# Application of Solar Dryer in Drying Chilli

by

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

DECEMBER 2010

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Universiti Teknologi PETRONAS
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(MECHANICAL ENGINEERING)

Approved by,

(Ms Chin Yee Sing)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

DECEMBER 2010

# 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.

NORZHAFRAN BIN NOR JAMAL

# ABSTRACT

Nowadays, agricultural products are always being stressed and emphasised by our government to increase the economic. Solar energy can be used as an important and environmental compatible source of renewable energy. The use of solar energy for drying effectively reduces the problems arising from generating energy by conventional method. Drying is one of preservation technique in processing agricultural product. In today's globalization era agriculture product is given great emphasis, the producers expecting a green technology which lower the cost and economical while consumers can be benefited by the decreasing of the price. From that, a research based study of solar application in drying the agricultural product such as chilli industry was carried out. Though this industry did have a big impact throughout the entire agricultural product, the demand of dried chilli is increasing. With a help of economical and green technology, the import of dried chilli can be decreased and also the price can be maintained. The aim of the study is to design a feasible solar dryer for the small producer and to be more specific, the project only aim for 1.5 kg chilli per batch in order to build the prototype. The project scopes include the design development of a hybrid 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 and specification of dryer. Result shows that the hybrid solar dryer is equipped with the 0.96 $m^2$ of solar air collector, 169 kg of vertical rock bed thermal storage and 0.55 m vertical drying chamber in order to dry 1.5kg of chilli continuously with a help of biomass fuel.

# ACKNOWLEDGEMENT

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

First and foremost I would like to take this opportunity to acknowledge and express my gratitude to those that has contributed directly or indirectly towards the success of my Final Year Research Project.

I would like to take this opportunity to express my heartfelt appreciation to my supervisor Ms. Chin Yee Sing for her great patience, assistance and guidance throughout this project.

Besides that, I would like to acknowledge Prof. Dato' Dr. Mohd Yusof Hj. Othman from UKM and also Mr. Shamsudin Ahmad from MARDI for their kind assistance throughout this project.

Not forgetting, a millions thanks to my family for their constant encouragement and love I have relied on throughout my studies. Their continuous motivation keeps me strong to complete the project.

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# NOMENCLATURE AND SUBCRIPTS

**Nomenclature**

| | |
|---|---|
| GMT | Greenwich Mean Time |
| PVT | Photovoltaic Thermal |
| MARDI | MARA Agriculture Research and Development Institute |
| S.G | Specific Gravity |
| A | Area |
| C | Draught Coefficient |
| $C_p$ | Specific heat of pebbles |
| g | Gravity |
| h | Enthalphy |
| H | height |
| $I$ | Solar Radiation |
| $l$ | Length |
| m | Mass |
| $m_a$ | Mass of air to dehydrate |
| M | Moisture content |
| $\rho$ | Density |
| q | Thermal energy |
| $\dot{Q}$ | Volume rate |
| T | Temperature |
| t | Thickness |
| V | Volume |
| w | Width |
| $\phi$ | Relative Humidity |
| L | Latent heat of vaporization |
| $\eta_d$ | Efficiency of solar air collector |
| $\omega$ | Humidity Ratio |
| $Q_s$ | Quantity of heat stored |
| $\tau$ | Time |
| R | Gas Constant |
| $\varepsilon$ | Void fraction |

**Subscript**

| | |
|---|---|
| a | Ambient |
| c | Solar collector |
| e | Exit |
| f | Final |
| I | Initial |
| w | Water |
| chilli | Chilli |
| pebbles | Pebbles |
| max | Maximum |

# CHAPTER 1 INTRODUCTION

## 1.1 Background of Study

The project is to construct conceptual design of an additional energy supply to be attached to an existing solar dryer. Basically, the solar dryer is used for drying food like herbs, fish, cocoa, and many others but chilli is taken specifically for this project. Drying is an excellent way to preserve food and solar food dryers are an appropriate food preservation technology for a sustainable world. [1] In Malaysia, there are 2 common types of dryer used by the farmers and industrial purposes. There are traditional solar drying and also conventional drying which use fossil fuel like jet heater and Liquefied Petroleum Gas as the heat source. [2]

## 1.2 Problem Statement

The problem encountered in this design is the only optimum time to consume solar energy is between 11 am to 3 pm at GMT +8:00. Between the ranges of the time, it is the best time to collect the solar energy for drying the chilli. During night, the solar dryer cannot be used. So, in order to continue the drying process, other energy needs to be supply to the existing solar dryer and some energy that is collected during day time can be stored.

## 1.3 Objective and Scope of Study

The objective of this project is to improve a basic solar dryer by adding additional energy supply which is economic and can operate continuously during days and nighttime. During the research, the area of study is including Mechanical Engineering Design which use AutoCAD software and also Fluid Mechanics. In order to calculate the optimum of force convection by the fan the remove the hot air to circulate in machine, some of the equation from Fluid Mechanics is used. Heat Transfer and Thermodynamic must be taken into account in this study since both are related to each other. This study is also to identify the requirement like the range of temperature to dry the chilli. Lastly, the modified solar dryer is to be analyzed for the cost of investment and the economic benefits of the dryer in term of production.

# CHAPTER 2 LITERATURE REVIEW

## 2.1 Relevancy of the Project

This project is relevant to the study of Mechanical Engineering which consists of many subjects such as heat transfer, fluid mechanics, thermodynamics, mechanical engineering design and also manufacturing technology. This project is also relevant to the recent technology of applying solar energy in agricultural field. The traditional method uses solar energy to dry food such as fish, herbs, fruits and vegetables.

Solar energy can be used as an important and environmental compatible source of renewable energy. The use of solar energy for drying effectively reduces the problems arising from generating energy by conventional method. Some of the example of conventional drying is using rubber wood, jet heater that uses kerosene as fuel and also some industrial use Liquefied Petroleum Gas as the heat source. [2]

The agricultural and marine products are dried by using solar energy because it is one of the most attractive and cost-effective application is by solar energy. Numerous types of solar dryers have been designed and developed in various parts of the world. Basically, there are four types of solar dryers; (1) direct solar dryers, (2) indirect solar dryers, (3) mixed-mode dryers and (4) hybrid solar dryers.

Figure 2.1 : Direct solar dryer[16]

Figure 2.2 : Indirect solar dryer[16]

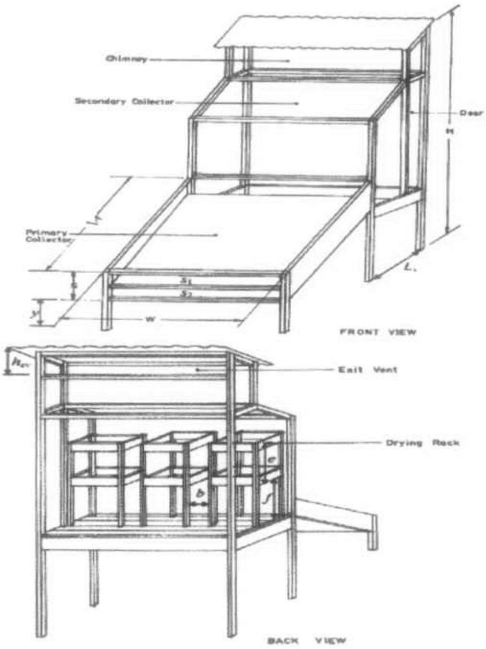


Figure 2.3: Mixed-mode solar dryer [4]

Figure 2.4: Solar hybrid dryer[16]

Traditional method of drying is by open air drying which the crops are placed in the open and exposed to both sun, wind and other undesired elements. Direct solar dryers are enclosed, insulated structures inside which both solar collection and drying takes place. Radiation is collected through a transparent cover in the drying chamber, which is ventilated for improved airflow. Trays carrying produce to be dried are placed inside the chamber. Indirect solar dryers have a collector and a separate drying chamber. They operate more efficiently and allow more control over the drying. The collector heats up air and the air then rises by convection, forcing its way through the racks of drying produce in the drying chamber. [7] A mix-mode dryer is combining 2 or more types of solar dryers. For, example, there is a design of mixed-mode natural convection solar crop dryer by combining direct and indirect solar dryers. [4] A hybrid solar dryer is when the solar dryer is integrated with other source of heat energy to overcome nighttime and also declining weather condition. It is integrated as a separate component. [6]

This project is a study of hybrid dryers featured to the product being dried, technical and economical aspects. The technical directions in the development of solar-assisted drying systems for agricultural produce are compact collector design, high efficiency, integrated storage, and long-life drying system and focus more for small farmers.

Before this, there is a research done by Syarizatul Nadia binti Rosdi on the application of solar energy in drying food. Figure 5 below is the design of her research.

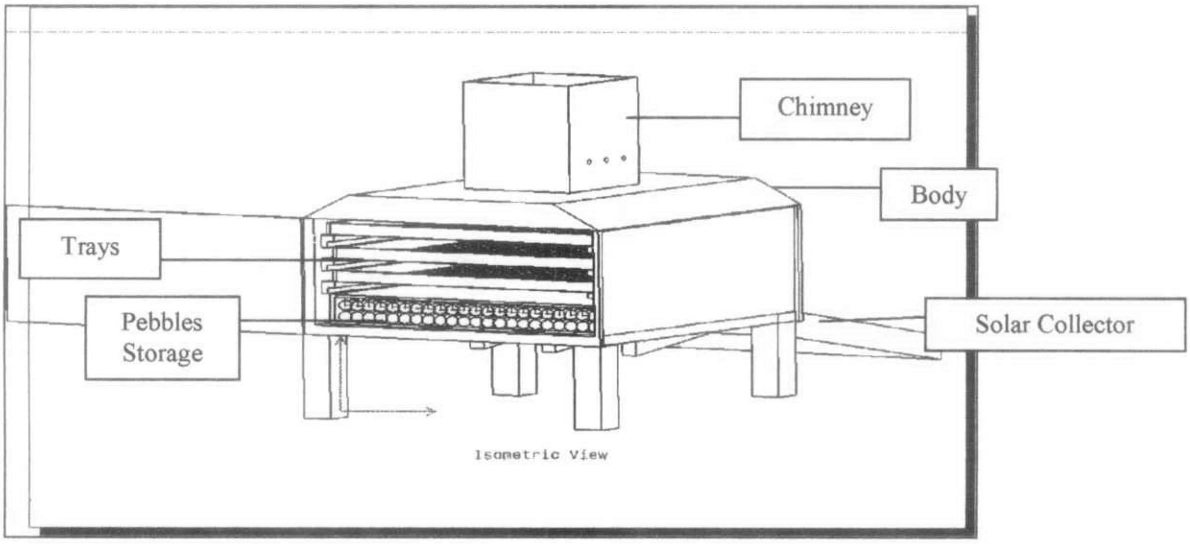


Figure 2.5: Previous design of solar dryer [3]

From the design, the main problem is the dryer cannot be operated continuously day and night and it only functions at day time. The project used a flat plate solar thermal collector for the solar dryer. This project is a continuation to overcome the problem by the existing design of solar dryer. So, in order to counter the problem, an additional energy must be supplied to the existing solar dryer to ensure it is can continuously drying food at night. By considering environmental aspect and cost effectiveness for small farmers, a suitable auxiliary energy must be chosen to be supplied to the existing solar dryer.

## 2.2 Photovoltaic thermal (PVT)

Photovoltaic thermal hybrid systems, sometimes referred to as Hybrid PV/T systems or PVT are systems that convert solar radiation into thermal and electric energy. These systems use a Photovoltaic which converts electromagnetic (photons) radiation into electricity and then a solar collector is used to capture the remaining energy and remove waste heat from the PV module. Photovoltaic (PV) cells suffer from a drop in efficiency with the rise in temperature due to increased resistance. [8]

A basic idea of PVT is the most absorbed solar radiation by a photovoltaic panel is not converted into electricity but contributes to an increasing of temperature of the module then reducing the electrical efficiency. This fact leads many researchers to develop hybrid photovoltaic thermal collector which can generate electric power and simultaneously produce hot water and hot air. The photovoltaic cells are in thermal contact with a solar heat absorber and the excess heat generated by the photovoltaic cells serves as an input for the thermal system. During the operation, a heat carrier fluid removes heat from the absorber and PV cells. These cooled cells then operate at a low and stable temperature for their electrical production. [7]

The PVT is usually use for water heater during summer and also space heating during winter for four season weather country. [1] In this project, the focus is more on the solar air collector since the used of heated air for drying purposes.

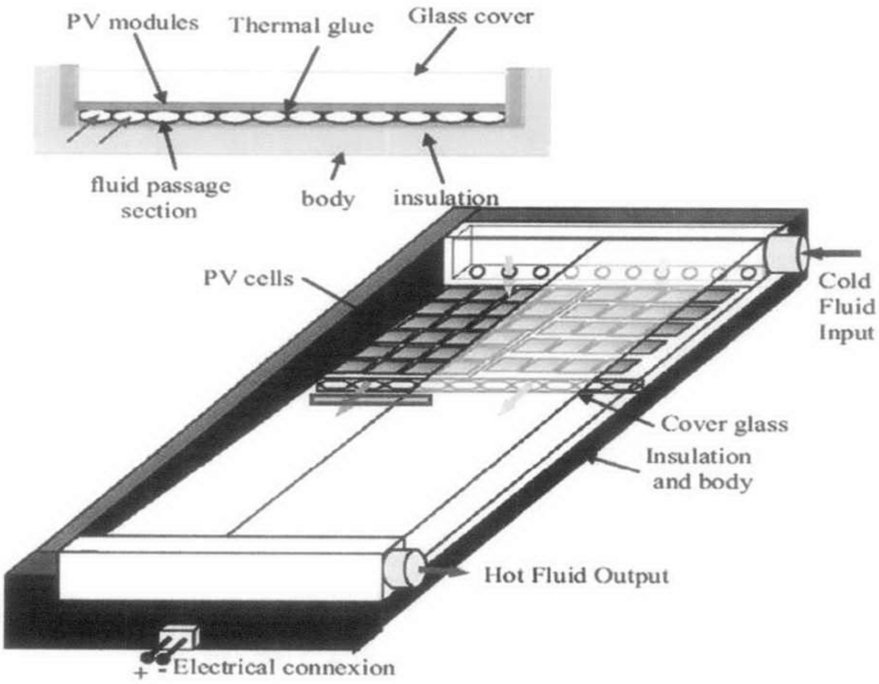


Figure 2.6: PVT panel [7]

The solar air collector is design to provide a simple and economical solution to PV cooling and the air can be heated to different temperature levels through forced or natural flow. Forced circulation is more efficient than natural circulation owing to better convective and conductive heat transfer but the required fan to drive forced circulation reduces the net electricity gain. Figure 2.6 above show a PVT module. The PV cells will collect and convert the radiation to electricity while the air will enter the in cold fluid input, the air will collect heat while it flows into fluid passage section and come out as hot air. [8]

Figure 2.7 give a rough idea to modify the existing solar dryer. At daytime, the solar dryer only use the hot air to dry the chilli. The PVT collector will store the electricity in a battery and the electricity is used to heat a heater to produce hot air at nighttime.

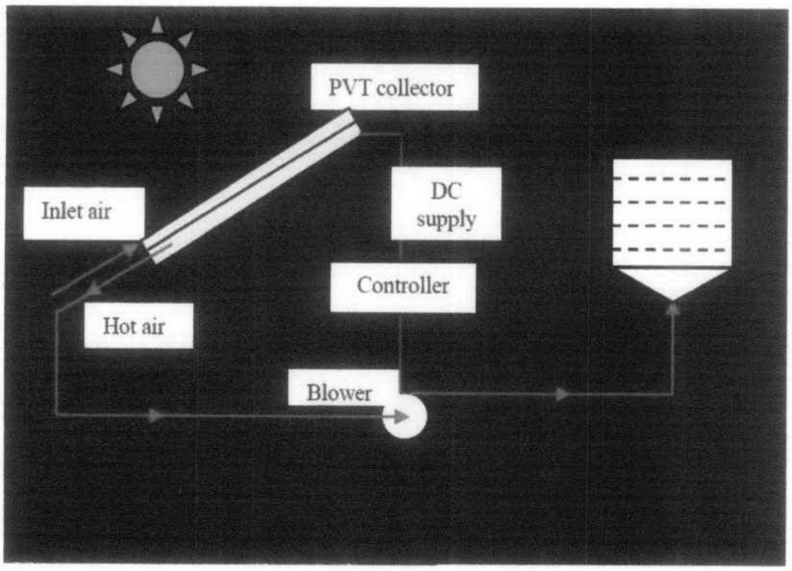


Figure 2.7: Basic system of PVT solar dryer [3]

The number of the photovoltaic cells in the system can be adjusted according to the local load demands and the need for an external electrical source can be eliminated by using this hybrid system. With a suitable design, one can produce a self-sufficient solar collector system that required no external electrical energy to run the system. [3]

The main advantage of air solar collector is the economical order compared to a combination of separate thermal and photovoltaic panels. PVT system is covered with a hybrid solar collector and produces more electrical and thermal energy.PVT are covered half with standard PV panels and half with conventional thermal collector. This is particularly useful because the space use is also reduced. The average temperature of operation for hybrid collector is generally lower than for a standard PV module, so its electrical production will be increased. Hybrid collector provides architectural uniformity on a roof in contrast to an association of two separate solar collectors. [7]

This solar-biomass hybrid drier is designed to use solar energy as main heat source and biomass stove is used only when solar is not available, during early morning, late evening, and cloudy weather conditions and at night. As the solar radiations falls on the glass surface, these enter inside the drier and get absorbed by the product and inside cabinet surface, resulting in an increase of the cabinet air temperature. This process produces temperature difference between inside and outside cabinet air temperatures. Heated air inside the cabinet goes upward and picks up the moisture from the product and comes out from the vents provided at the top of the drier. This action reduces the pressure inside the cabinet and ambient air is drawn into the drier through the inlet holes in the brick walls. A continuous flow of air is thus established. During periods of low or zero solar radiation, biomass stove is used for back-up heating. The combustion gases heat up the stove wall surface, which in turn warm the air as it moves over the outer surface. The warm air rises up into the drying chamber, evaporating and picking up moisture from the product as it passes through the trays, and then escapes through the top vents as before. Temperature inside the drier is controlled by regulation of entering air and burning rate of the biomass.[12]

An indirect type natural convection solar dryer with integrated collector-storage solar and biomass-backup heaters has been designed, constructed and evaluate. The major components of the dryer are biomass burner (with a rectangular duct and flue gas chimney), collector-storage thermal mass and drying chamber (with a conventional solar chimney). The thermal mass was placed in the top part of the biomass burner enclosure. There are some histories regarding the biomass burner. During 1973, Akyurt and Selçuk (1973) developed an indirect solar dryer with a backup gas burner. They found that the drying time could be shortened due to the inclusion of the backup heater. Bassey et al. (1987) used a sawdust burner to provide heat to a direct type solar dyer during bad weather and at night. In their study, the burner was not integrated to the dryer but used steam as a heat transfer medium. Bena and Fuller (2002) designed a direct solar dryer with an integrated biomass-backup heater. The thermal performance of their system was satisfactory. Prasad and Vijay (2005) also developed a direct solar–biomass dryer. The biomass burner has a rock slab on the top part which helps in moderating the temperature of the drying air. These dryer designs have a backup heater without thermal storage of captured solar energy. Consequently, the air temperature in the drying chamber drops down immediately to ambient temperature level after sunset. By that, it means solar-biomass also requiring backup heating even when the preceding day is sunny..

Biomass (especially fuelwood) is a dominant source of energy, and commonly burned using inefficient technologies in most developing countries (Kristoferson and Bokalders, 1991, Bena and Fuller, 2002 and Kaygusuz and Türker, 2002). This resource, if harvested sustainably, can provide the required backup thermal energy for solar drying in developing countries. However, information is scarce on solar drying with integrated collector-storage solar and biomass-backup heaters. The objective of the present study was therefore to develop a solar dryer with a storage component for both solar and biomass thermal energy.[11]

To select the design, the Pugh method is used. Pugh's Method Invented by Stuart Pugh the decision-matrix method, also Pugh method, Pugh Concept Selection is a quantitative technique used to rank the multi-dimensional options of an option set. It is frequently used in engineering for making design decisions but can also be used to rank investments options, vendor options, product options or any other set of multidimensional entities. [15]

A basic decision matrix consists of establishing a set of criteria upon which the potential options can be decomposed, scored, and summed to gain a total score which can then be ranked. Importantly, the criteria are not weighted to allow a quick selection process. [15]

The advantage of this approach to decision making is that subjective opinions about one alternative versus another can be made more objective. Another advantage of this method is that sensitivity studies can be performed. An example of this might be to see how much your opinion would have to change in order for a lower ranked alternative to out rank a competing alternative. [15]

Morphological analysis is another form of a decision matrix employing a multi-dimensional configuration space linked by way of logical relationships.The first step is to select the criteria for comparison. The list of criteria must be developed from the customer needs and engineering specifications. All team members should contribute in making the list. The list then should be debated until consensus is reached. The method is an iterative evaluation that tests the completeness and understanding of requirements, quickly identifies the strongest concept. The method is most effective if each member of the design team performs it independently. The results of the comparison will usually lead to repetition of the method, with iteration continued until the team reaches a consensus. [15]

Second step is to select the concepts to be compared. These alternatives should be those that proceed from the concept generation. It is important that all the concepts to be compared be at the same level of abstraction. [15]

The third step is to generate the score. A favorite concept should be selected as a ***datum***. All other designs are compared to its relative to each customer needs. For each comparison, the concept being evaluated is judged to be either better than ("+" score), about the same ("s" score), or worse than the datum ("-" score). [15]

The last step is to compute the total score. Three scores are generated, the number of plus scores, the number of minus scores and the total. If a concept has a good overall score or a high "+" score, it is important to notice what strengths it exhibits, that is, which criteria it meets better than datum. Same for "-" score. If most concepts get the same score on a certain criterion, examine that criterion closely. More knowledge may have to be developed in the area of the criterion. Or, it may be ambiguous, is interpreted differently by different members. [15]

# CHAPTER 3 METHODOLOGY

## 3.1 Process Flow

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

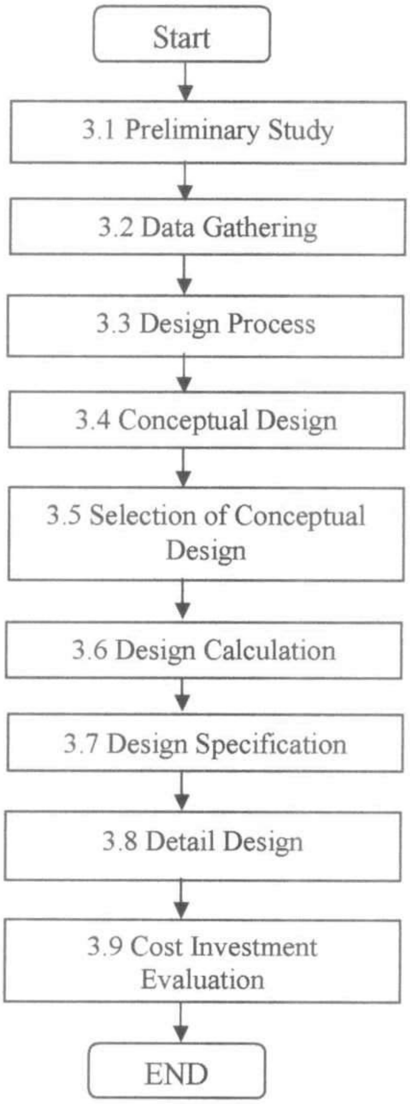


Figure 3.1: Project Flow

**3.1** Preliminary study is done by reading the material like journals, reports, and also thesis that are related to food drying and also solar drying. The information about chilli also is search by set up an interview with MARDI.

**3.2** The important data is gathered from the preliminary study. This data can be used during the calculations.

**3.3** Design process is done by identify the design requirement and also design constraint of the solar dryer. The design of the solar dryer is mainly focus on small farmers.

**3.4** Several design concept of solar dryer are chose to be evaluated in next step.

**3.5** From the conceptual design, one design is chose for further research.The selection is done by using selection matrix and scoring concept.

**3.6** The calculation is shown to prove the theory behind the design and how the design is produced.

**3.7** The design specification is done to show the needed of every part and also the material used. The discussion will focus on how the solar dryer works and the flow of the heat.

**3.8** Detail design is produce by using AutoCAD by following the measurement or value by the calculation.

**3.9** Lastly, the economic evaluation will be provided to show the payback period and net present value of the solar dryer.

## 3.2 Gantt Chart

Final Year Project I

| No | Details/Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Selection of project topic | ■ | ■ | | | | | | MID SEMESTER BREAK | | | | | | | | |
| 2 | Prelimary research work | | ■ | ■ | ■ | | | | | | | | | | | | |
| 3 | Submision of preliminary report | | | | O | | | | | | | | | | | | |
| 4 | Project work | | | | | ■ | ■ | ■ | | | | | | | | | |
| 5 | Submision of progress report | | | | | | | | | O | | | | | | | |
| 6 | Seminar | | | | | | | | | O | | | | | | | |
| 7 | Project work continues | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 8 | Submission of interim report draft | | | | | | | | | | | | | | | O | |
| 9 | Oral presentation | | | | | | | | | During study week | | | | | | | |

Final Year Project II

| No | Details/Week | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Design calculations | | ■ | ■ | ■ | | | | MID SEMESTER BREAK | | | | | | | | |
| 2 | Submission of progress report 1 | | | | | 0 | | | | | | | | | | | |
| 3 | Fabrication | | | | | ■ | ■ | ■ | | ■ | | | | | | | |
| 4 | Submission of progress report 2 | | | | | | | | | | 0 | | | | | | |
| 5 | Seminar | | | | | | | | | | 0 | | | | | | |
| 6 | Experiment | | | | | | | | | ■ | ■ | ■ | ■ | ■ | | | |
| 7 | Poster exhibition | | | | | | | | | | | | | 0 | | | |
| 8 | Submission of Dissertation FD | | | | | | | | | | | | | | | | 0 |
| 9 | Oral Presentation | | | | | | | | | During study week | | | | | | | |
| 10 | Submission of Dissertation | | | | | | | | | During study week | | | | | | | |

Figure 3.2: Gantt Chart

## 3.3 Data Gathering

Ipoh is chose as the location since experiments will be done after the solar dryer is fabricated. The relative humidity changes during days and night. So, the data must be gathered to determine the value to be used in calculations. The meteorological data is taken from Malaysia Meteorological website and the changes are shown as table below. The data is taken during May 2010.[19]

Table 3.1: Changes of Relative Humidity

| Time | Value of Relative Humidity |
|---|---|
| 08:00 | 98.0 |
| 09:00 | 95.0 |
| 10:00 | 91.0 |
| 11:00 | 80.0 |
| 12:00 | 74.0 |
| 13:00 | 67.0 |
| 14:00 | 67.0 |
| 15:00 | 66.0 |
| 16:00 | 70.0 |
| 17:00 | 87.0 |
| 18:00 | 97.0 |
| 19:00 | 97.0 |
| 20:00 | 97.0 |
| 21:00 | 98.0 |
| 22:00 | 100.0 |
| 23:00 | 91.0 |
| 24:00 | 97.0 |
| 01:00 | 98.0 |
| 02:00 | 96.0 |
| 03:00 | 94.0 |
| 04:00 | 98.0 |
| 05:00 | 97.0 |
| 06:00 | 97.0 |
| 07:00 | 98.0 |

Pre-treatment for chilies are done to produce a high quality dried chilies. The chilies are washed to ensure the cleanliness from dust and soil. The red chili can move to blanch but for green chili, it must be put in special room that contains ethylene gas for 48 hours. Before it is put to the dryer, the chilies in blanch in boiling water for 3 minutes. This step is to avoid the chilies to change in color. [5]

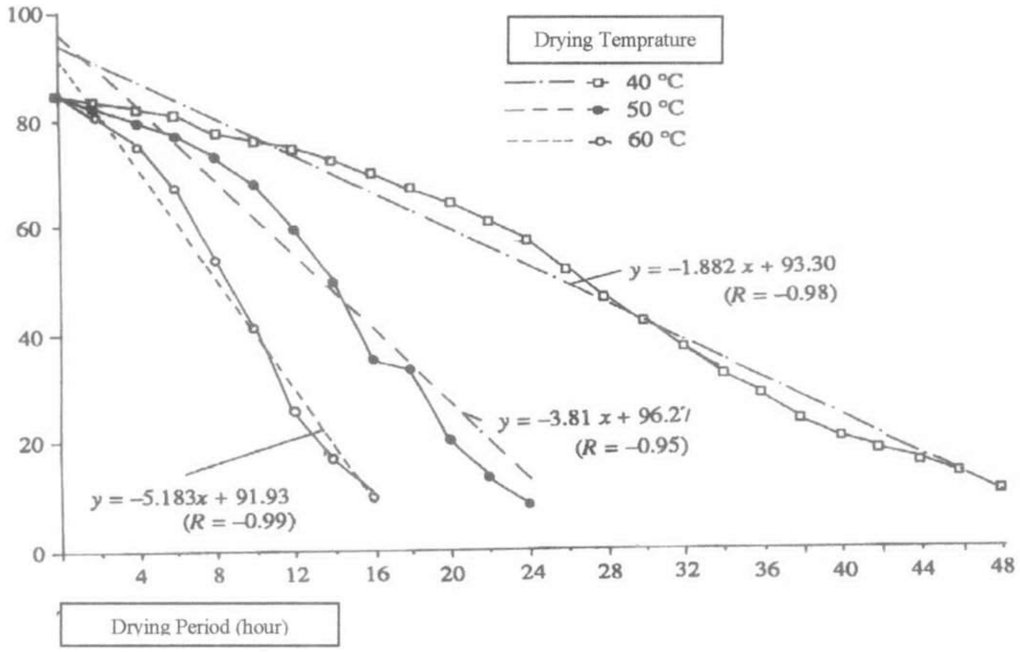


Figure 3.3: Drying Curve for Chilies [5] Reproduced by Norzhafran

The figure above shows a drying curves for chilies which are dried in different temperature. The temperature is 40° C, 50° C, 60° C. From the research done by MARDI, the best range of temperature is 50 Celsius to 60 Celsius. The reason is because the drying is more efficient between the ranges with a drying time within 24 hours and also the quality of the chilies is not affected. The total of production also can be increased by this range of temperature. [5]

Usually, the moisture content that must be reduced is from 84-86% to about 10% or less. So, the final moisture content must be less than 10%.The figure below shows that the moisture content reduced are almost the same by a differences in temperature. It means that a difference in temperature doesn't affect the final moisture content but the drying time will take much longer for a lower temperature than a higher temperature. [5]

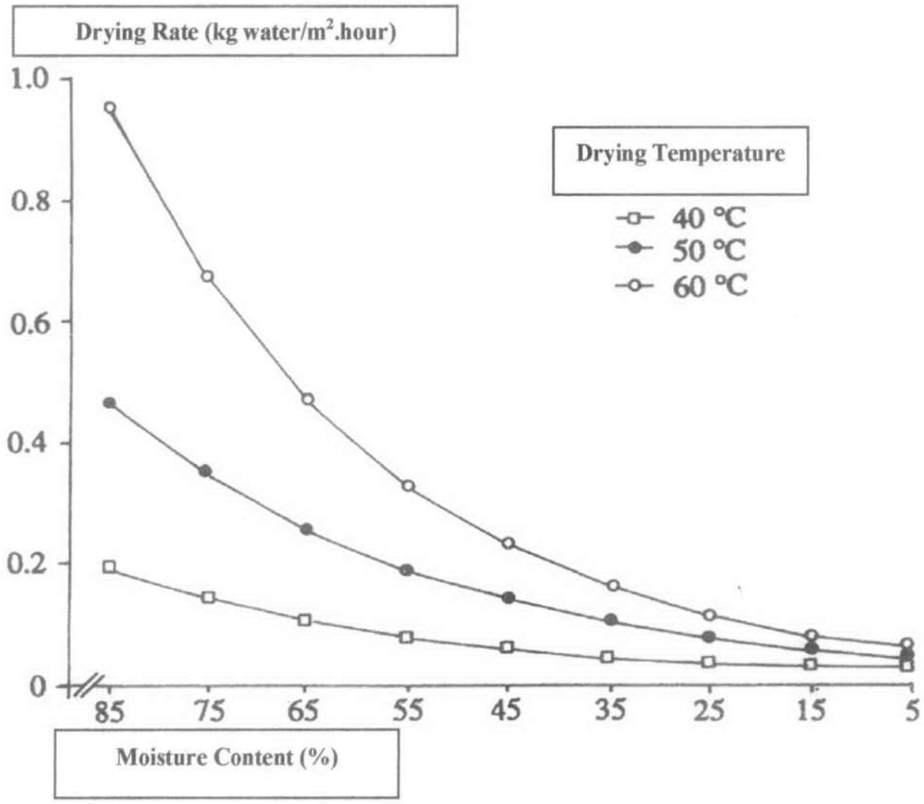


Figure 3.4: Graft between Drying Rate versus Moisture Content (%) [5]
Reproduced by Norzhafran

The quality of the chilies is depending on 4 physical parameters. They are aroma, color, pungency and also the total acceptance. Basically, MARDI use Hedonic Rating Test to determine the quality of the chilies. The test is done by 10 trained panel members. MARDI will provide the panel with a form to rate the chilies. Nine scale of hedonic will be chose from 1(not acceptable) to 9 (most attractive).The test was done by the MARDI and it result reflect that there are not much differences. The major differences is the pungency of the blanch chilies is lower than non-blanch chilies because of the moisture content is much lower than the dried chilies in the market. The user still accepts both chilies with a score of 7.1 and 7.2 out of 9. [5]

## 3.4 Design Process

### 3.4.1 Identification of Requirement

List of requirements was conducted in tend to solve or minimize the problems faced by the farmer in drying the chilli. Requirement of the system are summarized by Table 3.2.

| No | Factors | Problems | Requirements |
|---|---|---|---|
| **1.** | Location | Small Town | *Portable if possible<br>*Multi layer of drying tray / bin |
| **2.** | User | Lack of knowledge<br>Lack of money to invest | *Simple design<br>*Easy to maintain – less moving part<br>*Interactive manual<br>*Cheaper |
| **3.** | Climate | Intermittent solar radiation<br>Rainy period<br>High relative humidity | *Apply high thermal absorption of solar collector<br>*Use backup system<br>*Use external force device like fan / blower |
| **4.** | Cost | Higher investment or long payback period method | *Reduce product cost with cheap material but a good quality material |

Table 3.2: Requirement of the System

### 3.4.2 Conceptual Solar Dryer

After did some literature reviews, the rough conceptual designs were made. There are 2 design concepts for the project as described below:-

#### 3.4.2.1 PVT Concept

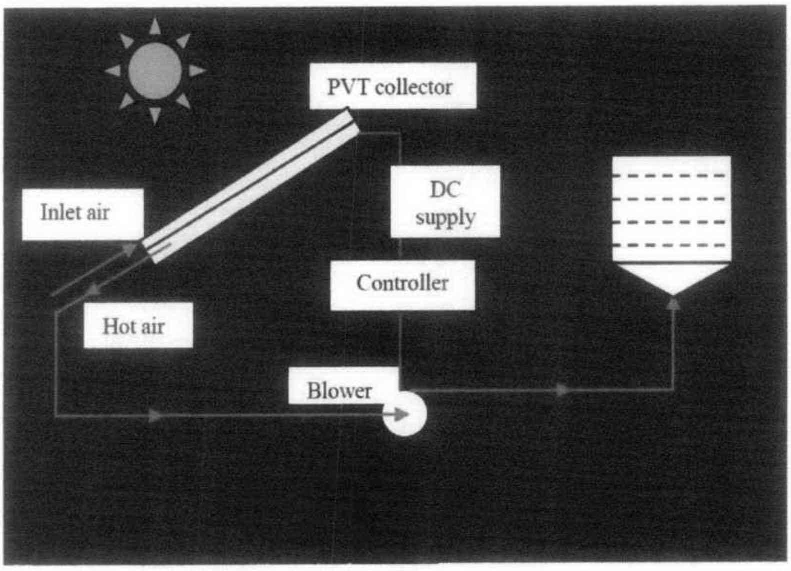


Figure 3.5: PVT Concept

Figure 3.3 shows the draft of the PVT conceptual outline. The design consists of PVT collector, blower or fan, dc supply or battery and controller. During day time, the PVT will collect thermal energy and supply the energy to the crop storage. During night time, the blower will supply heat to the crop storage. Thus, the solar dryer will operate continuously. Table 3.4 below shows the preliminary analysis of the first conceptual design.

Table 3.3: Advantage and Disadvantage of PVT Concept

| Advantages | Disadvantage |
|---|---|
| **Continuous drying** | Expensive |
| **Control of drying rate** | Applicable for large scale production |
| **Environmental friendly** | High maintenance cost |
| | High capital cost |
| | Direct dryer which reduce the vitamin contains |

### 3.4.2.2 Biomass Concept

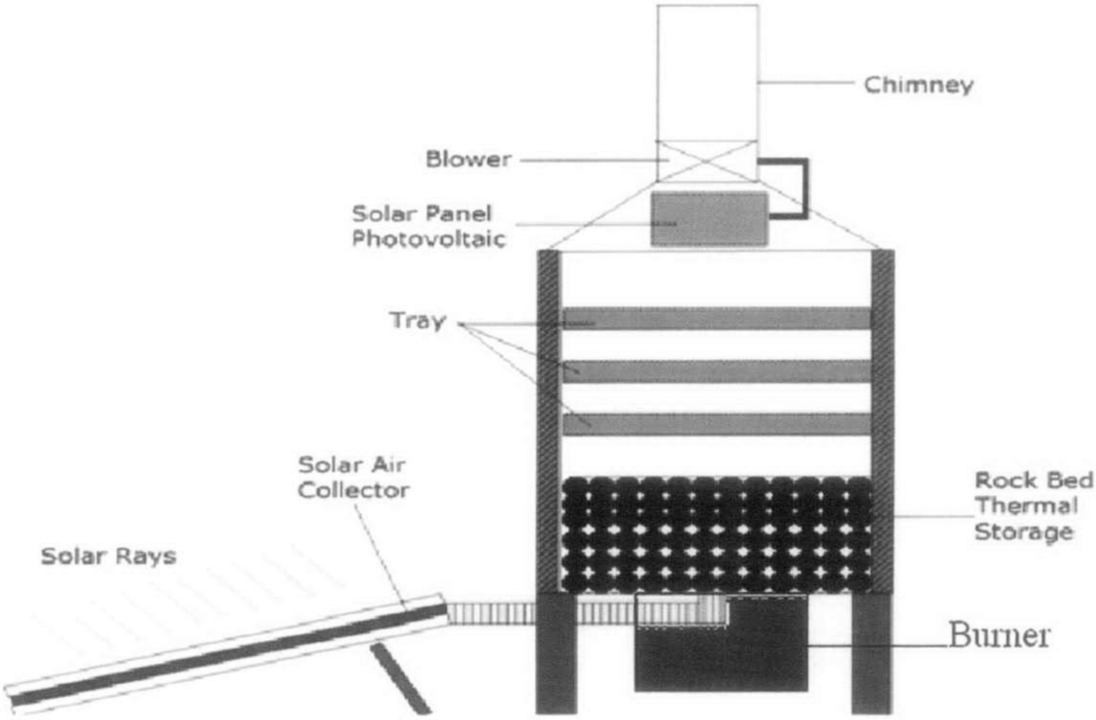


Figure 3.6: Biomass Concept

The biomass solar dryer is a hybrid solar dryer (shown by Figure 3.4). The design's components are; solar air collecor, thermal storage, drying trays,Perspex transparent roof and chimney for the air ventialation. Table 3.4 below shows the preliminary analysis of the first conceptual design.

Table 3.4: Advantage and Disadvantage of Biomass Concept

| Advantages | Disadvantage |
|---|---|
| **Moderate drying** | Capital Cost |
| **Continuous operation** | Information distribution |
| **Medium / Big scale** | Cannot control the drying rate |
| **Easy to setup** | |
| **Easy to operate and maintain** | |
| **Not require many labour** | |

## 3.5 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
ii. Able to operate continuously.
iii. Capital and maintenance cost are reasonable and affordable (Preferable capital cost: not exceed RM 5000).
iv. Easy maintenance and operation.
v. The solar dryer is long lasting (at least more than 15 years).
vi. Materials used are cheap and easy to find

## 3.6 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 concept screen can be as simple as a checklist of criteria in the form of questions that fall into two categories: "must-meet" and "should-meet" criteria. The concept screen works simply by comparison against a benchmark base option. It is easier to compare than to give absolute scores to something. By having fixed criteria which have to compare all options helps make scores fair and equitable.

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

Table 3.5: Selection Matrix of Conceptual Design

| Selection Criteria | Concept | |
|---|---|---|
| | **(1)** | **(2)** |
| **Reasonable Cost** | - | + |
| **Reliability** | + | 0 |
| **Long-lasting** | - | + |
| **Large quantity of production** | + | + |
| **Decreased labor cost** | + | + |
| **Increased productivity** | + | + |
| **Maximum solar energy** | + | + |
| **Product weight** | 0 | - |
| **Sum +'s** | 5 | 6 |
| **Sum 0's** | 1 | 1 |
| **Sum – 's** | 2 | 1 |
| **Net score** | 3 | 5 |
| **Rank** | 2 | 1 |

+ 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. The weighted scoring system is often used to evaluate and quantify a wide range of product concept criteria. Individual 'evaluation criteria' are scored and weighted to determine an overall concept score. Typically, the criteria are assigned values from 0 – 5, reflecting low to high scores; each criteria is also assigned a weighting factor that reflects its relative importance. Since some variables are more important than others, so that they are assigned a greater weighting in the overall score. Table 3.6 below shows the result of the screening matrix for design concept 1 and 2.

Table 3.6: Screening Matrix for PVT Concept (1) and Biomass Concept (2)

| Selection Criteria | Weight (%) | Concept | | | |
|---|---|---|---|---|---|
| | | (1) | | (2) | |
| | | Rating | Weighted Score | Rating | Weighted Score |
| Reasonable Cost | 30 | 1 | 0.30 | 4 | 1.20 |
| Reliability | 10 | 3 | 0.30 | 4 | 0.40 |
| Long-lasting | 10 | 4 | 0.40 | 4 | 0.40 |
| Large quantity of production | 10 | 5 | 0.50 | 5 | 0.50 |
| Decreased labor cost | 10 | 4 | 0.40 | 5 | 0.50 |
| Increased productivity | | | | | |
| Maximum solar energy | 10 | 5 | 0.50 | 5 | 0.50 |
| Product weight | | | | | |
| | 10 | 5 | 0.50 | 4 | 0.40 |
| | 10 | 2 | 0.20 | 3 | 0.30 |
| | Total Score | | 3.10 | | 4.20 |
| | Rank | | 2 | | 1 |

Rating Scale:

| Relative Performance | Rating |
|---|---|
| Much worse | 1 |
| Worse | 2 |
| Same | 3 |
| Better | 4 |
| Much better | 5 |

The best final concept selected is the last design with net score of 4.20. Basically biomass concept is friendlier user and cost lesser to the private farmer. The biomass design concept is chosen because it is very practical, not too expensive, improve quality of product as it was designed in a closed space. In addition, the biomass solar dryer can be easily setup, use and maintain and offer continuous operation.

Therefore, a biomass solar dryer is very practical and has a cheaper investment. The biomass solar dryer start functioning when the sun rise. The solar biomass dryer will try to gain the maximum heat as much as possible through its solar thermal collector during day time. When the sun set, the biomass will start functioning. With this understanding working principles, the detail design of this solar dryer was preceded. The advantages and disadvantages of biomass design concept are:

Advantages:-

i. Reasonable investment
ii. Easy to operate and maintain
iii. Not requires a specialized manpower
iv. The drying is quicker
v. The crops are well protected during the drying process
vii. Can be produced locally and from local available material
vi. Environmental friendly
vii. The solar air collector is cheaper compare to PVT collector

Disadvantages:-

i. The dryer should be operated properly to reach the good quality of the dried product.
ii. Require small investment monthly to buy biomass fuel.

## 3.7 Basic Product Structure

The complete product of solar food dryer composed of four main parts which are solar air collector, packed bed thermal storage, drying chamber, and chimney. Listed are the main components and their parts:-

i. Solar Air Collector

Solar air collector function is to supply the hot air indirectly to the drying chamber. The solar air collector will collect the solar energy and transmit the energy to the crops storage with a help of tube or hose. The main consideration of this collector is its capability to absorb and transfer the heat effectively. The capital investment for solar air dryer is also cheaper and can be bought at price range of RM240 to RM 1000.

ii. Packed Bed Thermal Storage

The packed bed thermal storage function is to store the heat during optimum time and used the heat back when the solar radiation decreases due to cloud and nighttimes. 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 1.5kg of chilli (for testing the performance). The drying chamber is also the main structure to attach all the components and those components will be placed accordingly. The components are:-

- a. Tray Frame
- b. Tray Support
- c. Pebble Thermal Storage Part
- d. Drying Chamber
- e. Frames

### iv. Chimney

Chimney act as the exit of the heated air after went through the main body. Chimney is the assembly of these parts:-

- a. Top transparent Perspex / glass

## 3.8 Design Calculations

The calculation is done to size the solar dryer. First, the size of drying tray is determined. Then, the quantity of heat used during day and night time in order to dry the chilli. Then, the size of thermal storage is calculated to size the bed packed thermal storage. The size of the chimney also must be determined in this calculation. In order to decrease the total cost in the research, the solar air collector is sized for 1.5 kg chilli and the material used to fabricate the solar air collector is come from waste product of lathe machine.

### 3.8.1 Determine the size of drying tray [3]

The tray size for the chilli can be related to the volume of the crop. The calculation is based on the specific gravity of the chilli. The specific gravity is between 0.848 to 0.863.For this calculation, the average of the range and which is 0.85 and it is taken for specific gravity, SG. [18]

$$\rho_{chilli} = SG \times \rho_w$$
$$\rho_{chilli} = 0.85 \times 1000 kg/m^3 = 850 kg/m^3$$
$$V = m/\rho_{chilli} = 1.5\text{kg}/850\text{kg/m}^3 = 1.764\text{x}10^{-3}\text{m}^3$$

Because of there are three trays provided in the dryer, each tray should capable in handling $\frac{1.764x10^{-3} m^3}{3} = 5.882x10^{-4}\,\text{m}^3 \approx 6.0x10^{-4}\,\text{m}^3$.

For one tray:-

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

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

If the thickness of one tray is fix to 0.05m,

$$V = 6.0x10^{-4} m^3 = l \times w \times 0.05m$$

Let $l = w$,

$$6.0x10^{-4} = 0.05w^{2}$$
$$w = 0.11m$$

Therefore, the tray size will be 0.11m x 0.11m x 0.05 m. The distance between trays is 0.05m. The distance between trays is selected in order to allow installation of tray support (max to 0.025m height).

## 1. Determine the quantity of heat needed at the drying tray [4]

### 2.1 For daytime used

i. Amount of moisture to be removed from product

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

$m_w = m_{chilli} ( M_i - M_f ) / (100 - M_f)$ (2)

For 1.5kg fresh chilli which need to evaporate 80% (wb) moisture content to 10%, the water need to be evaporated is:-

$m_w = 1.5 ( 80 - 10 ) / (100 - 10) = 1.167kg$

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

$m_a = m_w / (\omega_f - \omega_i )$ (3)

The $(\omega_f - \omega_i)$ can be found from the psychrometric chart.

Reading the psychrometric chart:-

Lets assume that the $T_{amb} = 27.5^{\circ}C$ is heated to, $T_{product} = 55^{\circ}C$. The initial relative humidity $\phi_i$ will be reduced from 75% to 18%.

If this heated air is used to remove the moisture from chilli of $M_i = 80\%$ until reach an equilibrium RH, $\phi_f = 90\%$, the temperature will drop to $32.5^{\circ}C$. Thus, the humidity ratio will be changed from 0.0185 to 0.028. Therefore, the difference of humidity ratio is equal to 0.0095.

Refer to Appendix E1, from point 1 to point 2. The temperature starts at 27.5° C and then move to relative humidity of 75%. From there, it moves to point 3 because of the temperature increase until it reaches 18% of RH. Thus, the temperature drop to 55°C.Due to humidify from the moisture release by the chili, the RH increase to 90% which is at point 4.There, the temperature is 32.5°C. Point 5 shows the new humidity ratio which is 0.028.Then, from there, the enthalpy can be find by moving to point 6.

$\therefore\ m_a = 1.5 / (0.0095) = 157.89$ kg

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

$$V_a = m_a RT_c / P \tag{4}$$

$$V_a = 157.89\ \text{kg} \times 2.87 \times 10^2\ \text{Jk}^{-1}\text{K}^{-1} \times 300.5\text{K} / 1.01325\ \times 10^5\text{Pa}$$

$$V_a = 134.39\ \text{m}^3$$

iii. Amount of thermal energy required

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

$$q = m_a (h_f - h_i) \tag{5}$$

From the psychrometric chart, the final enthalpy and the initial enthalpy are 129.5kJ/kg and 76kJ/kg. By referring to Appendix E-1, the initial enthalpy is shows at point 7 and the initial enthalpy is at point 6.

Thus the heat required is:-

$q = 157.89\text{kg}\,(129.5 - 76)$ kJ/kg

$q = 8.45$ MJ

Thus, the energy required for the dehydration process is 8.45 MJ.

### 1.2 Night-time used

i. Amount of moisture to be removed from product

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

$m_W = m_{chilli} ( M_i - M_f ) / (100 - M_f)$ (2)

For 1.5 kg fresh chilli which need to evaporate 80% (wb) moisture content to 10%, the water need to be evaporated is:-

$m_W = 1.5 ( 80 - 10 ) / (100 - 10) = 1.167kg$

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

$m_a = m_W / (\omega_f - \omega_i)$ (3)

The $(\omega_f - \omega_i)$ can be found from the psychrometric chart.

Reading the psychrometric chart:-

From the data get from Malaysian Meteorological,the ambient temperature, $T_{amb} = 25°C$ is heated to $T_{product} = 55°C$. The initial relative humidity $\phi_i$ will be reduced from 95% to 19%.

If this heated air is used to remove the moisture from chilli of $M_i = 80\%$ until reach an equilibrium RH, $\phi_f = 100\%$, the temperature will drop to $31.2°C$. Thus, the humidity ratio will be changed from 0.0190 to 0.286.

Refer to Appendix E-2, from point 1 to point 2. The temperature starts at 25° C and then move to relative humidity of 95%. From there, it moves to point 3 because of the temperature increase until it reaches 18% of RH. Thus, the temperature drops to 55°C. Due to humidify from the moisture released by the chili, the RH increase to 90% which is at point 4 and the temperature is 32.5°C. Point 5 shows the new humidity ratio which is 0.028.Then, from there, the enthalpy can be find by moving to point 6.

Therefore, the difference of humidity ratio is equal to 0.0122.

$\therefore\ m_a = 1.5 / (0.0122) = 122.95\text{kg}$

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

$$V_a = m_a RT_c / P \tag{4}$$

$$V_a = 122.95\ \text{kg} \times 2.87 \times 10^2\ \text{Jk}^{-1}\text{K}^{-1} \times 298\text{K} / 1.01325 \times 10^5\text{Pa}$$

$$V_a = 103.78\ \text{m}^3$$

iii. Amount of thermal energy required

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

$$q = m_a (\omega_f - \omega_i) \tag{5}$$

From the psychrometric chart, the final enthalpy and the initial enthalpy are 134kJ/kg and 74kJ/kg. By referring to Appendix E-2, the initial enthalpy is shows at point 7 and the initial enthalpy is at point 6.

Thus the heat required is:-

$q = 122.95\ \text{kg}\,(134 - 74)\ \text{kJ/kg}$

$q = 7.38\text{MJ}$

Thus, the energy required for the dehydration process is 7.38MJ

### 3.8.2 Determine the size of thermal storage [13]

i. Mass of pebbles required to store the heat for each square meter

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 20°C increase in thermal storage, the mass of pebbles required for each square foot of collector area is:

$$m_{pebbbles} = \frac{2}{3} \times I_{\max} /(T_{storage} \times \text{specific heat}) \quad [13] \tag{6}$$

$$= \frac{\frac{2}{3} \times 15876 \text{ kJ/m}^2 day}{60^o C \times 0.88 \text{ kJ/kg}^o C} = 200.45 \text{kg/m}^2 \; x0.78mx0.78m = 121.95kg$$

For the safety factor, the mass of pebbles is added to 10% which is about 134.15kg

ii. Height of the storage

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

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

$$\text{V} = \frac{134.15kg}{2700kg/m^3} = 0.05m^3$$

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

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

$$= \frac{0.05m^3}{0.61m^2} \approx 0.08m$$

iii. Quantity of heat stored

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

$$\text{Q}_s = mC_p \Delta T = 134.5kg \times 0.88kJ/kg.K \times (60-27)$$

$$\text{Q}_s = 3905.88kJ$$

iv. Void Fraction

The void fraction can be calculated from this equation:-

$$V = Q_s / pc(1-\varepsilon)\Delta T = 0.05m^3$$

$$0.05m^3 = \frac{3905.88kJ}{2700kg/m^3 \times 0.88kJ/kg.K \times 33K \times (1-\varepsilon)}$$

$$1-\varepsilon = 0.996$$

$$\varepsilon = 0.004$$

### 3.8.3 Determine the size of chimney [3]

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.

$$\dot{Q} = CA\sqrt{2gH\frac{T_i - T_e}{T_i}} \tag{10}$$

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

$V_a$ is taken from day time because it is larger than night time value.

$$\dot{Q} = \frac{V_a}{\tau} = \frac{134.39\ \mathrm{m}^3}{\frac{24\ \mathrm{hour}}{\mathrm{day}} \times \frac{1\ \mathrm{day}.3600\ \mathrm{s}}{\mathrm{hour}}}^{3} = 1.555x10^{-3}\ \mathrm{m}^3/\mathrm{s} \tag{11}$$

Thus, the input data for equation (11) is stated in Table 3.7:-

Table 3.7: Input Data for Sizing Chimney

| Parameter | Unit | Value |
|---|---|---|
| A (square shape) | $m^2$ | $w^2$ |
| $\dot{Q}$ | $m^3/s$ | $1.555 \times 10^{-3}$ |
| C | | 0.7 (draught coefficient) |
| $T_i$ | K | 300.5K |
| $T_e$ | K | 328 K |
| g | $m/s^2$ | 9.81 |
| w | m | 0.07 |
| H | | $(Q/CA)^2/(2 \times g \times ((Ti-Te)/Ti))$ |

For the square chimney, the height calculation results give 0.114 m.

Therefore, the square chimney with an area surface of 0.07 m x 0.07 m and 0.114 m height is chosen in order to draught out the $1.555 \times 10^{-3}$ $m^3/s$ moisture.

### 3.8.4 The total area of the system for collecting incident energy [4]

The overall system drying efficiency ($\eta_d$) is related to the effective total area surface of the collector which collects incident radiations. It is given by

$A_{c}= m_cL/ I\ \eta_d\ \tau$

where $A_c$ is the total area of the dryer receiving incident radiation, $\tau$ is the total time, L is the latent heat of vaporization and I is the intensity of radiation incident on a tilted surface. To achieve an optimal design, an average overall efficiency value of 12.5% can be assumed. The latent heat of vaporization for water is 2.743 MJ/kg and the time required to dry 1.5 kg of chilli is 86400 s (24 hours). The value of $I_t$ is 400 $w/m^2$

$A_{c}= 1.5kg \times 2.743\ MJ/kg / (400\ W/m^2 \times 0.125 \times 86400\ s)$

$= 0.95m^2$

### 3.8.5 Sizing the solar air collector [4]

The solar air collector used to provide the primary supply of energy to the dryer. Essentially, the absorber within the air heater converts direct and diffuse solar radiation into heat which is the transferred to the air flowing through it. A recommended range for optimum performance of the solar air collector is by taking the ratio of length to width as 1.5. The height of the solar air collector is fixed to 0.10 m for this calculation.[personal communication with Dr. Gilani on September 2010]

By $A_c$, the length, L and $W_s$ is determined as 0.8 and 0.54.

The sample calculation is:-

$0.95m^2 = 1.5\ W_s \times W_s$

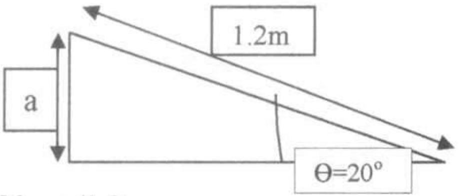
$0.95m^2 = 1.5\ W_s{}^2$

$W_s = 0.7968 \approx 0.8$ m

The size is of the length is 1.5 x 0.8m and equal to 1.2.

So, same size of solar air collector is used for crops storage and also pebbles storage. In order to collect the maximum solar energy, the solar air collector must be elevated.

To elevate the height in order the solar air collector panel is inclined 20°, trigonometric is used.[14] From the calculated height,



Sin 20= a /1.2,

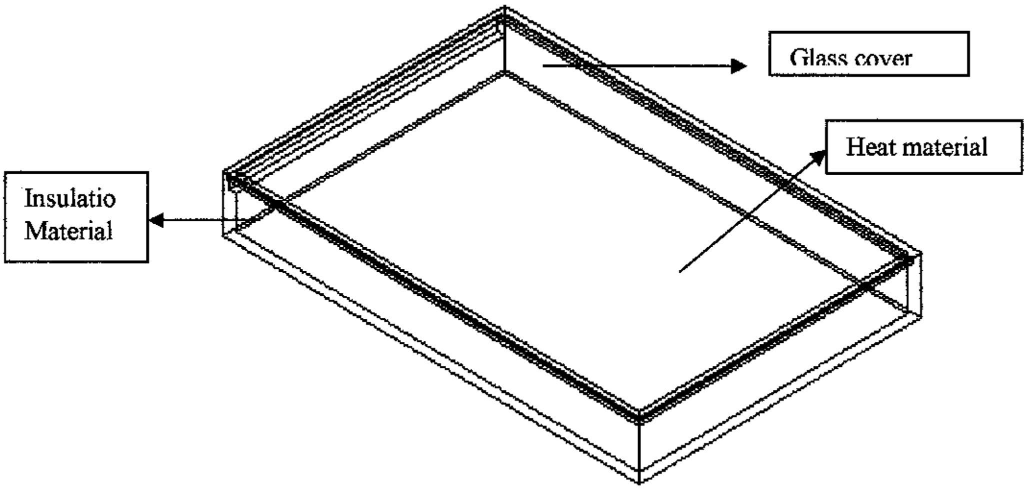
= 0.41m

The height of the base must be elevated to 0.41 m to ensure the incline angle of the solar air collector is 20°. The value is more than the minimum height of the base for both crops storage and also pebbles storage.

## 3.9 Material Selection

### 3.9.1 Solar Air Collector

In this project, the solar air collector used is a basic air collector that uses cheap material to test the efficiency of the crops drying. The collector is made from insulation material, wood. The chips from lathe machine are used as heat material and the chips are come from several materials such as steel, aluminium or copper. The cover of the solar air collector is made from glass.Two solar air collector is needed in this project, one is for crop storage and the other is for thermal storage.



### 3.9.2 Thermal Storage

Pebbless are among the solids that are able to store the energy efficiently. Compared to pebbles, magnesium oxide, aluminium oxide, the cost of the pebbles is lower, easy to find and also having good specific heat (0.71-0.92kJ/kg-K). Somehow, the thermal conductivity of the pebbles is the lowest (0.13 W-m/K) but still pebbles are the most reliable material for thermal storage in this project.

### 3.9.3 Drying Chamber, Chimney and Trays [3]

For a mixed mode dryer, the roof and main body use transparent and lightweight material. The roof should have good radiation transmitting. Therefore, there are two groups of materials can be considered, which are thermo sets and thermoplastics. In the thermoplastics group, the best choice is Perspex. Perspex 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 and window glazing. The advantages of using Perspex are

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

# CHAPTER 4 RESULTS AND DISCUSSION

## 4.1 Summary Calculation of Design

Table 4.1 shows the result of the design measurement:-

Table 4.1: Summary of Calculation Result

| No | Items | Value |
|---|---|---|
| **1.** | Size of Tray | **0.11m x 0.11m x 0.05m** |
| **2.** | Mass of water to be evaporated, $m_w$ | **1.16 kg** |
| **3.** | Mass of dry air needed, $m_a$ | **157.89 kg** |
| **4.** | Volume of air needed | **134.39 m³** |
| **5.** | Amount of heat needed at trays | **8.45 MJ (Daytime)**<br>**7.93 MJ (Nighttime)** |
| **6.** | Mass of pebbles, $m_{pebbles}$ | **134.15 kg** |
| **7.** | Height of thermal storage,H | **0.08 m** |
| **8.** | Void Fraction, $\varepsilon$ | **0.004** |
| **9.** | Solar Collector Area, $A_c$ | **0.8 m x 1.2 m** |
| **10.** | Height of chimney | **0.114 m** |

## 4.2 Design Feature 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 and the thermal storage consist of rock bed and also biomass burner attached below. Figure 4.1 shows the assembly drawing of the solar dryer.

## 4.3 Drawing of Components

### 4.3.1 Main Body (Drying Chamber and Chimney)

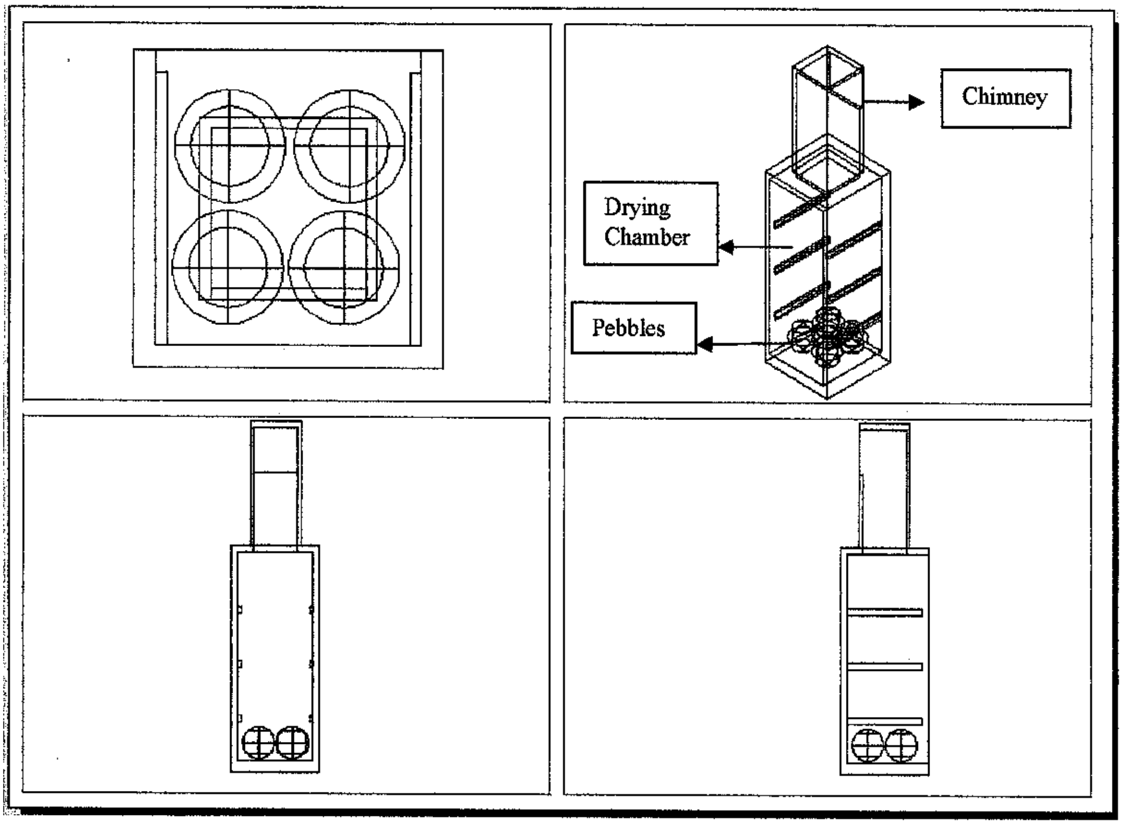


Figure 4.2: Drawing of the Main Body

The main body functions as a drying chamber. Hot air is supplied to the main body by solar air collector. An indirect supplied of hot air is from the solar air collector and there is also direct supply of hot air since the main body material is Perspex. The Perspex will collect the heat and by conduction, the heat transferred into the drying chamber. The direct heating is only occurs during daytime. All the part is joined by glue. The type of glue that can be used is chloroform or epoxy for Perspex. Epoxy is a better choice because it is quick, easy and has good bond strength to attach the Perspex. The chimney is directed to the back for safety purpose since the chilli produce hazardous gas if inhale in high volume. A packed of pebbles inside the drying chamber is to distribute the heat supplied by solar air collector evenly. The dimensions is show at the Appendix-C.

### 4.3.2 Trays

The 0.11m x 0.11m trays are being designed to support 0.5 kg fresh chilli per tray. This tray frames are made of Perspex. Then, the bottom of each tray is drilled with 0.005 m diameter hole to provide travel path for the hot air. The Perspex can be glued by epoxy as after they are cut into specified measurement. Perspex is used to ensure the cleanliness of the tray. If aluminium is used as the material of the tray, the corrosion might occur because the chilli is boiled first during the pre-treatment before the chilli is dried. Figure 4.3 shows the drawing of the tray.

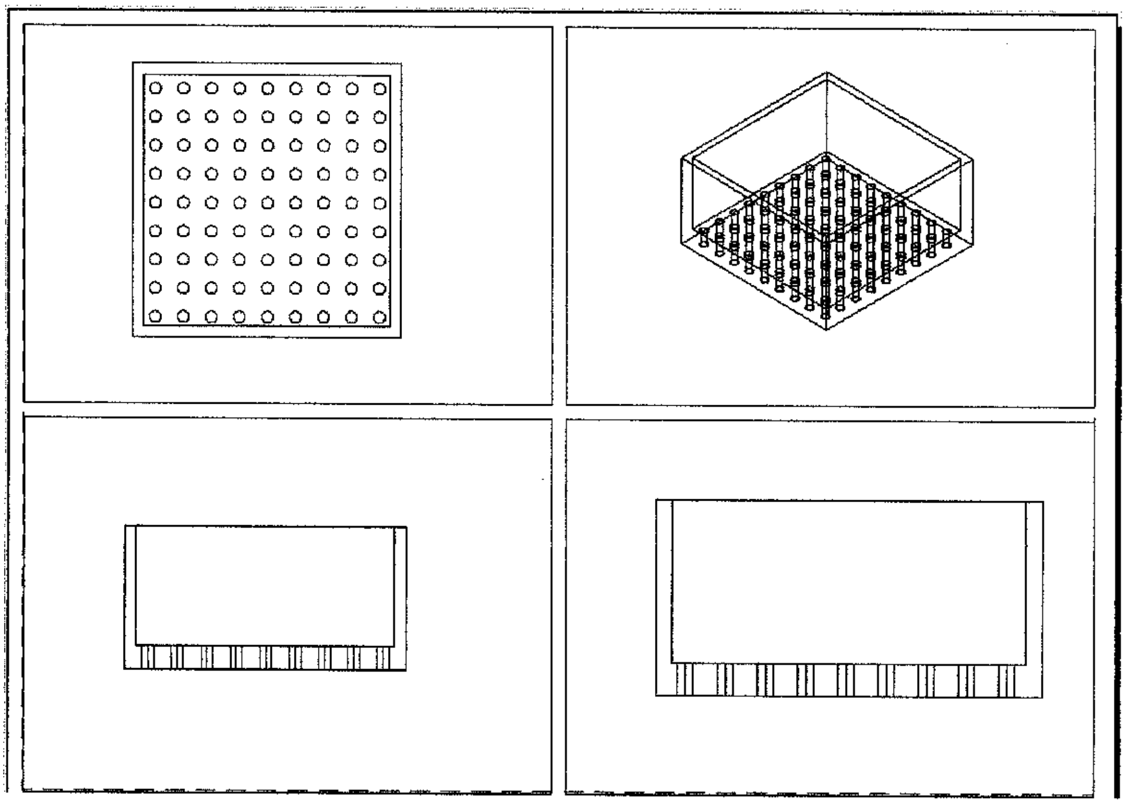


Figure 4.3: Drawing of the Tray

### 4.3.3 Packed Bed Thermal Storage and Biomass Burner Space

The packed bed thermal storage is made from Perspex. Then, an aluminium plate is put inside the packed bed thermal storage. The aluminium sheet function as a distributor of the heat collected from the biomass fuel. After that, the pebbles are put inside the container. The sizes of the pebbles are ranging from 4mm-64mm diameters. The pebbles need to be arranged compactly inside the 0.78m x 0.78m container. The pebbles used are the white river pebbles which are clean and have a smooth surface. The biomass burner space is used to burn the biomass fuel inside it. The heat from the biomass fuel will be transmitted and distributed equally by the aluminium sheet into the packed bed thermal storage. The burner space will be made from Perspex and on the inside of the burner, it will be covered by aluminium sheet. Figure 4.4 is the drawing of the rock bed thermal storage and also the biomass burner space.The complete dimension is showed at Appendix-A.

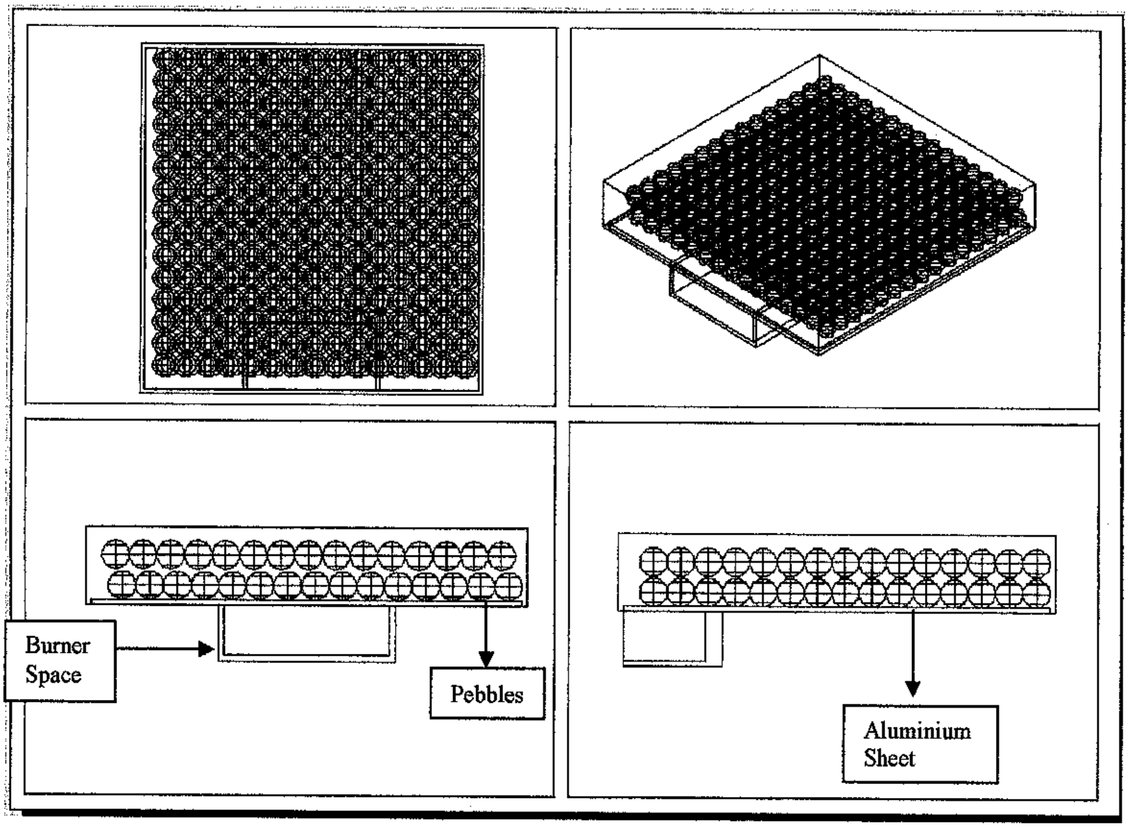


Figure 4.4: Drawing of Rock Bed Thermal Storage and Biomass Burner Space

### 4.3.4 Solar air collector

Solar air collector is made by using plywood and also wood as the main structure and it works as the insulations material. The glass thickness is 0.01 m. The mixture of metal chips from lathe machine will be put inside the solar air collector. It works as heater for the normal air. The normal air at ambient temperature will pass through the chips and absorb the heat and come out as hot air. The wood and plywood will be joined by nail but a seal is necessary to avoid the air from leaking out from the solar air collector.Further details on dimension is showed on Appendix-D.

Figure 4.5 shows the basic drawing of the solar air collector.

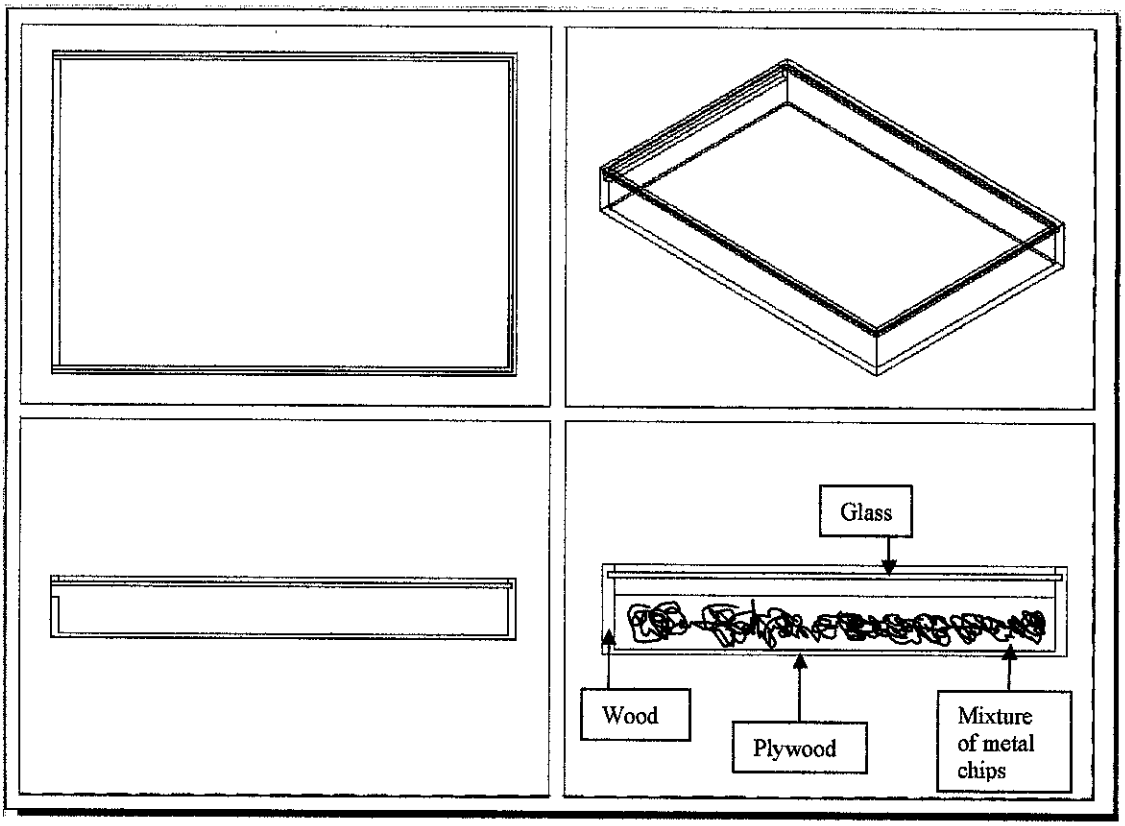


Figure 4.5: Drawing of the Solar Air Collector

## 4.4 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 solar dryer based on the estimation value.

Table 4.3: Bill of Material

| No | Types of Material | Estimated Quantity | Price | Estimated Cost |
|---|---|---|---|---|
| 1 | Plywood | 5 $m^2$ | RM 5 per $m^2$ | RM 25 |
| 2 | Wood | 18 m | RM 3.75 per m | RM 67.50 |
| 3 | Glass | 5 $m^2$ | RM 13 per $m^2$ | RM 45 |
| 4 | Pebbles | 180 kg<br>(9 bags) | RM 20 per bag | RM 180 |
| 5 | Perspex Sheet | 1 $m^2$ | RM 15.50 per $m^2$ | RM 15.50 |
| 6 | Perspex Plate | 2 $m^2$ | RM 18 per $m^2$ | RM 36 |
| 7 | Aluminium Sheet | 1 $m^2$ | RM 8 per $m^2$ | RM 8 |
| 8 | Aluminium Plate | 1 $m^2$ | RM 12 per $m^2$ | RM 12 |
| 9 | Nail (1") | | RM 5 | RM 5 |
| 10 | Epoxy Perspex | 4 tube | RM 5 per tube | RM 20 |
| | | | **Total Cost** | RM 414 |

# CHAPTER 5 CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

As conclusion, the innovation in drying technology is still low in Malaysia. The green drying technology in Malaysia is necessary and suits the climate. With a green drying technology, the problems and disadvantages faced by traditional drying method and conventional drying method can be overcome. Solar energy application especially in drying is a good alternative because the solar energy can be utilized freely, is renewable and is a type of sustainable energy. The solar dryer also increases the quality of the product.

The process of designing the solar dryer is important in order to reach an effective and economical solar dryer which can be used widely in Malaysia. More study and research in solar collector is important to increase the efficiency of collecting and transferring of the solar energy. The design process must meet the process constraint and requirement. With this in view, the project achieved its general objective in designing a solar dryer for the chilli in which meeting these design requirements; can dry up to 1.5 kg of chilli within a day with the help of biomass fuel to have a continuous operation. Based on the estimated bill of materials, the project is viable for further research since the aluminium and Perspex can be obtained from the lab. The prototype and also experiments are needed for further study this solar dryer.

## 5.2 Recommendation

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

### 5.2.1 Recommendation for Future Research

i. To build the prototype of the dryer and test the performance of the solar dryer. To determine the temperature inlet and outlet of the crop storage and the thermal storage, relative humidity, velocity inlet and outlet of the crop storage,biomass fuel used at night, total biomass fuel using only biomass to dry the chilli. These data can be measured by using hygrometer. With several experiments, the performance and reliability of the solar dryer can be measured.

ii. To be more focus on the solar air collector since it is the main part to collect the thermal energy from the sun and more research can be done on PVT collector on how to increase the efficiency. The energy department should focus on the collector more because it is the main part of the dryer and there are many applications that can get benefit from it such as solar chimney, power plant and also water heater.

iii. Simulation of the crop storage can be done for future research. This research can determine how the pebbles distribute the heat in the crop storage and show whether the heat is released evenly or not.

### 5.2.2 General Recommendation

i. The solar food dryer has a big potential to be commercialized since it is practical to be used in Malaysia. Furthermore, Malaysia lies on the equator which receives more sun rays. With the using of solar dryer, the food is produce in clean since the food is dried inside the container. This increase the quality of the product. In Malaysia, there are many foods that use drying method such as salt fish, cocoa, chilli, pepper and many more. Therefore, the solar food dryer is a good way to improve the existing drying method and even used green energy as the main source.

ii. The agricultural industry usually drying crops with traditional method. The government of Malaysia should focus and give support to improve the solar dryer technology and by that, it will enhance the production of agricultural product. This step will benefit all side including producers, consumer and also the economy of Malaysia. With using a green energy, Malaysia can save the environment and save it for future generations.

# REFERENCES

1. A.S. Mujumdar, *Handbook of industrial drying,* Second Edition, 1995,Taylor and Francais Group
2. Othman M.Y.H. and K. Sopian (2004). *Innovation in solar crop drying technologies.* In:World Renewable Energy Congress VIII, Denver, USA.Aug. 28 –Sept. 3, 2004.
3. Syarizatul Nadia binti Rosdi 2008, *Application of Solar Energy in Pepper Drying*, Undergraduate Thesis, Universiti Teknologi PETRONAS, Malaysia
4. F.K. Forson, M.A.A. Nazha, F.O.Akuffo, H. Rajakaruna,*Design of mixed-mode natural convection solar crop dryers: Application of principles and rules of thumb,* 2006, Kumasi Ghana
5. MARDI,*Report Cili,*2005 Malaysia
6. Gauhar A. Mastekbayeva, M. Augustus Leon and S.Kumar,1998 Performance Evaluation of a Solar Tunnel Dryer for Chilli ,Thailand
7. Christian Cristofari, Gilles Notton *, Jean Louis Canaletti,2009,*Thermal behavior of a copolymer PV/Th solar system in low flow rate conditions,* France
8. T.T. Chow ,2009,*A review on photovoltaic/thermal hybrid solar technology,*China
9. A.Samsudin, A.Mohd Taufik dan M.T. Othman, 1992,*Pengeringan Cili dengan Alat Pengering,* MARDI serdang, Kuala Lumpur, Malaysia
10. A. Madhlopa a,*,2006, G. Ngwalo b, *Solar dryer with thermal storage and biomass-backup heater,* Malawi Polytechnic, Malawi
11. Jaishree Prasad,V.K. Vijay,2005, *Experimental studies on drying of Zingiber officinale, Curcuma longa l. and Tinospora cordifolia in solar-biomass hybrid drier,* Indian Institute of Technology, New Delhi-110016, India
12. University of Lowell Photovoltaic Program (1992). Grain Dryer Project. pp. 2-18

13. ASHRAE, Design Manual Sec 3.7, Storage Subsystem Design (Air Collector) pp. 3-121

14. A. Fudholi *, K. Sopian, M.H. Ruslan, M.A. Alghoul, M.Y. Sulaiman, *Review of solar dryers for agricultural and marine products*,Solar Energy Research Institute, Universiti Kebangsaan Malaysia,Malaysia

15. Shigley, J. E. & Mischke, C. R., Mechanical Engineering Design, 8th edition in SI Units,
McGraw-Hill, New York, 2008.

Website:

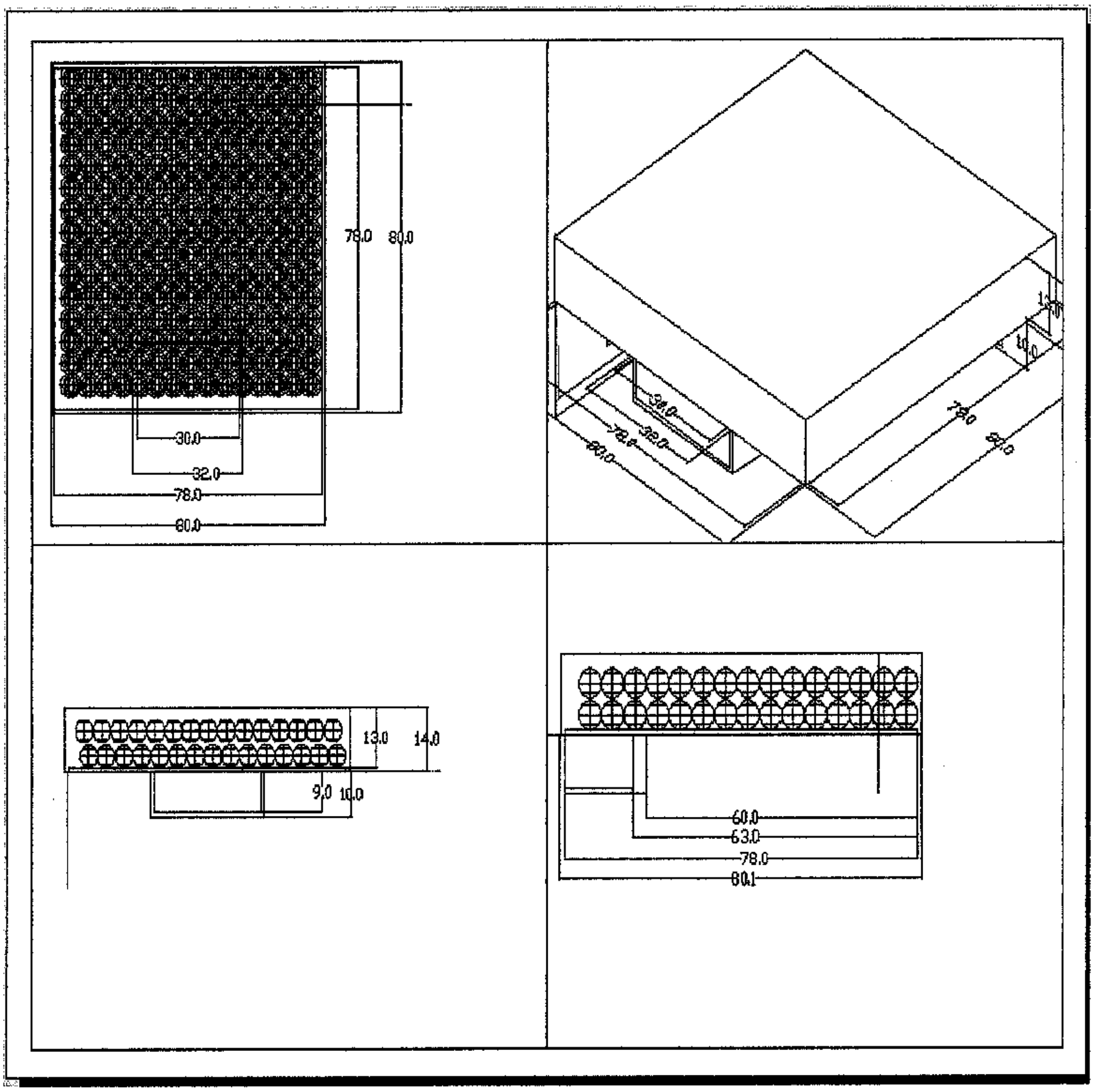
16. Renewable Energy Tecchnologies in Asia <http://igadrhep.energyprojects.net/Links/Profiles/SolarDryers/SolarDryers.htm>Accessed 9 March 2010

17. Energy for Sustainable Development <http://www.retsasia.ait.ac.th/photogallery_drying.htm> Accessed 9 March 2010

18. Relative Density/ Specific Gravity <http://www.alibaba.com/product-gs/261222556/Chili_oil.html>
Accessed 25 August 2010

19. Relative Humidity Data <http://www.met.gov.my/index.php?option=com_weathertimeseries&Itemid=907&purpose=humidity&lang=>
Accessed May 2010

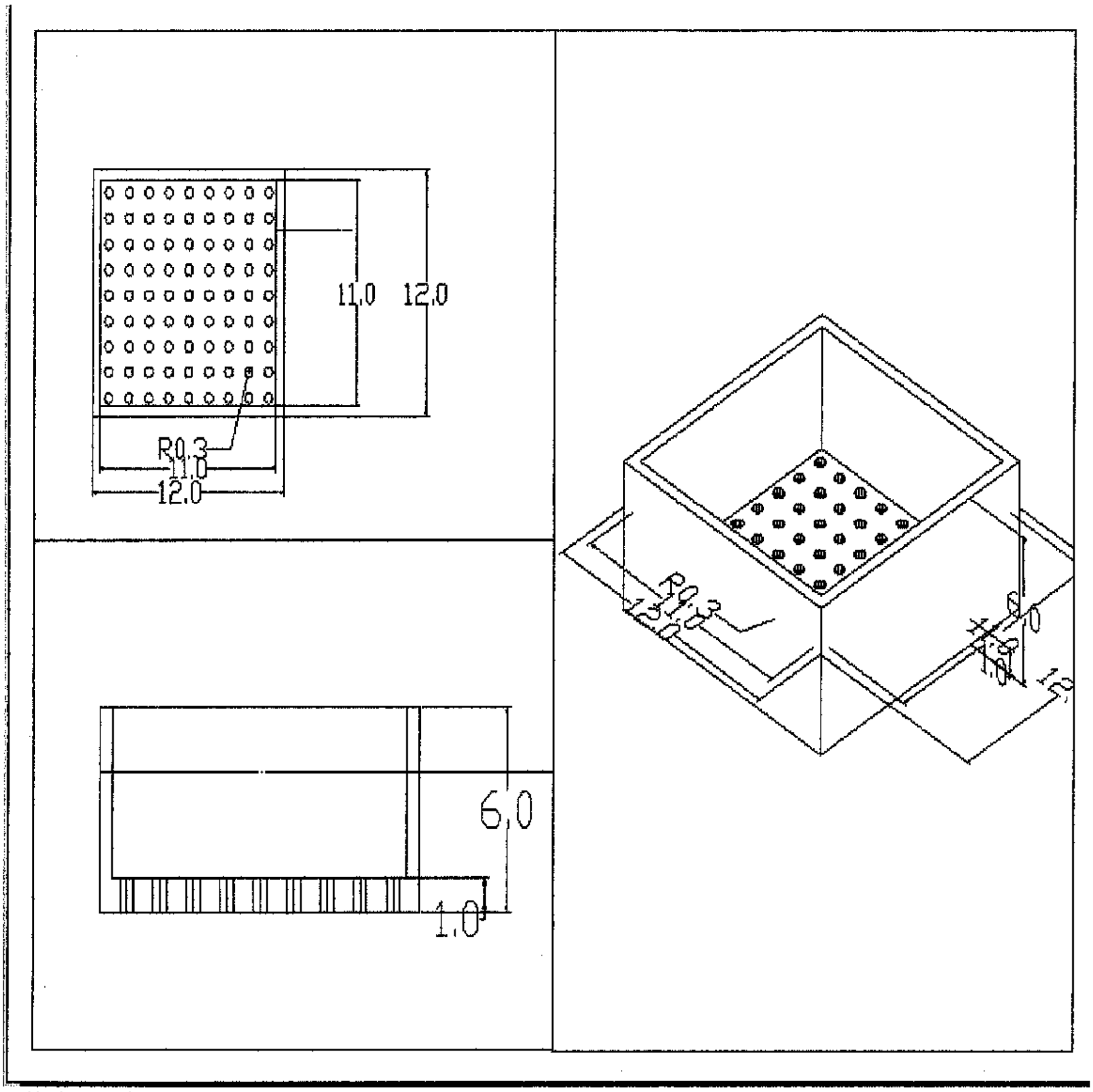
## APPENDIX- A



All the units are in centimeter, cm.

Appendix A: Detail Drawing of Bed Packed Thermal Storage

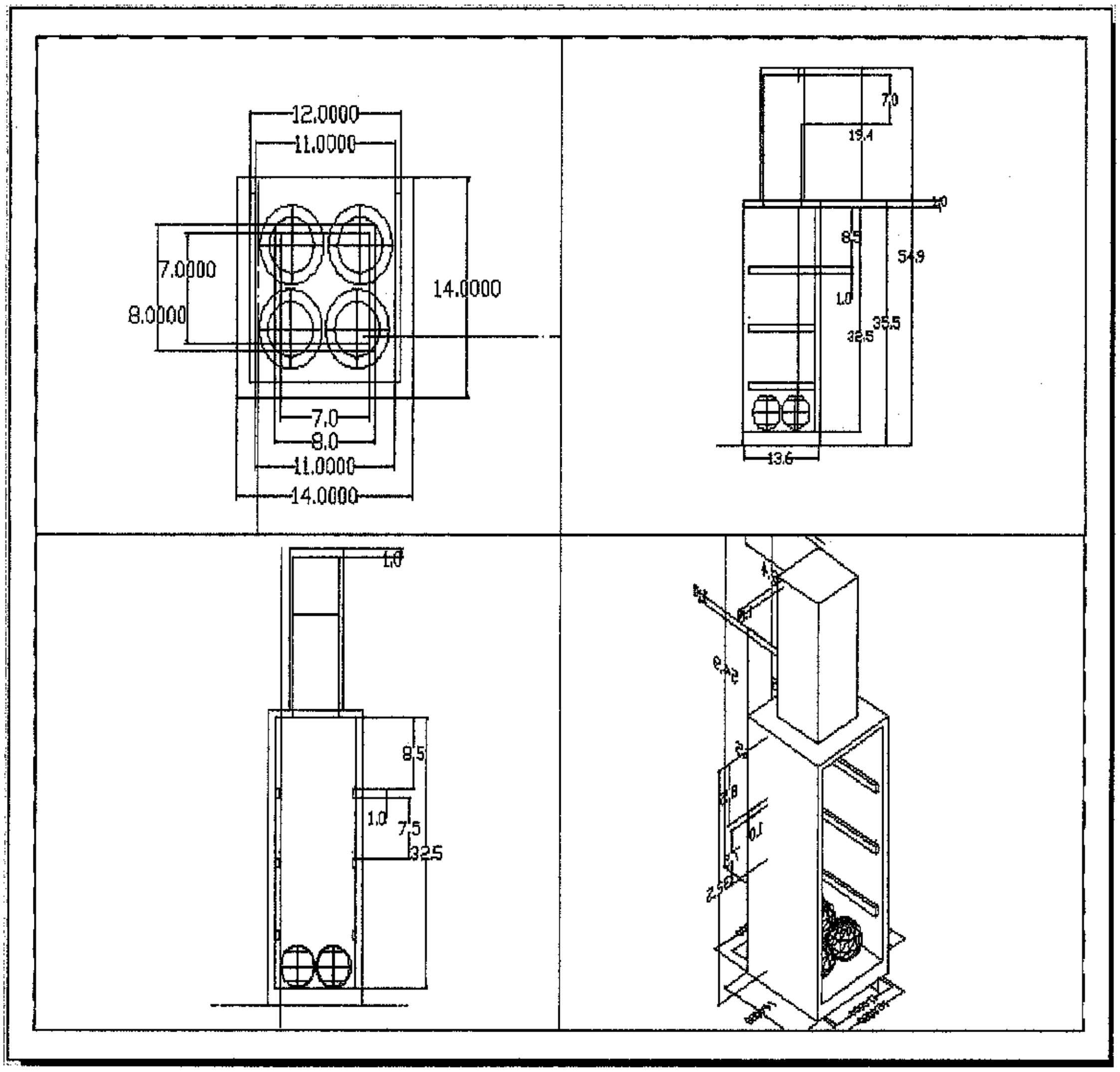
# APPENDIX- B



All the units are in centimeter, cm.

Appendix B: Detail Drawing of Tray

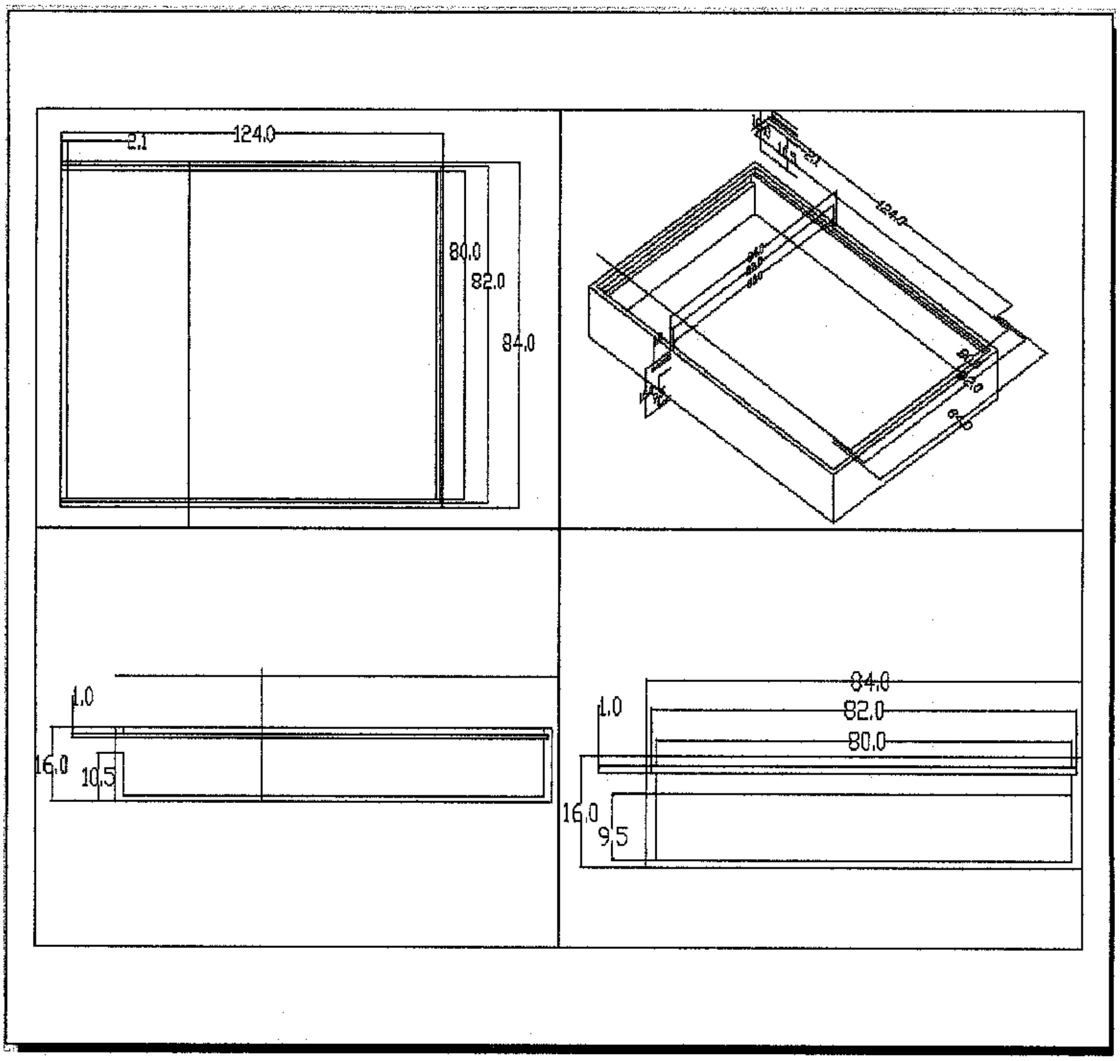
## APPENDIX- C



All the units are in centimeter, cm.

Appendix C: Detail Drawing of Drying Chamber and Chimney

## APPENDIX- D



All the units are in centimeter, cm.

Appendix D: Detail Drawing of Solar Air Thermal Collector

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# PSYCHROMETRIC CHART

## NORMAL TEMPERATURES

SI METRIC UNITS

Barometric Pressure 101.325 kPa

SEA LEVEL

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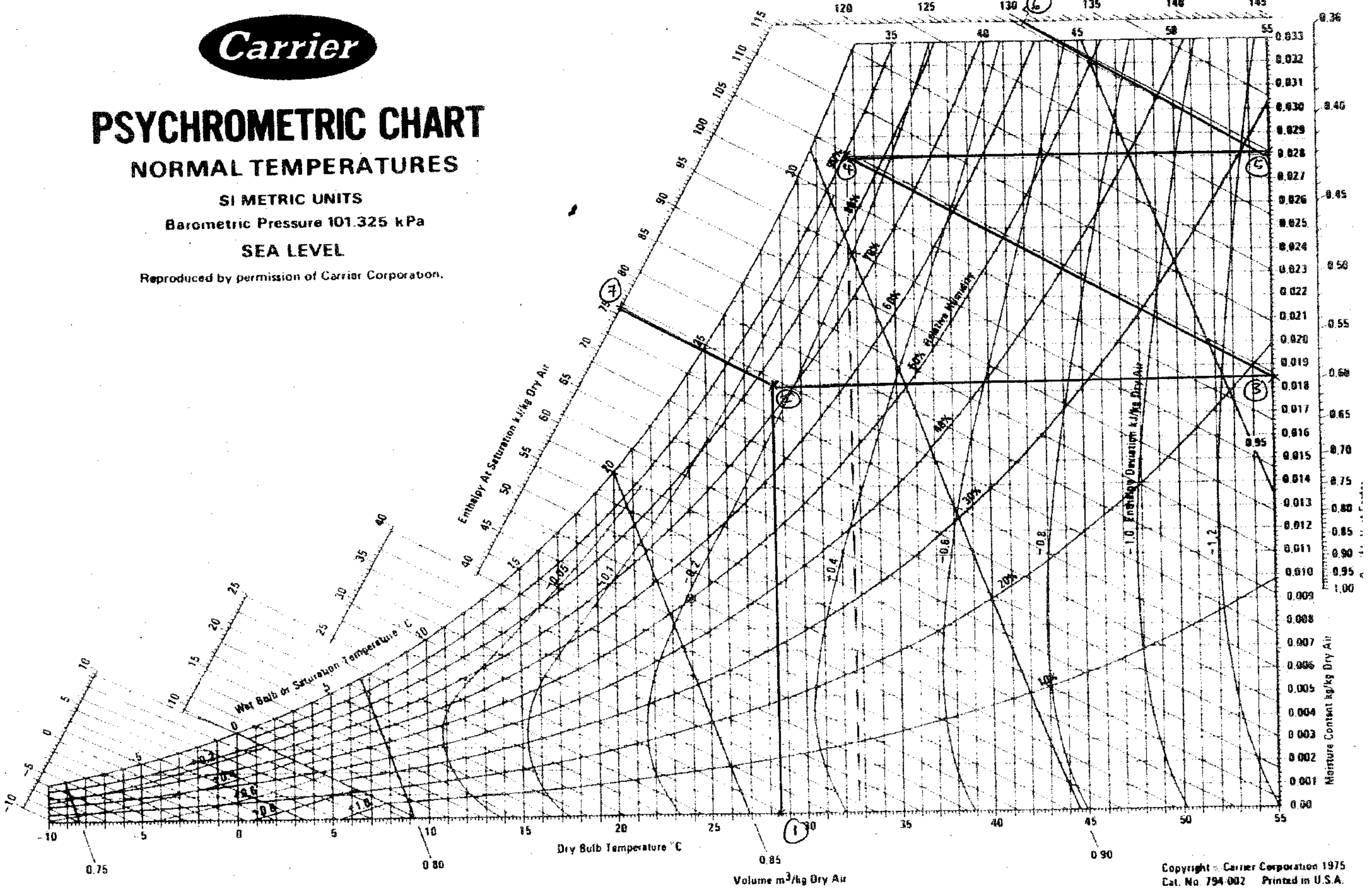

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# PSYCHROMETRIC CHART

## NORMAL TEMPERATURES

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