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Experimental Investigation for Augmentation of Thermal Performance of Solar Air Collector

Souleymane Sinon [a*], Salifou Tera [a], Oumar Sanogo [b], Sayouba Sandwidi [c], Bruno Korgo [a] and Sié Kam [a]

[a] *Laboratoire d'Energies Thermiques Renouvelables (LETRE), Université Joseph KI-ZERBO, Ouagadougou, Burkina Faso.*
[b] *Laboratoire des Systèmes d'Énergie Renouvelable et Environnement (LASERE), Institut de Recherche en Sciences Appliquées et Technologies (IRSAT/CNRST), Burkina Faso.*
[c] *Laboratoire de Physique et de Chimie de l'Environnement (LPCE), Université Joseph KI-ZERBO, Ouagadougou, Burkina Faso.*

Authors' contributions

This article is realized with the support of all authors. The author S. Sinon supervised the realization of the collector, established the measurement protocol and contributed to the writing. The author ST contributed to the setting up of the measurement instruments and the realization of the tests on the sensor. The author OS financed all the works on the realization and performance tests on the collector. The author BK contributed to the financing of the publication of the manuscript. The authors S. Sandwidi and SK contributed in the writing of the article. All authors have approved the final version of the article.

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ABSTRACT

This paper presents a study of the thermal performance of a solar air collector used to heat the drying air of a fruit and vegetable dryer. The prototype collector could be a viable solution to improve energy efficiency and food security in Burkina Faso and other developing countries, by contributing to the reduction of post-harvest losses and the increase of income for local agricultural

**Corresponding author: E-mail: sinonsouleymane777@gmail.com;*

producers. The collector is first realized by using black painted cans as air ducts, perforated to increase turbulence, and a glass covering the collection surface. After realization, the collector is connected to the dryer and a measurement campaign is conducted to evaluate the thermal performance of it. The measured parameters are the sunshine and the air temperature by keeping the air speed fixed at 0.3 m/s. The analysis of the results shows an important variation of the air temperature difference going from 0.1°C to 74.4°C, between the inlet and the outlet of the collector for an irradiation which varies between 142 W/m^2 and 837 W/m^2. The black painted surface of the air ducts as well as the increase in turbulence contributed to improve the efficiency of the collector which varies between 0.94% and 50.68% and allowing to record air temperatures ranging from 27.2°C to 69.2°C inside the dryer. This temperature range is favorable for the drying of most food products.

Keywords: Solar collector; forced convection; experimentation; performance; drying; turbulence.

ABBREVIATIONS

CNRST : Centre National de Recherche Scientifique et Technologique
IRSAT : Institut de Recherche en Sciences Appliquées et Technologies

NOMENCLATURES

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

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.

Solar air collectors are widely used in drying operations [1-3] because of the low installation costs. Also, their maintenance and technology do not require specialized manpower; they can also 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 [4-7]. Generally, the thermal performance of an air collector depends on the materials used in its construction, its shape, size and arrangement. The overall heat transfer coefficients in air-solar collectors are low due to the unfavorable thermophysical properties of the heat transfer medium (air) [8]. 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. MATERIALS AND METHODS

2.1 Materials

Solar energy is one of the most abundant sources of energy in Burkina Faso, with an estimated average daily sunshine of 5.5 kWh.m^{-2} and an insolation of 8.3 hours per day [9,10]. 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. Figs. 1 and 2 show respectively a diagram and a photo 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.

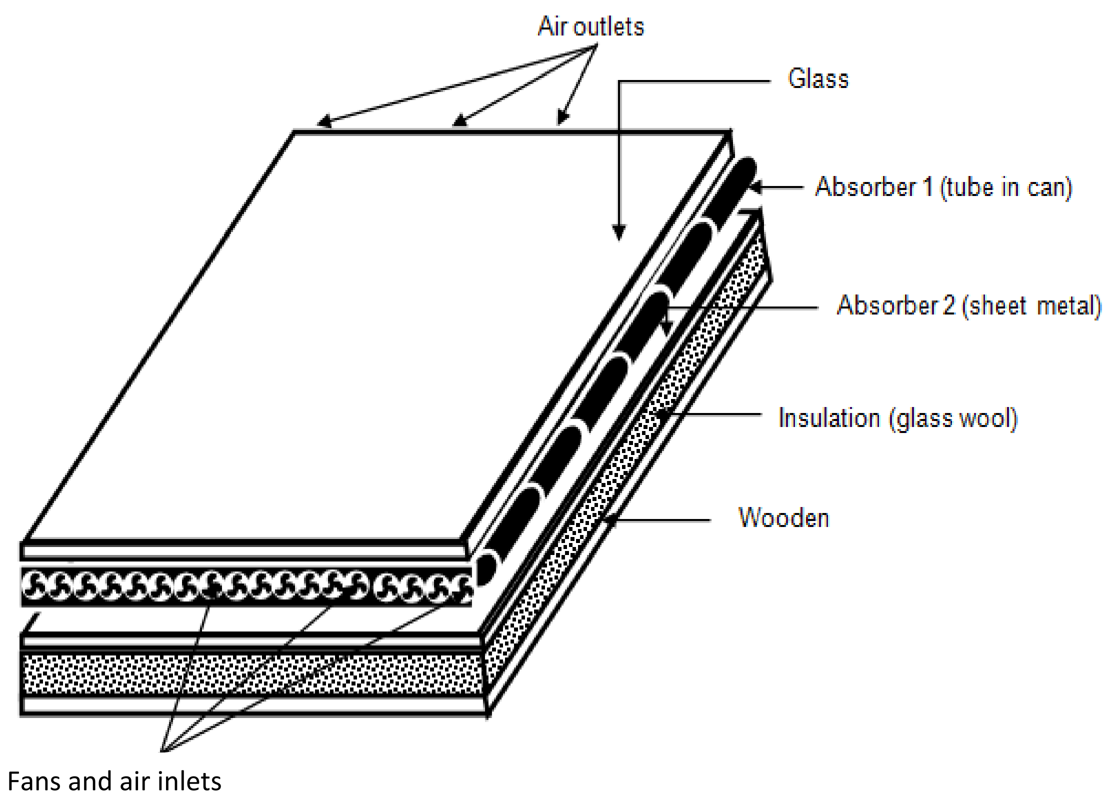

Fig. 1. Photo of the solar air collector

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±(*0.03+5%× 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

2.3 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):

$$\eta = \frac{Q_u}{Q_r} \tag{1}$$

With:

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

3. RESULTS AND DISCUSSION

Figs. 4, 5, 6 show the evolution of the sunshine and measured temperatures of the different elements of the solar air collector on 14/12/2020, 15/12/2020 and 17/02/2021 respectively. 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 [11] 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 sensor and the glass were respectively 117.5°C and 76.7°C.

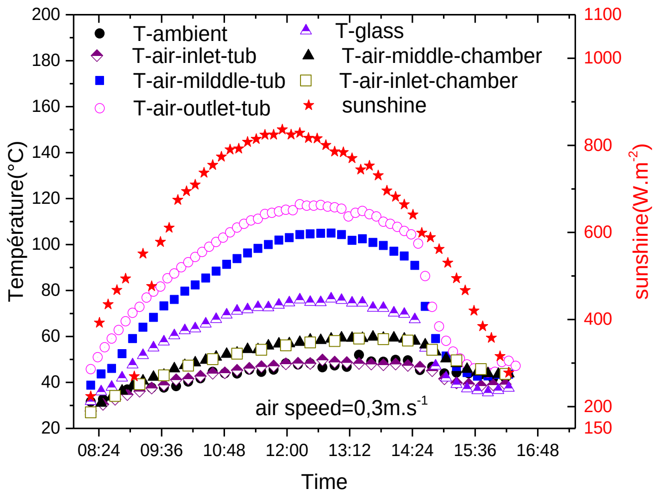

Fig. 4. Sunshine and temperature evolution on 14/12/2020

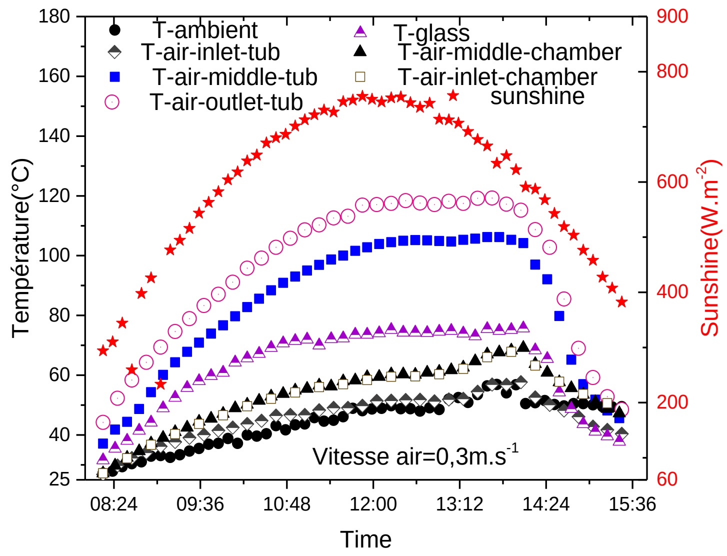

Fig. 5. Sunshine and temperature evolution on 15/12/2020

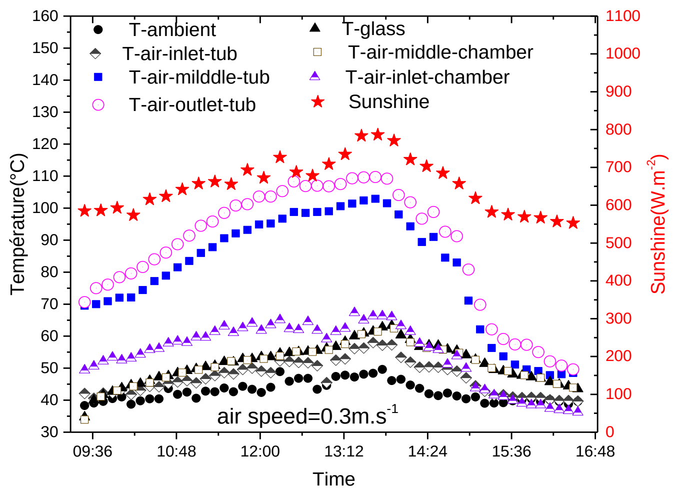

Fig. 6. Sunshine and temperature evolution on 17/02/2021

Figs. 7, 8, 9 show the difference in air temperature between the outlet and inlet of the collector. The difference varies between 0.1°C and 74.4°C. This important difference could 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 ranged from 37°C to 79°C. As for the air temperature in the dryer, it gives satisfactory results ranging from 27.2°C to 69.2°C.

The measurement of sunlight and air temperature allowed us to evaluate the thermal efficiency of the collector. Figs. 10, 11 and 12 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 0.3 m/s and a solar radiation of 588.33 W/m^2. 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. [12] with an air flow rate of 0.022 kg/s and an irradiance of 850 W/m^2. Therefore, the realized collector can satisfy the drying heat requirement of different fruits and vegetables.

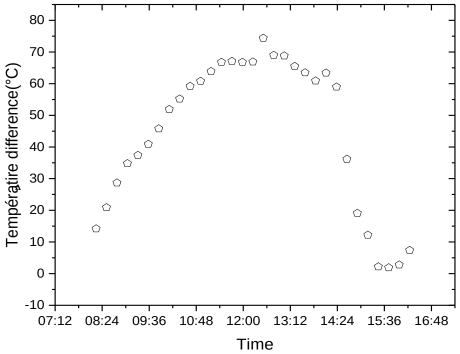

Fig. 7. Air temperature difference between the inlet and outlet of the collector on 14/12/2020

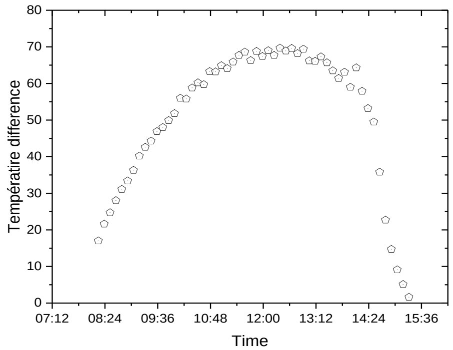

Fig. 8. Air temperature difference between the inlet and outlet of the collector on 15/12/2020

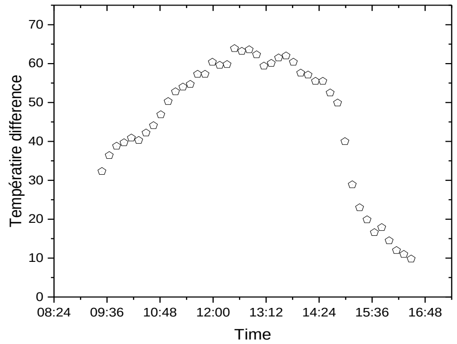

Fig. 9. Air temperature difference between the inlet and outlet of the collector on 17/02/2021

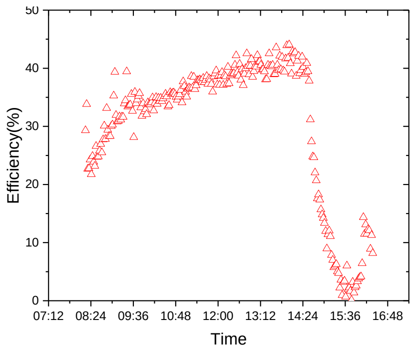

Fig. 10. Instantaneous Efficiency on 12/14/2020

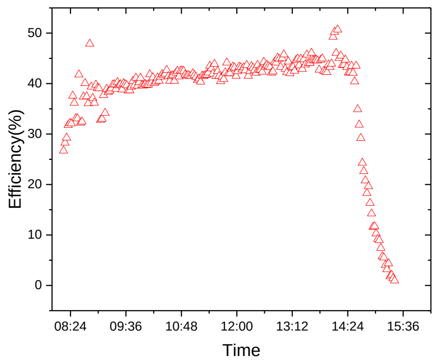

Fig. 11. Instantaneous Efficiency on 12/15/2020

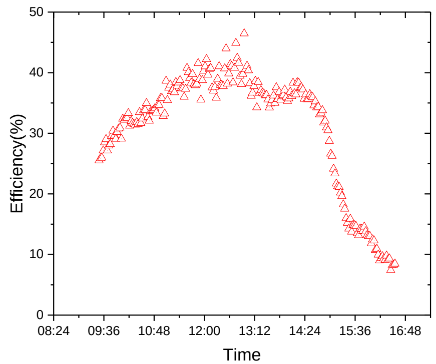

Fig. 12. Instantaneous Efficiency on 02/17/2021

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.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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