Design, Construction, and Evaluation of a Passive Solar Dryer for Sustainable Food Preservation

ABSTRACT

Solar drying is a very old but continuously explored technology so that everyone can use to dry food products from meat, vegetables, cereals and the dairy products. However, over the time with increased pollution to both the air and water, the sun drying has been deteriorating. Solar drying provides a safe and reliable environment for the quality of the dried products and its preservative duration. This study, design and construction of the solar drier device has been done for the purpose of drying a variety of food products..The principle of the dryer allowslighter hot air to rises up the altitude and cool the surface.In the raising process warm air comes in contact with the food slices and draws the moisture from it. The repeated cycle of this process makes it a very healthy, low cost long-termdrying mechanism. In the thermodynamics terms the sun's power or heat is used to dry up the moisture content of the fruits or vegetables.

The construction materials were wood, polyurethane glass, mild steel metal sheet and the trays. The optimum temperature of the dryer was 75^0C with a corresponding ambient temperature of 28^0C. The rapid rate of drying in the dryer reveals its ability to dry food items reasonably rapidly to a safe moisture. The capital cost involved in the construction of solar drier is much lower compared to that of a mechanical drier. Also from the test carried out, the simple and inexpensive solar drier was designed and constructed using locally sourced materials. The temperature inside the drier was found to be about three times than that of the outside atmospheric temperature. As per our experiment the maximum peak temperature inside the drying chambers was 75^0C during the mid-day (1.00pm) and an average of 57^0C in a fully sunny day (from 10:00am to 5:00pm). In seven (7) hours continuous drying in one full sunny day under the same climatic condition and in the same time the solar drier can remove maximum moisture contents from the food contents inside the drier for low moisture content food products. Experimental observation shows that the solar drier can be used as an alternative in case of food preservation and the efficiency is also acceptable. The people can make it on their homes especially in the developing countries where the energy demand is higher.

Key words: Design, Solar Dryer, technology, energy consumption

1. INTRODUCTION

1.1 BACKGROUND OF THE STUDY.

“The use of solar energy has great potential for promoting energy efficiency and reducing the environmental impact of energy consumption in the environment”(Xiao et al. 2024). “Solar dryer is a device that uses solar energy to dry substances, such as food, vegetables, fruits etc. Solar dryers fall into two broad categories; active dryers and passive dryers. Active dryers require an external means, like fans or pumps; for moving the solar energy in the form of heated air from the collector area to the drying beds. These dryers can be built in different size, depending on the needs of the user. Locally small solar dryers are preferred, since large dryers are more economical. Another category is Passive solar dryers which use natural solar-radiations to heat and move the air. The passive solar dryers can be subdivided into direct and indirect types. In direct solar dryer, food is exposed directly to the sun's radiations. This type of dryer typically consists of a drying chamber that is covered by transparent cover made of glass or plastic. The drying chamber is a shallow, insulated box with holes in it to allow air to enter and leave the box. The food is placed on a perforated tray that allows the air to flow through it and the food. On the other hand an indirect solar dryer is one in which the sun’s radiations do not strike directly the food to be dried. In this system, drying is achieved indirectly by using an air collector that channels hot air into a separate drying chamber. Within the chamber, the food is placed on mesh trays that are stacked vertically so that the air flows through each one”. (Ekechukwu and Norton 1999, Eze et al.. 2024).

“In this study, the solar dryer designed and constructed consists of two major compartments or chambers being integrated together. The solar collector compartment, which can also be referred to as the air heater and the drying chamber designed to accommodate two layers of drying trays on which the produces (or food) are placed for drying. In this solar dryer constructed, the greenhouse effect (an increase in the amount of carbon dioxide and other gases in the atmosphere) and thermo siphon principles are the theoretical basis”. (Ekechukwu and Norton1999). “Drying as a preservation technique is suitable to extend the storage life of minimally processed fresh produce, by removing its free available moisture content, which minimizes impact of natural senescence and spoilage microorganisms .Drying involves the simultaneous heat and mass transfer, during this process water is transferred from the core of the food material to the air-food surface interface via diffusion, and from the air-food interface into the surrounding atmosphere by convection . Furthermore, moisture content is removed to certain limit in the food product, which prohibits microbial growth” (Schiavone et. al 2013)

"The solar collector has an air vent (or inlet) where air enters and heated up. The hot air which is less dense than the cold air raised to the drying chamber and passing through the trays containing food, removing the moisture content and exits through the air vent (or outlet) near the top of the shadowed side. The hot air acting as the drying medium, extracts and conveys the moisture from the produce (or food) to the atmosphere under free (natural) convection, thus the system is a passive solar system and no mechanical device is required to control the intake of air into the dryer. The idea of using solar energy to produce high temperature dates back to ancient times. The solar radiation has been used by man since the beginning of time for heating his domicile, for agricultural purposes and for personal comfort. Modern research on the use of solar energy started during the 20th century. Development on the use of solar energy includes the invention of a solar boiler, small powered steam engines, solar battery etc. These inventions although they play a significant role in availability of energy, it is still difficult to market them in competition with engines running on inexpensive gas and oil. During the mid-1970's shortages of oil and natural gas, increase in the cost of fossil fuels and the depletion of other resources stimulated efforts in the United States to develop solar energy into a practical power source. Thus, interest was rekindled in the harnessing of solar energy for heating, cooling, generation of electricity and other purposes" (Leon and Mechlouch2002).

1. 12 CAPTURING SOLAR ENERGY

"Solar radiations can be converted either into thermal energy or into electrical energy. This can be done by making use of thermal collectors for conversion of solar radiations into heat energy or photovoltaic collector for conversion of solar radiations into electrical energy. In this study two main collectors were used to capture solar energy and convert it into thermal energy. The solar collectors are ordinary flat plate glass which then painted a black color so as to increase its ability of trapping the sun radiations and heat the air inside the dryer.

They are placed under the sun at a specific angle of incident depending on the geographical coordinate of the location where it is placed". (Bennamoun and Azeddine 2003)

"The concentrating collectors are the solar panels. Solar panel refers to a set of photovoltaic modules electrically connected and mounted on a supporting structure. The photovoltaic module is a packaged connected assembly of solar cells. Solar panels can be used as a component of a large photovoltaic system to generate and supply electricity, each module is rated by its direct current output power under Standard Test Conditions". (Bennamoun and Azeddine 2003)

"Drying is a fundamental process for preserving agricultural products, involving heat and mass exchanges. As a sustainable selection, researchers are focusing on solar dryers to improve drying efficiency, shorten drying times, and maintain product quality. Indirect type solar dryers (ITSD) have shown promise in post-harvest preservation. However, there is a lack of detailed investigation in their unique features, types, and performance-enhancement techniques. Thermal energy storage methods, which store excess energy for times when there is no solar irradiance, can improve the dependability of solar drying" (Shekela 2024).

"The study analyzes the thermal performance of an indirect-type solar dryer incorporated with a heat exchanger to recover heat from the exhaust. Data were recorded for 8 h from 9:00 to 17:00 from November to January to determine the drying rate for varying airflows from 2 l/s to 12 l/s under the weather conditions of Nepal and Bhutan. The air temperatures in multiple locations in the dryer were recorded and logged for 30-second intervals. The results indicated that incorporating a simple heat exchanger can achieve 78 % and 81 % effectiveness for the lowest tested airflow of 2.5 l/s and 2 l/s in Nepal and Bhutan" (Aacharya et. al. 2024). The heat transfer effectiveness increases with decreasing flow, resulting in a higher cold side outlet temperature of the heat exchanger for lower airflows. The solar air collector demonstrated efficient performance, achieving 80 % and 90 % efficiencies for the highest tested airflows of 12 l/s and 10 l/s in Nepal and Bhutan, respectively. Due to an increased heat transfer coefficient, the incoming air can effectively remove the accumulated heat from the absorber plate for higher airflows. The drying rates were observed to be the highest for 12 l/s, with a value of 85 g/(h × m^2) for apples and 10 l/s, with a value of 56 g/(h × m^2) for gingers in Nepal and Bhutan, respectively. From both cases, it can be concluded that the highest tested airflows provide higher air circulation for effective heat and mass transfer from the product to the surrounding air for drying.

1.2SOLAR DRYER DESIGN CONSIDERATION.

"The factors considered in the design and constructions of the solar dryer are the material selection and air flow mechanisms.

Materials Selection. The local and cheap materials were selected in the design so as to help local farmers to reduce the cost of drying. They were selected on the basis of availability, cost and durability amongst others". (Pangavhen et al 2002)

"Air Flow; The solar dryer were designed to help in the reduction of the moisture contents of the produce put in it. Thus, there was an air vent or inlet to the solar collectors where air enters and heated up within it. The hot air which was less dense was raised through the drying chamber, passing through the trays and reducing the moisture contents found on the produce and finally exits through the outlet near the top of the chamber". (Kurtbas and Turgut 2006)

"The hot air serves as the drying medium; it extracts and conveys the moisture from the produce or food to the atmosphere. Thus the system is a passive solar system and no mechanical device is required to control the intake of air into the dryer". (Kurtbas and Turgut 2006)

1.3PRINCIPLES OF BUILDING SOLAR DRYER.

The solar dryer considered in this study is simple and cheap. Here the product is placed on trays or shelves inside glass covered drying chamber. Solar radiations are thus not incident directly on the crop. The main principles involved in this study are as follows;

i. Black substance absorbs more heat than any other materials,

ii.Warm air is always lighter than cold air and,

iii.Air flows from high pressure to low pressure.

(Sebaii and Headley 2002)

"Air was allowed to flow through the heating chamber which was placed tilting at certain angle. Preheated air warmed during its flow through the heating chamber was ducted to the drying chamber to dry the product. The design involved the following parts:

An air-heating (solar energy collector) , Drying chamber, Air exhaust, Air inlet, Air vents, Dryer Trays, Glass and Wood". (Ikejiofor 1985)

1.4FUNCTION OF THE MAIN PARTS OF THE SOLAR DRYER.

"Air heater **(**solar energy collector**);** An air preheated is a general term used to describe any device designed to heat air before another process with the primary objective of increasing the thermal efficiency of the process. Air heating consists of heat absorber, silver sheet and air passage. Any black materials can be heat absorber. The air heater is constructed in such a way that it is an air tight from two sides and passage between bottom and top of the heater. It is rectangular in shape, where lower layer is black insulated, second layer is an air passage medium and top layer is transparent glass". (Akinola 1999)

"It is raised a bit from the ground to allow the cold air to flow in and is kept at certain inclination with respect to the reference ground. When the solar light is incident on the heater the air inside get warmed and pressure is also created low. When the cold air gets into the heater, it gets warmed and rises through the lower layer of shelves and exit from exhaust placed near the roof of the dryer. The sides of the air passages are covered by silver sheet to reflect the light within the heater, thus by trapping maximum sunlight inside. The air gets inside the heater due to the pressure difference between surrounding and the pressure inside of the dryer. The passage of air is considered on the basis that hot air is lighter than cold air, since the heater is raised at certain angle; it is obvious that the hot air will pass through the passage to the top". (Ikejiofor 1985)

"Drying chamber (main body of the dryer); drying chamber it is the main part of the dryer, where the products are being placed and gets dried there. It consist of layer of shelves made up of completely dried materials (to reduce moistures) having tiny holes for the passage of the rising warm (heated) air from the bottom. When the dried air passes through the layers, the produces placed inside dryer get dried. This warm air will contain moisture when it reaches the top of the dryer". (Enein2000)

The air exhaust;

"The air having passed over the dried substances becomes saturated with water and is discharged through the exhaust to avoid condensation of water vapors in the event that the system temperature falls. The size of the air exhaust should be small in order to slow the flow rate of warm air from dryer to atmosphere. If the size of the air exhaust is large, there is less chance of circulating warm air within dryer. So chances of drying produce are less. If there is no air exhaust, vegetables and fruits may also decay. Therefore it is necessary to have air exhaust". (Togrul and Pehlivan 2004).

"The Air Inlet;Air Inlet this is the opening through which air enters in the dryer and it is heated by the heat produced by the solar panel.

Air Vents; for air to flow into the solar dryer, a gap of about 5cm will be needed in an opening situated just below the glass solar collector so that the air coming in, can be heated". (Pangavhen et al 2002).

"Dryer Trays; Net cloth will be used as the dryer screen or trays to aid air circulation within the drying chamber. Two trays will be needed having wooden frames, the tray dimension will be 82cm x 72cm. 2.5cm x 2.5cm wooden stick will be used as frame. The average tray carrying capacity of the dryer is estimated at about 1kg per tray. However the size and number of trays can be increased according to the design specifications keeping in mind the equal spacing between the adjacent trays".(Bena and Fuller 2002)

"Glass; Transparent glass will be used as well as a mild steel of 1mm thick will also be used. It will be suggested that the glass covering should be 5mm thick to make the roofing of the chamber. The design of the drying chamber, making use of wooden wall sides and a glass top will protects the produce placed on the trays in the drying chamber from direct sunlight". (Sebaiiand Headley 2002.)

Wood; the pieces of wood were used for supporting other parts of the dryer including the flat glass, trays etc.

The general arrangements of all the above materials are seen in fig.**1**

1.5OPERATION OF THE DRYER

(a) (b)

Fig 1(A-B).The side view of the solar dryer.

Fig 1(a) above shows the side view of the solar dryer without air inlet part while fig 1(b) shows the side view of solar dryer with the air inlet part.

(a) (b)

Fig 2(A-B). The front view of the solar dryer.

Fig 2 (a) shows the front view of the solar dryer without air inlet par been attached.

Fig 2 (b) shows the front view of the solar dryer with two airinlet been attached together.

"The Solar dryer that we are going to construct is a passive system in the sense that it has no moving parts. It is energized by the sun's rays entering through the collector glazing. The trapping of the rays is enhanced by the inside surfaces of the collector that are painted black and the trapped energy heats the air inside the collector. The greenhouse effect achieved within the collector drives the air current through the drying chamber. If the vents are open, the hot air rises and escapes through the upper vent in the drying chamber while cooler air at ambient temperature enters through the lower vent in the collector. Therefore, an air current is maintained, as cooler air at a temperature 'T_a'enters through the lower vents and hot air at a temperature 'T_e'leaves through the upper vent. When the dryer contains no items to be dried, the incoming air at a temperature 'T_a' has relative humidity 'H_a' and the out-going air at a temperature 'T_e', has a relative humidity 'H_e'. Because T_e>$T_a$and the dryer contains no item, H_a>H_e. Thus there is tendency for the out-going hot air to pick more moisture within the dryer as a result of the difference between$H_a$andH_e. Therefore, insulation received is principally used in increasing the affinity of the air in the dryer to pick moisture". (Othman, Sopian, Yatim and Daud 2006)

"Solar Dryer Dimensions; The design of the chamber to hold the crop produce to be dried will be made spacious enough as possible of average dimension of 50 cm x30 cm x 30cm with air passage out of the chamber. The drying chamber will be roofed with glass tilted at the same angle with the angle of the solar panel. This is to keep the temperature within the drying chamber fairly constant". (Waewsak et al 2006.)

"Compartments; the drying chamber is to be divided into two compartments, by calculation; each chamber will have a space of 24.37cm. This will give room for two trays to be put into the drying chamber where the produce to be dried will be placed". (Waewsak et al 2006.)

"Storage has been a major challenge to Tanzanian farmer's right from the onset of agriculture. Food scientists have found that by reducing the moisture content of food to between 10 and 20%, bacteria, yeast, mold and enzymes are prevented from spoiling it. The flavor and most of the nutritional value is preserved and concentrated. Wherever possible, it is traditional to harvest most grain crops during a dry period or season and simple drying methods such as sun drying are adequate. However, maturity of the crop does not always coincide with a suitably dry period. Furthermore, the introduction of high-yielding varieties, irrigation, and improved farming practices have led to the need for alternative drying practices to cope with the increased production and grain harvested during the wet season as a result of multi-cropping".(Othman et al 2006).

Researchers have been coming up with theories and ideas on how to tackle this problem. However, moisture content reduction is essential before storage; crops must be dried before stored. Hence there is a need for reliable, efficient and cost friendly way of reducing moisture content of farm produce for effective storage. Due to this we decided to construct a simple and cheap solar dryer which is affordable by small scale farmers. (Bolaji 2005)

"For centuries, people of various nations have been preserving fruits, meat, fish and other crops have been used by drying. Drying is also beneficial for hay, copra, tea and other income producing non-food crops. With solar dryer, the availability of all these farm produce can be greatly increased.

Solar drying is the oldest method of food preservationuntil around the end of the 18^{th} Century when canning was developed, drying was virtually the only method of food preservation".(Bolaji2005)

"The energy input for drying is less than what is needed to freeze or can, and the storage space is minimal compared with that needed for freezing containers and canning jars. It was further stated that the nutritional value of food is only minimal affected by drying. Also, food scientists have found out that by reducing the moisture content of food to 10-20%, bacteria, fungi, enzymes are all prevented from spoiling it; microorganisms are effectively killed when the internal temperature of food reaches 62.7^{0}C".(Herringshaw2007).

"The flavor and most of the nutritional values of dried food is preserved and concentrated. Dried foods do not require any special storage equipment and are easy to transport. Dehydration of vegetables and other food crops by open air sun drying is not satisfactory because the products do dry un-evenly and deteriorate rapidly.

Studies show that food items dried in a solar dryer were superior to those which are sun-dried when evaluated in terms of taste, color and mold count. Solar dried foods are quality products that can be stored at less cost while still providing excellent nutritive value". (Nandi 2009).

"Solar dryers is used in agriculture for food and crop drying ,for industrial drying process, dryers can be proved to be most useful device from energy conservation point of view. It not only saves energy but also a lot of time, occupying less area, improves quality of the product, makes the process more efficient and protects environment too. Solar drying can be used for the entire drying process or for supplementing artificial drying systems, thus reducing the total amount of fuel energy required". (Bolaji 2005)

1.6 THE ADVANTAGES OF SOLAR DRYER;

“Solar dryers have the principal advantage of using solar energy-a free, available, and limitless energy source that is also nonpolluting. Drying most foods in sunny areas should not be a problem of lost vegetables, for example, can be dried in 2-1/2.to 4 hours, at temperatures ranging from about 43 to 67°Centigrade (lJ.Otol45°Fahrenheit). Fruits take longer, from 4to6 hours, at temperatures ranging from 43 to 66°Centigrade (110 to 150°Fahrenheit). At this rate, it is possible to dry two batches of food on a sunny day. A solar food dryer improves upon the traditional open-air systems in five important ways”;
(Bassey 1989)

“High rates of drying the produces. Food contents placed in the drying chambers can be dried in a shorter interval of time. Solar food dryers enhance drying times in two ways. First, the translucent or transparent glazing over the collection area traps heat inside the dryer, rising the temperature of the air. Second, the capability of enlarging the solar collection area allows for the concentration of the sun's energy”. (Bassey1989)

“High efficient of drying the produces. The foodstuffs can be dried more quickly and efficiently. This was especially true for produce that requires immediate drying--such as a grain with a high moisture contents. In this way, a larger percentage of food will be available for human consumption. Also, less harvest will be lost to marauding animals, vermin, and insect’s since the food will be in an enclosed compartment”. (Bena and Fuller 2002)

“It is safer. The foodstuffs inside the dryer were dried in a controlled environment, so that they are less likely to be contaminated by pests, and can be stored for long time without growing of toxic fungi on the food contents”. (Bena and Fuller 2002)

“It is healthier. Drying foods at optimum temperatures and in a shorter amount of time enables them to retain more of their nutritional value especially vitamin C. An extra bonus is that foods will look and taste better, which enhances their marketability”.
(Benaand Fuller 2002)

“It is cheaper. Using solar energy instead of conventional fuels to dry products, or using a cheap supplementary supply of solar heat in reducing conventional fuel demand can result in a significant cost savings. Solar drying lowers the costs of drying, improves the quality of products, and reduceslossesdueto spoilage". (Bena and Fuller 2002).It reduces volume of the products. The transportation costs to markets are reduced because of lower volume of agricultural products.(Bena and Fuller 2002).

1.7 CONSTRAINTS OF THE PROBLEM

"Drying processes play an important role in the preservation of agricultural products. They are defined as a process of moisture removal due to simultaneous heat and mass transfer. The purpose of this project is to present the developments and potentials of solar drying technologies for drying grains, fruits, vegetables, spices, medicinal plants. The traditional method of drying, known as ‗sun drying', involves simply laying the product in the sun on mats, roofs or drying floors. Major disadvantage of this method is contamination of the products by dust, birds and insects – Some percentage will usually be lost or damaged, it is labor intensive, nutrients loss, such as vitamin A and the method totally depends on good weather conditions. Because the energy requirements - sun and wind - are readily available in the ambient environment, little capital is required. This type of drying is frequently the only commercially used and viable methods in which to dry agricultural products in developing countries. The safer alternative to open sun drying is solar dryer. This is a more efficient method of drying that produces better quality products, but it also requires initial investments. If drying conditions such as weather and food supply are good, natural circulation solar energy, solar dryers appear to be increasingly attractive as commercial proposition". (ErtekinandYaldiz 2004).

The objective of this study was to design and construct a working solar dryer, specificallya box type solar dryer system with different wire mesh layersand evaluate the performance of the designed solar dryer.

1.8The significance of the study

Before storage, the moisture content of some produces need to be reduced to a certain safe level. The reduction in the level of moisture content of the produce will enhance its storage and preserve the produce from perishing. Construction of this solar dryer will aid farmers who seek better ways of sun-drying their produce as well as those who cannot afford to obtain or buy a costly electric dryer. Due to the erratic and epileptic supply of electricity in the country, there exists a cheap and efficient solar dryer which can be easily installed and very easy to use without any skill applied. (Ertekin and Yaldiz 2004)

2.0 THEORY

The energy balance on the absorber is obtained by equating the total heat gained to the total heat loosed by the heat absorber of the solar collector(Salaudeen 2011,Bolaji, 2008). Therefore,

$$IA_c = Q_u + Q_{cond} + Q_{conv} + Q_R + Q_P \qquad (1)$$

Where:

I = rate of total radiation incident on the absorber`s surface (Wm^{-2});

A_a= collector area (m^2);

Q_u = rate of useful energy collected by the air (W);

Q_{cond} = rate of conduction losses from the absorber (W);

Q_{conv} = rate of convective losses from the absorber (W);

Q_R = rate of long wave re-radiation from the absorber (W);

Q_P= rate of reflection losses from the absorber (W);

The three heat loses terms Q_{cond}, Q_{conv}, and QR are usually combined into one term QL;

$$Q_L = Q_{cond} + Q_{conv} \qquad (2)$$

If τ is the transmittance of the top glazing and I_T is the total solar radiation incident on the top surface therefore;

$$IA_c = \tau I_T A_c \qquad (3)$$

The reflected energy from the absorber is given by the expression:

$$Q_p = \rho\tau I_c A_c \qquad (4)$$

(Bolaji 2008)

Where by ρ is the reflection coefficient of the absorber. (Pangavhen et al 2002.)

Substitution equations (2), (3) and (4) in equation (1) yields:

$$\tau I_T A_c = Q_u + Q_L + \rho\tau I_c A_c or$$

$$Q_u = (\alpha\tau) I_c A_c (1 - \rho) - Q_L$$

For an absorber (1- ρ) =α and hence

$$Q_u = (\alpha\tau)I_c A_c(1-\rho) - Q_L \qquad (5)$$

Where by α is solar absorptance. (Pangavhen et al 2002.)

Q_L composed of different convection and radiation parts .It is presented in the following form ;(Bansal 1990)

$$Q_L = U_L A_c(T_c - T_a) \qquad (6)$$

Where u_L=overall heat transfer coefficient of the absorber ($Wm^{-2}K^{-1}$);

T_c=temperature of the collector `s absorber (K).

T_a=temperature of air. (Pangavhen, Malick and Buelow, 2002.)

From Equations (5) and (6) the useful energy gained by the collector is expressed;

$$Q_u = (\alpha\tau)I_T A_c - U_L A_c(T_c - T_a) \qquad (7)$$

Therefore the energy per unit area Q_u of the collector is given by:

$$Q_u = (\alpha\tau)I_T - U_L(T_c - T_a) \qquad (8).$$

If the heated air leaving the collector is at the collector temperature, heat gained by the air Q_g is:

$$Q_U = m_a C_{PA}(T_c - T_a) \qquad (9)$$

Where:$_a$= mass of air leaving the dryer per unit time (kgs^{-1}); C_{pa}=specific heat capacity of air ($kJkg^{-1}\,K^{-1}$). The collector heat removal factor F_R, is the quantity that relates the actual useful energy gained of a collector Eqn. (7), to the useful gained by the air, Eqn. (9). Therefore,

$$F_R = \frac{MaCpa(Tc - Ta)}{Ac[(\alpha\tau)IT - ULAc(T\boldsymbol{c} - T\boldsymbol{a})]} \qquad (10)$$

------Or

$$Qg = AcFR[(\alpha\tau)IT - ULAc(Tc - Ta)] \qquad (11)$$

The thermal efficiency of the collector is defined as (Itodo*et al*2002) is given inEquation (12);

$$\eta c = \frac{Qg}{AcIT} \qquad (12)$$

Energy Balance Equation for the Drying Process;

The total energy required for drying a given quantity of food items can be estimated using the basic energy balance equation for the evaporation of water (Youcef-Ali2001; and Bolaji 2005):

$$M_w L_v = M_a C_p (T_1 - T_2) \qquad (13)$$

Where: L_v = latent heat (kJ kg-1);

M_w= mass of water evaporated from the food item (kg);

M_a= mass of drying air (kg);

T_1 and T_2 = initial and final temperatures of the drying air respectively (K);

C_p= Specific heat at constant pressure (kJ kg^{-1} K^{-1}).

The mass of water evaporated is calculated from Eq. 14

$$Mw = \frac{m_i(M_i - M_e)}{100 - M_e} \qquad (14)$$

Where: M_i= initial mass of the food item (kg); M_e= equilibrium moisture content (%drybasis); M_i= initial moisture content (% dry basis).

"During drying, water at the surface of the substance evaporates and water in the inner part migrates to the surface to get evaporated. The ease of this migration depends on the porosity of the substance and the surface area available. Other factors that may enhance quick drying of food items are: high temperature, high wind speed and low relative humidity. In drying grains for future planting, care must be taken not to kill the embryo. In drying items like fish, meat, potato chips, plantain chips etc., excessive heating must also be avoided, as it spoils the texture and quality of the item". (Pangavhen et al 2002.)

3. LITERATURE REVIEW

"In many parts of the world there is a growing awareness that renewable energy has an important role to play in extending technology to the farmer in developing countries to increase their productivity" (Waewsak*2006*).

"Solar thermal technology is a technology that is rapidly gaining acceptance as an energy saving measure in agriculture application. It is preferred to other alternative sources of energy such as wind and shale, because it is abundant, inexhaustible, and non-polluting". (Akinola*et al*2006).

"Solar air heaters are simple devices that heat air by utilizing solar energy and are employed in many applications requiring low to moderate temperature below 80 ^{0}C, such as crop drying and space heating" (Kurtbas and Turgut 2006).

"Drying processes play an important role in the preservation of agricultural products, they are defined as a process of moisture removal due to simultaneous heat and mass transfer". (Ertekin and Yaldiz2004). "This article describes the design, construction, and performance evaluation of a natural-c onvection, solardryer capable of producing dried mango slices in rural Haitian communities. A sorption isotherm was developed for theTommy Atkins mango variety to determine target levels of moisture content needed to achieve required levels of wateractivity. The solar dryer was constructed and operated in Gainesville, Florida, during the summer of 2011. Performanceevaluation revealed cabinet temperatures between 37.0°C and 43.7°C during sunlight hours depending on airflow andloading conditions. Damper restriction was shown to effectively control flow rates to adjust temperatures within the dryer.Operating capacity of the dryer was 9.5 kg of fresh mango slices per 36 h, lowering the moisture content from 84.5%(w.b.) to 10.3% (w.b.) under a continuous mode of operation. The collector efficiency, pick-up efficiency, and system efficiency were 26.7%, 20.4%, and 25.9% respectively*in Design and Performance Evaluation of a Solar Convection Dryer for Drying Tropical Fruit*. Available from: https://www.researchgate.net/publication/239730898_Design_and_Performance_Evaluation_of_a_Solar_Convection_Dryer_for_Drying_Tropical_Fruit" [accessed Jan 11 2024].

Cevic et al, 2024 presents an extensive and thorough examination of solar cooking systems, offering a comprehensive overview of their design, functionality, and practical implications. Through a comprehensive review of existing literature and technological advancements, the paper highlights the various types of solar cooking methods and their respective benefits. The study delves into the environmental, social, and economic advantages of solar cooking systems, presenting their potential to reduce energy demands and cooking-related challenges in diverse regions. By synthesizing a wide range of research, this review serves as a valuable resource for researchers, policymakers, and individuals interested in harnessing solar energy for sustainable and efficient cooking solutions. Additionally, this study contributes to the understanding and promotion of solar cooking as a viable and environmentally friendly alternative. It also analyzes why solar cooking systems have not become widespread and reveals the obstacles facing them

"Solar cooking is identified as one of the most viable and sustainable cooking alternatives. Some of the key advantages of solar cooking strategies include food nutrition retention, low cost, and environment-friendly operations, etc. According to the highlights by Solar Cooker International (SCI), there are approximately 8,09,615 known solar cookers across India, mitigating about 12,06,326 metric tons of CO_2 emissions annually. However, about 51% of the population still relies on conventional polluting fossil fuel-based cooking systems responsible for about 10,85,867 premature deaths annually"(Thakur et al. 2023). Despite several environmental, economic, as well as health-related advantages, the corresponding adoption statistics are unsatisfactory.

"According to Ikejiofor (1985) two types of water are present in food items; the chemically bound water and the physically held water. In drying, it is only the physically held water that is removed. The most important reasons for the popularity of dried products are longer shelf-life, product diversity as well as substantial volume reduction. This could be expanded further with improvements in product quality and processapplications. The application of dryers in developing countries can reduce post-harvest losses and significantly contribute to the availability of food in these countries. Estimations of these losses are generally cited to be of the order of 40% but they can, under very adverse conditions, be nearly as high as 80%. A significant percentage of these losses are related to improper and/or untimely drying of foodstuffs such as cereal grains, pulses, tubers, meat, and fish". (Bassey 1989 and Togrul et al 2004).

"Traditional drying, which is frequently done on the ground in the open air, is the most widespread method used in developing countries because it is the simplest and cheapest method of conserving foodstuffs. Some disadvantages of open air drying are: exposure of the foodstuff to rain and dust; uncontrolled drying; exposure to direct sunlight which is undesirable for some foodstuffs; infestation by insects; attack by animal". (Madhlopa 2002).

“In order to improve traditional drying, solar dryers which have the potential of substantially reducing the above-mentioned disadvantages of open air drying, have received considerable attention over the past 20 years” (Bassey 1989).

“Solar dryers of the forced convection type can be effectively used. They however need electricity, which unfortunately is non-existent in many rural areas, to operate the fans. Even when electricity exists, the potential users of the dryers are unable to pay for it due to their very low income. Forced convection dryers are for this reason not going to be readily applicable on a wide scale in many developing countries. Natural convection dryers circulate the drying air without the aid of a fan. They are therefore, the most applicable to the rural areas in developing countries. Solar drying may be classified into direct, indirect and mixed-modes. In direct solar dryer the air heater contains the grains and solar energy passes through a transparent cover and is absorbed by the grains. Essentially, the heat required for drying is provided by radiation to the upper layers and subsequent conduction into the grain bed. In indirect dryers, solar energy is collected in a separate solar collector (air heater) and the heated air then passes through the grain bed, while in the mixed-mode type of dryer, the heated air from a separate solar collector is passed through a grain bed, and at the same time, the drying cabinet absorbs solar energy directly through the transparent walls or roof. Therefore, the objective of this study is to develop a mixed-mode solar dryer in which the grains are dried simultaneously by both direct radiation through the transparent walls and roof of the cabinet and by the heated air from the solar collector. The performance of the dryer was also evaluated”.(Akinola1999.)

Soponronnarit (1995) reviewed the research and development work in solar drying conducted in Thailand during the past 15 years (since 1980s). He found that, in terms of techniques and economy, solar drying for some crops such as paddy, multiple crops and fruit is feasible. However, the method has not been widely accepted by farmers. Most of the solar air heaters developed in Thailand has used modifications to the building roofs. Both bare and glass-covered solar air heaters were reported to be technically and economically feasible when compared to electricity but have not been able to compete with fuel oil.

Bahnasawy and Shenana (2004) developed a mathematical model of direct sun and solar drying of some fermented dairy products. The main components of the equations describing the drying system were solar radiation, heat convection, heat gained or lost from the dryer bin wall and the latent heat of moisture evaporation. The model was able to predict the drying temperatures at a wide range of relative humidity values. It also has the capability to predict themoisture loss from the product at wide ranges of relative humidity values, temperatures and air velocities.

Enein (2000) reported a parametric study of a solar air heater with and without thermal storage for solar drying applications. An optimization process for a flat-plate solar air heater with and without thermal storage was carried out. Three kinds of material for thermal storage were used, water, stones and sand. The average temperature of flowing air increases with the increase of the collector length and width up to typical values for these parameters. The outlet temperature of flowing air was found to decrease with an increase of the airflow channel spacing and mass flow rate. The thermal performance of the air heater with sensible storage materials is considerably higher than that without the storage. An optimal thickness of the storage material of about 0.12 m was found to be convenient for drying various agriculture products. In addition, the proposed mathematical model may be used for estimating of the thermal performance of flat platesolarair heater with and without thermal storage.

Pangavhen (2002) proposed a design, development and performance testing of a new convection solar dryer, the solar dryer is capable of producing average temperature between 50 and 55°C, which was optimal for dehydration of grapes as well as for most of the fruits and vegetables. This system was capable of generating an adequate natural flow of hot air to enhance the drying rate. The drying airflow rate increases with ambient temperature by the thermal buoyancy in the collector. The collector efficiencies ranged between 26% for mass flow rate of 0.0126 kg/s of air and 65% for mass flow rate of 0.0246 kg/s. This was sufficient for heating the drying air. The drying time of grapes was reduced by 43% compared to the open sun drying.

Bena and Fuller (2002) developed a direct-type natural convection solar dryer with simple biomass burner. It was expected to be suitable for small-scale processors of dried fruits and vegetables in non-electrified areas of developing countries. The capacity of the dryer was found to be 20–22 kg of fresh pineapple arranged in a single layer of 1-cm-thick slices. The key features of the biomass burner were found to be the addition of thermal mass on the upper surface, an internal baffle plate to lengthen the exhaust gas exit path and a variable air inlet valve. The author also suggested some modifications to further improve the performance of both the solar and biomass components of the dryer.

Ekechukwu and Norton (1999) presented a comprehensive review of the various designs, details of construction and operational principles for a variety of practical solar-energy drying systems. The appropriateness of each design type for applications used by rural farmers in developing countries was discussed.

Bennamoun and Azeddine (2003) studied a simple, efficient and inexpensive solar batch dryer for agricultural products through simulations. They used onion as the dried product, and the shrinking effect was taken into account. In addition, it was suggested that the study could be developed for other agricultural products and for the behavior of solar dryer in different seasons.

Sebaii (2002) reported a study of an indirect type natural convection solar which investigated experimentally and theoretically for drying grapes, figs, onions, apples, tomatoes and green peas. The drying constants for the selected crops were obtained from the experimental results and were then correlated with the drying product temperature. Linear correlation between drying constant and product temperature were proposed for the selected crops. The empirical constants of Henderson's equation were obtained for all the materials from investigation, which are not available in the literature. The proposed empirical correlation suggested that it could well describe the drying kinetics of the selected crops.

Gallali (2000) reported the result of an investigation of some dried fruit and vegetables (grapes, figs, tomatoes and onions) based on chemical analysis (vitamin C, total reducing sugars, acidity, moisture, and ash content) and sensory evaluation data (color, flavor, and texture). They compared products dried by solar dryers and natural sun drying. The study indicated that using solar dryers gives more advantages than natural sun drying, especially in terms of drying time.

Karathanos and Belessiotis (1997) reported the sun and solar air drying kinetics of some agricultural products, such as sultana grapes, currants, figs, plums and apricots. The drying rates were found for both solar and industrial drying operations. Air and product temperatures were measured for the entire industrial drying process. It was shown that most materials were dried in the falling rate period. Currants, plums, apricots and jigs exhibited two drying rate periods, a first slowly decreasing (almost constant) and a second fast decreasing (falling) drying rate period. In addition, they indicated that the industrial drying operation resulted in a product of superior quality compared to products dried by solar dehydration.

4. MATERIAL AND METHODS

4.1 MATERIALS AND APPARATUS

This design and construction of the solar drier device has been done for the purpose of drying a variety of food products. The construction materials were wood, polyurethane glass, mild steel metal sheet and the trays. The materials used for this study and their functions are listed below. The procedural steps are also discussed here.

Table.**1**Materials to be used

MATERIALS	FUNCTIONS
Aluminum foil for reflecting sun rays	For trapping sun radiations
Backing material (mat)	Insulator for the aluminum foil so that heat is not lost
Piece of wood	For making frame of flat plate solar panel
A pane of glass	For collecting heat for further absorption
Thermometer	For temperature measurements at different times.
Nails and glues	For gluing the foil on the cardboard
Insect net	To prevent insect from entering the dried food
Paint (black and gray)	To absorb all heats and maintain it

4.2 PROCEDURES;

1. Make the frame.
2. Clamp the 2 top sidepieces...
3. Make the door.
4. Add tray supports and the heat absorber.
5. Cover the frame.
6. Screen the vents.
7. Seal and paint
8. Make the drying trays
9. Attach the door
10. Use the solar dryer.

4. RESULTSAND DISCUSSION.

5.1 RESULTS

Collection within a month from 10:00 to 17:00 in the interval of one hour in each day of several months of this project. The data recorded are given in Table.2. for the representative days.

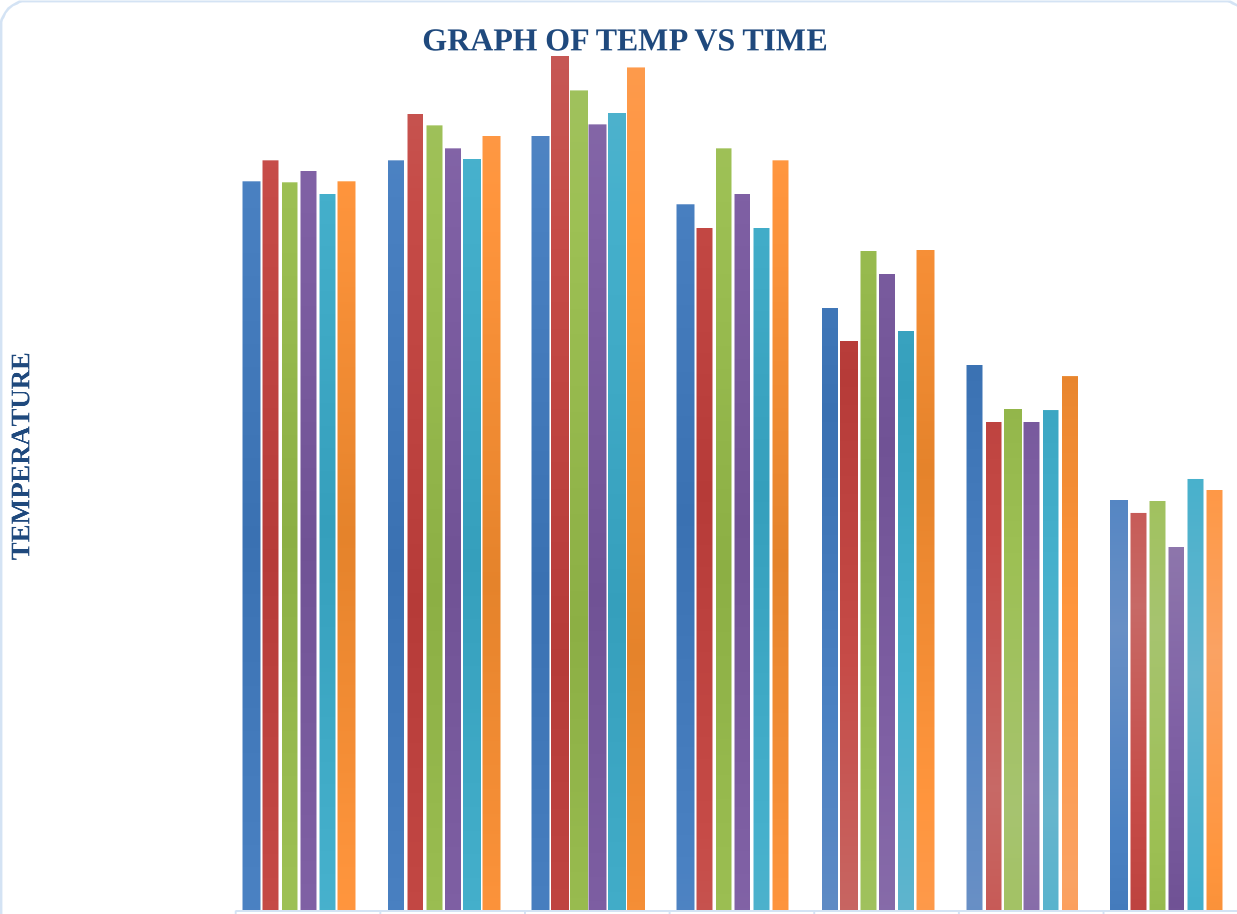
Table.2. Each hour temperature for the recorded days

SUNDAY							
Time(Hour)	10:00-11:00	11:00-12:00	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00
Temperature()	64	66	68	62	53	48	36
MONDAY							
Time(Hour)	10:00-11:00	11:00-12:00	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00
Temperature()	66	70	75	60	50	43	35
TUESDAY							
Time(Hour)	10:00-11:00	11:00-12:00	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00
Temperature()	64	69	72	67	58	44	36

WEDNESDAY							
Time(Hour)	10:00-11:00	11:00-12:00	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00
Temperature()	65	67	69	63	56	43	32
THURSDAY							
Time(Hour)	10:00-11:00	11:00-12:00	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00S
Temperature()	63	66	70	60	51	44	38
SATURDAY							
Time(Hour)	10:00-11:00	11:00-12:00	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00
Temperature()	64	68	74	66	58	47	37

5.2 DATA ANALYSIS;

Data analysis is the process of transforming raw data into usable information, often presented in the form of a published analytical article, in order to add value to the statistical output. In this study the data obtained were presented inform of graph which show the variation of temperature within a day from 10:00 to 17:00 for six days.



	10-11.	11-12.	12-13.	13-14.	14-15.	15-16.	16-17.
SUNDAY	64	66	68	62	53	48	36
MONDAY	66	70	75	60	50	43	35
TUESDAY	64	69	72	67	58	44	36
WEDNESDAY	65	67	69	63	56	43	32
THURSDAY	63	66	70	60	51	44	38
SATURDAY	64	68	74	66	58	47	37
Series7	0						

SUNDAY MONDAY TUESDAY WEDNESDAY THURSDAY SATURDAY

Fig. 3graphs show that the in all days temperature were maximum at 13:00.

The Fig. 3 graphs show that the in all days temperature were maximum at 13:00. Also the temperature seem to vary directly proportional to the amount of sunrays falling on the solar collectors, that was the temperature were less during morning and evening and were higher during noon. This were what made the temperature to be maximum at 13:00

5.3DISCUSSIONS;

After the study we have found that the solar drier gives about three times heat inside the chamber than that of the outside atmospheric temperature. Due to this case, the drying of food contents under the same climatic conditions and the same time inside the solar drier would be about three times than what is found outside the drier or in open sun drying.

4.4 ERROR ANALYSIS;

Sources of error;

The possible sources of error was:

1. Weather variation, during data recording the weather was changing gradually from sunny day to cloudy so it was hard to capture the higher temperature. Sometimes there were rain so that contributed to the source of error
2. Blockage of glass of the solar dryer, during experiment the side glass of the solar drier cracked so that might also be the source of error.

   Minimization of error;

1. To reduce the error caused by weather, the data should be collected during summer where the weather is quietly good such that it is 85% sunny.
2. The tool should be handed with special care.

5.5 CONCLUSION AND RECOMMENDATIONS

CONCLUSION;

The conclusions derived from thetest carried out thatthe solar drier can raise the ambient air temperature to a considerable high value for increasing the drying rate of the agricultural products and other food contents. The product inside the drier require less attention compared to those exposed directly on the open sun drying. This could be due to an attack of the products by rain, insects, dust and othercontaminations.

The capital cost involved in the construction of solar drier is much lower compared to that of a mechanical drier. Also from the test carried out, the simple and inexpensive solar drier was designed and constructed using locally sourced materials. The temperature inside the drier was found to be about three times than that of the outside atmospheric temperature. As per our experiment the maximum peak temperature inside the drying chambers was $75^{0}C$ during the mid-day (1.00pm) and an average of $57^{0}C$ in a fully sunny day (from 10:00am to 5:00pm). In seven (7) hours continuous drying in one full sunny day under the same climatic condition and in the same time the solar drier can remove maximum moisture contents from the food contents inside the drier for low moisture content food products. Experimental observation shows that the solar drier can be used as an alternative in case of food preservation and the efficiency is also acceptable. The people can make it on their homes especially in the developing countries where the energy demand is higher.

Generally the objectives of design and constructing solar drier have been succeeded because during the day time especially at 1.00 pm the temperature measured inside the device were reached up to 75 ^{0}C which is just enough temperature to dry food contents containing average amount of water contents. This show that when a food substances such as meat, fish, or even fruits are kept inside the solar drier would be dried and allowed to be stored for long time without being contaminated by germs. Instead of working of this solar drier up to this point, more research is needed to increase the capability of working of the solar drier to a point where it could be used be even to boil water to $100^{0}C$ and reduce the process of drying food locally which in most cases tends to lose the flavor of food contents or sometime even lead to spread of diseases due to direct exposure of the food contents to the environment.The use of external electrical supply is not provided keeping in mind the low cost and highly efficient, and self-reliable solar drier. The dryer is designed in such a way that maximum absorption of available heat is possible almost all day long. This is done with respect to the geographical location of our country, the sun's ray falls with certain degrees with respect to equator of the earth. However, the dryer inside personal residence, is done by connecting bulbs in parallel the glass panel. Bulbs act as a source of energy or heat and that solar drier can also be used during the night as well.

RECOMMENDATIONS;

The performance of existing solar food drier can still be improved upon especially in the aspect of reducing the drying time and probably storage of heat within the system by increasing the size of the solar collector. Also meteorological data should be readily available to users of solar products to ensure maximum efficiency and effectiveness of the system. Such information will probably guide a local farmer on when to dry the agricultural produce and when not to dry them. Solar drier with all its benefits, starting from environment-friendliness to its cost effectiveness, is yet to be accepted as a viable option for drying food contents. The effectiveness of this device is that, it only functions well in the presence of sunlight. The higher the solar radiations falling on the device the higher the efficiency of working of it. Thus, in day time drying of food contents through solar drier was not an issue, except at night due to the absence of temperature from the surrounding there must be replacement of back-up device, which used to stored energy throughout the day.

The results obtained showed a good progress which when improvedshall give excellent performance .Otherwise unfavorable results was obtainedduring cloudy weather interference condition(Waewsak, Chindaruksa, and Punlek, 2006).

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COMPETING INTERESTS
Authors have declared that no competing interests exist.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

5. REFERENCES

Aacharya,A., Rissler C.[c], Baral B., Lhendup T., Andersson M., Davidsson, H.. (2024),Development of a novel solar dryer with an incorporated heat exchanger,Solar Energy,Volume 269, 112327

Akinola, A.O. 1999. Development and Performance Evaluation of a Mixed-Mode Solar Food Dryer. M. Eng. Thesis, Federal University of Technology, Akure, Nigeria.

Akinola, A.O. and Fapetu, O.P. 2006. Exergetic Analysis of a Mixed-Mode Solar Dryer. J. Engin. Appl. Sci. 1: 205-210

Akinola, O.A.; Akinyemi, A.A. and Bolaji, B.O. 2006. Evaluation of traditional and solar fish drying systems towards enhancing fish storage and preservation in Nigeria. J. Fish. Int., Pakistan 1(3-4): 44-49.

Alamu, O.J; Nwaokocha, C.N and Adunola, O. 2010. Design and construction of a domesticpassive solar food dryer, Leonardo Journal of Sciences: 71-82.

Bahnasawy, A.J and Shenana, J.R. 2004. Evaluation of a solar crop dryer for rural applications inBotswana. Botswana Journal Technology 11(2): 58-62.

Bassey, M.W. 1989, Development and use of solar drying technologies, Nigerian Journal of Solar Energy 89: 133-164.

Bena, B and Fuller, R.J. 2002. Determination of the average coefficient of internal moisturetransfer during the drying of a thin bed of potato slices. Journal of Food Engineering. 48(2):95-101.

Bennamoun, N.P and Azeddine, H. 2003. Technical feasibility assessment of a solar chimney forfood drying, Solar Energy. 82: 198-205.

Bolaji, B.O. 2005. Performance evaluation of a simple solar dryer for food preservation. Proc. 6th Ann. Engin. Conf. of School of Engineering and Engineering Technology, Minna, Nigeria: 8-13.

Ceviz, M.A., Muratçobanoğlu,B., Mandev,E.,Afshari,F. (2024) A comprehensive review of solar cooking systems, Advanced Review. Edited by: Deborah Bleviss, Associate Editor and John Byrne

Ekechukwu, O.V., Norton, B., 1999. Review of solar-energy drying systems II: an overview of solar drying technology. Energy Conversion & Management.40 (6):615-655.

Enein, N.E. 2000. Experimental investigation of solar air heater with free and fixed efficiency andenergy loss, Intenational Journal of Science 1(1): 75-82.

Ertekin, C. and Yaldiz, O. 2004. Drying of eggplant and selection of a suitable thin layer drying model, J. Food Engin. 63: 349-359.

Eze,F. Egbo M, Anuta U.J., Ntitiriwa O.,B.R., Ogola J., and Mwabora J. 2024. A review on solar water heating technology: Impacts of parameters and Techno-economic studies. Bulletin of National Research Centre, 48, 29,3405

Gallali, G.; Garg, H.P and Prakash, J. 2000. Solar drying versus open sun drying, Aframeworkfor financial evaluation, Solar Energy.80:1568-1579. https://www.researchgate.net/publication/239730898_Design_and_Performance_Evaluation_of_a_Solar_Convection_Dryer_for_Drying_Tropical_Fruit [accessed Jan 11 2025].

Ikejiofor, I.D. 1985. Passive solar cabinet dryer for drying agricultural products. *In:* O. Awe (Editor), African Union of Physics. Proc. Workshop Phys. Tech. Solar Energy Convers, Univ. of Ibadan, Nigeria: 157-165.

Itodo, I.N.; Obetta, S.E.; and Satimehin, A.A. 2002. Evaluation of a solar crop dryer for rural applications in Nigeria. Botswana J. Technol. 11(2): 58-62.

Karathanos, K and Belessiotis, L. 2002. Natural convection solar dryer with biomass backupheater, Solar Energy.72:75-83.

Kurtbas, I. and Turgut, E. 2006. Experimental investigation of solar air heater with free and fixed fins: efficiency and energy loss. Int. J. Sci. Technol. 1(1): 75-82.

Leon, T.K; Mechlouch, R. F; and Brahim, A. B. 2002. A study of the drying effect on lemonslices using a closed-type solar dryer, Solar Energy.78: 97-103.

Madhlopa, A.; Jones, S.A.; and Kalenga-Saka, J.D. 2002. A solar air heater with composite absorber systems for food dehydration. Renewable Energy 27: 27–37.

Nandi, P. 2009. Solar Thermal Energy Utilization in Food Processing Industry in India. Journal of Science and Technology page: 123-131.

Othman, M.Y.H,;Sopian, K.; Yatim, B,amdDaud, W.RW,; 2006. Development of advanced solar assisted drying systems. Renewable Energy.31:703–709.

Pangavhen, P.H,;Malick, M.A.S. and Buelow, F.H. 2002. Modeling and experimental studies on anatural convection solar crop dryer, Solar Energy. 81:346-357.

Salaudeen O.2011, Design, Construction and Testing of a Solar Dryer ,Thesis, Department of Agricultural Engineering, College of Engineering, University of Agriculture, Abeokuta Ogun State

Schiavone, D., Teixeira, A. A. , Bucklin, R. A, and Sargent S. . 2013. Design and Performance Evaluation of a Solar Convection Dryer for Drying Tropical Fruit. Applied Engineering in Agriculture 29(3):391-401

Sbaii, S; Balladin, D.A and Headley, O. 2002. Solar dryer with thermal storage and biomassbackup heater, Solar Energy. 81:449-462s.
Shekata G. D., Tibba G.S., Baheta A.T., (2024),Recent advancements in indirect solar dryer performance and the associated thermal energy storage,Results in Engineering, Volume 24, 102877

Soponronnarit, O.1995. A solar air heater with composite absorber systems for food dehydration,Renewable Energy 27: 27–37.

Thakur. A., Rajat T., Dwivedi, K, A., Goel V.. (2023),Solar cooking technology in India: Identification and prioritization of potential challenges,Renewable Energy,Volume 219, Part 1

Togrul, I.T. and Pehlivan, D. 2004. Modelling of thin layer drying kinetics of some fruits under open-air sun drying process. J. Food Engin. 65: 413-425.

Waewsak, J.; Chindaruksa, S.; and Punlek, C. 2006. A mathematical modeling study of hot air drying for some agricultural products. ThammasatInt. J. Sci. Technol. 11(1): 14-20.
Xiao, H., Chen, A., Lai W., Lai, S. He, W., Deng, X. Zhang, C.and **Ren, H.**Application of Photovoltaic and Solar Thermal Technologies in Buildings: A Mini-Review**.** *Coatings* **2024**, *14*(3), 257
Youcef-Ali, S.; Messaoudi, H.; Desmons, J.Y.; Abene, A.; and Le Ray, M. 2001. Determination of the average coefficient of internal moisture transfer during the drying of a thin bed of potato slices. J. Food Engin. 48(2): 95-101.