



## Development of a Solar Dryer with Multi-Products and a Residual Moisture Control System

Nafisa A. ABDULHAMID<sup>1</sup>, Danladi D. USMAN<sup>2\*</sup>, Kabiru I. JAHUN<sup>3</sup>, Rotkangmwa J. SATTI<sup>4</sup>, Yahaya U. JAURO<sup>5</sup>, Abdulmajid M. HASHIR<sup>6</sup>, Yusuf G. SHIMBURA<sup>7</sup>

<sup>1,2\*,3,4,6,7</sup>Department of Agricultural and Bioresource Engineering, Faculty of Engineering and Engineering Technology, Abubakar Tafawa Balewa University, Bauchi, Nigeria

<sup>5</sup>Department of Agricultural and Bioenvironmental Engineering, Federal Polytechnic Bali, Taraba State, Nigeria

<sup>1</sup>lillys0274@gmail.com, <sup>2\*</sup>ddusman@atbu.edu.ng, <sup>3</sup>kijahun@atbu.edu.ng, <sup>4</sup>rotkangmwajoel@gmail.com, <sup>5</sup>omarjahya@gmail.com, <sup>6</sup>abdulmajidhashir@gmail.com, <sup>7</sup>yusufgarsama@gmail.com

### Abstract

By using solar energy to heat air and dry food materials, a solar drying system helps preserve and reduce agricultural produce waste. It also makes it easier to transport dried produce, which improves people's health and well-being. The project's goal is to create a solar dryer with a residual moisture control system that may shorten drying times and yield high-quality goods. Mild steel, collector glass, angle iron, metal sheet, aluminum foil, plywood, steel mesh wire, 12 V fans, and other materials were purchased locally for the production. A solar drying chamber with a rack of four wire mesh (net) trays and a solar collector (air heater) make up the dryer. The solar collector heats the air that enters through the air inlet before directing it into the drying chamber, where it is used for drying (removing the moisture content from the food ingredient or agricultural produce loaded). Temperature and humidity sensors, a control switch, and a 12V fan make up the residual moisture control system. It is anticipated that the dryer, which has a collector area of 0.637 m<sup>2</sup>, a drying chamber measuring 700 × 1325 × 600 mm, a collector inclination ( $\beta$ ) of 20.17 °, insulation thickness (tb) of 1.5 mm, and insolation on the collector (Ic) of 1215.15 W/m<sup>2</sup>, will dry two to three kilograms of goods. By enlarging the solar collector, current solar food driers can still be made better, particularly in terms of eliminating any remaining moisture and likely storing heat inside the system.

**Keywords:** Solar dryer, Solar collector, Residual moisture, Insulation, Polyurethane glass.

### 1.0 Introduction

One of the earliest and most popular ways to strengthen food is to preserve it by drying it. Food is dried to reduce moisture, allowing for long-term storage and corruption prevention (Ananta et al., 2024). Drying prolongs the product's shelf life by lowering microenzyme activity and slowing down chemical processes (Dare-Adeniran & Areola, 2022). Additionally, lowering the volume and weight of materials and packaging makes it easier to transport and store goods and lowers the expense of these processes (Rana et al., 2024). Inadequate preservation methods, especially for developed products, lead to mold and fungus attacks (Sadaf et al., 2026). An alternate method for retaining moisture in fruits, vegetables, and other agricultural goods is drying (Mulatu et al., 2023). Heat from a variety of sources, including the sun, electric converters, and burning biomass, can be used to remove moisture from items. Sun drying is economical and environmentally advantageous for low-temperature drying applications (Lingayat et al., 2021). However, this method is not frequently used, especially for fruits and vegetables with higher moisture content. Because of the sun's intermittent nature, the product takes a lengthy time to dry (Kumar and Singh, 2020).

Open sun drying is a traditional method for drying fruits, vegetables, crops, and agricultural leftovers. Open sun drying has several drawbacks, including lengthy drying times (Singh, 2011), dust pollution, losses from animal and bird incursion (Moses et al., 2013), product discoloration, and hardness (Chaatouf et al., 2021). Direct-type solar drying, which is simple, affordable, and easy to build, reduces the main drawbacks of open sun drying, such as losses from animals and birds and product contamination (Mustayen et al., 2014). In the drying chamber above the absorber plate, this method exposes the product directly to sunlight (Singh & Gaur, 2020). Direct-type solar dryers work well for small quantities of low-moisture products (Kumar et al., 2016). However, the associated drawbacks—limited drying capacity, inconsistent product quality, and reduced nutritional value—have restricted their application for light-sensitive products with high moisture content (Kumar & Singh, 2020). Indirect solar drying is chosen over both methods because of its enhanced performance, better product quality, and short drying time (Mohammed et al., 2020). Most crops spoil before they are sold because of inadequate drying, unfavorable weather, and other causes. End consumers are susceptible to infections that might result in fatalities or long-term illnesses when crops are contaminated by dirt, dust, insects, and rodents (Vijay et al., 2023). All things considered, this is a problem that requires research and mitigation, which solar dryers' intervention achieves. The project's objective is to design and construct a solar dryer that can dry agricultural products more rapidly and efficiently

while keeping the product from reabsorbing any residual moisture when solar radiation levels fall. The advantages of solar dryers include improved food quality, faster drying times, less loss of raw materials, and larger production scales (Wang *et al.*, 2018).

The purpose of this project was to design and construct a working solar dryer, namely a cubic system with wire mesh layers and a moisture control system. The goal of this research project is to design and construct a solar dryer with residual moisture remover (12 V fans) to stop wet air from returning during downtime or when solar radiation is at its lowest.

## 2.0 Materials and Methods/Methodology

### 2.1 Study Area

The study would be carried out in the Agricultural and Bioresource Engineering department's research laboratory (processing and farm power) at Abubakar Tafawa Balewa University (ATBU), Bauchi, Nigeria. The Research Laboratories are located in the Northern Guinea Savannah natural zone of Nigeria, specifically in ATBU, Bauchi. This region is located between latitudes 10° 17'N and longitudes 09° 49'E, with a mean elevation of roughly 650 meters above sea level (Kuhe *et al.* 2022).

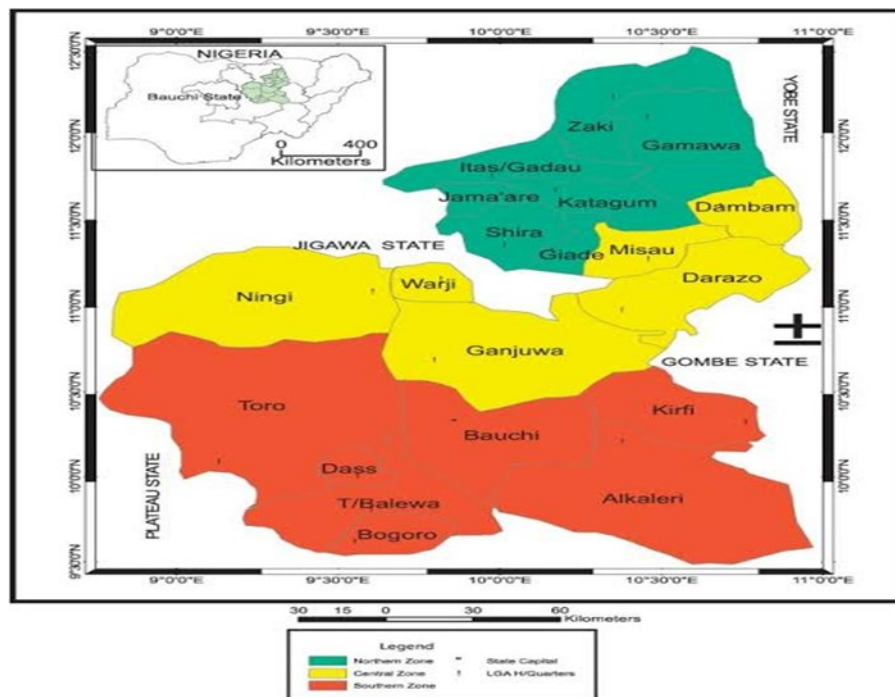


Figure 1: Map of Bauchi State showing the study location

### 2.2 Components and Materials Used

The solar drier device was designed and built with the intention of drying a range of food items. Wood, polyurethane glass, mild steel metal sheets, and trays were used in the construction. The items used in this experiment are listed below, along with their functions (Table 1). The solar food drier has two primary chambers or compartments:

- a. The solar collection chamber, sometimes known as the air heater.
- b. The drying chamber, which is built to hold four layers of wire mesh drying trays that are used to dry food or produce.

Table 1: The Solar Dryer's components

S/N	Components	Dimension/Specifications	Materials	Function
1	Frame	1500 mm × 700 mm × 400 mm/1587 mm	Mild steel	Provides structural stability
2	Solar Collector	980 mm × 650 mm (100 mm) thick	i. Black-painted steel ii. Glass cover	Absorbs solar radiation has a Glass cover 3-5 mm thick.

S/N	Components	Dimension/Specifications	Materials	Function
3	Drying Chamber	700 mm × 1325 mm	i. Mild steel sheet ii. Aluminium foil	Holds ginger; insulated walls (2 mm thick) retain heat. Size scales with trays.
4	Tray	615 mm × 530 mm, 2 mm (mesh size)	Steel mesh	4 trays to Hold ginger (3-5 cm thick layers).
5	Fans	12 V	Selected	Forces airflow; powered by solar panels
6	Solar Panels (PV)	100 W	Selected	Generates electricity (12-24 V, 20 W total) to power fans
7	Battery	50 Ah, 12 V	Selected	Stores energy (12 V, 50 Ah) for fan operation during low sunlight
8	Insulation	5 mm thick	Plywood	Thin layer in the collector sides.
9	Control Panel		Selected	Manages fan speed/power; includes on/off switch and temp/humidity display.
10	Temperature and Humidity Sensor		Selected	Regulating Residual Moisture.

### 2.3 Design Criteria

The following criteria guided the design of the dryer:

1. Small scale service.
2. Ability to remove residual moisture.
3. Exclusion of insects within the drying chamber.
4. Forced convection to improve efficiency.
5. Availability of solar powering the blowers.
6. Geographical and Meteorological information of the location.

### 2.4 General Description of the Solar Dryer

The most common cabinet form designs are wooden boxes with glass covers (Matavel *et al.*, 2022). Cardboard boxes and clear nylon or polythene can even improve certain forms. The suggested design is theoretically based on the greenhouse effect and thermosiphon ideas (Behera *et al.*, 2022). Air enters the solar collector by an air vent, also known as an inlet, and is heated by the greenhouse effect. In order to eliminate moisture from the food, the hot air then rises through the drying chamber, passes through the trays, and escapes via the air vent (or outlet) toward the top of the shadowed side (Nishanth *et al.*, 2023). In order to keep residual moisture from settling on the product, the residual moisture mechanism is activated when the temperature decreases and the humidity increases in the drying chamber. The fans then blast air that pushes the damp air out. Under free (natural) convection, the heated air acts as the drying medium, removing and moving the moisture from the produce (or food) to the atmosphere (Marinoni *et al.*, 2022). To control moisture reabsorption, the dryer's dual mode solar system needs a mechanical component.

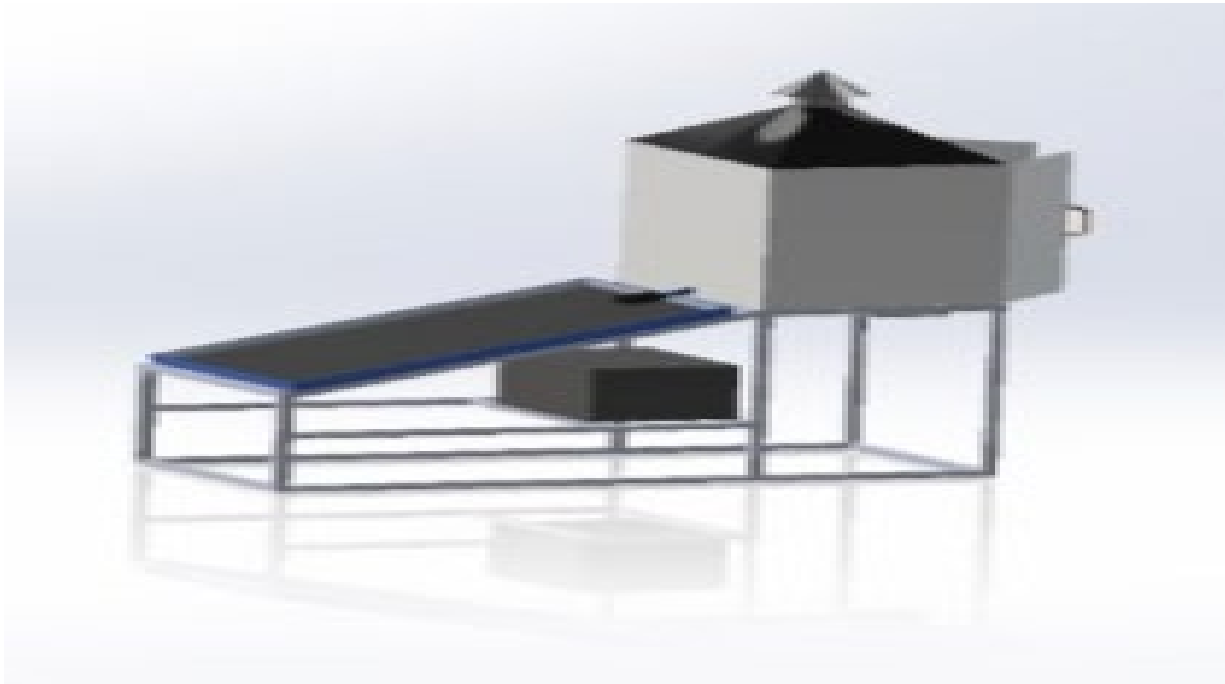


Figure 2: The Solar Dryer's conceptual design

## 2.5 Design Calculations

### 2.5.1. Tilt Angle ( $\beta$ ) of the Solar Collector

The angle of tilt ( $\beta$ ) was determined using equation (1) (Adegoke and Bolaji, 2000):

$$\beta = 10 + \text{lat } \phi \quad (1)$$

whereas Bauchi, where the dryer was developed, has a latitude of  $10.17^\circ\text{N}$ , the collector location's latitude is represented by  $\alpha$ .

### 2.5.2. The Collector Surface Area Insolation

Consequently, insolation was found on the collector surface as reported by Tyona & Ojiya (2020).

$$I_c = HT = HR \quad (2)$$

where, the average effective ratio of solar energy on a slanted surface to that on a horizontal surface is  $R$  (1.164), while the average daily radiation  $H$  on a horizontal surface is  $H = 978.69\text{W}/\text{m}^2$ .

### 2.5.3. Collector Area and Dimensions

The collector area was determined using equation (3) as reported by Chandan (2018).

$$A_c = (V_a \cdot \rho_a \cdot \Delta T \cdot C_{pa}) / I \eta \quad (3)$$

where,  $V_a$  = average air wind speed (m/s)

$\rho_a$  = air density (kg/m<sup>3</sup>),

$c_p$  = specific heat capacity of the air at s.t.p. (1005 J/kg°C)

$\Delta T$  = temperature difference i.e  $\Delta T = (T_o - T_a)^\circ\text{C}$

$I_c$  = the overall solar insolation at the collector plate

The length of the solar collector ( $L$ ) was obtained using equation (4) as reported by Chandan (2018);

$$L = A_c / B \quad (4)$$

### 2.5.4. The solar collector's insulator thickness

To find the base insulator thickness using plywood as insulating material ( $K = 0.13 \text{ W}/\text{mK}$ ), equation (5) below is used (Alamu *et al.*, 2010).

$$FR ma C_p (T_o - T_a) = K AC (T_o - T_a) / t_b \quad (5)$$

where,  $K$  = Thermal conductivity of the insulation material used in  $W/mK$ .

$$F = 10\% = 0.1$$

$$T_o = 600C \text{ and } T_i = T_a = 300C \text{ approximately}$$

$$ma = 5.76 \times 10^{-3} \text{Kgs}^{-1}$$

$$C_p = 1005 \text{J Kg}^{-1} \text{K}^{-1}$$

### 2.5.5. Determination of Heat Losses from the Solar Collector

Total heat transmitted and absorbed is given by (Chandan, 2018)

$$I_c A_c \tau \alpha = Q_u + Q_L + Q_s \quad (6)$$

where  $Q_s$  is the stored energy, which is regarded as insignificant.

$$I_c A_c \tau \alpha = Q_u + Q_L \quad (7)$$

Thus,

$$Q_L = I_c A_c \tau \alpha - Q_u \quad (8)$$

This heat loss encompasses the heat loss via the cover glass and the insulation from the sides.

## 3.0 Results and Discussion

The results of the solar dryer design and fabricated are presented in Table 2 below.

Table 2: Design Parameter Result of the Solar Dryer

S/N	Design Parameter	Value
1	Solar collector area ( $A_c$ )	0.637 $m^2$
2	Drying chamber size	700 × 1325 × 600 mm
3	Air vent opening	0.0637 $m^2$
4	Tray area (each)	0.326 $m^2$
5	Total tray area	1.304 $m^2$
6	Tray spacing	150 mm
7	Collector inclination ( $\beta$ )	20.17 °
8	Frame height	1.5 m
9	Mass of absorber plate	2.75 Kg
10	Mass of glass cover	6.37 Kg
11	Mass of chamber sheet	67.27 Kg
12	Mass of trays	5.12 Kg
13	Mass of frame	115.79 Kg
14	Accessories (PV, fan, battery)	29.00 Kg
15	Total mass of dryer	226.30 Kg
16	Fan power requirement	8.4 W
17	Solar PV capacity	100 W
18	Collector Insolation ( $I_c$ )	1215.15 $W/m^2$
19	Length of Solar Collector ( $L$ )	0.69 m
20	Insulation Thickness ( $t_b$ )	1.5 mm
21	Average Air Speed ( $V_a$ )	0.15 m/s
22	Air Flow Rate of ( $a$ )	5.76 x 10 <sup>-3</sup> Kg/s
23	Heat Loss ( $Q_L$ )	98.61 W



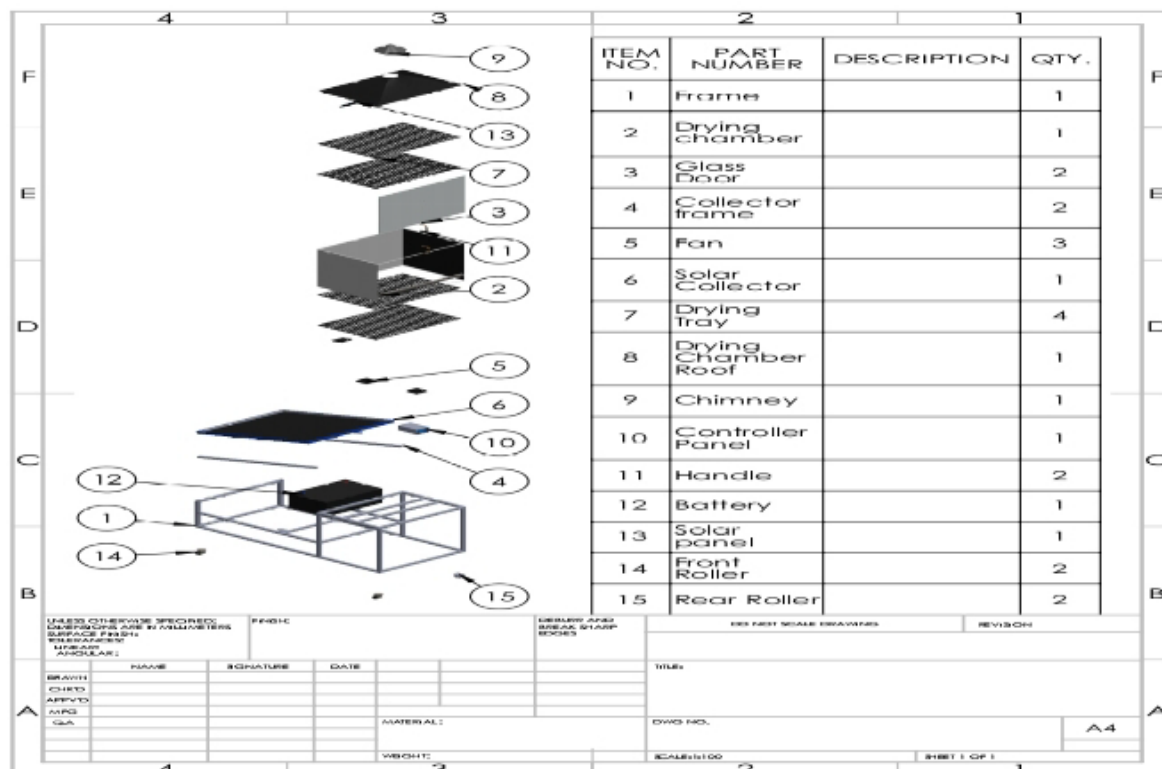


Figure 5: Exploded view of the Solar Dryer

**3.1 Construction Procedure**

The construction was done in stages as follows:

**Solar Collector Construction:** The collection structure was made of 980 x 650 mm mild steel angle bars. The absorber plate was made of a corrugated steel sheet that was 0.55 mm thick and painted black. The absorber was covered with 4 mm thick glass and insulated inside with a layer of plywood that was 5 mm thick.

**Drying Chamber Construction:** A 2 mm mild steel sheet measuring 700 x 1325 x 600 mm was used to construct the chamber. To improve heat reflection, aluminum foil was used to line the interior surface.

**Drying Trays:** Four trays, each measuring 615 × 530 mm, were made of mild steel square hollow rod fitted with galvanized wire mesh. The trays were placed 150 mm apart.

**Support Frame:** The dryer was mounted on a mild steel square tube frame of 1500mm × 700mm × 400mm/1587mm. The frame height was 1.5 m, inclined at 10° facing south to ensure maximum solar radiation.

**Electrical Setup:** A 100W photovoltaic panel, charge controller, thermostat and 12 V, 50 Ah battery were installed to power the DC fan for improved air circulation.

**Assembly:** The collector and drying chamber were joined using bolts and welded joints to form a compact system. The entire unit was painted with anti-rust paint.

The solar dryer's design and construction were tailored to the specific meteorological conditions of Bauchi, Nigeria (10.17°N), which influenced the critical collector tilt angle of 20.17°. This angle ensures optimal solar intercept throughout the year for that latitude. The solar collector, with an area of 0.637m<sup>2</sup>, was designed to maximize heat absorption using a black-painted corrugated steel absorber. The inclusion of 5 mm plywood insulation and a 4 mm glass cover serve to minimize convective and radiated heat losses, which were calculated at approximately 100.01 W. By utilizing the greenhouse effect, the collector successfully pre-heats the air before it enters the drying chamber. A standout feature of this prototype is the residual moisture control mechanism. Unlike passive "open sun drying" which is susceptible to weather fluctuations, this system will use a 12 V DC fan powered by a 100 W PV panel. The fan will improve drying efficiency by maintaining a consistent mass flow rate of air (5.76 X 10<sup>-3</sup> kg/s). The drying chamber is 700 mm, 1325 mm, 600 mm, offering a total tray area of 1.304 m<sup>2</sup> across four levels. This multi-tier design will maximize throughput for small-scale services. The use of aluminum foil lining within the chamber further enhances efficiency by reflecting radiant heat onto the product trays. While the total mass of the dryer is significant (226.30 kg, the inclusion of rollers (as seen in the exploded view) suggests a degree of necessary mobility for outdoor positioning.

According to the literature, open sun drying exposes food to dust and bugs and can take up to seven days compared to traditional techniques. By offering a physical barrier against insects and pollutants, cutting drying

times through improved thermal performance, and maintaining nutritional content by shielding the food from direct UV exposure, our indirect forced-convection model reduces these concerns.



Plate 1: Front view of the constructed dryer



Plate 2: Rear view of the constructed dryer

#### 4.0 Conclusion

Initial research on drying conditions informs the design and construction of a solar dryer. Fish, fruits, and vegetables can all be dried using the manufactured dryer. It is anticipated that the dryer, which has a collector area of 0.637 m<sup>2</sup>, a drying chamber measuring 700 × 1325 × 600 mm, a collector inclination ( $\beta$ ) of 20.17°, insulation thickness (tb) of 1.5 mm, and insolation on the collector ( $I_c$ ) of 1215.15 W/m<sup>2</sup>, will dry two to three kilograms of goods. In order to conduct experimental drying testing, a dryer prototype was built.

Solar technology has frequently been recommended for agricultural produce in order to save energy costs and economically accelerate drying, which would be advantageous for final high-quality dried products using solar energy. Controlled drying of agricultural goods has a number of benefits, including increased product quality, storage capacity and hygiene, less waste, and enhanced transportability in terms of both time and area. By expanding the size of the solar collector, the performance of the current solar food dryer can still be enhanced, particularly in the areas of removing leftover moisture and likely storing heat within the system. In order to maximize the system's efficacy and efficiency, customers of solar products need also have easy access to meteorological data.

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#### Declaration of Conflicting Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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