BACHELOR OF ENGINEERING (AGRICULTURAL ENGINEERING)

DESIGN, FABRICATION AND TESTING OF A SOLAR DRYER

BY

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DEDICATION

This project is entirely dedicated to my grandfather, Late Mr. Salau Oluboyo with thanks.

ACKNOWLEDGEMENT

Without any restraint, I wish to express my endless gratitude to my parents Mr. and Mrs S.O. Umar that funded my University Education up to this stage. I enjoyed their support and assistance through many difficult circumstances, without which, together with the will of Allah, I may never had reached this stage.

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ABSTRACT

A solar dryer was designed, fabricated, and tested with tomatoes. The tested tomato samples were harvested directly from a farm to reflect local farm conditions.

The collector was a flat-plate type while drying took place in an experimental drying house. Tests were carried out using the solar dryer and open air-sun drying to compare both methods.

Results showed that the solar dryer evaporated an average of 0.12grammes of water per grammes of tomato over that of open-air-sun drying. With high temperature recorded at the drying house (above 54°c) it can be used to dry most of the agricultural products.

LIST OF SYMBOLS NOTATIONS

Symbol	Description	Unit
H	Total solar radiation incident on a horizontal surface	W/m^2
Hd	Diffuse component of solar radiation on a horizontal surface	W/m^2
Ic	Solar constant	W/m^2 K
Rb	Ratio of beam radiation on a titled surface to that on a horizontal surface	W/m^2
T	Temperature	^oC
Me	Equilibrium moisture content (% dry basis)	
$\frac{dw}{dt}$	drying rate (kg/hr of water)	
fv	Water-Vapor transfer coefficient	$Kg/hr. m^2$
do	Solar Altitude angle	
Mo	Crop initial moisture content	
Pa	Water-Vapour pressure of air	Kg/m^2
Ps	Water-Vapour pressure at ts	Kg/m^2
K_f	Thermal conductance of air film	Cal/sm^2 ^oC

Symbol	Description	Unit
Tw	Water temperature (wet basis)	°C
Ta	Temperature of air	°C
hf	Content heat of vapourisation	Cal/Kg/M²
Qs	Collector Capacity (Power)	Watts
A_c	Surface Area	m²
Ti	Collector inlet	°C
T_2	Collector outlet	°C
T_3	Drying house inlet	°C
T_4	Drying house outlet	°C
δ	Solar declination angle	
So	Day-light duration (hours)	
Re	Mean radius of the earth	m
Rs	Mean radius of the sun	m
Ao	Collector air passage cross-section area	m²
As	Collector effective absorbing surface area	m²
σ	Stefan-Boltzman's constant	

Definitions

1. **Direct Solar radiation:** Solar radiation flux associated with the direct beam, and is measured to the beam.

2. **Diffuse Radiation:** Radiation received on the ground over the rest of the whole sky hemisphere from which it has been scattered in passing through the atmosphere.

3. **Solar declination:** The angular distance between the sun and the plane of the celestial equator.

4. **Thermal Radiation:** The radiant energy omitted by a body due to it's temperature.

CONVERSION TABLE

LENGHT

1 inch	=	2.54×10^{-2} m
1 foot	=	0.3048m
1 metre	=	39. 37 inches

AREA

1 in^2	=	645.2mm^2
1 ft^2	=	0.0929m^2

VOLUME

1 in^3	=	0.0164L
1 ft^3	=	0.0283m^3

TEMPERATURE

F = 1.8 C + 32

F = Farenheit; C = Centigrade

MASS

1 ounce (oz) = 28.35g

1 pound (lb) = 0.4536kg

1 hundred weight (cwt = 50.80kg

1 tonne = 1000 kg

VOLUMETRIC FLOW

1 ft^3 min^{-1} (cfm) = 4.72 X 10^{-4} m^3 s^{-1}

ENERGY

1 Calorie (cal) = 4.187 J

1 Kwh = 3.600 MJ

INSOLATION

1 Langley day^{-1} (Cal cm^{-3} day^{-1}) = 0.0418 MJm^{-2} day^{-1}

= 0.0116 Kwh m^{-2} day^{-1}

USEFUL CONSTANTS

BULK densities

Maize = 769 Kgm^{-3}

Specific heat (Constant Pressure)

Air = 1.005 KJ Kg^{-1} K^{-1}

glass = 0.7540 KJ $Kg^{-1}K^{-1}$

water = 4.187 KJ Kg^{-1} K^{-1}

Densities (at STP)

Air = 1.280Kgm^{-3}

water = 1000Kgm^{-3}

CHAPTER ONE

INTRODUCTION

Preservation of agricultural products is one of the oldest food industries. Ancient people discovered that they could keep crops for months by drying in the sun for several days.

Drying is usually accomplished by passing air of carefully regulated temperature and humidity over or through the agricultural products in the dryer. Drying minimises harvest losses, increases the quality and quantity of agricultural products to obtain a high drying performance and satisfactory results. Drying needs to be carried out with limitations based on the products temperature tolerance, humidity response, compression strength and fluidity. The drying air is either natural or heated and, or may be natural convection or forced draft.

One out of the many uses of solar energy since the dawn of civilization has been drying and preservation of agricultural surpluses. Basically crops are spread on the ground or flat floors often with no pre-treatment and are turned regularly until sufficiently dried so that they can be stored for later consumption. Little capital is required on the expenditure of equipment but the process is labour-intensive.

In developing countries the processing of crops poses a serious problem mainly because the farmers depend almost entirely on sun drying (Okas , 1988

At the West African Cocoa Research Institute in Ghana, a system of mobile trays is in use. The trays roll on metal rails and are relatively easily moved (Agbeola, 1977). In Nigeria, along the Benue river, sun-drying of fish is done on hot sand and sometimes along the hot tarred road. Obviously, sun-drying approach is not hygenic and results to significant loss of produce, specifically due to contarmination by:

(a) Dirt, dust, and wind-blown debris;
(b) Insect infestation, especially if there is rain during drying period
(c) human and animal interference;
(d) Interruption and wetting by rain

The quality of sun-drying products is often low due to lack of control over the drying rates. Specifically, improper drying of corn is attended by a positive danger of losing the entire havest as a result of mould growth and sprouting.

Solar drying is mostly achieved by the direct exposure of the products to the sun's radiation and by an indirect method in which heated air through solar collector is passed to the drying chamber. Research has shown (Arinze and Obi, 1984; Oje and Osunde, 1992) that indirect method is for more efficient, economic and reliable. The portion of the spectrum that includes most of the energy radiated is in the wavelength range of 0.3 - 3.0m (Duffie and Beckman, 1985).

A solar dryer can either be "passive" or "active". In "passive" type, heated air from solar collectors is transferred to the drying unit by natural convection otherwise called thermosphoning. While in "active" dryer, artificial means of transfering heated air is incorporated. Such means are the integration of mechanical pumps, sunction fans, compressors, and so on, which can supply what is described as the "motive force" (O fi O., 1982). Solar radiation collection is achieved by the use of Solar Collections which may be parabolic (concentrating) type or flat plat collector type. As for the tools which utilizes the sun's energy, the most efficient are flat plat collectors (Anderson et al, 1977).

An efficiently utilized solar energy, offers a means of providing low cost and reliable drying systems in the developing countries. The farming communities are often neglected in terms of provision of basic facilities, and yet over 80% of total agricultural output are produced (Falade et al, 1985). Experimental results have shown that solar dryer has considerable advantages over the traditional sun-drying method in terms of faster drying rate, less acess to spoilage by micro-organisms when crop is harvested at high moisture content and handling convinience.

The use of solar dryer although old but is relatively new in Nigeria, its adaptation should be made to the needs and resources of the farming establishment. In this study, the design considerations or criteria for a solar crop drying system are investigated. A flat plate absorber making use of direct solar trapping for the drying of agricultural products (corn). Other considerations are cost effectiveness, versability and availability of local materials for construction of solar dryer as to make the local farmer to afford the constructional cost.

1.1 THEORY OF CROP DRYING

Drying, in ordinary terms, is the removal of moisture from a substance. Technically, drying, in its ordinary applications, is a heat and mass transfer process involving vapourization of water in the liquid state, mixing the vapour with the drying air, and removing the vapour by naturally or mechanically carrying away the mixture. Sufficient heat for vapourization of product moisture must be supplied by reducing the sensible heat of the drying air or by applying heat directly to the product conduction, radiation, dielectric heating, or some other means.

The capacity of air for moisture removal depends on its humidity and its temperature. Spoilage is overcome when crop moisture content is reduced to about 14% to 8% wet basis.

1.2 Factors affecting the rate of drying

The main factors which affect the rate of drying are:

1) The physical and chemical properties of the product - shape size, composition, moisture content;
2) The geometrical arrangement of the product in relation to the heat transfer surface or medium;
3) The physical properties of the drying environment - air, temperature, humidity, velocity;
4) The characteristics of the drying commonly associated with farm products.

1.3

A) <u>The Constant rate period</u>

This is just like evaporation of moisture from a free water surface. Moisture content of crop usually about 70-75% wet basis and it occurs at the early stage of drying for wet crop. Crops at this stage, contain much water such that its surface acts like a free - water surface. Rate of moisture removal is constant and is largely dependent on:

(i) Velocity of the drying air

(ii) Difference in humidity between the ambient stream of air and the crop wet surface.

(iii) The crop's area exposed

(iv) The coefficient of mass transfer

Drying rate is constant, if the ambient condition is constant and this is mathematically represented as:

$$\frac{dw}{dt} = fv(Ac\ Ps - Pa) = Kf\ \frac{A(Ta-Ts)}{hf}$$

(Energy balance equation)

The constant rate period proceeds until free moisture of the crop gradually disappears to make drying rate progressively less. Grains do not exhibit constant rate unless they are harvested at a very immature state or have water condensed or rained on their surface.

1. 4

(B) <u>The falling rate period of drying</u>

While drying, a critical moisture content is approached which marks the transition between the constant rate and the falling rate of drying. The internal resistance moisture migration of the crop out-weighs the external resistance, while the only driving potential of the drying process (Ps -Pa) decreases with the drying rate.

In grains, the initial moisture content after harvesting is usually below the critical rate period. Hence, falling rate drying period is very important in the drying of harvested grains. It is difficult to predict the falling period of drying because of many consideration that come into play, amongst which are:

(a) the external transfer mechanism (the convective heat and mass transfer)

(b) the product interior transport mechanism (heat and mass diffusion)

Several theories have been proposed for predicting the drying behaviour of crops in the falling rate drying (cereals - e.g. grains) but only the semi-theoretical and empirical relationships have proved useful to the dryer designers (Brooker et al, 1974).

1.5 Moisture Content

The moisture content of a product is the amount of water contained in the product. It is expressed mathematically in percentages in terms of the wet weight (wet basis) or dry matter (dry basis) of the product, thus

$$\%\ \text{moisture content (wet-basis)} = \frac{W - d}{W} \times 100$$

$$\%\ \text{moisture content (dry basis)} = \frac{W - d}{d} \times 100$$

where W and d are the weights of the wet and the completely dry samples, respectively. The market price is usually determined on wet basis while dry basis moisture content is used in writing basic- equations and by engineers.

1.6 Equilibrium Moisture Content

It is necessary to dry each crop or product to its equilibrium moisture content. When the rate at which the product loses moisture to the surrounding environment is identical to the rate at which it absorbs moisture from the surrounding air, the product is said to be in equilibrium. The moisture content present in the product at equilibrium is known as the equilibrium moisture content or hygroscopic equilibrium.

Temperature has a significan effect on the equilibrium moisture content of a product. An increase in temperature at constant relative humidity decreases the equilibrium moisture content. Relative humidity also has some effect on equilibrium moisture content; an increase in relative humidity increases the equilibrium moisture content of a product. The variation of equilibrium moisture content of shelled corn with temperature and relative humidity is given below:

Table 2.0. Variation of Equilibrium Moisture Content OF Shelled corn with Temperature and Relative Humidity

Temperature, °C	Relative Humidity, %			
	40	50	60	70
25	9.80	11.20	12.90	14.00
30	9.00	10.20	11.40	12.90
38	8.70	9.00	11.00	12.50

Source: Agboola (1977)

1.7 Drying Parameters

The two major parameters in drying are time and temperature. If the time required to dry a product at a particular temperature is too long, mould and germination damage or other damages may occur and the value of the dried sample is reduced.

Excessive drying rate or high temperatures for drying may cause both physical and chemical damage to the product. Excessively high kernel temperatures in corn, for example, cause increase breakage, stress cracking and kernel discolouration and lead to a decrease in starch separation (millability), oil recovery and protein quality.

1.8 Characterization of Drying

Depending on the temperature ranges, drying can be divided into three categories. That is , low temperature drying, high temperature drying, and freeze drying.

1. Low Temperature Drying - This is a process of slow drying, usually performed at temperatures between 30°C and 50°C, with natural air or air heated only a few degrees above ambient. Corn drying temperature falls within this group, the favourable drying temperature being 45°c - 50°c

2. High Temperature Drying - High temperature drying has been the primary method of drying food products in the developed countries. Air at temperature of 50°C or above is employed in drying extremely moist products for example, fruits, vegetables, and so on. Grains which is used for animal feed can be dried quickly at high temperatures because quality is not a consideration in this case.

3. Freeze Drying - Freeze drying accomplishes the removal of water from fluids (fruits juices) or solids. Most freeze - dried operations are performed between - 10°C and - 40°C under low pressures. It is an expense, slow operation, but it has definite advantages for heat sensitive materials

1.9 Justification

- Problems of conventional sun drying: - Contamination, loss of products, and over drying is minimized.
- high cost of or aunavailability of improved drying equipments, high cost of energy source is considered.
- Solar dryer is inexpensive to construct no running cost, faster rate of drying, and not labour intensive.

1.10 OBJECTIVES

The general objective of this project is to design and construct a portable solar dryer to be used for drying agricultural products. The temperature in the drying chamber will be between 35° to 45°. Contamination and crop loss will be reduced to minimum.

The specific objectives are:-

i. To design a suitable dryer for drying agricultural products particularly grain and tomatoes over a given preiod.

ii. To construct the unit from locally available materials so as to make it affordable to the rural farmers.

iii. To test unit in order to determine its performance with respect to its drying rate and capacity.

CHAPTER TWO

LITERATURE REVIEW

Solar - powered drying systems are probably the keystone to wide-spread application of solar energy. Past literatures has dealt primarily with solar-cooling systems and absorption systems that are not mainly used for drying.

Igbeka,(1982) made an experimental passive solar dryer with a concentrating collector and recorded a higher drying efficiency on evaluations, in comparison with open air solar drying.

Based on the problems encountered, he recommended the following:

(a) Success is only achieved through positive economic consideration.

(b) Proper insulation is required to minizes heat losses in the drying chamber.

Ofi, O. (1982), evaluated a solar dryer using a flat plate collector and recorded a favourable drying condition in the drying unit of up to 50^{o}C above embient, through under no-load test.

Arinze,(1983) designed and constructed a solar crop dryer with a thermal storage system. A favourable computer stimulation of the system performance was achieved but no actual drying was carried out this enhancing the practicability of the experiment Bamiro and Ideriah (1982), determined the optimum collector orientation for Ibadan, Nigeria and obtained optimum indications corresponding to maximum incident solar energy (beam, diffuse and reflected radiation). A rannge of 7.43^{o} to 15^{o} was recommended for optimum collector inclination (titled angle of collector surface)

Aracye, 1984) designed, fabricated, and tested solar dryer using both active and passive method. It was effective and good drying result was obtained, but there was a lot of heat losses due to the fact that the collector does not project directly to the drying chamber.

Brown, (1981) designed and fabricated a solar dryer for agricultural products using locally available wood materials. The wood materials deterioriated an collapsed within two years of fabrication due to rainfall, high susceptability of wood to bio-deteriorations, hence, there were failures regarding the durability and economic life considerations.

Owokoya, (1992) designed and fabricated a solar air heater though, it has good heat absorption but innefective due to heat losses through the casing.

Finally, in many of these research projects mentioned above, there is nothing to suggest that any investigation relating to combined system (direct and indirect) solar dryer has been carried out, except that of Araoye (1984), which has high heat losses. Attentions are carefully paid to suggestions and recommendations given out from many previous but similar experiments on solar dryers. Drying hazards being faced by farmers is being studied and incorporated in removing them to make the solar dryer cost-effective.

2.1 DRYING TECHNOLOGY

Various methods of drying may be classified into three categories, thus:-

a. Traditional or sun-drying method

b. conventional drying technique, and

c. Solar drying technology

Traditional or sun-drying method

This is the method in which farmers depend almost entirely on natural - or sun drying. A common method used is to spread the crops on concrete or brick floors and sometimes on mats.

Conventional Drying Technique

Conventional drying technique involves the use of mechanical dryers. Hot air from a heater or furnace is passed through a batch of crop or substance being dried. The furnace is usually fossil - fired but electrically heated furnace is often used for small scale drying. A fan or blower is usually employed for the movement of the drying air.

In these systems, the time required to reduce the product to the desired moisture content, or the drying rate, is governed by the air temperature, air relative humidity and air flow rate.

Solar Drying Technology

Research on the effective use of the energy from the sun started about two decases ago. This has led to various practical applications of Solar energy, one of which is solar dryring.

In Nigeria and in other tropical countries, solar energy appears to be abundant all the year round. The applicability of dryers with solar heated air to improve on sun-drying technique is therefore not questionable.
It has some advantages over the conventional mechanical dryers especially with respect to cost and adaptability to small scale farmers and industries. Some of the crops commonly grown in developing countries (e.g. corn) may be better suited to solar drying technologies than the fossil - fuel - fired drying systems because case hardening and other damage are likely to be less at the low temperature characteristic of solar dryers.

2.2 SOLAR ENERGY UTILIZATION

Solar energy is the electro magnatic wavelength radiation which emanates from the sun due to its surface temperature of about $6000^{o}K$. The total energy production of the sun amounts to about 3.86×10^{26} watts but from the sun-Earth geometry, only a minute fraction of this energy is intercepted by the earth. The rest simply disappears through space into the vastness of the universe. The universal availability of solar energy has prompted a long history of investigations as to how best to utilize it. The pre-historic mass used Solar energy for the drying of his fruits and when his technological level improved, he was able to concentrate this energy to produce fire.

In order to design solar energy systems for specific technological and economic needs, which also facilitates the end-use matching of such systems, a knowledge of the quantity and quality of the availabile solar radiation is imperative. For such designs, one must calculate the amount of solar energy indident on the collector each month. One way of doing this is to use the coverage daily solar radiation on a horizontal surface for the location with adjustments made for the collector tilt such data is usually obtained from long-term averages of solar radiation based on many years data. For the developed world, actual measurements of solar radiation on a continuous basis have been going on for nearly fifty years.

In the developing world, such data is scarse and when available is neither continuous nor raliable. The required data must therefore be obtained from correlations.

2.3 THE SUN

The sun is a repository of about limitless energy. It is a gaseons sphere of great density , with a core temperature of millions of degrees. At this temperature thermonuclear process involving the hydrogen atom occur on a scale surpasing human imagination. The sun's surface (photosphere) is composed of hot ionized gases. Most of the visible and informed radiation from the sun is emutted from the photosphere, which acts essentially as a black-body of about 6000°K. other basic characteristics of the sun are:

mass (m) = $(1.991 + 0.002) \times 10^{30}$ Kg

Radius (r) = $(6.960 + 0.001) \times 10^{8}$ m

Average density (d) = $1.40 + 0.002$ g/cm^3

(Dixon, A.E. 1980)

Sun is a rotating mass, whose equitorial region rotates in 24 days while the regions nearest to the poles rotates 30 days. Sun is considered as an inexausible energy source.

2.4 GLOBAL SOLAR ENERGY AVAILABILITY

Since we rely almost completely on the sun; The earth and its atmosphere received on a continuous basis about 1.73×10^{17} Watts of radioactive energy from the sun, an amount which is over 500 times more than the other sources of the earth's energy (terrestrial energy)

One of the problems with this energy is that is suffers attenuation due to absorption and scattering in the terrestrial atmosphere and is intermittent because of the relative motions between the earth and the sun as the unsteady nature of the terrestrial environment. The radiation received on the earth's surface is therefore of low grade energy and consist of direct radiation and diffuse radiation, as opposed to the radiation in the earth's outer atmosphere which is basically direct radiation.

Solar radiation is usually available in several forms in terms of the type of irradiance (global, direct and diffuse), the time basis (hourly, diarnal, monthly, seasonal or yearly) and the surface placement (horizontal or titled). Each of these has its particular usage in a specific application. A practical method of presenting spartial variations of solar radiation is by means of maps prepared on a temporal basis. Thes maps reflect the levels of solar energy potentials and give at a glance, a clear idea of the degree of applicability of various solar energy conversions systems for the indicated locations.

2.5 Solar Radiation Availability in Nigeria

(A) Measured Data

The status of solar radiation measurements in Nigeria is still not adequate It is only recently that some research stations in the country have embarked on continuous monitoring of radiation data using modern instruments like Eppley thermoelectric Pyramometer for global radiation measurements, schadded Pyranometer for diffuse radiation and Pyrheliometer for direct radiation measurements.

Most of these centres are scattered all over the country in such places as Nsukka, Lagos, Ibadan, Ife, Zaria, Kano Sokoto, and Birnin-Kebbi.

The results from these works have been arranged and compiled into Solar radiation maps for Nigeria for the twelve months of the year, North-South irradiation values of over 20 MJ/M^2 day are observed generally in the Semi-arid North while the lowest values of about 12 MJ/M^2day occur in the more humid and Forest regions of the South (Ezekwe, 1993) Ezekwe and Ezeilo, 1981, Iderrah 1981, and Oje, 1990).

(B) CORRELATION

While continuous solar radiation measurements have only been recent, climatological variables such as sunshine duration, cloudiness, humidity and ambient temperatures have been recored for over forty years at weather stations located in Lagos, Enugu, Ibadan, and Kaduna. Some effort have been made to obtain useful correlations relating these variables to the total daily insolation. The global radiation relation found to be applicable for the climatological data of Minna is

H =

where so = day light duration, D = dust haze attenuation coefficient,

R = relative humidity

H = global irradiation.

2.6 SOLAR RADIATION MEASUREMENT

A. Solar constant

This is the intensity of solar radiation at the upper limit of the earth's atmosphere on a unit area of surface normal to the sun's rays. The most probable average value is 1.35 kilowatts per square metre (Faris, 1983).

(B) Insolation

Insolation usually refers to the Solar radiation at the earth's surface per unit area and unit time. It includes both direct radiation from the sun and the indirect radiation from the sky due to scattering of the solar radiation by molecules or other particules. The term "global radiation" is sometimes used instead of insolation.

( )

(C) Sunshine Duration

The average daily radiation is a function of the sunshine duration at a particular location. Most important method used for measuring sunshine is the campbell - stokes sunshine recorder.

CHAPTER THREE

METHODOLOGY

3.1 SOLAR COLLECTORS

There are two basic types of Solar energy collectors, namely; flat plate and parabolic/concentrating collectors. A Solar collector is a special form of heat exchanger that transforms solar radiant energy into heat energy.

Flat plate collectors are used for low thermal process and applications where moderate temperature up to 100°C or below is required. Hence they are widely used for water heating, crop drying, heating and cooling of buildings and so on. They have advantages of using total solar radiation (both diffuse and beam) and require little maintenance compared with focusing/concentrating collectors.

The drying of agricultural products is only desirable under moderate temperatures that can reduce the water content without damaging the product hence, the use of flat plate collectors is most appropriate, and emphasis is limited only on flat plate solar collectors.

In general, all flat-plate collectors have essential component which are common except the geometry. These components are:

(i) The transparent cover
(ii) The absorber plate
(iii) Thermal insulation
(iv) Passage or channel
(v) The housing or casing

<u>The transparent cover</u>

Transparent cover is incorporated to provide insulation at the top of the absorber plate or significantly, the short-wave solar radiation to absorber plate Glass is commonly used because of its excellent weatherability and good mechanical properties. Glass has solar transmittance (85% - 92%) and can be very transparent if it has a low oxide content. It is opaque to long-wave radiation and thus reduces radiation losses compared with plastics

The absorber plate

The primary function of the absorber plate is to absorb the (beam, diffuse, and reflected) solar radiation. The absorber plate is made of blackened steel material. A blackbody is a perfect absorber and emitter of radiation" (Duffie and Beckman, 1980).

Thermal Insulation

The thermal insulation at the back and sides of the collector is to minimize heat losses. The materials is able to withstand maximum temperature that is generated by the absorber plate (up to 100°C). A minimum thickness of 500mm and 25mm insulation at the back and sides respectively of the collector plate have been recommended and otherwise called as "Standard Design" (Arinze,1983).

Common thermal insulating materials also available are fibreglass, rockwool, sawdust, wood shavings, coconut fibre and so on. They are characteristics of low coefficient of thermal conductivities.

The Passage/Channel

The heated air or liquid is being transferred from the solar collector via an open channel to the drying chamber.

The housing or casing

This is made of seasoned wood and plywood nailed together to prevent heat losses.

3.2 Determining Optimum Collector Slope

From a general knowledge of the apparent movement of the sun it can be seen that during the drying season the sun will be overhead at or near the Northern hemisphere a south facing collector will receive most insolation (Oje and Osunde, (1992), Arinze (1985), Sambo, (1985), and Hamiro and Ideriah, 1985)

To calculate the optimum slope angle, December 15, is taken as the midpoint of drying season. Angle of declination, is calculated from the equation

$$= 23.45 \sin \left(360 \frac{284 + n}{365}\right) \quad \ldots\ldots\ldots\ldots\ldots \text{eqn } 3.0$$

For December 15, n= 349

Hence, $= 23.45 \sin \left(360 \frac{284 + 349}{365}\right)$

$$= 23.45 (- 0. 993)$$

$$= - 23. 3^{\circ}$$

To maximize the level of insolation on a collector the simplest approach is to situate the collector so that it is perpendicular to insolation at mid-day of the drying season.

3.3 Collector Tilt Angle and Facing

It has been established that the efficiency of flat plates in collecting solar energy depends, on the inclination of the plate to the horizontal. Various formulae have been proposed for determining the Optimum tilt angle which gives maximum collection efficiency for a flat plate at a given location. Notable among these are the formulae that say that for maximum efficiency, tilt angle should be:

(a) 10° greater than the latitude angle at the location;

(b) 15° greater than the latitude angle the location:

(c) 0.9 times the latitude angle at the location;

(d) 1.5 times the latitude at the location;

(e) the latitude angle at the location (Kulade et al, 1985)

Rather than adopt any of the above formulae, the average of the values given for Minna (Latitude 9.58°N and longitude 6.33°E) by the five formulae. This leads to the choice of 15°as the design tilt angle. The collector is to be oriented to face the equator (South).

Daily solar insolation (global radiation) on horizontal surfaces for various latitude in Nigeria as done by Ezeilo (1985), Simonson (1984), Faugbonle (1981), Ezekwe (1983) and Oje and Yemnde (1992), an interpolation was done for Minna to get the average hourly insolation as 825 W/M°K. The altitude for Minna is 323 metres (see appendix).

To calculate the angle of indidence for insolations for a horizontal surface θ_h, since the slope angle is zero:

Cos θ_h = snd. snϕ + cos . Cos . Cos

= latitude value for Minna

hour angle

Calculate from equations 2.0

therefore = − 19.1° on November, 15

= − 23.5° on December 15

= − 21.3° on January 15

Estimated means value of θ_h over day can be made by assuming a 12 hour day and dividing it into four 3 hour periods and calculating θ_h for each period.

To varies from − 90° at 0600hrs to + 90° at 1800 hrs

To for 0600hrs to 0900hr = − 67.5°

0900hr to 1200 hr = − 22.5°

12 00hr to 1500hr = − 22.5°

1500hr to 1500hr = − 67.5°

For December 15, for the period 0900hrs to 1200hrs, Cos Q = 0.937.

Daily radiation on a horizontal surface is approximately 19.20 MJ m^2 day $-^1$

Insolation on horizontal surface for the period 0900-1200 hr on December 15 is calculated thus:

Insolation (Ih) = 825 W/m^2 for the period 0900 − 1200

Cos θ = Sin δ Sin ϕ Cos β

− sin δ cos ϕ sin β cos ω

+ cos δ cos ϕ cos β cos ϖ

+ cos δ sin ϕ sin β cos ω cos ϖ

+ cos δ sin β sin ω Sin ϖ

ϕ = latitude, ω = surface azimuth angle,

ϖ = hour angle, δ = declination angle, β slope angle

and for the period of 0900 − 1200

Cos = 0.937

Therefore, insolation intensity on the collector surface

$$I_s = I_h . \frac{\text{Cos } \theta}{\text{Cos } \theta_h}$$

$\cos \theta$ for period 0900 - 1200 = 0.937

$\cos \theta_h$ for period 0900 - 1200 = 0.780

Therefore, $\frac{\cos \theta}{\cos \theta_h} = 1200$

$Ic = Ih \times 1.2 = 1.20 \times 825 = 990 \; W/m^2$

3.4 Determination of the collector Area

Aimed to design a collector that could generate heat energy. Therefore the heat to be generated by the collector from the insolation gives:

$$Qc = Ic \, Y \qquad 4.1$$

where Ic = Insolation ($825 \; W/m^2$)

= transmissivity of the cover plate = 0.88

= absorptivity of the absorber plate = 0.86

The required collector capacity is 300 - 400 watts to be used for heating, drying, and cooling applications (Kreider and Kreith, 1978)

from equation 4.4.10

$$350 = 825 \times 0.88 \times 0.86 \, Y$$

Therefore $Ac = \frac{350}{825 \times 0.88 \times 0.86} = 0.56 m^2$

3.5 Determination of the collector loss Coefficient

(a) Heat loss coefficient from the top. The major heat loss from the collector is from the top and the heat transfer coefficient for the top is given by

$$= \left(\frac{N}{(344/Tp)(Tp-Ta)/(N+f)^{0.31}} + \frac{1}{hw} \right)^{-1}$$

(Duffie and Beckman, 1974)

$$= \frac{(Tp + Ta)(Tp^2 + Ta^2)}{\left((Ep + 0.0425N(1-Ep))^{-1} + \left((2N + f - 1)\, Eg \right)^{-1} - N \right)}$$

Where:

N = 1 (glass cover)

F = factor = $(1 - 0.04\, hw + 5.0 \times 10^{-4}\, hw^2)(1 + 0.058\, N)$

$hw = 3.7 + 3.8V$, when V = 2.24 m/s

Thus, substituting the values of hv^2, f and hw = 14.21 W/m°

$$= \left(\frac{1}{(344/320.33)\,(320.33 - 303)/(1+0.563)^{0.31}} + \frac{1}{14.21} \right)^{-1}$$

$$+ \frac{5.67 \times 10^{-8}\,(320.33 + 303)\,(320.33^2 + 303^2)}{\left(0.86 + 0.0425\,(1-0.86)\right)^{-1} + \left((2+0.563 - 1)/0.88\right)^{-1}}$$

$= \underline{6.66\ W/m\ ^{\circ}C}$

(b) Heat loss coefficient from the Back and Sides

The loss co efficient from back and sides depends on the thermal conductivity of the insulator material and the thickness of the insulation material.

The insulation material chosen is polyurethane foam (rigid) with thermal conductionty (K) = 0.0245 W/m°C

$U_{back} = \frac{K}{L}$; L = back insulation thickness (5cm)

$U_{back} = \frac{0.0245}{0.05} = 0.49\ W/m^2\ ^{\circ}C$

The side heat loss is taken to be negligible since proper insulation was made.

$U_l = U_t + U_{back} + U_{side}$

$= 6.66 + 0.49 + 0 = 7.15\ W/m^{\circ}C$

3.6 Design Calculation

Diagram (design diagrams) are at the back envelope

Flat Plate Collector

The collector is of conventional design in which the air heating medium is above the absorber plate (from the determination of the collector area, = 3.4).

Length = 0.888m

Width = 0.61m

Height = 0.1m

Collector volume = 0.888 X 0.61 X 0.1 = 0.054 m^3

Area of the collector plate = 0.888X 0.61 = 0.54m^2

Collector cross-sectional area = 0.61 X 0.1 = 0.061m^2

or various advantages of glass like low values of longwave loss, it was chosen as the collector top cover Glass thickness for the design is 3cm (Standard).

he absorber Plate

ue to availability and cost, steel sheet are used. The absorber plate was nailed to the wooden sides. The base and sides of the casing are 5 cm and 2.5 cm respectively from the absorber plate and packed with foam insulation of 24kg/m^3 density and thermal conductivity of 0.0245W/m°C

Distance between glass cover and the absorbing plate is 4.7 cm length of the air passage 0.88m

Effective cross-sectional area of the air passage of the collector (ao)

Ao = 0.88 X 0.047 = 0.041m^2

Effective collector surface area is given by

A Ac = effective width X length

= 0.88 X 0.61 = 0.54m^2

The Drying House

The drying house is constructed with plywood and seasoned wood. It is sized taking into consideration the collector area.

Length = 0.60 m

Width = 0.60 m

Height from ground - 1.20 m

Normal height - 0.95m

Volume capacity = 0.6 X 0.6 X 0.95 = 0.342m^3

The plywood and the seasoned wood is treated with aluminium paint to make it water-proof resistant. The top is conically shaped with blacken steel plate with an opening which provides proper ventilation and eliminate condensation of vapour resulting from drying.

Drying Floor

The floor is made of wire gauze (1.27 cm) to hold maize cobs and other crops/products of size 2.5 cm and above.

Side Surfaces

(a) bottom = 60 cm X 60 cm = $0.36 m^2$

(b) 2 sides of 60 X 90.5 cm = $0.54 m^2$

(c) another 2 sides of 60 X 90.5cm = $0.54 m^2$

Length = 60cm

Width = 60 cm

Height = 90.5 cm

Drying house Materials for construction

1. 1 piece of (1.27 cm thickness) plywood
2. 2 pieces of (2.54 X 10.16 X 76.20 cm) well-seasoned wood (1" X 4" X 30")
3. Foam as insulator
4. ½", 1", 2" nails and screws
5. White glue
6. Putty
7. Aluminium paint.

TABLE 1. PROPERTIES OF SOME COVER MATERIALS

Material	Solar Transmittance	Longwave Transmittance	Other Characteristics
Glass 3.18 mm	0.88	0.03	.Breaks easily .Sharp edges, especially when broken .No static charge buildup .Cleans easily .Solar trasmittance does not change over time .Abrasion resistance surface
Flat FRP .Regular 25-mil	0.83	0.12	.Cannot tolorate Temp>200oC .Sags when warm, requires closely spaced supports
Flat FRP 4-mil	0.73	0.06	.Surface and solar transmittance gradually deteriorate .Light weight and tough .No static charge buildup .Easy to seal and fasten to collector frame
Polyethylene 4-mil	0.89	0.80	.Tough but punctures easily .Susceptible to wind damage unless collector is inflated .Solar trnsmittance degrades rapidly .Light weight
Polyester 5-mil	0.87	0.32	.Flexible film,light weight .Vibrates in wind and damages easily .Rapid ultraviolet degradation .Not recommended for collectors with single cover
Polycarbonate 1.59 mm	0.84	0.06	.Punctures easily .High thermal expansion .Solar transmittance slowly deteriorates over time .Light weight
Polyvinyl Floride (PVC) 3-mil	0.91	0.43	.Hard to handle and install .Shrinks at high temp. .Light weight .Expected life of about 10 years.

TABLE I. PROPERTIES OF SOME SURFACE COATINGS USED IN FLAT-PLATE COLLECTORS

Coating	Solar energy absorptance α	Long-wave radiation admittance[a] ε	Reference
Black enamel paint	0.83	0.83	Sabbagh, J. A. *et al*
Tar	0.86	0.86	Sabbagh, J. A. *et al*
Lamp-black	0.95	0.95	Sabbagh, J. A. *et al*
Nickel black (oxides *and* sulphides of Ni and Zn) on polished Ni	0.91-0.94	0.11	Tabor, H. *et al*
Nickel black on galvanized iron (experimental)	0.89	0.12	Tabor, H. *et al.*
Nickel black on galvanized-iron (commercial)		0.16-0.18	Tabor, H. *et al.*
Nickel black, two layers on electroplated Ni on mild steel (after 6-h immersion in boiling water)	0.94	0.07	Tabor, H. *et al.*; Schmidt, R. N. *et al.*
CuO on Ni (made by electrode deposition of Cu and subsequent oxidation)	0.81	0.17	Kokoropoulos, P. *et al.*
Co_3O_4 on Ag (deposition and oxidation)	0.90	0.27	Kokoropoulos, P. *et al.*
CuO on Al (by spraying dilute $Cu(NO_3)_2$ solution on hot Al plate and baking)	0.93	0.11	Hottel, H. C. and Unger, T. A.
Copper black on Cu (commercial treatment of Cu with solution of NaOH and $NaClO_2$)	0.89	[illegible]	[illegible]
Ebanol C on Cu (commercial Cu blackening treatment giving coatings mostly consisting of CuO)	[illegible]	[illegible]	[illegible]
CuO on anodized Al is treated (Al with hot $Cu(NO_3)_2$ – $KMnO_4$ solution and baked)	0.85	0.11	Tabor, H.
Al_2O_3-Mo-Al_2O_3-Mo-Al_2O_3-Mo-Al_2O_3 interference layers on Mo	0.91	0.085[b]	Schmidt, R. W. *et al*
PbS crystals on Al	0.89	0.20	Williams, D. A. *et al*

[a] At temperatures typical of flat-plate solar collectors.

[b] Measured at 260°C (500 °F).

TABLE II: PROPERTIES OF COMMONLY USED INSULATION MATERIALS IN FLAT PLATE COLLECTORS

Material	Approximate Density (kg/m^3)	Thermal Conductivity ($Wm^{-1}{}^{o}C^{-1}$)
Mineral wool (clay wool, fibreglass, rock wool)	12-14	0.0332-0.0404
Hair felt	80	0.0389
Granulated cork	120	0.0476
Re-granulated cork (0.474 cm particles)	30	0.04471
Compressed cork	86-176	0.0418-0.0462
Straw	10-13	0.0576
Sawdust	13-240	0.0649
Vermiculite (granulated)	128	0.0721
Polyurethane foam (rigid)	24	0.0245
[illegible] (expanded)	16	0.0303

CHAPTER FOUR

The laws of thermodynamics (first and second laws) are of practical restrictions to the efficiency of energy transformation, particularly that such transformation from one to another can never abtain a 100% efficiency. The results obtained in this project are proofs of these fundamental thermodynamic laws.

Generally, weather conditions was noted to have considerable variability hourly, daily, and yearly thus a solar system of this project, may not necessarily perform according to expectations at all times.

Tests on drying were carried out using fresh tomatoes, which reflected the local harvest practice. Tomatoes were weighed and put in the drying house. Succeeding changes in weights were recorded at a time interval of two hours. An open air-sun drying was also carried out as a control, while changes in weight were recorded simultaneously with ones in the drying house.

The ambient and drying house temperatures were recorded at the same time interval for weights recording.

TEST RESULTS

Tables 4 (a) to 4(c) give the weights of tomatoes tested, the moisture removed every two hours and the total moisture removed per day.

It is evident that the drying rate of the drying house was far more than that of open sun-air drying. It was also observed that temperature of up to 54°c can be obtained in drying house.

The ambient and drying house temperatures were taken at the same interval of time for weights recording.

Tables 4(a) to 4(d) give the ambient and drying house temperatures. From the table it is evident that the drying rate of the drying house was far more than that of the open-sun-air drying. It was also observed that temperature of up to 35°c can be obtained in the drying house.

For instance, on 31/3/94, the total moisture removed from the open-sun drying was 10.54 grammes whereas the drying house recorded not less than 14.53 grammes. For the result obtained on 31/3/94, the average amount of water removed per weight of tomatoe was 54.7% wet basis of tomato while the control open air-sun drying was 66.7% wet basis of tomatoe. A difference of 0.12g of tomatoe is the advantage.

RESULT DEDUCTION:

Since the temperature obtainable from the drying house is above 50°c, it can be used for a variety of farm crops drying. It can equally be useful for yams, mello, okro, amaratus, and other leafy vegetables. Desired temperature range can be effected if a gate is provided at the collector inlet either to increase or reduce the amount of air passing through the collector.

Table 4a: All temperature reading are in cent igrades

Solar Dryer Temperature and observations

T_1 = ambient temperature

T_2 = Drying house temperature

Time of day	T_1	T_2
Day 1: 28/3/94		
9.00	31	40
10.00	33	42.5
11.00	35	56
12.00	36	70
13.00	36.5	67
14.00	32	60
15.00	32	50
16.00	37	49
17.00	38	47
18.00	38	44

TABLE 4b

Time of day	T_1	T_2
Day 2: 29/3/94		
9.00	30	41
10.00	33	45
11.00	35	60
12.00	35.5	71.5
13.00	35	70.0
14.00	37	61
15.00	37	60
16.00	36	55
17.00	36.5	52
18.00	37	43

Table 4c:

Time of day	T_1	T_2
Day 3: 30/3/94		
9.00	26	38
10.00	30	50
11.00	32	59
12.00	36	69
13.00	36	63
14.00	37	62

tAble 4c: cont.

day 3: 30/3/94		
15.00	36	53
16.00	36	52
17.00	35	48
18.00	35	43

Table 4d:

Time of Day	T_1	T_2
Day 4: 31/3/94		
9.00	31	40
10.00	33	42
11.00	34	53
12.00	36	71
13.00	36	67
14.00	36	70
15.00	37	50
16,00	37	50
17.00	36.5	47
18.00	36	43

Mioisture removed in grammes (g) = M.R

Tomatoe weights and moisture removal (grammes)

Table (e)

Time	Solar dryer	M.R	SunΘdrying	M.R.
30/3/94				
9.00	253.29	-	253.34	-
11.00	250.85	2.44	251.66	1.68
13.00	219.42	31.43	226.26	25.40
15.00	153.65	65.77	181.24	45.02
17.00	138.64	15.01	169.02	12.22
Total M.R/day		114.65		84.32

Table 4(f)

Time	Solar dryer	M.R.	Sun-drying	M.R.
Day 2: 31/3/94				
9.00	265.84	-	265.43	
11.00	248.36	17.48	249.32	16.11
13.00	198.26	50.10	206.06	43.26
15.00	166.98	31.28	176.79	29.27
17.00	153.97	13.01	166.11	10.68
Total M.R/day		111.87		99.32

CHAPTER FIVE

1 CONCLUSION AND RECOMMENDATION

1. CONCLUSION

Temperatures as high as 71.5°c was obtained at the drying house which can be used for the drying of agricultural products. It was found out after testing that solar dryer is more efficient for drying than the open-air-sun drying. It can also be used for the drying of fish. The moisture content removed by solar dryer was of average 0.12g than that of open-air-sun drying.

1.1 RECOMMENDATIONS

Potential effects of providing a variable gate at the collector air inlet, should be studied. Providing avariable gate allows air amount variation, hence, allows variable drying house performance for variety of crops.

2. A more thorough evaluation of the system should be carried out. This could be determined in this project because it was of a short-time evaluation.

3. The use plexiglass or polythene as cover material instead of glass because of availability and cheapness.

APPENDIX

Estimated daily mean solar Radiation for Minna

Month	Hm (MJ/M^3/day	Ic (W/m^2)
January	21	743.83
February	24	800.03
March	24	856.82
April	24.50	879.64
May	22	870.54
June	21	853.44
July	19.5	854.99
August	20	865.48
September	19.0	852.35
October	18.50	829.08
November	20.50	770.71
December	19.20	726.42

Mean $\frac{9903.33}{12}$

$= 825.277 \text{ w/m}^2$

In the above interpolation, average day-light was taken at 12 hours.

REFERENCES

BOOKS

1. Anderson, Bruce: Solar Energy: Fundamentals in Building Design, New York: M C Graw-Hill (1977)

2. Beckman, W. A. et al. Solar Heating Design, New-York: John Willey and Sons (1977)

3. Beckman, W. A, and Duffie, J. A: Solar Engineering of Thermal Processes, New York: John Wiley (1980)

4. Bonar, W.D. and Moris, N: Understanding our Atmospheric Environment, San Francisco: W.H. Freeman and Company (1973)

5. Carl, W. Hall: Drying Farm Crops. Agricultural Consulting Associates, Inc (1957)

6. Callaghan, P.W.O.: Design and Management for Energy Conservation, New York: Pergamon Press Inc (1981)

7. Dixon, A.E. et al: Solar Energy Conversion - An Introductory Course, Canada: Pergamon Press Inc (1978)

8. Craig, B. S: Energy Management Principles New-York: Pergamon Press Inc. (1981)

9. Kreith, F. and Krender, J. F.: Principles of Solar Engineering, USA: Hemisphere Publishing Corporation (1978)

10. Kreith, F. and Kreider, J. F.: Solar Heating and cooling, Washington DC: Hemisphere publishing Press Corporation (1977)

11. Schubert, R. C. and Ryan, L.D.: Fundamentals of Solar Heating, New York: Prentice - Hall Inc (1927)

12. Sherrat, A.F. C.: Application of Ambient Energy in Buildings: London: J. W. Arrowsmith Ltd (1983)

13. Soyigh, A.A.M. Solar Energy Engineering New York: Academic Press Ltd. (1977)

JOURNALS AND OTHER RESEARCH PAPERS

13.

14. Arnoye, O. S.: Design, fabricated and Testing of a Solar Dryer. Project Report Ibadan (1984)

15. Aránza, E. A.: Design and Construction of a Solar Crop Dryer and Thermal Storage system. Original report Nsukka (1983)

16. Bamiro, O. A. and Ideriah, F. J. K. : Determination of the Optimum Collector orientation for Ibadan, Nigeria Nigeria Journal of Solar Energy Vol. 4 (1985)

17. Brown, G. L.: Design, Construction and Performance of a Solar Agricultural Dryer A final year undergraduate project Report, University of Ibadan (1981)

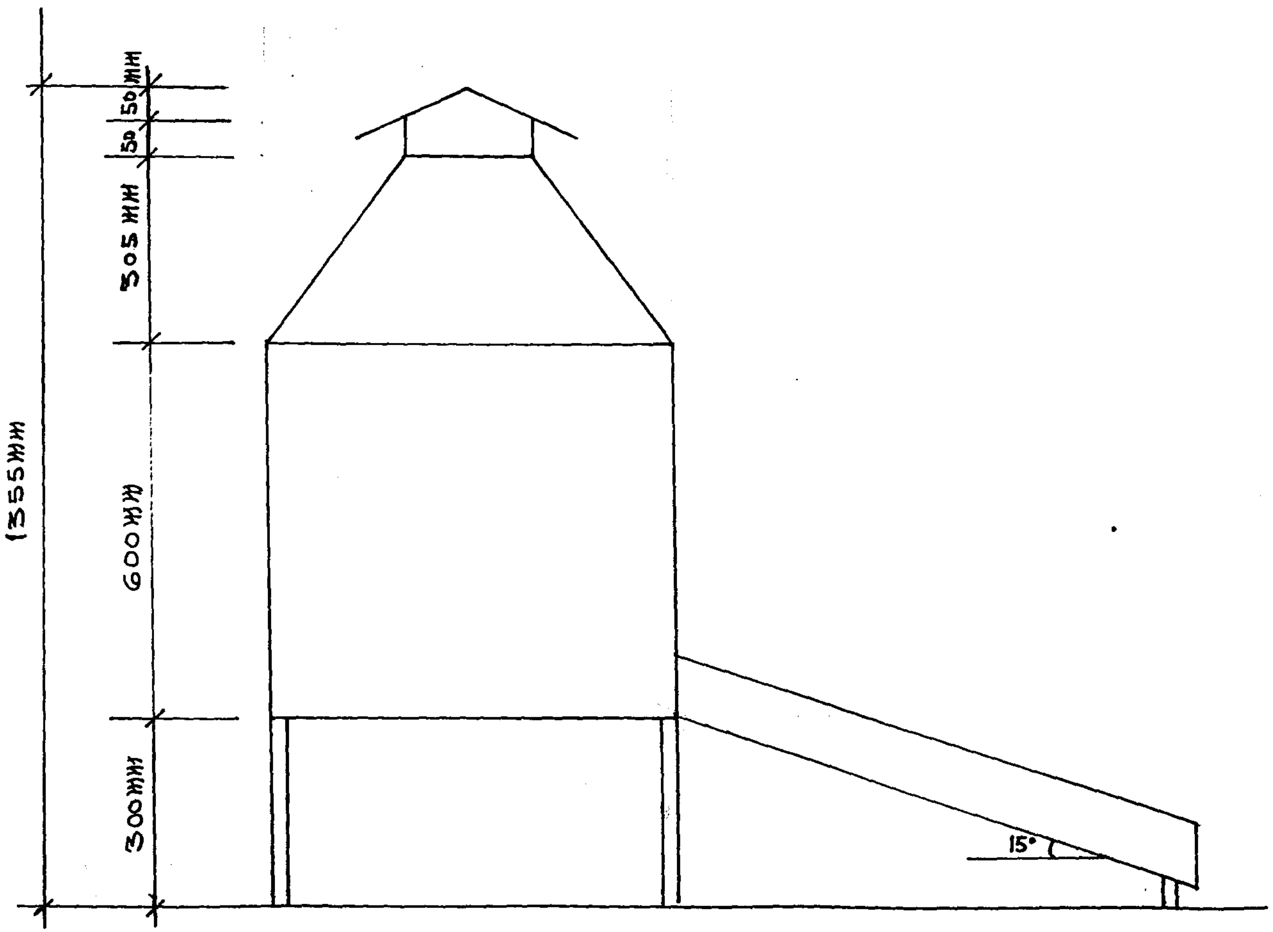
18. Igbeka, J. C.: Solar Energy Utilization for Drying Agricultural Products Paper presented at the International Symposium on Solar Energy Utilization, Ontario, Canada, (1980).

19. Mohammed, G.A.O. : Design and Construction of a flat plate passive Solar Energy Crop Dryer; A final year undergraduate project report, University of Ibadan, (1981).

20. Ofi, O.: Construction and Evaluation of a Solar Dryer Journal of Solar Energy, Vol. 4 page 47 - 59 Published by Solar Energy of Nigeria, Zaria (1982)

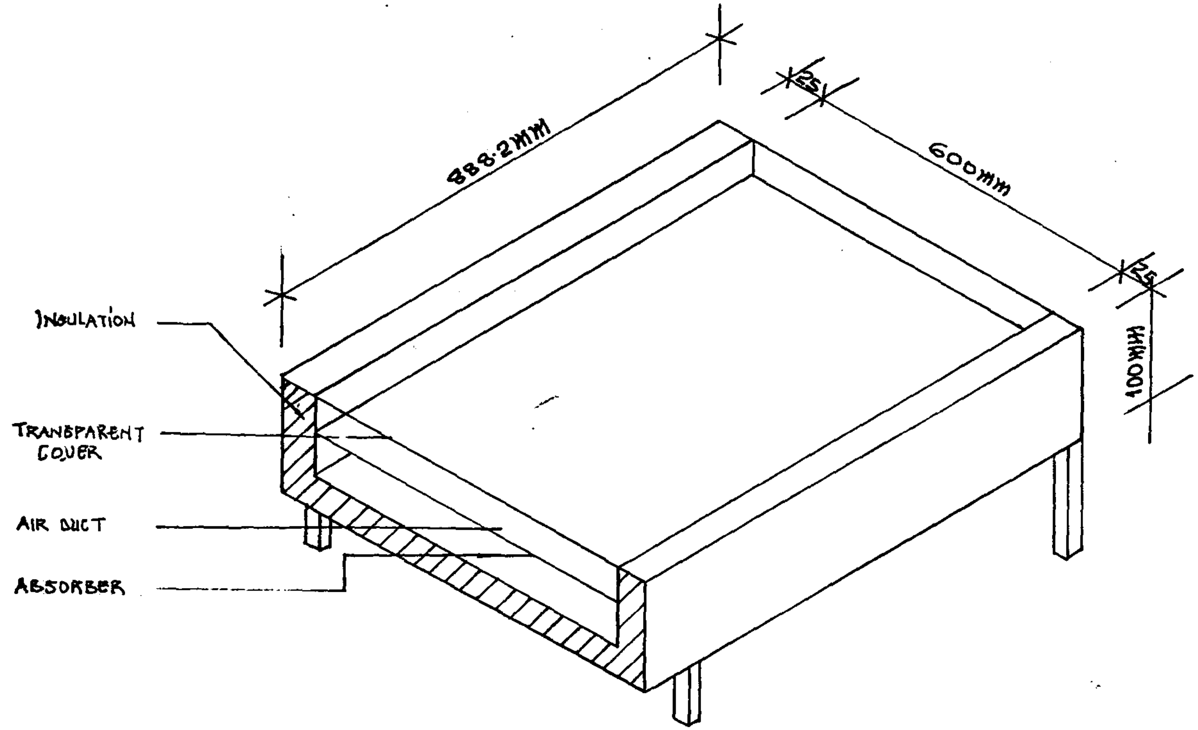
21. Osunde, Z. O. and Oje K.: Computer simulation of available Solar radiation on Horizontal collectors case study of Minna. A paper presented at the annual conference of the NSAE FUT, Minna 17 - 20 November, 1992

22. Owokoya O. Design and Construction of Solar Air Heater. A final year undergraduate report, Federal University of Technology, Minna, (1992).



DRYING HOUSE ELEVATION

Notes.		
SCALE 1:10		
DESIGNED BY	TRACED BY	CHECKED BY
Umar A.I		Osunde & Onuachu

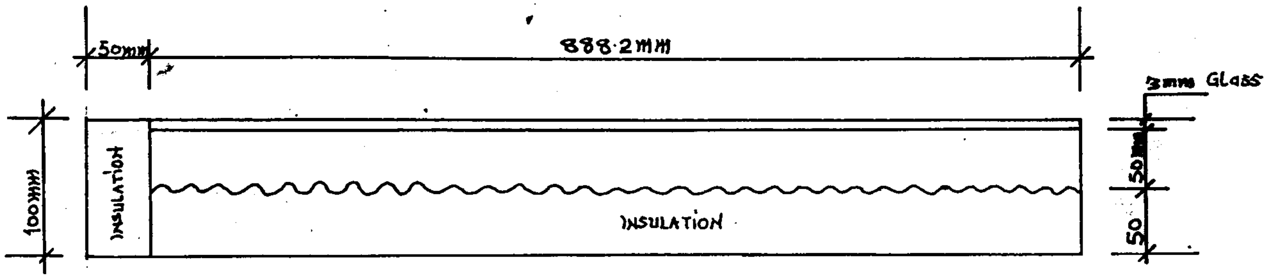


SCHEMATIC DESIGN OF SOLAR COLLECTOR.

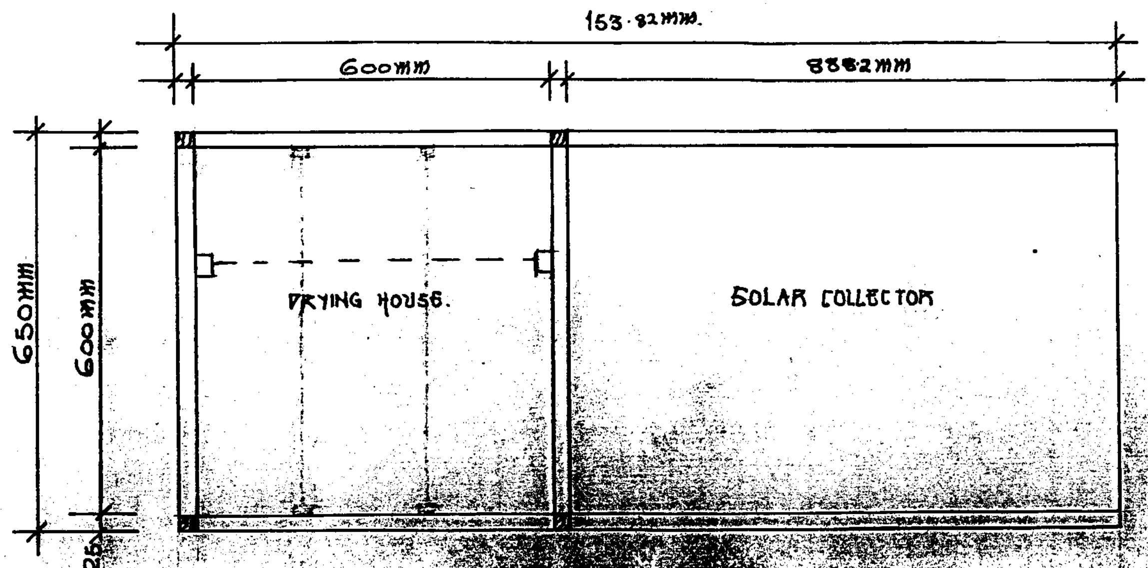
Notes

SCALE 1:10

DESIGNED BY	TRACED BY	CHECKED BY
Umar A.I		Mrs. Osunde & Mr. Onuachu



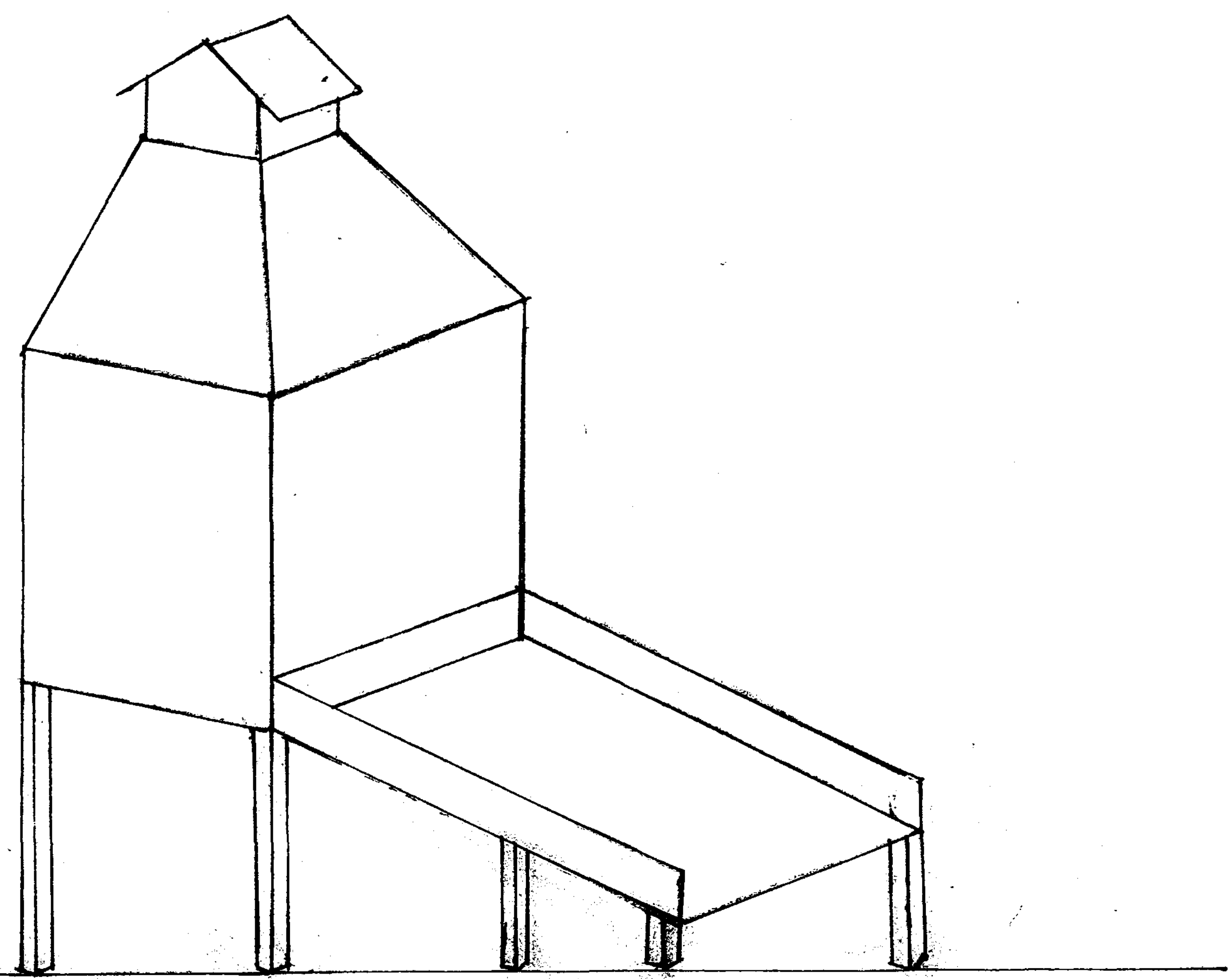
CROSS SECTION OF SOLAR COLLECTOR (1:5)



DRYING HOUSE PLAN (1:10)

Notes

SCALES 1:5 & 1:10		
DESIGNED BY	TRACED BY	CHECKED BY
Umar A.I		Mrs. Osunde & Mr. Onuoche



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