Application of Solar Energy in Drying Pepper

by

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Dissertation submitted in partial fulfilment of
the requirements for the
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
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Approved by,

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(Assoc. Prof. Dr. Chalilullah Rangkuti)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

December 2008

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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SYARIZATUL NADIA BINTI. ROSDI

ABSTRACT

Drying is an important and key preservation technique in processing agricultural product. In today's globalization era where food and agriculture product is given great emphasis, the producers and consumers is expecting a better and advanced technology drying technique that utilizes the free renewable and sustainable environmental friendly energy like solar. With this in view, a research based study of solar application in drying the agricultural product with specification to the pepper industry, was carried out. The aim of the study is to design a feasible solar dryer for the small producer. The project scopes include the design development of an active mixed mode solar dryer equipped with the thermal storage for a continuous operation. Thus, in order to reach the project's scopes and objective, all the design processes such as identification of dryer's requirements, conceptual design, stating the design constraint, design calculation, specification of dryer and the economic evaluation had been accomplished. Result shows that the mixed mode designed dryer which equipped with the 7.46m² solar air collector, 0.13m vertical rock bed thermal storage, 12V fan PV powered and 0.475m vertical drying chamber is able to dry 100 kg of fresh pepper berries in two days continuous operation. With four years of payback period, the dryer can be very economical and valuable investment for the producers.

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In the name of Allah, The Most Gracious and The Most Merciful.

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NOMENCLATURE AND SUBCRIPTS

Nomenclature

MARDI	MARA Agriculture Research and Development Institute
MPB	Malaysia Pepper Board
IKIM	Institut Kemajuan Ikan Malaysia
A	Area
C	Draught Coefficient
C_p	Specific heat of pebbles
g	Gravity
h	Height
I	Solar Radiation
l	Length
m	Mass
m_a	Mass of air to dehydrate
M	Moisture content
ρ	Density
q	Thermal energy
Q	Volume rate
T	Temperature
t	Thickness
V	Volume
w	Width
ϕ	Relative Humidity

Subscript

a	Ambient
c	solar collector
e	Exit
f	Final
I	Initial
w	Water

CHAPTER 1
INTRODUCTION

1. BACKGROUND OF STUDIES

Intensive performance shown by this country's agricultural sector in the Eight Malaysia Plan demands better innovation and modification of the agricultural processing technologies so that more production and export volume can be delivered. This includes the technology for drying which becomes one important preservation process in marketing the commodity. Besides using old method of sun drying, *many commercial crop drying technologies have been developed in this country and mostly use fossil fuel especially diesel. Solar drying provides an alternative to the use of fossil fuel.* However the problems related with the lack of information and promotion, expensive and *disadvantage in term of intermittent nature and the low intensities of solar radiation dampened the entry of these technologies in this country*. [1]

1.1 Pepper Drying

Pepper, a main agricultural export commodity that contributes to the county income, requires a better quality of drying process. Based on current research in this country, pepper processing still uses the traditional drying technique (sun drying) that has lots of disadvantages.

1.2 Solar Application in Drying Pepper

Solar drying which utilize a renewable, free and sustainable energy source have been in research for several years. The method offers less drying losses (compared to sun drying) and show lower operational costs than the conventional drying. It is expected to be a very economical but yet practical and productive alternative to conventional drying.

Through this solar application, the world energy also can be saved and the production of dried product could be optimized by its rapid drying and minimal maintenance cost. Malaysia is among the gifted county with the sunny days, but the application of this sustainable energy technologies are still not been extensively applied in the crops drying massively. Thus, this is quite an opportunity loss to the country as one of her main export commodities is the dried agricultural products like pepper, coffee, cocoa, herbs and vegetables.

2. PROJECT BACKGROUND

This project is to study the application of solar in pepper drying, kicks-off by investigating the current drying methods applied in Malaysia, along with the study of potential application of solar energy technology in improving the available technique. The project focused on the private or small farmers who require a practical solution of continuous rapid dryer.

3. PROBLEM STATEMENT

Agricultural is a major source of income to Malaysia especially which involves to foreign exchange and trade. Among the source of export is pepper, which demands are ever increasing. Back in 1960 until today, pepper contributes over RM 100 millions per year to Malaysia income, making us among the top five pepper supplier over the world. In the production aspect, drying is one main and important process. However, the technique used in Malaysia is still the same; the traditional technique of open space drying is time consuming. It took about seven days for a complete drying. Even though it is using a free energy source and requires little investment, this method faced significant losses caused by drying contamination from pathogenic germs, birds and insects as well as by enzymatic reactions (caused by heterogeneous and insufficient drying). The technique is also a disadvantage in the rainy period which will interrupt the drying process.

Thus, the rapid drying that utilize the free renewable energy source like solar is more desirable. To design this system which is faster than normal air-drying and offers better quality is the biggest challenge of the project.

3.1 Significance of Project

The significance of this project is that, the agricultural sector and body in Malaysia would be able to refer to it as a point of reference that would be able to implement the design system which is expected to optimize the production with best quality. This project could be feasible for further research in the agricultural preservation using the future energy.

4. OBJECTIVE

The objective of this project is to design a practical solar dryer for pepper which are economic, rapid drying and operates continuously.

4.1 Scope of Study

The scope of this project is to study and practise the design processes involved in inventing a practical solar dryer for pepper. In this project, the data of related parameters such as drying properties of pepper and meteorological data were gathered in order to assist the design processes.

The scope of the study include:-

1. Studying the application of solar energy in replacing current methods.
2. Identifying the criteria, parameters and requirements needed for a good solar drying system.
3. Identifying the requirement and design constraint for the dryer.
4. Calculating the design parameter of solar dryer.
5. Analyzing cost of investment and the economic benefit of the dryer.

5. RELEVANCY OF PROJECT

For more proves and evidence to support the findings in implementing the system, lots of researches had been done from extracting and analyzing journals, articles and the interviews with specific party like MPB and MARDI. What will be eventually covered are the study and research of the current technique of drying, how it can be improved by the effective solar design and how to design an effective solar dryer that could be implemented economically by the private or small farmers and also for the domestic usage.

5.1 Feasibility of Project (Scope and Time Frame)

The feasibility of the project was depending on time and the knowledge limitation, also, on the sources from the journals researched. Basically, the project completion was delayed and not able to meet the timeframe due to knowledge limits, insufficient journals and supporting materials, and not delegated the tasks within the planned period efficiently.

CHAPTER 2
LITERATURE REVIEW

1. DRYING

"Product may be dried for these reasons: to improve the shelf life of product, to control textures properties such as crispness (biscuit), to standardize composition and to reduce weight for transport". [2]

The statement proved that drying is one of important operation unit and technique to preserve and enhance the quality value of a product. That is why this process had being practical globally and by this nation since time immemorial; dries fish, crops, herbs etc. Somehow, till today, most of the producer used the cheapest way of sun drying in order to dehydrate their products. This included the commodity of pepper berries where drying becomes among the most important manufacturing process that need to be controlled in standardizing its product quality and composition. Basically, for the pepper berries, after the harvesting and cleaning process, the crops was drying immediately on the open floor under the sun radiation for four to seven days. This process is compulsory to reduce the original moisture content of 80% (wb) to the international export standard of 12%. As today world expects for the best quality, the method of sun drying seems to be inefficient anymore and need some modification. Moreover, one of the researches done by MARDI showed that most of bacterial contamination of the pepper berries was due to exposure of the pepper on the floors and substandard of drying process. [3]

Therefore, the advanced drying techniques must be studied and analyzed so that a better efficient dryer could be designed and applied widely. Appendix-A shows the current drying method applied commercially for agricultural commodity in Malaysia which could be divided into two categories; open sun drying and conventional drying.

2. SOLAR APPLICATION IN DRYING FOOD

2.1 Solar Energy

Solar energy is a free, environmentally friendly and abundant energy source that everyone can use. Since it is renewable, it becomes the most important and one of our prime sources of energy that can be applied for various activities especially in preservation of foods or solar drying. The utilization of this free, non-pollutant energy will offer a clean and less operating cost. In order to utilize the energy, there are several difficulties must be overcome; the main problem the periodic character of solar radiation. Due to this matter, a storing part of the energy gained during radiation periods is introduced. Nevertheless, it is only possible with the use of an auxiliary energy source because even the radiation periods it self may produce certain difficulties. First, the intensity of incident radiation is a function of time. This circumstance demands adequate control strategy and the means necessary for the control. Second problem is caused by the low energy density of solar radiation, which requires the use of large energy-collecting surfaces (collectors). Therefore, it requires heat stores, auxiliary energy source, control system, and large surface solar collectors as the solution. From previous study on the techno economics of solar drying, it has led to the knowledge of three important matters, which are the main factors, their roles and influencing mechanisms. One of the main discoveries was that solar energy could economically used for drying only if the purpose can be coordinated with the specific characteristics of solar radiation. Thus, geographic circumstances deciding the number of sunny days yearly and the incident radiation intensity give different energy gain in various areas of the Earth. The relatively small energy flux density of solar radiation implies that it is particularly suited to drying processes with small energy demands while higher energy demands require concentrating collectors. Such collectors are generally expensive. However, during the last decades, several developing countries have started to change their energy policies toward further reduction of petroleum import and to alter their energy use toward the utilization of renewable energies. The developing countries are situated in climatic zones of the world where the radiation is considerably higher than the world average of 3.82

kWh/m² day. Table 2.1 below show the daily average horizontal insolation data and sunshine hours are given for some developing countries.

Table 2.1: Daily Average Horizontal Insolation Data in the Developing Country [14]

Country	**Average Insolation (kWh/m² day)**	**Sunshine Hours (h/d)**
Cameroon	3.8 – 5.5	4.5 – 8
Egypt	6	9.6
Guatemala	5 – 5.3	-
India	5.8	8 – 10
Indonesia	4.24	-
Kenya	5.25 – 5.6	6 – 7
Malaysia	**4.41**	-
Mali	4.34	8.4
Mauritius	4.5	7
Mexico(Jalapa, Veracruz)	4.65	-
Nicaragua	5.43	-
Nigeria	3.8-7.15	5-7
Papua New Guinea	4.6 – 9.6	4.5 – 8
Philippines (Metro Manila)	4.55	-
Sierra Leone	3.4 – 5.3	3 – 7.5
Thailand	4.25 – 5.66	-
Togo	4.4	5.5-7.2

2.2 Solar Dryer

"*Drying is an excellent way to preserve food and solar food dryers are an appropriate food preservation technology for a sustainable world.*" [4]

Solar dryer is an appropriate alternative for the drying technology. Thus, it have been rapidly developed to replace the open space drying and become a good alternative for the energy consumption used by current mechanical drier. Basically, the dryer

The available solar dryers systems could be categorized into two types of the system; natural convection or forced convection of heat transfer. In a natural convection system, the flow of air is caused by the fact that the warm air inside the dryer is lighter than the cooler air outside. This difference in density creates a small pressure difference across the bed of grain, which forces the air through it. This system is quite slower than the in forced convection system where external devices like fan or blower is used to create the airflow and thus reduce the drying time.

2.3 History of Solar Dryer

The good history of solar dryer is given by Sodha et al. He stated that solar dryer was developed from so far vary from the simple small cabinet dryer to the forced convection dryer where solar energy is used to heat the air and the heated air will be used to evaporate or absorb the moisture from the product. The small cabinet or box type of solar dryer is the simplest dryer where the heating of air and moisture removal takes place in the same unit. The first designer of this type of dryer was Lawand and the design was field tested for many times and many years, now widely used in many countries with some modifications of the original design.

Further studies of this dryer, conducted by Garg and Krisnan in India, Harahap et al. in Indonesia and Pablo in Philippine found out that the drying rate can be increased by combining the air heater and the box dryer which is known as shelf type dryer. This shelf type of dryer is used for drying grapes in Australia by Szulmayer, orchards in USA and fruit drying in Turkey where Akyurt and Selcuk then developed the dryer to be supplemented with the auxiliary energy for its continuous operation. [5]

2.4 Solar Dryer in Malaysia

In 1993, the solar black box dryer was bought by the MARDI and LKIM in order to dry the crops and the fishes in the larger scale. The black box solar dryer was covered by the transparent Perspex and has been equipped with the auxiliary heater (diesel) for a continuous operation. The dryer was functioned efficiently at the both sunny day and night. Figure 2.1 shows the solar box dryer used by MARDI.

Figure 2.1: Solar Black Box Dryer at MARDI, Serdang

Below are some researches which relate to the solar dryer in Malaysia and her neighbor:-

M.Y.H. Othman and K. Sopian studied the impact of a grooved solar collector to their solar assisted drying system. They used (3 x) 4.6m x 1.0m x 0.15m collector with V-groove absorber to enhance the heat transfer surface area which directly will improve the performance of the system. They also included the system with the 10kW auxiliary heat source for continuous operation. The system tested by drying chili to have an overall drying efficiency of 20-30%, producing average drying chamber temperature of 50 °C with this condition; flow rate of 15.1 m^3/min, an average solar radiation of 700 W/m^2 and ambient temperature of 27 – 30 °C. Thus, the moderate temperature produced is suitable to dry the crop or agricultural product and V-groove collector proved to be more efficient. [6]

(Refer Appendix-B: Solar assisted drying system with v-grooved collector)

In 1999, M.Y.H. Othman and K. Sopian [1] also designed another solar assisted drying system with double pass solar collector. They performed the experimental studies on the performance of a double-pass solar collector with porous media in the second or lower channel. In their experiment, centrifugal blower is used to induce the hot air and the findings were; Outlet temperature is about 90 °C at an average solar radiation level between 900 - 1000 W/m^2. In general, the outlet temperature does not drop drastically when the solar radiation decreases due to passing clouds or rain as in any conventional solar air collector. The outlet temperature goes down gradually in the evening even at low solar radiation levels. This is because of porous media in the second channel acts as the storage media for the system. [1]

(Refer Appendix-C: Solar assisted drying system with double pass solar collector)

Sopian et al. (2000) introduced the first multiple pass concept for the air-cooled PVT systems suitable for drying system. The double-pass flow enhanced cooling of the photovoltaic cells and thus increasing the efficiency of the systems. The PVT collector with CPC and fins has better performance compared to others. The characteristics of the collector are measured at solar radiation level of 700 W/m^2 and airflow rate at 0.1 kg/s with inlet temperature ranging from 30^{o}C to 54^{o}C. Thermal efficiency of the system is in the range of 48% to 63.6% with air temperature output of 35.5^{o}C to 58^{o}C. [1]

(Refer Appendix-D: PVT solar dryer)

In 2001, a complicated solar dryer system was developed by Yahya. The solar assisted dehumidification system is an effective and viable alternative to the many present drying techniques. The system consists of evacuated tube solar collectors, dehumidification system and the drying chamber. A temperature of 40°C and air at relative humidity of 20 - 30 % can be achieved in the drying chamber and the operated continuously since an auxiliary heater has been installed in the storage tank. [1]

(Refer Appendix-E: Solar Assisted Dehumidification System)

In 2006, a solar tunnel dryer with a polycarbonate cover was designed and constructed by S. Janjai and T. Keawprasert. The dryer consists of two parts, namely solar collector and a drying tunnel which both parts connected in series. The polycarbonate cover used to reduce heat losses while allowing the incident solar radiation transmit into dryer. Experiment done by drying the jackfruit and high quality products in term of flavour, colour and texture were obtained. For most cases, the temperature of drying air varied from 35 to 60°C from 9 am to 5 pm. [7]

From the literature review, the general views on the application of solar dryer in this country are obtained. The utilization of this technology is still low in Malaysia, may be due to the less confidence among the users, higher investment cost of solar dryer, lack of promotion, lack of information distribution on this technology and less awareness of this future prime energy among the people. Generally, the research done in Malaysia only focused on the larger association like MARDI and not to the small farmer. Thus, a design process of solar dryer for this small or private farmers must be go through in order to attract the citizens to the usage of this free and renewable energy sourced dryer.

CHAPTER 3

METHODOLOGY

1. PROJECT OVERVIEW

Process flow to describe the methodology of the study is shown as Figure 3.1.

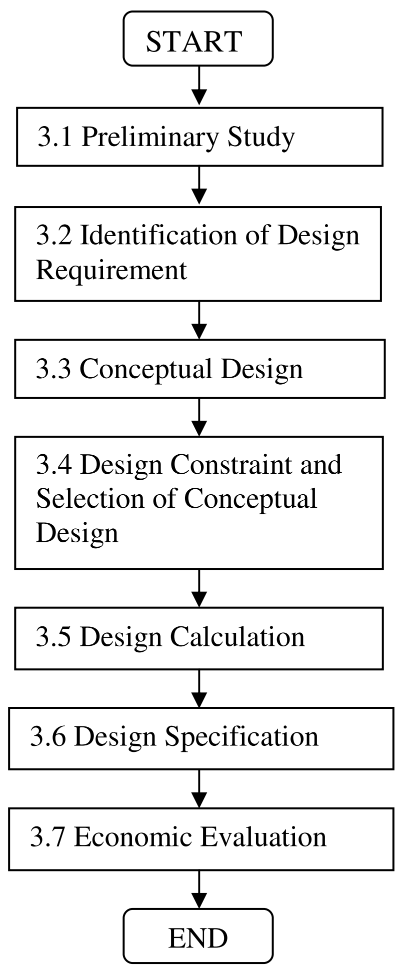

Figure 3.1: Project Flow

2. DATA GATHERING

Pepper berries have been identified as the commercial trial crop for designing stage of this project. Its hygroscopic characteristic and its value towards nation economic were the main factor for the selection. Basically, most of agricultural commodities like cocoa, mango slices etc. have similar drying characteristics and little different of drying rate compared to pepper.

Sri Aman is among the main and big cultivation area for pepper in Sarawak (more than 866 hectare), thus her meteorological data was used for this project. The data for year 2003 was taken from Malaysia Meteorological Website. Figure 3.2 shows the daily average of solar radiation and temperature for the area.

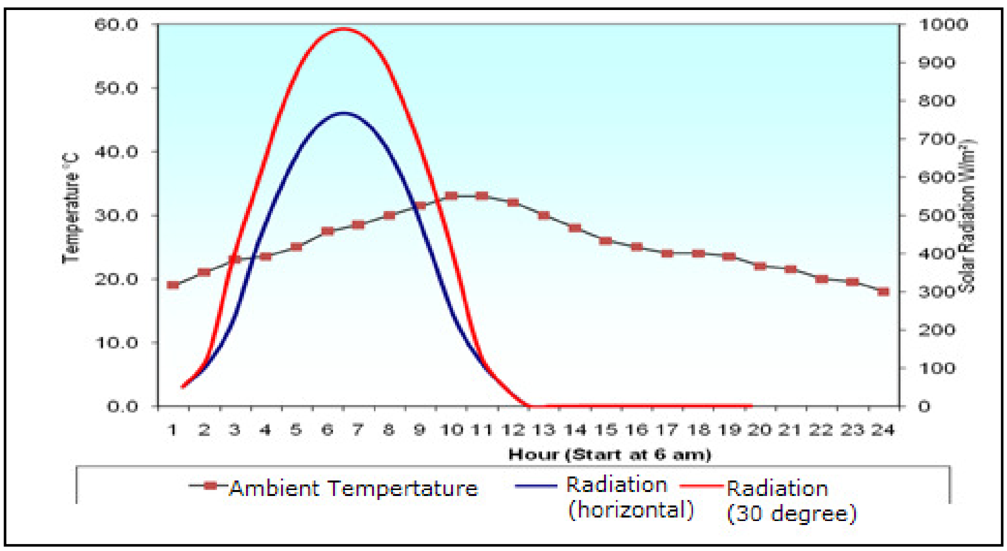

Figure 3.2: Average Hourly Solar Radiation and Temperature during April in Sri Aman

2.1 Meeting with MPB Staff

For gathering the data and identify the requirement of the solar dryer, a meeting with the MPB Johor Branch Manager, Mr. Stephen Somalia and Mr. Augustine (Sarawak Branch) was conducted at MAHA. The summary of these data which described in Table 3.1 is important for the design calculation stage.

Table 3.1: Data of Focus Location and Pepper

Items	Condition / Assumption
Location	Sri Aman, Sarawak
Crop	Pepper berries
Drying period	March-July (during harvesting season)
Drying batch	100 kg of fresh pepper berries (Average pepper berries gained by small farmer per day: 50kg-100kg)
Initial moisture content	80% w.b.
Final moisture content	12% w.b.
Ambient air temperature	26.5°C
Ambient relative humidity	75%
Incident solar radiation,	50-1000 W/m².day
Specific Gravity of Pepper	>1.12

MPB suggested to analyze some weaknesses faced by pepper commodity in order to indicate their possible improvement by the drying process. Table 3.2 describes the considered factors in analyzing the weaknesses of pepper.

Table 3.2: Considered Factors in Analyzing Weakness

No	Weakness	Way to Improve
1.	Fluctuating Price – The unstable price of pepper in the international market made the farmers less interest of efficient drying process.	• Improve quality of product. The quality of product can be improved by a hygiene processing system.
2.	Sun Drying Process • Moulding • Bacteria attack • Rainy weather • Natural environment; animals pass by	• Design good drying system that utilizes a friendly environmental energy. The design must cater all the disadvantages of sun drying.
3.	High Cost	• Use free energy and sustainable energy. Try to design lower investment, operating and maintenance cost of dryer. • Consider to design the passive solar dryer or backup system that applies another renewable energy like wind or biomass.

4.	Remote area – far distance from town	• Minimize / not consume the electricity • Design technology that portable and flexible to be used in the remote area.
5.	Bad promotion / Less knowledge about the solar dryer	• Every design should include the brief manual for the installation, operation and troubleshoot.

3. DESIGN PROCESSES

3.1 Identification of Requirement

List of requirements was conducted in tend to solve or minimize the problems faced by the farmer in drying the pepper. Requirements of a new system are based on the findings of the meeting with the MPB people. Among the requirement of the system are summarized by Table 3.3.

Table 3.3: Requirement of the System

No	Factors	Problems	Requirements
1.	Location	Located far away from the town Rural – mostly used generator Less of space	*Use thermal storage rather than auxiliary heater *Portable if possible *Multi layer of drying tray / bin
2.	User	Lack of knowledge / Conventional thinker Lack of money to invest	*Simple design *Easy to maintain – less moving part *Interactive manual *Cheaper
3.	Climate	Intermittent solar radiation Rainy period High relative humidity	*Apply high thermal absorption of solar collector *Use backup system *Use external force device like fan / blower
4.	Pepper	Must dry just after had been plucked Must dry in shorter period if possible	*Dryer built near / inside the farm
5.	Cost	Higher investment or long payback period method will down the users	*Use cheaper but good quality material and components

3.2 Conceptual Design

After did some literature reviews, the rough conceptual designs were made. There are four design concept for the project as described below:-

3.2.1 Design Concept (1)

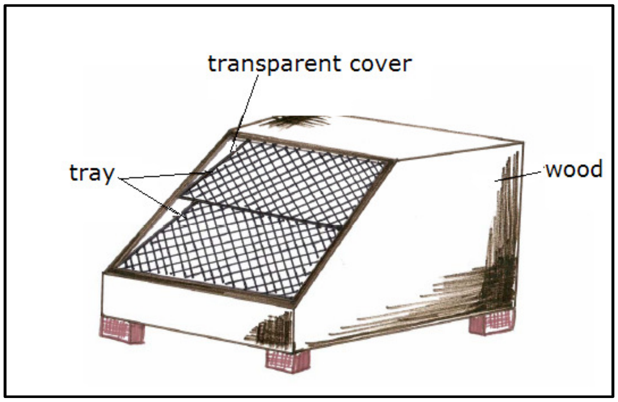

Figure 3.3: Design Concept 1

Figure 3.3 shows the draft of the first conceptual design. This is the simplest design of solar dryer which using a direct solar energy. Eventually, the dryer had been constructed and applied mostly at the foreign country. The main components are the wooden frame (acting as the drying chamber), the glass roof (solar collector) and the trays (for the thin layer drying). It works with this principle: Solar radiation will be transmitted directly to the trays through the glass roof and trapped some heat. Thus it is functioning as the greenhouse. It can be improved by adding some venting: inlet vent at the bottom of dryer, outlet vent at the top and by adding the black absorber. Table 3.4 below shows the preliminary analysis of the first conceptual design.

Table 3.4: Advantage and Disadvantage of Design Concept 1

Advantages	Disadvantage
Very cheap	Lower drying rate
Can be built and use easily	Applicable for small scale production
	Poor ventilation
	Low quality of product
	Direct dryer which reduce the vitamin contains

3.2.2 Design Concept (2)

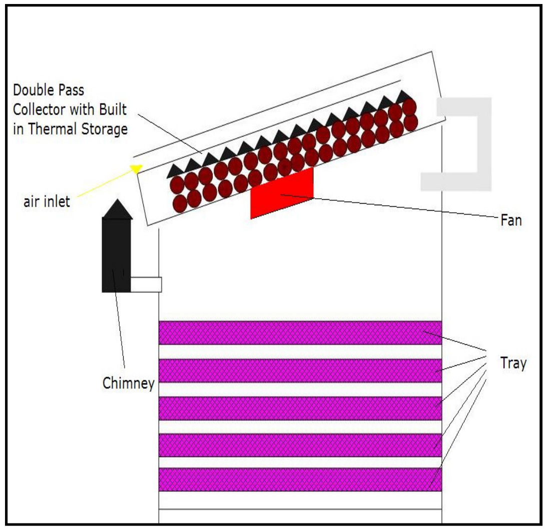

Figure 3.4: Design Concept 2

The second solar dryer is an indirect active mode dryer (Figure 3.4). The design composed of five major components; double pass v-grooved solar collector with a built in thermal storage (important for the continous drying / temporary backup), chimney and drying chamber (contains of layered drying trays). Table 3.5 below shows the preliminary analysis of the first conceptual design.

Table 3.5: Advantage and Disadvantage of Design Concept 2

Advantages	Disadvantage
Rapid drying	High capital cost – solar collector, thermal storage and fan
Good ventilation – fan and chimney	High maintenance cost – electricity / battery to run the fan
Continuous operation	
Medium scale	

3.2.3 Design Concept (3)

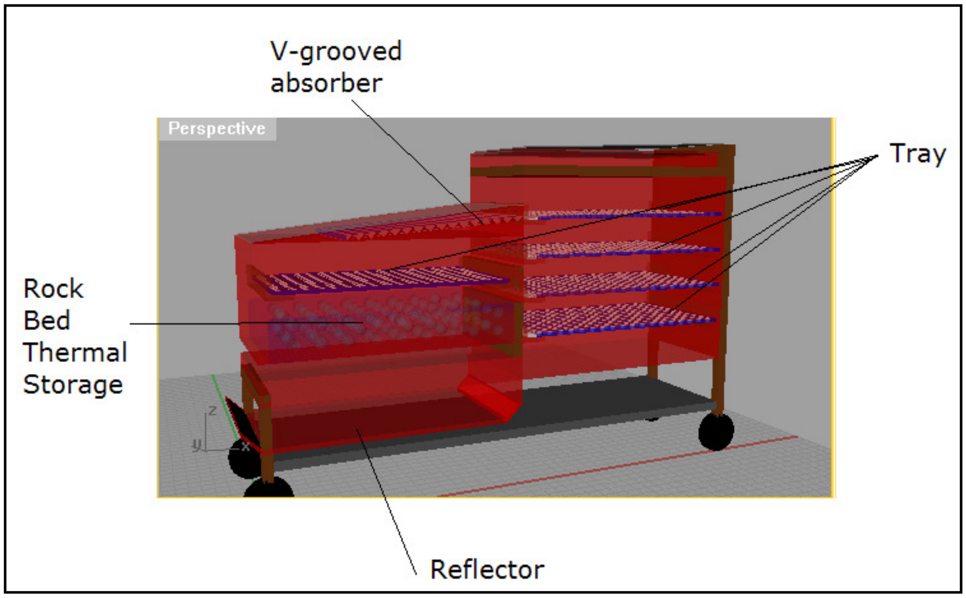

Figure 3.5: Design Concept 3

The third solar dryer is a mixed mode pasive dryer (Figure 3.5). The design composed of these components; three solar collector (two v-grooved solar collector with a built in thermal storage on the top and one reversed absorber at the front bottom), a container of packed bed thermal storage on the top of reverse absorber, reflector for the reversed absorber, drying chamber which contains four trays and the main body which made of perspect or glass cover. The dryer is equipped with the height maintenanced trolley for easy mobilization. Table 3.6 below shows the preliminary analysis of the first conceptual design.

Table 3.6: Advantage and Disadvantage of Design Concept 3

Advantages	Disadvantage
Rapid drying	High capital cost – solar collector, thermal storage and fan
Good transmission system / greenhouse effect	High maintenance
Continuous operation	Heavy
Medium / Big scale	Information distribution
Easy to mobilize	

3.2.4 Design Concept (4)

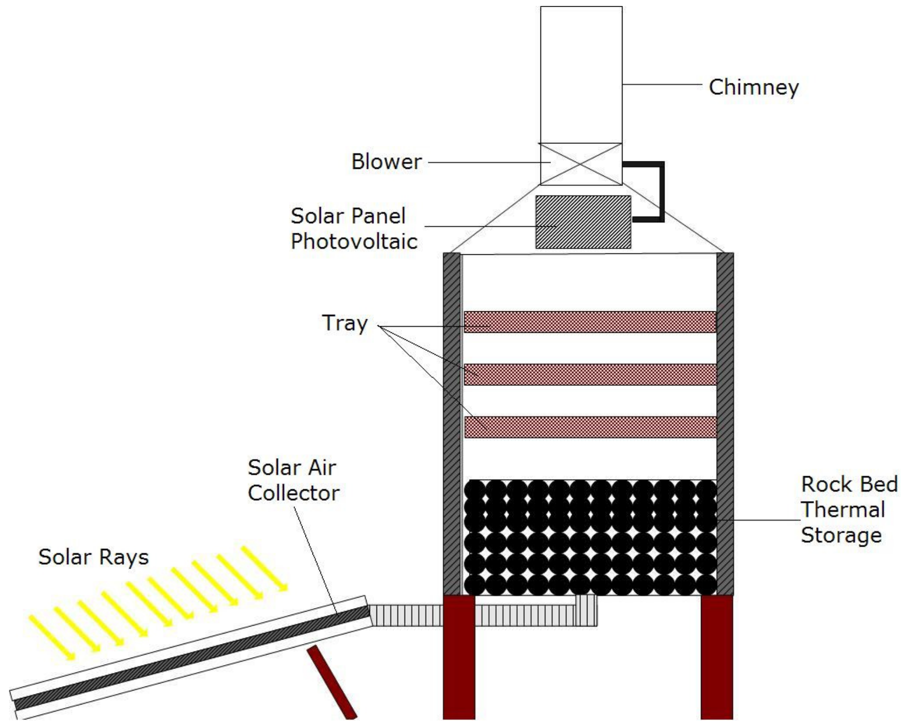

Figure 3.6: Design Concept 4

The fouth solar dryer is a mixed mode pasive dryer (shown by Figure 3.6). The design composed of these components; the air solar collecor, thermal storage, drying trays, arcyclic perspect transparent roof and chimney for the air ventialation. The components designed to setup, operate and maintain. Table 3.7 below shows the preliminary analysis of the first conceptual design.

Table 3.7: Advantage and Disadvantage of Design Concept 4

Advantages	Disadvantage
Moderate drying	Capital Cost
Good transmission system	Information distribution
Continuous operation	
Medium / Big scale	
Easy to setup	
Easy to operate and maintain	
Not require many labour	

3.3 Design Constraints

Design constraints of this project were chosen after indicating the general requirements on the solar dryer. Stated below are the constraints:-

i. Design must be suitable for the usage of small farmer / private farmer.
ii. Able to dry 100kg of pepper or other crops faster than sun drying.
iii. Able to operate continuously.
iv. Capital and maintenance cost are reasonable and affordable (Preferable capital cost: not exceed RM 2000).
v. Easy maintenance and operation.
vi. The solar dryer is long lasting (at least more than 15 years).
vii. Materials used are cheap and easy to find
viii. Dryer will dry the crops uniformly
ix. Product weight is lower
x. Flexible
xi. Able to acquire maximum solar energy

3.4 Selection of Conceptual Design

Selection of design is made based on the design constraint. The screening and scoring processes are the methods to choose the best design.

The screening concept is to make a quick evaluation aimed at a producing a few viable alternatives. Concept screening uses a reference concept to evaluate concept variants against selection criteria and a coarse comparison system to narrow the range of concepts using consideration.

After the concept screening process, the top two rated concepts will continued with the concept scoring for further selection of final concept. The steps for concept screening in sequence are:

i. Prepare the selection matrix
ii. Rate the concepts
iii. Rank the concepts
iv. Combine and improve the concepts

v. Select one or more concepts

vi. Reflect on the results and the process

Table 3.8 below shows the result of the selection matrix for all conceptual designs.

Table 3.8: Selection Matrix of Conceptual Design

Selection Criteria	**Concept**			
	(1)	**(2)**	**(3) Reference**	**(4)**
Reasonable Cost	+	-	0	0
Flexibility	0	-	0	+
Reliability	-	0	0	+
Long-lasting	0	+	0	0
Large quantity of production	-	0	0	0
Decreased labor cost	0	0	0	0
Increased productivity	-	+	0	+
Maximum solar energy	-	0	0	0
Product weight	+	-	0	0
Sum +'s	3	2	0	3
Sum 0's	3	5	10	7
Sum – 's	4	3	0	-
Net score	-1	-1	0	3
Rank	3	3	2	1
Continue	**No**	**No**	**Yes**	**Yes**

+ FOR "BETTER THAN", 0 FOR "SAME AS", - FOR "WORSE THAN

Concept scoring is a more careful analysis of these relatively few concepts in order to choose the single concept most likely to lead to product success. Concept scoring may use different reference points for each criterion. Concept scoring uses weighted selection criteria and a finer rating scale. Concept scoring may be skipping if concept screening produces a dominant concept. The concept scores are determined by the weighted sum of the ratings. It also goes through the six steps processes like in screening method.

Table 3.9 below shows the result of the screening matrix for design concept 3 and 4.

Table 3.9: Screening Matrix for Design Concept 3 and 4

Selection Criteria	**Weight (%)**	**Concept**			
		(3) Reference		**(4)**	
		Rating	**Weighted Score**	**Rating**	**Weighted Score**
Reasonable Cost	20	2	0.40	3	0.60
Flexibility	10	3	0.30	4	0.40
Reliability	10	4	0.40	4	0.40
Long-lasting	10	4	0.40	4	0.40
Large quantity of	5	5	0.25	5	0.25
production	5	4	0.20	5	0.25
Decreased labor cost	15	5	0.75	5	0.75
Increased productivity	15	5	0.75	4	0.75
Maximum solar energy	10	2	0.20	3	0.30
Product weight					
	Total Score		3.65		4.10
	Rank		2		1
	Continue		No		Yes

Rating Scale:

Relative Performance	**Rating**
Much worse than reference	1
Worse than reference	2
Same as reference	3
Better than reference	4
Much better than reference	5

From this screening and scoring method, the best final concept selected is the last design with net score of 4.10. Basically this design concept is quite similar to the second and third design concept but it is friendlier user and cost lesser to the private farmer. The second design requires more energy to be distributed in the drying chamber, thus it is less desirable for the small farmer. Whereas, the design chosen is very practical, not too expensive, improve quality of product as it was designed in a closed space and can extract the sun energy in mixed mode. In addition, the dryer is quite flexible compared to the rest as it can be easily setup, use and maintain and offer continuous operation.

Therefore, it is very practical with a cheaper investment. Solar food dryer function when the sunrise, the solar food dryer will try to gain the maximum heat as much as possible through its effective v-grooved solar collector and high transmittance of Perspex roof. The dryer was painted black in order to absorb much heat. Then, the air ventilation (in and out) is quite good with the assistance of chimney. Chimney which made of high absorption material and painted black will increase the velocity of wet air so that the drying process will be faster. With this understanding working principles, the detail design of this solar dryer was preceded. The advantages and disadvantages of design four are:

Advantages**:-**

i. Reasonable investment

ii. Easy to operate and maintain

iii. Not requires a specialized manpower

iv. The material is well controlled drying

iv. The drying is quicker

v. Flexible

vi. The crops are well protected during the drying process

vii. Can be produced locally and from local available material

vii. Environmental friendly

viii. The air solar collector is better compare to other design concepts

Disadvantages:-

i. Introduction to the technology – need to do extensive promotion or attractive manual distribution

ii. The dryer should be operated properly to reach the good quality of the dried product.

iii. Still require the investment

3.5 Product Structure

The complete product of solar food dryer composed of five main parts which are solar air collector, packed bed thermal storage, drying chamber, chimney and main frame. These components require other assisting parts, which have different functions but compliment each other to make the solar food dryer functioning. Listed are the main components and their parts:-

i. Solar Air Collector

Solar air collector functions to supply the hot air indirectly to the drying chamber. The main consideration of this collector is its capability to absorb and transfer the heat effectively.

ii. Packed Bed Thermal Storage

The main characteristics of the thermal energy storage is its capacity per unit volume or weight, the temperature range over which it operates (the temperature at which heat is added to an removed from system), means of addition and removal of heat, temperature stratification of the storage unit, power requirement for addition or removal of heat, container, means of controlling thermal losses from the storage and cost.

A well design packed bed using rocks has several characteristics; heat transfer coefficient between air and solid is high, conductivity of the bed is low when there is no air flow, pressure drop through the bed is low and container cost is low. Thus, the basic components for the packed bed thermal storage are:-

a. Container
b. Pebble Rock

iii. Drying Chamber

Drying chamber must able to dry the load of 100kg of pepper. The components are:-

a. Mesh
b. Tray Frame
c. Tray Support

iv. Main Body

The components of the main body includes:-

a. Pebble Thermal Storage Part
b. Drying Chamber
c. Frames

v. Roof Frame

Roof is the assembly of these parts:-

a. Top transparent Perspex / glass
b. Aluminium Square Chimney

3.6 Design Calculation

To carry out the design calculation and sizing the dryer, the design conditions and assumptions shown in Table 1 are used.

Beside that, the main points that were considered in designing the forced convection solar dryer system are:-

i. Amount of moisture to be removed from a given quantity of fresh pepper berries.
ii. The quantity of air needed for drying.
iii. Determine energy received by the dryer per day.

Thus, in order to detail all the design of components involved, the steps as stated below were performed:-

1. Determine the size of dryer. The size of dryer was determined as a function of the drying area needed per kilogram of pepper.
2. Determine the climatic data like mean average day temperature in April, relative humidity and mean solar radiation. This data will assist to find the total heat energy required to evaporate the water.
3. Determine the area of collector
4. Determine the size of thermal storage
5. Determine the chimney sizing

3.6.1 Determine the size of drying tray

Drying tray size for pepper is a direct function to the volume of the crop. The calculation is based on the info of pepper's specific gravity, which is higher than 1.12. [13]

$$p_{pepper} = SG \times p_{water}$$
$$p_{pepper} = 1.12 \times 1000 kg/m^3 = 1120 kg/m^3$$
$$\text{V} = \text{m}/p_{pepper} = 100\text{kg}/1120\text{kg/m}^3 = 0.0893\text{m}^3$$

Because of there are three trays provided in the dryer, each tray should capable in handling $\frac{0.0893}{3} = 0.030\text{m}^3$.

For one tray:-

i. The tray is in rectangular shape. As the volume formula is:-

$$\text{V} = l \times w \times t \tag{1}$$

If the thickness of one tray is designed to be 0.05m,

$\text{V} = 0.03\text{m}^3 = l \times w \times 0.05m$

Let's $l = w$,

$0.03 = 0.05w^2$

$w = \sqrt{0.6} = 0.78\text{m}$

Therefore, the tray size will be 0.78m x 0.78m x 0.05 m. Due to resistance of the air flow, the air gap between the trays must be reduced as much as possible. 0.05m was selected as the air gap distance between the trays in order to allow installation of tray support (max to 0.025m height).

3.6.2 Determine the quantity of heat needed at the drying tray

i. Amount of moisture to be removed from product

The amount of moisture to be removed from the product is calculated using this formula:-

$m_w = m_p (M_i - M_f) / (100 - M_f)$ (2)

For 100 kg fresh pepper which need to evaporate 80% (wb) moisture content to 12%, the water need to be evaporated is:-

$m_w = 100 (80 - 12) / (100 - 12) = 77.27kg$

ii. Mass of dry air to evaporate the water from fresh pepper

$m_a = m_w (w_f - w_i)$ (3)

The $(w_f - w_i)$ can be found from the psychrometric chart.

Reading the psychrometric chart:-

Lets assume that the $T_{amb} = 27.5^{o}C$ is heated to $T_{product} = 45^{o}C$. The initial relative humidity ϕ_i will be reduced from 78% to 29.5%.

If this heated air is used to remove the moisture from pepper of $M_i = 80\%$ until reach an equilibrium RH, $\phi_f = 90\%$, the temperature will drop to $30^{o}C$. Thus, the humidity ratio will be changed from 0.0182 to 0.0238.

Therefore, the difference of humidity ratio is equal to 0.0056. This means that the capability of heated air (ABC) for dehydration is nearly $\frac{0.0056}{(0.019 - 0.0182)} = 7$ times greater than the unheated air (AD).

$\therefore$ $m_a = 77.27 / (0.0056) = 13798$ kg

$\therefore$ The corresponding volume of air required for dehydration is,

$V_a = m_a RT_c / P$ (4)

$V_a = 13798\,kg \times 2.9 \times 10^2\ Jk^{-1}K^{-1} \times 300.5K / 1.01 \times 10^5\,Pa$

$V_a = 11.905x10^3\ m^3$

iii. Amount of thermal energy required

If the amount of water (m_w) is vaporized in time, τ then the heat absorbed by the drying load can be described by;

$q = m_a (h_f - h_i)$ (5)

From the psychrometric chart, the final enthalpy and the initial enthalpy are 108.39kJ/kg and 92.11kJ/kg.

Thus the heat required is:-

q= 13798kg (108.39 – 92.11) kJ/kg

q= 193.56MJ

Thus, the energy required for the dehydration process is 193.56MJ.

3.6.3 Determine the size of thermal storage

i. Mass of pebbles required to store the heat

Thermal storage capacity should be adequate to store approximately 2/3 of thermal energy that collector can collect and deliver on a clear sunny day during space heating seasons.

Assume maximum solar energy collected is 15.876 MJ/m² of collector and 20ºC increase in thermal storage, the mass of pebbles required for each square foot of collector area is:

$$m_{pebbbles} = \frac{2}{3} \times I_{\max} /(T_{storage} \times \text{specific heat}) \quad [16] \tag{6}$$

$$= \frac{\frac{2}{3} \times 15876 \text{ kJ/m}^2 day}{60^o C \times 0.88 \text{ kJ/kg}^o C} = 200.45 \text{ kg}$$

For the safety factor, the mass of pebbles is added to 10% which is about 220.5kg

ii. Height of the storage

If the rock density selected is 2700kg/m³, the volume will be used is:

$$\text{V} = \frac{m_{pebbles}}{\rho_{pebbles}} \tag{7}$$

$$\text{V} = \frac{220.5kg}{2700kg/m^3} = 0.08m^3$$

As the area of the storage is 0.78m x 0.78m, the height of the storage will be:

$$\text{h} = \frac{\text{V}}{\text{A}} \tag{8}$$

$$= \frac{0.08m^3}{0.61m^2} \approx 0.13m$$

iii. Quantity of heat stored [17]

Quantity of heat stored by the rocks can be calculated as below:-

$$Q_s = mC\Delta T = 220.5kg \times 0.81kJ / kg.K \times (60-27)$$
$$Q_s = 5893.97kJ$$

iv. Void Fraction [17]

The void fraction can be calculated from this equation:-

$$V = Q_s / pc(1-\varepsilon)\Delta T = 0.08m^3$$
$$0.08m^3 = \frac{5893.97kJ}{2700kg / m^3 \times 0.81kJ / kg.K \times 33K \times (1-\varepsilon)}$$
$$1-\varepsilon = 1.06$$
$$\varepsilon = 0.06$$

3.6.4 Determine the size of solar collector

i. Total of energy provided by a unit area of collector for dehydration

As computed before, the energy needed to dehydrate the moisture is 194MJ.

ii. Collector Area

$$q = 194MJ = A\eta G = A \times 0.65 \times 20MJ / m^2 \times 2days \quad (9)$$
$$A_c = \frac{194}{26} = 7.46m^2$$

3.6.5 Determine the size of chimney

The draft or draught flow rate induced by the stack effect can be calculated with the equation presented below. For the chimneys, where air is on the outside and heated air is on the inside, the equation will only provide an approximation. Also, *A* is the cross-sectional flow area and h is the height of the chimney.

$$Q = CA\sqrt{2gh\frac{T_i - T_e}{T_i}} \quad (10)$$

The volume rate of the air need to be removed can be calculated by this formula:-

$$Q = \frac{V_a}{t} = \frac{11905\ m^3}{2\,\text{day} \times \frac{24\,\text{hour}}{\text{day}} \times \frac{1\,\text{day}.3600\,\text{s}}{\text{hour}}}^{3} = 0.069\,m^3/s \quad (11)$$

Thus, the input data for equation (11) is stated in Table 3.10:-

Table 3.10: Input Data for Sizing Chimney

Parameter	Value
Q	$0.069\ m^3/s$
C	0.7 (draught coefficient)
Ti	45ºC = 318K
Te	27.5ºC = 300.5K
G	9.81m/s

Parameter	Value
w, width	0.38 m
A (square)	w^2
A (round)	$3.14 \times w^2/4$
H	$(Q/CA)^2/(2 \times g \times ((Ti\text{-}Te)/Ti))$

For the square chimney, the height calculation results give 0.432m while for the round chimney, the height is 0.78m.

Therefore, the square chimney with an area surface of 0.38mx0.38m and 0.432m height is chosen in order to draught out the $0.069m^3/s$ moisture.

3.6.6 Determine the height of base support

The base of the solar dryer must able to support the loads on it. Approximately, all the loads on the base are the total mass of these loads: 100kg of crops, trays, roof and chimney and the pebbles storage.

These loads can be approximately total up to be (100kg + 5kg+10kg+220kg) = 335 kg.

Thus, the height of the support can be approximately calculated by this formula:-

$$F = \sum m.g = pgh \quad (12)$$

The sample of calculation:-

Force to downwards (by the loads) = Force to upward (by the base support)

335kg x 9.81m/s = 9.81 m/s x $2700kg/m^3$ (density of aluminium) x h

h = 0.12m.

Therefore, the base support (assumed made of aluminium) must at least have this height; 0.12m.

3.6.7 Determine the size of fan

In order to calculate the power requirement of the system, the total pressure drop in the system must be calculated first. The total pressure drop is equals to the pressure drop in the grain depth, ducting or manifold and pressure drop at the rock thermal storage.
For the 0.15m grain depth, the assumption of pressure drop was 0.018" of water. This was based on the pressure drop calculated for the rice. Meanwhile, the pressure drop for the ducting and manifolds is assumed to be 1" of water The pressure drop at the thermal storage can be calculated from below formula [15]:-

$$\Delta p = \frac{LG^2}{pd}(21 + 1750\frac{\mu}{Gd}) \quad (13)$$

Where L = Length of bed = 0.78m
G = mass flow rate / area = 0.02kg/m²s
p = air density = 1.1774kg/m³
d = average rock size = 0.0254m
μ = viscosity of air = 0.0000116 kg/ms

Thus, the pressure drop for thermal storage is equals to 0.629mm = 0.025inch.
The expected total pressure = 1+0.018+0.025inch = 1.043inches of water.
The power required to drive the fan is the total product of pressure drop and volume flow rate:-

$$P = \Delta p \times C \times V \quad (14)$$

Where Δp = 1.043inch

C = $7.055 \times 10^{-3} kghr / m^2$ in water sec.

V = 139.61m³/hr

The power calculated is 1.027kg-m/s or equals to 0.0135×10^{-3}. If the fan and motor efficiency is 75%, the power required to drive the motor is 0.023HP.

4. MATERIAL / COMPONENT SELECTION

4.1 Solar Air Collector

In this project, the solar air collector is not being designed due to lack of knowledge and time management. Thus, the selection of component is made by comparing the available product in the market. Two modular solar collector arrays which each having 4.8m^2 gross areas were selected from Solar HRV 1500GS type. The collectors are able to supply the outlet temperature up to 70°C.

4.2 Main Body and Trays

The main body of the solar dryer was composed of the frames, insulation material, the walls and the support tray. The frames of the body should be lightweight (easy to transport and setup), long lasting, high corrosion resistance and able to occupy the loads. Among the best materials for the frames is the aluminium or alloy. Aluminum is one of the lightest engineering metals, having strength to weight ratio superior to steel. Lightweight is perhaps aluminum's best known characteristic and with a density of 2.7x 10^3 kg/m^3 is approximately 35% that of steel. The major advantages of using aluminum are tied directly to its remarkable properties. When the surface of aluminum metal is exposed to air, a protective oxide coating will be formed. This oxide layer is corrosion resistant and aluminum is an excellent conductor of both heat and electricity. The great advantage of aluminum is that by weight, the conductivity of aluminum is around twice that of copper.

4.3 Thermal Storage

The type of storage used in this project is the sensible heat storage that able to store the heat up to 100ºC. This type of storage was chosen because it is simpler in design, relatively expensive and reliable with the air as the medium. Rocks are among the solids that able to store the energy efficiently. Compared to pebbles, magnesium oxide, aluminium oxide, the cost of the rock is lower, easy to find and also having good specific heat (0.71-0.92kJ/kg-K). Somehow, the thermal conductivity of the rock is the lowest (0.13 W-m/K).

4.4 Roof

For designing a mixed mode dryer, the transparent and lightweight roof is needed. The roof should have good radiation transmitting. Therefore, there are two groups of materials can be considered, which are thermo sets and thermoplastics. Compare both groups, thermoplastic is the better choices because thermoplastics can be repeatedly softened and remolded by heat and pressure while thermosetting cannot be re-soften after being subjected to heat and pressure. In the thermoplastics group itself, the best choice is Perspex. Perspex is a trade name of Lucite International and is polymethyl methacrylate (PMMA) acrylic sheet, which is manufactured from methyl methacrylate monomer (MMA). Perspex is extremely versatile and can be used in diverse applications like signs, visual communication, window glazing, acoustics, architecture, furniture and car windows. The advantages of using Perspex are

- High shock, abrasion and flex resistance
- Excellent transmissivity (85%)
- Excellent weather
- Low density and light weight compared with glass
- Clear sheet offers excellent optical clarity
- Comprehensive range of colors and finishes
- 100% recyclables

4.5 Fan Selection

The fan will be powered by the photovoltaic in order to save the future operating cost and easy use in the rural area. As already noted, the theoretical estimated power requirement to drive the motor is about 13 Watts. This can be supplied by small photovoltaic panel. Thus, the actual fan was chosen has this specification: -

- Power required to operate motor = 3.96Watts

- Operating voltage =12.0V
- Operating Current = 0.33 A
- Power required to start the motor = 12.0 Watts
- Starting current = 0.5A

To power this fan, an Arco Solar PV module, Model No M53 was selected. This module has an open circuit voltage, Voc = 21.7V and a short circuit current, Isc = 2.7A at a temperature of 25°C and solar irradiance of 1000 W/m² at noon. [15]

5. ECONOMIC EVALUATION

In this section, two evaluation methods were used and described, which are the net present value analysis method and the payback period analysis method, which are widely used in economic analysis:

5.1 The payback period method

In this evaluation method, the period required to recover an initial investment is determinant. The Payback Period defined as the length of time required to recover an initial investment through cash flows generated by the investment. The Payback Period gives the level of profitability of an investment in relation to time. The shorter the period is the better the investment opportunity.

$$\text{Payback Period} = \frac{\text{Investment}}{\text{Cash Flow (year)}} \quad [18]$$

The Payback Period is a tool that is easy to use and understand, but it has its limitations. Payback period analysis does not address the time value of money, nor does it go beyond the recovery of the initial investment.

5.2 The Present Value Method (NPV)

The basic principle of this method is to evaluate the present value of the cash flows that occur during the lifetime of the project. Net present value in this project defined as the sum of the present values of the annual cash flows minus the initial investment. The annual cash flows are the net benefits generated from the investment during its lifetime. These cash flows discounted or adjusted by incorporating the uncertainty and time value of money. This method is one of the most robust financial evaluation tools to estimate the value of an investment.

Net present value uses a discount rate or the opportunity cost of capital to reduce the expected free cash flows and the project's terminal value. The goal of the method is to determine the value created from the underlying investment. The formula to calculate the NPV is as follow and simplified in mathematical terms:

$$NPV = initial + investment = \sum_{t=1}^{t=\text{end of project}} \frac{(\text{Cash Flow at Year 1})}{(1+r)^t} \qquad [18]$$

Where:

r = interest rate.
t = year of investment.

Note: Initial investment cash flow is negative while the cash flows for the following years are generally positive.
The investment to be consider economical when the net present value has to be positive or at worst zero. Obviously, the higher the net present value is the more economically is the measures.

CHAPTER 4

RESULTS AND DISCUSSION

1. SUMMARY CALCULATION OF DESIGN

Table 4.1 shows the result of the design calculation:-

Table 4.1: Summary of Calculation Result

No	Items	Value	Data/Equation used
1.	Size of Tray	0.78m x 0.78m x 0.05m	V_{crop} , t_{tray} / (1)
2.	Mass of water to be evaporated, m_w	77.27 kg	m_p , M_i , M_f / (2)
3.	Mass of dry air needed, m_a	13798 kg	m_a , w_i , w_f / (3)
4.	Volume flow rate	0.069m³/s	V_{crop} , t_{tray} / (11)
5.	Amount of heat needed at trays	193.56 MJ	h_f , h_i / (5)
6.	Mass of pebbles, $m_{pebbles}$	220.5kg	C_p , $T_{storage}$, T_{max} /(6)
7.	Height of thermal storage	0.13m	(8)
8.	Void Fraction	0.06	
9.	Solar Collector Area, A_c	7.46 m²	(9)
10.	Height of chimney	0.432m	(10)

2. DESIGN FEATURES AND SPECIFICATION

Basically, the solar dryer was designed to have these components; solar air collector, drying chamber which composed of rock bed thermal storage, three units of drying trays, transparent roof and chimney. Figure 4.2 and 4.3 shows the assembly and exploded view of this dryer.

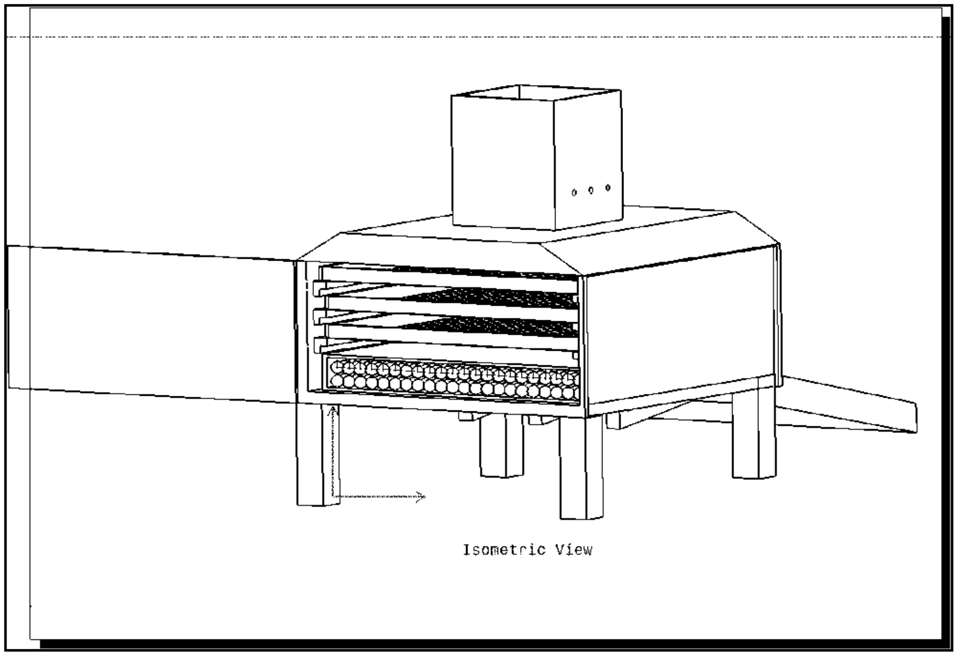

Figure 4.1: Assembly Drawing

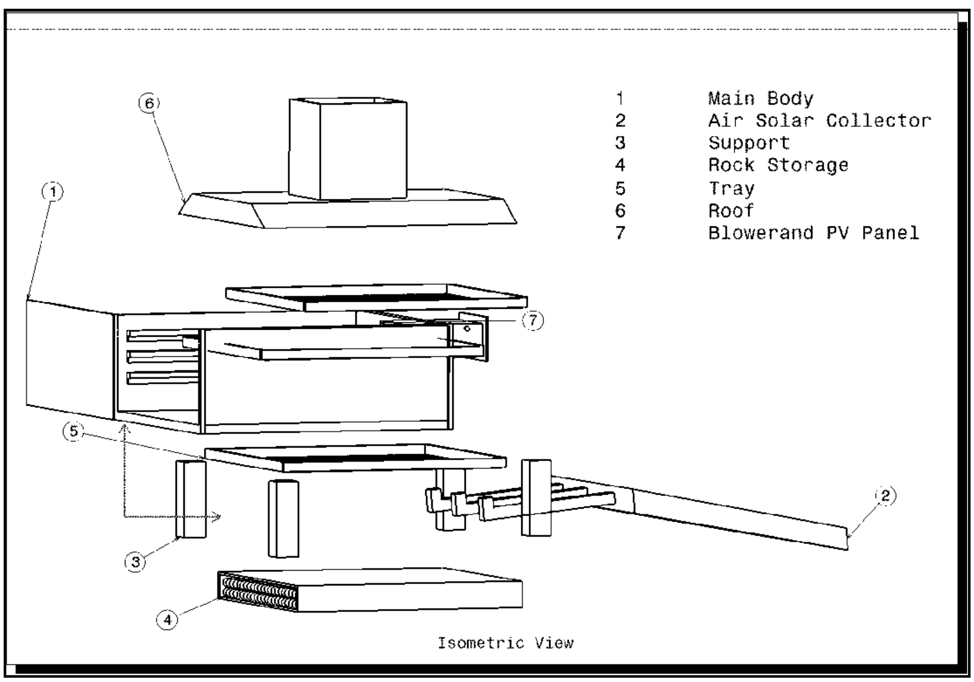

Figure 4.2: Exploded view of solar dryer

The corrugated flat plate solar collector is used to heat the inlet air (27.5ºC) and to supply the hot air (above 70ºC) to the drying chamber. The hot air will go through the rock bed thermal storage so that some excessive heats can be stored by the rocks at the high radiation. About 50ºC hot air will go upwards to the drying tray to remove the moisture contains inside the pepper. The drying trays will also be heated through the transparent roof. The blower powered by the solar PV panel will circulate the air inside the drying chamber. Thus, with this blower and chimney, the air flow will be increased. The more the airflow increase, the faster the drying process. Table 4.2 shows the specification of these components:

Table 4.2: Specification of the Solar Dryer

Components		Specs	Reason
Collector	Size	2 units of 4.8 m² (2.4m x 2m)	With safety factor of 1.32
	Type of absorber	Flat plate corrugated absorber	Good performance (50%-60% efficiency)
	Absorber Material	Corrugated Aluminium Sheet, painted black	To maximize surface exchange in order to increase thermal exchanges by convection.
	Glazing	Glazed tempered glass	Weak conductivity: $\lambda = 0.045\text{d Wm}^{-1}K^{-1}$
	Insulator	Polyisocyanurate, R3.3	Good insulation from convection
	Inner part	Covered with silver surface	High thermal loss reduction
Air Circulation	Chimney	H: 0.43m D:0.38m Square Aluminum	To vent out the moisture rapidly
Drying Chamber	Type	3 Shelf Tray	
	Tray Size	0.78m x 0.78m x 0.05m	To occupy 33.33kg pepper/tray
	Tray material	Mesh aluminium wire : 0.045m hole	Lightweight, able to support the materials (0.05m is the general size of pepper berries)
Thermal Storage	Size	1.13m in height, Area:0.78mx0.78m Filled with 220.5kg rock pieces Void fraction: 0.06 Density of rock: 2700kg/m³	Calculation
	Container	1m x 1m Insulator: Glass Wool (20mm)	Avoid heat loss
	Type	Packed pebble bed storage	Relatively inexpensive, high thermal inertia, suits the heating application

3. DRAWING OF COMPONENTS

3.1 Main Body

The main body is functioning as the drying chamber which gets the hot air from the indirect solar air collector and also a direct heating from the transparent roof. Basically this main body contains of aluminium square tube frames in order to support the base, aluminium sheet walls and the roofs. The aluminium square tube and aluminium angle need to be connected together by using the blind rivet in order to form the frames. After the frames being constructed, the base of aluminium, the walls which contained of three support trays and the roof assembly can be installed by using the nuts and screws. For the walls, the U type frame used. These frames then being insulated by the glass wool in order to prevent the heat loss from the drying chamber and covered by the aluminium sheet. The aluminium sheets are painted black to absorb more heat. Figure 4.4 shows the rough drawing of the main body which support the drying chamber.

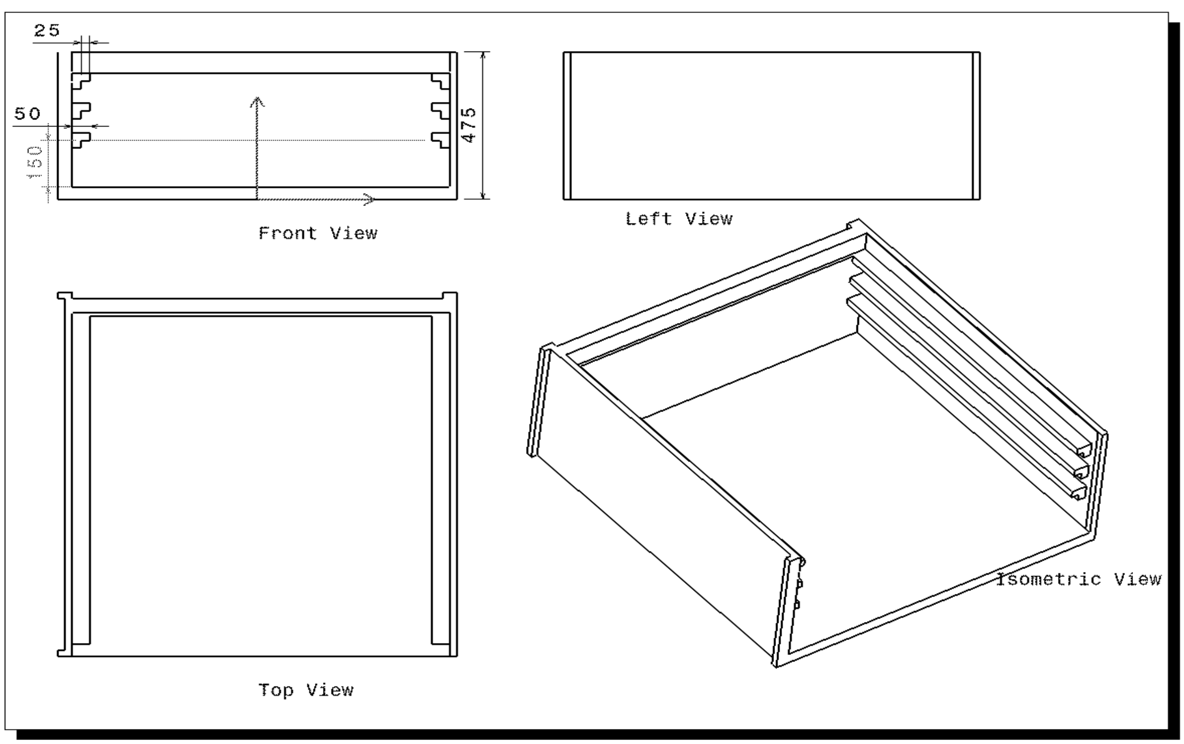

Figure 4.3: Drawing of the Main Body

3.2 Trays

The 0.8m x 0.8m trays are being designed to support 100kg fresh pepper berries. This tray frames are made of aluminium square tube and aluminium angle. Then, the mesh aluminium wire is assembled at the bottom of the frames by using the rivet. Mesh aluminium is being used because it has a good conductivity and will give better heat transfer. Figure 4.5 shows the drawing of the tray.

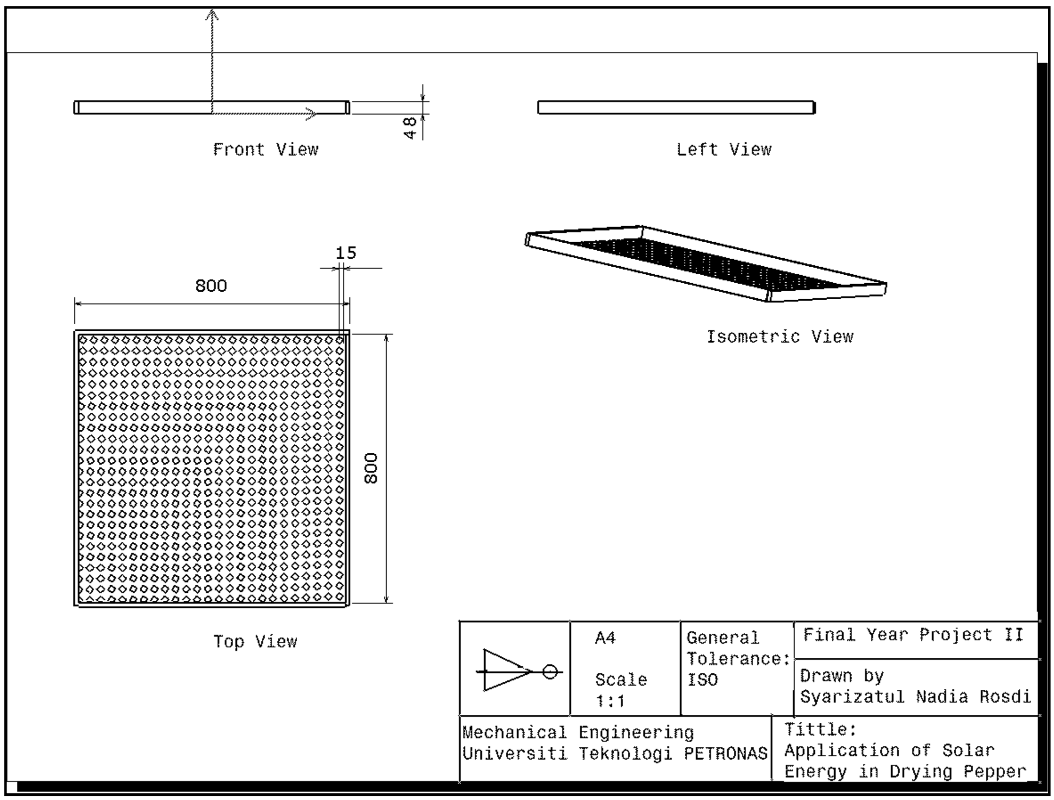

Figure 4.4: Drawing of the Tray

3.3 Packed Bed Thermal Storage

The vertical pack bed thermal storage contains the insulated aluminium container, the rocks and the cold and hot ports. The 20-50mm diameters of rocks need to be arranged compactly inside the 1mx1m container. The rocks used are the rounded river stones which have clean and uniform surfaces. Figure 4.6 is the drawing of the rock bed thermal storage.

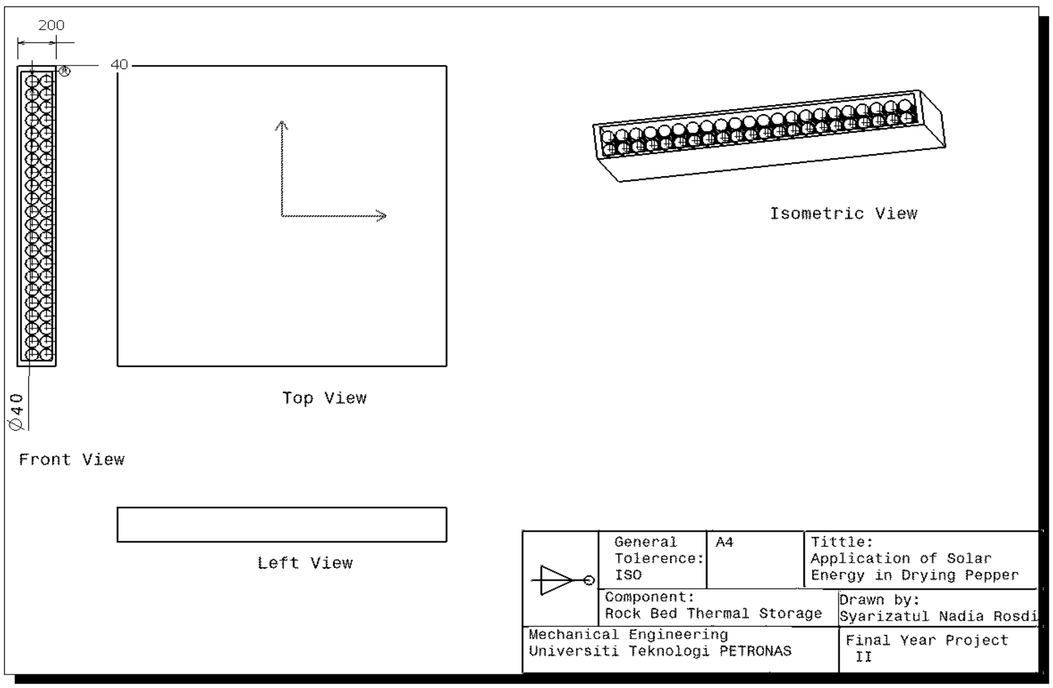

Figure 4.5: Drawing of Rock Bed Thermal Storage

3.4 Roof and Chimney

Roof is made of the Perspex and being assembled with an aluminium square chimney. This assembly is designed to give a direct but safe heating to the crops inside the drying chamber. The 432 mm tall chimney is made to venting out the moisture of the crops and also to fasten the dehydration process. The warm air from the bottom of the drying chamber will be draught out by this chimney. Chimney functions to increase the pressure drop and flow of air inside the drying chamber. The chimney also will allow the fresh air outside the chamber to be draught in. Figure 4.7 shows the basic drawing of the chimney.

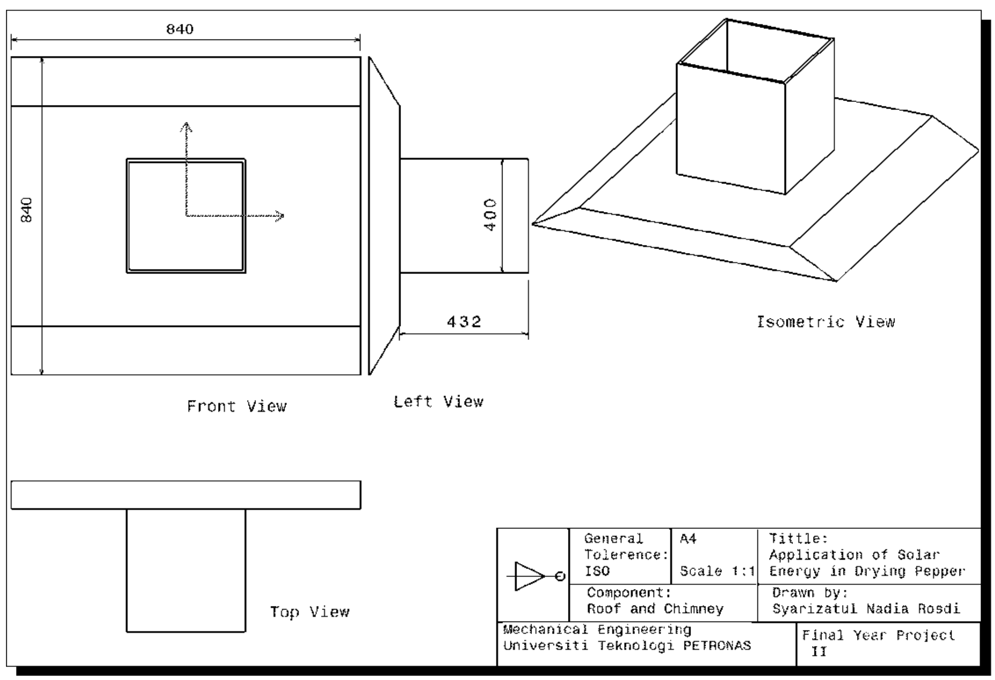

Figure 4.6: Drawing of the Chimney and Roof

4. BILL OF MATERIAL

Bill of material is the list of material used to develop the prototype and the cost involved. Table 4.3 below shows the bill of material for the dryer based on the estimation value.

Table 4.3: Bill of Material

No	Material	Quantity	Estimated Cost
1.	**Main Body**		
	Aluminium Angle (20feet)	4 pieces*20"	RM 32.00
	Aluminium Square Tube (20 feet)	1 piece*20"	RM 25.00
		2 pieces*22½"	RM 5.20
		2 pieces*18½"	RM 3.90
	Aluminium Sheet	6 meter	RM 33.00
	Sliding Rail	16"	RM 14.40
	Rivet	650 pieces	RM 9.75
	Glass Wool		RM 30.00
2.	**Roof**		
	Acyclic Sheet (Perspex)	3 sheets (clear)	RM 46.50
	Screw and nuts	300	RM 5.00
3.	**Thermal Storage**		
	Container	1 unit (1m*1m)	RM 20.00
	Rock Pebbles	250 units	RM 250.00
4.	**Solar Air Collector**		
	Flat plate (1mx1m)	2 unit	RM 2000.00
5.	**Trays**		
	Net	4 units	RM 5.00
6.	**Support**		
	Wood	1 unit	RM 20.00
7.	12 V DC Fan (1/38 HP)	1 unit	RM 300.00
		TOTAL	**RM 2599.75**
		Labour	RM 50.00
		Tool	RM100.00
		TOTAL INVESTMENT COST (RM)	**RM 2749.75**

5. ECONOMIC EVALUATION

5.1 Payback Period Method

$$\text{Payback Period} = \frac{\text{investment}}{\text{cash flow (year)}} \quad [18]$$

Annually, pepper will only be dried and harvested for 3-5 months. In Malaysia, the period of drying and harvesting extended from March to July (five months). Thus, the cash flow should be made in these five months. For the cash flow of cultivating and producing the pepper, the data were referred to the Pepper Production Guide to Asia and the Pacific, published by International Pepper Community (IPC). Table 4.4 below stated the cost and profit gained for 1 ha of pepper cultivated area for year 2007:-

Table 4.4: Cost of Pepper Production

	January	**February**	**March**	**April**	**May**	**June**
Pepper (kg/day)	30.5	19.5	17.5	20.5	19.5	50
Pepper (kg/month)	915	585	525	615	585	1500
Price Black Pepper	7.26	7.50	7.58	6.97	6.99	8.00
Monthly income	**6640.95**	**4389.24**	**3981.96**	**4287.73**	**4086.54**	**12000.00**
Labor	808.75	808.75	808.75	808.75	808.75	808.75
Crop Management	497.92	497.92	497.92	497.92	497.92	497.92
Operation Cost	**1306.67**	**1306.67**	**1306.67**	**1306.67**	**1306.67**	**1306.67**
Net Cash Flow	**5334.29**	**3082.58**	**2675.29**	**2981.06**	**2779.87**	**10693.33**
Cumulative Cash Flow	**5334.29**	**8416.86**	**11092.15**	**14073.21**	**16853.08**	**27546.42**

Based on the above data, the input for the payback period method for 0.4 ha can be summarized as below:-

Initial cost = RM 2749.75

Yearly return = RM 27546.42/ (1/0.4ha) = RM 11018.57

$$\text{Payback Period} = \frac{\text{Initial Cost}}{\text{Yearly Return}}$$

$$= \frac{\text{RM 2749.75}}{\text{RM11018.57}} = 0.25$$

0.25 is a reasonable and can be considered as lower payback period. If the solar dryer can be last to 10 years, the users can payback in just 4 years.

5.3 Net Present Method

Net Present Value (NPV)

$$NPV = \text{initial investment} + \sum_{t=1}^{t=\text{end of project}} \frac{(\text{Cash Flow at Year 1})}{(1+r)^t} \qquad [18]$$

Net Present Value

Initial cost = RM 2749.75

Interest rate, r = 10 %

Yearly return = RM 11018.57

At 1st year,

$$NPV = \text{initial investment} + \sum_{t=1}^{t=\text{end of project}} \frac{(\text{Cash Flow at Year 1})}{(1+r)^t}$$

$$= RM2749.75 + \frac{RM11018.57}{(1+0.1)^1}$$

$$= RM\,12766.63$$

Repeat same method to calculate net present value for others years and the results are showed as table 4.5 below.

Table 4.5: Net Present Value for 10 Years

NPV (1)	**NPV (2)**	**NPV (3)**	**NPV (4)**	**NPV (5)**	**NPV (6)**	**NPV (7)**	**NPV (8)**	**NPV (9)**	**NPV (10)**
12766.63	11856	11028.2	10275.6	9591.42	8969.45	8404.02	7889.99	7422.7	6997.89

From the net present method, we could see that during the 10 years lifetime of the solar dryer usage, the value is still positive. Thus, the investment for this solar dryer can be financially affordable for the small farmer.

If the farmers just want to start their cultivation of pepper using the solar dryer, this type of cash flow may be expected (Table 4.6):-

Table 4.6: Cash Flow of 10 Years Pepper Drying and Production.

Year	1	2	3	4	5	6	7	8	9	10
Cost of Materials	14678.4	1870	2390	2390	2390	2390	2390	2390	2390	2390
Cost of Labour	3882	3440.4	5052.8	7442.8	7306.4	7306.4	7306.4	7306.4	7306.4	7306.4
Production	1400	1500	1890	2000	2100	2160	2160	2160	2160	2160
Revenue	11200	12000	15120	16000	16800	17280	17280	17280	17280	17280
Operating Cost	18560.4	5310.4	7442.8	9832.8	9696.4	9696.4	9696.4	9696.4	9696.4	9696.4
Net Cash Flow	-7360.4	6689.6	7677.2	6167.2	7103.6	7583.6	7583.6	7583.6	7583.6	7583.6
Cum. Cash Flow	-7360.4	-670.8	7006.4	13173.6	20277.2	27860.8	35444.4	43028	50611.6	58195.2

The net present value over the values of internal rate return can be obtained as:-

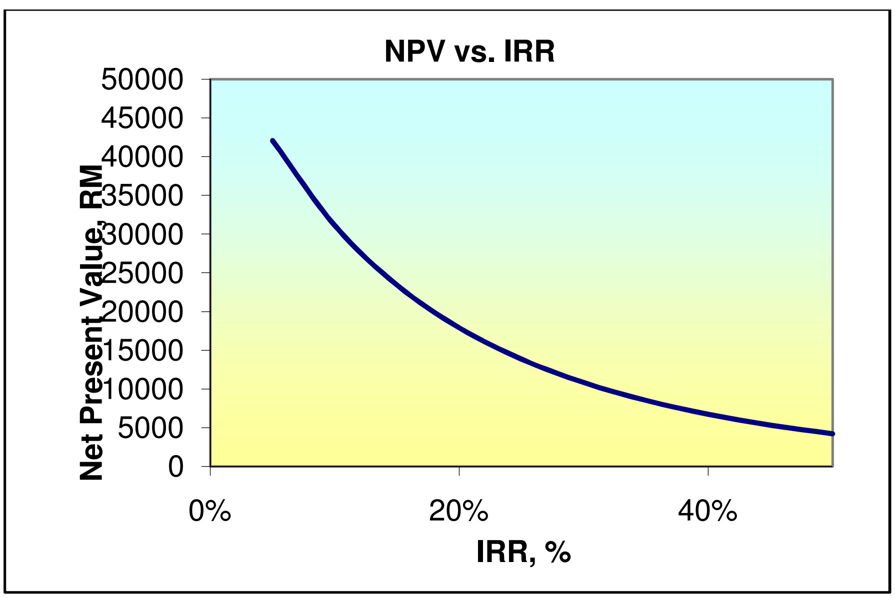

Figure 4.7: Net Present Value versus IRR

Above figure shows that the more IRR increase, the more net present value decrease. Somehow, up to 50% IRR, the farmer still able to invest in this solar dryer.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

1. CONCLUSION

From the preliminary study and literature review, the innovation in drying technology for the crops in this county is necessary to overcome the problems and disadvantages faced by the traditional and conventional dryer. Solar energy application in drying which utilized free, renewable and sustainable energy had been proven to be good alternatives to these current dryers. Thus, the process in designing the practical and efficient solar dryer for the crop is important in order to reach the effective solar dryer. The design process must meet the process constraint and requirement. With this in view, the project reached its general objective in designing a solar dryer for the pepper which meeting these design requirements; can dry up to 100 kg of pepper in two days, continuous operation. This solar dryer is also designed to expedite the drying process as compared to the current method of drying by using the fan PV powered and chimney. The dryer had been designed to have these components; flat plate solar air collector, $0.78m^2$ x 1.13m rock bed thermal storage, square chimney and 0.78m x 0.78m square trays. Theoretically, based on the estimated bill of materials, the payback period for the designed dryer which is 4 years payback period also can be considered lower. Thus the project is viable for further research and development.

2. RECOMMENDATION

The recommendation divided into two, which are for the future research of project and also for the general recommendation:-

2.1 Recommendation for Future Research:-

i. To build up the dryer (prototype) and test the performance of the dryer in the field. This methodology can measure the actual performance and reliability of the designed dryer. It also can measure the accuracy of the design parameters.
ii. The design also can be improved with the addition of biomass burner. The burner can be designed series or at the bottom of the packed bed thermal storage so that it can charge the rocks and at the same time, supply heat to the drying chamber during the rainy day, monsoon season or at the night. Yet, further study and investigation regarding this recommendation has to be made in order to design a safe and environmental friendly burner.

2.2 General Recommendation:

i. The solar food dryer is potential to be commercialized since it is practical, economical that only uses the solar energy as the only main source. Therefore, the solar food dryer is a good way to improve the existing drying method.
ii. The industry of drying crops is so potential to be one of the contributors to agricultural based industry and taking the weather factor into consideration, the government of Malaysia should take the solar dryer technology as a new focus to support and improve the production of agricultural products, thus benefitting the producers, consumers and the economy of Malaysia as a whole.

CHAPTER 6
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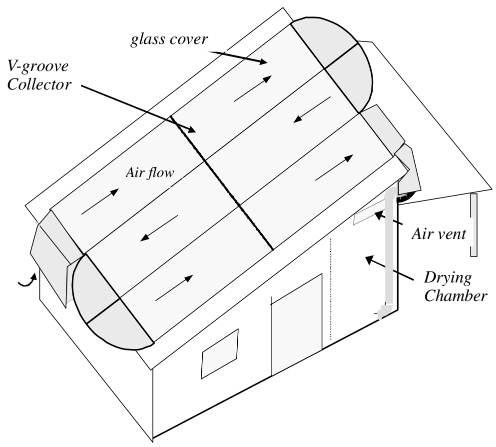
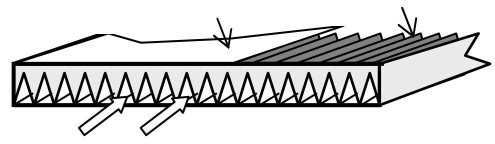
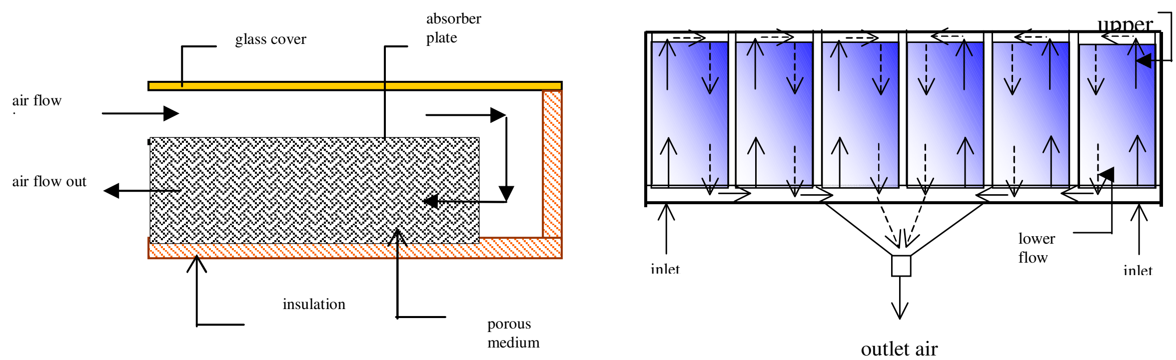




Cross section of the solar collector

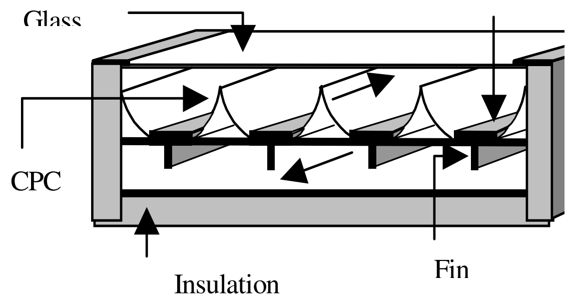
System components	Specifications
Collector	
Size	(3x4.6m) x 1.0m x 0.15m
Type of absorber	V-groove back-pass.
Absorber material	Folded aluminum sheet
	SWG22: 244cm x 122 cm.
Angle of groove	49° and height 7.8 cm.
Collector area	100 cm x 460 cm per unit collector.
Total collector area	13.8 m^2.
Top cover	Glass: thickness 2.5 mm; one side tempered.
Insulator	Fibreglass wool; 2.5 cm thickness, density 46.0 kgm^{-3}.
Air Circulation	
Two unit axial fan	2700 rpm, 85 W: 230 V (AC), single phase motor.
Ducting	18 cm outlet diameter: PVC pipe.
Air flow rate	6.0 – 16.5 m3 min-1.
Drying Chamber	
Type	Adjustable set of shelved frame.
Size	1.0m x 3.0 m x 3.0 m.

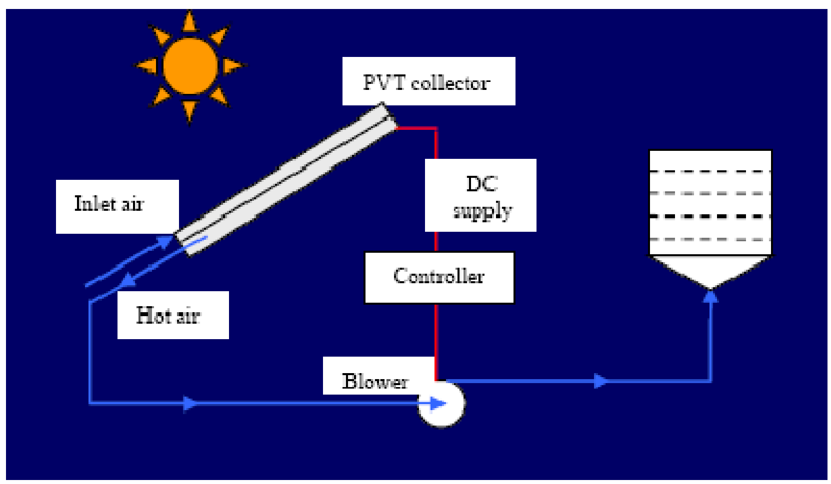
Appendix A: Schematic Drawing and Specification of Solar Assisted Drying System



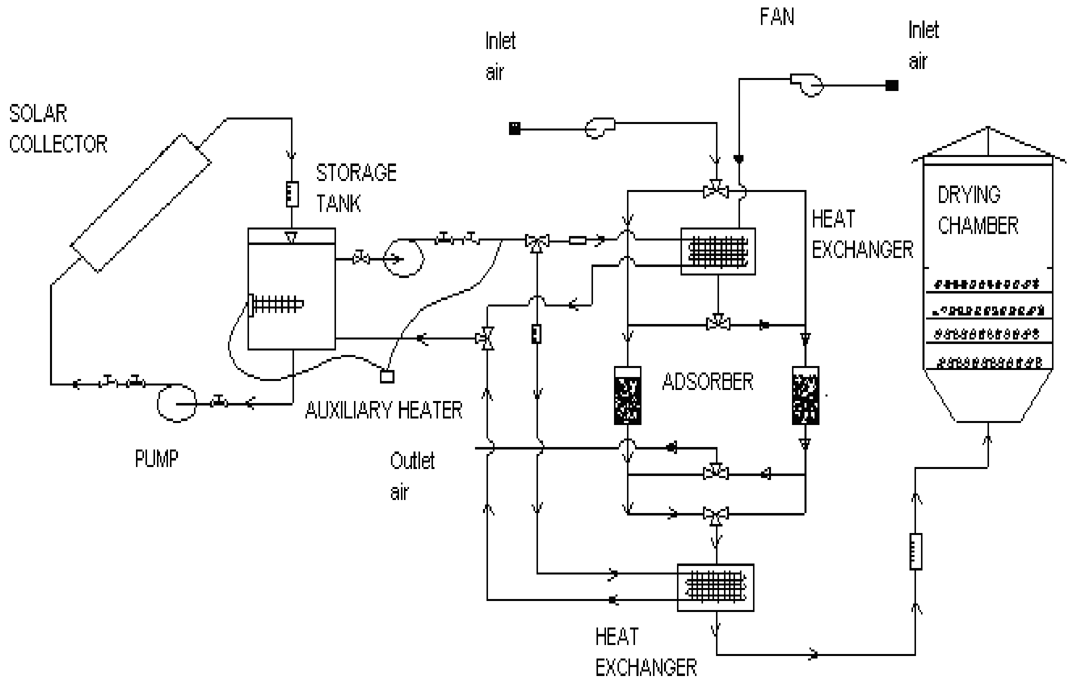
System components	Specifications
<u>Collector</u>	
Type of absorber	Double pass with porous medium in the lower pass
	3.5 cm in the upper channel & 10.5cm in the lower channel
Absorber material	Aluminum sheet
	SWG22: 244cm x 122 cm.
Collector area	120 cm and 240 cm per unit collector.
Total collector area	17.3 m^2: arranged as 2 banks of 3 collectors each in series.
Top cover	Glass: thickness 2.5 mm; one side tempered.
Insulator	Fibreglass wool; 2.5 cm thickness, density 46.0 kgm^{-3}.
<u>Air Circulation</u>	
Centrifugal blower	0.11 kW, 230 V rotating at 2520 RPM .
Ducting	18 cm outlet diameter: PVC pipe.
Air flow rate	-
<u>Drying Chamber</u>	
Type	Flat bed.
Size	1.5m x 1.5 m x 2.0 m.

Appendix B: Schematic Drawing and Specification of Double Pass Solar Collector with Porous System





Appendix C: Schematic Diagram of Double-Pass Photovoltaic Thermal Solar Collector System with CPC and fins



Appendix D: Schematic diagram of solar assisted dehumidification system

Appendix E: Design Calculation Formula

i. Amount of moisture to be removed from 80 kg of peppers

The amount of moisture to be removed from the product is calculated using this formula:-

$$m_w = m_p (M_i - M_f)/(100 - M_f)$$

ii. Quantity of heat needed to evaporate the amount of moisture

By calculating the amount of moisture need to be removed, the quantity of heat to evaporate that moisture is calculated as following:-

$$Q = m_w x h_{fg}$$

The amount of latent heat of evaporation needed is a function of temperature and moisture content of the crop. The latent heat vaporization was calculated using equation given by Youcef-Ali et al. (2001) as follows:

$$h_{fg} = 4.186x10^3 (597 - 0.56(T_{pr}))$$

Thus, the total heat energy, E(kJ) required to evaporate water was calculated as follows:

$$E = m'(h_f - h_i)t_d$$

The enthalpy (h) of moist air in J/kg dry air at temperature T (ºC) can be approximated as: (Brooker et al., 1992)

$$h = 1006.9T + w(2512131.0 + 1552.4T)$$

iii. Average drying rate

Average drying rate, m_{dr} was determined from the mass of moisture to be removed by solar heat and drying time by following equation:

$$m_{dr} = m_w / t_d$$

The mass of air needed for drying was calculated using equation given by Sodha et al. (1987) as follows:-

$$m' = m_{dr} / [w_f - w_i]$$

iv. Solar drying system collector area, A_c

From the total useful heat energy required to evaporate moisture and the net radiation received by the tilted collector, the solar drying system collector area, A_c found from:

$$A_c I\eta = E = m'(h_f - h_i)t_d$$

Therefore, area of solar collector could be simplified as:-

$$A_c = E / I\eta$$

In addition, the volumetric airflow rate, $V_a = \frac{m_a}{p_{air}}$

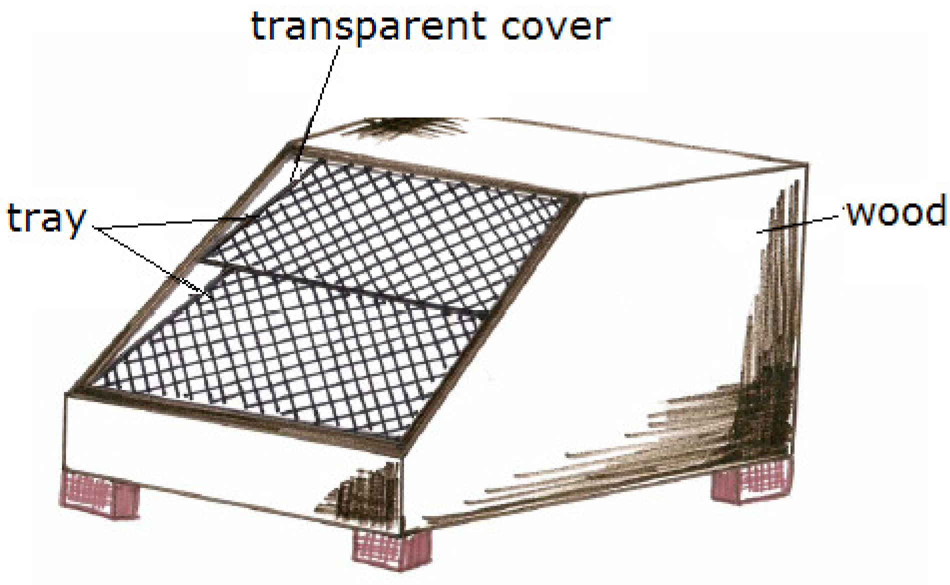
v. Air vent dimensions

The air vent is calculated by dividing the volumetric airflow rate by wind speed:

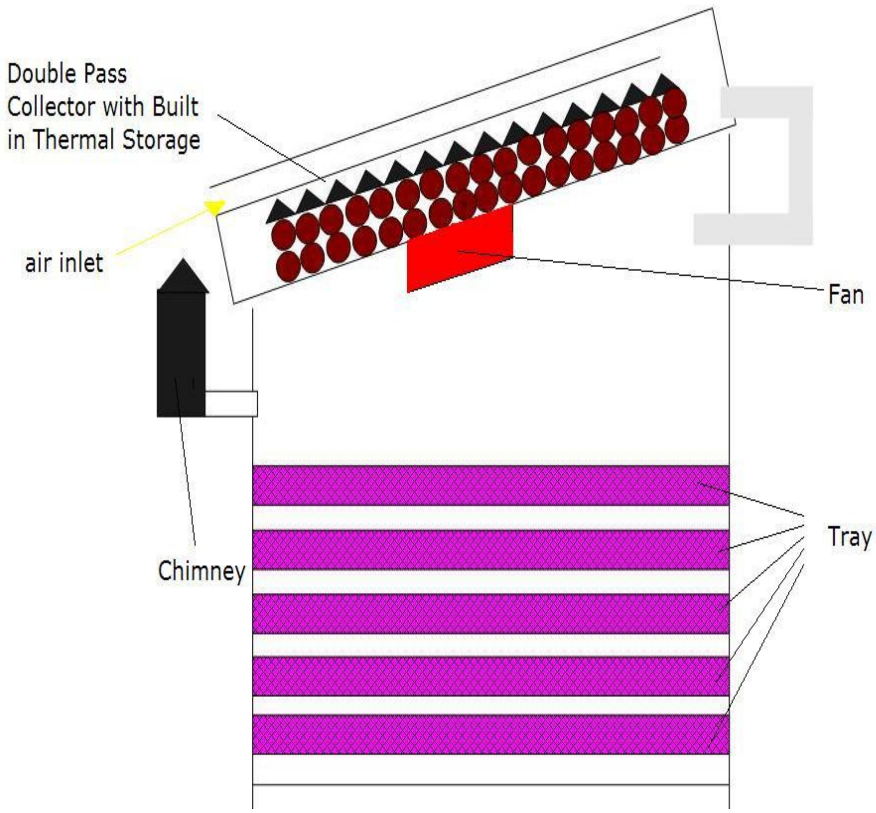
$$A_v = \frac{V_a}{V_w}$$

Length of air vent will be equal to the length of dryer. The width of air vent given as:

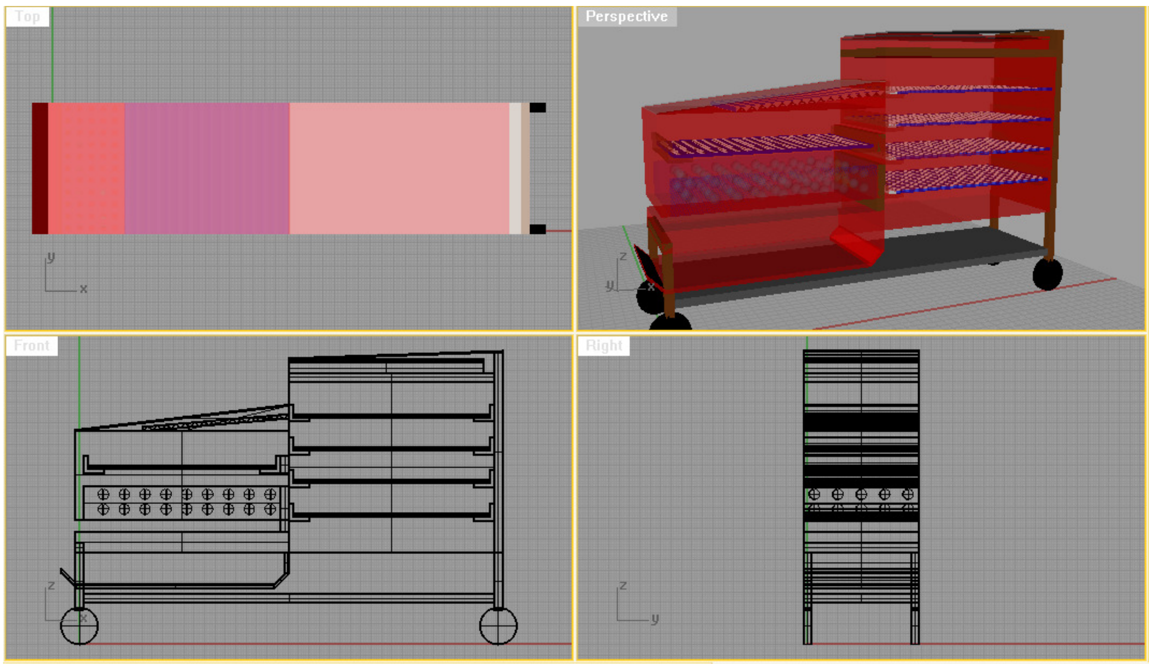
$$B_v = \frac{A_v}{L_v}$$



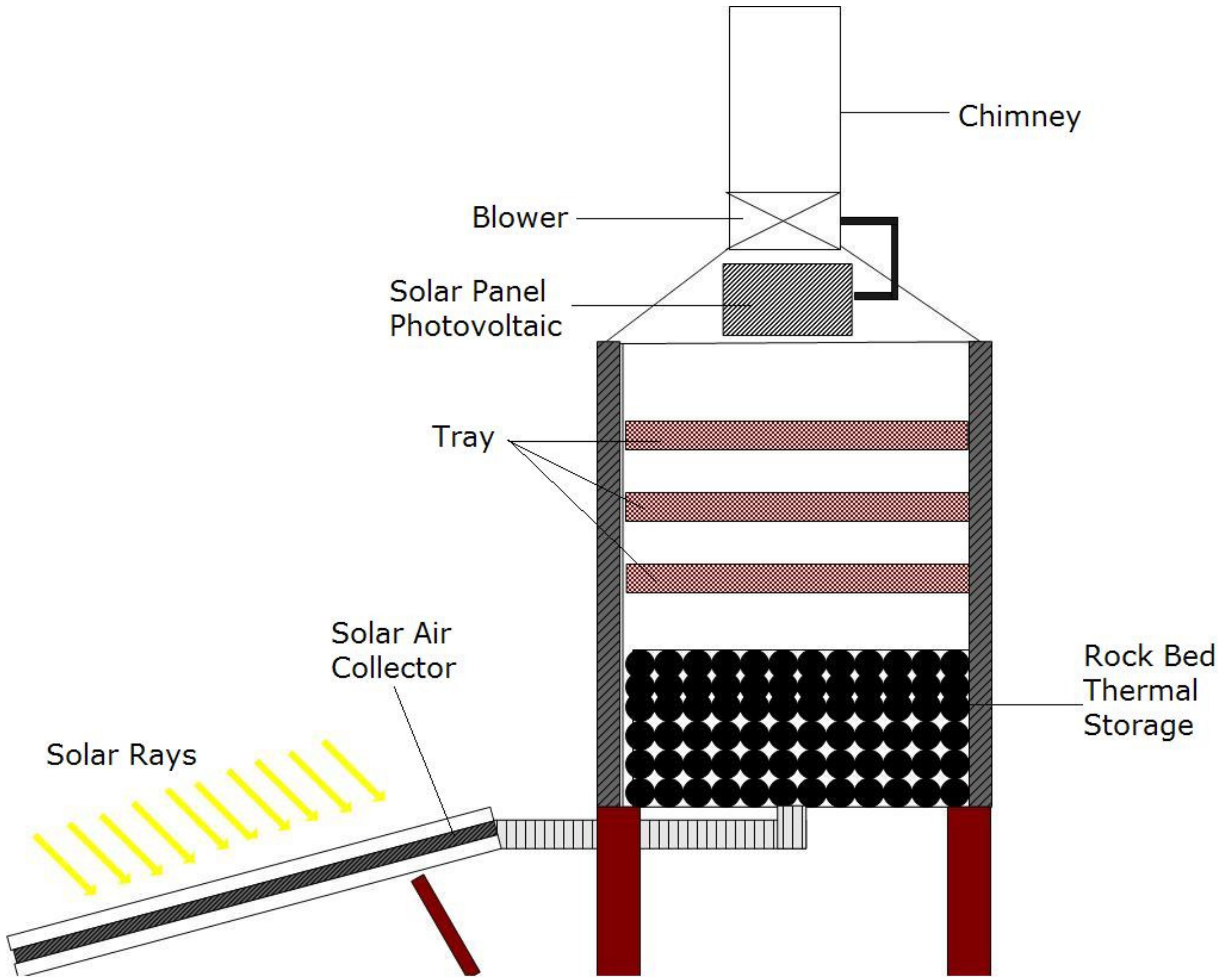
Appendix F: Design Concept 1



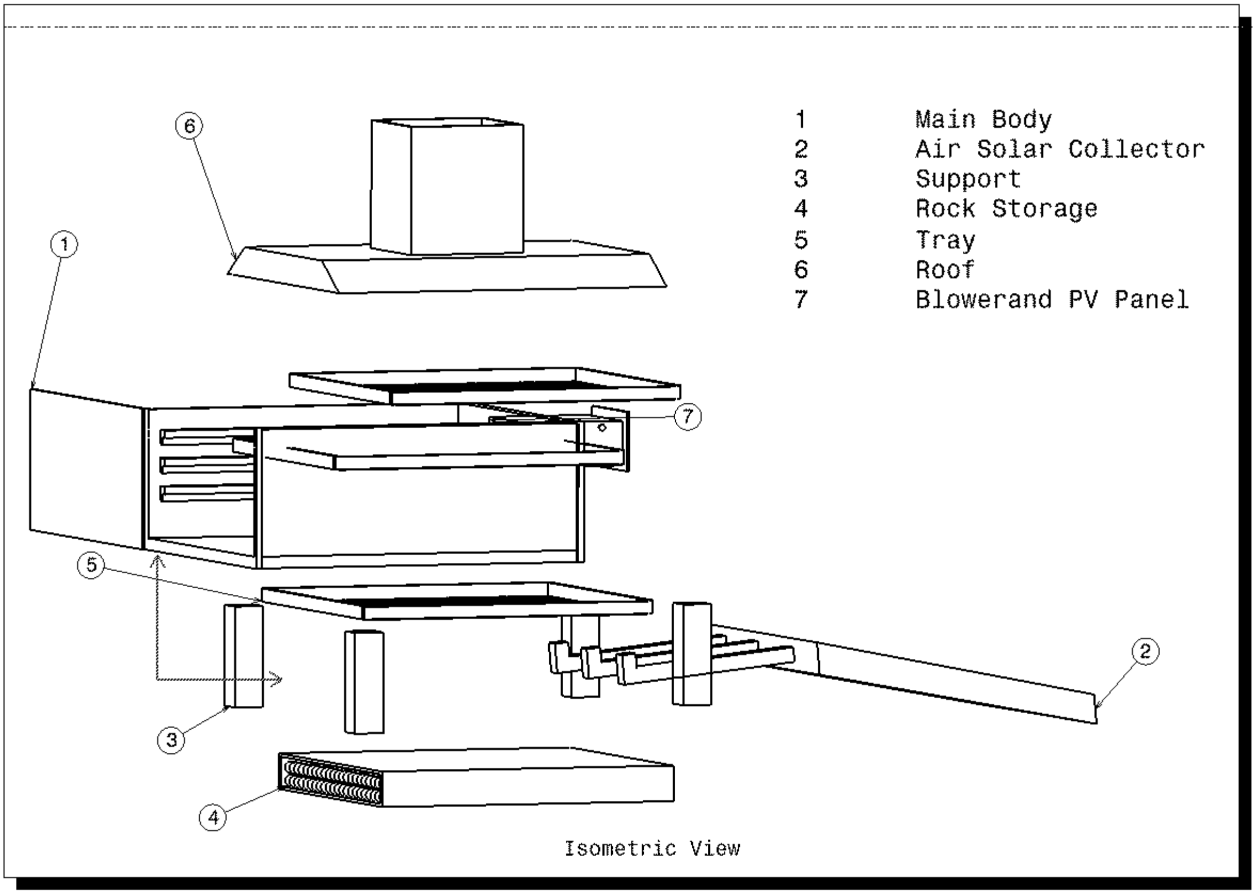
Appendix G: Design Concept 2



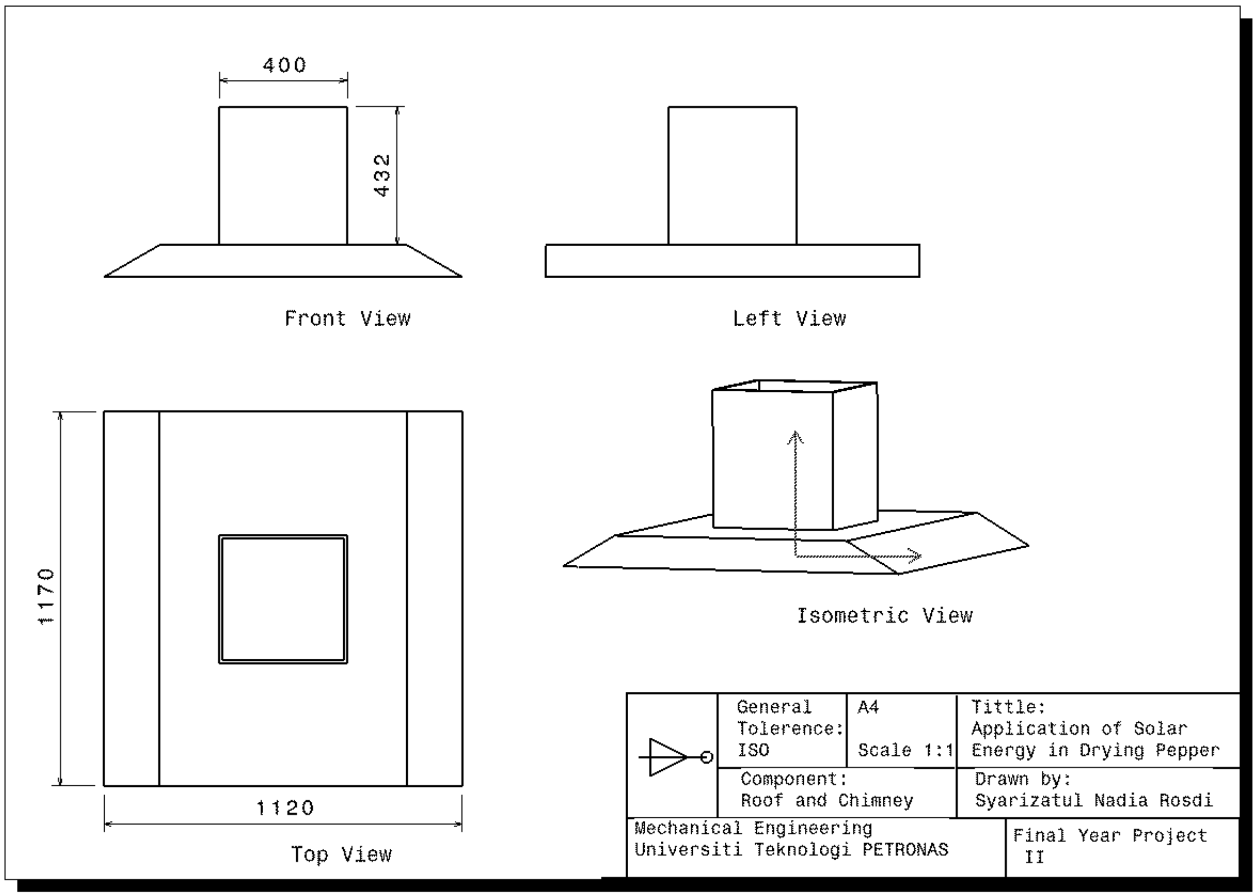
Appendix H: Design Concept 3



Appendix I: Design Concept 4



Appendix J: Exploded View of Solar Dryer



Appendix K: Design of Roof and Chimney