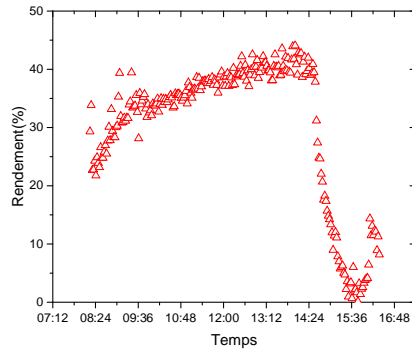


Fig. 7: Instantaneous yield on 12/14/2020

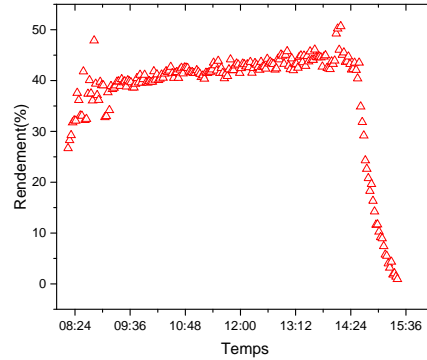


Fig. 8: Instantaneous yield on 12/15/2020

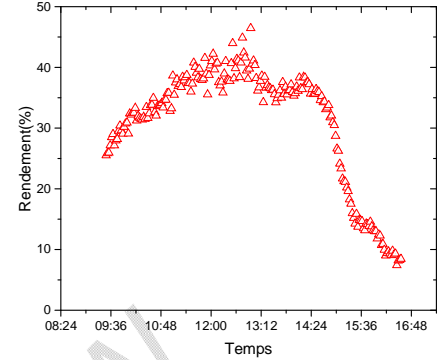


Fig. 9: Instantaneous yield on 02/17/2021

4. CONCLUSION

In this work, a solar air collector has been realized largely with local materials, then the thermal performances of this one are evaluated. The study on the realized collector allowed to show that the temperatures of the air at the exit of the collector are function of the sunning. Also, the configuration inside the tubes (air duct) and the absorber in sheet metal increases the conversion of solar rays into heat and thus allows to obtain quite high temperatures of the air at the exit of the collector as well as inside the drying chamber thus supporting the drying of the agroalimentary products which are exposed there.

REFERENCES

- [1] S. Karsli, "Performance analysis of new-design solar air collectors for drying applications," vol. 32, pp. 1645–1660, 2007.
- [2] A. Abene, V. Dubois, M. Le Ray, and A. Ouagued, "Study of a solar air flat plate collector: Use of obstacles and application for the drying of grape," *J. Food Eng.*, vol. 65, no. 1, pp. 15–22, 2004.
- [3] M. Ben-Amara, I. Houcine, A. A. Guizani, and M. Maalej, "Efficiency investigation of a new-design air solar plate collector used in a humidification-dehumidification desalination process," *Renew. Energy*, vol. 30, no. 9, pp. 1309–1327, 2005.
- [4] H. Esen, "Experimental energy and exergy analysis of a double-flow solar air heater having different obstacles on absorber plates," *Build. Environ.*, vol. 43, no. 6, pp. 1046–1054, 2008.
- [5] D. Eizenga, "Burkina Faso," *Africa Yearb.*, vol. 12, pp. 53–63, 2016.
- [6] Y. Azoumah, E. W. Ramdé, G. Tapsoba, and S. Thiam, "Siting guidelines for concentrating solar power plants in the Sahel: Case study of Burkina Faso," *Sol. Energy*, vol. 84, no. 8, pp. 1545–1553, 2010.
- [7] A. COMPAORE, "Étude énergétique d'un séchoir hybride solaire-gaz pour applications au séchage de l'oignon « Violet de Galmi » Thèse de doctorat en Physique Appliquée(Université Ouaga I Pr Joseph KI-ZERBO, Burkina Faso)," 2016.
- [8] A. O. Dissa, J. Bathiebo, S. Kam, P. W. Savadogo, H. Desmorieux, and J. Koulidiati, "Modelling and experimental validation of thin layer indirect solar drying of mango slices," *Renew. Energy*, vol. 34, no. 4, pp. 1000–1008, 2009.

Nomenclature

ρ_{air}	Density of the air	$(kg.m^{-3})$
V_{air}	Air speed	$(m.s^{-1})$
Se	Air inlet cross section in a tube	(m^2)
c_p	Specific heat of the air	$(J.kg^{-1}.\text{°C}^{-1})$
T_{as}	Air temperature at the sensor outlet	(°C)
T_{ae}	Air temperature at the sensor inlet	(°C)
A_c	Collecting surface of the sensor	(m^2)
G	Solar irradiation	$(W.m^{-2})$

UNDER PEER REVIEW