FACULTY OF ENGINEERING

DEPARTMENT OF AGRICULTURAL MECHANIZATION AND IRRIGATION ENGINEERING

FINAL YEAR PROJECT REPORT

DESIGN AND FABRICATION OF A DOMESTIC SOLAR DRYER FOR BANANA FRUITS

BY

NAKANYIKE REGINA MARY

BU/UG/2012/1771

regina.nakanyike@yahoo.com

+256 779 208 100 / +256 706 415 698

MAIN SUPERVISOR: MR. OWAA JOHN ELIAS SULTAN

CO-SUPERVISOR: DR. CATHERINE WANDERA

SUBMITTED IN PARTIAL FULFILMENT FOR THE AWARD OF A BACHELOR OF AGRICULTURAL MECHANISATION AND IRRIGATION ENGINEERING OF BUSITEMA UNIVERSITY

MAY 2016.

DECLARATION

I ***Nakanyike Regina Mary BU/UG/2012/1771,*** declare that this project report is my original work organized with the help of my supervisors and has never been submitted to any institution of learning for any academic award.

Signed: ....Nakanyike..........

Date: ....17/05/16..........

APPROVAL

This is to certify that ***Nakanyike Regina Mary*** prepared this project report under my supervision and is now ready for presentation to the Department of Agricultural Mechanization and Irrigation Engineering of Busitema University for an award of a Bachelors degree of Agricultural Mechanization and irrigation engineering with my approval.

Signature: ....

Mr. Owaa John Elias Sultan

Date 18/05/2016

MAIN SUPERVISOR

Signature: ....,

Dr. Catherine Wandera

Date.../........./...........

CO-SUPERVISOR

DEDICATION

I dedicate this report to my daughter Tabitha, my mother Mrs. Justine Nsubuga, my brothers and sisters.

ACKNOWLEDGEMENT

First and foremost I thank the almighty God who has been with me since I started this project work; glory and honour be unto Him.

I am greatly indebted to my project report supervisors Mr. Owaa John Elias Sultan and Dr. Catherine Wandera who tirelessly advised and guided me throughout the preparation and organization of this project report; may the almighty God reward them abundantly.

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Lastly I thank my friends and family members my mother Mrs. Justine Nsubuga, my husband Mr. Ayebare Joseph, my father Mr. Nsubuga Edward, my brothers and sisters, classmates and friends for the moral, financial, and spiritual support they offered me during the preparation and organization of this project work; may you live to see God's goodness in this land of the living.

EXECUTIVE SUMMARY

Many farmers of the world are faced with the problem of reducing the moisture content of their harvested crops to prevent spoilage during storage (Bukola and Bolaji, 2008); banana is one of the most important crops in Uganda with 16 million people depending on the plant as a source of food and income (Kikulwe, 2008). According to (Byarugaba, 2000), Uganda produces a lot of cooking bananas of lack of value addition most of it goes to waste. Well as traditional sun drying is the oldest, simplest and widely used method, it is unhygienic and time consuming. In addition, the direct mode dryers being used are associated with long drying hours and loss of the product quality. Improved sun dryers are expensive because they require more than one energy source. A solar dryer utilizing energy from the sun and a slotted air chamber for proper heat distribution to drying trays in the drying chamber was designed, fabricated and tested in this study and was be for use by farmers for drying of bananas in rural areas of Uganda and at the domestic level.

The production potential of bananas in Uganda, characterization of bananas varieties grown in Uganda as well as the different drying methods and technologies were presented in chapter two of this study; additionally the different ways in which dried banana products could be utilized were presented.

Chapter three presented the various methods and tools that were used in achieving the objectives of the study which included; characterization of the banana varieties grown in Uganda, design of a solar dryer for drying bananas, fabrication of a prototype of the solar dryer as well as performance testing and economic evaluation of the dryer.

The major findings and discussion of the results from the performance testing of the dryer were presented in chapter four of this report.

Chapter five presented the challenges faced in carrying out this study, the conclusions as well as recommendations.

This report also contains lists of references and appendices

ACRONYMS

hrs	hours
i.e	that is to say
m^2	square meter
m^3	cubic meter
e.t.c	etcetera
J/Kg	Joules per Kilogram
MT	million tones
g	grams
e.g	for example
NPV	Net Present Value
ppm	parts per million
kJ	Kilo joule
W/m^2	Watts per meter squared
FAO	Food And Agricultural Organisation
UNCST	Uganda National Council for Science and Technology
Lat	Latitude

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CHAPTER ONE

1.0 Introduction

This chapter presents the background to the study, problem statement, objectives, justification, purpose, as well as scope and limitations of the study.

1.1 Background

Most of the farmers of the world are normally faced with the problem of reducing the moisture content of their harvested crops to prevent spoilage during storage. The situation is worse for farmers in the rural areas of developing countries where there is no access to electricity and harvested crops are often stored in heaps (Bukola and Bolaji, 2008). Banana is one of the most important crops in Uganda with 16 million people depending on the plant as a source of food and income (Kikulwe, 2008). According to (Byarugaba, 2000), Uganda produces a lot of cooking bananas of lack of value addition most of it goes to waste; thus losses from bananas as an agricultural produce in banana growing in the rural areas of Uganda are an important issue. The practical use of the energy from the sun for the purpose of drying agricultural products will go a long way in reducing post-harvest losses (Lawrence, 2013).

Traditional sun drying is one of the oldest, simplest and widely practiced drying method by local farmers in the rural areas. The process requires relatively low capital investment, large drying area, is time consuming and is generally unhygienic. Mechanized dryers, which are of recent being preferred to the traditional open air sun drying process, are much faster in drying process, use less drying area, but require a substantial quantity of fossil fuels or electricity to operate which makes it energy intensive (Ertekin and Yaldiz, 2004; Giri and Prasad, 2007; Ajao and Adegun, 2009; Yesilata and Aktacir, 2009). However, the ever rising cost of electricity and natural fuels coupled with the growing concern about their availability in both the short and long terms, has resulted in growing interest in the use of renewable resources especially solar energy; in both direct and indirect forms (Adaramola *et al.* 2004; Koua *et al.*, 2009); most of the solar dryers are however associated with high humidity levels in their drying chambers that results in longer drying hours of the crop under consideration.

A solar dryer utilizing energy from the sun and a slotted air chamber for proper heat distribution to drying trays in the drying chamber was designed, fabricated and tested in this study and will be for use by farmers for drying of bananas in rural areas of Uganda and at the domestic level.

1.2 Problem Statement

The banana growing areas of Uganda lack improved postharvest handling methods for bananas resulting in continued wastage of bananas in terms of quality and quantity. The direct mode dryers being currently used are associated with high humidity levels, longer drying hours and loss of the organoleptic properties of the food product at the end of the drying period. Well as the somewhat improved dryers are being used, they are expensive as they require more than one energy source in addition to solar energy because they use fans which require electricity in order to run.

1.3 Objectives of the Study

1.3.1 Main Objective

To design and fabricate a domestic solar dryer for banana fruit.

1.3.2 Specific Objectives

i. To characterize the banana varieties in Uganda
ii. To design a solar dryer for drying bananas
iii. To fabricate a prototype of the designed solar dryer
iv. To test the performance of the dryer
v. Economic analysis of the dryer

1.4 Justification

Banana is a perishable fruit and it is easily wounded, contaminated during handling and transportation well as its quality is deteriorated at high temperature and relative humidity. Therefore the domestic solar dryer for banana fruit to be designed in this study will dry and maintain the quality of the bananas thus increase shelf life of the bananas and will make the bananas easy to transport because of reduced bulkiness, towns will be lifted of the burden of the garbage resulting from peelings and bananas will be available as food in the future.

1.5 Purpose of the study

The study will focus on the design and fabrication of a domestic solar dryer for banana fruit using relatively cheaper, easy to work with and readily available materials; the implementation of use of this dryer will help increase incomes of farmers through sale of dry banana to industries that make banana by – products and will be a solution hunger in Uganda. Additionally, this will help reduce accumulation of banana bio waste in those towns that consume it. Value addition to bananas in this way will also increase on the government revenue.

1.6 Scope and limitations of the study

This study was limited to the design, fabrication, and testing of a domestic solar dryer for banana fruit; the solar dryer that was designed was limited to drying only raw peeled and sliced green bananas. The drying equipment was made of relatively cheap, easy to use and readily available materials.

CHAPTER TWO

2.0 Literature Review

The production potential of bananas in Uganda, characterization of bananas varieties grown in Uganda in terms of their physical and chemical characteristics as well as the different drying methods and drying systems applicable to bananas are presented in this paragraph. Additionally the different ways that dried banana products can be utilized are presented.

2.1 Production Potential of Bananas in Uganda

The According to (UBOS, 2010), the national production of banana (food type) during the period under reference was estimated was 4 million MT from a total area of 807,000Ha. In terms of regions, the Western Region reported the highest production of banana (food – type) with a total output of 2.7 million MT .Isingiro district with 597,000 MT from 45,000 Ha reported the highest production of banana (food – type). This was followed by Mbarara with a production of 540,000MT from 32,000 Ha and then Bushenyi (344,000 MT from 110,000 Ha).

2.2 Characterization of Bananas varieties grown in Uganda

Bananas grown in Uganda are characterized according to sugar and moisture contents; those that have got a high sugar content are mostly eaten raw as dessert bananas well as those with high moisture content are used for juice extraction; bananas with moderate moisture and sugar contents are cooked and eaten as food.

2.3 Preparation steps of bananas for drying

Steps involved in preparing bananas for drying are explained below:

Washing; a relatively large container filled with water containing 15 ppm chlorine is used to wash the bananas in order to remove any dirt and pathogens that could be on the banana fruit; another washing is recommended so as to wash the chlorine off the fruit.

Peeling and cutting; banana pulp is separated from the banana peels by using stainless steel knives; this is done manually on a working bench. The banana fruits are then sliced lengthwise to a thickness of about 3mm.

Pretreatment before drying; according to (Rozis, 1997), it is recommended to either soak the banana slices in lemon juice of lemon per liter of water for about 5 hours or; to soak the banana slices in sweet lemon water (juice of a single lemon and 700g of sugar per liter of water)

Drying; the sliced banana fruits are displayed on dryer trays and then loaded into the dryer.

2.4 Parameters that affect drying

The following are the parameters that affect the drying of bananas:

i) Environmental Parameters

The drying rate is dependent upon three major factors, namely:

Air temperature; the rate of drying increases with the increase in air temperature and vice versa, however, the equilibrium moisture content falls as air temperature increases. This means that, the rate at which moisture is absorbed from the surrounding is lowered and this in turn leads to a high drying rate as the rate at which moisture loss from the food product to the environment occurs is increased.

Air velocity; high air flow velocities lead to faster drying rate well as low flow velocities lead to low drying rates as the rate of moisture removal is low.

Effect of air humidity; when the humidity of air increases the rate of drying decreases; this is because there is a low capacity of the air to absorb moisture from the crop. This moisture in turn is instead added to the crop being dried making the product being dried damp.

ii) Physical parameters

Physical parameters of banana fruits that affect the drying rate include: an initial moisture content of 74% a recommended final moisture content of 15%, maximum temperature of 70 ^{0}C, a drying ratio of 1/10 without preliminary soaking and 1/5 after preliminary soaking (Rozis, 1997).

2.5 Banana fruit sun dryers

- **Traditional sun dryer**

In this method, the crop to be dried is placed on ground or on mats and tarpaulins and left to dry; the product is taken and kept from the night humidity and from rains. This method is rudimentary and exposes the drying crop to contamination, attack by insects and rodents and loss of product quality because of the direct heat from the sun; however, it remains the cheapest and most common method of drying (Megha, 2015).

- **Improved Solar dryers**

i) Direct solar dryers

A direct solar dryer is one in which the material is directly exposed to the sun's rays; this dryer comprises of a drying chamber that is covered by a transparent cover made of glass or plastic. The drying chamber is usually a shallow, insulated box with air holes in it to allow air to enter and exit the box. The product samples are placed on a perforated tray that allows the air to flow through it and the material (Murthy, 2009). Figure 2.5 below illustrates the principle used by direct mode dryers.

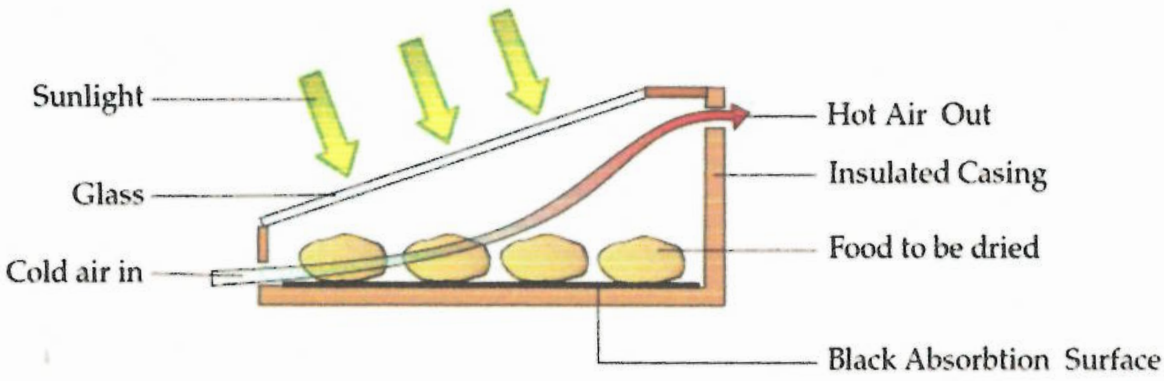

Figure 2.5 Operation principle of a direct solar dryer (Karthikeyan, 2013)

ii) Indirect solar dyer

The solar radiation gained by the system is utilized to heat the air which flows through the product to be dried in this dryer. Heated air is blown through the drying chamber. At the top of drying chamber vents are provided through which moisture is removed (Umesh, 2013).

iii) Mixed mode dryers

These types of solar dryers use a combined action of the solar radiation incident directly on the material to be dried and the air pre-heated in the solar air heater that provides the energy required for the drying process (Megha and Sanjay, 2015).

iv) Greenhouse solar dryers

With these types of solar dryers, the banana slices to be dried are placed on the floor / platform of the green house and the banana slices are dried as a result of the greenhouse effect.

2.6 Drying methods applicable to bananas

According to mode of heat transfer, drying methods can be divided into:

a) Conduction Drying: In this method, conduction is the principal mode of heat transfer and the vaporized moisture is removed independently of the heating media.

b) Convection drying can be classified as;

i) Natural air drying where the unheated air as supplied by nature is utilized.

ii) Supplemental heat drying; drying with supplemental heat just sufficient to cause a temperature rise from 50 to 100^0 C and this heat is supplied to drying air.

iii) Heated air drying; where air is heated to a considerable extent.

c) Radiation drying; radiation drying is based on the absorption of radiant energy of the sun and its transformation into heat energy by the crop; sun drying is an example of radiation drying.

2.7 Dried banana products' utilization

Dried bananas in Uganda bananas can be processed into other products such as figs and flakes by drying ripe bananas. Green bananas can be dried into chips, which can later be reduced into flour; which can then be used to make many different bakery products e.g biscuits, cakes or to make fried products, or made as ugali (Mukiibi, 2001).

CHAPTER THREE

3.0 Methodology

This chapter presents the various methods and tools that were used in achieving the objectives of the study which included; characterization of the banana varieties grown in Uganda, design of a solar dryer for drying bananas, fabrication of a prototype of the solar dryer as well as performance testing and economic analysis of the dryer.

3.1 Objective 1: Characterization of the banana varieties grown in Uganda

There are a variety of bananas grown in Uganda; however, those that are suitable for cooking were characterized in terms of moisture, size, starch and fiber content so as to able to determine which the most suitable variety for drying was. Table 3.1 below represents how the different varieties will be characterized.

Table 3.1 Characterization of the banana varieties in Uganda

Characteristics	Varieties		
	A	B	C
Moisture content			
Size			
Starch content			
Fibre content			

3.2 Objective 2: Design of the solar dryer

3.2.1 Design considerations of the dryer

The design considerations that were made included the following;

- The dryer ensured that the product quality was maintained.
- Cost effectiveness of the dryer was ensured by fabricating the dryer from readily available materials.

- The design process ensured that the dryer can be operated with minimum skills,
- The dryer design and selection of materials ensured that the dryer required minimum maintenance costs.

3.2.2 Design of the solar dryer components

3.2.2.1 Design of the solar collector

The purpose of the solar collector in this banana dryer prototype was to heat the air to be used for drying the banana slices. The capture of heat and the thermal conversion to heat were completed by the greenhouse effect; this collector consisted of a cover material whose purpose was to transmit the solar radiation which was then absorbed by the blackbody; the heat that was absorbed was used to heat the air to a temperature sufficient for drying. A gap was left between the cover material and the absorber plate to ensure effective air circulation. The properties that defined a cover material required in the design were transmittance, absorbance, α, and emittance. Well as the property that defined the absorber surface was; the total heat flux that is emitted, E_b. by the black body. Therefore the parameters that were considered in the design of the solar collector included; energy emitted by a black body, the solar radiation intensity, collector overall heat loss, useful energy gained by the collector, collector overall heat loss, area of the solar collector, air mass flow rate over the absorber surface and angle of inclination of the solar collector.

a) Energy emitted by a black body

The Total heat flux emitted by a black body during thermal radiation is given by equation (1)

$$E_b = \delta T^4 \qquad \text{..(1)}$$

Where:

E_b - is the total heat flux emitted

T - is the temperature of the black body

δ - is Stefan – Boltzmann's constant = 56.7x 10 $^{-12}$ (kW/m ^{2} /K ^{4})

b) Solar radiation intensity

The total solar radiation, I_T on the solar collector surface was obtained from equation (2) and by considering Lambert's law which states that the total radiation which passes through the hemispherical surface of the earth is constant and is only maximum when the latitude $\phi=0^0$ and zero when $\phi=90^0$.

$$I_T = \frac{\delta T^4}{\Pi} \quad \text{...(2)}$$

Where;

I_T - Total solar radiation (W/m^2)

Π - pie (a constant)

c) Solar Collector overall heat loss

Thermal loss from the collector to the surrounding was considered to occur by conduction, Convection and radiation. The heat loss from the plate through the glass cover was considered as the top loss, from the plate through the insulation as the back loss and the side of the collector casing as the edge loss. Thus the overall heat loss coefficient U_L, was the sum of the top, back and edge loss coefficient and was given by equation (3) according to (Tiwari, 2002).

$$U_L = U_T + U_b + U_e \quad \text{...(3)}$$

Where;

U_L - Collector overall loss coefficient (W/m^{2}K)

U_T - top loss coefficient (W/m^{2}K)

U_b - back loss coefficient (W/m^{2}K)

U_e - edge loss coefficient (W/m^{2}K)

d) Useful heat gain

The maximum possible useful energy gain in a solar collector occurs when the whole collector is at the inlet fluid temperature (Lawrence, 2013). The useful energy absorbed by the solar collector was obtained from equation (4) according to (Duffie, 1991).

$$Q_u = m_a c_p (T_o - T_i) \text{...(4)}$$

Where;

Q_u	-	useful energy trapped by the soar collector (J)
m_a	-	mass of flow rate of air (Kg)
c_p	-	specific heat at constant pressure (kJ/Kg^{0}C)
T_o	-	air temperature at the outlet of the solar collector in ^{0}C
T_i	-	air temperature at the inlet of the solar collector in ^{0}C

e) Actual useful gain

The actual useful energy gain was determined by multiplying the collector heat removal factor F_R by the maximum possible useful energy gain ,Q_u, and the expression is known as the "Hottel Whillier -Bliss equation according to (Duffie, 1991) as cited in (Lawrence, 2013).

$$Q_a = F_R A_c \left[I_T (\tau\alpha) - U_L (T_i - T_a) \right] \text{.......................................(5)}$$

Where:

Q_a	-	actual useful energy (Joules)
T_a	-	is the ambient temperature (^{0}C)
F_R	-	Collector heat removal factor
τ	-	Transmittance of absorbing material and absorber plate
T_i	-	Inlet temperature (^{0}C)
U_L	-	Overall collector heat loss coefficient
A_C	-	Collector surface area
I_T	-	Total solar radiation (W/m^2)
α	_	Absorbance of absorbing cover and absorber plate

f) Area of the solar collector

This was obtained as A_c from equation (6) as

$$A_c = \frac{Q_a}{F_R[I_T(\tau\alpha) - U_L(T_i - T_a)]} \quad \text{...(6)}$$

g) Air mass flow rate on the absorber plate

The mass flow rate of air on the absorber plate was determined by considering the average air speed of the test location and was obtained from equation (7) below according to (Lawrence, 2013).

$$V = V_a hb \quad \text{...(7)}$$

Where;

V_a - Ambient air velocity (m/s)

h - Air gap height (m)

b - Collector breadth (m)

Thus the mass flow rate of air, m_a, was obtained from equation (8)

$$m_a = \rho_a V \quad \text{...(8)}$$

Where; ρ_a =1.2kg/m^3

The thermal efficiency, η_c of the solar collector was defined from equation (9) below according to (Itodo *et.al*, 2002).

$$\eta_c = \frac{Q_u}{A_c I_T} \quad \text{...(9)}$$

Angle of inclination of solar collector

The angle at which the solar collector was inclined to the horizontal obtained from considering equation (10) according to (Duffie, 1991).

$$\alpha = lat\varphi + 15 \quad \text{...(10)}$$

Where; lat $\varphi = 0.68^0$

α is the angle of inclination

3.2.2.2 Design of the drying chamber

The drying chamber in this dryer model had drying trays where the banana slices to be dried were placed; these were separated by a gap, x, such that condensations of the moisture from the bananas did not take place; x ranges between 0.1 to 0.2m (Phardi, 2013). The parameter that defined the capacity and size of the drying chamber was the actual heat required to dry the bananas and was computed from Equation (11), basing on basic principles of heat transfer by (Karlekar and Desmond, 1982).

$$Q = m_b c_b (T_o - T_i) + m_w L \qquad (11)$$

Where;

m_b - mass of the banana slices (Kg)

c_b - Specific heat capacity of the banana equal to 3.35 kJ/Kg^{0}C

T_o - Temperature at outlet of solar collector /^{0}C

T_i - Air temperature at the solar collector inlet / ^{0}C

L - Latent heat of vaporization of water in kJ/kg = 2260kJ/kg, from Liley, 1997

m_w - Mass of water to be removed from the bananas (Kg)

The drying rate was obtained from equation (12)

$$m_{dr} = \frac{m_w}{t} \qquad (12)$$

Where:

m_{dr} - drying rate in Kg/hr

3.2.2.3 Designing the drying trays

These were used to hold the banana slices during drying; they were to be made to have a base that would not deteriorate the properties of the banana slices during .The number of the drying trays that were made for this dryer were to be determined physically by considering the height of the drying chamber. The parameter that defined the size of the drying trays was the bulk density of the raw peeled green banana.

Designing the loading door

The loading door was to be dimensioned basing on the overall height of the dryer considering an effective fit and the drying chamber to enable ease of loading the banana slices for drying. The parameter that defined the size of the loading door was the height of the drying chamber, h, the width of the dryer ,w, and the width of the drying tray.

Designing the Slotted Air chamber

The volumetric flow rate of air was considered to be the sum of the volumes of the individual air slots to the drying trays. Parameters that were considered in their design included;

- The mass flow rate of air into the solar collector box ,m_a
- The quantity of heat required to dry the banana slices ,Q
- The number of the drying trays, n

Dryer Frame

The dryer frame formed the skeleton onto which the rest of the drying components were mounted; it was also responsible for holding the drying trays. The material that formed the dryer walls was determined from the need for additional heating according to (Bukola, 2011) or if additional heating was not necessary. Therefore the parameters that defined the dryer frame were the weight of the dryer components, the quantity of heat required for drying the bananas and the thermal properties of the cover material.

Design of the solar chimney

The solar chimney was necessary for exiting the air after drying the bananas; the solar chimney works in a way that it traps heat from the sun and transmits part of it to the air circulating around it. The air which is at the top of the chimney and which has been heated is warmer than the air from the drying chamber. Thus according to thermodynamic and Archimedes' principles, the heated air at the top is less dense than the incoming air from the dryer. Thus it is pushed out by difference in pressure. The parameters that defined the size of the solar chimney was the chimney height, h, and its diameter, d.

3.3 Objective 3: Fabrication of the designed solar dryer

3.3.1 Material selection

The material that was used in fabricating this solar dryer was chosen basing on the following:

- Thermal properties,
- Solar radiant properties,
- Availability of the material
- Cost of the material

3.3.2 Fabrication of the different components

Table 3.3 below represents the proposed material, possible fabrication methods and tools that would be used in fabrication the different solar dryer components.

Table 3.3 Fabrication of the different components

Component	**Sub component parts**	**Proposed Material**	**Possible Fabrication methods**	**Fabrication tools**
Solar collector	- Cover material	glass, metal sheet, polythene sheet	Glass cutting, grinding, welding, cutting	Glass cutter, metal grinder, welding machine
	- Absorber plate	Wood, metal	Cutting, grinding	Wood saw, grinder

	- Collector box	Metal, wood	Cutting, grinding	Wood saw, metal grinder
Dryer frame	- Frame skeleton - Cover material	Wood, metal, plastic sheet	Cutting, grinding	Wood saw, metal grinder
Drying chamber	- Tray rails	Wood, metal	Cutting, grinding	Wood saw, metal grinder
Slotted air chamber	-	Wood, metal	Cutting, grinding	Wood saw, metal grinder
Drying trays	- Base - Tray walls	Plastic nets, stainless steel nets, aluminum nets, wood and metal for the tray walls/ guards	Cutting, grinding	Wood saw, metal grinder
Chimney hood		Wood, metal - Proposed Shape (rectangular, trapezoidal and cylindrical)	Cutting, grinding	Wood saw, metal grinder
Chimney		- Proposed shapes;	Cutting, bending,	Hack saw, wood saw,

		cylindrical, rectangular - Material: metal, wood	rolling, grinding	welding
Loading door		- Metal, wood	Cutting, grinding	Wood saw, metal grinder

3.4 Objective 4: Testing the performance of the prototype

3.4.1 Testing for dry effectiveness

The dry effectiveness of the banana slices was tested for by determining the amount of water on wet basis that was derived from the dry banana slices after drying as shown in equation (13).

$$M_c\, wetbasis(\%) = \frac{m_f - m_{ds}}{m_f} X100 \quad \text{....................................(13)}$$

Where:

M_c - Moisture content on wet basis (%) derived from the bananas

m_f - Mass of the initial sample of the wet banana slices (Kg)

m_{ds} - Mass of the dry banana slices (Kg)

3.4.2 System Efficiency

The drying system efficiency described the effectiveness of the dryer in drying the banana slices. The parameters that defined the system efficiency were; the quantity of energy required in drying the bananas, the area of the solar collector, the solar radiation intensity and the drying time according to (Hassanian, 2009). Thus the efficiency of the drying system was determined from equation (14) below:

$$n_{ds} = \frac{m_w L + m_b c_b (T_o - T_i)}{A_c I_T t} \quad (14)$$

Where:

m_w	-	Mass of the evaporated water (Kg)
c_b	-	Specific heat capacity of the banana which is about 3.35 kJ/Kg^{0}C
t	-	is the time the banana slices take to dry in seconds
I_T	-	Amount of solar radiation falling on the solar collector in W/m^2
L	-	is the latent heat of evaporation of water (kJ/Kg)
A_c	-	The area of the solar collector in m^2
T_0	-	Temperature of the air at the entrance of the air collector
T_i	-	Temperature at the inlet of the box /^{0}C
m_b	-	mass of the dry banana slices
n_{ds}	-	System drying efficiency

3.4.3 Procedure for testing quality of the product

The quality of the product was evaluated using visual observation by taking into consideration the final colour of the slices and the sound produced when a given slice was being broken. Observations on the ease of breakage were also taken because a fairly dry sample will not give a cracking sound when being broken.

3.4.4 Analysis of performance test results

The analysis of performance test results was done using Microsoft excel through use of graphs to plot the variations in the drying temperature with time, and system efficiency with the different mass of the slices.

3.5 Objective 4 cont'd: Economic Analysis of the dryer

3.5.1 Rate of Return from the dryer

This is the profit from the dryer investment considering a certain period of its use.

This will be calculated using equation (14)

$$ROR = \frac{Profits}{Dryer \quad Cost} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(14)$$

3.5.2 Net Present Value (NPV)

This will be used in estimating the excess of cash follow during the use of the dryer; considering even (frequent) cash flows, equation (15) represents how the NPV valve will be estimated;

$$NPV = RX\frac{1-(1+i)^{-n}}{i} - initial \quad investment \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(15)$$

R - is the net cash flow expected will be received in each period

i - is the required rate of return per period

n - are the number of periods during which the project is expected to operate and generate cash inflows.

CHAPTER FOUR

4.0 Results and discussions

This chapter presents the results, discussions and major findings of the study.

4.1 Objective 1: Characterization of the banana varieties grown in Uganda

The characterization of the banana varieties in Uganda was done by taking into consideration characteristics such as moisture content, starch, fiber content, taste when raw as well as the visual observation of the size of the bananas.

Table 4.1 Characterization of the banana varieties in Uganda

Characteristics	Varieties		
	Cavendish / matooke	Plantain / sukaali ndiizi	Kabana 1&3
Moisture content	70 – 75%	About 80% for the case of Sukaali Ndiizi when ripe and about 70 – 75% for the case of jonga.	About 75%
Size	medium	Smaller and long e.g gonja, sukaali ndiizi is the shortest of all bananas.	Long and bigger than all matooke
Starch content	Starchy	Very starchy than most bananas for the case of gonja and about 1-2% for the case of Sukaali – Ndiizi when ripe.	Very high starch content more than for matooke and less than for plantains

Fibre content	Few	More fibers than for matooke	High fiber content
Taste	Relatively stinging bitter latex	Very sweet	Has strong stinging bitter latex when raw

However, due to lack of documented and reliable information concerning the characterization of banana varieties grown in Uganda, the characteristics above have been based on information that describes the qualitative nature of the bananas. For example cooking bananas have a moisture content of about 70 – 74%; dessert bananas have a moisture content of about 75% well as juice bananas have moisture content of about 80%. Therefore, basing on the above description, the varieties that were considered for this study are the Cavendish variety locally known as Matooke and were taken to have a moisture content of 74% according to (Rozis, 1997) and (UNCST, 2007).

4.2 Objective 2: Design of the solar dryer

4.2.1 Design of the solar dryer components

4.2.2.1 Solar Collector

The purpose of the solar collector in this banana dryer prototype was to heat the air to be used for drying the banana slices. It measured 0.61x0.45x0.15m with the size of the air gap as 0.3mx0.035m; glass was considered as a cover material since it had a high transmittance of 0.6 and absorbance 0.24. The size of the gap between the glass cover and the absorber material to enable proper circulation of air was 0.15m; the solar collector box was made out of wood, with plywood painted black as the absorber surface. The parameters that were considered in the design of the solar collector were:

a) Solar radiation intensity

The amount of solar radiation falling on the surface of the solar collector was determined from equation (1) by considering the total heat flux emitted by the black body and according to Lambert's law thus;

$$I_T = \frac{\delta T^4}{\Pi}$$

$$I_T = \frac{56.7x10^{-12} X318^4}{\Pi}$$

$$=0.18456 \text{ kW/m}^2$$

b) Volumetric flow rate on the absorber plate

The rate of air flow on the absorber surface was computed from equation (7) by considering the ambient air velocity of Tororo according to Climwat FAO, (2005) as;

$$V = V_a hb$$

$$V = 0.18x0.3x0.035$$

$$= 0.00189 m^3/s$$

c) Thus the mass flow rate of air was determined from equation (8) below;

$$m_a = \rho_a V$$

$$m_a = 1.2x0.00189$$

$$= 0.002268 kg/s$$

d) Useful heat gain

The useful heat gained by the solar collector was computed from equation (4) below;

$$Q_u = m_a c_p (T_e - T_i)$$

$$Q_u = 0.002261x1004(37-25)$$

$$= 27.23 J$$

e) Area of the solar collector

This was determined from equation (6)

$$A_C = LXW$$

$$= 0.61 X 0.45$$

$$= 0.2745 m^2$$

f) Angle of inclination

The angle at which the solar collector was inclined to the horizontal was 30^0 and was obtained from equation (10) according to (Duffie, 1991).

g) The thermal efficiency,

Thus the overall efficiency of the solar collector was determined from equation (9) according to (Bukola, 2011).

$$\eta_c = \frac{Q_u}{A_c I_T} = \frac{27.23}{0.2745x0.18456x10^3} x100 = 54\%$$

4.2.2.2 Design of the drying chamber

The drying chamber in this dryer model measured 0.56x0.455x0.695m, it had three drying trays that were separated by 0.15m such that condensations of the moisture from the bananas do not take place (Phardi, 2013). The actual heat required to dry the bananas and was computed from Equation (11), basing on basic principles of heat transfer by (Karlekar and Desmond, 1982).

$$\begin{aligned} Q &= m_b c_b (T_0 - T_i) + m_w L \\ &= 2x3.35(36-25) + 1.582x2260 \\ &= 3649.02kJ \end{aligned}$$

The drying rate was obtained from equation (12)

$$\begin{aligned} m_{dr} &= \frac{m_w}{t} \\ &= \frac{1.582}{24} = 0.066Kg/hr \end{aligned}$$

4.2.2.3 Designing the drying trays

This dryer had three drying trays and each measured 0.55x0.45x0.85m; the base of the trays was made from stainless steel mesh and were sized basing on the overall width of the drying chamber and stack height was based on the height of the dying chamber.

4.2.2.4 Designing the loading door

The loading door measured 0.61x0.25x0.55m and was made to be completely covering the width of the dryer and was made of plywood as it was not necessary to have a heavy door for this dryer.

4.2.2.5 Designing the Slotted Air chamber

This measured 0.455x0.04x0.565m and each slot was separated from each other by 0.15m. There were three slots on this chamber because of the need of supplying air to the three drying trays.

4.2.2.6 Dryer Frame

The dryer frame was made out of 0.25x0.25x0.002m iron hollow sections and a thin plastic sheet was used to form the frame walls since these would supply the additional heat that was need for drying. At the section of the drying chamber, the dryer frame had angle bars at 45^0 welded onto it to form the rails on which the trays were to be slid during the loading and unloading of the bananas.

Design of the solar chimney

The solar chimney was made out of a thin metal sheet of steel and measured 0.175m in height and 0.075m in diameter.

4.3 Objective 3: Fabrication of the designed solar dryer

4.3.1 Material selection

The material that was used in fabricating this solar dryer was chosen basing on the following: Thermal properties e.g thermal conductivity of wood, glass and steel, Solar radiant properties for the case of glass with transmittance 0.6 and absorbance 0.24, Availability of the material because the material that was used in the fabrication of this prototype was readily available in the test area and was available at a reasonable cost.

4.3.2 Fabrication of the different components

Component	Sub component parts	Designed Material	Fabrication methods used	Fabrication tools used
Solar collector	- Cover material	Glass	Glass cutting	Glass cutter
	- Absorber plate	Ply Wood	Cutting	Wood saw
	- Collector box	Wood	Cutting	Wood saw
Dryer frame	- Frame skeleton - Cover material	Hollow sections of iron metal and polythene was used a cover material	Cutting, grinding	Wood saw, metal grinder
Drying chamber	- Tray rails	Metal	Cutting, grinding	Hack saw, metal grinder
Slotted air chamber	-	Wood	Cutting	Wood saw
Drying trays	- Base - Tray walls	stainless steel nets for the base, wood for the tray walls/ guards	Cutting, grinding	Wood saw, metal grinder
Chimney hood		metal trapezoidal	Cutting, grinding	metal grinder
Chimney		cylindrical steel was used	Cutting, bending, rolling, grinding	Hack saw, welding
Loading door		- wood	Cutting,	Wood saw

4.4 Objective 4: Testing the performance of the prototype

4.4.1 Testing for dry effectiveness

$$M_c\, wetbasis(\%) = \frac{m_f - m_{ds}}{m_f} X100 \qquad (13)$$

$$M_c\, wetbasis(\%) = \frac{2 - 0.418}{2} X100 = 79.1\%$$

The moisture content on wet basis (%) describes the percentage of the water that was evaporated from the banana slices. The amount of water lost from the bananas was high for the first sixteen drying hours compared to the rest of the drying time. The rate of loss of moisture was low for the other eight hours of the drying time; this means than the dry bananas were left at 20.9% wet basis.

4.4.2 System Efficiency

The efficiency of the drying system was determined from equation (14) below:

$$n_{ds} = \frac{m_w L + m_b c_b (T_o - T_i)}{A_c I_T t} \qquad (14)$$

$$n_{ds} = \frac{1.582x2260 + 2x3.35(36-25)}{0.2745x0.18456x86400} = 83.3\%$$

The domestic solar dryer was found to be 83.3% efficient at deriving the water about 58.5% of the 74% of the whole moisture content of the banana slices.

Figure 4.4(a) describes the drying process taking place when the designed solar dryer was loaded with the samples

Figure 4.4(a): Domestic solar dryer for banana fruits in operation

4.4.3 Procedure for testing quality of the product

The dry product was tested for by breaking the slices and recognizing the sound produced due to the researcher's inability of accessing a moisture meter for testing the final moisture content from the neighbouring agricultural institutions. The dry samples produced a cracking sound when breaking compared to those that were not dry. The samples were also kept almost free from moisture for three weeks and it was recognized that moulding had not occurred on their surfaces.

4.4.4 Analysis of performance test results

The analysis of performance test results was done using Microsoft excel through use of graphs to plot the mass of water lost with time and variations of temperature in the different drying trays. tables 4.4(a) and table 4.4(b) show the moisture in % and the variations of the drying temperature in drying trays 1, 2 and 3.

Table 4.4(a) Moisture loss (%) with drying time

Drying time (hrs.)	Mass after time t /g	Mass of water / g	Moisture loss (%)
2	1530	470	23.5
4	1316	684	34.2
6	1108	892	44.6
8	1010	990	49.5
10	1046	954	52.3
12	886	1114	55.7
14	850	1150	57.5
16	788	1212	60.6
18	670	1330	66.5
20	616	1384	69.2
22	484	1516	75.8
24	418	1582	79.1

From table 4.4(a), figure 4.4(b) was created.

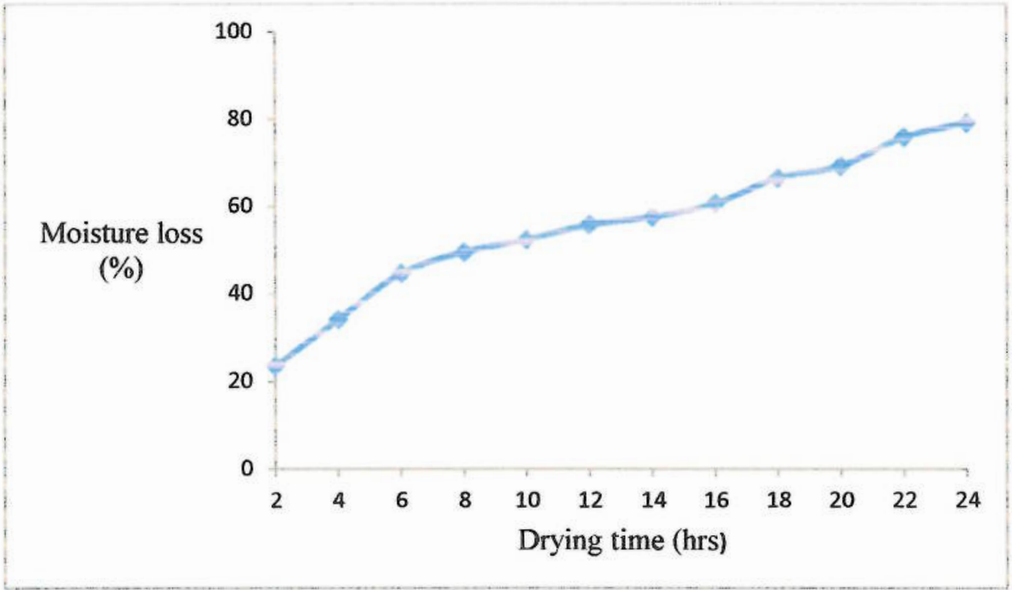

Figure 4.4(b) Moisture loss (%) with respect to the drying time in hours

Table 4.4(b) Average tray drying temperature with average drying time

Average Drying time (hrs.)	Average tray temp ^0C
0	28
2	33
4	37
6	34
8	32

Figure 4.4(c) below was generated from table 4.4(b) above.

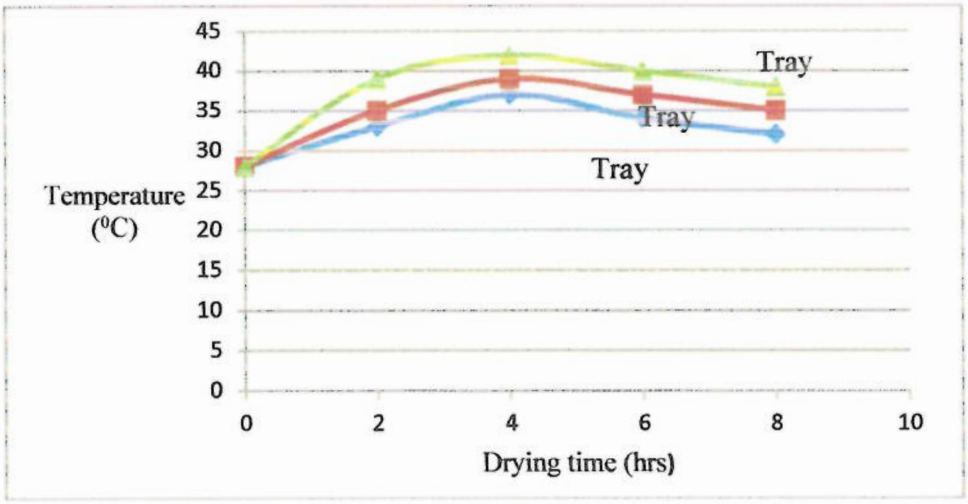

Figure 4.4(c) A variation of temperature within the trays in the drying chamber

According to figure 4.4(c), the temperature in trays 2 and 3 was higher compared to that in tray 1. This is because the trays exhibiting higher temperature variations received more heating through the transparent plastic material on the chimney hood compared to tray 1 which received less of this heating. Most of the drying on tray 1 was due to the energy from the solar collector.

4.4.5 Performance testing procedure

The banana slices lost most of the moisture during the first sixteen drying hours i.e the first two drying days compared to the rest of the eight hours on the third drying day. There were Moisture reabsorption cases and these were exhibited by the bananas when weighed the following day after having been dried previously. When the slices of the partially dry banana slices were weighed, it was found that there was an increment in the mass.

4.5 Objective 4 cont'd: Economic analysis of the dryer

The economic analysis of the designed solar dryer was done using the following methods;

1) Net present worth method

Let the capital cost of investing in this dryer be 10% per annum; table 4.5 represents the initial cost and assumed values of the various costs at the end of the three years.

Table 4.5 Net present worth method

Year	Narrative	Cash flow(Shs.)	Discounting factor	Present value(Shs)
0	Initial investment	500,000	1	(500,0000)
3	Salvage value	200,000	0.7513	150,000
1-3	Annual maintenance and operational cost	100,000	2.4869	(248,690)
1-3	Annual Sales revenue	800,000	2.4869	1,989,520
			NPV	1,390,830

Since NPV>0, then it is worthy investing in the solar dryer

This mean that investing in the designed solar dryer is a viable project thus a risk worth taking as the invested capital plus the profits of 1,390,830 will be gained.

2) Rate of Return from the dryer

$$ROR = \frac{\text{Profits}}{Dryer \quad Cost}$$

$$ROR = \frac{1{,}390{,}830}{500{,}000} = 2.8x$$

For every dryer cost, it returns 2.8 times its initial cost, the project is thus viable.

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APPENDIX I: DRYER DIAGRAMS

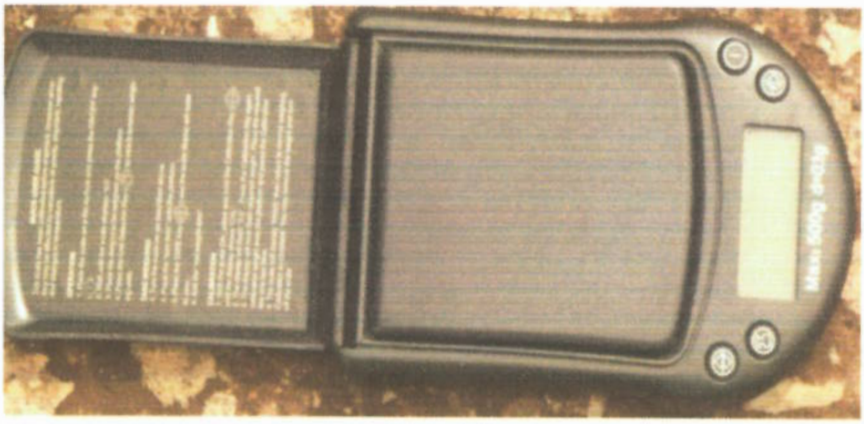
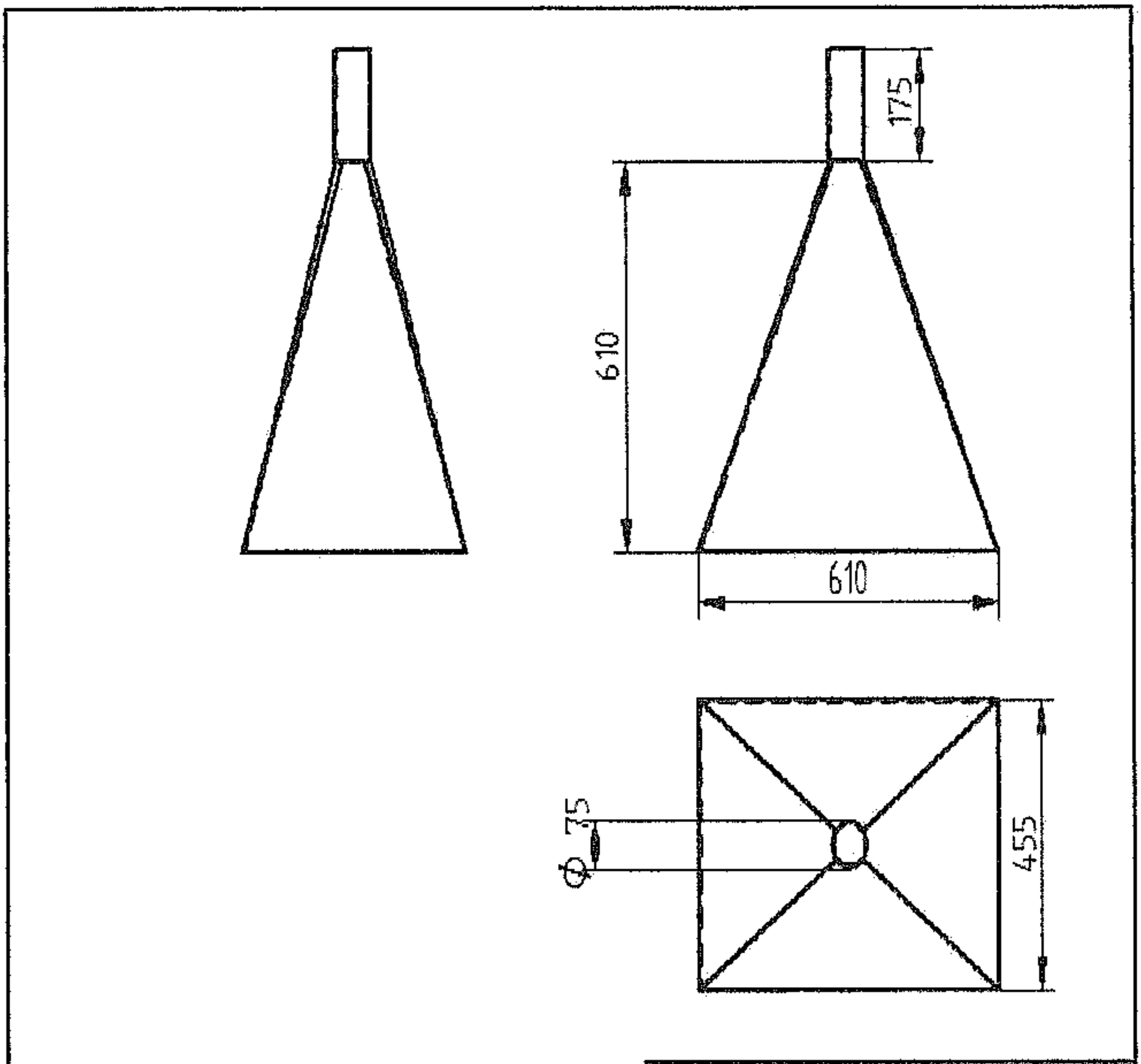


Figure 1: Digital Weighing scale (Max 500g)

Figure 2: The designed Domestic Solar dryer for banana fruits

APPENDIX II: ENGINEERING DRAWINGS (DRYER COMPONENT PARTS)



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DRAWING BY: NAKANYIKE REGINA	CHECKED BY DR.WANDERA	DATE : 12/4/16
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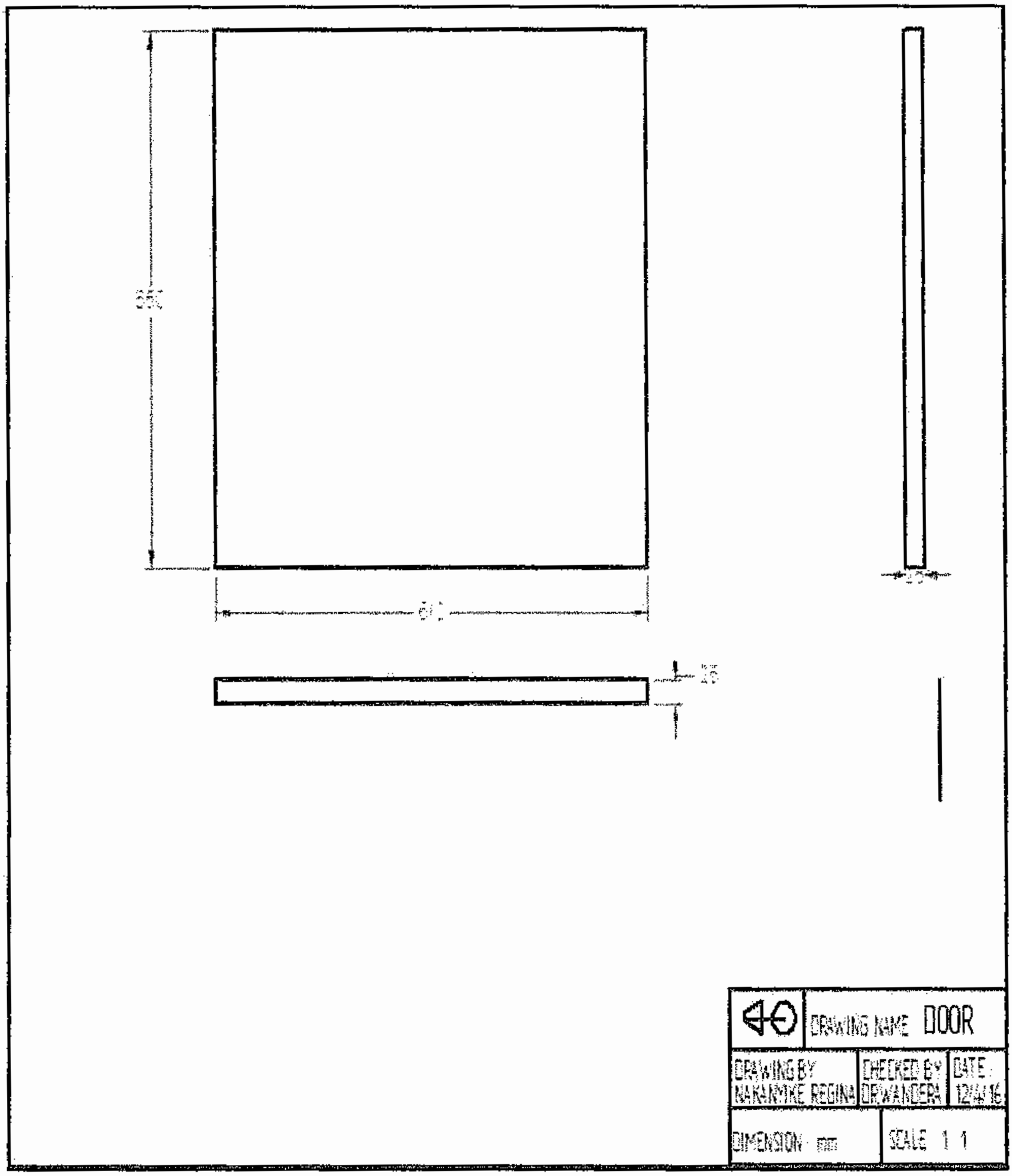
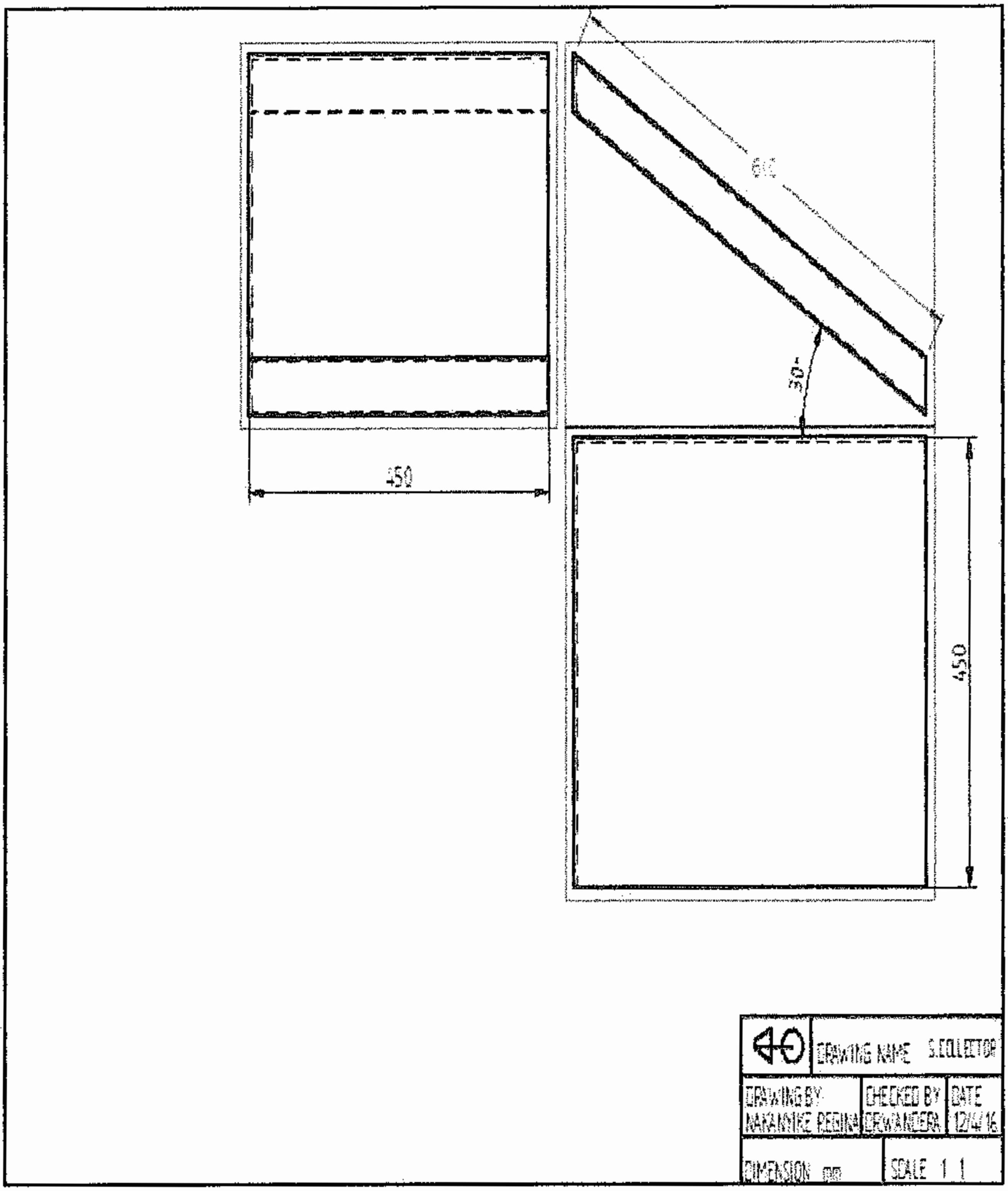
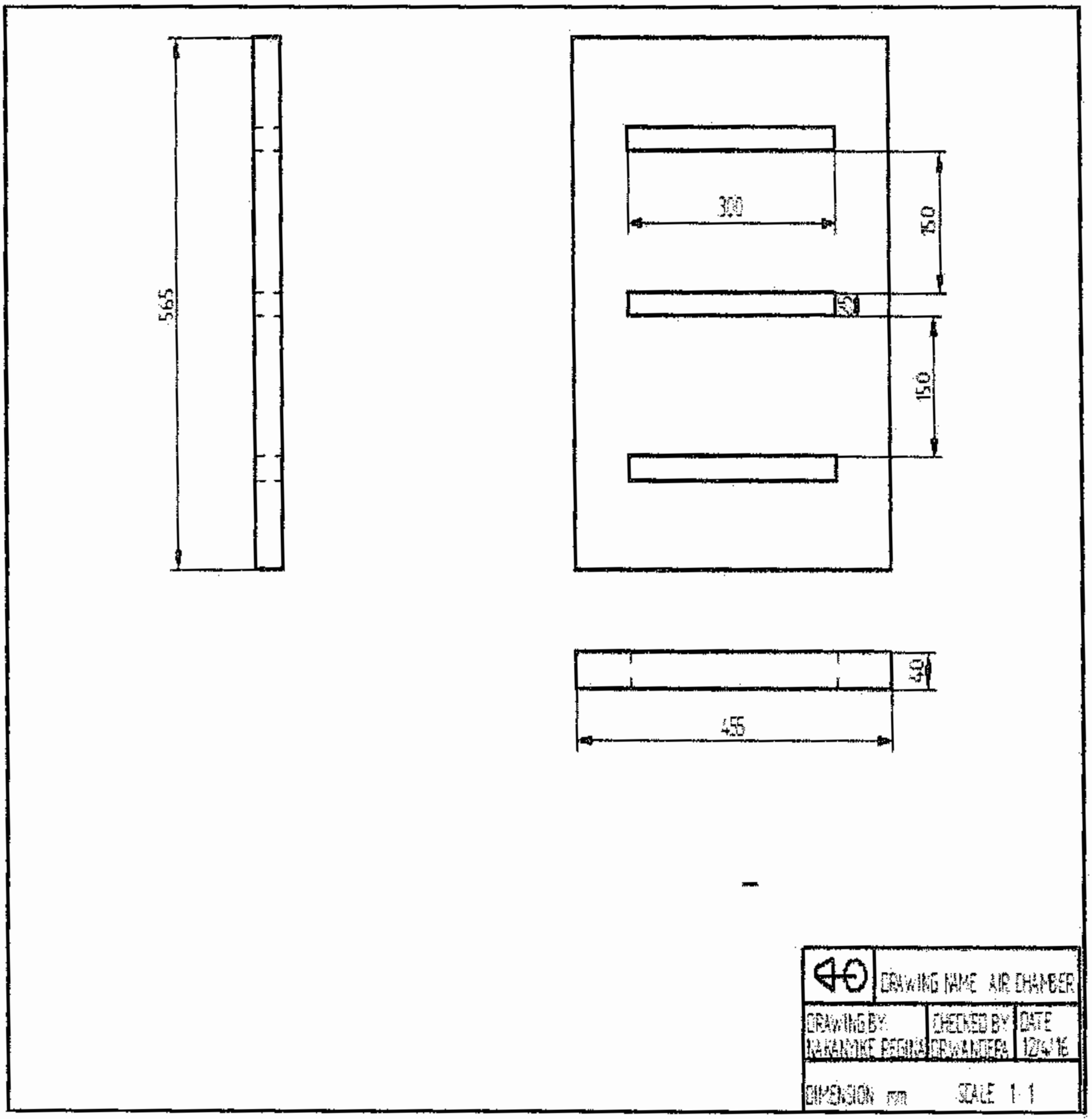

DRAWING NAME DOOR
DRAWING BY
NAKANYIKE REGINA
CHECKED BY
DR.WANDERA
DATE
12/4/16
DIMENSION mm
SCALE 1 1



450
30°
450
DRAWING NAME S.COLLECTOR
DRAWING BY: NAKANYIKE REGINA
CHECKED BY DEWANGERA
DATE 12/4/16
DIMENSION mm
SCALE 1 1


565
300
150
150
40
455
DRAWING NAME AIR CHAMBER
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CHECKED BY
DATE
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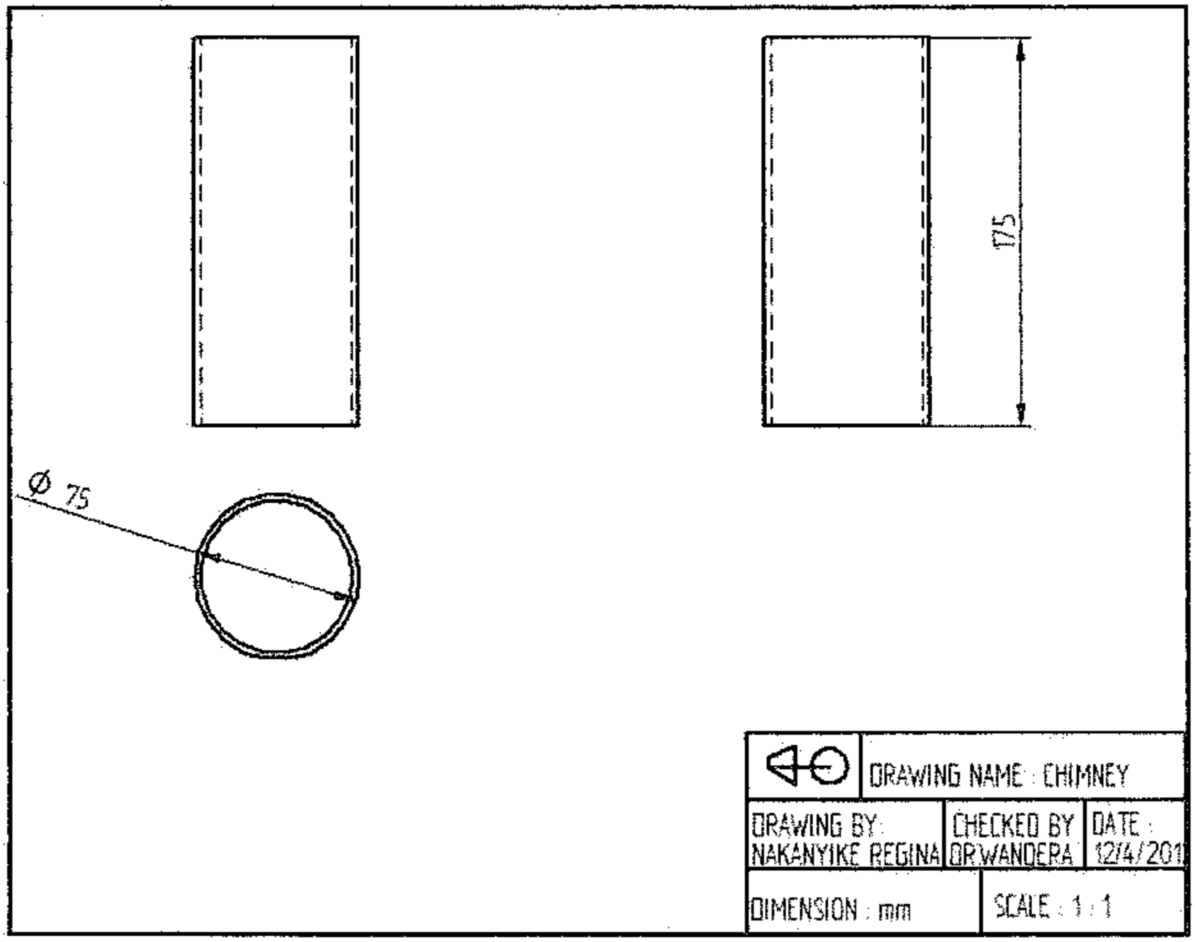
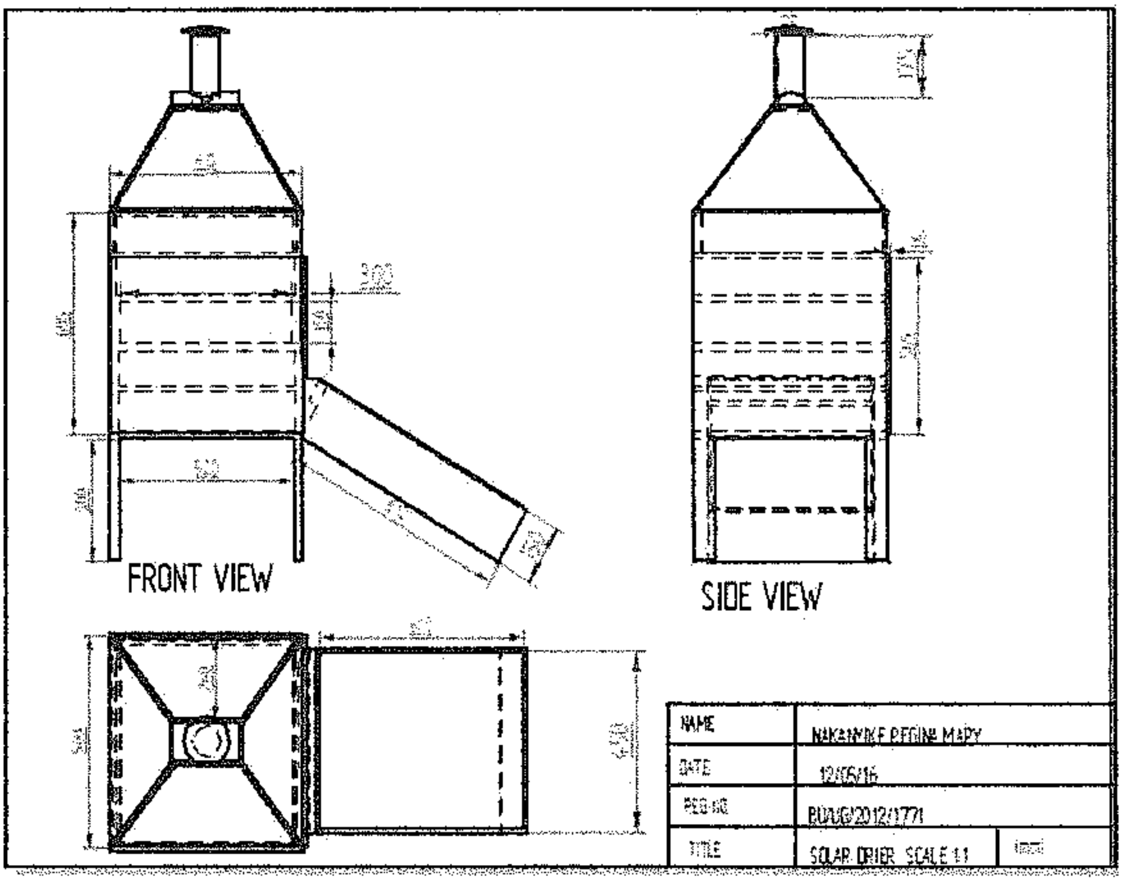
SCALE 1:1



175
Ø 75
DRAWING NAME : CHIMNEY
DRAWING BY:
NAKANYIKE REGINA
CHECKED BY
DR WANDERA
DATE :
12/4/201
DIMENSION : mm
SCALE : 1 : 1

APPENDIX II: CONT'D ENGINEERING DRAWINGS (DRYER)



APPENDIX III: BUDGET FOR THE DESIGNED SOLAR DRYER

No.	Item	Unit cost	Quantity	Total cost
1.	Agricultural polythene	10,000	1	50,000
2.	Glass	20,000	1	100,000
4	Transport	50,000	1	50,000
6.	Stationery i.e Printing, books, paper	50,000	5	50,000
7.	Cost of fabrication	128,000	1	128,000
8.	Airtime	10,000	20	20,000
11.	Hollow sections	25,000	1	25,000
12.	Self-tapping screw	300	40	12,000
13.	Flat bars	10,000	1	10,000
14.	Stainless steel mesh	15,000	1	15,000
15.	Mild steel plate	10,000	1	10,000
16.	Paint (aluminum & black)	30,000	1 @	30,000
	Total			500,000