RICE INDUSTRY TOWARDS 100% SSL

NAPiCEX 2015

Adding Solar Thermal Drying Technology into Paddy Value Chain in Enhancing Both Yield and Bottom Line

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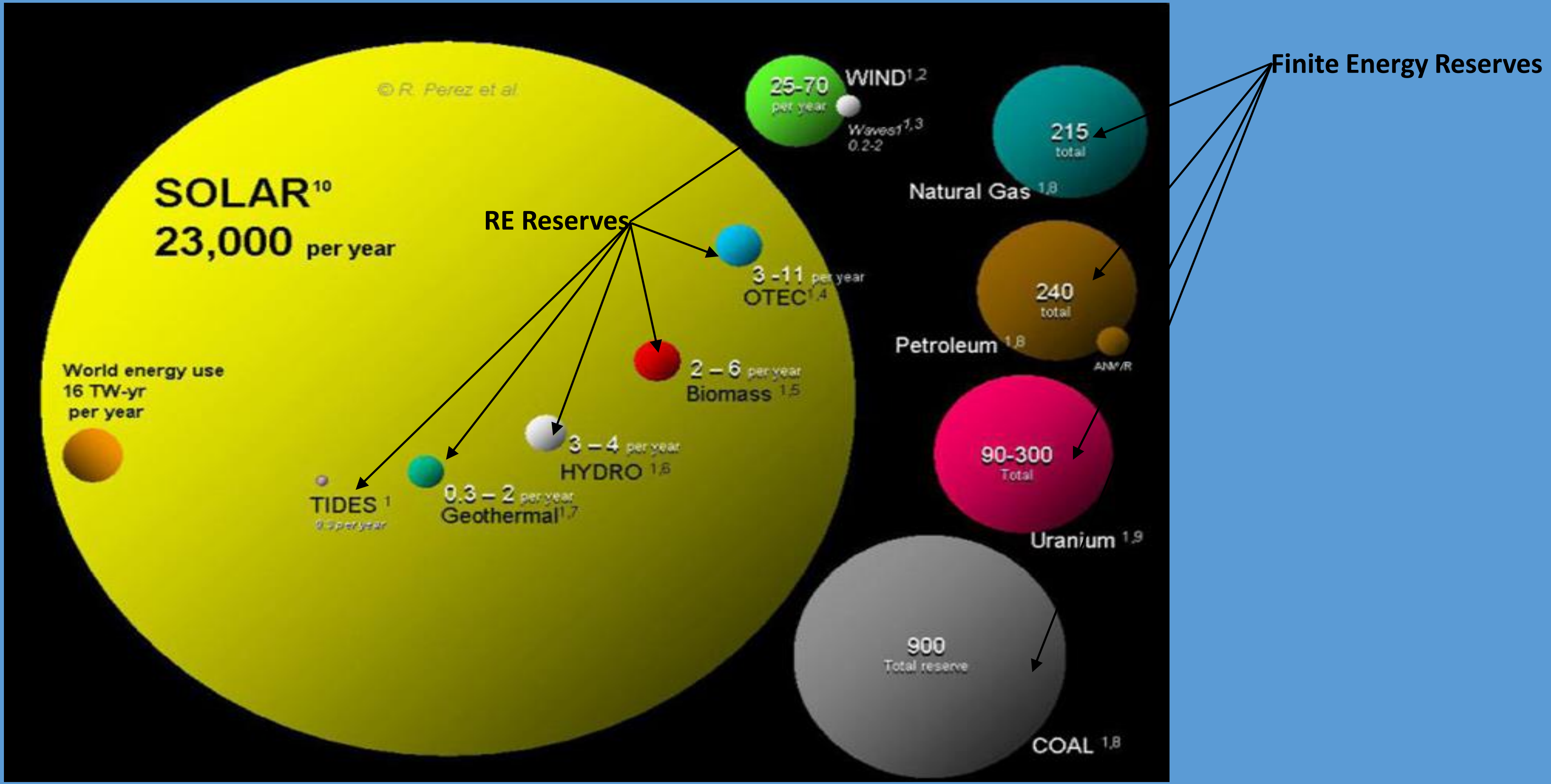
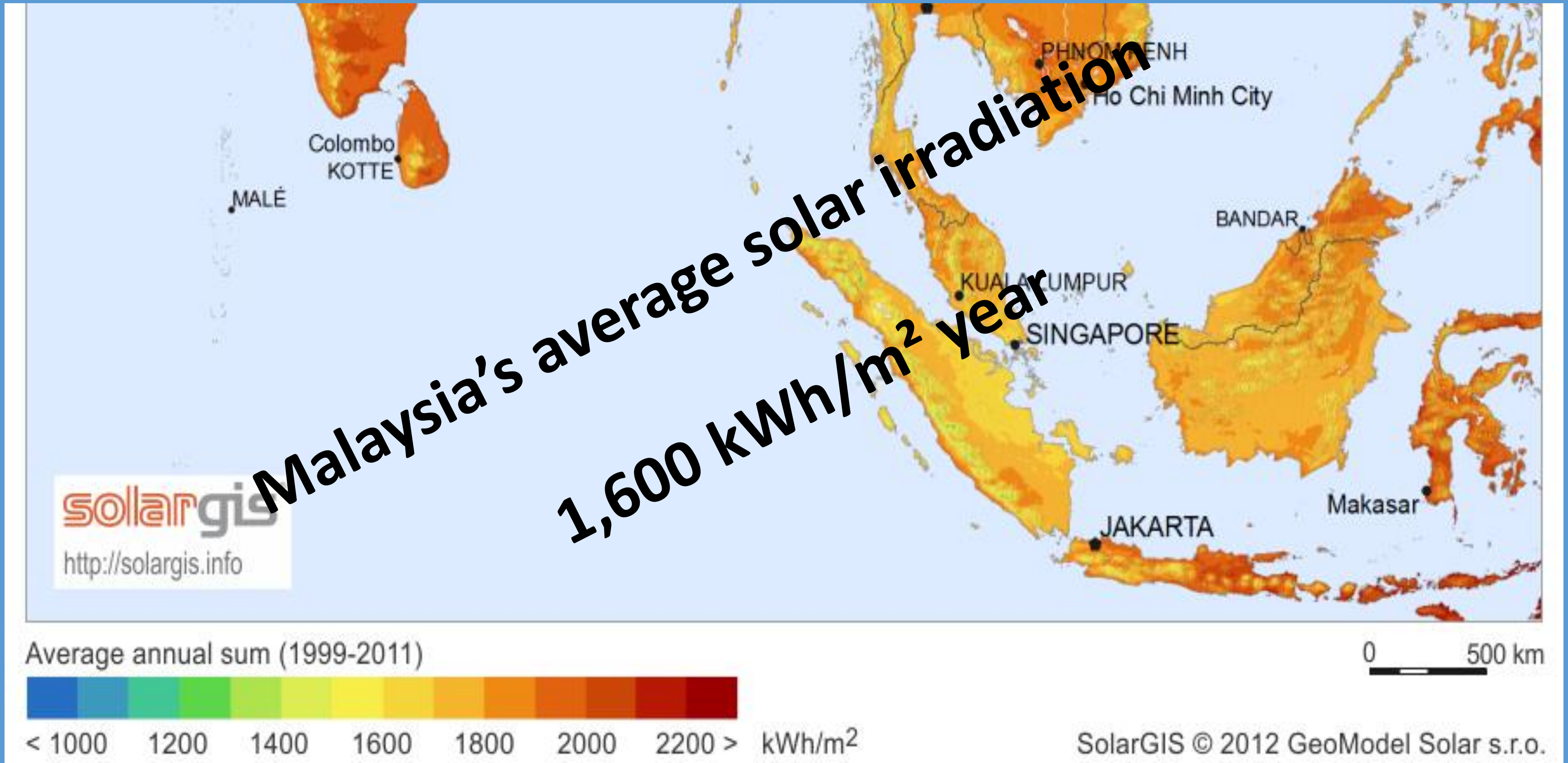


Fig 1: The Power of Solar Energy Comparing Finite and RE Reserves (in TWh /year).

Source: Richard Perez of the University of Albany, NY, USA; Marc Perez of AltPower Inc., NY, USA

Solar Irradiation Malaysia



Why Paddy Drying ?

- Rice is harvested at high moisture contents >20%
- Quality deterioration starts immediately after harvest
- The wetter the grain the faster the loss of quality
- Different MC for different purposes (see Table)

Purpose	Required MC	Potential problems
2 - 3 weeks storage	14 - 18%	Molds, discoloration, respiration loss
8 - 12 months storage	<= 13%	Insect damage
> 1 year storage	<= 9 %	Loss of viability
Milling	14%	Damaged grains, cracking

Improper Drying

- **Heat build-up**
  - from natural respiration
  - excellent growth conditions for molds and insects
- **Mold development**
  - propagate diseases in the grain
  - may release toxins into the grain
  - proper drying and storage can reduce propagation of molds
- **Insect infestation**
  - insects are always a problem in stored grain
  - at lower moisture content insect activities are lower
  - proper drying helps keeping insects at acceptable level (4 insects per kg)

Improper Drying

- **Discoloration/Yellowing**
  - heat build-up in the paddy grain before drying
  - drastically reduces the market value of rice
- **Loss of germination and vigor**
  - active respiration depletes the nutrition reserves
  - molds and diseases can reduce the ability of the seed to germinate
  - the lower the MC at the beginning of storage, the longer the seed remains viable

Improper Drying

- **Loss of freshness/odor development**
  - Heat build up -> musty odor in rice.
  - Reduces the market value of rice.
  - If from mycotoxin-producing fungi rice might become unusable.
- **Reduced head rice yield**
  - moisture adsorption of individual dry grains with moisture contents below 16% - fissuring
    - mixing dry with wet grains
    - Exposing dry grains to humid air
  - Fissures cause cracking in milling process -> reduced the head rice recovery.

Equilibrium Moisture Content (EMC)

- Rice is hygroscopic
- Equilibrium moisture content (EMC)
  - If grain is exposed to air for a longer time it will reach EMC
  - Dry grain will adsorb water from humid air
  - Wet grain will dry
- Grain properties
  - Moisture Content, MC
  - Temperature
- Air properties
  - Relative Humidity, RH
  - Temperature

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Milling	14%	Damaged grains, cracking

	Storage Temperature (°Celcius)						
Relative Humidity	22°C	24°C	28°C	32°C	36°C	40°C	44°C
50%	11.2	10.9	10.7	10.5	10.2	10.0	9.9
55%	11.7	11.5	11.2	11.0	10.8	10.6	10.4
60%	12.3	12.0	11.8	11.6	11.4	11.2	11.0
65%	12.7	12.6	12.4	12.2	12.0	11.8	11.6
70%	*13.5*	13.3	13.1	12.8	12.6	12.5	12.3
75%	14.3	*14.0*	*13.8*	13.6	13.4	13.2	13.0
77%	14.6	14.2	*14.1*	***13.9***	13.7	13.5	13.4
79%	14.9	14.7	14.5	14.3	*14.1*	*13.9*	13.7
81%	15.3	15.1	14.9	14.6	14.5	14.3	*14.1*
83%	15.7	15.7	15.3	15.1	14.9	14.7	14.5
85%	16.1	15.9	15.7	***15.5***	15.3	15.1	15.0
87%	16.6	16.4	16.2	16.0	15.8	15.6	15.5
89%	17.2	17.0	16.8	16.6	16.4	16.2	16.1
91%	17.9	17.7	17.5	17.3	17.1	16.9	16.7

INNOVATIVE SOLAR SYSTEMS & TECHNOLOGY FOR PADDY DRYING

- Most of the Solar Dryers Systems have been Designed for Specific Products
- Quality Requirements; Characteristics of Product and Economic Factors affect the Choosing of Solar Dryer
- Four Types of Solar Dryers;
    - Direct solar dryer
    - Indirect solar dryer
    - Mixed-mode dryer
    - Hybrid solar dryer
- Based on System Design and Energy Utilization Mode, System can be Categorized :
    - Passive dryers
    - Active dryers.

INNOVATIVE SOLAR SYSTEMS & TECHNOLOGY FOR PADDY DRYING

- In order to Ensure the Safety and Guarantee the Quality of the Product, **Heat Pump Low Temperature Thermal** makes the System an Admirable Match for Domestic and Industrial Thermal Applications
- Combination of Solar Technology and **Heat Pump** make the System more Efficient in Energy Utilization.
- There are Three Influencing Factors regards **Heat Storage** that Affects Drying of the Product:
  - Drying Period can be Extended, Based on the Stored Energy,
  - Extra Energy can be Stored, To Avoid from Over Drying the Products,
  - Controlled Drying Air temperature, To Stay Away from Any Material Damages

INNOVATIVE SOLAR SYSTEMS & TECHNOLOGY FOR PADDY DRYING

- The Structure of All Types of Solar Dryers Consists of Three Parts:
  - Solar Collector
  - Drying Chamber
  - Chimney
- Important Parameters for Designing a Solar Dryer:
  - Collector Design
  - Efficiency of System,
  - Storage Unit
  - Drying System Practical Life

The Potential of Solar Thermal Technologies in Paddy Drying

- The solar thermal system technology can heat large volumes of incoming air up to 55°C (100°F) above ambient, making it ideally suited for many crop drying applications
- The solar air heating system may provide all of the heat during a sunny day or act as a pre-heat during cloudy conditions. It can either act in a standalone capacity via modular solar thermal system, or as a pre-heat to traditional mechanical operation dryers

Solar Collector on the Roof Top

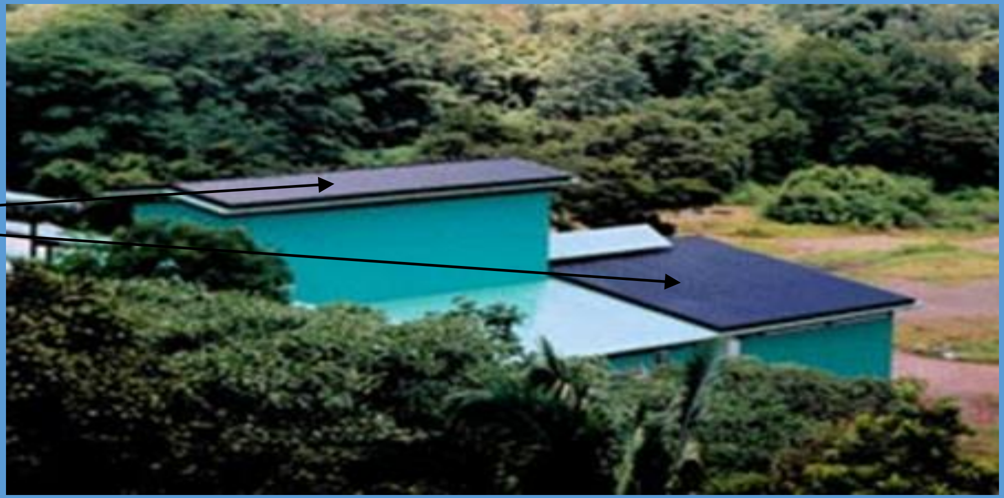


Fig 5: Solar Thermal System is used to dry coffee beans in Panama

The Potential of Solar Thermal Technologies in Paddy Drying

- Many of the world's most important crops need to be dried to remove moisture as part of the production process
- Removing the moisture from crops such a coffee beans, tea leaves, cocoa, nuts, fruit, *rice*, spices, corn, etc. is an essential process that helps transform the raw goods into the final product

The Potential of Solar Thermal Technologies in Paddy Drying

- It is also extremely resource intensive when using mechanical drying methods that rely on wood, propane or oil
- In more traditional drying operations, it is common for produce to be passively air-dried in the sun, which takes significantly longer than mechanical drying and can lead to a higher rate of spoilage, mycotoxins and uneven moisture levels
- Agricultural and agri-food operators consume tremendous quantities of energy which represent a sizable proportion of their total input costs
- Rising energy prices has been putting downward pressure on agricultural incomes in countries around the world, which is why solar thermal energy represents a tremendous opportunity for the agricultural sector
- Incorporating solar thermal technology into a drying operation produces a double-benefit in terms of improving both the process of drying and the final product

The Potential of Solar Thermal Technologies in Paddy Drying

- Substantially reduces the dependency on fossil fuels or electricity has a myriad of positive effects, including:
  - Lower operating costs
  - Decreased reliance on fuels that need to be transported to remote sites
  - Counteracting deforestation by reducing the quantity of trees that are harvested for fuel
  - Lower humidity in the incoming air (because it is heated before entering the building or drying chamber) which means that the air has been preconditioned to absorb more moisture
  - GHG emission reductions
  - Producing a high quality finished product that is eco-friendly and was processed using "clean & green" energy
  - Proper drying is also associated with a decreased incidence of mycotoxins, especially on corn (maize) and other crops. Adequate drying of crops is essential to help minimize the risk of mould growth and mycotoxins after the harvesting of crops

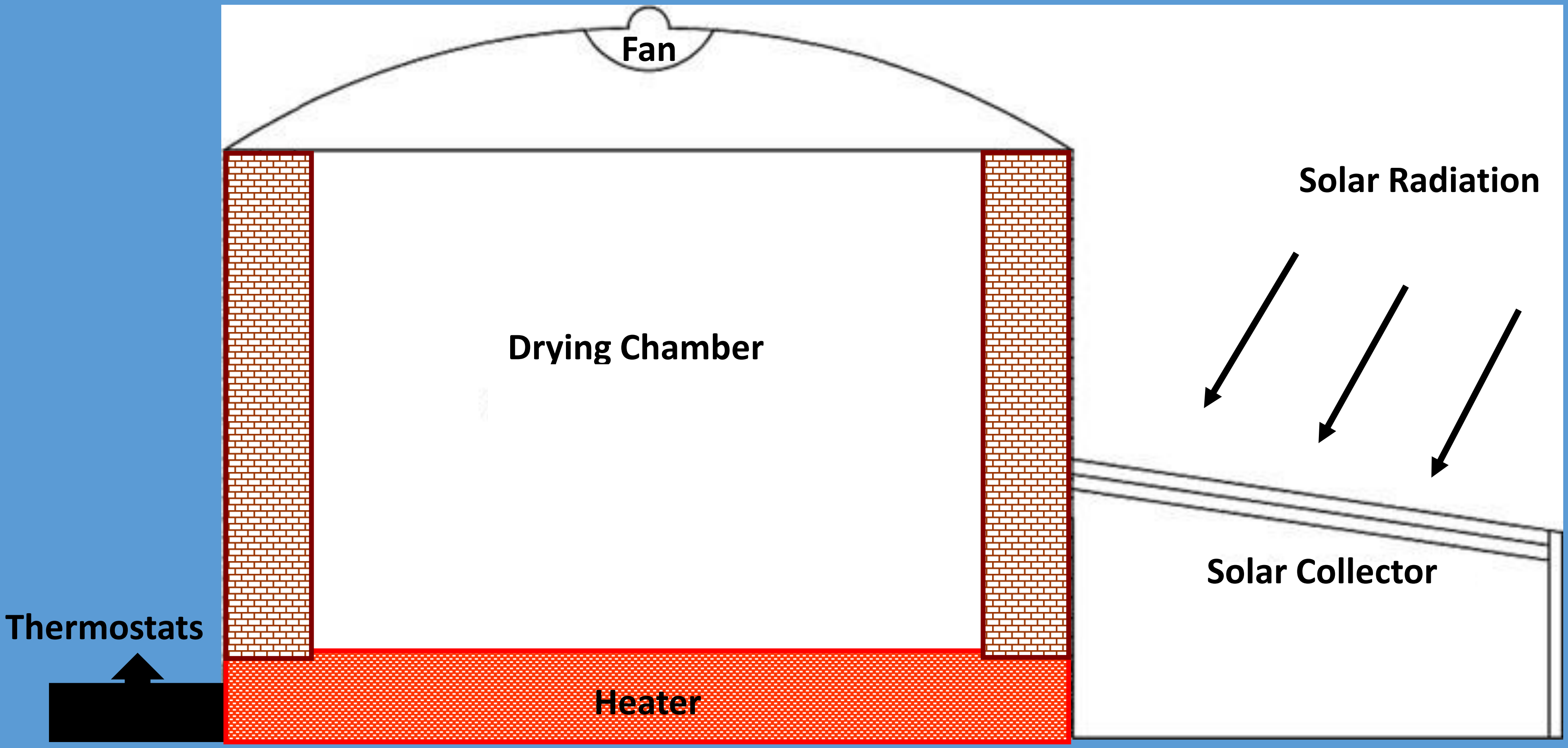
The Potential of Solar Thermal Technologies in Paddy Drying

- Substantially reduces the dependency on fossil fuels or electricity has a myriad of positive effects, including:
  - Solar thermal systems may reduce or eliminate poly-aromatic hydrocarbons (PAHs) created by displacing conventional fossil fuels used in active drying systems
  - As countries around the world embrace the principals of organic agriculture and sustainable production, they are also looking at how their food is processed and if it is safe and eco-friendly.

Fig 6. Jujube Drying China

Fig 7. Cocoa Drying Malaysia

Fig 2: Schematic Diagram of Solar Thermal Dryer



Installed Capacity and Market Potential Solar Thermal Drying

- Almost all industrial process heat demand requires heat in temperature ranges that can be provided by a solar thermal system. Most applications are in the low to medium temperature ranges (Table 1)
- An extremely high percentage of heat demand in the low temperature range is found in
    - food,
    - beverages
    - paper and
    - textiles
- With medium temperature ranges in the
    - Plastics
    - Chemical Industries
- These industries require more than 50% of their total process heat in the temperature range up to 250°C for such diverse applications as drying, cooking, cleaning, extraction and many others (IEA, 2007a; Taibi *et al.,* 2012).

Installed Capacity and Market Potential for Solar Thermal System

Industrial Operation Temperature Range (°C)

Food

Drying 30-90
Washing 60-90
Pasteurising 60-70

Paddy Drying Temperature

Beverage

Boiling 95-105
Sterilising 110-120
Heat Treatment 40-60
Washing 60-80
Sterilising 60-90
Pasteurising 60-70
Cooking & Drying 60-80

Table 1: Industrial Processes and Temperature Levels

Selection of Collector for Process Heating Applications

The following are the collector types suitable for heating process in the range of 20 ^{O}C to 200 ^{O}C

- Flat-plate collector (FPC)
- Double-covered flat-plate collector (FPC-DG)
- Evacuated tube collector (ETC)
- Evacuated tube collector with flat reflector (ETC-FR)
- Evacuated tube collector with CPC-reflector (ETC-CPC)

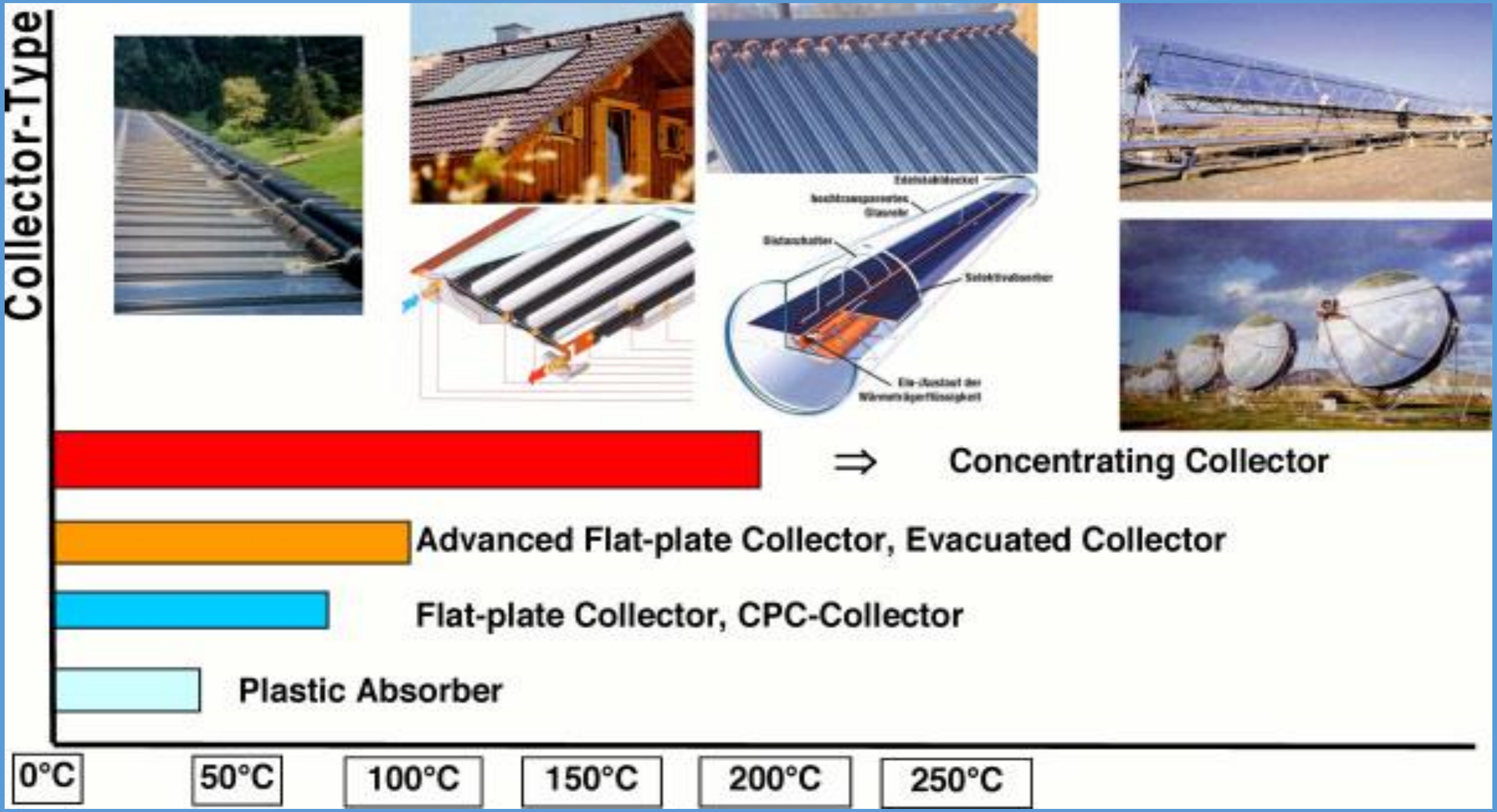


Fig 3. Collector Types and Working Temperatures for Solar Thermal Systems

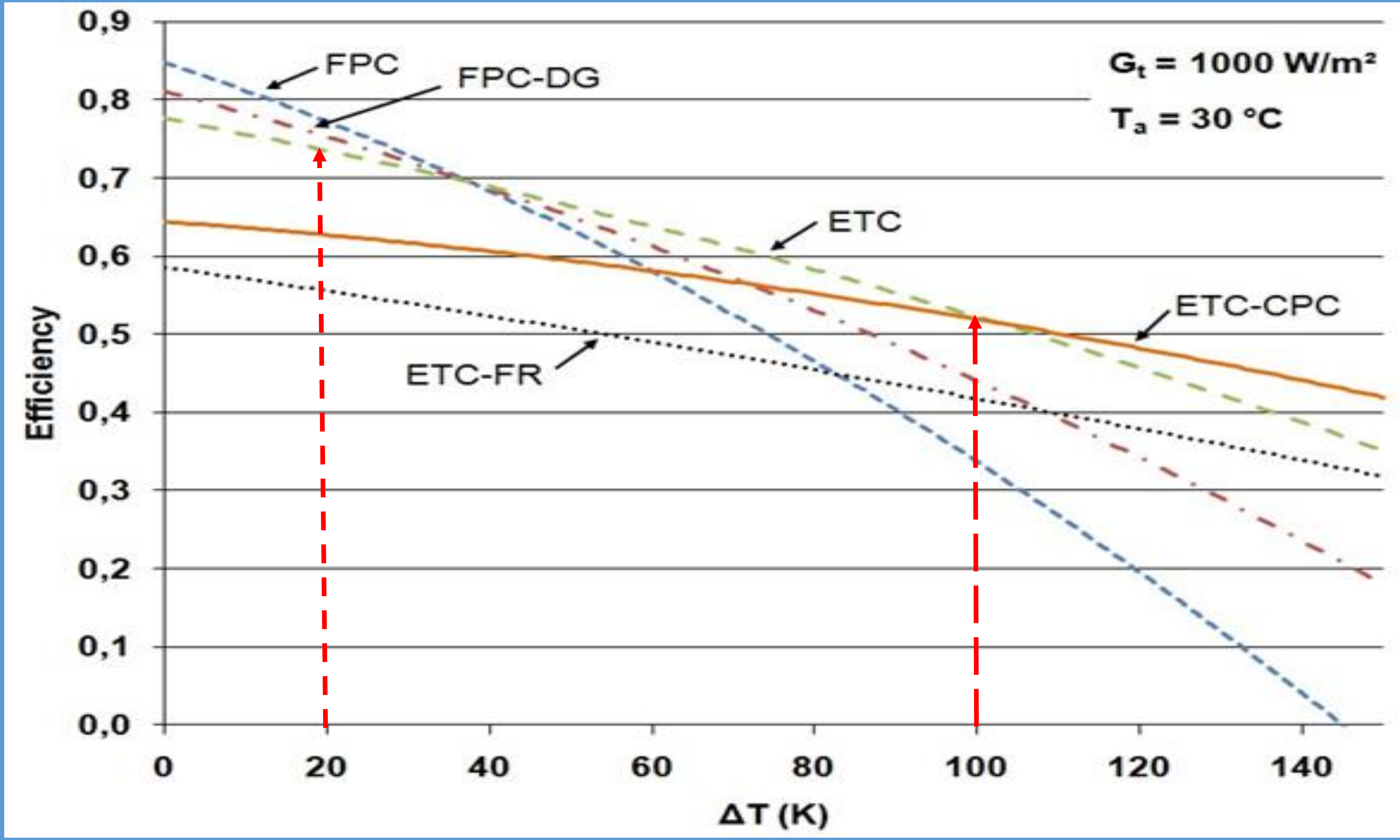


Fig. 4: Efficiency Curves for Each Collector Type

Fig 8. Solar Dryer for Farms

System Design for Paddy Solar Drying

- Solar drying is an alternative option to conventional sun drying and hot air drying for several reasons, mainly due to the unlimited and renewable source of solar radiations, which can be harvested by using appropriate solar collector system
- This eliminates the use of fossil fuels and reduces environmental impact due to consumption of non-renewables (Green and Schwarz, 2001).
- Generally, Solar Drying Shows Several Benefits as Follows; (Esper and Mühlbauer, 1998)
  - Significant Improvement in Product Quality (colour, texture and taste)
  - No Contamination by Insects, Microorganism and Mycotoxin
  - Reduction in Drying Time up to 50%
  - Reduction of Drying and Storage Losses
  - Considerable Increase in Shelf life of Dried products.

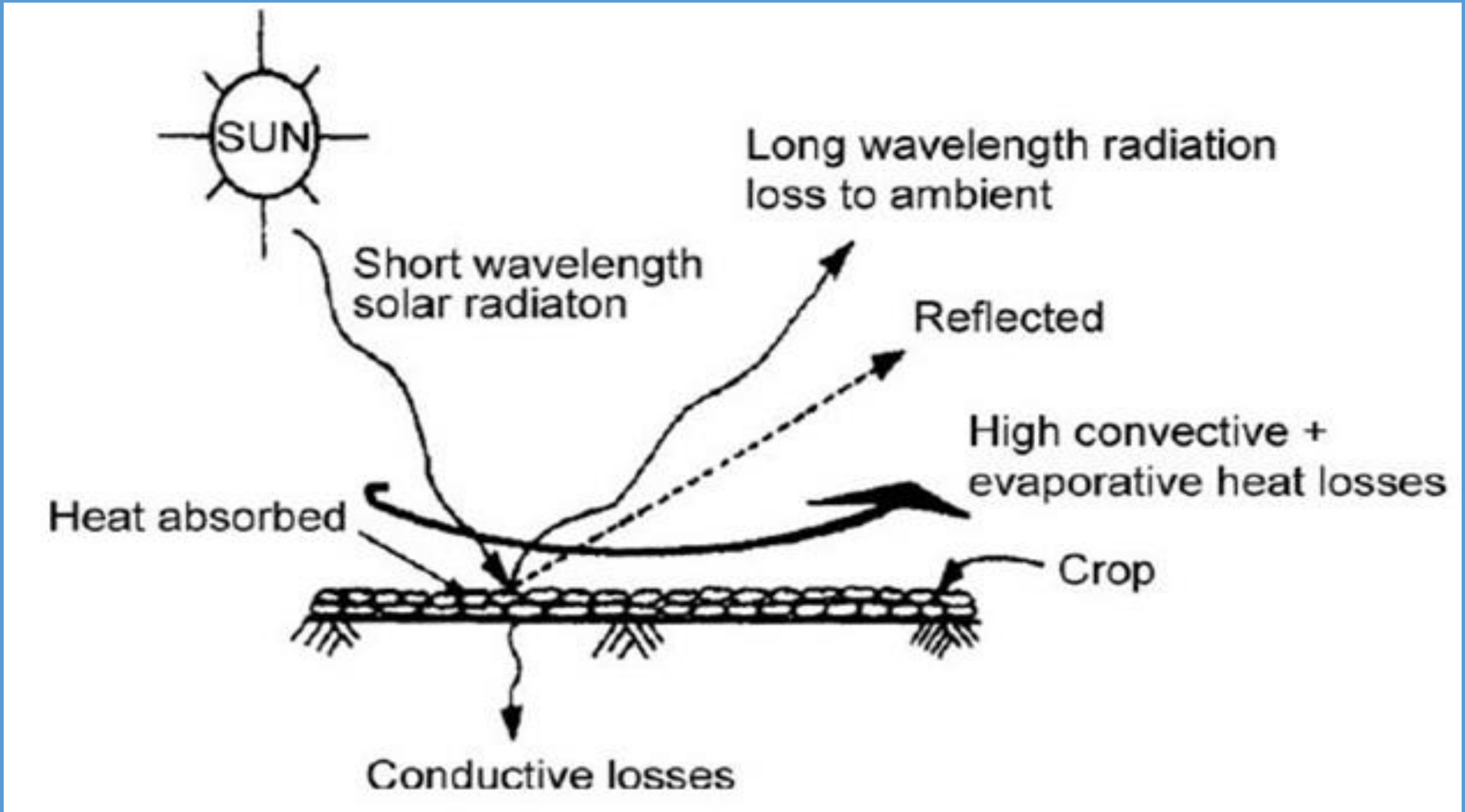


Fig 9. Working Principle of Open Sun Drying (Sharma et al. 2009)

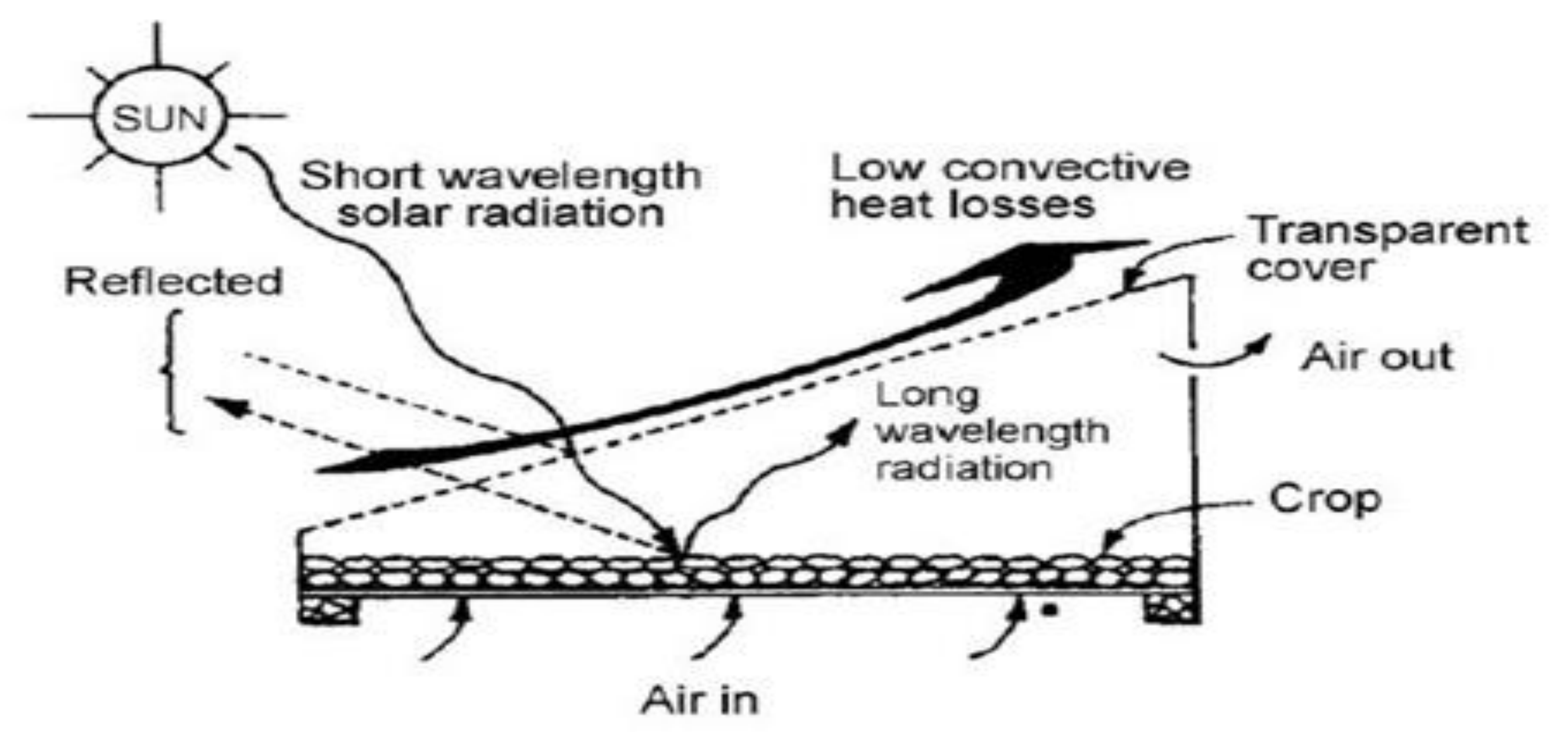


Fig 10. Working Principle of Direct Solar Drying (Sharma et al. 2009)

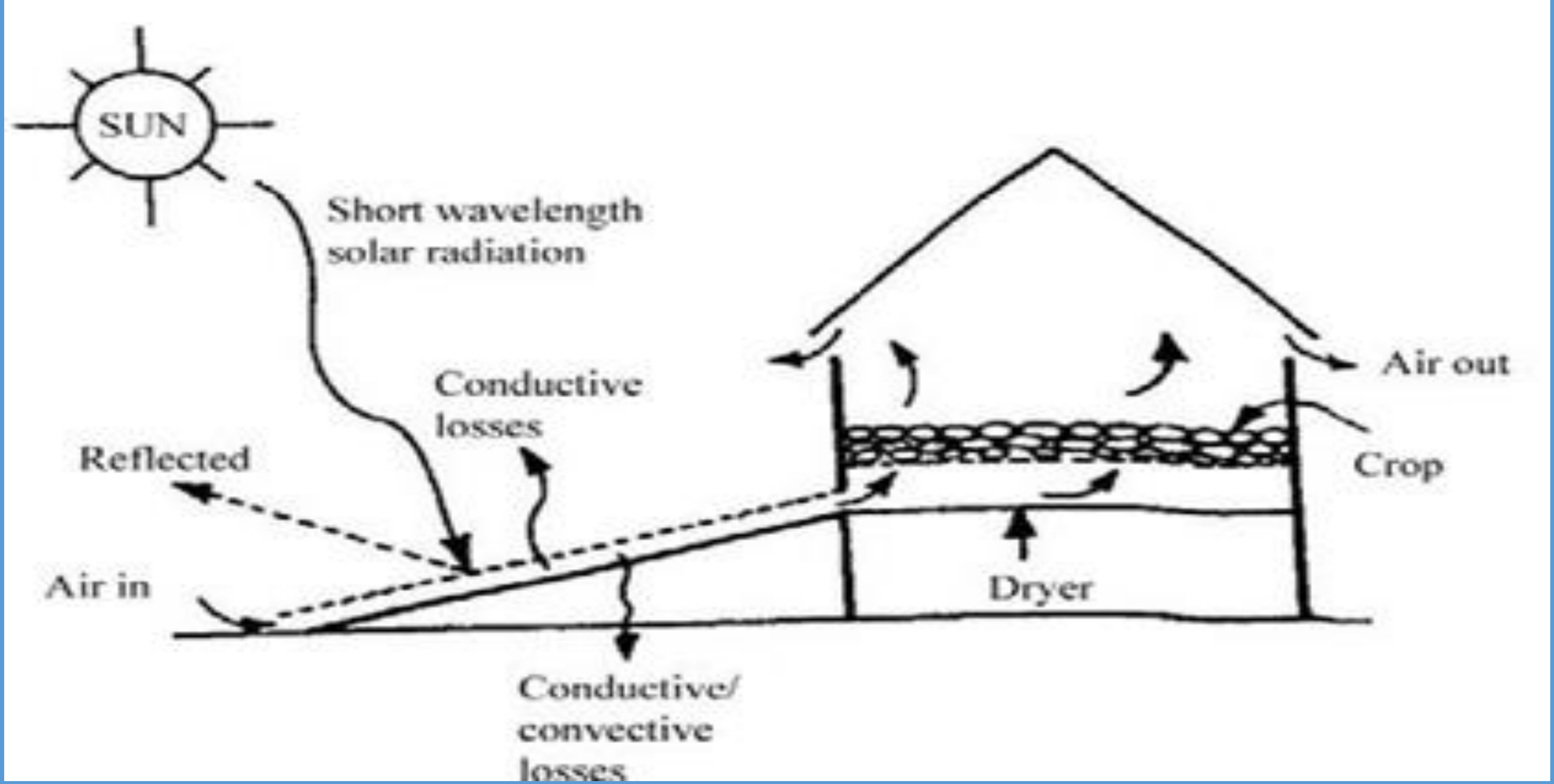


Fig 11. Working Principle of Indirect solar Drying System (Sharma et al. 2009)

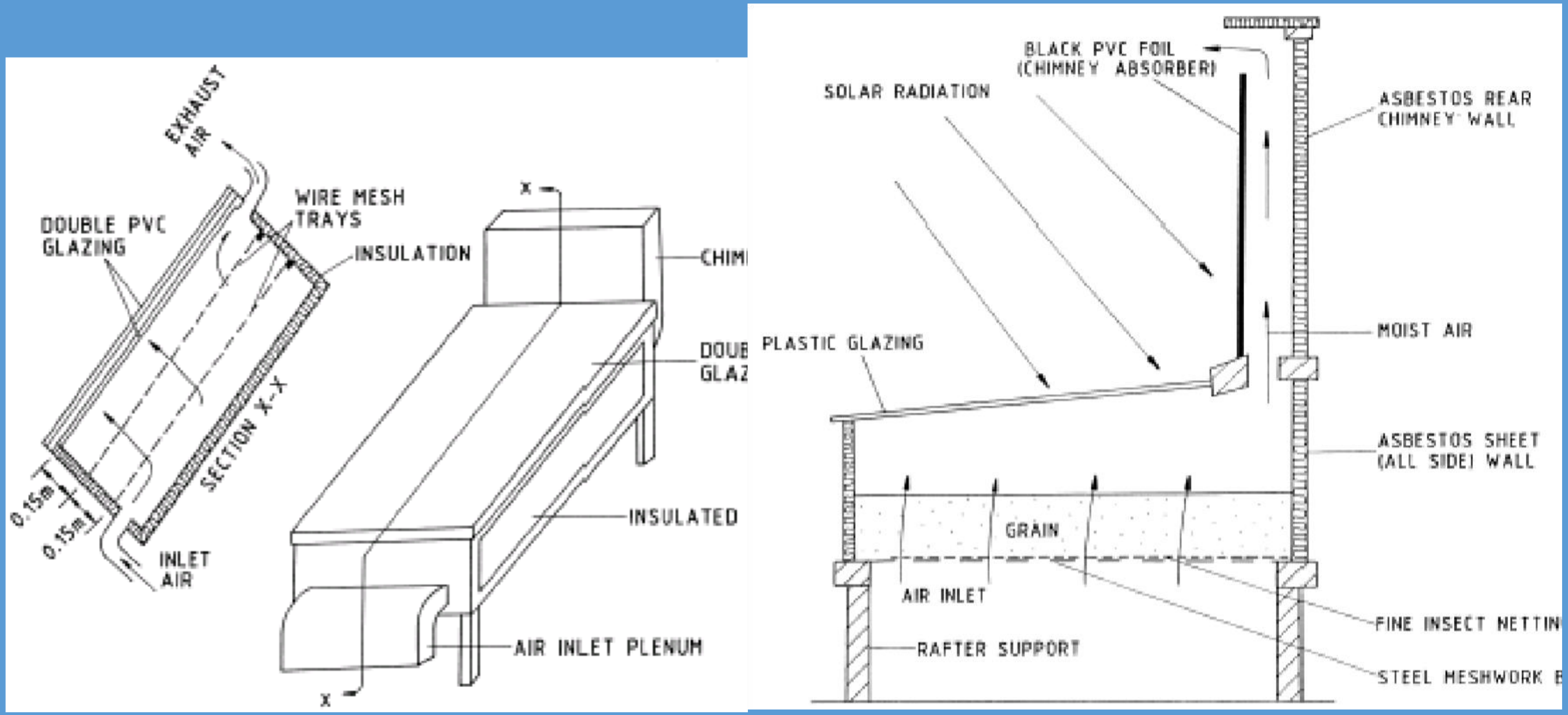
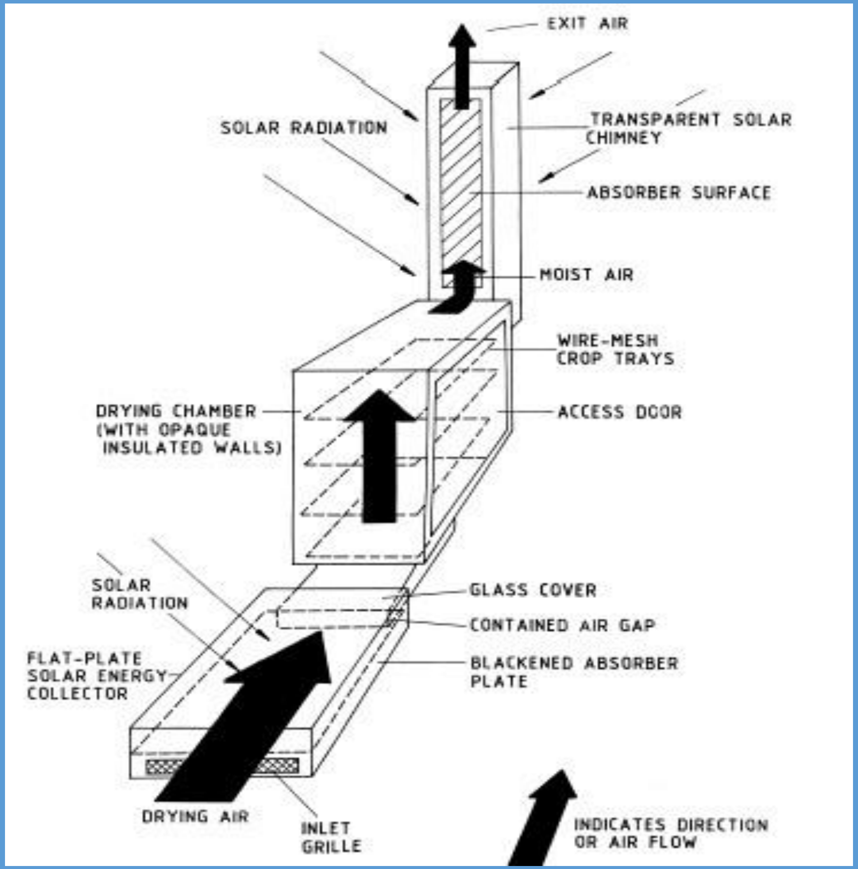


Fig 12. A Direct Passive Natural-Circulation Solar Energy Cabinet Dryer (Ekechukwu and Norton, 1999)



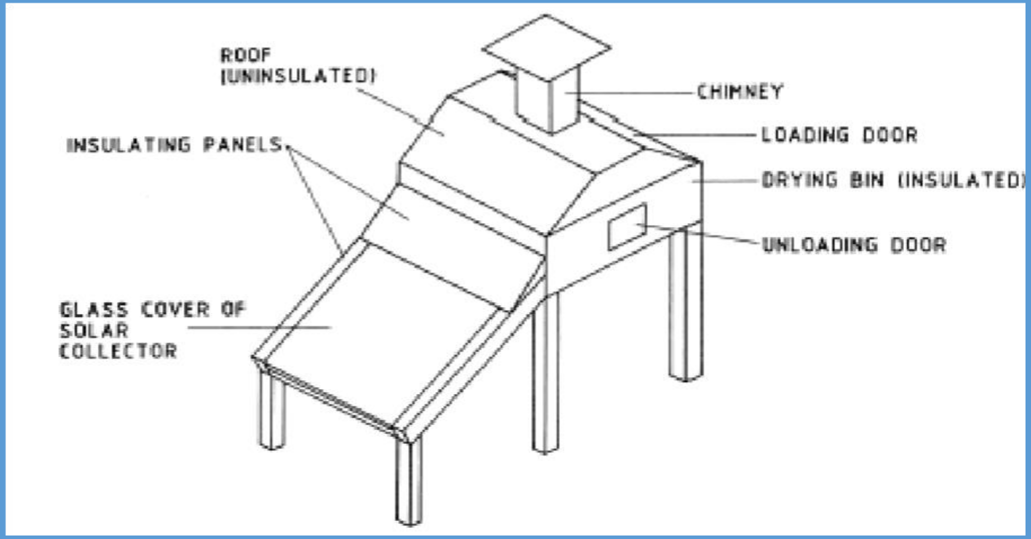
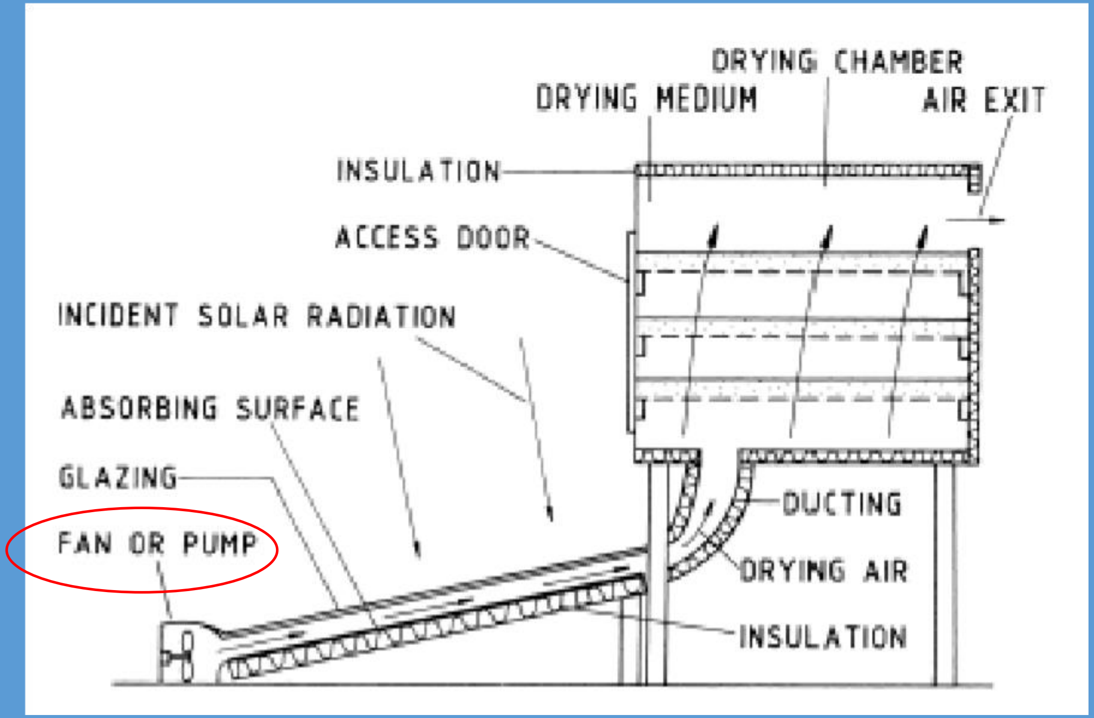


Fig 13. Indirect Passive Natural-Circulation Distributed-Type Solar Dryer (Ekechukwu and Norton, 1999)



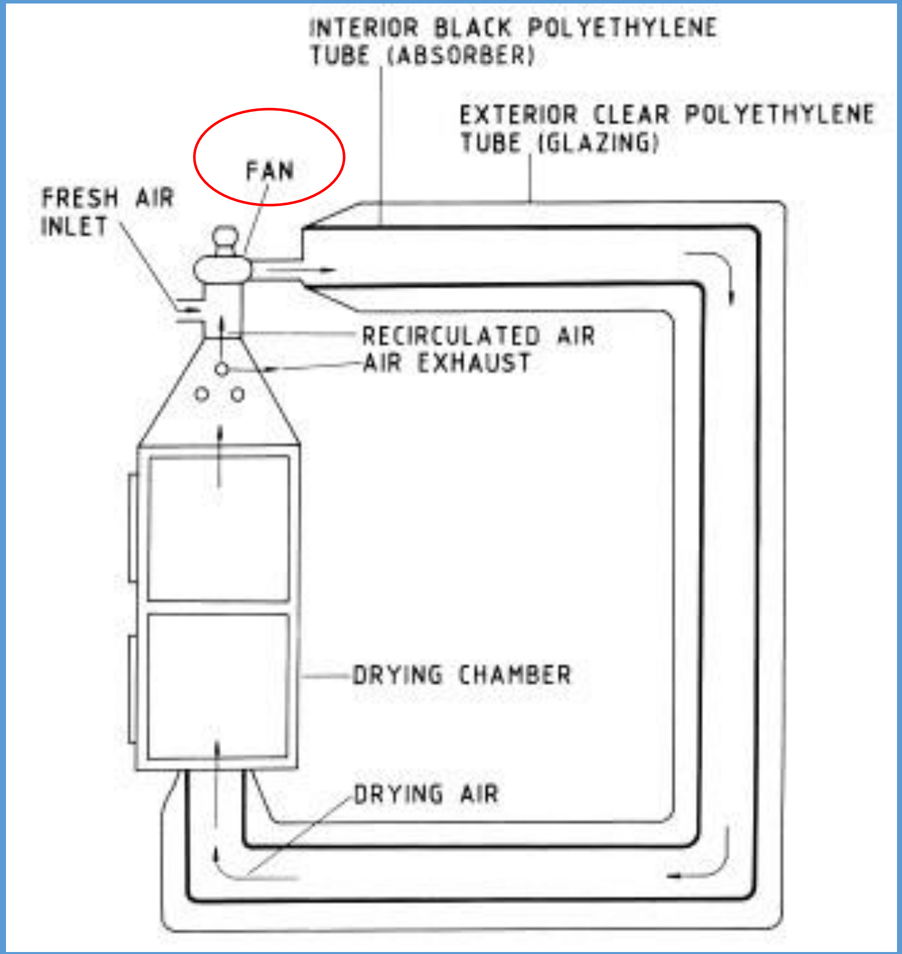
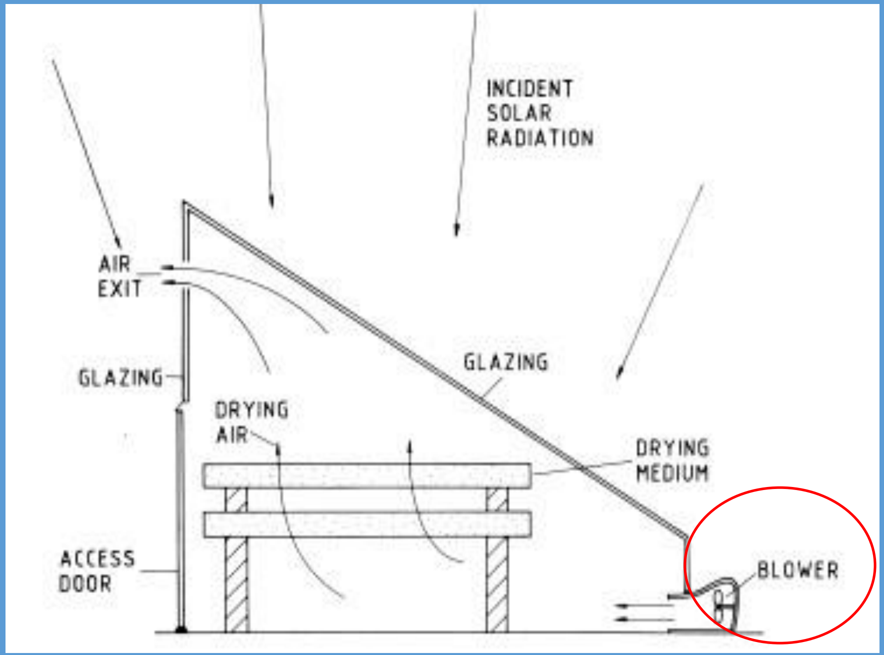


Fig 14. Indirect Active Type Solar Energy Dryer
(Ekechukwu and Norton, 1999)



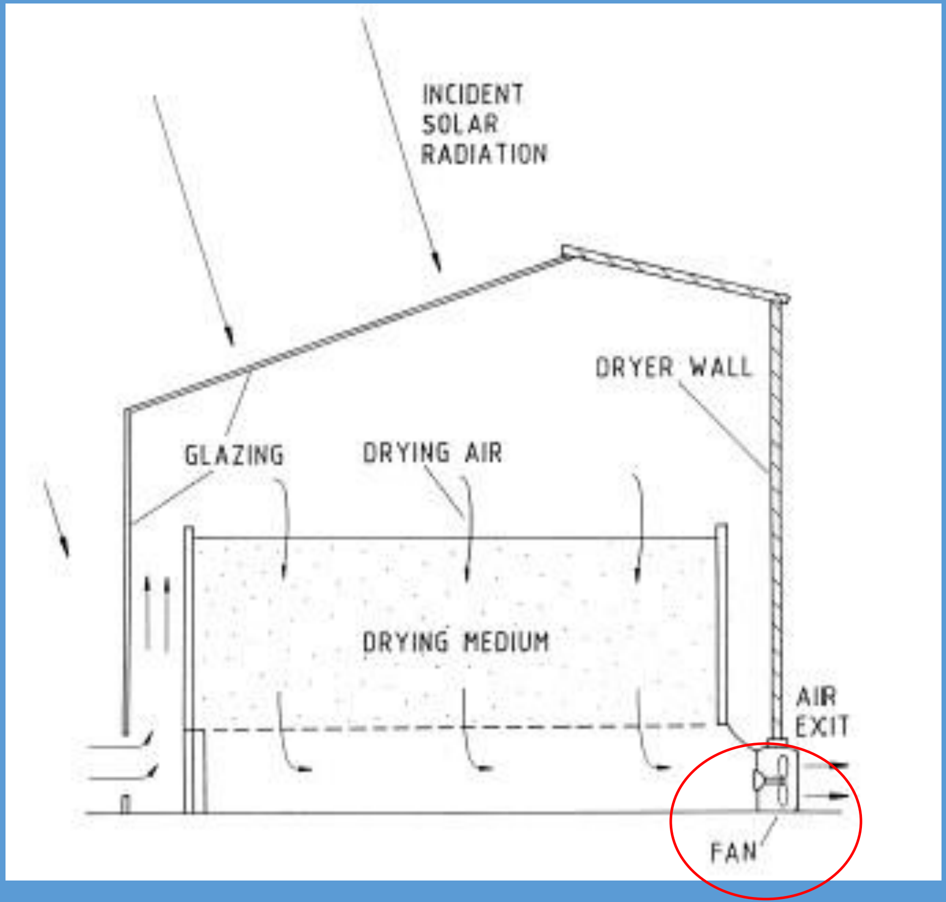


Fig 15. Direct Active Type Solar-Energy Drying Systems (Ekechukwu and Norton, 1999)

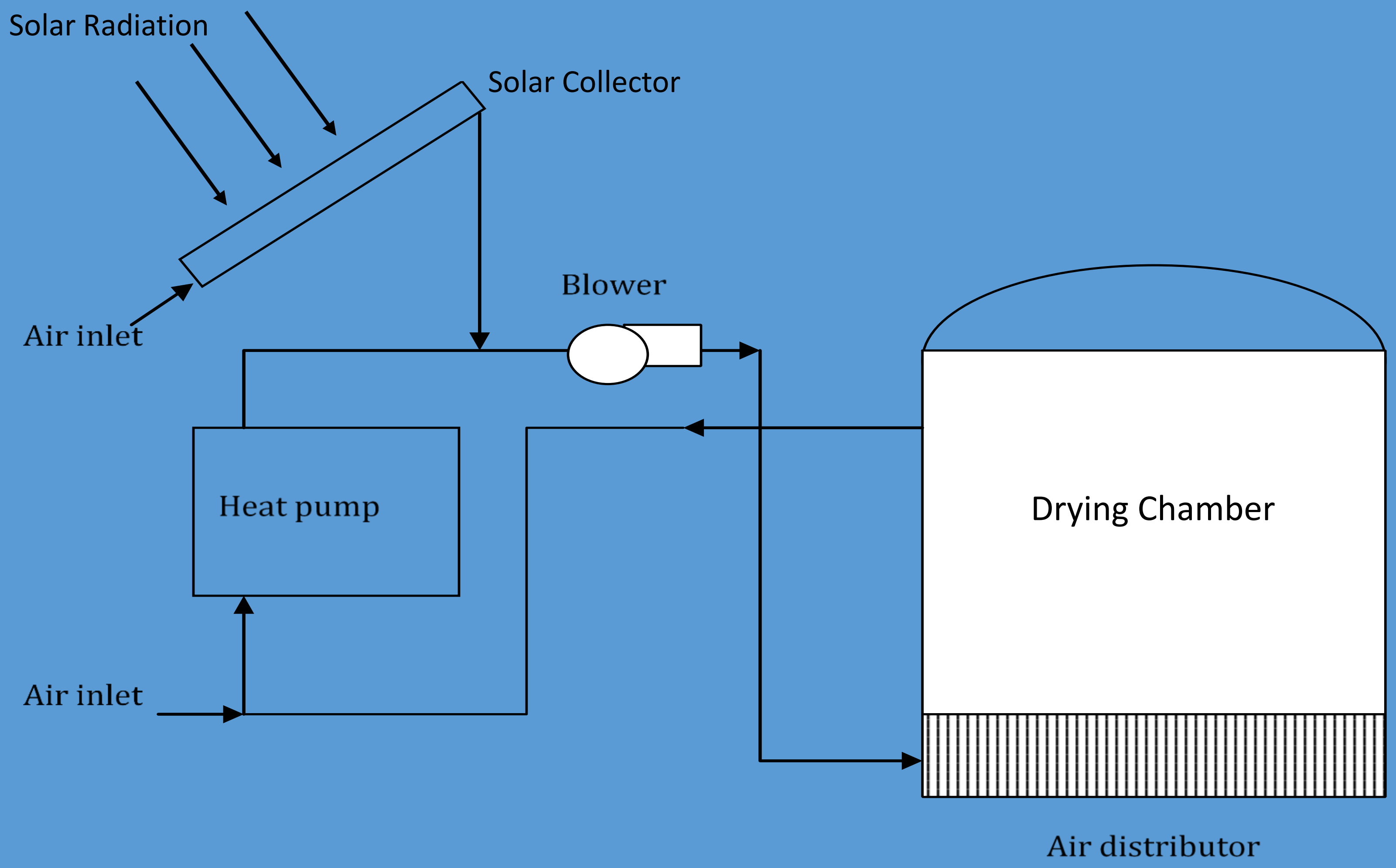


Fig 16. The Schematic Layout of the Solar Assisted Heat Pump Granary (Li et al. ,2011)

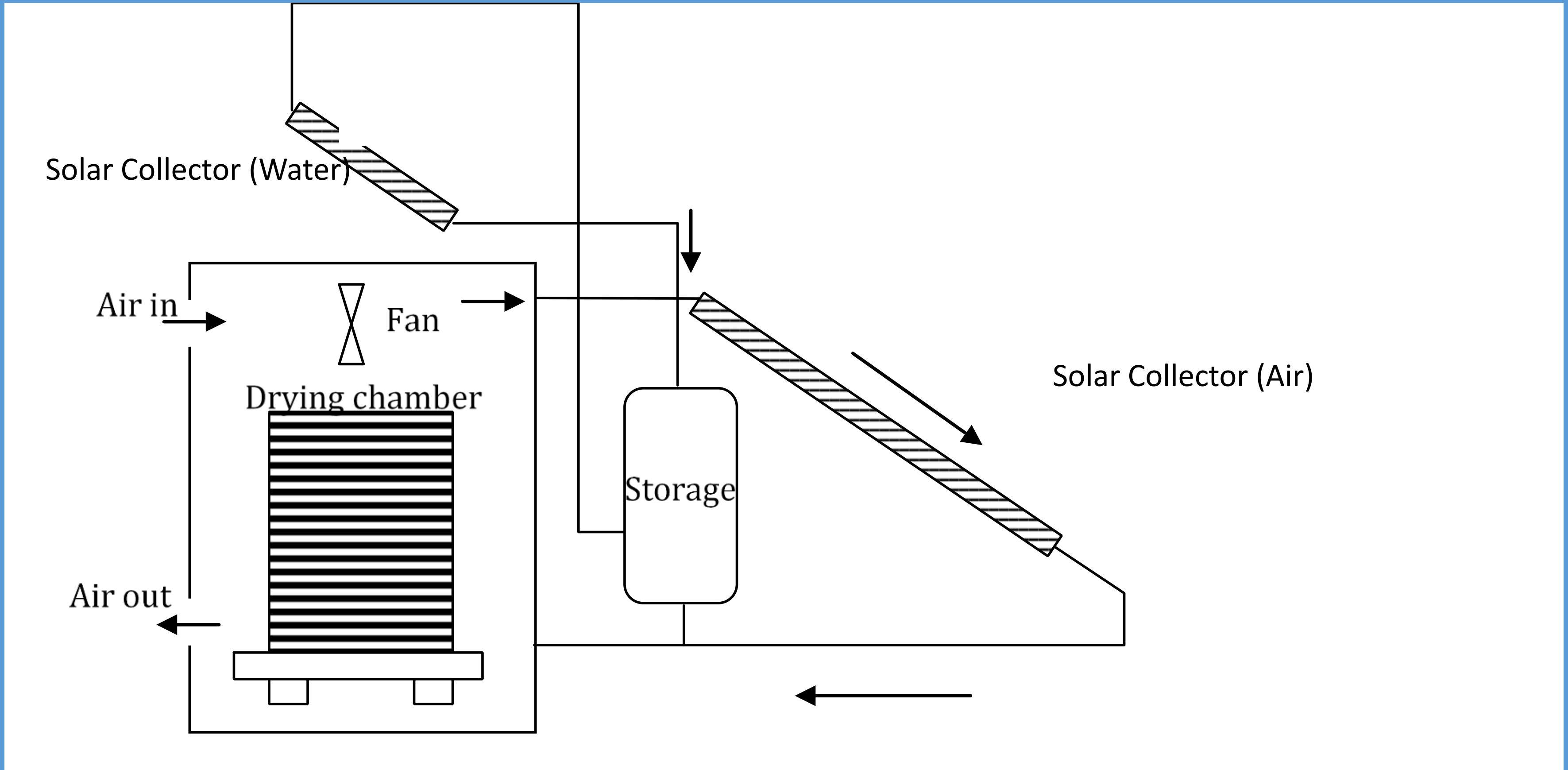


Fig 17. The Active Solar Dryer With Energy Storage

Table 2. Checklist for Evaluation and Selection of Solar Dryers

Parameters	Features
1. Physical features of dryer	• Type, size and shape • Collector area • Drying capacity/loading density (kg/unit tray area) • Tray area and number of trays • Loading/unloading convenience
2. Thermal performance	• Solar insolation • Drying time/drying rate • Dryer/drying efficiency • Drying air temperature and relative humidity • Airflow rate
3. Properties of the material being handled	• Physical characteristics (wet/dry) • Particle size • Acidity • Corrosiveness • Toxicity • Flammability • Abrasiveness
4. Drying characteristics of the material	• Type of moisture (bound, unbound, or both) • Initial moisture content • Final moisture content (maximum) • Permissible drying temperature • Probable drying time for different dryers
5. Flow of material to and from the dryer	• Quantity to be handled per hour • Continuous or batch operation • Process prior to drying • Process subsequent to drying

Table 2. Checklist for Evaluation and Selection of Solar Dryers

Parameters	Features
6. Product qualities	• Shrinkage • Contamination • Uniformity of final moisture content • Decomposition of product • Over-drying • State of subdivision • Appearance • Flavour • Bulk density
7. Recovery problems	• Dust recovery • Solvent recovery
8. Facilities available at site of proposed installation	• Space • Temperature, humidity, and cleanliness of air • Available fuels • Available electric power • Permissible noise, vibration, dust, or heat losses • Source of wet feed • Exhaust-gas outlets
9. Economics	• Cost of dryer • Cost of drying • Payback
10. Other parameters	• Skilled technician and operator requirements, • Safety and reliability • Maintenance

Table 3. Performance Study of Different Solar Dryers

Type of Dryer	Findings & Performance
Direct solar dryer	• This is one of the simplest solar dryer of low capacity • Solar radiation is the main source and overcome the dis-colourness of the crops • Temperature is the main factor on drying rate and in off shine hours the drying technology is affected
Indirect solar dryer	• Reverse flat plate collector was used and gave best result • High quality drying products get by producing higher efficiency • It is available for small farms and under bad weather it produces good quality products • The drying time is eminently decreased and drying efficiency is good
Mixed mode solar dryer	• Get optimal value of drying sectors using computer modelling • Contains separate collectors and this dryer is used for drying crops in wet season • The drying rate was highest and this kind of dryer is used for drying rough rice • This dryer gives satisfactory result for best drying efficiency and moisture content • Artificial network is used and predicting the potentiality of the dryer • Solar dried rice resulted in higher degree of whiteness than sun dried rice • Samples dried in solar dryer are similar in flavour than those dried under the sun.
Natural convection solar dryer	• It is a low cost solar dryer and gives vary satisfactory result • It is low cost and its performance is satisfactory • Design of this dryer is very simple and gives high efficiency
Forced convection solar dryer	• Simple, available and locally found materials are used to make this type of dryer • Save a large amount of fuel. Product quality is better than any others and keeps products neat and clean • In ambient temperature this kind of dryer is more appropriate for drying pistachio and product is perfectly dried in this dryer • This dryer is suitable for prediction the temperature and moisture content under control and constant rate • The parameters of drying system are time dependent and it is performed to predict the drying rate

Source : Mustayen *et al*, 2014

Barriers to Growth of Solar Dryers

- **Awareness:** The number of solar thermal installations for industrial processes is very small, and most decision makers in relevant industries have never heard of, or even seen, a SHIP system. This is a key barrier to the broad adoption of SHIP.

- **Confidence only in long-term proven technology:** Most managers are very conservative when it comes to basic infrastructure needs. Especially when mission-critical heating processes are concerned, they will almost always choose conventional, long-term proven technology. Any potential day of delay or interruption seems more dangerous to them than reliance on unpredictable future prices of conventional fuels.

- **System cost**: Like most renewable energy technology, SHIP systems have typically higher investment costs, but save conventional energies throughout operation. With current technology, financial payback times are often beyond commercial requirements.

Barriers to growth of Solar Dryers

- **Lack of Technology**: Many industrial processes require higher temperatures than the typical solar thermal applications (domestic hot water, space heating, swimming pool heating). New designs, sometimes new materials, are needed to cater for these higher temperature demands.

- **Lack of Suitable Planning Guidelines and Tools**: So far, only few engineering offices and research institutes have experience with SHIP installations. Planning guidelines and tools for typical industrial use cases are still missing.

- **Lack of Education and Training**: Only few professionals have attended courses on SHIP. Without that knowledge, very few will offer SHIP solutions to their (potential) customers.

Recommendations

- Specific awareness raising campaigns targeted at decision makers in the industry most suitable for solar thermal process heat, e.g. food and textile industry
- Large number of demonstration projects – to gain more experience, develop planning guidelines and to increase confidence in this emerging technology.
- Financial incentives to companies, which install solar thermal systems to drive their industrial processes.
- Funding of R&D into new technologies, which can improve the viability of SHIP installations, e.g. medium temperature collectors, improved heat transfer fluids.
- Training courses for professionals – to raise awareness and to overcome the current lack of expertise amongst professionals (planners, installers).

Field Drying

- **Why field drying?**
  - Waiting for the thresher
  - Manual threshing
- **How?**
  - Spreading the crop in the field
  - Stacking/piling
- **Advantages**
  - Can reduce MC by 1% per day
- **Disadvantages**
  - Rapid quality deterioration
  - Shattering
  - Losses to bird and rodents when spread in the field
  - Heat build up and rapid quality deterioration in piles
  - Re-wetting from straw in piles

It is impossible to produce good quality grains with field drying practices.
Field drying should therefore be avoided.

Paddy Drying Study (Jittanit et al., 2010)

- Rice - The Most Consumed Cereal Crops, Especially in Most Asian Countries
- Moisture Content of Harvested Paddy Usually Very High in between 20 – 25% ,
- It Needs to be Dried Down to 12 – 14% Moisture content
- Rice Drying is An Energy Intensive Process
- Specific Primary Energy Consumption Could Range from 1.587 to 6.89 MJ/kg H_2O evaporated
- Jittanit et al., (2010) Investigated a Two-Stage Drying Technique
- Fluidized Bed Drying at 100 – 110°C Was Used in the First Stage
- Drying with ambient air by an Indirect type solar dryer was used in the second stage
- Ambient air heated by the solar collector that is installed before the drying chamber

Paddy Drying Study (Jittanit et al., 2010)

- After Comparing the Energy Usage with An Industrial Drying Unit, it was found that the best combination was obtained from drying using an Industrial Dryer (1st stage) and a Solar Dryer (2nd stage)
- Specific Primary Energy Consumption was Lower in the Solar Dryer at 2.88 MJ/kg H_2O evaporated as Compared to the Industrial dryer at 4.72 - 6.29 MJ/kg H_2O evaporated
- Energy Saving Between 41.5 and 60.8 Thai Baht/ton Paddy was Estimated and Potential Saving of 1.27 – 1.82 million Thai Baht was Calculated Based on a 30,000 ton Paddy Processing Plant
- Solar drying has proved to be viable in drying various agricultural commodities provided the surrounding conditions (weather, insolation, location, etc) are conducive for the implementation of this type of drying technique
- However, there are still many issues that must be overcome especially in the transfer of technology and the commercialization of this drying technology to the potential users

Paddy Drying Study (Jittanit et al., 2010)

- Training, guidance and management of the whole processing steps, which includes solar drying, should be emphasized to ensure quality control of the dried product.

Table 4. Difference Between Open Sun Drying and Solar Drying

Open Sun drying	Solar Drying
Traditional method	More recent invention
Delayed drying	Fast drying
Problems of contamination by birds, insects, etc	No contamination
Less hygienic & less clean	Highly hygienic & very clean
Inferior quality products	Best quality products
May not meet GMP	Meets GMP requirements
Drying possible only on sunny days	Drying possible on all days including cloudy and rainy days with Storage backup
Poor sensory qualities to products - Appearance/Colour & Textures	Highly acceptable sensory qualities to products -attractive appearance, colour & Texture
Uneven drying	Even/Uniform drying
More nutrient loss	Better nutrient retention
Low profit margins	Best profit margins due to quality products
Space required is bigger	Less space required

Source: Jittanit et al., 2010

CONCLUSION

- The application of Solar Thermal Energy in the Paddy Value Chain (Paddy Drying) sector was reviewed and presented in this paper
- It has been proven that **Solar Thermal System** would be the **Suitable Options/Innovative Replacement** in Paddy Drying Application since the solar Thermal System makes the systems maintenance free while has no mpact on the environment
- However, the cost of the system is a major factor to choose the source of energy while the initial cost of the solar system needs more studies, and it makes the system more sensitive to the proper design
- Moreover, the efficiency of the Solar Thermal Systems need to be considered and improved to enthusiasm governments to invest and rely more on the alternative energies rather than fossil fuels while in the past few decades by permanent increasing in the cost of conventional energy

- Majority of governments become more interested to associate with renewable energy (RE) sources to support their industries and society’s requirements, which cause a considerable improvement in the solar sector