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Report on

The Solar Dryers and Solar Drying Technology and Design

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Project: TF/CMB/04/001

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EXECUTIVE SUMMARY

Traditional methods of drying agricultural and marine products such as open air drying where the products are exposed directly to the sun has many disadvantages. It includes degradation by wind-blown debris, rain, and insect infestation, human and animal interference. It will result in contamination of the products. Therefore, solar assisted drying system is an effective and viable alternative to the many current drying techniques. Consequently, harnessing of solar energy using the appropriate technology for the drying process could be achieved without much difficulty. There are many innovative ways of using solar assisted drying systems for agricultural produce and it depends of many factors including the drying temperature and duration of time to achieve the required quality of produce.

The duration of the first visit to Cambodia was from the 20^{th} – 26^{th} June 2011. It included visits to various drying facilities and well as interview with farmers and fisherman and several relevant stakeholders such as government officials, fabricators and academics. The outcome of the first visit is the identification of the commodity to be dried and the local capabilities of designing and fabricating solar dryers. The outcome of the second visit on the 22^{nd} – 25^{th} August 2011 were the completion of a capacity building workshop on solar drying technologies and designing solar drying systems for rural areas and the detail design and economic analysis of the solar assisted drying system.

The followings are the overall achievements from the two visits:

- Design the solar dryer in close consultation with technical officer of general department of energy.
- Identification of fish as the commodity to be dried since is abundant has higher market value
- Identify potential local fabricators of solar driers
- Assess technical capability of potential local fabricators
- Analysis of to be data collected
- A feasibility report with all necessary technical information including Drawings,, Bill of quantities (BOQ) and Technical specifications of the solar drier
- Training design, installation and fabrication of solar dryer
- Detail design the solar assisted drying system

- Identify potential local fabricators of solar assisted drying system components and assess technical capability of potential local fabricators
- Estimate Investment cost of the facilities and the payback period of the proposed design.

The solar assisted drying consists of a solar collector, ducting systems, fan, auxiliary heater, control system, and the drying chamber. Details on each components of the system have been developed and documented. The area of the solar collector is fixed at 17.5m^2. The solar collectors are of the double-pass type with fins attached to the lower pass of the solar collector. Electricity, LPG or even diesel can be used as auxiliary heaters. The fan can also be operated using electricity from the grid or electricity from photovoltaic panels. From the discussion with stakeholders, local UNIDO consultant, farmers and fisherman, the commodity chosen is fish. Other reason for choosing fish is the price, the popularity of the commodity and reliable supply of fish in the local market. The initial and final moisture contents are 78% and 10% respectively. For 100 kg of fresh fish, the drying time required is 14 hours. Conventional, open drying will require at least 5 days.

The finned air electric heater of 5 kW was used as auxiliary heating unit for supply heat in the lower solar radiation. The heater was controlled with ON/OFF controller and was set at 50^oC. The heater will be activated if the hot air temperature was lower than 50^o C and off if the hot air temperature was more than 50^oC.

It is therefore recommended that the solar assisted drying system without the PV system for fish to be installed in the Kampong Thom area. The unit including the control and data acquisition system can be developed and fabricated locally.

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CHAPTER 1

POTENTIAL OF SOLAR DRYING IN CAMBODIA

1.1 INTRODUCTION

Traditionally all the agricultural crops were dried in the sun. Traditional methods of drying such as open air drying where the product to be dried is exposed directly to the sun has many disadvantages such degradation by wind-blown debris, rain, insect infestation, human and animal interference which will result in contamination of the product. Therefore, solar assisted drying system is an effective and viable alternative to the many current drying techniques. Consequently, harnessing of solar energy using the appropriate technology for the drying process could be achieved without much difficulty. There are many innovative ways of using solar assisted drying systems for agricultural produce and it depends of many factors including the drying temperature and duration of time to achieve the required quality of produce.

Solar drying technology can be use for poverty alleviation by increasing the living standards of the rural population through provision of energy services for productive use and income generation. Hence, a suitable solar drying system can be design and fabricated as a pilot project. It is doing this by demonstrating through selected pilot projects in business model the potential and impact that tailor-made energy services based on renewable energies can make in improving the socio-economic livelihoods of rural communities.

This chapter will elaborate on the potential of solar drying in Cambodia for selected agricultural and marine products, present status of drying facilities, estimation of commodity production, present capabilities of designing solar dryers, and identification of potential local fabricators of solar driers.

1.2 PRESENT STATUS ON DRYING AND VISIT TO DRYING FACILITIES

The visit to some of the drying activities in rural Cambodia will be presented. This visit is to verify the work conducted by the local consultant, Mr Sok Bun Heng on the status of drying practices in selected provinces in Cambodia. The local consultant has conducted extensive studies earlier including the present drying practices, types and amount of commodities dried as follows:

1. Shrimp - Kampot and Siem Reap
2. Pepper – Kampong Cham and Kampot

3. Banana-Kampong Cham
4. Fish –Kampong Thom, Pursat and Siem Reap

The visit was conducted from 20th June till the 23rd June 2011. However, due to time constraint only the drying facilities for banana, shrimp, fish and pepper in Kampong Cham and Sieam Reap were visited. We covered a total of 800km of travelled to the sites. as well as interview famers and owners of the facilities. All of the drying facilities are operated by individual farmers. No cooperatives or famers/fisherman association operate the drying facilities and hence, all drying related activities were on individual basis. No solar dryers or solar assisted drying system were used in the drying processes.

Banana – Kampong Cham

Pepper – Kampong Cham

Fish – Siem Reap

Shrimp – Siem Reap

Figure 1.1 Potential commodity to be dried using solar dryers and the locations

1.3 ESTIMATION OF COMMODITY PRODUCTION

The quantity of the commodity namely shrimp (Kampot and Sieam Reap), pepper – Kampong Cham and Kampot, banana-Kampong Cham and fish –Kampong Thom, Pursat and Siem Reap that is available for drying has been studied. The exercise requires a lot of effort but is highly recommended. It require cooperation with governmental agencies and other related organizations to determine accurately as possible the type and quantity of agricultural or marine produce that potential could be dried. With these data, the operational period of the solar dryer and the operation modes (co-operative or community based) for harvesting the commodity can be determine. It is also important to indicate the availability of the electricity grid to the community since this will determine the type of solar dryers to be design later.

As shown in Figure 1.1, the present method of drying is mostly open drying of direct drying under the sun. However, this method has many disadvantages including degradation by wind-blown debris, rain, and insect infestation, human and animal interference which will result in contamination of the commodity.

The following information is required for the design of the solar dryers:

(a) How much of the farmers of fishermen crop or fish are dried?
(b) Any processing carried out after harvesting or catch before drying?
(c) What is the moisture content of the commodity before and after drying or weight of commodity before and after drying?
(d) What is the actual method use to dry the commodity?
(e) What is the cost involve in drying of the commodity?
(f) Any problem experience with these methods such as high capital cost, labor intensive, use of fossil fuel and poor product quality
(g) Any post drying processing operations carried out before sale or storage?
(h) Any form or means of storage of the dried commodity before further processing, sales or consumption?

1.3.1 SHRIMP

Quantity of Fresh Commodity Production

Shrimp in Kampot is caught by several individual fishermen from the sea with quantity of about 10-30 kg per each fisherman per day. The shrimp is sold to dry shrimp producer in Treuy Kosh village, Tunop viilage and Prek Krieng village. There are about 5-6 producers in each village. Each producer buy fresh shrimp from minimum of 50kg to maximum of 1,000kg per day to produce about 5-100kg of dry shrimp per day. Shrimp in Siem Reap province is caught by several individual fishermen from the Tonle Sap Great Lake with quantity of about 10-20 kg per each fisherman per day.

Table 1.1 Quantity of Fresh Commodity (Weekly Production – Shrimp)

Location: *Prek Kreng village, Prek Thnot commune, Teuk Chhou district, Kampot* Name of Famer/Fisherman : *Prek Sareun* Commodity*: Shrimp* Mode of Production: *Individua*	
Day in the week	Quantity of fresh commodity (kg)
Monday	20-100
Tuesday	20-100
Wednesday	20-100
Thursday	20-100
Friday	20-100
Saturday	20-100
Sunday	20-100

Table 1.2 Quantity of Fresh Commodity (Monthly Production - Shrimp)

Location: *Prek Kreng village, Prek Thnot commune, Teuk Chhou district, Kampot* Name of Famer/Fisherman : *Prek Sareun* Commodity*: Shrimp* Mode of Production: *Individual*	
Month	Quantity of fresh commodity (kg)
January	600-3,000
February	600-3,000
March	600-3,000
April	600-3,000
May	600-3,000
June	3,000-5,000
July	3,000-5,000
August	3,000-5,000
September	3,000-5,000
October	3,000-5,000
November	3,000-5,000
December	3,000-5,000

The shrimp is sold to dry shrimp producer in Tachrognieng village, Kampong Khlaing commune, Sothnikom district with average price of 3,000 -8,000 Riels or about US$0.75-US$ 2 per kilogram. There are about 3-4 producers in this village. Each producer buy fresh shrimp from minimum of 200kg to maximum of 1,000kg per day to produce about 20-100kg of dry shrimp per day and sell to whole sellers with average price of 30, 000 to 65,000 Riels or about US$7.5 to US$16 per kilogram.

Present Method of Drying

There are three steps for making dried shrimp. Fresh shrimp was boiled before drying and/or smoking. If there is sun light then the producer will dry their boiled shrimp under the sun light first and if it is not dry enough they will have to use fire to dry the boiled shrimp.

The producers in Kampot use both methods for drying. Drying under sun shine and smoking process. After boiling the boiled shrimp was dried under sun light, if there is sun shine, and if no sun shine then they just dehydrate by smoking process. It takes only one day for drying the fresh shrimp and spend about US$5 for charcoal and electricity and about USD10 for labor.

The producers in Siem Reap use only single method-drying under sun shine. If there is no sun shine, then they just spread the boiled shrimp on the flattery material and waiting for sun shine to dry. It may take 1-3 day for drying boiled shrimp depending on availability of sun shine and spend about US$10 per day for labor.

Table 1.3 Present Status and Method of Drying - Shrimp

Produce	Present Drying System	Energy Source	Weight (kg)		Drying Time (hrs)
			Before Drying	After Drying	
Shrimp	Direct under sun	sun	7	1	10-15
Shrimp	smoking	charcoal	7	1	3

Post drying process

Another activity for producing dried shrimp is to remove the shrimp skin. After drying they also have to remove the skin of the shrimp before selling to whole sellers.

Product quality

According to producers, there seems not a serious problem in term of quality of the product. The dried shrimp product is considered good enough in term of quality.

Market of the dried commodity

There is good market for dried shrimp. The producers don't have to store dried shrimp for long as there are lot of whole sellers waiting to buy their dried shrimp.

In Kampot, the dried shrimp are sold to the whole sellers in Kampot town every day with price of 35, 000 to 65,000 Riels or about US$7.5 to US$16 per kilogram.

In Siem Reap, the dried shrimp are sold to whole seller in Siem Reap town every 2-3 days with average price of 30, 000 to 65,000 Riels or about US$7.5 to US$16 per kilogram.

1.3.2 PEPPER

Quantity of Fresh Commodity Production

Two main provinces that grow pepper are in Kampong Trach district in Kampot province and Memot district in Kampong Cham province. Pepper is grow by individual family with the minimum quantity of few hundreds to maximum of few thousands clumps per family. Average quantity of fresh pepper picked by each family varied from minimum of 10 to maximum of 100 kg per time, depending on size of the planting area of the family and kind of dried pepper to be produced.

Table 1.4 Quantity of Fresh Commodity (Weekly Production – Pepper)

Location: Kampong Trach district, Kampot province Name of Famer: Ngoun Lay Commodity: Red and white pepper Mode of Production: Individual	
Day in the week	Quantity of fresh commodity (kg)
Monday	10-30
Tuesday	No picking
Wednesday	No picking
Thursday	No picking
Friday	No picking
Saturday	10-30
Sunday	No picking

There are three kind of dried pepper to be produced, black, white and red. if they want to produce black pepper they will pick the fresh pepper only when it become yellow, but if they want to produce red pepper then they have to wait until it become red, and if they want to produce white pepper then they have to remove the skin of the dried red pepper. Hence, the frequency of picking pepper is also varied from family and depending on kind of dried pepper they want to produce. For black pepper, the picking interval is 15-20 days. For white and red pepper is 4-5 days. Farmers start to pick pepper from early March to end of May.

Table 1.5 Quantity of Fresh Commodity (Monthly Production -Pepper)

Location: Kampong Trach district, Kampot province Name of Famer: Ngoun Lay Commodity: Red and white pepper Mode of Production: Individual	
Month	Quantity of fresh commodity (kg)
March	20-100
April	20-100
May	20-100
June	20-100

Present Drying Practice

The same method of drying is applied for drying pepper in both places is to dry under sun light. The fresh pepper after picking were spread on flattery material and dry directly under sun light.

Table 1.6 Present Status and Method of Drying - Pepper

Produce	Present Drying System	Energy Source	Weight (kg)		Drying Time (hrs)
			Before Drying	After Drying	
Pepper	Direct under sun	sun	100	35	20-40

Post drying process

Another activity after drying is sprinkling to take out unnecessary debris. The dried pepper then was put in the bag and wait for selling to whole seller or to the pepper association.

Product quality

There is not a big problem for dried pepper. The dried pepper is considered as good quality when it was dried under sun light. If there is not enough sun light the farmer just spread it and waiting for sun light to dry it again. If there is not enough sun light for drying the fresh pepper then only color its is not good, but it can be recovered when it was dried again.

Market of the dry commodity

The dried pepper was sold to the association or to middleman with price of about US$5 per kilogram. In both provinces there is an association for promotion of market. Most famers sell their dried pepper to association as they get better price than selling to middleman.

1.3.3 BANANA

Quantity of Fresh Commodity Production

It is well know in Cambodia that banana is grown a lot in Chamkarleur district of Kampong Cham province with each family own up to 10 hectares of banana plantation.

However, according to the farmers in that area, there is a change recently for some farmers to turn their land from banana to rubber plantation as the price of rubber gone up.

Banana is harvested by each family every 15-20 days with quantity of about 1,000 hands of banana (about 500kg of unpeeled banana or approximately about 350kg of peeled banana) and transport by truck about 5 km to their home for selling to middleman as fresh banana with average price of 1000 riel (about US$0.25) per hand of banana. Only few families in this area produce dried banana and not all the fresh banana that they harvested, but only some portions of it.

The banana harvested from plantation need to keep for few days until it become ripe then they have to peel the skin of the banana before drying.

Present Drying Practice

For family who are producing dried banana their just dry directly under sun light. There are 4-5 families in the village who produce dried banana with quantity of about 50-100kg per time. They produce dried banana only when they harvest and only during month of December to May while there is no rain and no flies.

Table 1.7 Present Status and Method of Drying - Banana

Produce	Present Drying System	Energy Source	Weight (kg)		Drying Time (hrs)
			Before Drying	After Drying	
(without skin)	Direct under sun	sun	100	25	40-50

Market of the dry commodity

The dried banana was sold to the middleman at the producer house with average price of about US$0.75-1 per kilogram. There are few middlemen in the area waiting for buying the dried banana and transport to Phnom Penh or other province to sell to whole sellers.

1.3.4 FISH

Quantity of Fresh Commodity Production

Three well known places for making dried fish are Stuong district in Kampong Thom province, Krokor district in Pursat and Dam Dek commune of Sothnikom district in Siem Reap province.Fresh fish in those three areas is caught from natural water body like river or lake or from raising place.There are more than 10 dried fish producers in each area. They buy fresh fish from fishermen or from fish raisers with quantity of about 100-200kg per time to produce dried for selling to whole sellers in local market or to travelers. There is no fix interval for making dried fish, but usually about 5-7 days depending on selling rate of their dried fish stock. Fresh fish was cut open and putting salt and some other ingredients before drying.

Present Drying Practice

The fish was dried on the rack with size of about 1.5-2m width and 3-4m long. and take about 1-3 days for drying before selling depending on availability of sun shine.

Market of the dried commodity

Dried fish was produced mainly for selling to travelers on the road with average price of 30,000-40,000 Riels (about US$7-10) perkilogram. In general, they can sell up to 100kg per week.

1.4 PRESENT CAPABILITIES OF DESIGNING SOLAR DRYING SYSTEM

Three institutions namely the Royal University of Agricultural, Institute of Technology Cambodia and National Technical Training Institute have experience working with solar dryers.

The solar dryer is a relatively simple concept. The basic principles employed in a solar dryer are firstly converting light to heat: Any black on the inside of a solar dryer will improve the effectiveness of turning light into heat. Next, trapping heat and isolating the air inside the dryer from the air outside the dryer makes an important difference. Using a clear solid, like a plastic bag or a glass cover, will allow light to enter, but once the light is absorbed and converted to heat, a plastic bag or glass cover will trap the heat inside. This makes it possible to reach similar temperatures on cold and windy days as on hot days. Finally moving the heated air to the food to be dried. Both the natural convection dryer and the forced convection dryer use the convection of the heated air to move the heat to the food.

There are a variety of solar dryer designs. Principally, solar dryers can be categorized into three groups: a) natural convection dryers, which are solar dryers that use the natural vertical convection that occurs when air is heated and b) forced convection dryers, in which the convection is forced over the food through the use of a fan and c) tunnel dryers.

Both the solar dryers at the Royal University of Agricultural and the Institute of Technology Cambodia are of the natural convection type. The one in the National Technical Training Institute was of the force convection type but has been dismantled.

Mr Ek Sopheap, Vice Dean, Faculty of Agro- Industry, Royal University of Agricultural. Phnom Penh

The natural convection solar dryer

The cabinet dryer

Figure 1.2 Faculty of Agro- Industry Royal University of Agricultural. Phnom Penh

Figure 1.3 Testing of food quality

Mr Ek Sopheap, Vice Dean, Faculty of Agro- Industry, Royal University of Agricultural. Phnom Penh has the capability of designing natural convection solar dryers and also a laboratory for testing food quality.

Figure 1.4 Mr Phol Norith, Deputy Director in charge of Planning and Project Development, Institute of Technology Cambodia, Phnom Penh

Figure 1.5 The experimental natural convective solar dryer located on roof top

The institute of technology Cambodia has two departments namely (a) the Energy and Electrical Engineering and (b) the Industrial and Mechanical Engineering. Both have experience in planning renewable energy projects, automation and control systems and mechanical workshops. The institute also offers the use of AutoCAD computer software for detailed drawings of the solar collector and systems.

Figure 1.6 Mr Toch Sovanna, Department of Energy Techniques, Ministry of Industry Mines and Energy (MIME), Phnom Penh and showing commitment by MIME for the solar dryer project.

Figure 1.7 Mr Chhar Khemarin, Deputy Director of Administration, National Technical Training Institute (NTTI), Phnom Penh, showing the site where the dismantled forced convective solar dryer was installed.

1.5 PRESENT CAPABILITIES OF LOCAL FABRICATORS

It is very important that all of the components of the solar dryers be fabricated locally. This will save cost and boost the economic and social activities of the local industries. In addition, a control system is needed for continous operation of the new solar dryers. The Centre Kwam Ngoy located at Olympic Quarter in Phnom Penh is very suitable for fabrication of such dryers. The centre is also capable of fabricating gasifiers and has mechanical workshop located outside Phnom Penh.

Discussing the concept of solar assisted drying system to Im-Saroeun, President du CKN, Centre Kram Ngoy, Phnom Penh.

Automatic control systems CKN

Simple Robotic System interface CKN

Figure 1.8 Fabrication facilities at the Centre Kwam Ngoy located at Olympic Quarter in Phnom Penh

1.6 CONCLUSIONS

(a) Based on the visit to the drying facilities sites, it is proposed that a forced convective solar assisted drying system be fabricated for fish since it has reliable output and highly priced. Although shrimps as the quantity and highly priced but many other processes involved during the drying processes.

(b) The present solar drying capabilities among the local institution are simple convective solar drying system. A forced convective solar assisted drying system is recommended. The life cycle cost of a forced convective solar assisted drying system is sometimes more favorable compared to the simple convective solar dryers. This has to do with the high output and resulting in shorter payback period.

(c) Potential for engaging local fabricators is huge and this would enable cost reduction as well enhancing the local economy. Local fabrication include, solar collector, auxiliary heating system, ducting, drying chamber, and control systems.

(d) A high performance solar assisted drying system with drying capabilities of 150 – 200 kg with solar collector areas of about $20m^2$ should be constructed as a showcase.

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CHAPTER 2

CONSULTATION WORKSHOP ON SOLAR DRYING TECHNOLOGY AND DESIGNING OF SOLAR DRYERS

2.1 INTRODUCTION

Solar assisted drying system is one of the most attractive and promising applications of solar energy systems. Traditionally all the agricultural crops were dried in the sun. Drying is one of an important post handling process of agricultural produce. It can extend shelf life of the harvested products, improve quality, improve the bargaining position of the farmer to maintain relatively constant price of his products and reduces post harvest losses and lower transportation costs since most of the water are taken out from the product during the drying process.

Direct sun drying requires large open space area, and very much dependent on the availability of sunshine, susceptible to contamination with foreign materials such as dusts, litters and are exposed to birds, insect and rodents. Hence, most agricultural produce that is intended to be stored must be dried first. Otherwise insects and fungi, which thrive in moist conditions, render them unusable.

The technical directions in the development of solar assisted drying systems system for agricultural produce are compact collector design, high efficiency, integrated storage, and long-life drying system Hence, a capacity building workshop on solar drying technologies and designing solar drying systems for rural areas has been organised by UNIDO in collaboration with Department of Energy Techniques, Ministry of Industry Mines and Energy (MIME) on the 22 till the 25^{th} August 2011 in Phnom Penh.

2.2 OBJECTIVES OF THE WORKSHOP

(a) to promote the use of environment friendly solar drying technologies for developing Asian countries

(b) to present the state of the art review on solar drying technologies for agricultural and marine products
(c) to present case studies and design tools for solar system sizing and costing
(d) to introduce economics analysis for life cycle cost of solar drying systems
(e) to conduct detail design of the solar drying system
(f) to conduct detail bill of materials for the solar drying system
(g) to prepare detail design for local fabricators.

2.3 PARTICIPATION OF THE WORKSHOP

Ten (10) participants attended the workshop from the following organizations: Department of Energy Techniques, Ministry of Industry Mines and Energy (MIME), Institute of Technology Cambodia, Royal University of Agricultural, National Technical Training Institute (NTTI), and Centre Kram Ngoy.

2.4 WORKSHOP PROGRAMME

Table 2.1 The Workshop Programme

August 22 2011 (Monday) Venue: Department of Energy Techniques, Ministry of Industry, Mines and Energy	
8.00 a.m.	Registration and Arrival of Participants
8.30 a.m.	Self introduction, Training Objective and Programme
9.00 a.m.	Photo session and Tea Break <u>FACILITIES:</u> A small classroom which can accommodate 10 participants LCD projectors Whiteboard markers Flip Charts
9.30 a.m.	Lecture 1: Overview of Renewable Energy Technologies
11:00 a.m.	Lecture 2: State of the Art Solar Drying Systems
12.00 p.m.	Lunch Break
14.00 p.m.	Lecture 3: Evaluation of Solar Drying Potential and Pre-drying Processing Operations
15.30 p.m.	Lecture 4: Solar Radiation and the Mechanism of Drying
16.30 p.m.	End of Day 1

August 23 (Tuesday) **Venue: Department of Energy Techniques, Ministry of Industry, Mines and Energy**	
8.30 a.m.	Arrival of Participants FACILITIES: A small classroom which can accommodate 10 participants LCD projectors Whiteboard markers Flip Charts
9.00 a.m.	Lecture 5: Solar Dryer Classifications
10.00 a.m.	Tea Break
10.30 a.m.	Lecture 6: Solar Collector Design and Dryer Selection and Design
12.00 p.m.	Lunch Break
14.00 p.m.	Lecture 7: Experimental Methodology From Theory into Practice
15.30 p.m.	Lecture 8:Life Cycle Cost Analysis
16.00 p.m.	End of Day 2
August 24 (Wednesday) **Venue: Department of Energy Techniques, Ministry of Industry, Mines and Energy**	
8.30 a.m.	Arrival of Participants DETAILED DESIGN PROCESSES FACILITIES: A small classroom which can accommodate 10 participants LCD projectors Whiteboard markers Flip Charts AutoCAD software and Computers
9.00 a.m.	Detailed Design 1 – Solar Collectors
10.00 a.m.	Tea Break
10.30 a.m.	Detailed Design 2 – Solar Collector Array
12.00 p.m.	Lunch Break
14.00 p.m.	Detailed Design 3 – Fan Sizing and Ducting System
15.30 p.m.	Detailed Design 4 – Drying Chamber Design
1600 p.m.	End of Day 3

August 25 (Thursday) Venue: Department of Energy Techniques, Ministry of Industry, Mines and Energy	
9.00 a.m.	Arrival of Participants DETAILED DESIGN PROCESSES FACILITIES: A small classroom which can accommodate 10 participants LCD projectors Whiteboard markers Flip Charts AutoCAD software and Computers
9.30 a.m.	Detailed Design 5 – Auxiliary heater and Control System
10.30 a.m.	Tea Break
11.00 a.m.	Detailed Design 6 – Costing of Systems
12.00 p.m.	Lunch Break
15.00 p.m.	Detailed Design 6 – Final Design Completed
16.00 p.m.	End of Workshop

Figure 2.1 the venue of the workshop - Department of Energy Techniques, Ministry of Industry Mines and Energy (MIME)

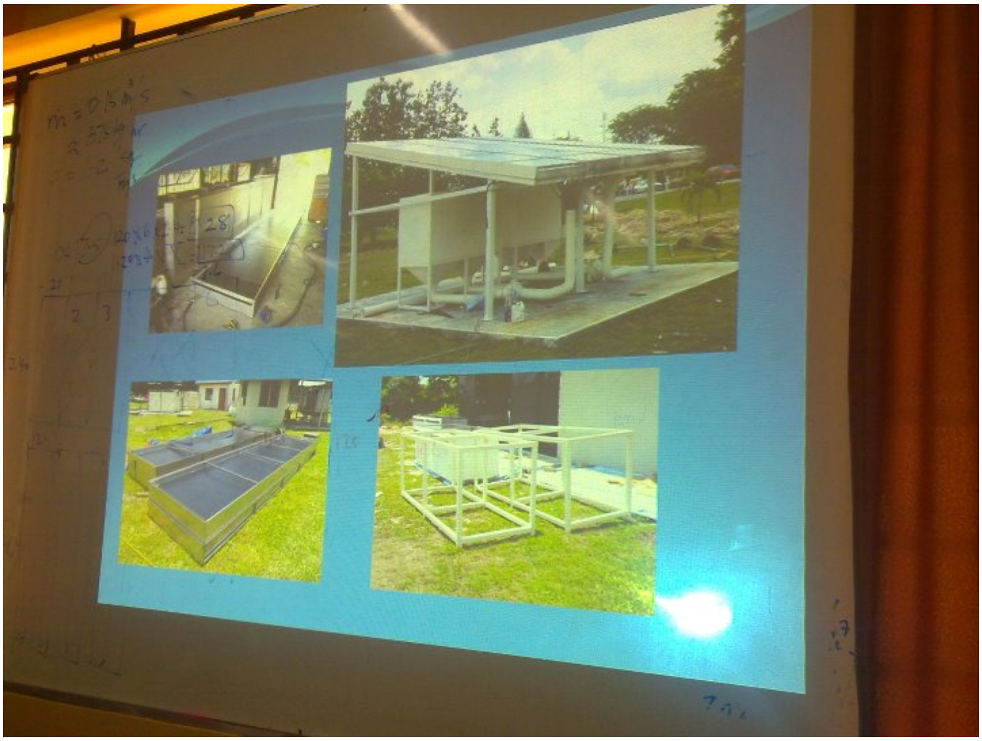

Figure 2.2 Presentation on overview on existing solar drying technologies

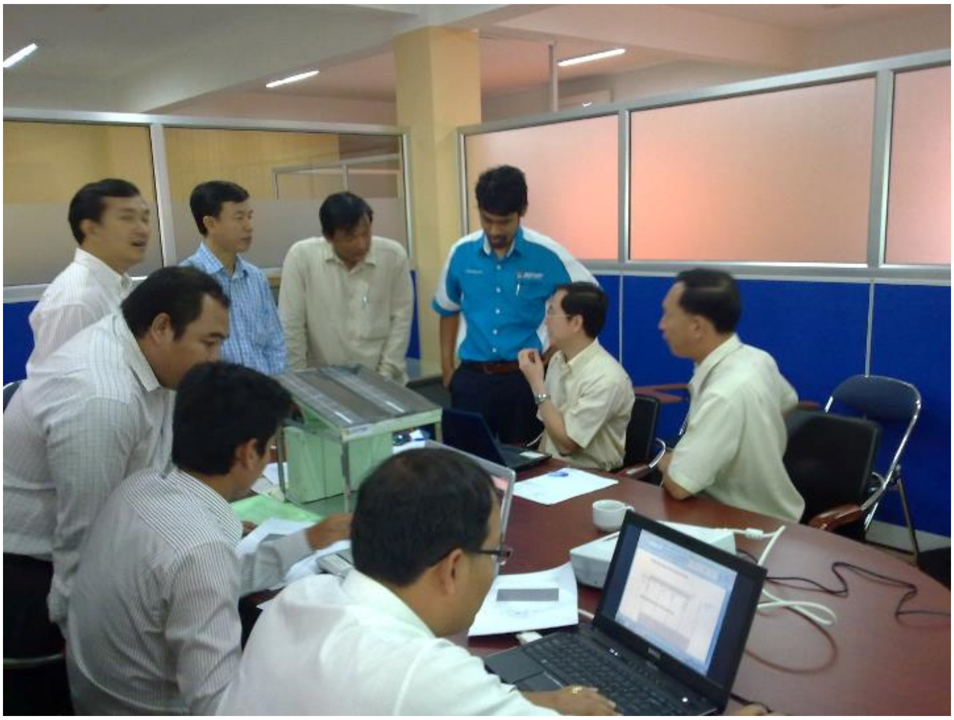

Figure 2.3 Designing details of solar dryers using AutoCAD


Figure 2.4 Group Discussion on designing details of solar dryers

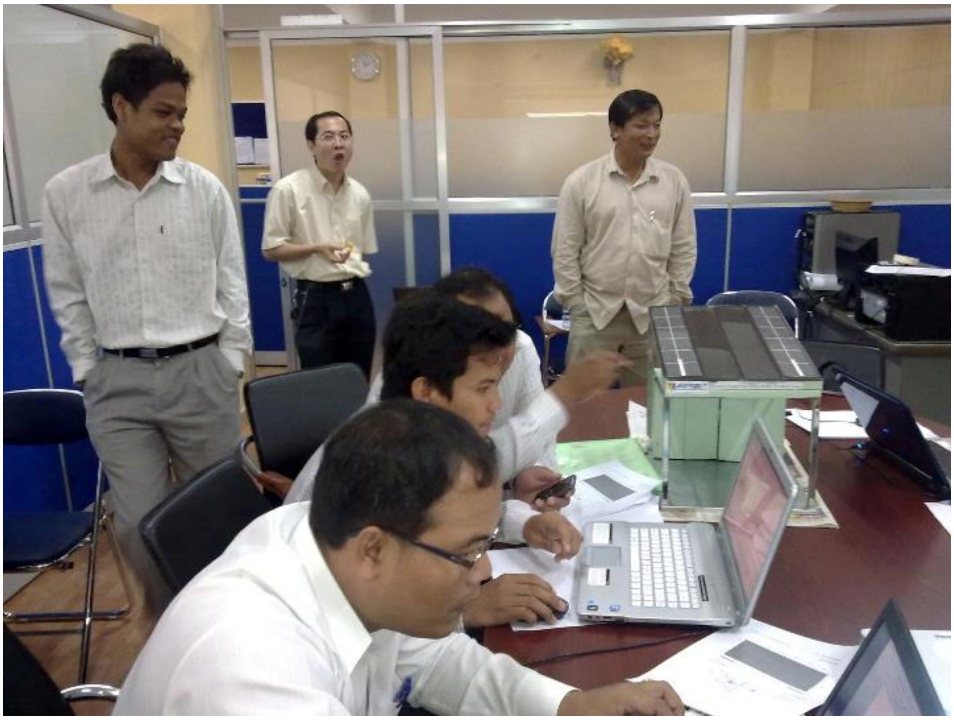
Figure 2.5 Designing details of solar dryers

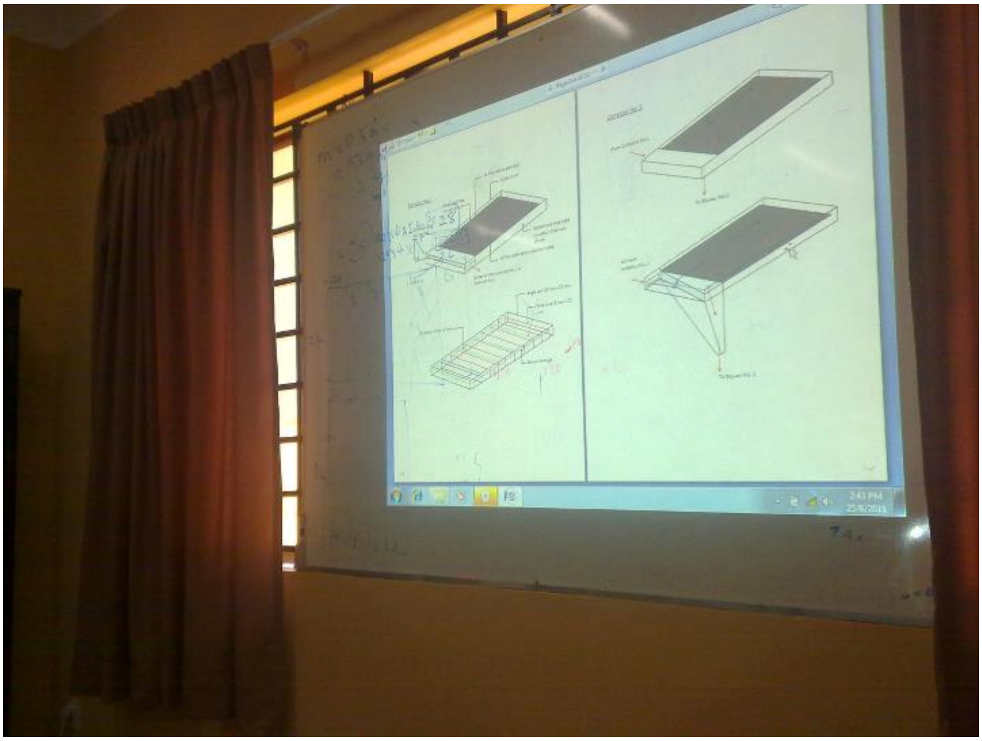

Figure 2.6 Presentation on designing details of solar collectors

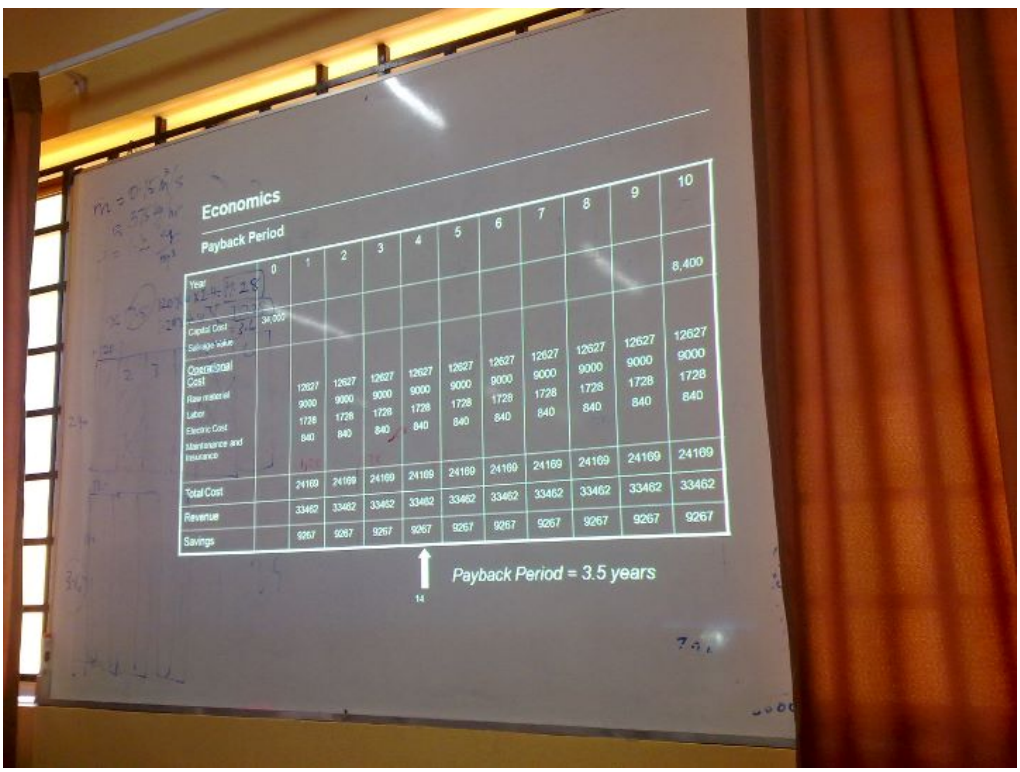

Figure 2.7 Presentation on Economic Analysis

2.5 CONCLUSIONS

The followings are the outcome of the workshop:

1. Presentation of the state of the art review on solar drying technologies for agricultural and marine products
2. Presentation of case studies and design tools for solar system sizing and costing
3. Economics analysis for the life cycle cost of solar drying systems
4. Detail design of the solar drying system (solar collector, collector, array, ducting system and drying chamber)
5. Details bill of materials for the solar drying system
6. Detail design specifications for local fabricators
7. A course evaluation was conducted by UNIDO Cambodia. Some have given favourable remarks and some has indicated that the workshop should have details on the mathematical models.

CHAPTER 3

DESIGN PARAMETERS FOR THE SOLAR ASSISTED DRYING SYSTEMS

3.1 INTRODUCTION

Five provinces in Cambodia, namely Pursat, Kampot, Kampong Cham, Kampong Thom and Siem Reap were selected for the location of the solar dryers. The commodities to be dried using solar dryer and the locations are as follows:

1. Shrimp - Kampot and Sieam Reap
2. Pepper – Kampong Cham and Kampot
3. Banana-Kampong Cham
4. Fish –Kampong Thom, Pursat and Siem Reap

The parameters are (a) what commodity to be dried (b) capacity of commodity to be dried (kg) (c) solar collector area (m^2) (d) total drying time.

3.2 METHODOLOGY

For preliminary analysis and development of the design concept of the solar dryers the following procedures has been adopted (a) Determination of the moisture remove during drying process for various commodities – this will indicate the drying time needed. (b) Determination of the concept design of the solar assisted drying system. At this moment it is better to design one solar drying system to be used in all the villages. The different will be on the availability of electricity from the grid or diesel as backup power.

The psychrometric chart has been used to calculate amount of moisture to be removed during the drying process. The chart represents the state of a given atmosphere by a point which gives the dry-bulb, wet-bulb, relative humidity, specific volume and saturation temperature of the atmosphere. The chart as well as the psychrometric processes such as heating, cooling, dehumidification etc can be seen in APPENDIX A.

The solar assisted drying consists of a solar collector, ducting systems, fan, auxiliary heater, control system, and the drying chamber as shown in Figure 1. The area of the solar collector is fixed at 17.5m^2. Electricity, LPG or even diesel can be used as auxiliary heaters. The fan can be operated using electricity from the grid or electricity from photovoltaic panels.

3.3 THE BASIC DESIGN

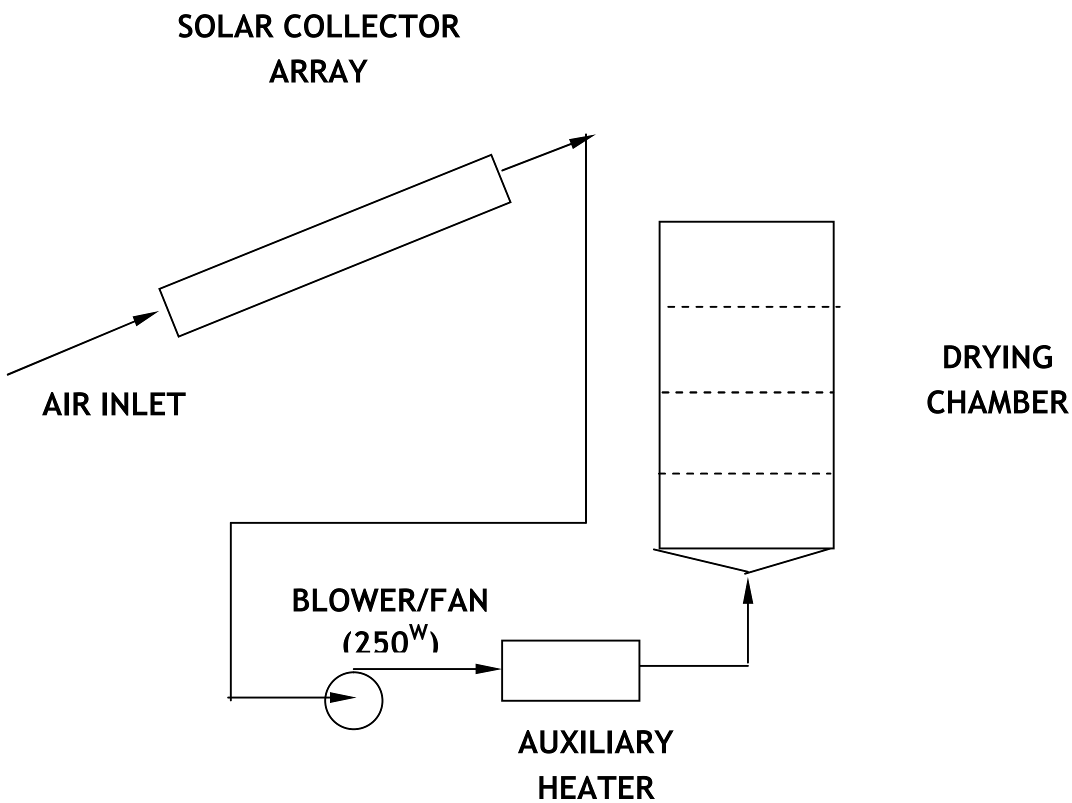

Figure 3.1 The basic design of the solar assisted drying system

The basic components of a solar assisted drying system are solar collector, blower unit, auxiliary heater and the drying chamber. Air will be heated in the solar collector and will be directed to the drying chamber by the blower. An optional auxiliary heater is used when the temperature of the drying chamber falls below a specific temperature. This will ensure continous operation drying of the system.

ASSUMPTIONS:

The wet bulb temperature of inlet air to the solar collector – Twb_{in} = 24 ^{o}C

The dry bulb temperature of inlet air to the solar collector – Tdb_{in} = 27 ^{o}C

The dry bulb temperature of the outlet air from the collector – Tdb_{out} = 55 ^{o}C

The collector area – A_c = 17.5 m^2

The drying capacity of drying chamber = 100 kg

The mass flow rate - m_a = 750 kg/hr (0.15 m^3/s)

Solar irradiance - I_T = 550 W/m^2

Solar collector efficiency – η_c = 55 %

3.4 SAMPLE CALCULATION FOR SHRIMP

3.4.1 MOISTURE REMOVAL

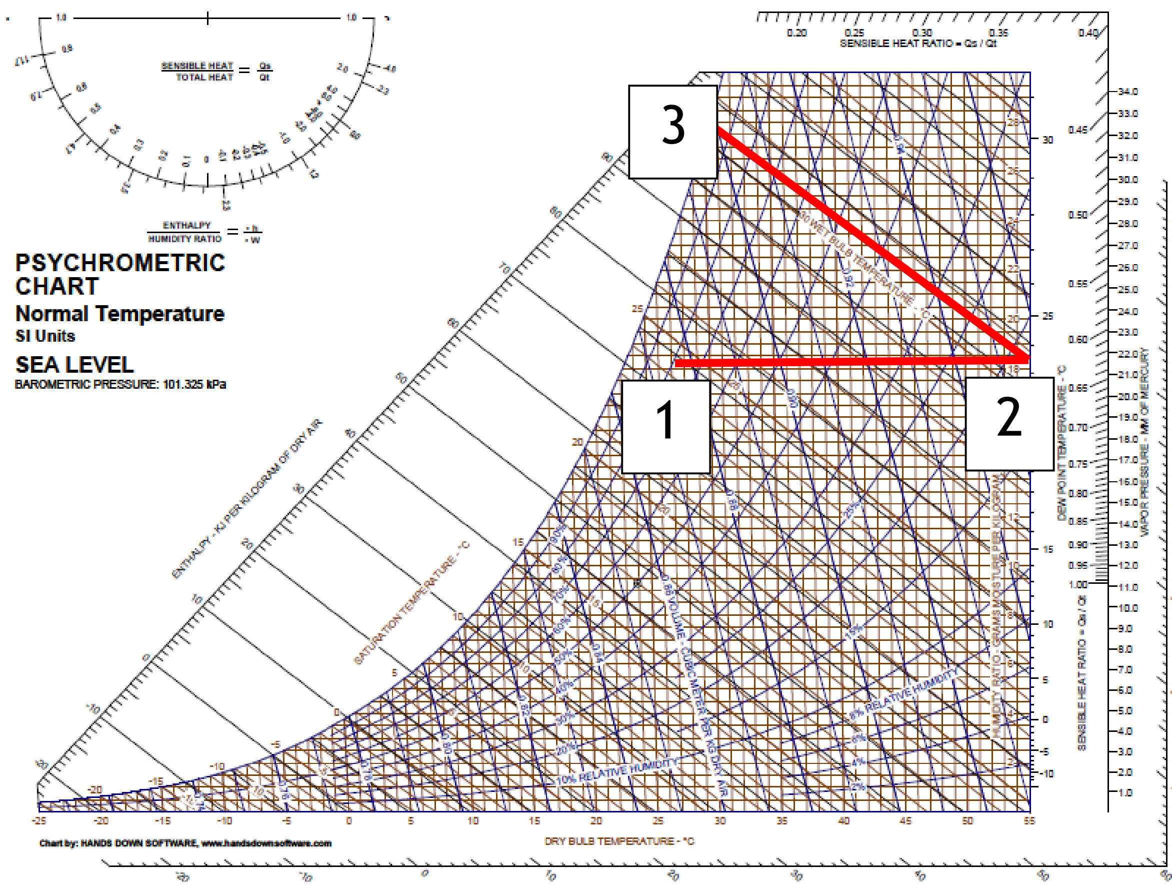

Figure 3.2 The psychrometric chart and process

Figure 3.2 shows the pychrometric chart for the drying process and the removal of the moisture from the air by the solar collector and drying chamber.

<u>At state 1</u>

RH_1 = 97 %

ω_1 = humidity ratio = 18 gram of moist air /kg of dry air

Tdb_{in} = 27 ^{o}C

At state 2

RH_2 = 23%

ω_2 = 18 gram of moist air /kg of dry air

At state 3

RH_3 = RH saturated = 100%

$\omega_3 = \omega_{as}$ adiabatic saturated humidity ration entering drying chamber

Tdb_3 = 29.9 ^{o}C

Mass flow rate of dry air (Ga) = $\frac{\text{ma}}{\omega+1}$

where $\omega = \omega_1 = \omega_{in} =$ 18 gram of moist air/kg of dry air.

Hence, $G_a = \frac{750\,kg/hr}{\frac{(0.018+1)kg}{kg\ dry\ air}}$ = 736.7 kg of dry air/hr

Rate of moisture removed from the dried commodity (shrimp):

$W = G_a \times \Delta\omega$

$\Delta\omega = \omega_{as} - \omega_{in}$ = (26.8 – 18) gram of air/kg dry air

W= 6.48 kg moist air/hr

3.4.2 SOLAR COLLECTOR AREA

Area of Solar Collector = $A_c = Q_u/(\eta \times I_T)$

$Q_u = m_a C_p (T_{out} - T_{in})$

T_{out} = 55 ^{o}C

T_{in} = 27 ^{o}C

C_p = 1.006 kJ/kg K

$Q_u = m_a C_p (T_{out} - T_{in})$ = 750 kg/hr x 1.0056 kJ/kg K x (55 – 27) K = 17353.5 kJ/hr

I_T = 550 W/m^2 = 550 J/s/m^2 x kJ/1000g x 3600s/hr = 1980 kJ/hr/m^2

A_c = 17353.5 (kJ/hr)/(0.55x 1980 kJ/hr/m^2) = 16.5 m^2 ≈ 17.5 m^2 (fixed). Hence, collector array has the configuration as shown in Figure 3.2.

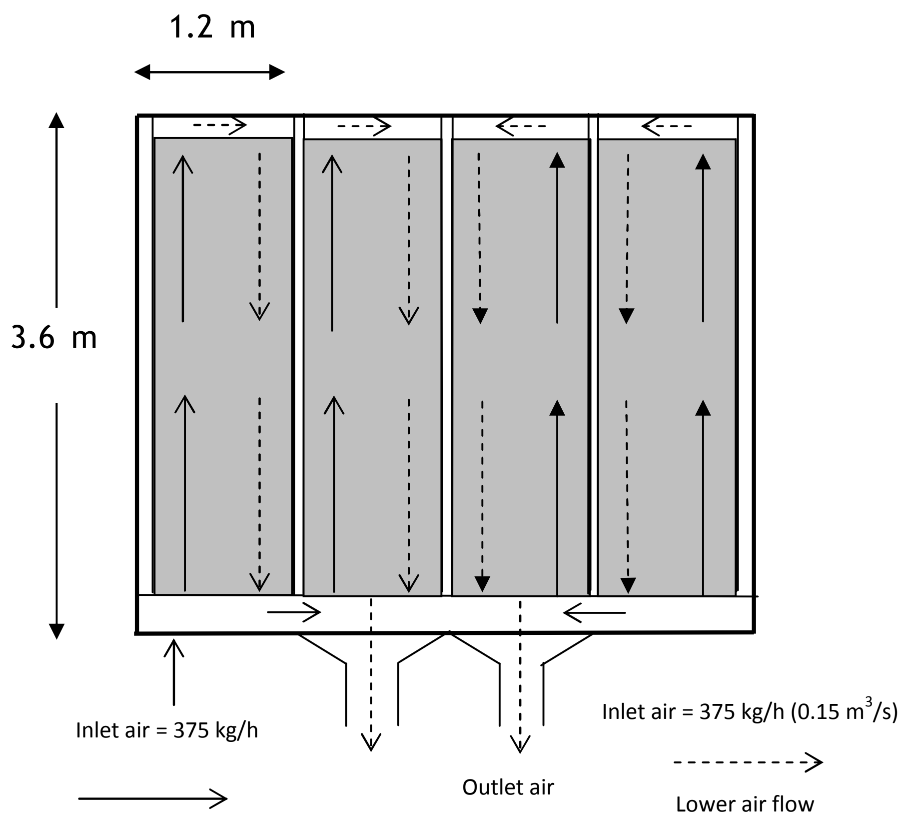

Figure 2 The collector area configuration and dimensions

3.4.3 TOTAL DRYING TIME

Drying Chamber Capacity = 100kg

Initial Moisture content - MC_i = 80 %

Final Moisture content = MC_f = 10 %

Total initial moisture in shrimp = 100 kg x 80 % = 80 kg

Total final moisture in shrimp = 80 kg x 10% = 8 kg

Total moisture removal – 80 kg – 8 kg = 72 kg

Time needed for drying is as follows:

Time = Total moisture removal /(Rate of moisture removed from the dried commodity (shrimp) x efficiency of drying chamber)

The efficiency of the drying chamber is assumed to be 80%.

Hence, the time needed for drying shrimp = 72 kg moisture removed/(6.48 kg/hr of moisture removed x 0.8) = 14.8 hrs.

If the dryer operated 24 hours with the auxiliary ON, the drying time will be 14.8 hrs. However, if only 5 hours of drying per day is allowed since no available electricity or diesel to run the auxiliary then the drying time will be 3 days.

3.5 CONCLUSIONS

Summary of all other commodities is shown in Table 3.1. The tables shows the summary for all the products It shows the initial and final moisture contents, drying capacity and drying time for all the products.

From the discussion with stakeholders, local UNIDO consultant, farmers and fisherman, the commodity chosen is fish. Other reason for choosing fish is the price, the popularity of the commodity and reliable supply of fish in the local market. The initial and final moisture contents are 78% and 10% respectively. For 100 kg of fresh fish, the drying time required is 14 hours. Conventional, open drying will require at least 5 days.

Table 3. 1 Summary for all the products (fish has been chosen as the product to be dried for solar dryer as highlighted in the table)

PRODUCTS	INITTIAL MOISTURE CONTENT (%)	FINAL MOITURE CONTENT (%)	DRYING CAPACITY (kg)	DRYING TIME (hours)
SHRIMP	80	10	100	14.8
PEPPER - RED - WHITE - BLACK -	 45 55 70	 10 10 10	 100 100 100	 8.0 10.0 12.5
BANANA	76	10	100	13.5
FISH	78	10	100	14.0

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2. Supranto, M. H. Ruslan, M.A.Alghoul, M.Y. Sulaiman, Azami Zaharim And K. Sopian, Estimating the A Solar Assisted Drying System Capacity for Marine Products, Proceedings of the 3rd WSEAS Int. Conf. on RENEWABLE ENERGY SOURCES, 331-335.

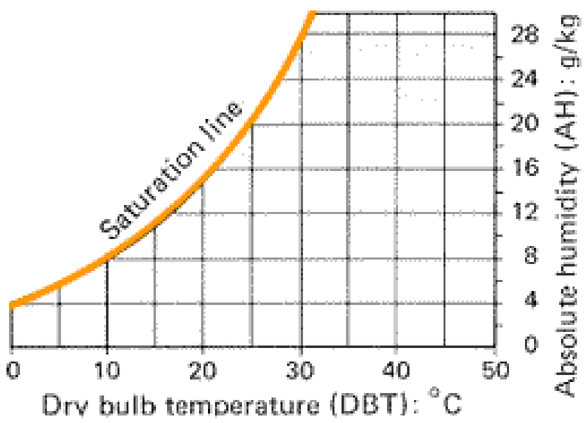
APPENDIX A: THE PSYCHRIOMETRIC AND PROCESSES

THE PSYCHRIOMETRIC CHART

The psychrometric chart represents the state of a given atmosphere by a point which gives the dry-bulb, wet-bulb, relative humidity, specific volume and saturation temperature of the atmosphere.

Saturation humidity line

Absolute humidity (AH) is the vapor content of air, given in grams of water vapour per kg of air, i.e. g/kg. Air at a given temperature and pressure can support only a certain amount of moisture and no more. This is referred to as the saturation humidity (SH). If this is plotted on a graph against the dry bulb (air) temperature (DBT), we have the basis of the psychrometric chart and we get what is called the saturation humidity line.

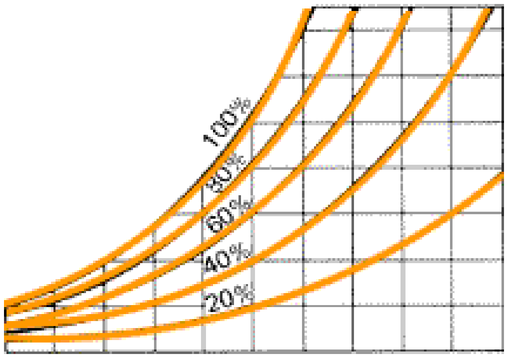


Relative humidity line

Relative humidity (RH) is an expression of the moisture content of a given atmosphere as a percentage of the saturation humidity at the same temperature:

RH = 100 x AH/SH (%)

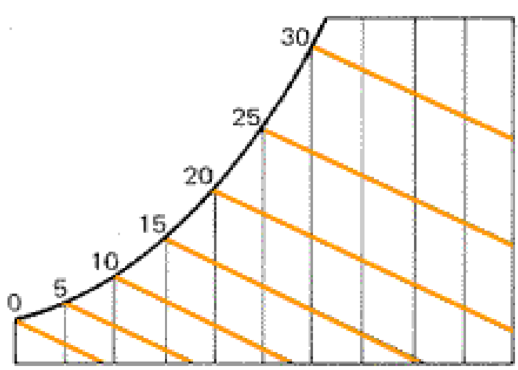
Relative humidity lines are plotted on the psychrometric chart by halving each SH ordinate to obtain the 50% curve, and further proportionate subdivision gives any intermediated RH curve.



Relative humidity lines (RH): %

Wet bulb temperature lines

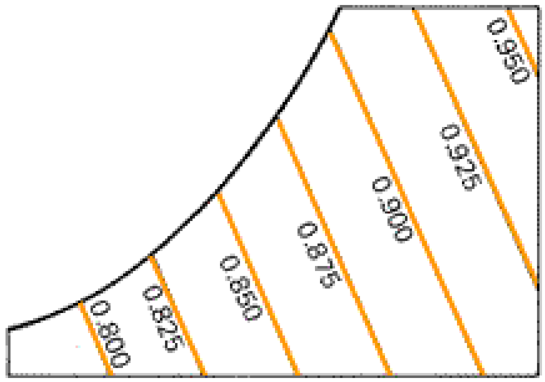
Wet bulb temperature (WBT) is measured by a hygrometer (or psychrometer). This consists of two thermometers, one measuring the DBT, the other having its bulb enclosed in a wet wick. 'Web bulb depression' is noted as the difference in the temperatures between the wet wick thermometer and the DBT. The difference happens as the wet wick thermometer is cooled down by the evaporation on the wick. The amount of evaporation is a direct indication of the moisture carrying capacity of the atmospheric air at that temperature and that lowers the WBT. When the air is saturated, there is no evaporation, thus the DBT and WBT readings are identical, the depression is zero. In this way, the 'status point' is determined at the intersection of the vertical DBT line and the sloping WBT line of the psychrometric chart.



Wet bulb temperature (WBT) lines: °C

Specific volume lines

Specific volume (Spv) (reciprocal of density, in m^3/kg) of the air-vapour mixture is indicated by another set of slightly more sloping lines on the psychrometric chart. This will be useful for the conversion of volumetric air flow quantiites into mass-flow rates.

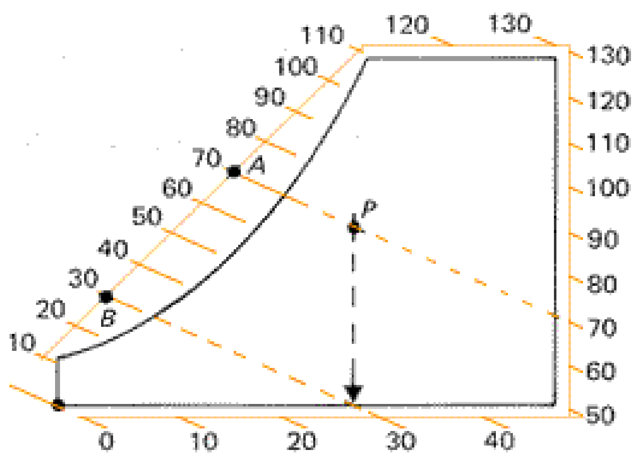


Specific volume (sv) lines: m^3/kg

Enthalpy lines

Enthalpy (E) is the heat content of unit mass of the atmosphere, in kJ/kg, relative to the heat content of 0°C dry air. It was omitted from the psychromteric chart shown above to avoid confusion which a third set of lines will cause. The enthalpy lines would almost, but not quite, conincide with the WBT lines. To avoid the confusion in representing it, the enthalpy scale is given at the perimeter of the chart and can be read by using a straight edge.

For air condition P the enthalpy is read at point A. The sensible heat component can be read at point B, corrosponding to the enthalpy of dry air at the same temperature. The remainder, ie, A - B, is the latent heat content.



Enthalpy (H) lines: kJ/kg

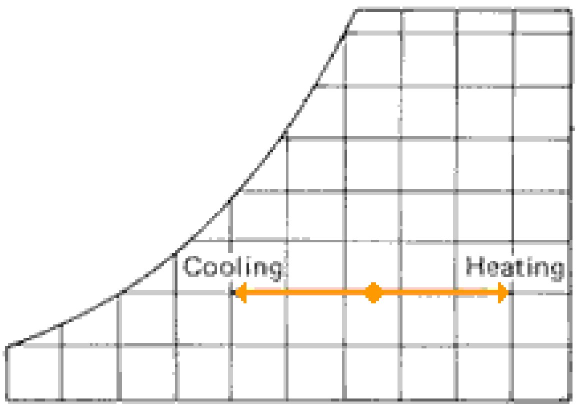
THE PSYCHRIOMETRIC PROCESSES

The state of a given atmosphere is represented by a point on the chart, known as the status point. If any two of the three commonly available characteristics DBT, WBT and RH are known, the others can be read from the chart. Psychrometric processes, ie, changes in the condition of the atmosphere, can be represented by the movement of this status point in the following ways:

Heating or cooling

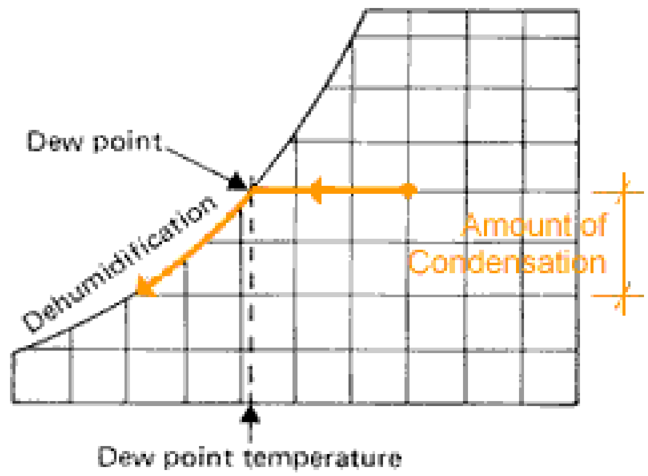
The addition or removal of heat, without any change in the moisture content (AH), resulting in the change in DBT. The status point will move horizontally to the left (cooling) or to the right (heating).

Note that while the AH does not change, the change in temperature means the relative humidity (RH) changes. It increases if the temperature lowers and vice versa.



Dehumidification by cooling

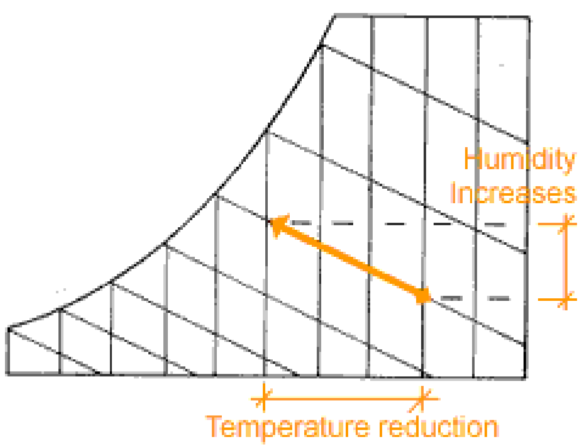
If, as a result of cooling, the point moving towards the left reaches the saturation line, some condensation will start. The DBT corresponding to this point is referred to as the dew-point temperature of the original atmosphere. If there is further cooling, the status point will move along the saturation line and condensation will occur. The reduction in the vertical ordinate (on the AH scale) represents the amount of moisture precipitatied, ie, condensed out. This process will reduce the absolute humidity, but will always end with 100% RH.



Adiabatic humidification (evaporative cooling)

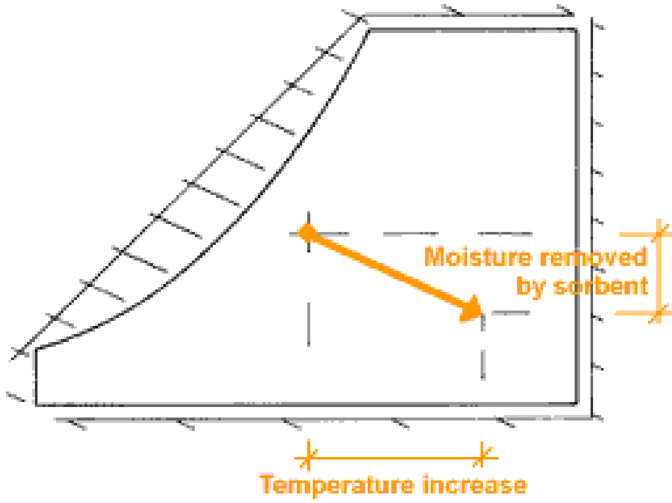
If moisture is evaporated into an air volume without any heat input or removal (this is the meaning of the term 'adiabatic'), the latent heat of evaporation is taken from the atmosphere. The sensible heat content - thus the DBT - is reduced, but the latent heat content is increased. The status point moves up and to the left, along a WBT line. This is the process involved in evaporative cooling.

Note that by this process, the relative humidity is increased. It increases only until it hits the saturation line, at which it becomes 100%. Beyond it there is no decrease in sensible temperature. This is the reason why during hot and humid months, evaporative cooling is ineffective and uncomfortable.



Adiabatic dehumidification (by sorbents)

If the air is passed through a chemical sorbent material (eg, silica gel), some of the moisture is removed and the latent heat of evaporation is released. There will be an increase in sensible heat content, thus in the system (ie, if the process is adiabatic), the state point will move down and towards the right along an enthalpy line.



Mixing

If two air streams are mixed, having:

-mass flow rates m1 and m2,

-dry bulb temperatures t1and t2,

-enthalpies H1and H2, the result will be:

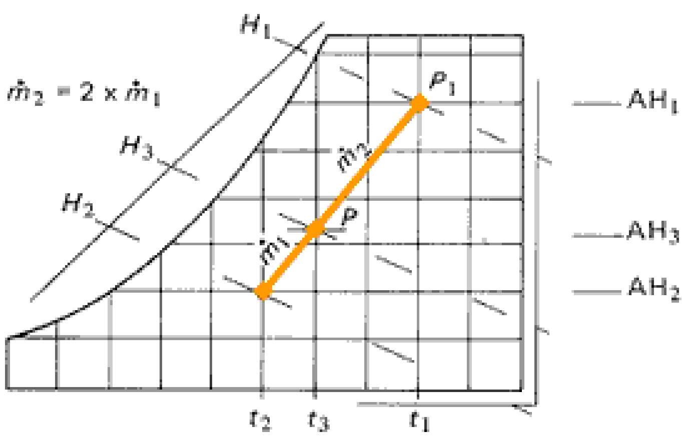
$m1t1 + m2t2 = [m1 + m2]t3$,

$m1H1 + m2H2 = [m1 + m2]H3$

Therefore:

$t3 = (m1t1 + m2t2) / m1 + m2$

$H3 = (m1H1 + m2H2) / m1 + m2$



The psychrometric chart can be used to establish the value of t3 and H3. The two state points are connected by a straight line, which is then divided in inverse proportions of m1 and m2. If the mass flow rate m1 is the greater, the resulting point P will represent the state of the combined air stream.

CHAPTER 4

DESIGN OF THE SOLAR ASSISTED DRYING SYSTEM

4.1 THE SOLAR ASSISTED DRYING SYSTEM

The potential of using solar energy in the agricultural marine sectors have increased due to fluctuation in the price of fossil fuel, environmental concerns and expected depletion of conventional fossil fuels. Solar assisted drying system is one of the most attractive and promising applications of solar energy systems in tropical and subtropical countries. Traditionally all the agricultural crops were dried in the sun. Drying is one of an important post handling process of agricultural produce. It can extend shelf life of the harvested products, improve quality, improve the bargaining position of the farmer to maintain relatively constant price of his products and reduces post harvest losses and lower transportation costs since most of the water are taken out from the product during the drying process.

Direct sun drying requires large open space area, and very much dependent on the availability of sunshine, susceptible to contamination with foreign materials such as dusts, litters and are exposed to birds, insect and rodents. Hence, most agricultural produce that is intended to be stored must be dried first. Otherwise insects and fungi, which thrive in moist conditions, render them unusable.

Other limitations were given by the availability of appropriate drying equipment which is technically and economically feasible and the lack of knowledge how to process agricultural products. Up to now only a few solar dryers who meet the technical, economical and socio-economical requirements are commercially available. The technical development of solar drying systems can proceed in two directions. Firstly, simple, low power, short life, and comparatively low efficiency-drying system. Secondly, high efficiency, high power, long life expensive drying system. Various solar dryers have been developed in the past for the efficient utilization of solar energy.

Many studied have been reported on solar drying of agricultural products. Several studied have been done in the tropics and subtropics to develop solar dryers for agricultural products. Basically, there are four types of solar dryers; direct solar dryers, indirect solar dryers, mixed-mode dryers, and hybrid solar dryers. Figure 4.1 shows a systematic classification of available solar dryers for agricultural and marine products, based on the design of system components and mode of utilization of solar energy.

The energy requirement for agricultural products can be determined from the initial and final moisture content of each product. Products have different drying rate and maximum allowable temperature.

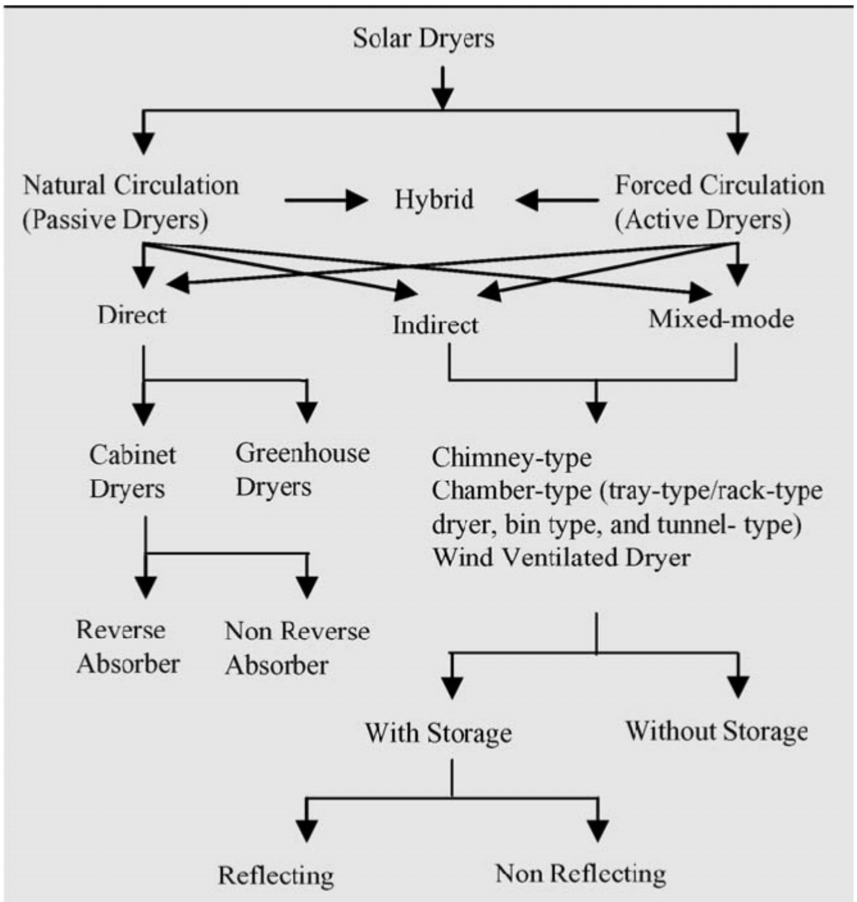


Figure 4.1 Classification of solar dryers and drying modes

The basic components of a solar assisted drying system are solar collector, blower unit, auxiliary heater and the drying chamber. Air will be heated in the solar collector and will be directed to the drying chamber by the blower. An optional auxiliary heater is used when the temperature of the drying chamber falls below a specific temperature. This will ensure continous operation drying of the system. Figure 4.2 shows the solar drying system to be adopted for drying of fish in Cambodia.

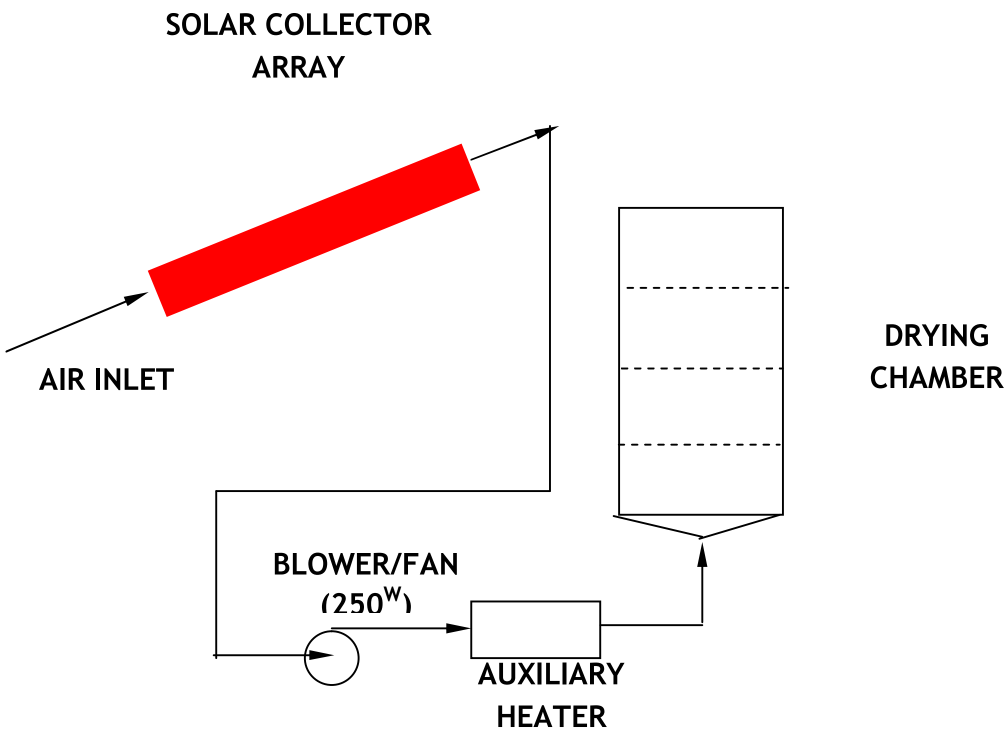


Figure 4.2 The basic design of the solar assisted drying system

4.2 THE SOLAR COLLECTOR

The design of suitable air collectors is one of the most important factors controlling the economics of the solar drying. To date, flat plate solar collectors are widely used. Air may be allowed to flow above, below or both sides of the absorber plate. Air flow under the absorber plate reduces the heat losses through the glazing. Major heat losses from the collector occur at the front cover, because the front face must be exposed to atmosphere, whereas the sides and the back of the collector can be insulated adequately.

The double-pass solar air heater with fins will be used in Cambodia. Air type collectors have two inherent disadvantages: low thermal capacity of air and low absorber to air heat transfer coefficient. Different modifications are suggested and applied to improve the efficiency. The double concept will reduce the cover losses while the fins will enhance heat transfer and will increase the collection efficiency of the system. Experimental studies indicated the superiority of the performance of the double-pass air heater over the single-pass.

4.2.1 BASIC OPERATION OF THE COLLECTOR

The collector consists of the glass cover, the absorber plate, insulation, and the container. One glass cover is used and when the sun sunshine on it, the absorber will absorb the solar radiation. The absorber will be heated. Incoming air form the inlet initially enters through the first channel formed by the glass covering the absorber plate and then through the second channel formed by the back plate and the finned absorber plat, transferring the heated air from the absorber plate and fins to the outlet of the collector.

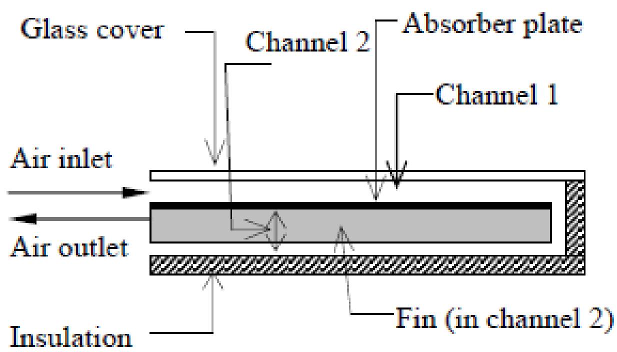


Figure 4.3 The double-pass solar collector with fins

4.2.2PERFORMANCE PARAMETERS OF THE DOUBLE PASS SOLAR COLLECTOR

The performance data for the double-pass collectors have been obtained from experiments conducted at the Solar Simulator, located in the Solar Energy Research Institute, Universiti Kebangsaan Malaysia. Some aspects of the performance will be elaborated and use for the solar drying systems to be installed in Cambodia.

Figure 4.4 shows the variation of temperature with experiment time is about 75 minutes for solar radiation of 788 W/m^2 and mass flow rate at 0.039 kg/s. Generally, temperatures increased constantly up to 60 minutes and then tended to approach a constant value. The effect of solar radiation on the efficiency of the solar collector is shown in Figure 4.5. At the solar radiation at 423W/m^2 to 788W/m^2 increase efficiency is about 20-25%. Figure 4.6 shows the effect mass of flow rate on the efficiency of the double-pass solar air collector with fins absorber. The efficiency of the collector is strongly dependent on the flow rate. The collector efficiencies increase with flow rate, efficiency increase is about 40 % at mass flow rate of 0.04 kg/s to 0.084 kg/s.

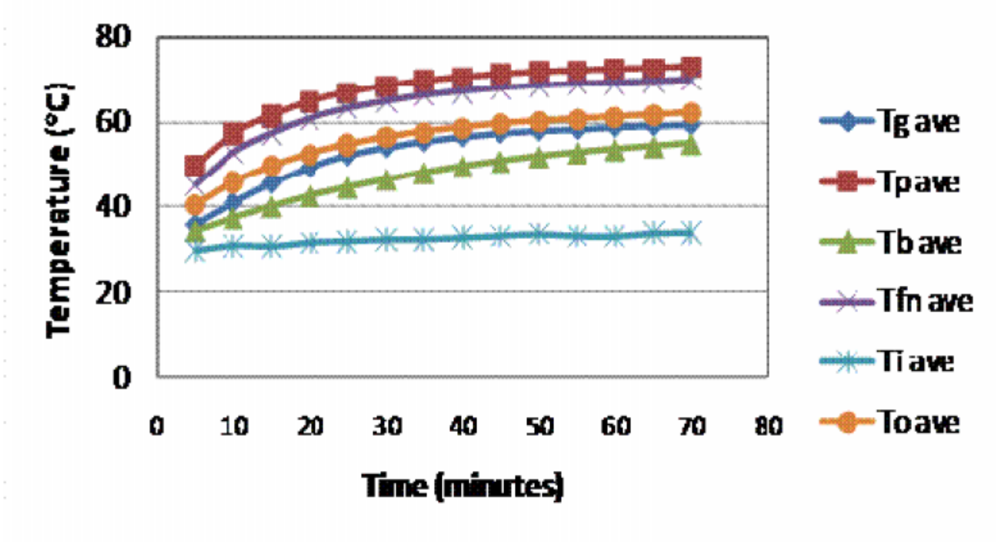


Figure 4.3 Temperature rise in solar collector with time

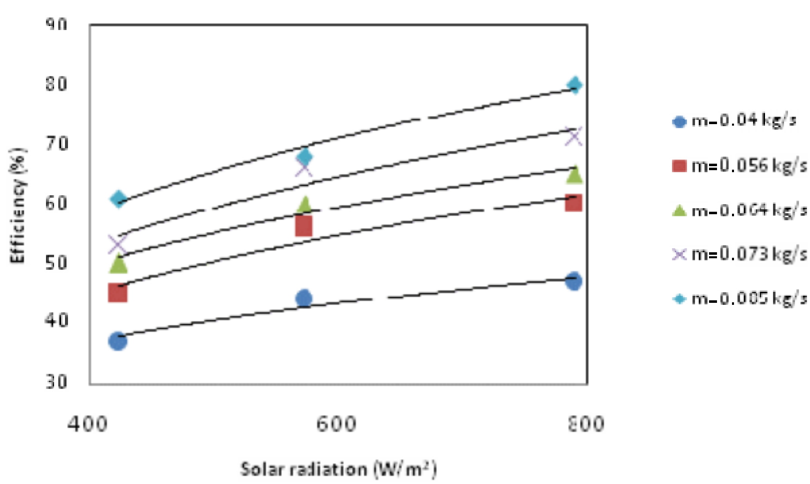


Figure 4.5 The effect of solar radiation on efficiency at different mass flow rate

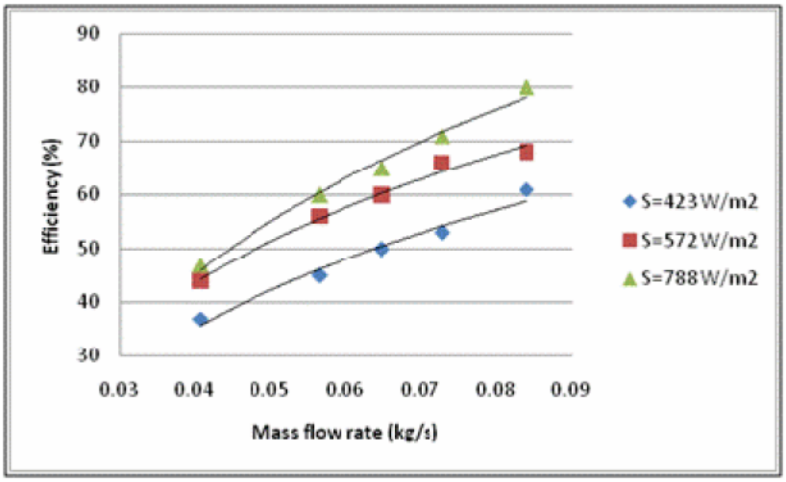


Figure 4.6 The effect of solar radiation and mass flow rate on efficiency

To determine the physical characteristics of the collector, one represents effectiveness with efficiency curve, i.e. efficiency versus the reduced temperature parameters $(T_o\text{-}T_a)/S$. It will results where the slope is equal to F_oU_L and the y-intercept is equal to $F_o(\tau\alpha)$. The respective efficiency equation and the physical characteristic of the collector are presented in Table 4.1.

Table 4.1 Efficiency, loss factor and efficiency equation of double-pass solar air collector with fins

S (W/m2)	$F_o(\tau\alpha)$	F_oU_L
788	0.88	7.7
572	0.76	5.8
423	0.66	5.6

The efficiency and collector outlet temperature were an important parameter for a wide variety of applications, such as solar industrial process heat and solar drying of agricultural produce. Outlet temperature was investigated for mass flow rates from about 0.03 to 0.09 kg/s.

Figure 4.7 shows the optimum operating condition with respect to efficiency and outlet temperature were determined for S=788 W/m^2. The optimum efficiency (70-80%) lies between the mass flow rates 0.07-0.09 kg/s. A mass flow rate of about 0.063 kg/s is considered for solar drying of agricultural produce. Minimal increase in the efficiencies occurs as the mass flow rate is increased, therefore, operating at these conditions will only increase the blower power.

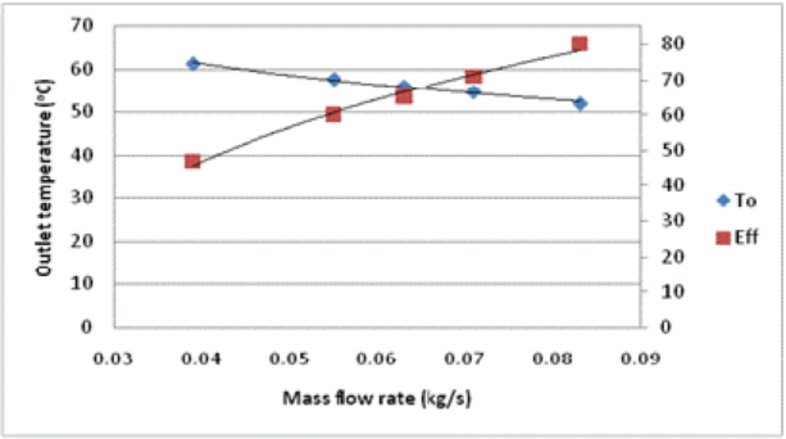


Figure 4.7 Variation of T_o and η with mass flow rate at S=788 W/m^2

Figures 4.8 to 4.10 show the variation of increase temperature (T_o-T_i) and efficiency with mass flow rate for S=788 W/m2, S=572 W/m^2 and S=423 W/m^2, respectively. As seen in the figures, as efficiency increased with flow rate, increase temperature (T_o-T_i) decreased correspondingly.

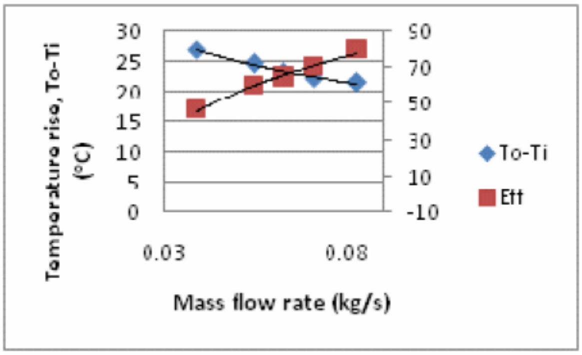


Figure 4.8 Variation of T_o-T_i and η with mass flow rate at S=788 W/m^2

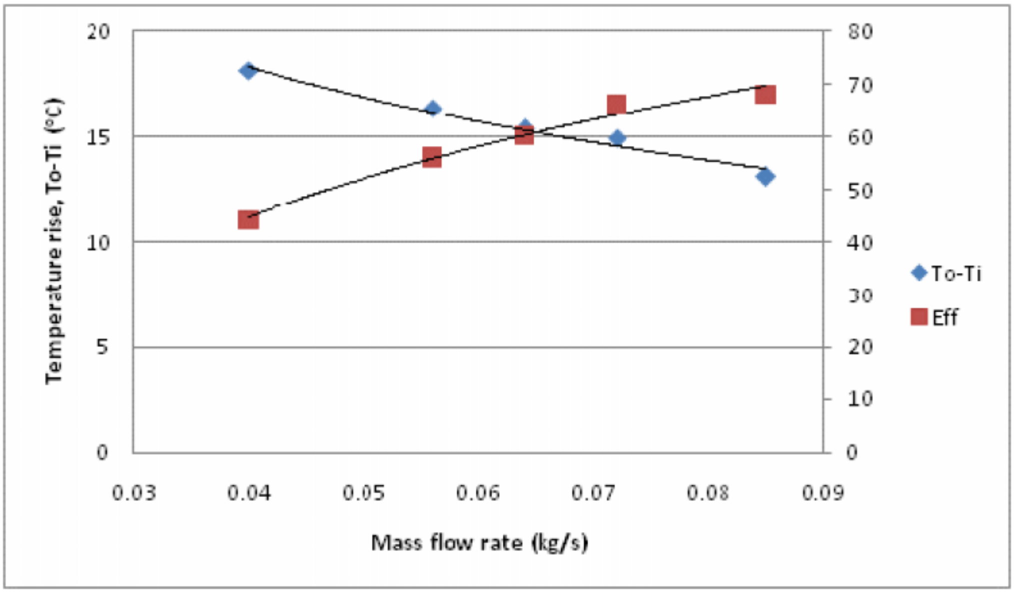


Figure 4.9 Variation of T_o-T_i and η with mass flow rate at S=572 W/m^2

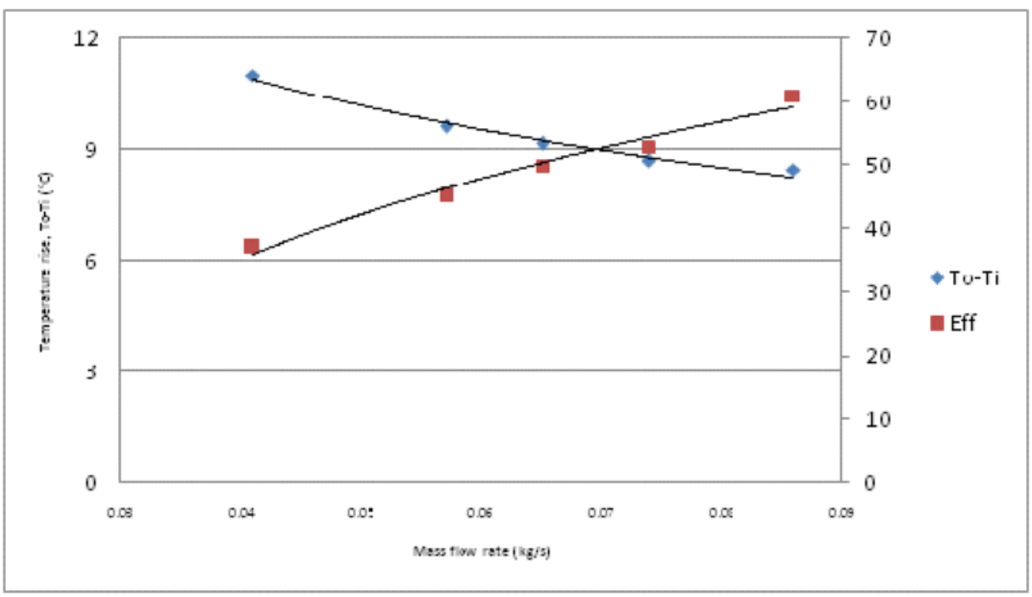


Figure 4.10 Variation of T_o-T_i and η with mass flow rate at S=423 W/m^2

4.2.2 DETAILS OF SOLAR COLLECTOR

The collector width and length were 120 cm and 360cm respectively. The upper channel depth is 3.5 cm and the lower depth is 7 cm. The details of the collector are shown in Figures 4.11 and 4.12. There are 33 fines. The depth of the fins is 6 cm and the length is 10 cm. The bottom and sides of the collector have been insulated with 2. 5cm thick fiberglass to minimize heat losses.

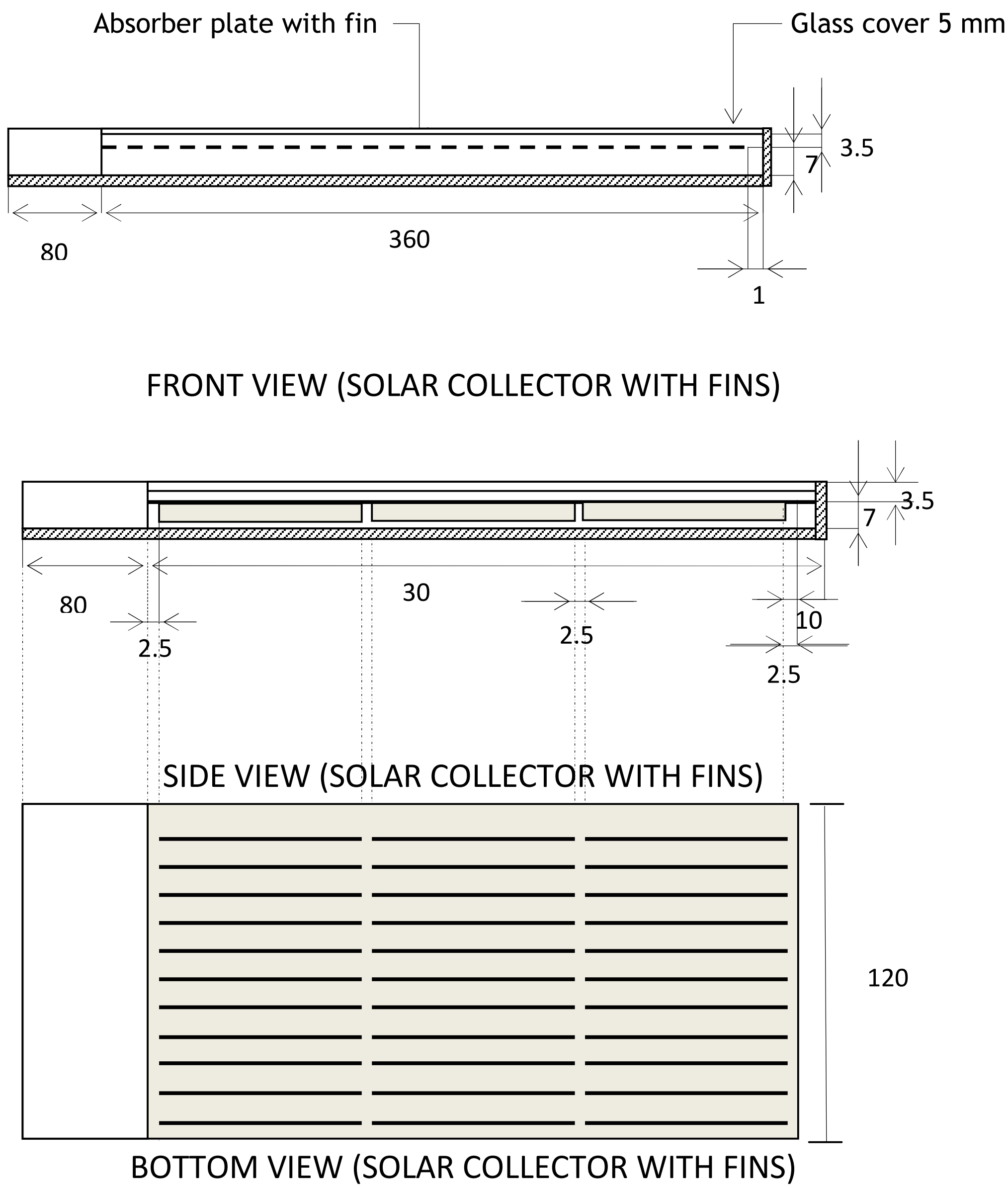
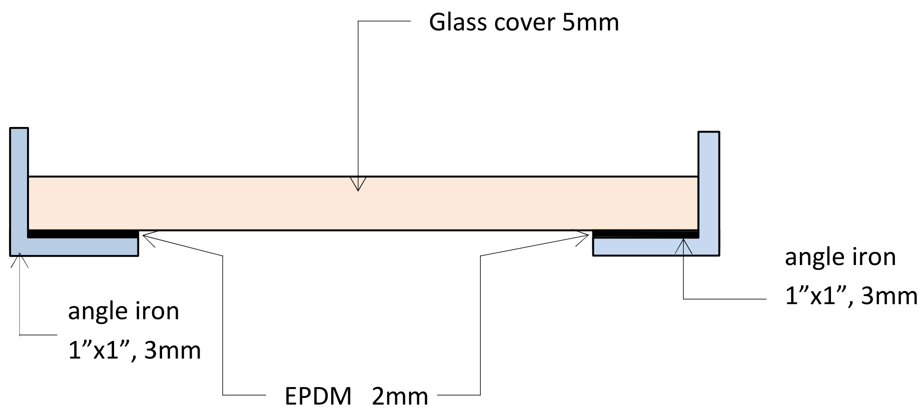


Figure 4.11 Details of the double-pass solar collector with fins



Glass cover with silicone seal

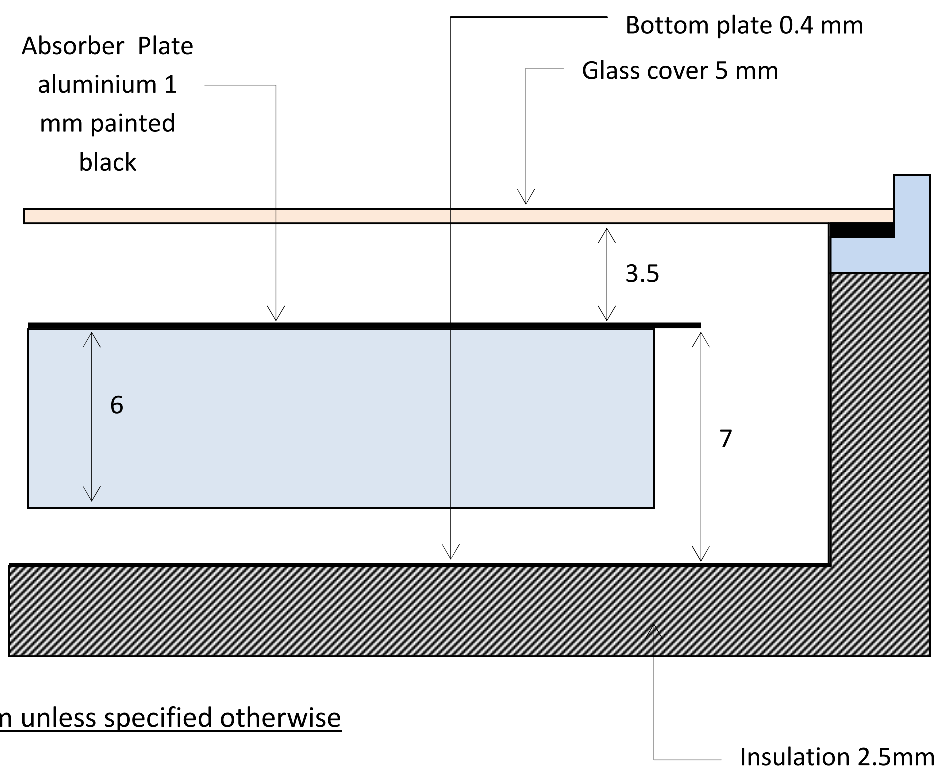


Figure 4.12 Details of the double-pass solar collector with fins and attachments to glass cover and container

4.3 THE SOLAR COLLECTOR ARRAY

The solar collector array consists of 4 solar collectors (A1-A2 and B1-B2), arranged as 2 banks (A and B) as shown in Figure 4.13. Each banks (A and B) has two collectors connected in series. Air enters the two inlets of the upper channel of collectors A1 and B1 and flows in the lower channel of collectors A1 and B1. The air flows to collectors A2 and B2 through the internal manifolding connecting collectors A1-A2 and B1-B2. . Finally, the hot air from the two banks of collectors (A and B) were mixed and induced by a centrifugal blower to a common outlet and directed to drying chamber. The blower power rating was 0.25 kW, 230V rotating at 2520 RPM. The collector was tilted at 15^o from the horizon.

The finned air electric heater of 5 kW was used as auxiliary heating unit for supply heat in the lower solar radiation. The heater was controlled with ON/OFF controller and was set at 50^{o}C. The heater will be activated if the hot air temperature was lower than 50^o C and off if the hot air temperature was more than 50^{o}C. The details of solar collectors A1, A2, B1 and B2 are shown Figures 4.14 to 4.17.

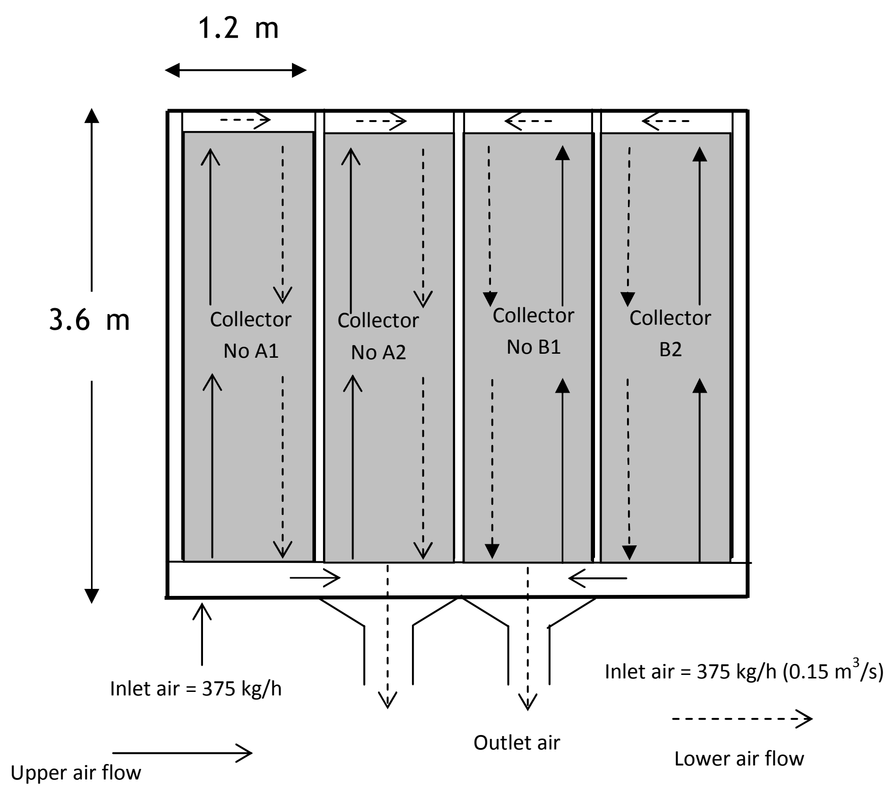
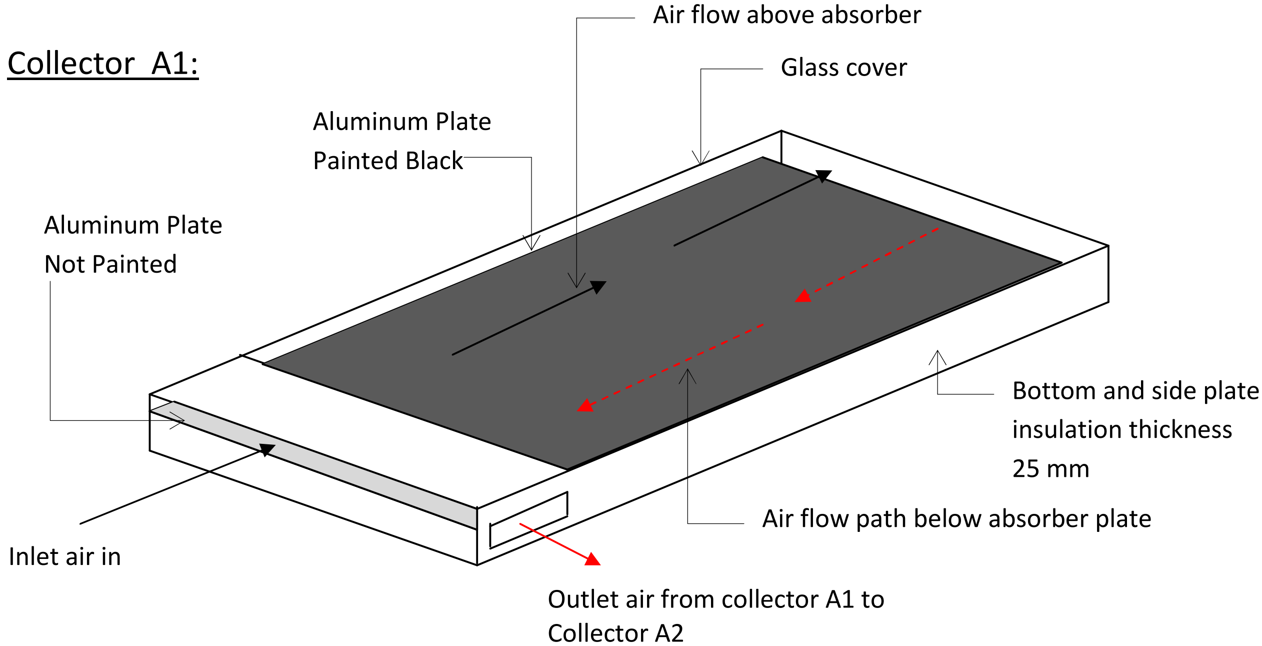


Figure 4.13 The collector array configuration and dimensions

Collector A1:



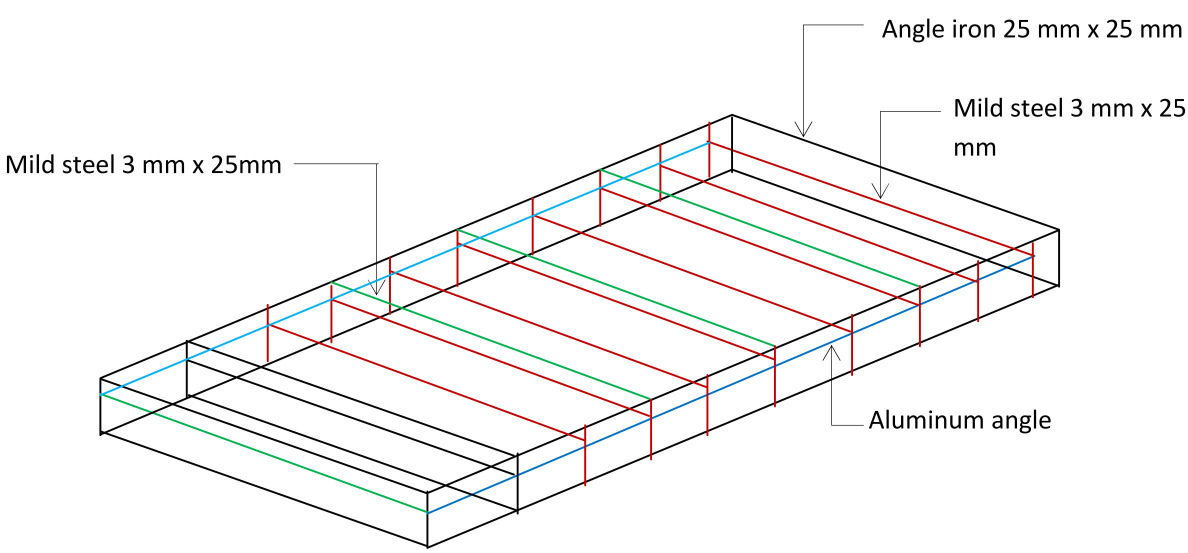


Figure 4.14 Details of Solar Collector A1

Collector A2

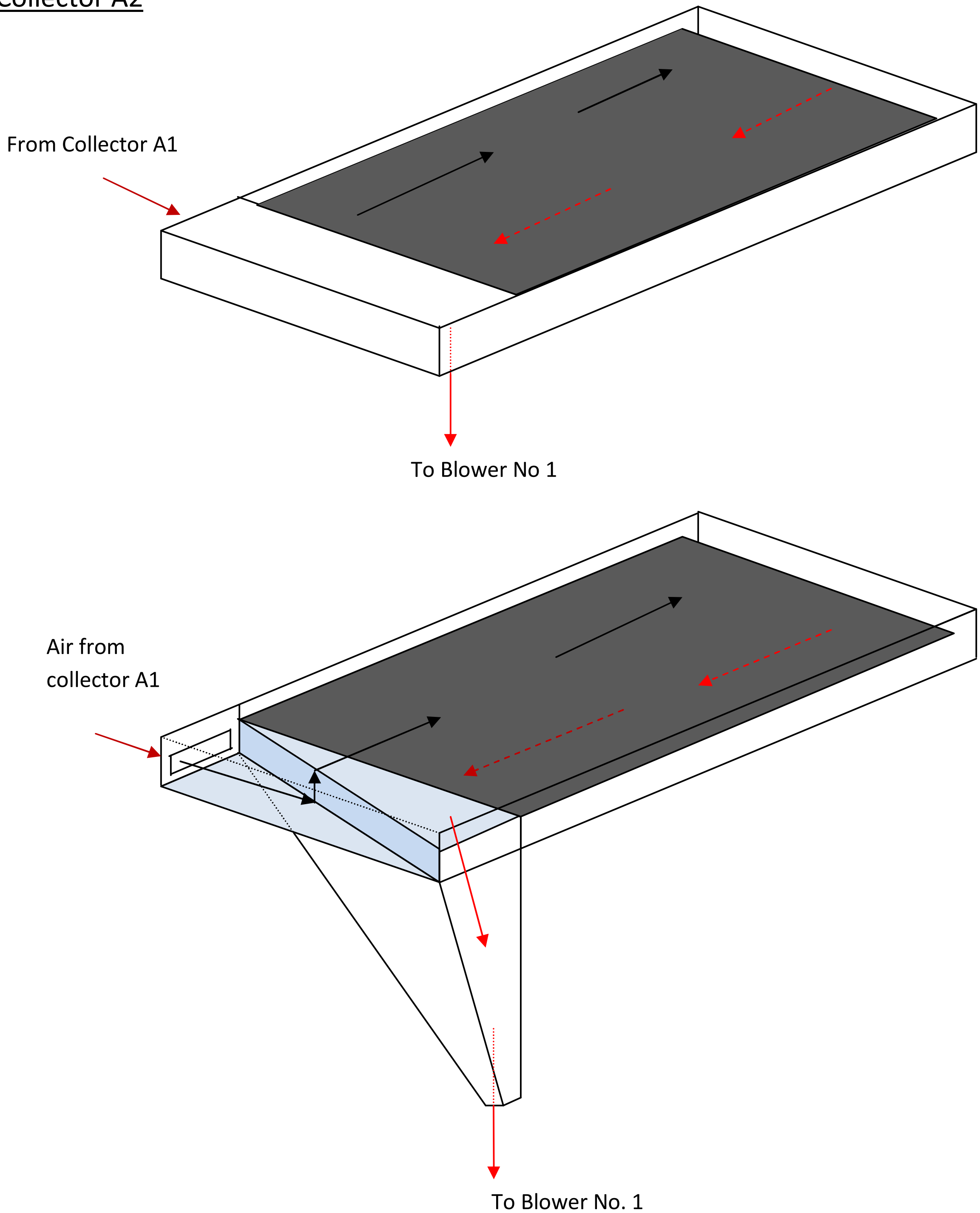


Figure 4.15a Details of Solar Collector A2

<u>Collector A 2</u>

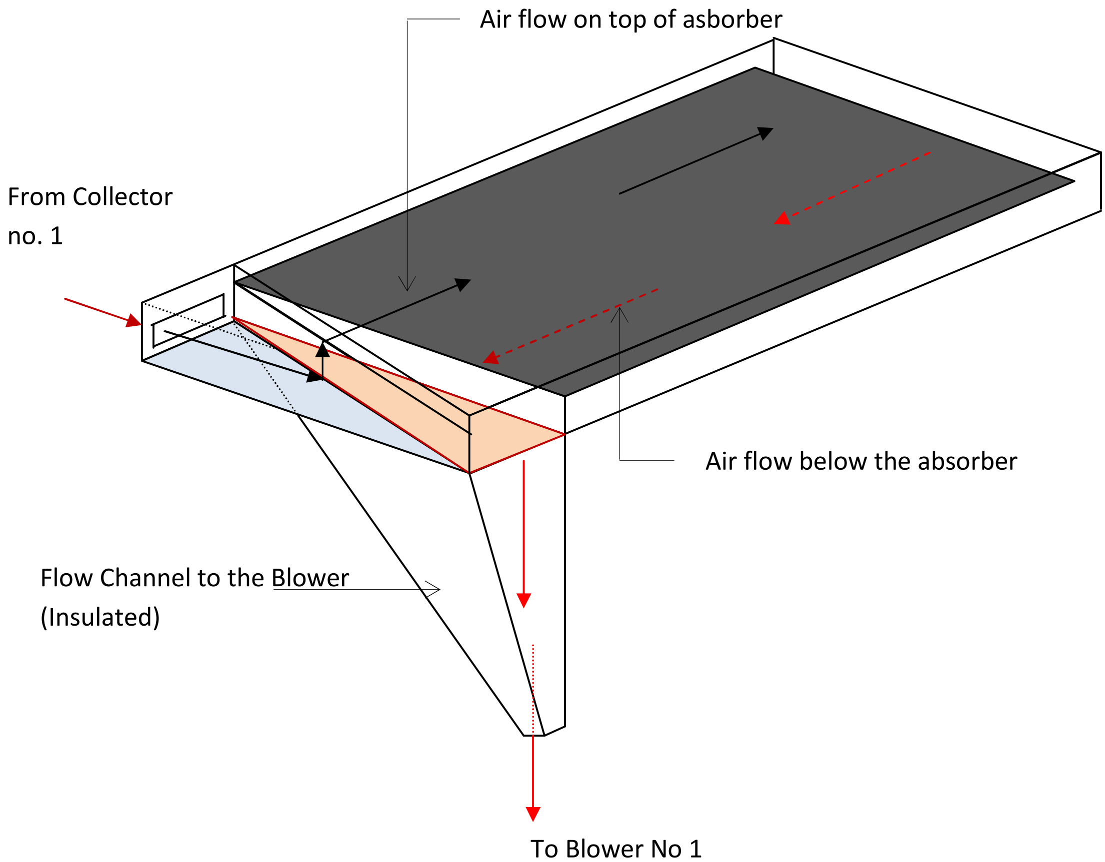


Figure 4.15b Details of Solar Collector A2

Collector B1.

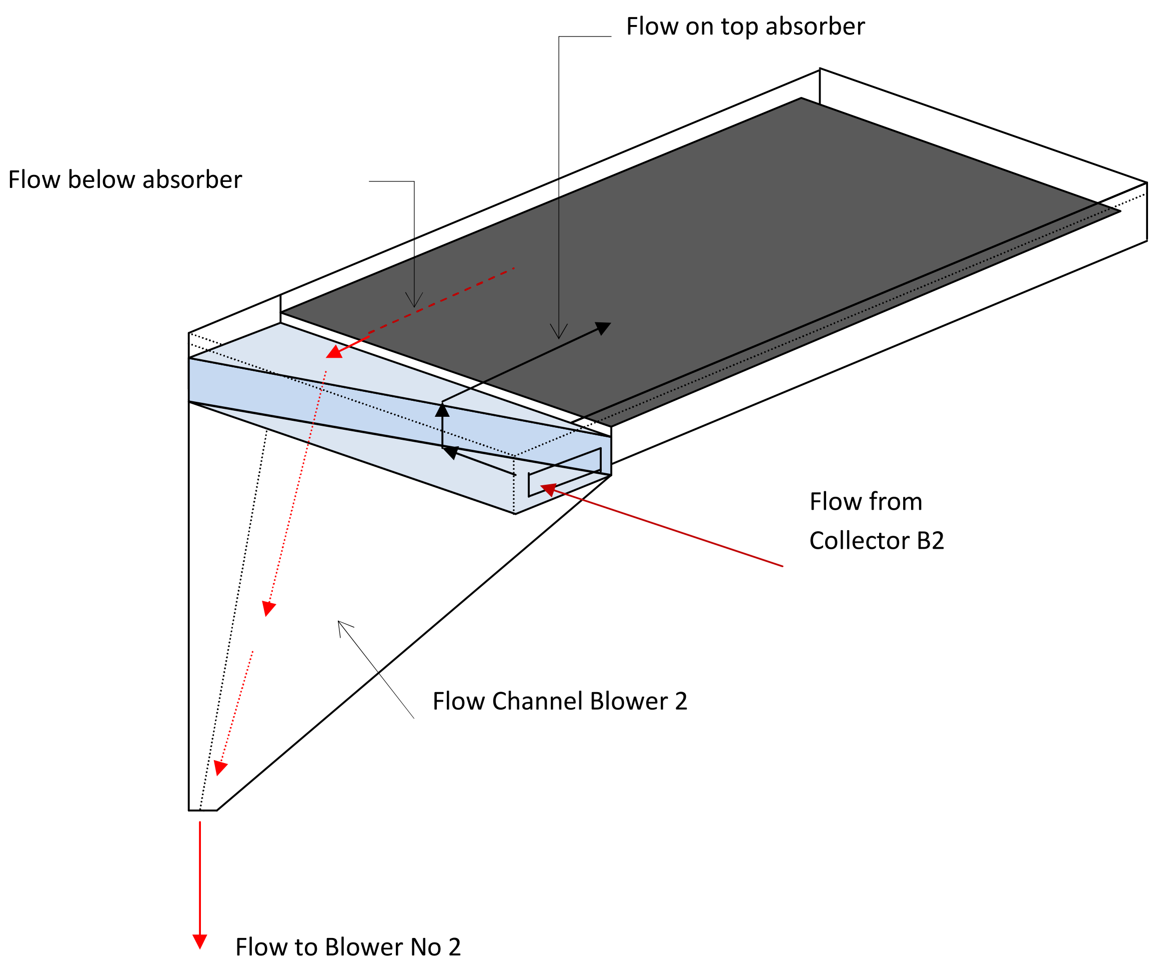


Figure 4.16a Details of Solar Collector B1

Collector B1

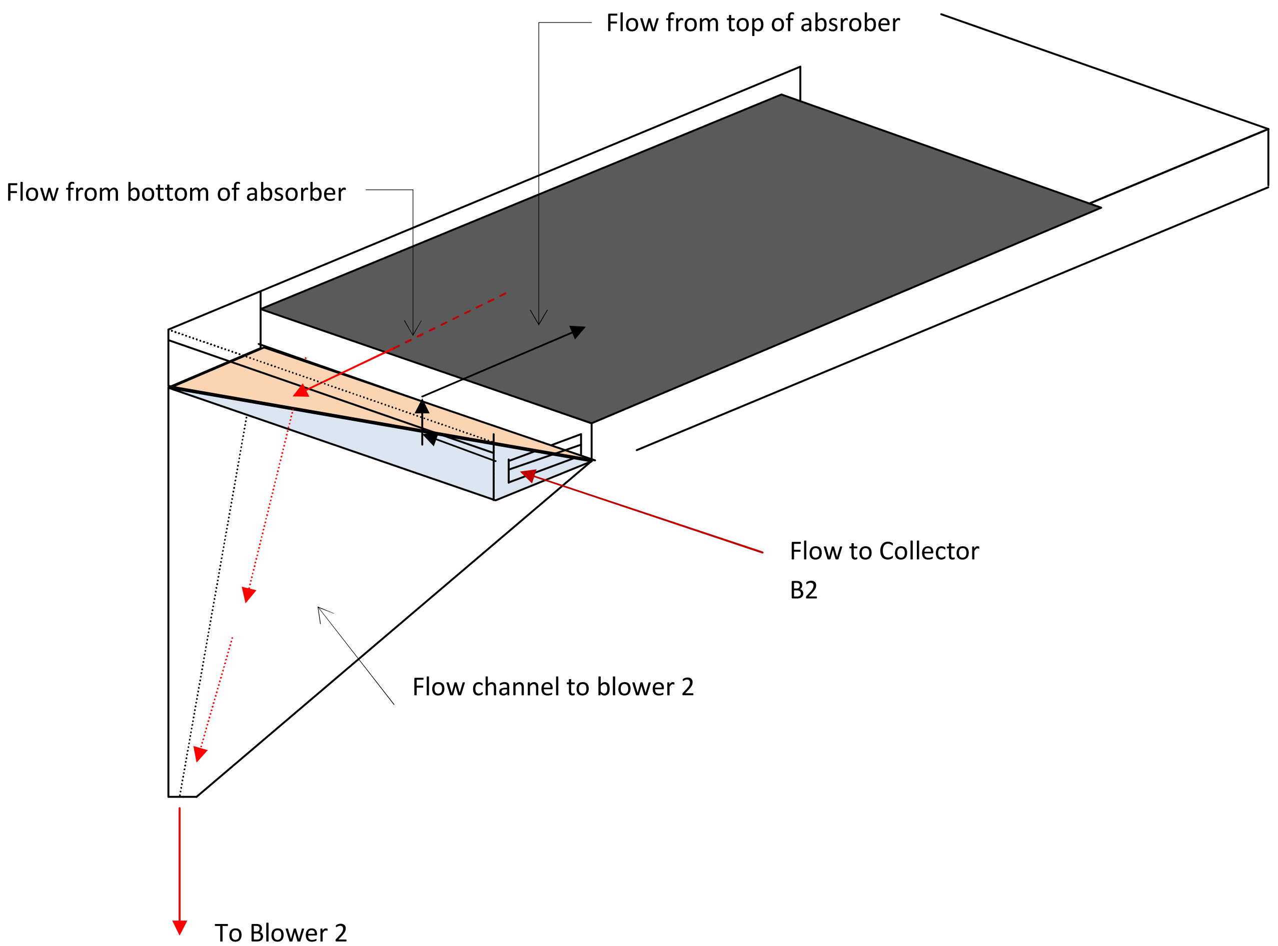


Figure 4.16b Details of Solar Collector B1

Collector B2

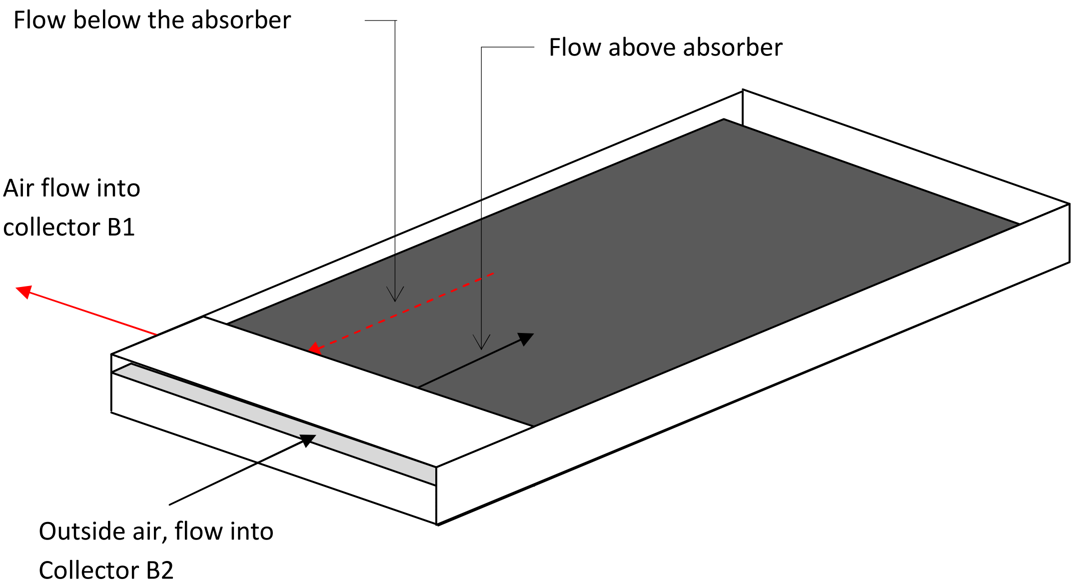


Figure 4.17 Details of Solar Collector B2

4.4 THE DUCTING SYSTEM

The solar collector arrays are connected through ducts deliver and remove hot air from the collectors. Two 125W fans are needed for air flowing into the drying chambers. Traditionally, air ductwork is made of sheet metal which is installed first and then lagged with insulation as a secondary operation. Ductwork manufactured from rigid insulation panels does not need any further insulation and is installed in a single fix. Light weight and installation speed are among the features of preinsulated aluminium ductwork, also custom or special shapes of ducts can be easily fabricated in the shop or on site.

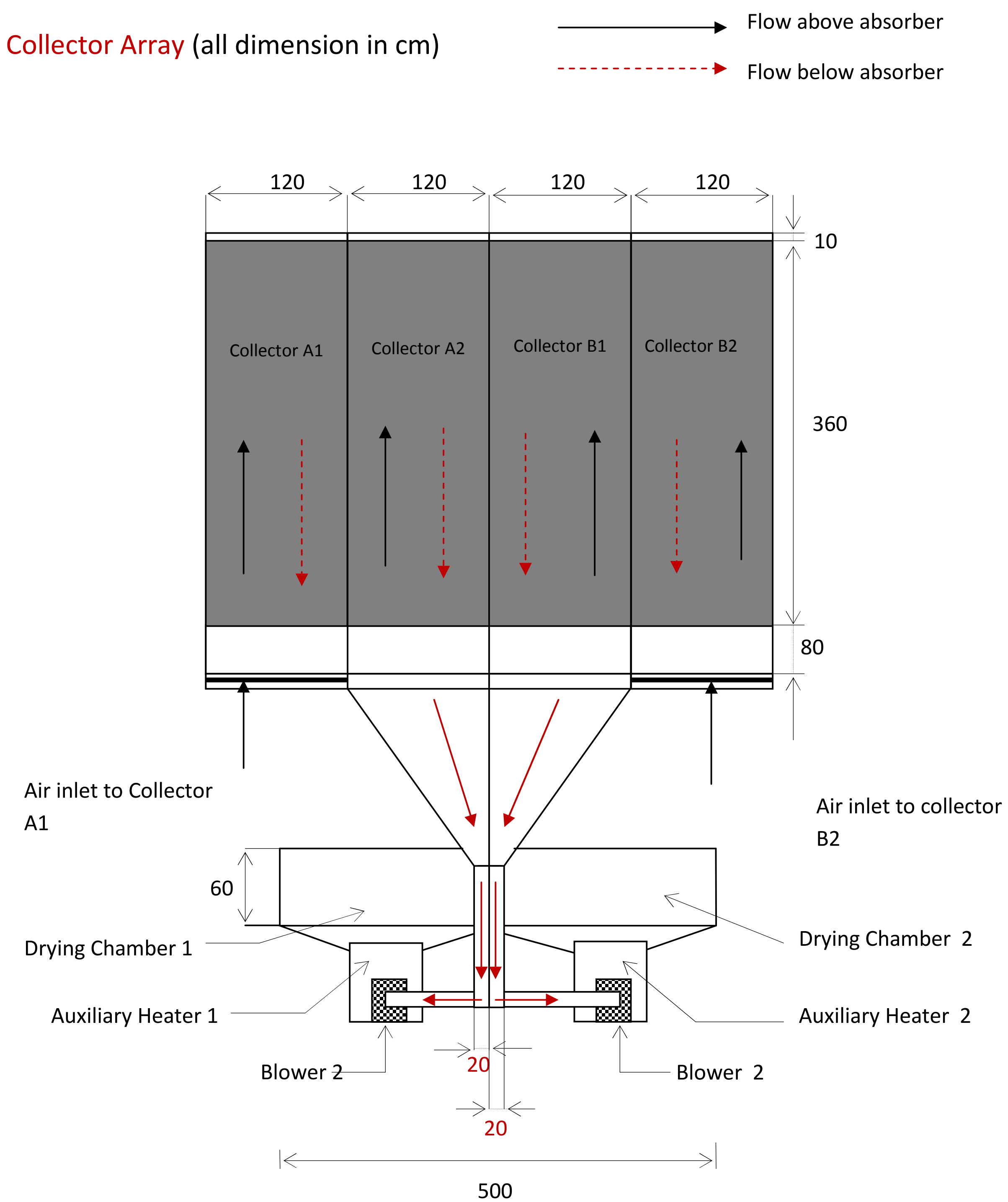


Figure 4.18a Details of the Ducting System

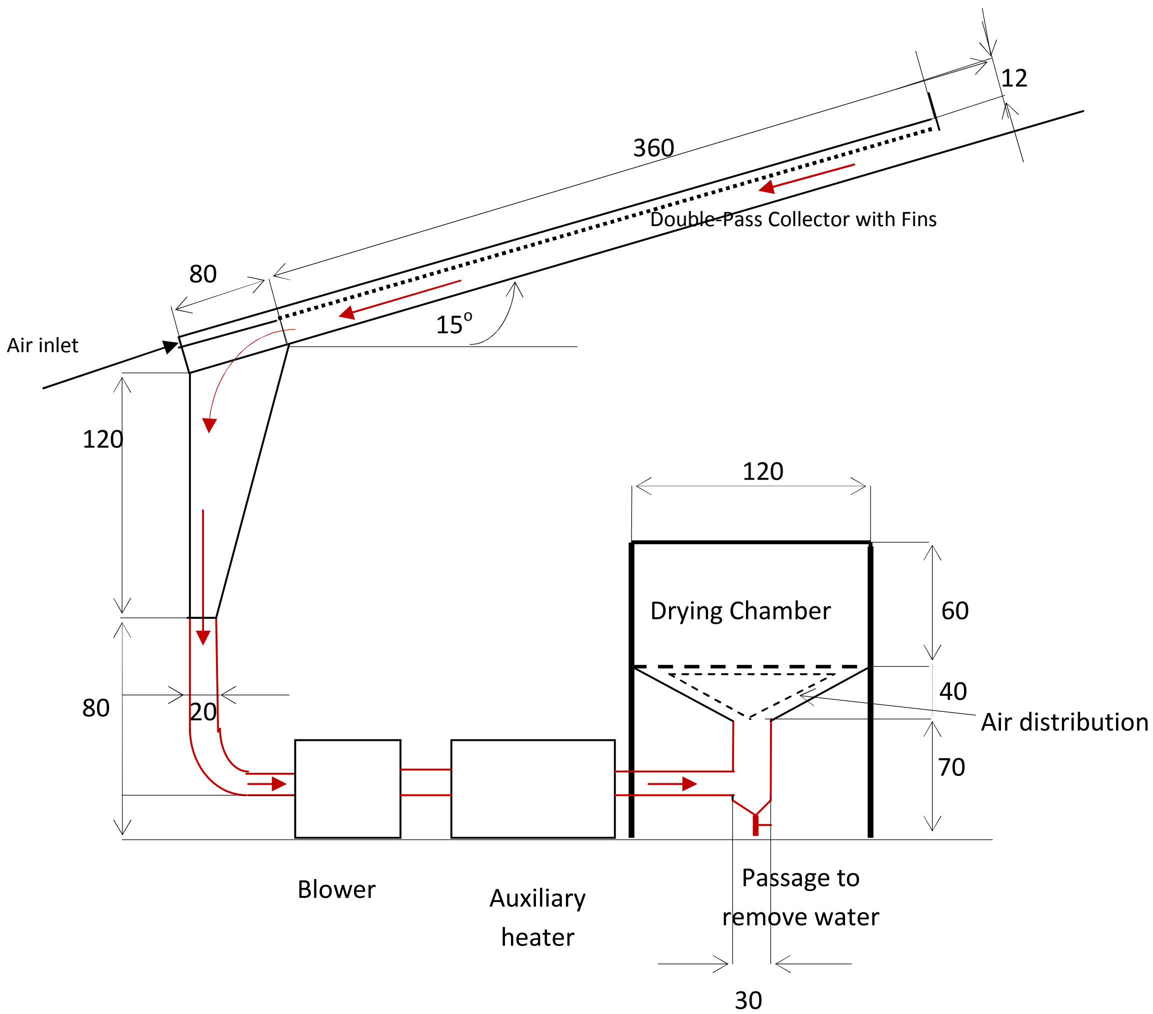


Figure 4.18b Details of the Ducting System

4.5 DRYING CHAMBER

Two drying chambers with opening doors are used. The size of each drying chamber is 120 cm x 250 cm. The bottom of the drying chamber has perforated plate for air flowing through the ducting system into the drying chamber. It has also side opening for air to be driven out of the chamber. Both chamber can handle a total of 100kg of fresh fish.

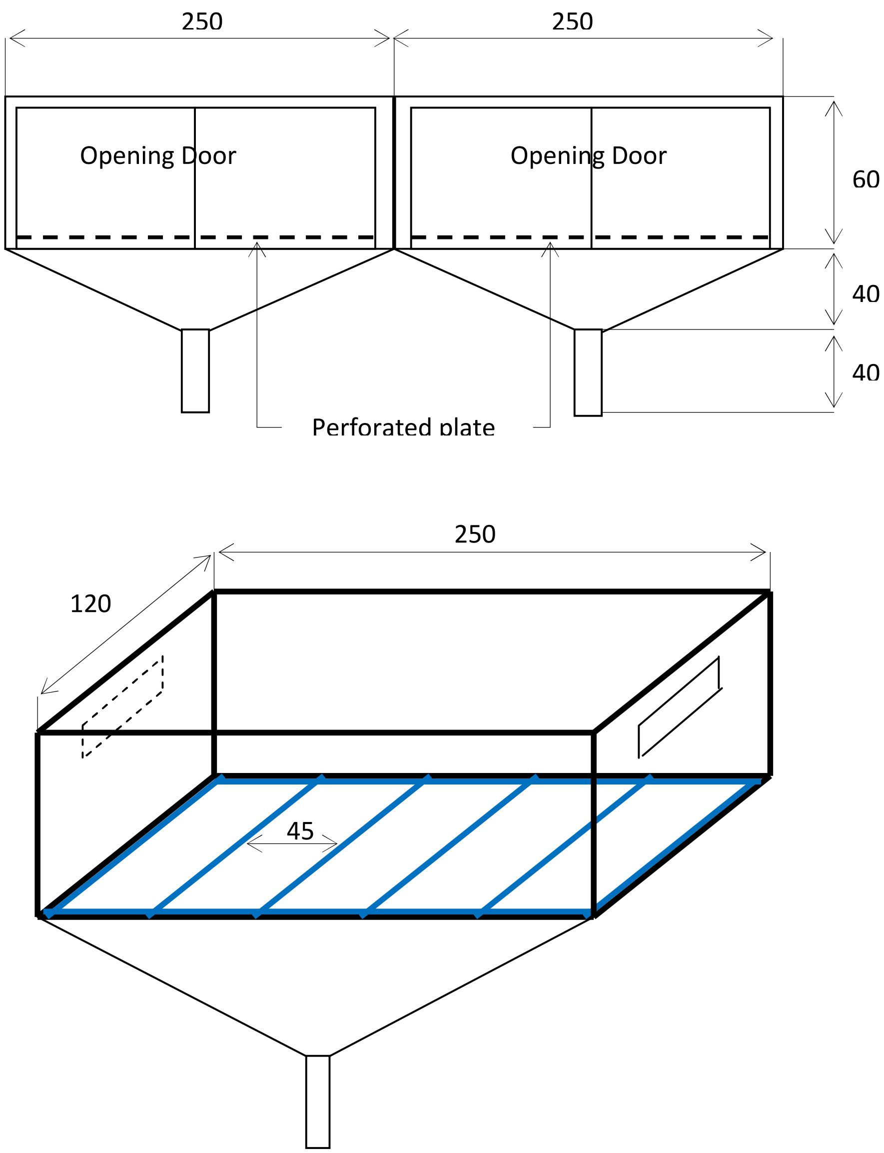


Figure 4.19 Details of the Drying Chamber

4.6 THE SUPPORT STRUCTURE

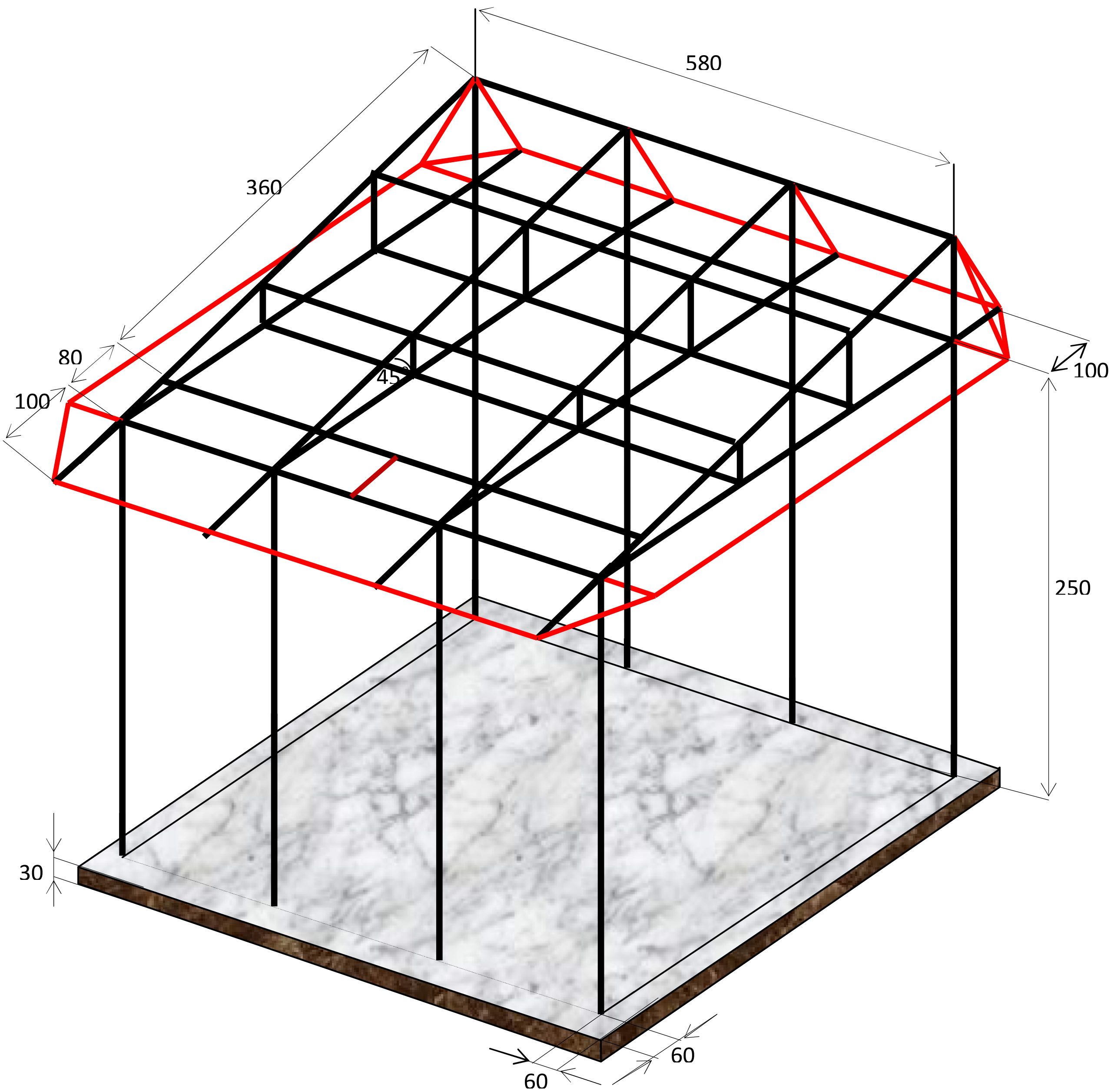


Figure 4.20a Details of the Collector Support Structures

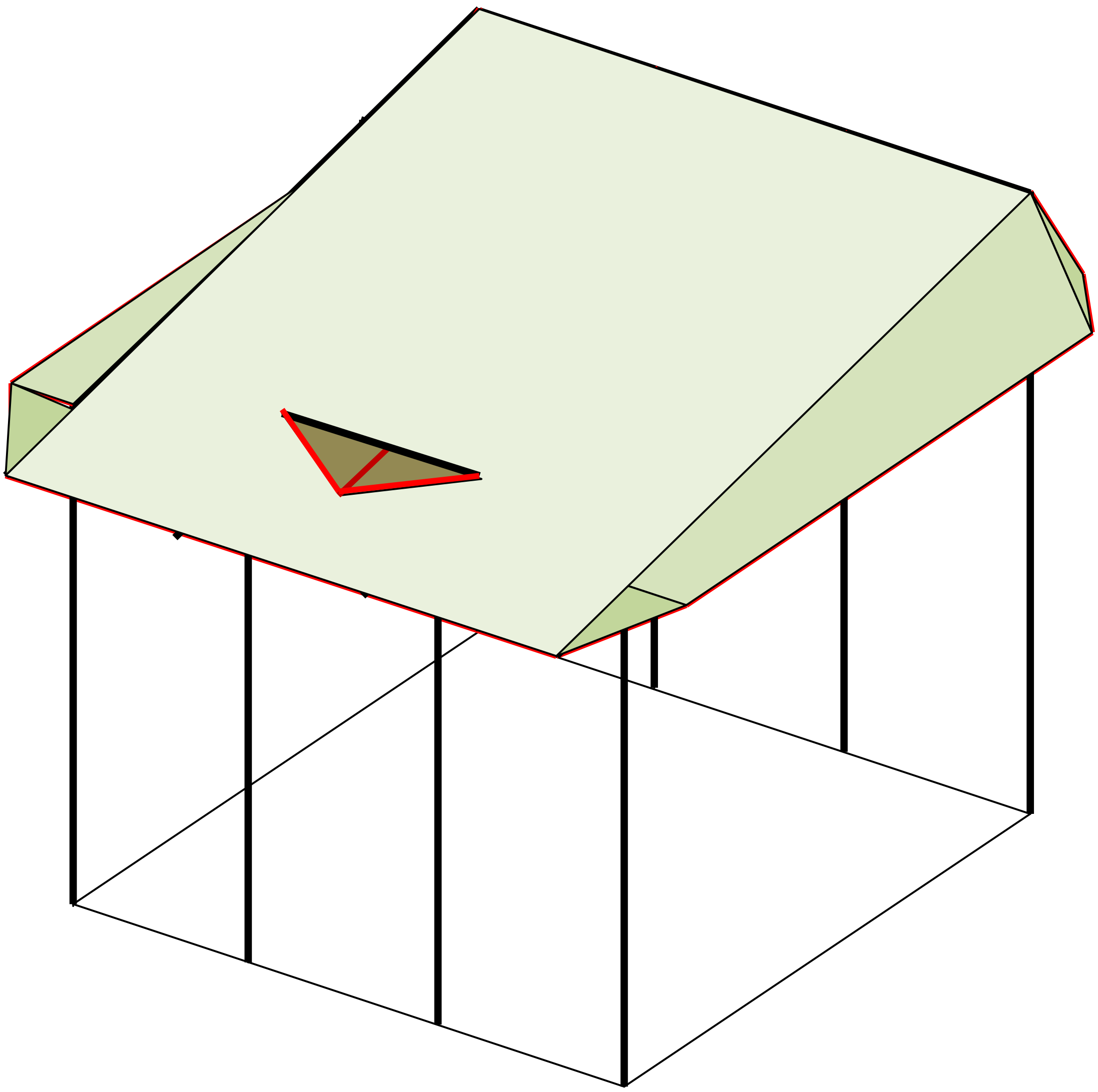


Figure 4.20b   Details of the Collector Support Structures

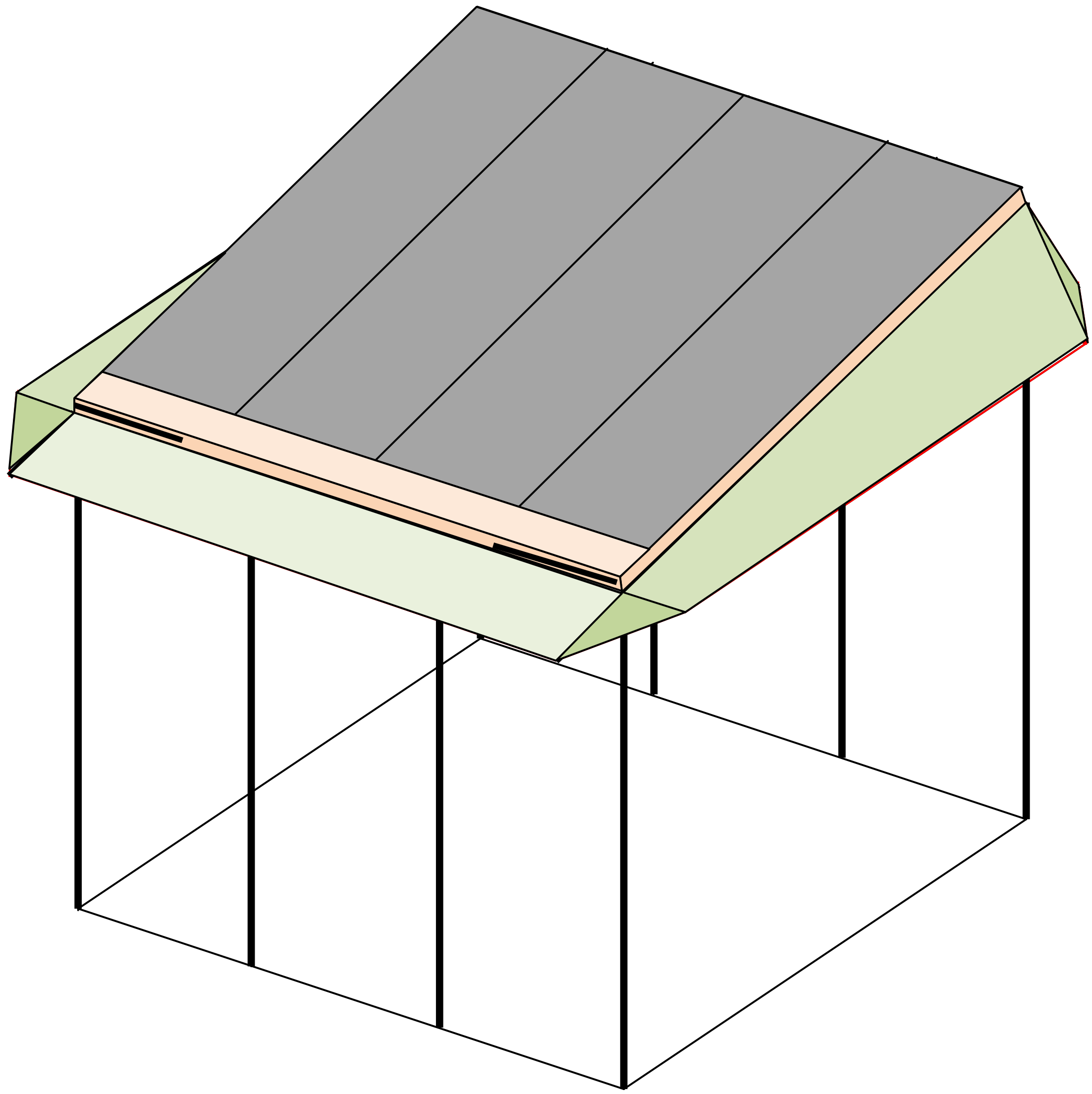


Figure 4.20c Details of the Collector Support Structures

4.7 MEASUREMENT OF DRYER PERFORMANCE AND DATA ACQUISITION SYSTEM

4.7.1 SYSTEM DRYING EFFICIENCY, ηd

The system efficiency is the ratio of the energy required to evaporate the moisture to the heat supplied to the dryer and is the measure of overall effectiveness

$$\eta = \frac{WL}{I_c A_c}$$

W = weight of moisture evaporated (kg)

L = Latent heat of evaporation of water (at temperature of dryer) (kJ/kg)

I_c = Solar radiation on collector surface (kJ/m^2)

A_c = Collector area (m^2)

4.7.2 COLLECTION EFFICIENCY, ηc

The collection efficient is related to the solar collector. It is the ratio of the heat received by the drying air to the isolation at the collector absorber.

$$\eta = \frac{V\rho C\Delta T}{I_c A_c} \times 100\%$$

V= volumetric flowrate of air (m^3/s)

ρ = Air density (kg/m^3)

Δ T= Air temperature elevation (C)

I_c = Solar radiation on collector surface (kJ/m^2)

A_c = Collector area (m^2)

4.7.3 PICK – UP EFFICIENCY, ηp

$$\eta = \frac{M_0 - M_t}{V\rho t(h_{as} - h_{i})}$$

Mo = Mass of commodity at time t=0 (kg)

Mt = Mass of commodity at time t (kg)

h_i = absolute humidity of air entering the drying chamber

h_{as} = adiabatic saturation humidity of the entering the dryer

T = drying time (s)

V= volumetric flowrate of air (m^3/s)

ρ = Air density (kg/m^3)

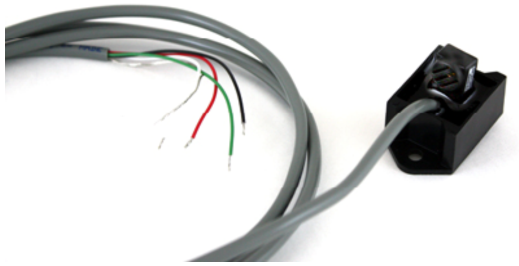
4.7.4 EXPERIMENTAL PARAMETERS

Instrumenting a solar assisted dryer to determine its operating characteristics is not difficult and the parameters are easy to measure provided the correct procedures are followed. The following parameters (with instrumentation use in brackets) are monitored.

- Air temperature – ambient, leaving the collector/entering the drying chamber, leaving the drying chamber (thermocouples)
- Relative humidity (sensors or wet bulb/dry bulb thermometers)
- Air flow rate (turbine flow meter)
- Pressure Drop (manometer)
- Solar radiation (pyranometer or solarimeter)
- Weight (load cell or weighing machines)

Figure 4.21 Pyranometer – Measure Global Solar Irradiation

4.22 Thermocouple – Measurement of temperatures



4.23 Humidity sensor – measurement of relative humidity

Figure 4.24 Load Cell – To measure weight loss of dried commodity

Figure 4.25 Turbine flowmeter – measurement of air flow rate

4.7.5 DATA ACQUISITION SYSTEM

A data acquisition system consists of many components that are integrated to sense physical variables, by using transducers to convert the physical variable to an electrical signal, then condition that electrical signal to make it readable by an analog-to-digital converter. After being converted by the A/D, a computer can then read that data and process, analyze, store and display the acquired data with the help of software.

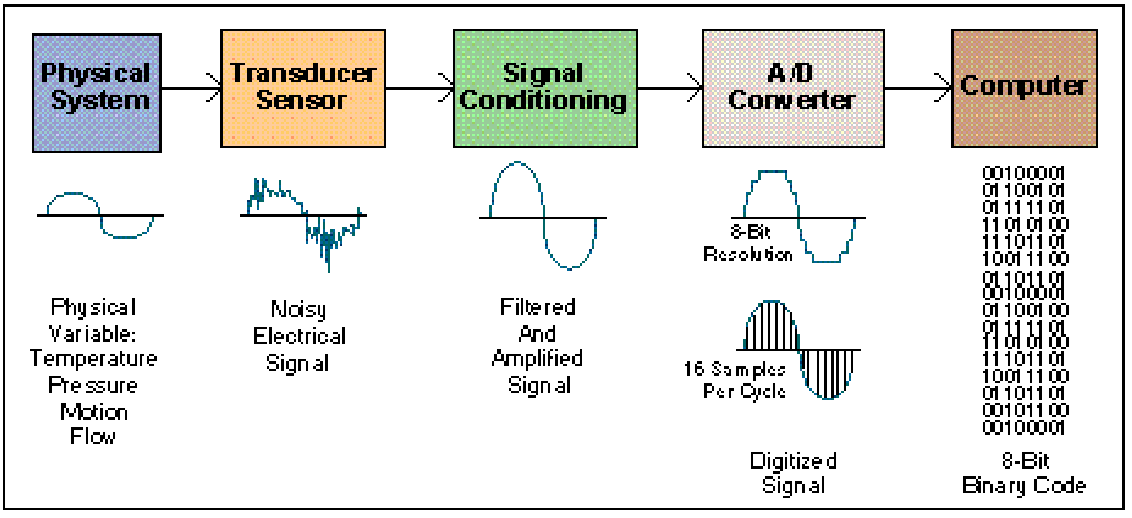


Figure 4.26 Data Acquisition System Block Diagram

In the signal conditioning stage, electrical signals are conditioned so they can be used by an analog input board. The signal may be conditioned by amplification, where the power of the signal is increased to make it easier to read in more detail. Isolation may also occur, so that the input and output circuitry do not interfere with each other. The signal may also be filtered, to remove noise or unwanted frequencies from the signal. Linearization happens to help make the output proportional to the input. An A/D converter takes a continuous analog input signal, such as a strain gage, and converts it to a digital signal. A digital signal is either on or off, like a light switch.

Data acquisition software can be the most critical factor in obtaining reliable, high performance operation. Software transforms a personal computer and data acquisition software into a complete acquisition, analysis, and display system. There are different types of data acquisition software... custom programmable software and pre-built data acquisition software packages. The alternative is to use data acquisition software. This does not require traditional programming.

Developers can design custom instruments best suited to their application. Examples are Testpoint, SnapMaster, LabView, DADISP, DASYLAB, and others. There are many factors to consider while designing a Data Acquisition System.

Is it a fixed or a mobile application?

What is the type of input/output signal: digital or analog?

What is the Frequency of input signal ?

What is the needed Resolution, range, and gain?

Is it important to have Continuous operation?

Is there Compatibility between hardware and software. Are the drivers available?

What is the Overall price of the system?

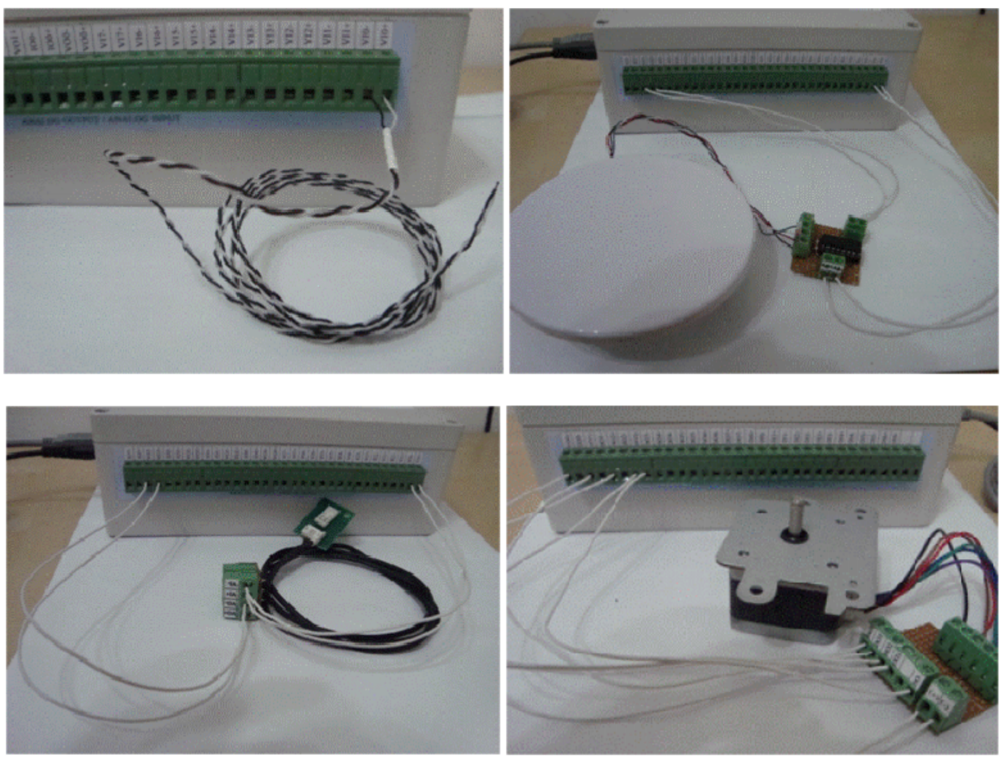
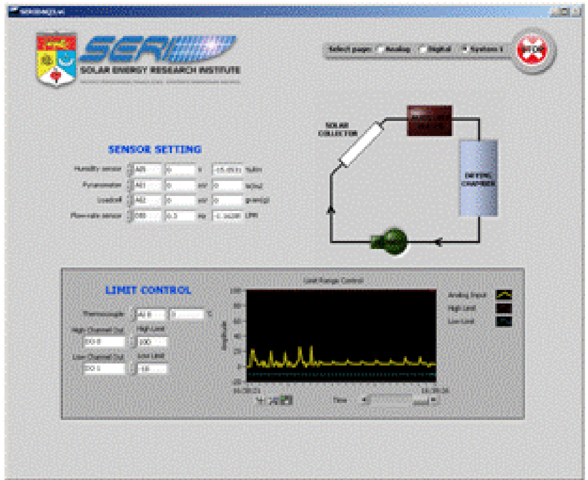


Figure 4.27 Data acquisition sensors



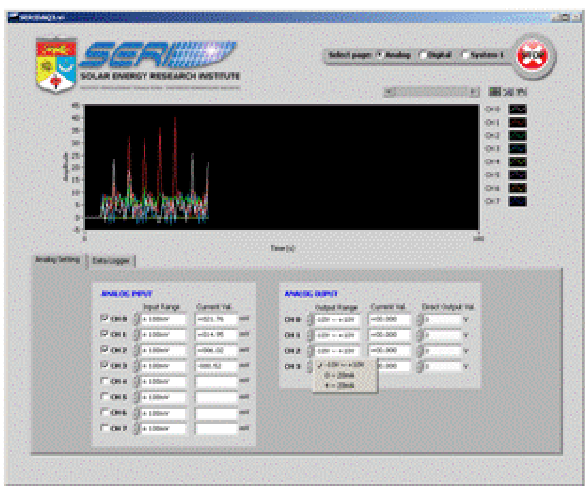


Figure 4.28 Data acquisition software display

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