**Science Journal of Energy Engineering**
2017; 5(6): 130-135
http://www.sciencepublishinggroup.com/j/sjee
doi: 10.11648/j.sjee.20170506.11
ISSN: 2376-810X (Print); ISSN: 2376-8126 (Online)

Review Article

# Design and Optimization of Domestic Solar Dryer

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**To cite this article:**
Hakizimana Eustache, Emmanuel Dushimire, Charlotte Amizero. Design and Optimization of Domestic Solar Dryer. *Science Journal of Energy Engineering*. Vol. 5, No. 6, 2017, pp. 130-135. doi: 10.11648/j.sjee.20170506.11

**Received**: September 28, 2017; **Accepted**: October 16, 2017; **Published**: November 24, 2017

**Abstract:** This paper presents the design, simulation and optimization of a mixed-mode solar dryer based on the climatic data of location Kigali and mangoes were used as a reference product. The model was simulated using TRNSYS software for thermal analysis and the results was shown on a graph which presents the useful temperature gain for drying. The results were used for solar drying simulation to evaluate its performance in terms of drying rate, here MATLAB was utilized for this. It is clear on the graph how the moisture content of mangoes decreases with time up to 10%, which is their equilibrium moisture level for safe storage. The optimization of the model was further done with the modification of the solar dryer by making the front wall of the drying chamber with a glass which adds a greenhouse effect, hence a further increase in drying temperature. The solar drying simulation was again carried out and a clear difference in drying time was observed in the drying rate graph where the time of moisture content removal was reduced from 24 hours to 10 hours.

**Keywords:** Solar Energy Technology, Energy Resources, Engineering Design

## 1. Introduction

In many countries of the world, the use of thermal systems in the agricultural area to conserve vegetables, fruits and other crops has shown to be practical, economical and responsible approach environmentally. Solar heating systems to dry food and other crops can improve the quality of the product, while reducing the post-harvest spoilage of the crops. Dryers have been developed and used to dry agricultural products in order to improve shelf life. Most of these either use an expensive source of energy such as electricity or a combination of solar energy and other form of energy. Most projects of these natures have not been adopted by the small farmers, either because the final design and data collection procedures are frequently inappropriate or the cost has remained inaccessible. Solar drying has been considered as one of the foremost promising areas for the use of solar power, particularly within the field of food preservation. Open Sun drying is the most common methodology utilized in tropical countries for the drying of agricultural product, foodstuff etc. Despite the fact that the method is easy, it suffers from the disadvantages like insect infestation, microbic contamination etc. Products dried during this approach are unhealthful and typically unsuitable for human consumption. Therefore, the solar dryer is the best alternative solution for all the drawbacks of ancient drying. As compared to natural open drying, solar dryers generate higher temperatures, lower relative humidity, and lower product wet content and reduced spoilage throughout the drying process. But the main limitation of the solar dryer is that it works only if the sun is shining. It may be mitigated by storing excess energy throughout the peak time and use it in off-sunshine hours or once the energy accessibility is inadequate [1].

In solar drying, solar dryers are specialized devices that control the drying process and protect agricultural produce from damage by insect pests, dust and rain. In comparison to natural"sun drying", solar dryers generate higher temperatures, lower relative humidity, and lower product moisture content and reduced spoilage during the drying process. In addition, it takes up less space, takes less time and relatively inexpensive compared to artificial mechanical drying method. Thus, solar drying is a better alternative solution to all the drawbacks of natural drying and artificial mechanical drying, the solar dryer can be seen as one of the solutions to the world's food and energy crises. With drying, most agricultural produce can be preserved and this can be achieved more efficiently through the use of solar dryers [2].

Drying and preservation of agricultural products have been one of the oldest uses of solar energy. The traditional method, still widely used throughout the world, is open sun drying where diverse crops, such as fruits, vegetables, cereals, grains, tobacco, etc., are spread on the ground and turned regularly until sufficiently dried so that they can be stored safely. But, there exist many problems associated with open sun drying. It has been seen that open sun drying has the following disadvantages, it requires both large amounts of space and long drying time. The crop is damaged because of the hostile weather conditions; contamination of crops from the foreign materials, degradation by overheating, and the crop is subject to insect infestation, the crop is susceptible to reabsorption of moisture if it is left on the ground during periods of no sun, and there is no control of the drying process. This could lead to slow drying rate, contamination and poor quality of dried products, and loss in production. Thus, Solar drying will improve the quality of the crop to be dried, reduce spoilage by contamination and local overheating, reduce spillage losses, speed up the drying process, achieve better quality control, and reduction in drying time.

# 2. Method

The solar dryer considered in this project is the natural convection solar dryer. Here the product is located on the trays and shelves inside an opaque drying chamber. Solar radiation is thus not incident directly on the crop. Preheated air warmed during its flow through a low-pressure thermal solar energy, air heater, is addicted to the drying chamber to dry the product. Because the products are not subjected to the direct sunshine, localized heat damage does not occur. A typical natural convection solar dryer is made up of the following units:

a. A drying chamber.
b. An air-heating solar energy collector, which consists of the cover plate, absorber plate, and insulator (wood).

## *2.1. Design Model Specification and Description*

### *2.1.1. Design Model Specification*

The solar dryer has the shape of a home cabinet with a tilted transparent top. The angle of the slope of the dryer cover is 1.9706°S for the latitude location Kigali (Rwanda). It is provided with air inlet and outlet holes at the front and back respectively. The outlet vent is at a higher level and inlet vent at a lower level of the natural flow of preheated air into the drying chamber. The vents have fix covers which control the air inflow and outflow. The movement of air through the vents when the dryer is placed in the path of airflow brings about a thermo-siphon effect (a method of passive heat exchange, based on natural convection, which circulates the fluid without the necessity of a mechanical pump) which creates an updraft of solar heated air laden with moisture out of the drying chamber. The source of air is a natural flow.

### *2.1.2. Design Model Description*

A $0.4m^2$ flat plate collector with insulation at base and variable tilt angle goes to attach in front of the drying system, the collector contains a toughened glass that was placed on the collector at a distance of 20 mm from the absorber plate. This area in between permits the air to flow within the dryer. The plate will paint with matt finished black color. The air gets heated because it travels from the inlet to the drying system with the absorption of solar radiation on the plate. A Greenhouse is the drying chamber in this set-up. Agro crops which need drying is kept in trays in different layers. The greenhouse front wall covers with plexiglass.

## *2.2. Solar Dryer Design Consideration*

The following points have been considered in the design of the natural convection solar dryer system:

a. The amount of moisture to be removed from a given quantity of fresh harvest
b. A harvesting period during which the drying is needed
c. The daily sunshine hours for the selection of the total drying time
d. The quantity of air needed for drying
e. Daily solar radiation to determine energy received by the dryer per day
f. Wind speed for the calculation of the air-vent dimensions

***Table 1.*** *Design conditions and assumptions.*

| Items | Conditions and assumptions |
|---|---|
| Location | Kigali (latitude, 1.9706° S) |
| Crop | Mango |
| Variety | Kitchener |
| Drying period | December to February |
| Drying per batch | 2 day/batch |
| Loading rate ($m_p$) | 1kg sliced mango |
| Initial moisture content (moisture content at harvest), $M_i$ | 60%wb |
| Final moisture content (moisture content for storage), $M_f$ | 10%wb |
| Ambient air temperature, $T_{am}$ | 25°C (average for December) |
| Ambient relative humidity, $RH_{am}$ | 53% (average for December) |
| Maximum allowable temperature, $T_{max}$ | 60°C |
| Drying time (sunshine hours) $t_d$ | 10 hours (average for December) |
| Incident solar radiation I, | $480W/m^2$ or $17.3MJ/m^2$/day (average for past two years) |
| Collector efficiency, η | 30% |
| Wind speed | 2.97m/s |
| Thickness of sliced mango | 3mm |
| Vertical distance between two adjacent trays | 250mm |

*Design Procedure*

The size of the dryer was determined as a function of the drying area needed per kilogram of pulp of fruit. The drying temperature was established as a function of the maximum limit of temperature the fruit might support. From the climatic data (Kigali), the mean average day temperature in December is 25°C and RH is 53%. From the psychometric chart the humidity ratio is 0.01kg $H_2O$/kg dry air. From the result of the preliminary experiments on crop done by Sandeep Pancha 31 [14]. The optimal drying temperature was 70°C and final moisture content of mango for storage was 10%wb. The corresponding relative humidity is 51% (sorption isotherms equation).

Complete Design Model for Domestic Solar dryer

***Figure 1.*** *Back side view of solar dryer.*

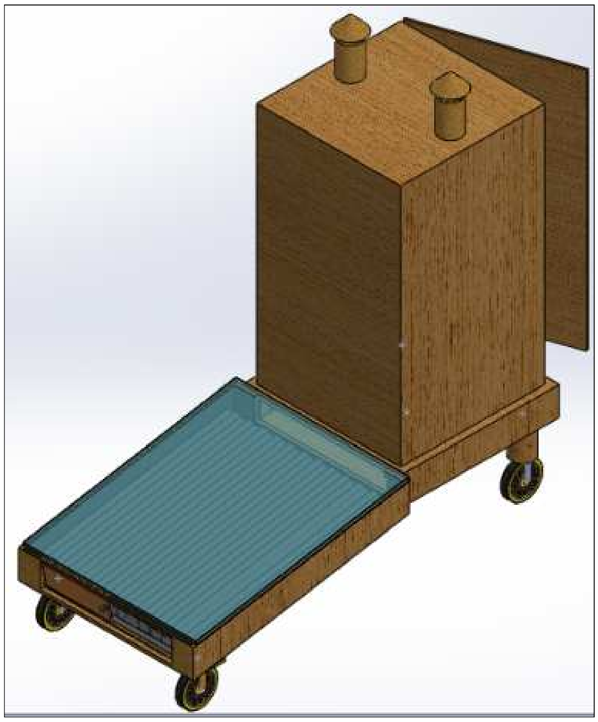

***Figure 2.*** *Isometric view of solar.*

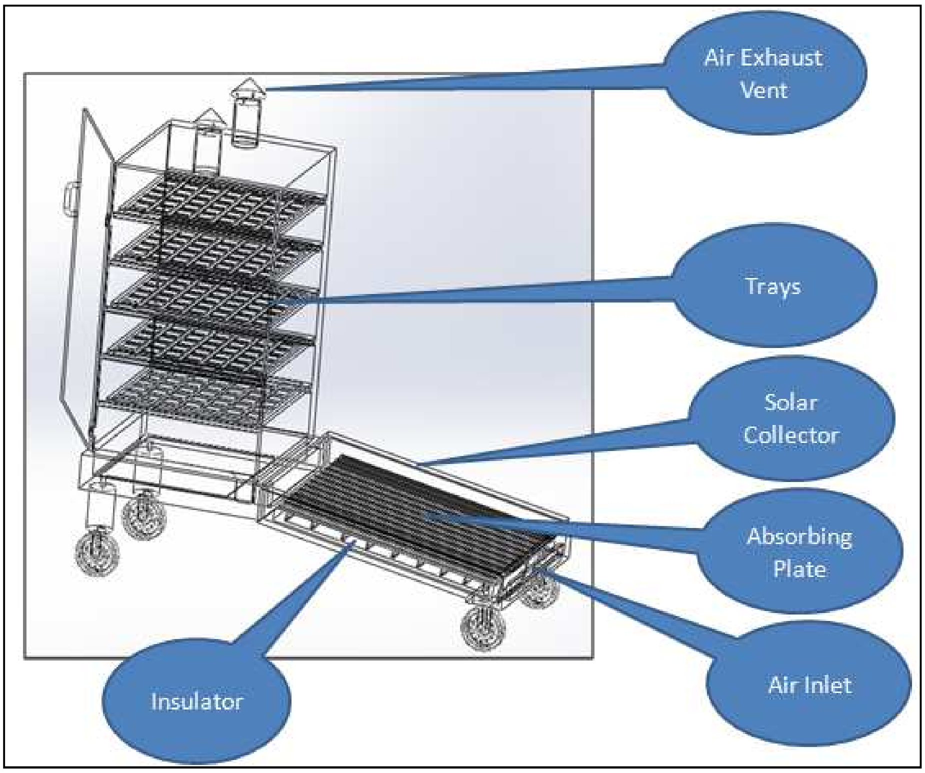


***Figure 3.*** *Wireframe presentation of solar dryer.*

## 3. Simulation Results

Here, the dryer includes two techniques. One is drying with hot air obtained using a solar air heater or a solar flat plate collector. Another drying technique is a solar greenhouse. Thermal simulations were carried out for analyzing the heat gain and temperature. The Useful gain of solar air heater and variation in ambient and outlet temperature for the month of December is analyzed using TRNSYS simulation which is shown in figure 6.

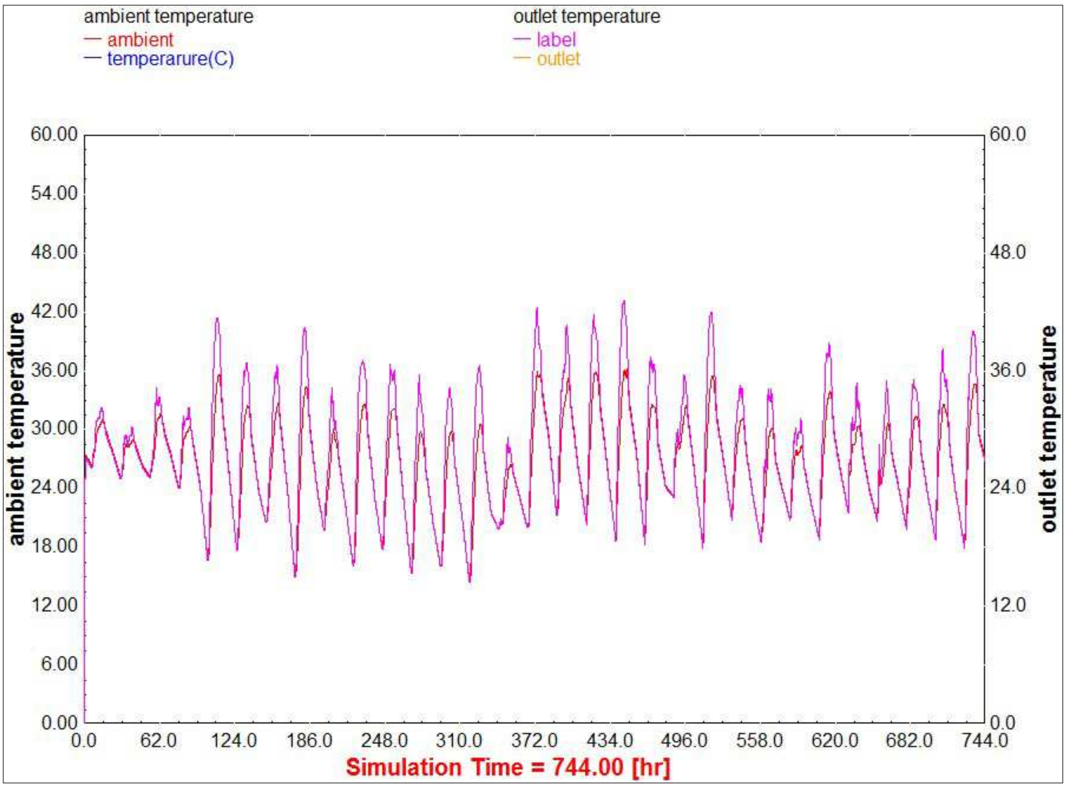


***Figure 4.*** *Ambient temperature versus outlet temperature of solar air heater.*

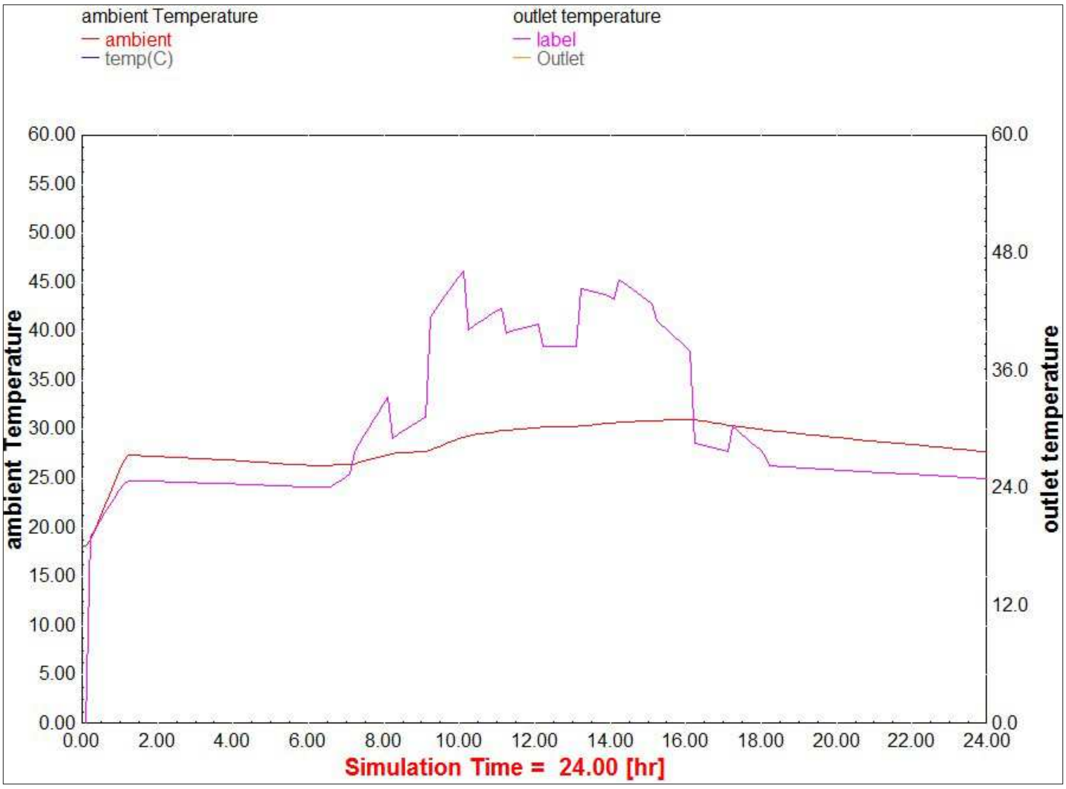


***Figure 5.*** *Ambient temperature versus outlet temperature of solar air heater on a time basis.*

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A Solar greenhouse is almost equal to a solar sunspace which is a default component available in TRNSYS. An attached sunspace can be thought of as a large solar collector where the space between the glazing and absorbing surface is large. After passing through the glazing the radiations trapped are trapped in the sun.

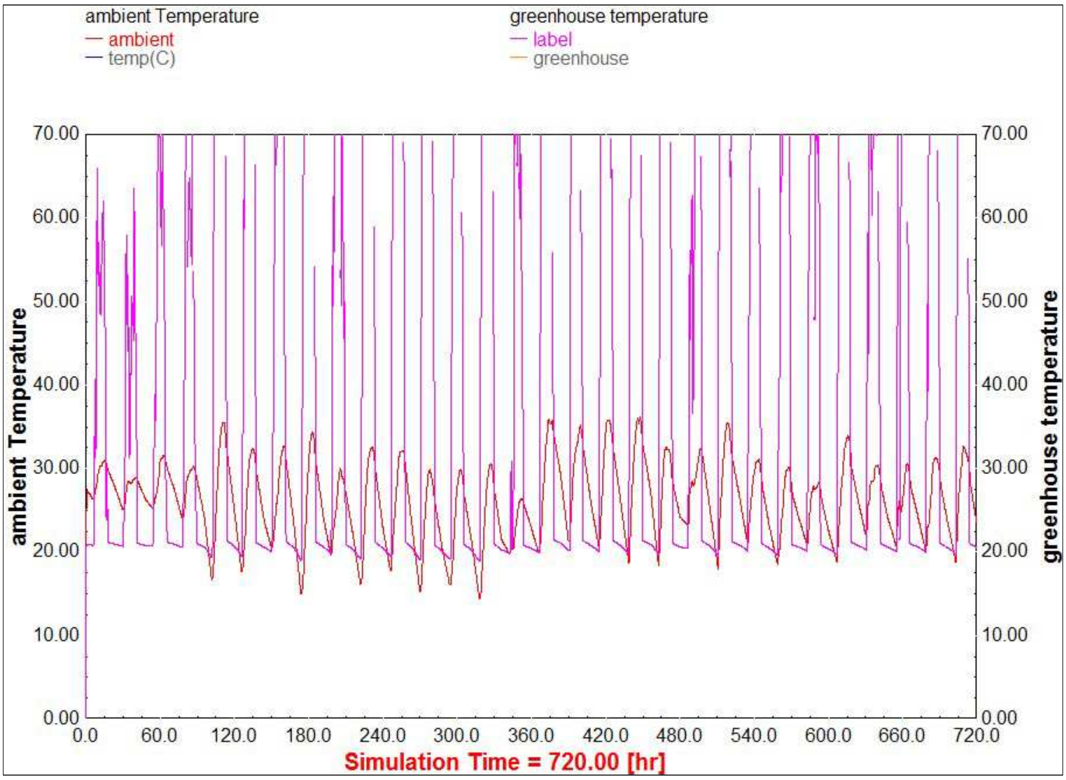


***Figure 6.*** *Ambient temperature versus greenhouse temperature.*

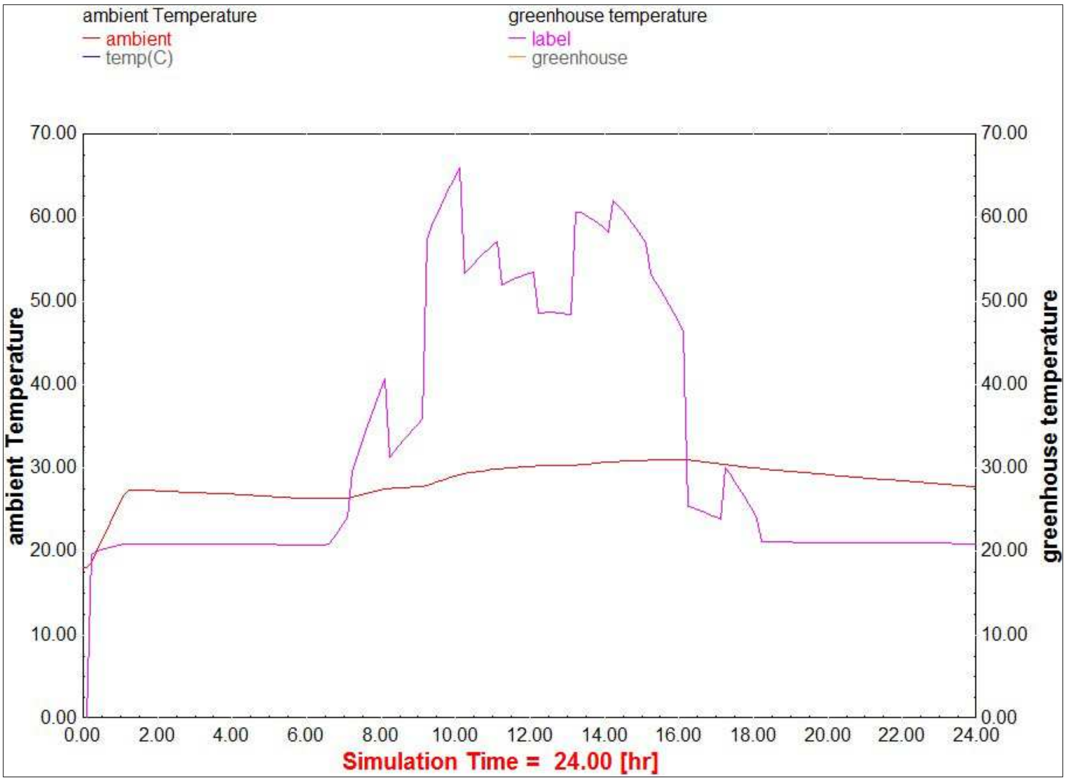


***Figure 7.*** *Ambient temperature verus greenhouse temperature in time basis.*

# 4. Conclusion

Solar drying could be a promising technology for drying of food product for a developing country like Rwanda, where solar power is considerable. This will be dramatically reduce the post-harvest food spoilage that could be a major concern for the ever-increasing society like Rwanda. Although the drying conditions for each product are totally different, a dryer can be modeled in such a way that it will dry any product with smart control parameters like temperature and also the mass flow. The mixed mode solar dryer is an alternate to overcome the disadvantages of ancient open sun drying and use of maximum accessible solar radiations. The model was designed based on the climatic data of location Kigali and a $0.4m^2$ solar air heater raises the drying temperature up to 45°C and dries a kilogram of fresh mango slices in 24 hours to reduce its moisture content from 60% up to 10% for safe storage. The model was optimized by adding another glass on the front wall to increase the drying efficiency. The modified model was able to raise the drying temperature around 60°C and the drying time was reduced to 10 hours. The simulation study shows that the solar dryer can effectively be used for fast drying purposes. Increased drying temperature helps to reduce the drying time which is one of the important plus points.

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