

DESIGN AND FABRICATION OF A SOLAR POWERED FOOD DRYER

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FACULTY OF ENGINEERING

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A PROJECT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS

FOR THE AWARD OF BACHELOR OF ENGINEERING (B.ENG) DEGREE IN

INDUSTRIAL

ENGINEERIN

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CERTIFICATION

This is to certify that this project, the design and fabrication of a solar powered food dryer from locally sourced materials was carried out by OKHOMINA KING OSARUESE under the supervision of Engr. ETUK in the Department of Production Engineering in accordance with the rules and regulations of the university. I further declare that where works of other persons have been used or referred to, such sources have been duly acknowledged.

DR. ENGR. ETUK MIKE

Project Supervisor

DATE

Head of Department

DEDICATION.

This project is dedicated to Almighty God, for unto Him I give all the glory and praise for His endless grace and wisdom that saw me through the completion of this work.

ACKNOWLEDGEMENT

First and foremost, my heartfelt gratitude goes to the Almighty God for constant grace, guidance and strength have seen me through every phase of my academic journey.

I wish to express my profound appreciation to my Mum Mrs Okhomina Juliet. I owe special thanks for her prayers, encouragement, and unconditional love. Her resilience and endless support have been my greatest comfort and motivation throughout this journey and to My wonderful siblings (Eddie, Williams, Fortune, Becky and Favour) for their steadfast love.

I am equally indebted to my project supervisor, Dr. Engr. Etuk Mike, whose mentorship, constructive criticism, and valuable insights played a significant role in shaping this work. His patience, guidance, and professional expertise were instrumental in the successful completion of my design and project report.

To my colleagues and friends, I express my sincere appreciation for your cooperation, ideas, and contributions during the fabrication and writing processes. Working alongside such supportive individuals made this journey both productive and memorable.

May God, in His infinite mercy, continue to bless and prosper the work of their hands.

ABSTRACT

This study focuses on the design, fabrication, and performance evaluation of a solar thermal dryer developed using locally available materials to enhance the drying of agricultural products in both rural and urban environments. Traditional open-air drying methods commonly practiced in Nigeria are fraught with challenges such as contamination, theft, unfavorable weather, and inconsistent drying rates, leading to significant post-harvest losses. To mitigate these limitations, a solar-powered thermal drying system was developed to harness the abundant solar energy available in tropical regions.

The research methodology involved a comprehensive review of literature on solar energy utilization, the development of suitable design concepts, determination of relevant design and environmental parameters, material selection, fabrication, and experimental testing. The solar dryer design integrates a photovoltaic-powered air blower and a thermally heated chamber, providing controlled airflow and consistent heat distribution for effective moisture removal.

Findings from related studies and prototype evaluations revealed that solar thermal dryers offer improved drying efficiency, reduced drying time, and enhanced product quality compared to conventional methods. The project demonstrates the potential for affordable, energy-efficient, and environmentally sustainable drying technology adaptable for small-scale farmers and households. Furthermore, the design can be scaled up for commercial use, promoting local manufacturing, job creation, and the wider adoption of renewable energy technologies in Nigeria.

Keywords: Solar energy, solar thermal dryer, agricultural drying, photovoltaic blower, renewable energy, moisture removal.

TABLE OF CONTENTS

COVER PAGE.....	Error! Bookmark not defined.
TITLE PAGE.....	Error! Bookmark not defined.
CERTIFICATION	iii
DEDICATION	iv
ACKNOWLEDGEMENT	v
ABSTRACT	vi
CHAPTER ONE.....	1
INTRODUCTION	1
1.1 Background to the study	1
Material sourcing and selection	2
1.2 Statement of the Problem.....	2
1.3 Significance of the Project.....	3
1.4 Aims and Objectives of the Project	3
1.5. Project methodology	4
CHAPTER TWO	5
LITERATURE REVIEW.	5
2.1 Background to the study	5
2.2 Sun-powered thermal power	6
2.3 Drying process using sun-powered power.....	7
2.4 Related Literatures.....	7
2.5 Limitations of previous Research	9
CHAPTER THREE	11
METHODOLOGY	11
3.1 THE WORKING PRINCIPLE OF A SOLAR DRYER.....	11

3.1.1 HEAT SOURCE	11
3.1.2 CIRCULATION FAN	11
3.2 DESIGN METHOD	11
3.2.1 Energy Required to Heat up the Space	19
3.4 Simulation To Determine The Thermal Flow Distribution And Relative Humidity	27
3.4.1 Fluid Subdomain.....	27
9 Boundary Conditions	30
3.4.2 GOAL TABLE.....	31
CONCLUSION.....	36

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

There is a huge market for products that could aide drying of farm-based substances and limit or eradicate the setbacks that are encountered with the conventional or traditional drying methods. Different method of drying has been proposed by different researchers but there is still room for improvement in many of the devices utilized for drying amongst which is the sun-powered thermal dehydrators. Nigeria enjoins abundance of sun being a country with tropical geographical regions hence; has a high potential of harnessing the suns thermal power for effective use in domestic and industrial purposes. The use of photovoltaic panels to power air blowers which blow heated air via a glaze from the sun into the drying chambers is here in explored in this research.. Considering the huge population of Nigeria of over 200million people who at different times and at different places tend to utilize sun for drying substances but rely on outdoor or open air sun drying which is froth with some setbacks which include theft, animal invasion, exposure to dirt and bacterial, unfavorable weather attack such as rainfall and uncontrolled exposure to rain and excessive sunlight which can sometimes lead deterioration of the substances being dried. These setbacks have led to the study and invention of modified dehydrators for agro products and other substances in modern times. Studies have been performed for drying with the utilization of various forms of methods and power ranging from gas, charcoal and electrical fired dehydrators

The aim of the project is to design, fabricate and test a sun-powered thermal dehydrator using locally sourced substances suitable for use in rural and urban environments.

The project can be developed on a larger scale for wealth and job creation

The method adopted for the execution of the project include the followings;

Test and evaluate the effectiveness of the sun-powered thermal dehydrator.

Active sun-powered thermal setups lead to a reduction of primary power consumption when replacing conventional technologies and can be combined with nearly all types of back-up heat sources.

Material sourcing and selection

Sun-powered power is available in enormous quantities in majority of places. Current limitations, for instance at high latitudes or in the case of limited space for heat storage, this can largely be overcome through research and development.

- 2.4 Farm-based Substances Drying Using Dedicated Compartments
- Determination of variables and parameters

1.2 Statement of the Problem

Agricultural and other materials drying is an essential activity carried out by humans in virtually all regions of the world. Conventional method of drying involves outdoor exposure of the materials being dried to air and sunlight in outdoor spaces. However; the method is faced with some setbacks which include exposure to dirt and stains, theft, animal invasion and unfavorable weather conditions such as rain and excessive sunlight etc. This has led to development of mechanical drying facilities with controlled drying process. These mechanical drying facilities often powered by electricity, gas, fuel or active and passive sunlight all have their limitations or disadvantages. They can be very expensive to acquire, not easily accessible and easy to use by locals living in rural areas and could be ineffective in the absence of electrical energy supply. It is therefore in a bid to mitigate all these setbacks that it has necessary to design a solar thermal dryer using locally sourced materials suitable for use in the drying of agricultural materials.

1.3 Significance of the Project

The current project is relevant in the optimization of agricultural drying which is a necessitated activity carried out by humans all over the world. The pathway for the execution of the project is relevant to academic knowledge and innovation in the area of design and manufacture from which significant data can be obtained for further study and or research and production purposes. The economic importance of the project includes the followings;

- i. It is a viable project that can be commercialized for income
- ii. The project can be developed on a larger scale for wealth and job creation

1.4 Aims and Objectives of the Project

1.4.1 Aim of the project

The aim of the project is to design, fabricate and test a solar thermal dryer using locally sourced materials suitable for use in rural and urban environments.

1.4.2 Objectives of the project

The objectives of the project are;

- i. To identify the physical variables associated with drying
- ii. To determine the design parameters of the solar thermal dryer.
- iii. To design and fabricate a solar thermal dryer
- iv. Test and evaluate the effectiveness of the solar thermal dryer.

1.5. Project methodology

Regarding the drying of Farm-based produce, there are four major drying techniques namely: open air drying, fire wood/fuel drying, electrical drying and sun-powered drying (Akinboro et al., 2012). This is due basically to the heating up to vaporization point of the moisture contained in the clothes and the eventual movement of the vaporized moisture away from the clothes with the help of moving wind. Some of these techniques also find use in the drying of other substances such as clothes however; with their respective limitations or challenges. space heating). Active sun-powered thermal setups have numerous benefits that make them attractive solutions for meeting heating and cooling needs, including:. Sun-powered power is a resource that can reduce the external power dependency for many countries. In the building sector, this means domestic hot water heating, space heating, swimming pool heating, and space cooling with heat driven cooling technologies. The sun-powered resource for sun-powered heating and cooling technologies is unlimited therefore; sun-powered thermal setups for heating and cooling can be used in cold, temperate and mild climates. The heated fluid which can be gaseous or liquid in the collectors is used either directly (e.g., to heat swimming pools) or indirectly with the use of an absorber or heat exchanger to transfer the heat to its final destination (e.g. In Nigeria, sun-powered thermal power has been developed for various applications; some of which include sun-powered cookers, sun-powered clothes washers and dehydrators and drying of farm-based produce. In open drying for example where the substances to be dried are exposed to the outdoor weather elements such as sun light and wind, the air flow and heat from the sun combines to aid the removal of moisture from substances or clothes. Key applications for active sun-powered thermal technologies are those that require low temperature heat. The amount of heat power produced per square meter of collector surface area varies with design and location, (Faninger, 2010). In the active sun-powered thermal setups, there is of use sun-powered collectors

CHAPTER TWO

LITERATURE REVIEW.

2.1 Background to the study

To determine the design parameters of the sun-powered thermal dehydrator.

Fabrication of the sun-powered thermal clothes dehydrator

It is a viable project that can be commercialized for income

When such devices can as well utilize the heat from the sun for drying, it means they assume designs which enables them to harness the sun rays and heat for use in drying of fabrics inside it.

The use of dedicated compartments is partly due to the reasons of safeguarding the agro-substances, ensuring controlled drying even during unfavorable outdoor weather conditions. The impact of sun heat aids temperature increase of the ambient air which circulates around the substances.. Cory (2003). The use of dedicated compartments or devices for drying can be dated back to as far as the 18th century or even farther absence of electrical power supply. Farm-based and other substances drying is an essential activity carried out by humans in virtually all regions of the world. These mechanical drying facilities often powered by electricity, gas, fuel or active and passive sunlight all have their limitations or disadvantages. This has led to development of mechanical drying facilities with controlled drying process

It is therefore in a bid to mitigate all these setbacks that it has necessary to design a sun-powered thermal dehydrator using locally sourced substances suitable for use in the drying of farm-based substances.. Conventional method of drying involves outdoor exposure of the substances being dried to air and sunlight in outdoor spaces. However; the method is faced with some setbacks which include exposure to dirt and stains, theft, animal invasion and unfavorable weather

conditions such as rain and excessive sunlight etc. They can be very expensive to acquire, not easily accessible and easy to use by locals living in rural areas and could be ineffective in the

For large-scale production the limitations of open-air drying are well known. A part of the power received is reflected back and the remaining is absorbed by the surface depending upon the color and nature of the substances being dried. Among these are high labor costs, large area requirement, lack of ability to control the drying process, possible degradation due to biochemical or microbiological reactions, insect infestation, time consuming, requires a large area for spreading the produce out to dry and so on.. Open sun drying has been used since time immemorial to dry farm-based substances and many other products. The process is also labor intensive and time consuming. Open sun drying is generally done by exposing the substances to be dried on a line, ground, mat or concrete floor where they receive short wavelength sun-powered power and natural air circulation during the day. However, there are losses like the long wavelength radiation loss from the surface of the material to the ambient air through moist air and also convective heat loss due to the blowing wind through moist air over the material surface (El-Sebaai and Shalaby, 2012). The absorbed radiation is converted into thermal power and the temperature of the material starts to increase. Open sun drying utilized widely by many rural and urban dwellers has inherent limitations which include material losses, bacterial attacks, animal encroachment, unexpected down pour of rain and other weathering effects etc

2.2 Sun-powered thermal power

Sun-powered power is a renewable power source generated from sun light. The sun which is the source of sun-powered radiation is a continuous fusion reactor. A major advantage of sun-powered power in comparison with other forms of power is that, it is clean and can be supplied without environmental pollution. It can also power sun-powered cooling setups. Over the past century,

fossil fuels provided majority of worlds power, because these were much cheaper and more convenient than power from alternative power sources until recently when environmental pollution became of grave concern (Soteris, 2009).. This power is used to dry substances or heat water and other fluids. Sun-powered thermal technology uses the sun's power, rather than photovoltaic devices to generate low-cost, environmentally friendly thermal power. Sun-powered power is essentially black body radiation corresponding to a temperature of about 6000k and is therefore of high thermodynamic quality (Faninger, 2010)

The economic importance of the project includes the followings;. The pathway for the execution of the project is relevant to academic knowledge and innovation in the area of design and manufacture from which significant data can be obtained for further study and or research and production purposes. The current project is relevant in the optimization of farm-based drying which is a necessitated activity carried out by humans all over the world

2.3 Drying process using sun-powered power

The sun-powered thermal dehydrator will be tested and evaluated based on the prevailing weather conditions of its geographical location however; its use is intended for both rural and urban environments.. Weather conditions as may be applicable will be considered for the geographical location of the project design and production. This project is focused on the design and fabrication of a small scale sun-powered thermal dehydrator for use in the drying of farm-based substances. Environmental conditions and design variables of the drying process will be considered for drying

2.4 Related Literatures

Amiebenomo et al (2013) designed and developed solar clothes dryer whose graphic views are shown in Figure 2.1. The solar clothes drier had faster drying time using low cost and superior energy efficiency. The device consisted an inclined flow chamber (solar collector) and a drying

compartment. Using an average drying chamber temperature of 50 °C for safe drying of the clothes, the authors showed in their experimental results that the number of clothes, percentage moisture removal and solar radiation mode had highly significant ($P < 0.05$) effect on the drying time.

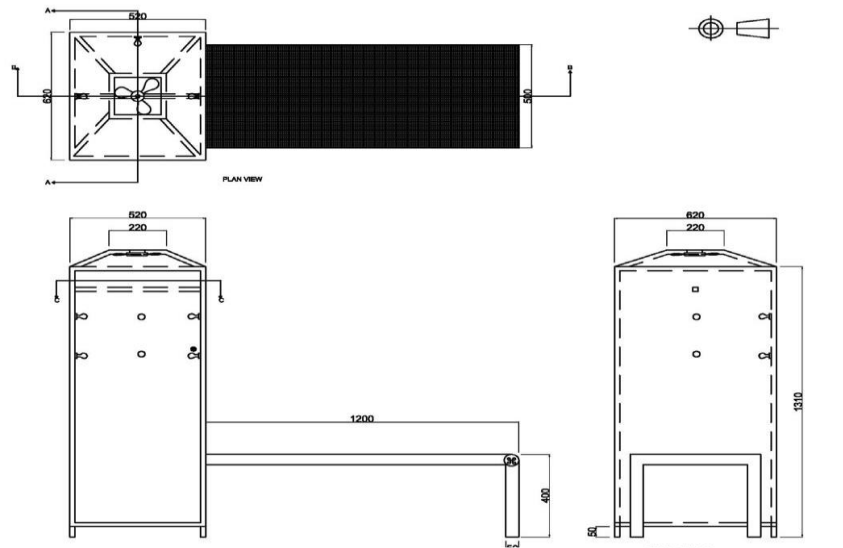


Figure 2.2 Amiebenomo et al (2013) solar clothes drier.

Mumba (1995) designed and developed a solar grain dryer with photovoltaic powered air circulation. The important feature in this new dryer was the use of photovoltaic solar cells incorporated in the solar air heater section to power a D.C. fan. This photovoltaic powered air circulation induces passive control over the drying air temperature. The dryer can dry 90 kg maize grain per batch from an initial moisture content of 33.3% dry basis to under 20% dry basis in just 1 day. The controlled drying air temperature has an upper limit of 60°C to prevent grain overheating and cracking.

Alahmer and al-dabbas (2014) designed and constructed an energy efficient passive solar powered clothes dryer shown in Figure 2.2. The authors derived a mathematical model for the solar dryer followed with a performance analysis which showed that the solar dryer had an average drying

rate of 0.35 kg/h and drying time of 3 hours on a typical day where local ambient humidity was low at 35% and at a moderate outdoor wind speed. The authors also used computational fluid dynamic CFD of transient thermal behavior based on Navier-Stokes equations to demonstrate the prevailing temperature rises in the solar natural-ventilation system associated with the internal heat flux due to solar radiation and moisture removal.

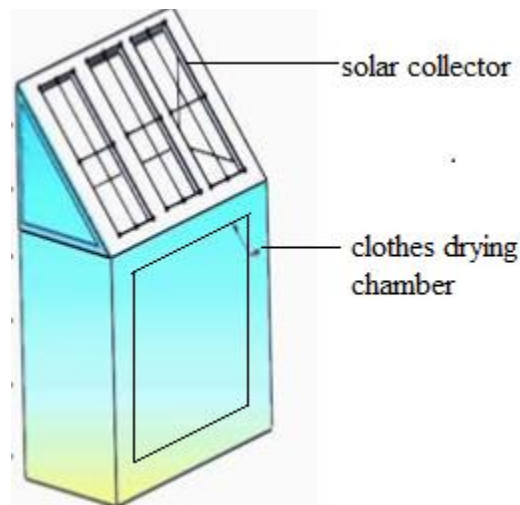


Figure 2.2 Alahmer and al-dabbas (2014) solar powered clothes drier

Sarsilmaz et al. (2000) conducted experiments on drying of apricots in a newly developed rotary column cylindrical dryer equipped with a specially designed air solar collector. It was used to investigate optimum drying air rate and rotation speed of dryer, to maintain uniform and hygienic drying conditions and to reduce drying times. Drying operation is of prime importance which is applicable to almost all the agricultural products.

2.5 Limitations of previous Research

In the previous works, some limitations of the work include the works of Amiebenomo et al (2013) whose solar drier was quite bulky, space consuming due to its different solar collection and drying chamber compartment. The work of Alahmer and al-dabbas (2014) which dwelled more on

simulation of the process with no emphasis made on the mode of air source and its mode of circulation. The work of George et al, (2019) who designed a vacuum clothes drier. Their prototype was a bit sophisticated for ease of production and use by rural dwellers. The work of Mumba (1995) which was a photovoltaic cell powered had the disadvantage of being expensive to produce or acquire since the solar facilities involved are modern solar gadgets which are not cheap and not common to find in many places especially rural environments. Piecing these shortcomings of the reviewed literatures together, the present study intends to solve some of the significant problems encountered in the previous work. The proposed design of active solar agricultural materials dryer will have an air draft to enhance moisture removal.

CHAPTER THREE

METHODOLOGY

3.1 THE WORKING PRINCIPLE OF A SOLAR DRYER

The solar dryer is designed to ensure the proper drying of agricultural products by efficiently implementing solar energy from incident radiation over an absorbent plate. The dryer is usually cladded to prevent heat loss while ensuring the effective control of the drying air's humidity. The dryer usually consists of the drying chamber, low power consumption fans and ducts as well as insulation and the dryer mainframe. The fans may be connected to an external power source whereas DC powered fans may be connected to an internal DC battery.

3.1.1 HEAT SOURCE

The heat source is required to heat up the dryer while the temperature sensor and switch connection monitors and regulates the heating process.

3.1.2 CIRCULATION FAN

The fan is used to change the air within the dryer ensuring that moist air is pushed out of the dryer

3.2 DESIGN METHOD

The design was carried out in the following steps

1. Estimation of aggregate solar radiation available
2. Determination of the functional requirements for the dryer
3. Calculation of parameters and their limits to achieve the requirements determined above
4. Simulation of the working environment by applying the calculated parameters in a CFD simulation
5. Modelling the incubator and generation of fabrication drawings for the fabricator

3 FUNCTIONAL DESIGN REQUIREMENTS

It is crucial in machine design to determine the functional design requirements. The design requirements control the design of the project throughout the design process. The following design requirements were drawn:

1. Determination of Dryer Capacity
2. Determination of Energy Required and solar energy available
3. Sizing of Circulating fan

4 Solar Energy Available

The solar energy is calculated for the mean day of all the months from January to December, the average energy available is then calculated and used in the remaining calculations. It is assumed that cloud cover is always at 0.3 at the location.

The dryer is to be used in Edo State, Nigeria which is on a latitude of 6.6342° N, and longitude 5.9304° E. (Anon., 2012)

The Value of Solar Constant G_{sc} was taken as $1367\text{W}/\text{m}^2$. (John & William, 2013)

The extraterrestrial radiation is calculated using the expression

$$G_c = G_{sc} \left(1 + \left(0.33 \cos \frac{360n}{365} \right) \right)$$

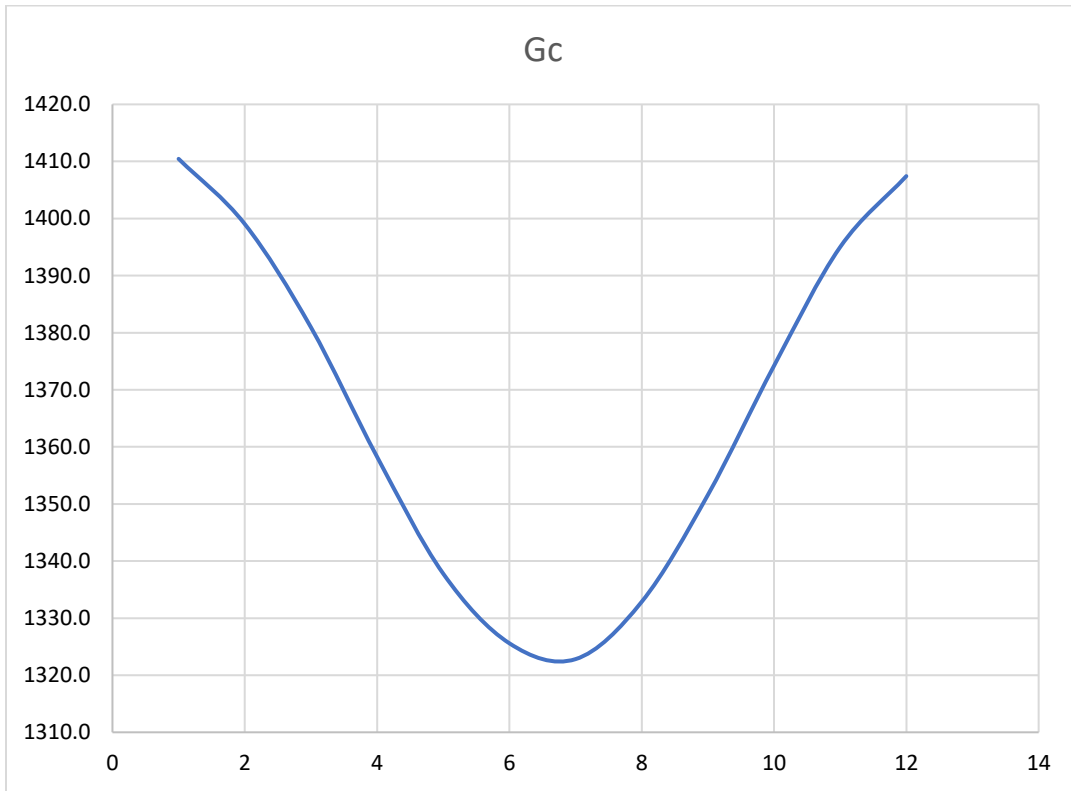
Where n is the number of days. The number of days can be calculated using the following table

Months	
January	i
February	31 + i
March	59 + i
April	90 + i
May	120 + i
June	151 + i
July	181 + i
August	212 + i
September	243 + i
October	273 + i
November	304 + i
December	334 + i

The calculated extraterrestrial radiation for the average days of the year is shown below

Months	Day	n	B	δ	Gc
January	17	17	15.78	-20.917	1410.5
February	16	47	45.37	-12.9546	1399.0
March	16	75	72.99	-2.41773	1381.0
April	15	105	102.58	9.414893	1358.3
May	15	135	132.16	18.79192	1337.8
June	11	162	158.79	23.08591	1325.6

July	17	198	194.30	21.18369	1322.8
August	16	228	223.89	13.45496	1332.9
September	15	258	253.48	2.216887	1351.6
October	15	288	283.07	-9.5994	1374.2
November	14	318	312.66	-18.912	1395.0
December	10	344	338.30	-23.0496	1407.4



This extraterrestrial radiation is not the available radiation to the flat plate, the slope of the plate, the hour angle and the solar azimuth angle also affects the amount of solar energy available.

The amount of radiation incident on the horizontal surface at any day and time of the year can be obtained by the relation

$$I_0 = \frac{12 \times 3600 \times G_c}{\pi} \times (\cos \phi \cos \theta (\sin \omega_2 - \sin \omega_1) + \frac{\pi(\omega_2 - \omega_1)}{180} \sin \phi \sin \theta$$

The average radiation measured at noon when calculated for the above stated location over a year's period in MJ/m² was obtained to be 4.74MJ/m².

Solar Radiation is usually separated into two components

The beam radiation component and the diffuse radiation components.

These components can be estimated by using a parameter known as the sky clearness index k_T .

The clearness index data as provided by (Njoku, et al., 2022)

Table 4b Monthly percentage cumulative frequency distribution of daily clearness index for Benin City

Months	Values of f for $K_T \leq K_T$												Average monthly \bar{K}_T
	0.0 - 0.19	0.20 - 0.29	0.30 - 0.34	0.35 - 0.39	0.40 - 0.44	0.45 - 0.49	0.50 - 0.54	0.55 - 0.59	0.60 - 0.64	0.65 - 0.69	0.70 - 0.74	0.75 - 0.79	
Jan (621)	0.00	0.33	1.62	3.24	7.11	28.21	55.91	90.21	99.23	100.00	100.00	100.00	0.53
Feb (565)	1.24	1.95	4.61	12.76	30.64	65.51	88.52	97.73	99.33	99.87	100.00	100.00	0.47
Mar (620)	0.97	2.91	9.04	18.08	40.02	69.54	89.71	95.84	99.39	99.88	100.00	100.00	0.46
Apr (600)	1.84	7.51	11.51	19.68	33.68	64.68	86.02	98.36	100.00	100.00	100.00	100.00	0.46
May (620)	2.42	8.72	14.85	20.02	31.48	58.42	79.88	95.53	99.57	100.00	100.00	100.00	0.47
Jun (600)	2.00	9.00	18.34	29.34	53.34	81.01	94.18	99.02	99.86	100.00	100.00	100.00	0.43
Jul (620)	3.23	16.62	33.24	54.54	77.13	95.04	99.24	100.00	100.00	100.00	100.00	100.00	0.38
Aug (591)	3.23	19.53	40.83	63.74	85.68	97.62	99.88	100.00	100.00	100.00	100.00	100.00	0.36
Sept (600)	3.17	13.51	29.18	49.52	73.19	95.03	99.37	100.00	100.00	100.00	100.00	100.00	0.39
Oct (620)	1.13	8.55	15.33	24.85	39.85	70.50	90.34	98.41	99.87	100.00	100.00	100.00	0.45
Nov (600)	0.34	1.34	2.84	5.18	10.02	25.52	56.86	86.03	98.03	100.00	100.00	100.00	0.53
Dec (620)	0.17	0.50	0.67	2.13	5.20	18.43	44.89	83.44	96.67	99.90	100.00	100.00	0.55

The ratio of beam radiation to the diffuse radiation component can be estimated hourly, daily or monthly.

The value of this energy on a flat surface would depend on the area of the plate and the slope or inclination β of the surface is given by the parameter R_b . The Parameter is given by

$$R_b = \frac{\cos \theta}{\cos \theta_z}$$

Where θ_z is the zenith angle and is given by the relation

$$\theta_z = \cos^{-1}(\cos \phi \cos \delta \cos \omega + \sin \phi \sin \delta)$$

For sloping surfaces, it is accurate to augment the latitude by either adding the slope angle for locations in the southern hemisphere or subtracting in the northern hemisphere. This is because

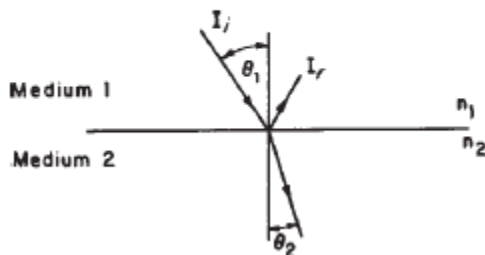
Fixed flat plate collectors are at optimum when the solar azimuth angle, γ is at 0° in the northern hemisphere or 180° in the southern hemisphere.

The Equation Becomes

$$R_{b(s,n)} = \frac{\cos(\phi \pm \beta) \cos \delta \cos \omega + \sin(\phi \pm \beta) \sin \delta}{\cos \phi \cos \delta \cos \omega + \sin \phi \sin \delta}$$

The angle of inclination is at 6.55° .

The dryer is fitted with a collector. This plate helps to collect radiant energy and convert it to heat energy. This energy is then transferred to evaporate moisture from the product to be dried via forced convection. The rest of the system is sealed by insulation material to avoid energy loss. The collector plate is sealed via a glass lid to avoid successive loss to the atmosphere. The top loss coefficient is the loss through the glass cover due to emittance and absorptance. The transmittance of the glass is not 1, hence some of the solar radiation is reflected.



The solar absorptance of the glass τ_a is calculated by:

$$\tau_a = \frac{I_{transmitted}}{I_{incident}} = \exp\left(-\frac{KL}{\cos \theta_2}\right)$$

where K is the proportionality constant, the extinction coefficient, the value of K varies from approximately 4 m^{-1} for “water white” glass (which appears white when viewed on the edge) to approximately 32 m^{-1} for high iron oxide content (greenish cast of edge) glass.

The transmittance at normal incidence is given by the equation

$$r(0) = \frac{n - 1}{n + 1}$$

Where n is the refractive index of the glass

For the solar dryer, at normal incidence

$$r(0) = \frac{0.526}{2.526} = 0.0434$$

At 6.55 , the refraction angle of θ_2 is gotten by

$$\theta_2 = \sin^{-1} \left(\frac{\sin 6.55}{1.526} \right) = 34.58$$

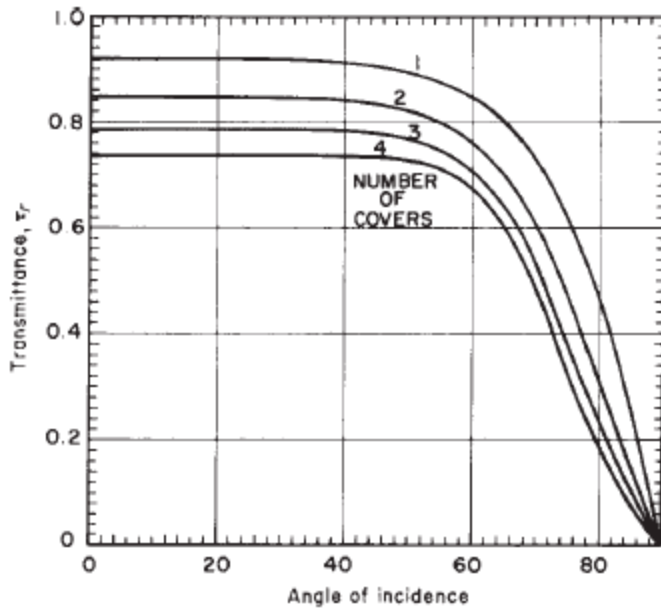
The Reflectance is given by

The reflectance of the glass is given by

$$r(60) = \frac{r_{\perp} + r_{\parallel}}{2} = \frac{1}{2} \left(\frac{\sin^2(\theta_2 - \theta_1)}{\sin^2(\theta_2 + \theta_1)} + \frac{\tan^2(\theta_2 - \theta_1)}{\tan^2(\theta_2 + \theta_1)} \right)$$

$$r(60) = \frac{1}{2} \left(\frac{\sin^2 - 25.4}{\sin^2 94.58} + \frac{\tan^2 - 25.4}{\tan^2 94.58} \right) = 0.093$$

The transmittance can be calculated or read off from the chart below



The value of the transmittance of one cover from the graph for a refractive index of 1.526 at 60° incidence is found to be 0.85.

The absorptance transmittance product ($\tau\alpha$) $\cong 1.01 \times \tau\alpha$ and α is usually 0.9 for clear glazing

The absorptance of the plate also varies as a function of material nature and it is not realistic to assume a perfect black body, (John & William, 2013) provides the absorptance coefficient for some materials used as collector plate absorbers as shown below

Thus, the radiation transmitted to the plate is given as $I_t = 1366 \times 0.85 \times 1.01 \times 0.9 = 1055.5W/m^2$

The total Area of the plate

$$Area = L \times B = 0.477 \times 0.6 = 0.282$$

Therefore, the heat Energy on the plate per unit area is given as

$$H = 0.282 \times 1055.5 = 302.481W$$

3.2.1 Energy Required to Heat up the Space For Air

Volume of Dryer = 0.0828m³

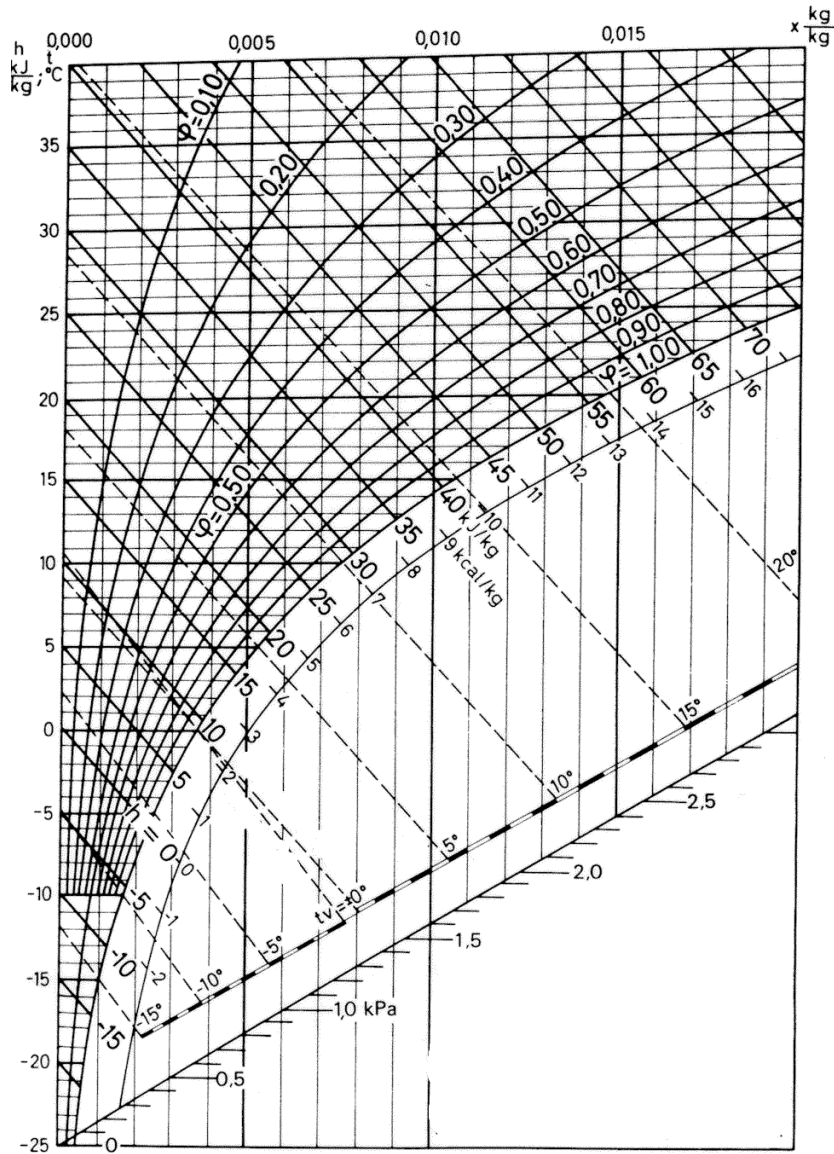
Since the air is humid at 50% relative humidity, the equation below is used to find the energy required to raise the temperature of the air to the required drying temperature of 40⁰C.

$$HB - HA = (1005 + 1884 * \omega) \times TB - (1005 + 1884 * \omega) \times TA$$

Where ω = absolute Humidity

And T_A and T_B are the lower and upper end temperatures respectively

From Mollier diagram, we can obtain the humidity ratios of the air at these temperatures of 25⁰C and 40⁰C.



At $20^{\circ}C$, the humidity ratio yields = $0.008\frac{kg}{kg}$

While at $40^{\circ}C$. = $0.020\frac{kg}{kg}$

$$HB - HA = (1005 + 1884 * 0.020) \times 313 - (1005 + 1884 * 0.008) \times (298) =$$

7302.3J

Trays

Trays are made significantly of steel material

The weight of the egg tray from the mass properties evaluation from the CAD model is 2041g=
2.041Kg

C_p for PVC = 1.6KJ/Kg

$$Q_t = 0.242 \times 0.510 \times (38 - 25) = 1.60KJ$$

For 2 trays

$$Q_{tT} = 1.06 \times 4 = 6.42KJ$$

For Produce to be Dried:

For the purpose of this calculation, we estimate that the substance to be dried is potatoes which has a specific heat capacity of 3.39KJ/Kg

We assume a total mass of 3Kg per batch

$$Q_t = 6 \times 3.39 \times (38 - 25) = 264.42KJ$$

Total Energy Required:

$$Q_T = 264.42 + 6.42 + 1.184 = 272.024KJ$$

5 Heat Loss Through Walls

The walls of the incubator are clad with 10mm hardboard insulation. Applying one dimensional heat transfer and assuming steady state conditions. The heat is transferred from the air to the insulation via conduction then to the through the insulation and to the steel via conduction

The heat flow via conduction is given by

$$q = \frac{(T_{hot} - T_{cold})}{R} \quad \text{with} \quad R = \frac{k}{LA}$$

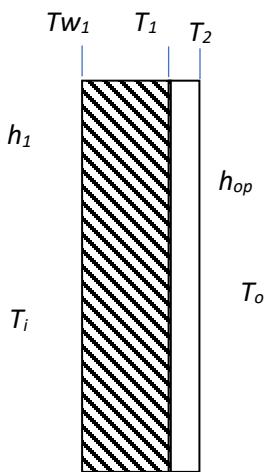
The heat flow by convection or radiation is given by

$$q = \frac{(T_{hot} - T_{cold})}{R} \quad \text{with } R = \frac{1}{hA}$$

Thermal resistance Ra through a path a is given by the sum of the resistances of the interior film, each wall layer

and the exterior film.

We consider the four walls and the glass door which has no insulation.



$$h_i = 100 \text{ W/m}^2\text{k}$$

$$h_o = 10 \text{ W/m}^2\text{k}$$

$$A_{wall} = 0.128 \text{ m}^2$$

$$A_{top/bottom} = 0.105 \text{ m}^2$$

$$k_1 = 0.022 \text{ Wm}^{-1}\text{k}^{-1}$$

$$k_2 = 237 \text{ Wm}^{-1}\text{k}^{-1}$$

$$L_1 = 0.01 \text{ m}$$

$$L_2 = 0.002 \text{ m}$$

$$AR_{Total} = A \left(\frac{1}{h_i} + \frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{1}{h_o} \right)$$

$$R_{Total} = \left(\frac{1}{100} + \frac{0.01}{0.22} + \frac{0.004}{237} + \frac{1}{10} \right) = 0.155A$$

For the side walls

$$Q_w = UA_{wall}\Delta T \quad \text{where } U = \frac{1}{R}$$

$$Q_w = 2 \times \frac{1}{0.155} \times 0.128 \times (37.5 - 25) = 20.64W$$

For top and bottom

$$Q_{tb} = UA_{tb}\Delta T$$

$$Q_{tb} = 2 \times \frac{1}{0.155} \times 0.105 \times (37.5 - 25) = 16.94W$$

For Glass door

$$U = \frac{k}{x} = \frac{0.9}{0.01} = 90$$

$$Q_{glass} = 90 \times 0.0748 \times (37.5 - 25) = 56.1W$$

Q loss from body is given by

$$Q_T = Q_w + Q_{tb} + Q_{glass} + Q_E$$

$$Q_T = 20.64 + 16.94 + 56.1 + 2.2 = 95.88W$$

Applying a safety factor of 10%

$$\text{Therefore } Q_w = 1.1 \times 112.38 = 105.47W$$

6

7 Capacity Determination

The active internal space of the dryer is very important and affects majority of the calculations that will be carried out. The dryer is the shape of a trapezium of the dimensions shown below. This shape was influenced by the angle of inclination of the solar collector plate plus the required space.

The volume of the dryer is calculated thus:

$$V = \frac{1}{2}(A + B)h$$

$$V = \frac{1}{2}(.556 + .267).727 = 0.598m^3$$

$$\text{Volume inside the Cabinet } (V_i) = 489 \times 430 \times 394 = \frac{43056000}{1000000000} = 0.0828m^3$$

8 Amount of Moisture Evaporated

Convective Heat Transfer

The air is assumed to enter at 20°C at atmospheric pressure. The fan used is rated at 70 CFM 12V DC. We can now convert this to m³/s by multiplying by 1/2118.88. We get 0.033m³/s

The Velocity of the air can then be obtained using the relation

$$V = Q/A$$

The Area covered by the fan blades is given by

$$A = \pi r^2 = 3.142 \times 0.045^2 = 0.00636m^2$$

$$V = \frac{0.033}{0.00636} = 5.188m/s$$

From Analysis the plate has an average temperature of 80°C. and a width of 0.447m

The Length of the plate is at 0.6m

$$\text{Film Temperature becomes } = T_f = \frac{T_w + T_\infty}{2} = \frac{80 + 20}{2} = 50^\circ C$$

Properties of air at 50°C is given as

$$\rho = 1.093 \text{ kg/m}^3$$

$$\nu = 17.95 \times 10^{-6} \text{ m}^2/\text{s}$$

Prandtl number $Pr = 0.698$

Thermal Conductivity, $K = 28.26 \times 10^{-3} \text{ W/mK}$

Reynolds number is given by

$$Re = \frac{UL}{\nu} = \frac{5.333 \times 0.6}{17.95 \times 10^{-6}} = \frac{3.198}{17.95} \times 10^{-6} = 1.7817.95 \times 10^{-5} < 5 \times 10^{-5}$$

Therefore, the flow is laminar.

Hydrodynamic Boundary layer thickness is given by

The hydrodynamic boundary layer thickness is given by

$$\delta_{hx} = 5xRe^{-0.5} = 5 \times 0.6 \times (1.78 \times 10^5)^{-0.5} = 0.007110 \text{ m}$$

The thermal boundary layer thickness is given by

$$\delta_{hx} = \delta_{hx} Pr^{-0.333} = 0.00711 \times (0.698)^{-0.333} = 0.0080 \text{ m}$$

The local Heat Transfer coefficient is calculated thus

$$Nu_x = 0.332 Re^{0.5} Pr^{0.33} = 0.332 (1.78 \times 10^5)^{0.5} (0.698)^{0.33} = 124.265$$

The

We know that Local heat transfer coefficient is given by

$$h_x = Nu_x \frac{K}{L} = \frac{124.265 \times 23.26 \times 10^3}{0.6} = 4.82 \text{ W/m}^2 \text{ K}$$

The average heat transfer coefficient is given by

$$h = 2 \times h_x = 2 \times 4.82 = 9.64 \text{ W/m}^2 \text{ K}$$

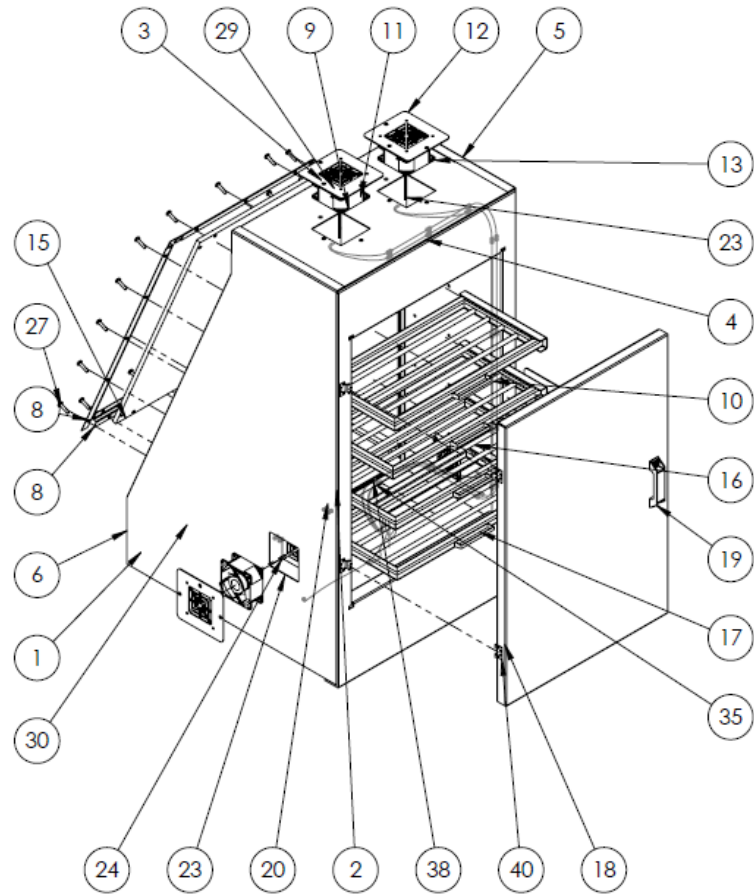
Therefore the heat transfer is given by

$$Q = hA(T_w - T_\infty) = 9.64 \times (0.6 \times 0.447) \times (80 - 20) = 155.12688W$$



3D image of Solar Dryer

ITEM NO.	PART NUMBER	QTY.
1	Frame	1
2	Panels	6
7	Angles	2
8	Glass Support	4
9	Ventilation Fan Frame	1
10	Inner Cabinet	1
11	Ventilator Fan Blade	1
12	Fan Plate	4
13	Ventilation FanSolar Dryer	3
14	Black Plate	1
15	Glass Lid	1
16	Rail	8
17	Tray	4
18	Door	1
19	Handle	1
20	Insulation	1
23	Duct	4
25	12V DC Battery	1
26	Terminal	2
28	Connector	1
40	Hinge	4



3.4 Simulation To Determine The Thermal Flow Distribution And Relative Humidity

A steady state simulation to study the thermal and flow properties. The model was simplified to reduce the computational requirement. The temperature and velocity flow patterns are investigated to ensure the temperature and pressure of the system.

3.4.1 Fluid Subdomain

The Fluid Subdomain was set as the volume domain inside the incubator. The Fluid selected was air (Ideal). The thermodynamic properties are as follows

Parameter	Unit	Value
Reference Axis		X
Boundary Layer		Laminar
Approximate Pressure	Pa	101325
Humidity	%	70
Turbulence Parameters		
Turbulence Intensity	%	0.1
Turbulence Length	M	0.00444

The properties of air are listed below

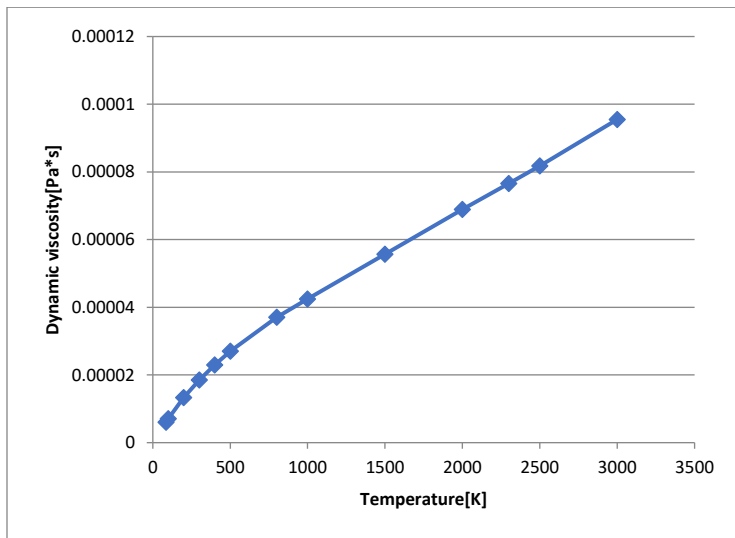
Air

Path: Gases Pre-Defined

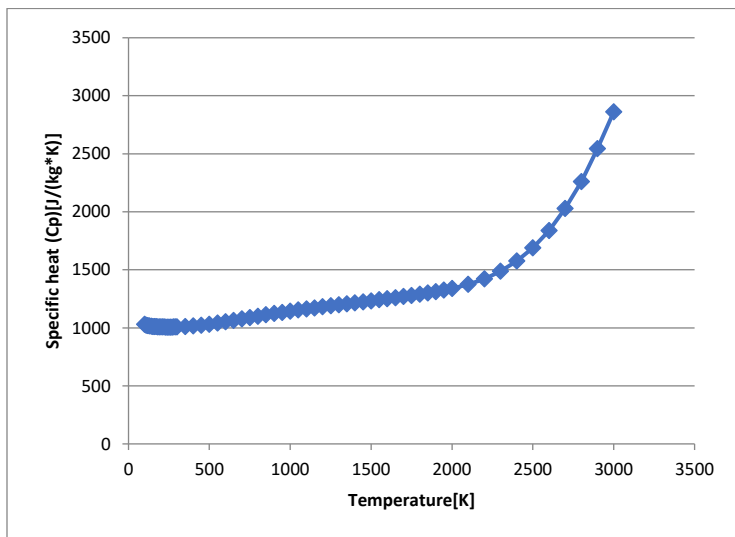
Specific heat ratio (Cp/Cv): 1.399

Molecular mass: 0.0290 kg/mol

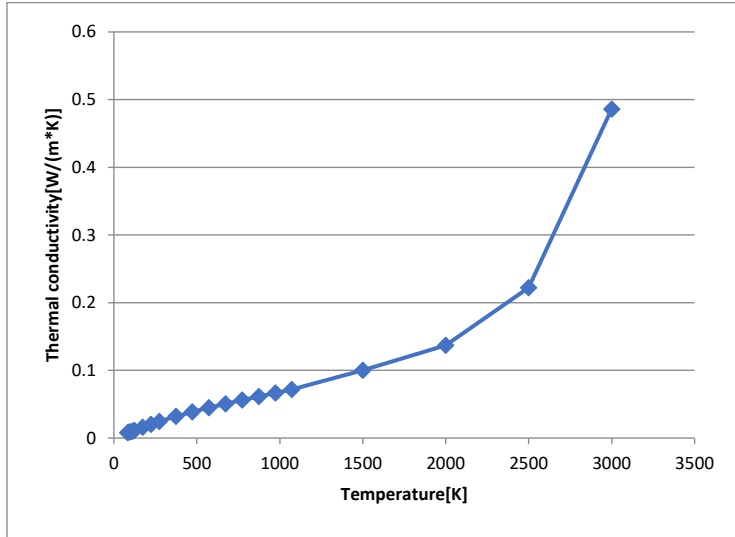
Dynamic viscosity



Specific heat (Cp)



Thermal conductivity



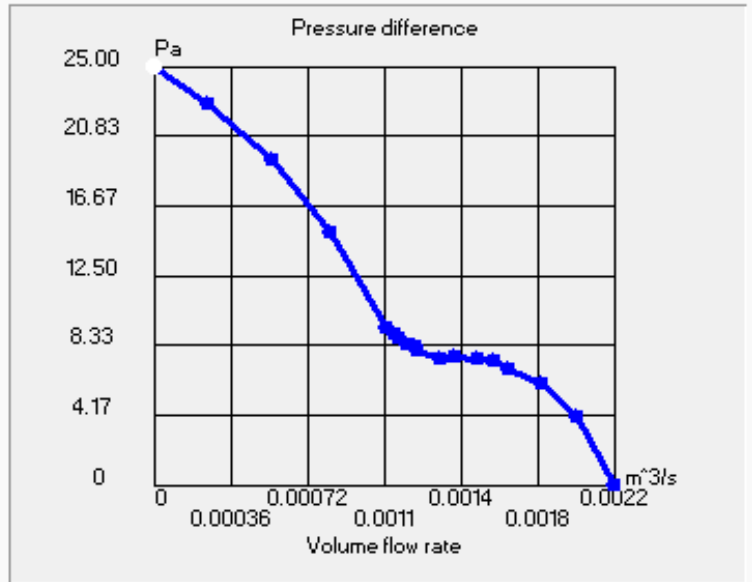
9 Boundary Conditions

The Boundary conditions were set to simulate the conditions of the incubator.

An External inlet fan was used to simulate the inlet fan. The axial 405F was used. The fan parameters are shown below

Parameter	Unit	Value
Reference Axis		X
Volume Flow Rate	m ³ /s	0.00013214529
Boundary Layer		Laminar

Volume flow rate	Pressure difference
0 m ³ /s	25 Pa
0.000256667 m ³ /s	22.76 Pa
0.000563333 m ³ /s	19.3998 Pa
0.000833333 m ³ /s	15 Pa
0.0011 m ³ /s	9.3598 Pa
0.001135 m ³ /s	9.0198 Pa
0.00116 m ³ /s	8.765 Pa
0.001198333 m ³ /s	8.4 Pa
0.001231667 m ³ /s	8.1999 Pa
0.001248333 m ³ /s	8 Pa
0.001351667 m ³ /s	7.5 Pa
0.001416667 m ³ /s	7.625 Pa
0.001526667 m ³ /s	7.5 Pa
0.001601667 m ³ /s	7.375 Pa
0.001676667 m ³ /s	6.875 Pa



An environment out let was located at the top of the dryer to serve as outlet for the air.

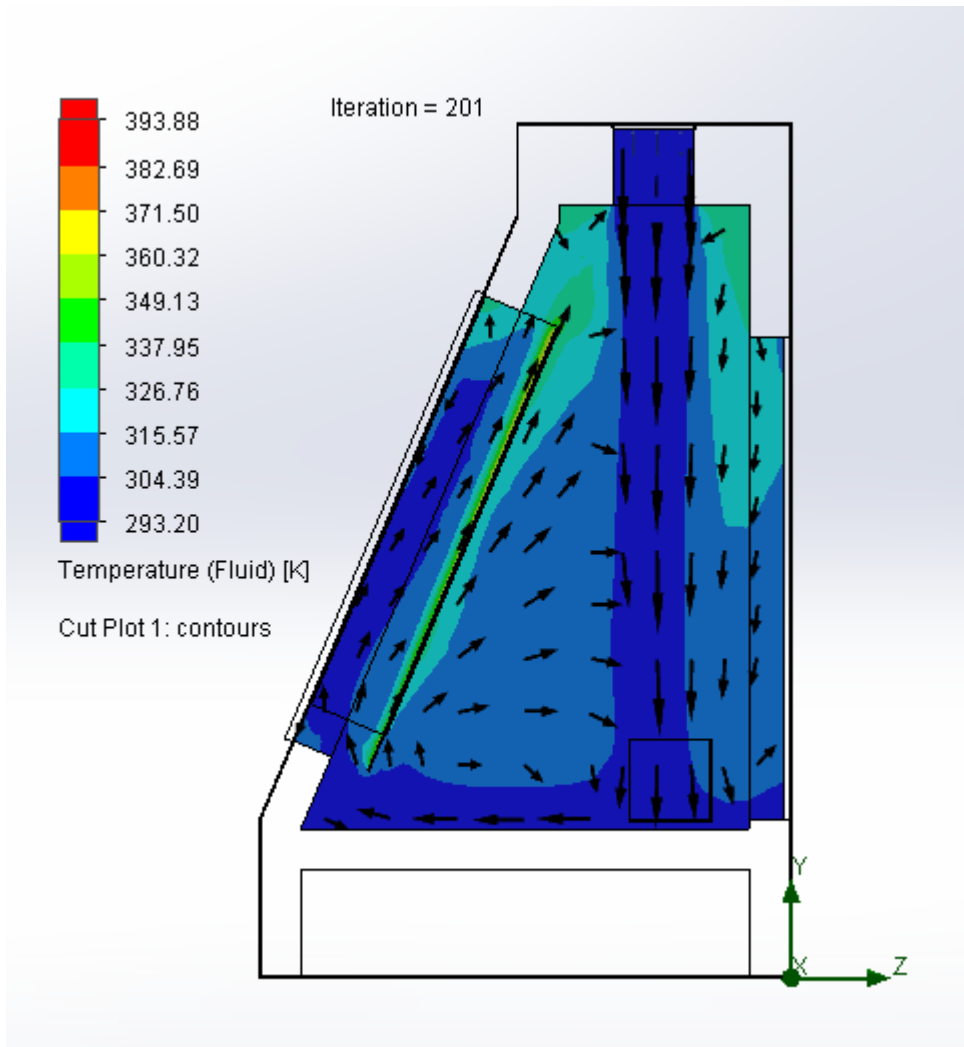
A surface heat source was applied to the collector plate.

3.4.2 GOAL TABLE

The goal of the simulation was to observe how long it would take to raise the average temperature of the incubator from 25⁰C to 37⁰C. The temperature plots and the velocity contours can be used to predict the performance of the system. The goals monitored during the simulation are as follows

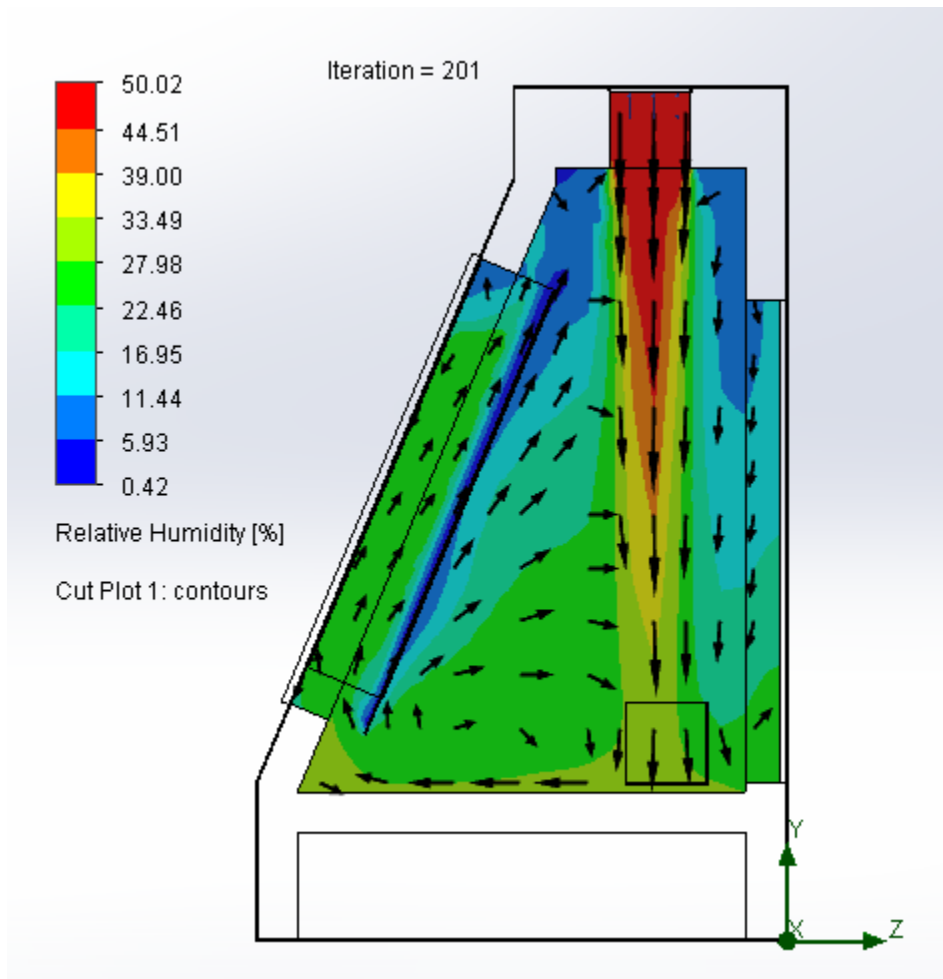
Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
GG Av Temperature (Fluid)					
1	[K]	310.0810251	309.991996	309.800918	310.0810251
GG Av Relative Humidity 1	[%]	21.05115304	21.14383404	21.05115304	21.27346708
SG Av Temperature (Fluid)					
1	[K]	293.1995414	293.1995414	293.1995414	293.1995414

SG Volume Flow Rate 1	[m ³ /s]	0.023668455	0.023668341	0.023667979	0.023669351
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Temperature contour on the mid Y-Z axis showing air flow

The average temperature inside the dryer rose from room temperature at 293K to 310K at steady state. It can be seen that the highest temperatures occur around the region where the collector plate is located. The hot air is also circulated via the fan.



Plot along the mid YZ plane showing Relative Humidity

The drop in relative humidity shows that the air has the ability to evaporate more water as it is now farther from its dew point at that temperature. This will cause them to pick up fresh moisture and become dense causing them to flow to the bottom of the dryer due to the pressure from the fan

coupled

with

gravity.

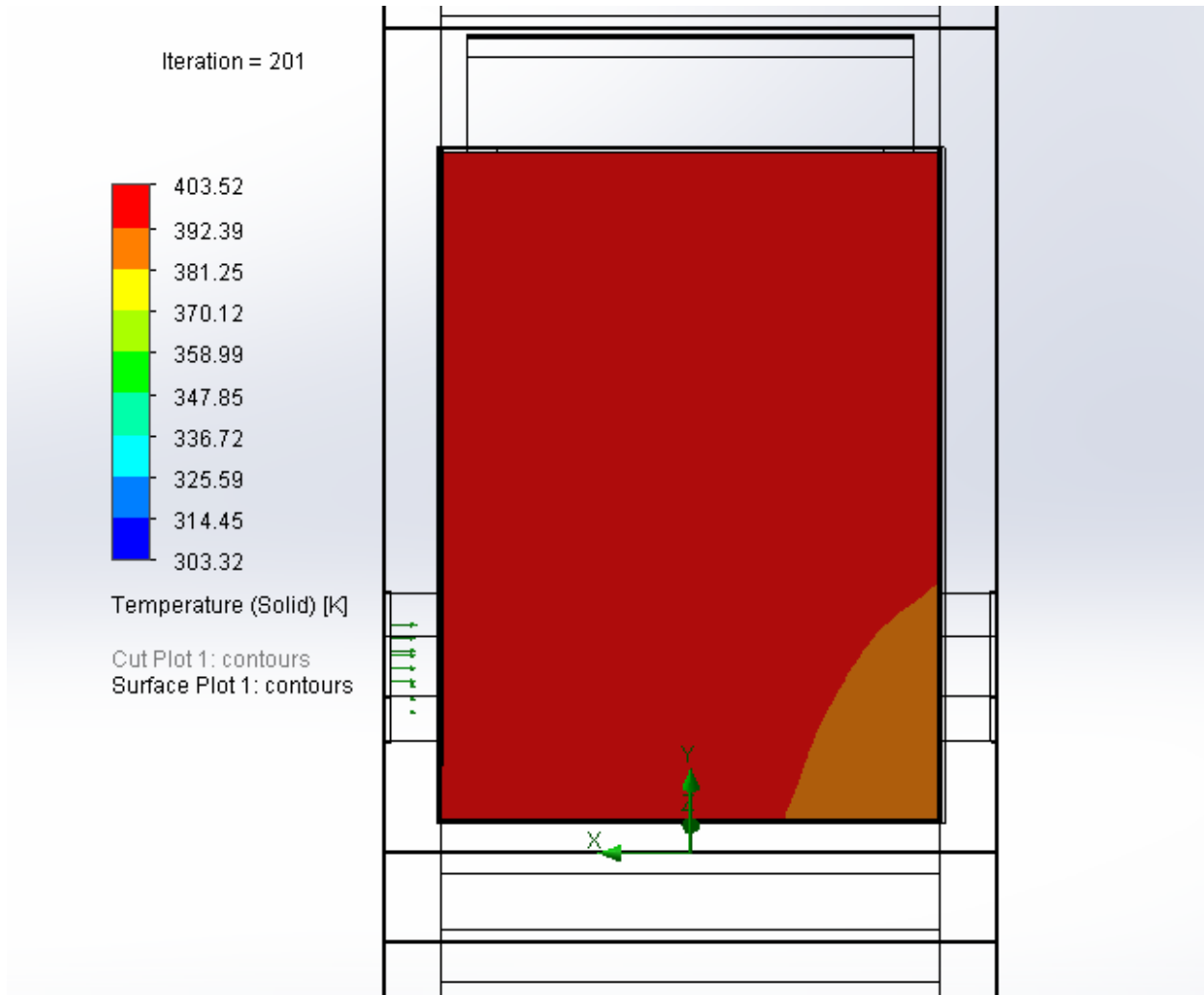
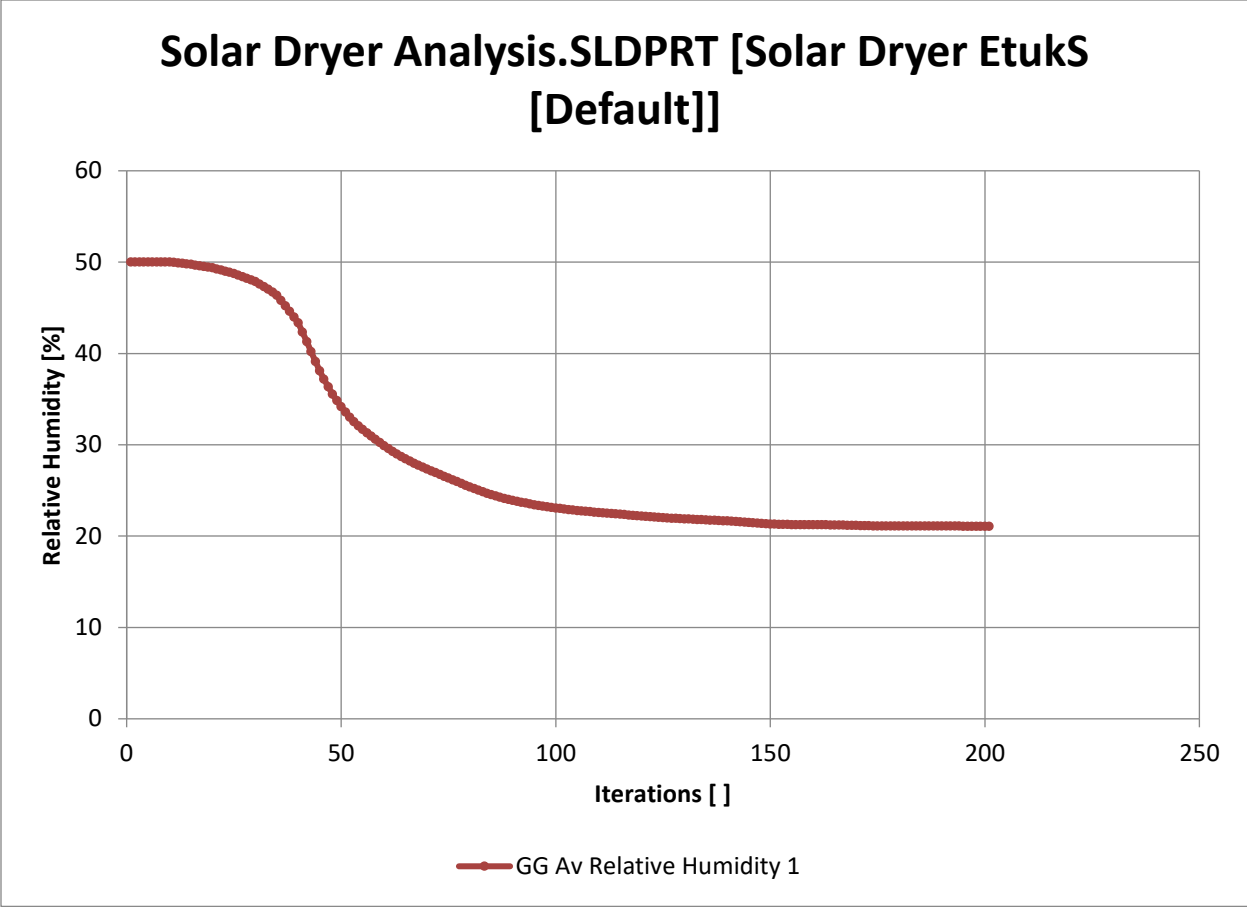
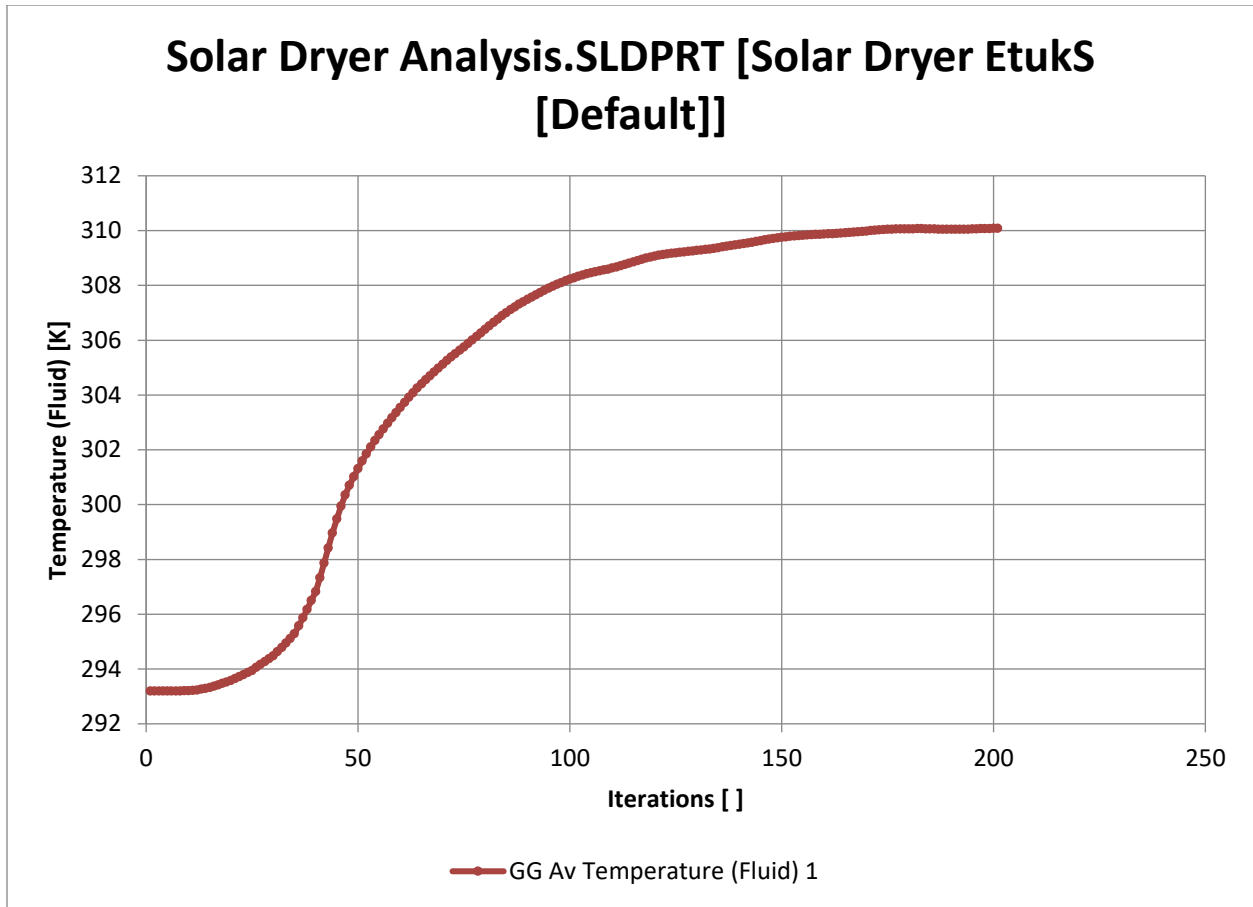


Fig 2: Copper Plate Surface Temperature



Average Relative Humidity Graph



Average Temperature graph

The relative humidity can be seen to have fallen steadily until attaining a value of 21% after 201 iterations. The enthalpy content of the air has increased and this will allow the air to absorb more water vapour. This hot air is blown over the substrate to be dried thus causing it to evaporate moisture from the liquid surface.

CONCLUSION

From the results, we see that the enthalpy content in the air has resulted in the loss of moisture from the air. We see an overall temperature rise of 11⁰C which corresponds to an energy rise of 7.2KJ of energy. It is worthy to note that the amount of water vapor in the air has not changed but the relative distance between the water molecules have increased

