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Design and Implementation of Low-Cost Solar Dryer Based Android for Agricultural Crops

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***Abstract*—Smartphone technology is developing very quickly and becoming an integral part of our lives. The technology provides many conveniences the users can obtain, including in agriculture. One such convenience is in providing better way to dry horticultural crops for farmers, since the traditional drying method has many drawbacks. In addition to the long drying processing time, the traditional method also damages many crops and reduces net production. To overcome this problem, the convenience that exists in smartphone technology can be combined with PV (Photovoltaics) technology, producing an alternative solution to replace the traditional drying process. This study aims to design a low-cost drying agricultural product using a wi-fi Sonoff module to control and send signals using the E-WeLink application installed on smartphones that can be applied to small-scale agro-industrial farmers. A solar dryer was tested on chili and corn seeds. Experimental results revealed that the time efficiency has improved by about 26.67% for chili and 27.27% for corn seeds compared to conventional processes. Meanwhile, in terms of energy required for the drying process, this system succeeded in producing 25% - 45.11% efficiency compared to the energy required with conventional processes. In addition, the system can be used as a source of lighting, which can be monitored and controlled from a smartphone application via a wi-fi network**

***Keywords*—android, dryer system, solar system, Wi-Fi.**

I. INTRODUCTION

Drying is generally considered an energy-intensive and cost-effective method that can improve the storability of various agricultural products. During the simultaneous transfer of heat and mass, water evaporates near the surface through various mechanisms, such as liquid and vapor diffusion, capillary and gravity flow, and flow caused by contraction and pressure gradients [1]. The reduction in moisture content extends the shelf life of the product, reduces the volume of the material, increases the durability of the product, and saves transportation, packaging, and storage costs . For the drying of horticultural products such as corn and chili, traditional outdoor drying is still the most commonly used method for smallholder farmers [2], [3], [4]. This process is carried out by placing the dried product on the vacant area or roadside near the farmer's residence. Although the traditional drying method is inexpensive, the traditional drying method has some limitations like intermittent availability, space availability, and high initial cost. [5]. In terms of quality, dried products made by the traditional method often suffer significant damage from rain, insects, birds, and other external factors [6] [7]. With traditional methods, farmers also need to control the process. For instance, rain affects the drying process where many crop yields fail and are wasted.

Another study [8] reported that the key factors affecting food loss in developed countries occurred in the consumption stage, while in less developed countries, most of the losses occurred in the early stage of the value chain, especially in the post-harvest processing and processing stage [9] [10]. The high rate of food loss leads to food shortages and makes millions of people in low-income countries malnourished [11] [12]. In terms of product quality improvement, greenhouse dryers were introduced in many places in Indonesia in 1999 [13]. One of these methods is the Solar Dryer Dome, or the tunnel and greenhouse dryers' system. The solar dryer dome system uses solar energy built as a dome using polycarbonate material with a good efficiency by using sunlight which able to processes and dries large-scale agricultural products to last 10 to 30 years. The transparent dome material allows sunlight to penetrate and absorb the dome with constant heat [14]. With this method, the drying process will generate the result faster than the traditional drying process. Functionally, this method can answer farmers' problems with the drying process. However, on the other hand, not all farmers can cover the cost of the Solar Dryer Dome system. The technology still faces challenges, such as high investment costs and a long PBP, especially for small-scale cooperatives and smallholder farmers [15] [16].

Photovoltaic (PV) is a current technologically and commercially mature technology that can use solar energy to generate and supply short- and medium-term electricity. With continuous and advancement of technology, the increase of installed capacity, the reduction of prices, and the encouraging laws and policies, photovoltaics will continue to maintain rapid growth and eventually become an important global energy supplier [17] [18] . From this condition, it is necessary to find the right drying technology solution for the small-scale agro-industry sector, considering the financing capability. In addition, integrating suitable drying technology-based photovoltaic (PV) drive systems to power the fans of active dryers may be an attractive option, especially for smallholder farmers or agricultural entrepreneurs, which can significantly reduce post-harvest Loss, improve the quality of food, and create income and employment opportunities.

This work aims to design and implement a low-cost solar dryer system as an alternative solution for the small-scale agro-industry sector. The basic concept of this work uses a solar home system as an energy source that is connected to an Android-based mobile device via Wi-Fi. By implementing the PV, the solar energy source from this system can be processed not only for the needs of the drying process but also can be used to meet the lighting needs in the farmer's environment. A system connected to a cellphone allows users to monitor the energy generated for the drying process and the electricity consumption used for lighting throughout the drying area.

II. HISTORY AND RELATED WORKS

Since time immemorial, open-air drying has been used for crops, seeds, fruits, meat, fish, wood, and other agricultural and forestry products. However, traditional open-air drying has many limitations in supporting mass production with high-quality demands. Renewable energy is energy derived from natural processes and does not involve the consumption of exhaustible resources such as fossil fuels and uranium [19], Indonesia has huge renewable energy sources such as solar energy, wind energy, micro-hydro, and biomass energy. Despite the fact that the state encourages the use of renewable energy, it only contributes about 3% [19].

Many technologies have been implemented to improve the prototype of a solar dryer to support the agro-industry using a solar home system as an energy source based on android via Wi-Fi. The study conducted by Priyanka et al. [20] developed the system that includes PV, dryer, controller ATmega16, sensor, LCD, Xbee, SD card, and mobile phone. Solar panels will produce electricity to dry agricultural produce. The function of the sensor is to monitor and control the dryer. The sensor will send the information (humidity, current, voltage, date, time, on/off) and transfer it to the SD card for data storage. The information stored will be transferred via the internet and displayed via SMS. At the same time, the LCD will display information on the device.

The other research conducted by V.N.Patil et al. [21] uses an Arduino Uno's microcontroller, temperature sensor LM 35, relay, solar panel, battery, and solar charge controller. The solar panel translates the electricity into a battery. Battery save energy and output power supply for Arduino. Arduino connected to LCD and sensor LM 35 inside the solar dryer. Arduino can relay the humidity, time, and temperature on the LCD. Data reading is done once every half hour. Another work [22] developed a forced convection solar dryer that consists of a solar flat plate air heater, centrifugal blower, reducer flexible connector. This system is made up of a black absorber glass cover and an aluminum air duct through which air was routed and hardened. The collector output was connected to the dryer chamber inlet using a connector constructed of unique fiber reinforced plastic pipe (stable up to 200°C).

All the researchers, as mentioned above, did their experiments separately and only read data from the solar dryer. Nevertheless, in this work, we arranged for the solar dryers to be controlled in one system using the solar home system as an energy source. The device is connected to a cellphone allows users to monitor the energy generated for the drying process and the electricity consumption used for lighting throughout the drying area. By using photovoltaic (PV), the solar energy source serves not only the needs of the drying process but also can be used to supports the lighting requirements in the farmer's environment.

III. DESIGN METHOD

A. Overall System Design

This section introduces and explains the system design of the device prototype. Design is constructed in three categories; hardware, software implementation, and output. The block diagram of the device is shown in Fig. 1 which divided into three sections. In section 1, the photovoltaic translates solar radiation into electrical energy. The electricity generated will be stored in the battery and controlled by the controller. A Solar Charge Controller (SCC) is a relatively important part of solar panels that aims to regulate voltage or current, keeping the battery from overcharging. It aims to optimize the system and thus maintain battery life which can be maximized. Electrical energy stored in the battery is used to turn on the Direct Current (DC) or electronic devices with capacity of 220 Volt voltage. Inverters are needed to change the current from a Direct Current (DC) to an AC (Alternating Current) [23].

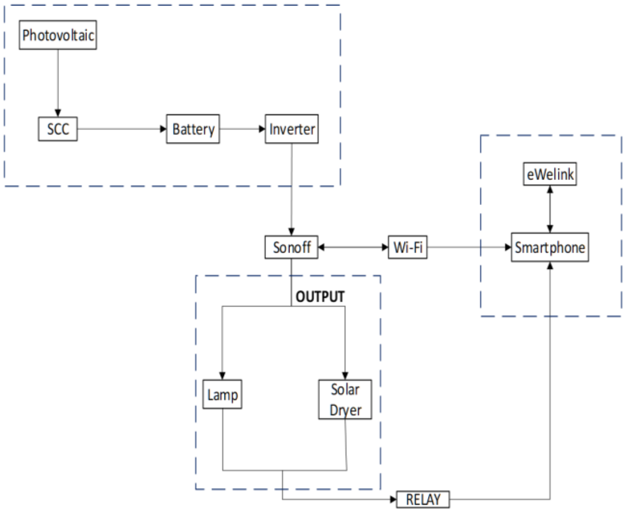

Fig. 1. Block diagram of low-cost solar dryer based android

Section 2 connects the Sonoff to a switch and links it to the inverter – see Fig. 2. With the DS18B20 sensor, sonoff is able to read the temperature for the solar dryer output with the maximum temperature of 125° C [24]. The data is transferred to the smartphone through the eWeLink application. eWeLink is a platform that enables connections between diverse smart hardware. This app supports various brands of smart devices, including Sonoff. eWeLink works with IFTTT [25], which can serve as a control center via a smartphone. Furthermore, all data related with the lamp or solar dryer usage can be monitored via the eWeLink application.

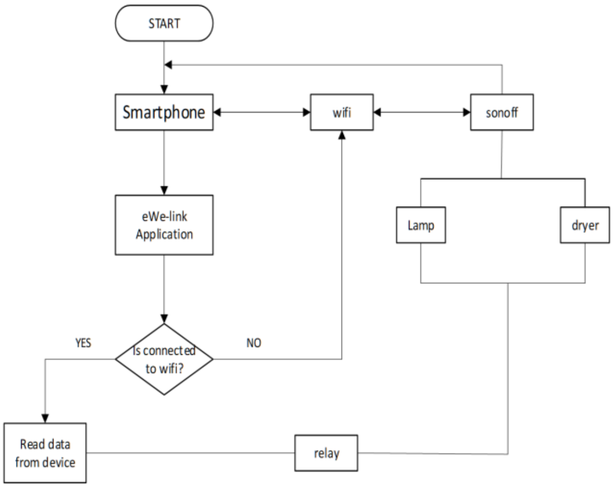

Fig. 2. Flow chart of low-cost solar dryer based android

In section 3, the lamp and solar dryer, as shown in Fig. 3, were used for the output. The application can control the output, and the data needed during the experiment can also be viewed in the eWeLink application. The numbers inside Fig.

3 are: (1) Photovoltaic, (2) Solar Dryer, (3) Solar Charge Controller, (4) Battery, (5) Inverter, (6) Sonoff, (7) Plugs, (8) Lamp.

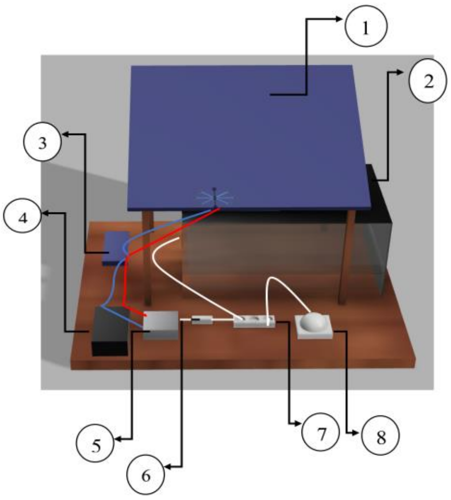

Fig 3. The design of low-cost solar dryer based android

B. Solar Dryer System Design

The heat energy used to raise the temperature could be calculated using (1), (2), and (3):

$$Q_{total} = Q_u + Q_l \tag{1}$$

$$Q_u = m \text{ x } C_p \text{ x } \Delta t \tag{2}$$

$$Ql = m \times \lambda \tag{3}$$

The collector area and total energy required with assumed drying time and the intensity of the sun was estimated by (4) and (5):

$$A = \frac{Qtotal}{Qt} \tag{4}$$

$$Qt = \frac{Ir}{td} \tag{5}$$

With the collector area as calculated by (4), the dryer efficiency could be calculated as (6):

$$np = \frac{Qc}{Qrs} \times 100\% \tag{6}$$

where:

$$Qc = (mb - mk) \times hfg$$

$$Qrs = A \times Ir \times t$$

Where:

Qu = the amount of heat energy of solar collector (J)
Ql = the latent heat (J)
Q_{Total} = the total of heat energy from solar collector (J)
Qt = Total energy required with assumed drying time and the intensity of the sun (J/m^2)
λ = latent heat of vaporization, kJ/kg
Cp = specific heat of air at constant pressure (J.kg/^{o}C)
T = temperature changes (^{o}C)
A = area of dryer collector (m^2)
I_r = intensity of the sun radiations (w/m^2)
t_d = Assumed drying time (hours)
n_p = the dryer efficiency achieved by dryer system (%)
Qrs = Radiation energy that arrives at the dryer (kJ)
Qc = heat of clove heating, (kJ)
mb = mass of the product before dried (kg)
mk = mass of the product after dried (kg)
hfg = enthalpy of evaporation at average temperature (kJ/kg)

The solar dryer system is designed with the spesifications as below:

- The initial water content for chili is 77.8 % / kg.
- The initial water content for corn is 22% /kg.
- Chili mass (m) = 1000 gram = 1kg
- Dryer width (purposed for this work) = 0.2 m
- The length (purposed for this work) = 0.15 m
- Intensity of the sun = 244.5 w/m^2
- Initial air temperature (T_i) = 35^{o}C
- Drying air temperature (T_f) = 50^{o}C
- Cp = 1,02 kJ/kg^{o}C
- λ = 2358.9 kJ/kg

To achieve the evaporation of water in chili with a certain weight, the heat collector of the required heat needs to be calculated using (1), (2) and (3):

$$Q_{total} = Qu + Ql = 1851.07 \text{ KJoule}$$

Area of dryer collector as purposed for this work with assumed 8 hours per days and intensity of the sun = 244.5 W/m^2 was calculated with (4) and (5):

$$A = \frac{Qtotal}{Q} = 0.26 \text{ m}^2$$

The data above is a calculation for a prototype with a small scale. Apart from being affected by the insulator, the dryer's output is also determined by the sun's strength.

C. Hardware Design

One of the functions of the Solar Charge Controller (SCC) is to prevent excessive battery energy charging by limiting the amount and rate of charge to the battery [26]. The SCC also prevents the battery from draining by shutting down the system if the stored power drops below 50 percent capacity and charging the battery at the correct voltage level. This helps keep the battery longer and healthier. This helps keep the battery longer and healthier. Calculating the electricity requirements is a necessary step to determine the needs of solar panels and the capacity of the batteries based on the system requirement. The size of the solar panel, the battery capacity, and the efficiency of solar panel are identified by (7), (8), and (9):

$$Solar\ Panel = \frac{total\ daily\ usage\ load}{n\ Battery + solar\ panel\ insulation} \tag{7}$$

$$\text{Battery Capacity} = \frac{n\ x\ total\ daily\ usage\ load}{V_{dc}} : DoD \tag{8}$$

$$\text{The efficiency of } Solar\ Panel\ (r) = \frac{Wp}{STC \times A} \tag{9}$$

Total output energy of the solar panel was calculated using 10:

$$E = A \text{ x } r \text{ x } H \text{ x } P_R \tag{10}$$

Where:

E = total amount of solar panel output energy (kWh/hour/day)
A = total surface area of solar panel (m^2)
r = solar panel efficiency (%)
H = Solar radiation incident (kWh/m^2/day)
P_R = Assumed Performance ratio in the photovoltaic system (0.75)
W_p = maximum power of solar panel (Wp)
STC = Standard Test Condition (irradiation 1000 W/m^2)

D. *Software Design*

This work used eWeLink that connected to the Smartphone. The eWeLink Apps is used to control Sonoff devices via Smart-mobile. There are several control functions options as represented in the apps, namely: the function to turn on/off the system, the statistical function, the setting function to turn on/off the lights, the power setting function for the solar dryer, and the function to control the Overload Protection System (OPS), as described on Fig.4.

Set thresholds for the Overload Protection System (OPS).

Min. Power 1 W

Max. Power 400 W

Max. Current 20 A

Max. Voltage 250 V

307.56 Power

1.56 Current

198.27 Voltage

(a) (b) (c)

Fig.4 The display of e-Welink application: (a) Lamp and solar dryer on/off function (b) OPS Realtime statistic (c) Lamp Realtime statistic

Several data are able to be monitored, particularly: real-time energy usage information data, the history of energy usage, and the device activation schedule. For this system, the technical specifications used an area: 1 Watt power (min), 400 Watt power (max), 20 A, and 250 Volt voltage. Through the OPS function, it is possible to limit the maximum and minimum power as needed. The device will automatically turn off if the power used exceeds the specified OPS level.

IV. RESULTS AND ANALYSIS

The power incident on a PV module is determined by the angle between the module and the sun, as well as the power contained in the sunlight. The power density on the surface is equal to that of the sunshine when the absorbing surface and the sunlight are perpendicular to each other (in other words, the power density will always be at its maximum when the PV module is perpendicular to the sun). The power density on a fixed PV module, on the other hand, is smaller than that of incident sunlight because the angle between the sun and a fixed surface is always changing. The component of incident solar radiation that is perpendicular to the module surface is the quantity of solar radiation incident on a tilted module surface.

The experiment was conducted in Cikarang, which is located at latitude -6.283° and longitude 107.168°. Table I shows the solar radiation incident data. The Calculation of the solar panel's energy output meas the area of the solar panel, including the frame, the performance of the solar panel, the incident of solar radiation in the specific position, and photovoltaic system losses with the solar radiation incident data as below.

TABLE I. SOLAR RADIATION INCIDENT DATA WHICH LATITUDE -6.283^{O} AND LONGITUDE 107.168^{O}

	Jan	Feb	Mar	Apr	May
SSEHRZ	4.18	4.25	4.76	4.82	4.74
Tilt 6	4.15	4.20	4.70	4.84	4.85
Tilt 21	4.13	4.11	4.55	4.88	5.09
Tilt 90	2.08	1.86	1.76	3.10	3.10

The above parameters are the monthly average of the cumulative incident of solar radiation for a given month:

- SSEHRZ: Horizontal surface at the surface of the earth.
- Tilt 6: six degrees tilted surface at the surface of the earth (°C).
- Tilt 21: twenty-one degrees titled surface at the surface of the earth (°C).
- Tilt 90: ninety-one degrees titled surface at the surface of the earth (°C).

The system was designed with a 5 watt lamp for 12 hours/day, and 10 watt Solar Dryer for 5 hours/day. The size of the solar panel capacity and the battery capacity was identified by (7) and (8):

$$Solar\ Panel = \frac{total\ daily\ usage\ load}{n\ Battery + solar\ panel\ insulation} \approx 20\ \text{Wp}$$

$$\text{Battery capacity} = \frac{1\ x\ 110}{12\ V_{dc}}\ 80\% \quad = 11.4\ Ah$$

The corresponding solar panel efficiency based on (9):

$$r = \frac{Wp}{STC \times A} = \frac{20\ W}{1000\frac{W}{m^2} \times 0.087} = \ 0.229$$

Performance ratio in the photovoltaic system is assumed as the default, with PR = 0.75, with consideration six degrees tilted surface at the surface of the earth provided 4.20 solar radiations as data given in Table.I. The total output energy for February based on (10):

$$E\ = 0.087\ m^2 \times 0.229\ \frac{\frac{kWh}{m^2}}{day} \times 4.20\ \times 0.75 = 0.0627\ \frac{kWh}{day}$$

Total output energy for 12 hours = $E\ = 62.7\ Wh$

A. *Chili Experiment*

In this experiment, 2 kg of chili was used, divided into two groups. The first 1 kg was allocated for conventional drying, while the other 1 kg was spent on drying using a dryer system. The observations were made for 11 days for the conventional process, with varying solar conditions. In this experiment, the object of observation is the object's weight after the drying process ends (for 11 days), the chili drying quality, and the duration of the drying process. The object's weight is considered because it will affect the product's price. The comparison of the drying process using a dryer system and conventional methods is described in Fig.5.

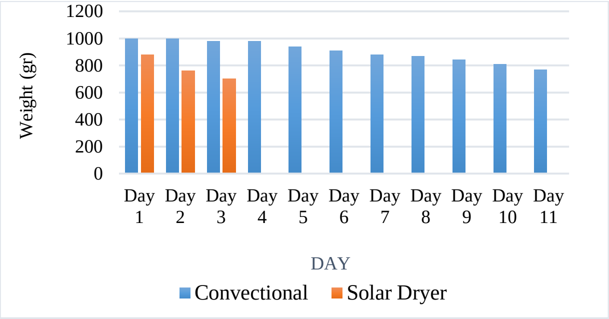

Fig 5. Comparation of conventional and solar dryer duration process

The experimental results of the conventional process show that the conventional drying process requires a much longer time, up to 11 days, to produce chilies with drying conditions as needed. In terms of quality, some of the chilies with the poor quality. Overall, during the long drying period, chilis are affected by changes in temperature, insect infestation, exposure to dust and wind. Moreover, the second condition was the experimental results using a solar dryer system. The testing was conducted for three days with a temperature setting of 80°C. After three days, the result of chili drying achieved more or less the same as chili conditions from the conventional process with less number of chilies with the poor quality. The results of chili quality using a dryer system had better quality than the conventional system.

In general, there are two differences between chilies dried using a solar dryer compared to conventional systems, specifically: drying process using a solar dryer is more efficient in terms of energy usage, and the quality of chili using a solar dryer is better than the conventional drying. From the comparison chart of Fig.5, it can be seen that using a dryer is faster, 27.27%, than traditional drying.

The efficiency energy was calculated based on the (6):

$$\text{np} = \frac{Qc}{Qrs}\text{x}100\% = \frac{458800\ KJoule}{1830816\ KJoule}\text{x}100\% = 25\%$$

B. *Corn Seeds Experiment*

In this experiment, 2 kg of corn seeds were used, divided into two groups. The first 1 kg of corn seeds was allocated for the solar dryer system, while the other 1 kg was spent on conventional drying. The observations were made with varying solar conditions, with the object of observation being the weight of the corn seeds after reaching the final target condition, the corn seeds drying quality, as well as the duration of the drying process. A maximum temperature of 127°C was used for the solar dryer experiment. Total drying using the solar dryer needed 16 hours 30 minutes. Dry corn seeds conventionally take fifteen days, much longer than drying corn seeds using a dryer system, with approximately the same drying results. Fig. 6 and 7 show graphs of the results of drying corn seeds with the solar dryer and by conventional means.

Drying using a solar dryer is more efficient because the drying time is faster by 26,67% than traditional drying and with a specific temperature at127° C.

For the efficiency energy it was calculated as (6):

$$\text{np} = \frac{Qc}{Qrs}\text{x}100\% = \frac{899248\ \text{KJoule}}{1830816\ KJoule}\text{x}100\% = 49.11\ \%$$

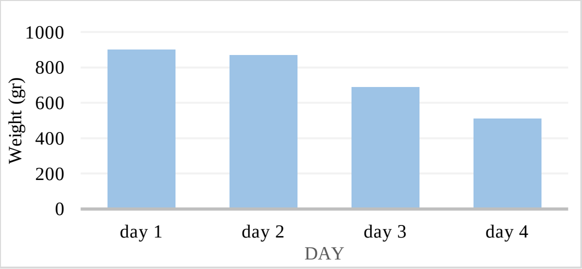

Fig. 6 Drying corn seeds duration process with solar dryer

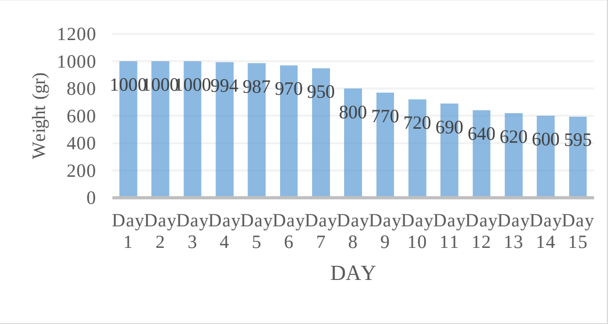

Fig 7. Drying corn seeds duration process with conventional method

V. CONCLUSION

The Solar dryer system has been successfully designed and used. Experimental results show that using an average temperature of 80 C for chili and 127°C for the corn seeds in the drying system, compared with the traditional process, the drying time efficiency has increased by about 26.67% for chili and 27.27% for corn seeds. At the same time, in terms of the energy required for the drying process, the system can produce efficiency of 25% for chili and 45.11% for corn seed compared with traditional processes. In addition, the system can be used as a light source, which can be monitored and controlled from a smartphone application via a Wi-Fi network. This application can read all the data generated by the dryer system. For future development, several improvements can be proposed, including energy experiments. To achieve more accurate results, they should be carried out in large areas without walls or house dividers. The solar dryer design can be improved for better crop drying; the battery's capacity can be increased so that it can be used for larger projects.

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