DETAILED PROJECT REPORT ON
SOLAR AIR HEATING FOR PADDY DRYING

Submitted to

MINISTRY OF FOOD PROCESSING INDUSTRIES (MFPI)

GOVERNMENT OF INDIA

As part of project titled

STUDY, INVESTIGATION AND DEMONSTRATION (THROUGH PILOT UNITS) ON THE LARGE LEVEL SOLAR HEATING TECHNOLOGY TO MEET THERMAL REQUIREMENTS IN FOOD PROCESSING INDUSTRIES.

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TAMILNADU, INDIA

SEPTEMBER 2000

DETAILS OF THE PROJECT UNDERTAKEN

Name of the R&D Project:	STUDY, INVESTIGATION AND DEMONSTRATION (THROUGH PILOT UNITS) ON THE LARGE LEVEL SOLAR HEATING TECHNOLOGY TO MEET THERMAL REQUIREMENTS IN FOOD PROCESSING INDUSTRIES.
Sanction Number:	1/2/97(RP)-FPI
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Date of start: (receipt of funds)	22/04/1998

Duration of the project	TWO AND A HALF YEARS

EXECUTIVE SUMMARY

India has attained self-sufficiency in food production and three fourth of the population use rice as their staple food. The last kharif and rabi seasons accounted for 83.4 million tonnes of paddy production. Paddy is consumed either as raw milled rice or parboiled rice. In India more than 60% of the paddy is parboiled. Drying paddy from moisture content of 30%-wet basis to 10% wet basis is an energy intensive operation. Due to the good sunshine available, open sun drying is widely practised for drying paddy. It is estimated that 1-5% of the produce is lost during the process of open sun drying. Conventional drying practices using machinery is slowly and steadily replacing open sun drying due to the constraints like time of drying, land requirement and huge labour force. The modernisation of the rice mills has resulted in increased fossil fuel demand to feed the furnaces. As estimated, 96 litres of diesel is required to dry 12 tonnes of parboiled paddy in a day. Since this operation is prolonged (8hrs) and uses low temperature (60^0C) air there exists the possibility of solar paddy drying.

A model modern rice mill processing 12 tonnes of paddy per day at Theni in Tamilnadu was analysed for the feasibility study. The operating parameters were 12,000-m^3/hr hot air at a temperature of 60^0C. After a detailed study of the process and other details, a 212m^2 roof integrated overflow system with aluminium absorber is proposed and the details attached therewith are reported. A Processing time management is recommended to optimise the use of collector so that it can operate as Full Energy Delivery system.

The proposed system was simulated using the operating parameters and an efficiency of 50% is anticipated and the heat removal factor obtained is 0.7. Assuming similar energy requirements, the energy fractions that the solar heating can provide in Orissa and Uttar Pradesh is around 77% followed by Bihar, Chandigarh and Gujarat. On the economic front the payback period for the investment is around two years and the expected fuel saving per year is around Rs.3±0.25 lakhs. The Government incentives for solar air heating are also highlighted.

If solar air heating can be installed in 1.211 million m^2 of available roof, then a fuel saving of 200.16 million litres of diesel can be achieved per annum. This can save us 72.86 million U.S.$ worth of diesel imports and save the environment from

addition of 5,80,464 tonnes of CO_2 per annum. Apart from these projections, the inherent advantages and disadvantages of solar heating are explained with solutions to overcome the disadvantages. The project has explained the technical and economic viability of solar air heating to dry paddy. Recommendations like setting a demonstration unit, providing some incentives and publicising the advantages of the system are provided for further development and propagation of the technology.

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Chapter 1 INTRODUCTION

A) BACKGROUND

In India around three fourth of the population use Rice as their food. The Indian's association with rice cultivation is lost in antiquity. Rice has got integrated into the life of the Asian community, be it in their food habits or in religious ceremonies. India stands second in production of Rice (21.5 percentage of world production) next to China (34.5 percentage of world production) as per the statistics for triennium average of 1995 –1997 (Refer Table 2.1). Rice has the distinction of providing more calories per hectare than other cereal crops. The nutritional value is also high among cereals and other grains. The net protein utilisation value for rice is 63, compared with 49 for wheat and 36 for maize. Rice is relatively non-allergic and has an enduring palatability (7). With the ever-increasing population, the need for rice to feed the masses is increasing. Thanks to our technological leap that we have been able to sustain a positive growth in rice production in our country. The Green revolution ushered us into a New World where the possibility of famine death is a distant past. The food corporation of India (FCI) stocks a vast quantity of food grains primarily rice (to the tune of six months demand for food) to cater to the people in case of emergencies.

The advances in the field of production of paddy is being countered by a considerable loss of the produce due to poor post harvesting and processing management. A national figure of 2.5% for food grains loss by rodents and 2.55% by insects have been accepted in India. One estimate made for rice in south East Asia reveals drying losses at 1-5% and storage losses at 2-6% totalling 3-11% of the total production (6). This is because of the fact that paddy is subjected to more handling and processing steps before being made consumable.

The harvested paddy is to be dried to preserve the same. In India, more than 60% of the paddy is subjected to parboiling (7). Parboiling is a hydro thermal treatment given to paddy which changes the physical, chemical and Organoleptic properties of the rice (5). In simple terms, it is partial boiling with kernel intact, which involves soaking and steaming. Parboiling imparts hardness to the grain and helps in the milling operation. The advantage of parboiling is that the parboiled rice contains more B group vitamins and a little more protein than milled raw rice. Moreover it provides a better storage option. Parboiling results in higher milling recovery, translucent kernels, greater nutrient status, easy hulling, less susceptible to insect attack during storage, higher oil in bran with better stability, less cooking loss, more swelling when cooked to the desired softness and easy digestibility with high protein efficiency rating.

B) **OBJECTIVES**

1. To find out the drying requirements of paddy drying.
2. Determining the scope on installation of solar air heating for drying paddy.
3. Finding the Technical and economic feasibility of installing solar air heaters for paddy drying.

C) **SIGNIFICANCE OF THE PROJECT**

The end of the project will explore all the possible energy saving methods to be adopted in the modern rice mills. The feasibility on incorporating the technology of solar air heating in paddy drying will make a definite impact on the energy costs incurred by the millers and help them in saving the energy cost. The project will act as a tool in spreading the technical and economic feasibility of installing SAHS for drying paddy.

D) **SCOPE OF THE PROJECT**

The project aims at studying the energy requirements existing in the modern rice mills and the options available before the millers on energy conservation. Since paddy drying is an energy intensive process utilising low temperature hot air for drying, the possibility of incorporating Solar Air Heating System to reduce the millers dependence on fossil fuel is to be made based on the economic viability.

Chapter 2 PADDY – OVERALL VIEW

A) PRODUCTION OF PADDY

India has attained self-sufficiency in food grains. Agriculture remains the backbone of our country and paddy cultivation occupies a major portion of the food grain cultivation. In India, paddy cultivation is done in two seasons namely kharif and rabi. Kharif is the major season, which coincides with the monsoon and starts in the month of July-August. During the last kharif season, the paddy production stood at 72.3million tonnes from a cultivation area of 40 million hectares. The Rabi seasons share in production is only 11.1 million tonnes with the cultivation area being 3.8 million hectares(10). India stands second in world rice production (see Table 2.1). The geographical distribution of food grains production as distributed among the Indian states is given in Table 2.2.

Tables 2.1 Production of Rice by the world countries for the triennium average 1995 –1997

Country	Production (Thousand tonnes)	% share of the country of world production
Bangladesh	33321	5.9
Brazil	10183	1.8
Myanmar	18040	3.2
China	194293	34.5
India	121422	21.5
Indonesia	50493	9.0
Japan	12965	2.3
Pakistan	6318	1.1
Philippines	11306	2.0
Thailand	21770	3.9
Egypt	5089	0.9
U.S.A.	7924	1.4
Russian Federation	393	0.1
World	563881	

[Source –10]

Table 2.2 State wise area, production and yield of food grains (1998-1999)

States	Area (M.Hectares)	Production (M.Tonnes)	% of total production	Yield (kgs/hectare)
Andhra Pradesh	7.19	14.40	7.1	2003
Assam	2.67	3.43	1.7	1288
Bihar	8.96	12.91	6.4	1441
Gujarat	3.90	5.57	2.7	1426
Haryana	4.49	12.12	6.0	2700
Himachal Pradesh	0.84	1.49	0.7	1760
Jammu & Kashmir	0.88	1.52	0.7	1728
Karnataka	7.38	9.98	4.9	1352
Kerala	0.39	0.69	0.3	1768
Madhya Pradesh	17.79	19.80	9.8	1113
Maharashtra	13.09	12.75	6.3	974
Orissa	5.38	5.81	2.9	1080
Punjab	6.12	22.91	11.3	3741
Rajasthan	13.46	12.93	6.4	961
Tamilnadu	4.45	10.14	5.0	2278
Uttar Pradesh	20.52	40.15	19.8	1957
West Bengal	6.54	14.37	7.1	2198
Others	1.31	2.07	1.0	1580
All India	125.36	203.04	100.0	1620

[Source Department of Agriculture & Co –operation web site]

B) MARKET PRICE

The market price of rice varies widely with the variety. They are available from the cost of Rs. 10/kg to Rs.30/kg depending on the quality of the rice. The government fixes the minimum support price for paddy from season to season based on the recommendations made by the Commission for Agricultural Costs and Prices (CACP). The objective of this practice is to provide adequate incentives for increasing investment and supplying agricultural products at reasonable prices to consumers.

C) PADDY PROCESSING

Dried paddy can be stored for a longer time and hence can be processed throughout the year. Rice is available in two forms, namely raw milled rice and parboiled rice. The raw milled rice is obtained by milling the dried paddy. Parboiling hardens the rice grains sufficiently during the process and results in improved milling properties, leading to a high head rice yield. It is also beneficial from the nutritional point of view, since milled parboiled rice contains more B group vitamins and a little more protein than milled raw rice. It has also better storage properties. In parboiled rice, paddy is subjected to the processes of drying, parboiling and milling. The process is described in detail in the flow chart given in Figure2.1.

The parboiling consists of three phases namely soaking, steaming and drying.

a) Soaking:

Soaking is a water diffusion process by which the grain absorbs water and swells. This process can help in the reduction of steaming required. This process is also known as steeping or imbibition. Soaking provides sufficient quantity of water to the starch granules for gelatinization. There are two kinds of soaking namely cold soaking and hot soaking. In cold soaking paddy is soaked in cold water in large cement tanks for a day. This prolonged soaking can impart odour to the paddy. In the hot soaking method paddy is steamed for about 5-10 minutes and then soaked in warm water and is given a second steaming after draining the water. In hot soaking the paddy is soaked in hot water (60 – 70^0 C) which reduces the soaking time to about 3 to 4 hours.

b) Steaming:

Steaming is done to partially boil the paddy. The paddy soaked is piled in a bin and steam is passed for about 10 minutes. When the kernels break open, steaming is stopped. The traditional process involves placing water and paddy in a vessel and heating with firewood. The boiling water parboils the submerged grain while steam parboils the remainder. A modern parboiling tank introduced by CFTRI is shown in Figure 2.2.

c) Drying

Drying is a thermodynamic process wherein moisture is removed from the material by vapour pressure difference between grain and the ambient air (2). Open sun drying is the most commonly used practice, whereas some modern rice mills use conventional dryers.

d) Milling

Milling consists of husking and polishing. The parboiled / raw paddy is husked by abrasive action and then polished. The rice thus gets separated. Most of the rice mills burn the husk for their energy requirements.

D) QUALITY SPECIFICATIONS

Even though Rice is not subjected to much quality checking by the Government, uniform specifications have been formulated for all varieties of paddy. The specification reads that "The paddy shall be in sound merchantable condition, sweet, dry, clean, wholesome of good food value, uniform in colour and size of grains and free from moulds, weevils, obnoxious smell, argemone mexicana and kesari, admixture of deleterious substances or colouring agents and also conforming to Prevention 0f Food Adulteration Act (PFA) standards".

A classification of Rice suggested for trade and commerce in India by Ramiah committee by considering the two-way classification by Food and Agricultural Organisation (FAO) on the length and length/breadth ratio is provided in Table 2.3. The classification was based on raw brown rice or raw low-polished milled rice. In this classification the scented variety will be placed in the appropriate class on the basis of the kernel dimension and then will be allowed a premium in price for their scent (8).

Table 2.3 Systematic classification of rice.

Long Slender (L.S)	Length –6 mm and above, L/B –3 and above
Short Slender (S.S)	Length –less than 6mm, L/B –3 and above
Medium Slender (M.S)	Length –less than 6mm, L/B –2.5 To 3.0
Long Bold (L.B)	Length –6mm and above, L/B –less than 3
Short Bold (S.B)	Length –less than 6mm, L/B –less than 2.5

[Source –Rice research in India, ICAR]

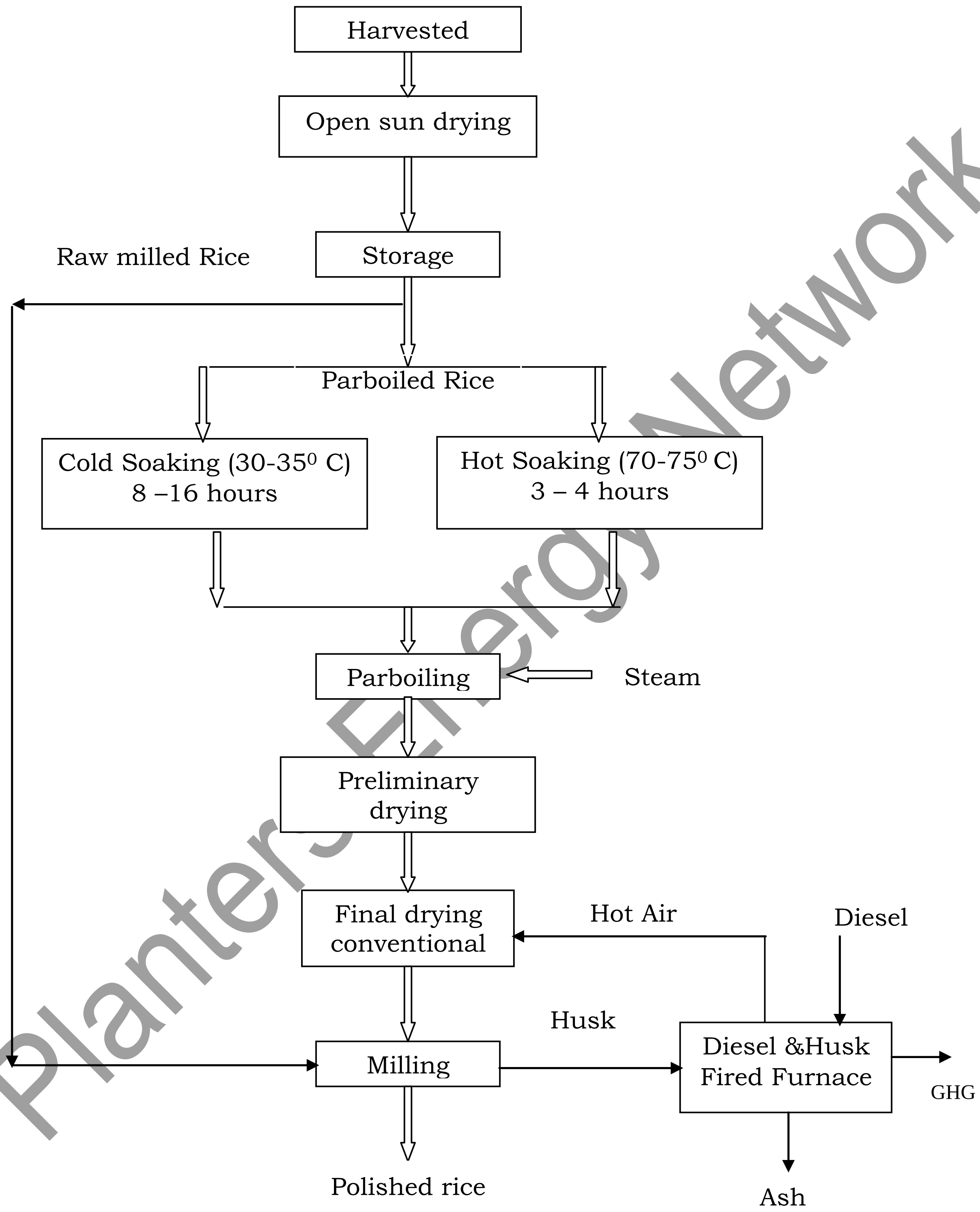
Another classification commonly in use in the current market is based on the Length (L) Breadth (B) ratio. The classification is done as superfine (L/B ratio more than 3.0), Fine (L/B ratio between 2.5 to 3.0) and common (L/B ratio less than 2.5) groups. The varieties with natural aroma will be taken under scented group. The other schedules of specifications are given in Table 2.4.

Table 2.4 Specifications for quality of paddy

Constituents		**Maximum limits %**
Foreign Matter	Inorganic	1.0
	Organic	1.0
Damaged, discoloured, sprouted and weevilled grain		3.0
Immature, shrunken and shrivelled grain		3.0
Admixture of lower varieties		10.0
Moisture		18.0

[Source- 4]

Fig 2.1 Flow chart for processing harvested paddy



Chapter 3 DRYING AND ENERGY CONSUMPTION

The harvested paddy contains a moisture content varying between 16 % to 20 % depending upon the season of harvesting and the variety. The harvested paddy should be dried to maintain quality, minimise losses by wastage and prepare the grain for further storage and milling operation. Drying also imparts paddy, resistance to biological deterioration, mould growth, fermentation, sprouting and discoloration. By drying, a lower moisture level (~14%) is obtained which renders the grain dormant and increases the shelf life to longer periods under proper conditions. The delay in drying the grain after harvesting results in qualitative loss in products. It is better to dry the grain as soon as possible after harvesting to prevent loss in dry weight and reduced rice recovery. Rapid drying can cause cracks and result in rice breakage during milling. This is due to the formation of a moisture gradient within the grain. One of the processes by which the rice is given hardness to resist breakage is parboiling. Parboiling involves steam cooking which provides paddy with 30 % moisture. This too is to be dried to the storage moisture content of 13-14 % before being milled.

A) CONVENTIONAL DRYING PROCESSES

Newer processes and drying techniques keep evolving for processing paddy. But they can be broadly classified into the following groups:

A.1) Open sun drying

The oldest and most widely used mode of drying is by tapping the unlimited energy of the sun to dry the paddy. This is accomplished by spreading the raw/parboiled paddy on the levelled or cement platform to a thickness of about 5 – 10 cm depending on the moisture content of the paddy. This mass is often stirred or otherwise raked by human labour till it has attained the desirable moisture content. The drying is stopped when the moisture content is reduced which is found by chewing the paddy. In rural areas people also use public roads for drying paddy.

This method of drying results in about 0.4 percent of the paddy lost to the birds, insects and rodents. This also causes breakage during milling due to uncontrolled and non-uniform drying.

Figure 3.1 Open yard sun drying

A.2) Mechanical drying

This process utilises hot air to remove the moisture content of paddy to required levels. This method provides an alternative to the various shortcomings of sun drying. It is reliable and can be used in all climates. A lot of mechanical dryers are used with modifications to suit ones own needs. Some of the major developments in mechanical drying are listed below.

(i) Batch dryer

1. Bag dryers
   These types of driers are suited for drying smaller quantities of grains. In this process of drying the grains are sacked in bags and placed above openings in the building which are covered with perforated mats. Hot air is blown through the holes with a burner and an air blower assembly. The air is heated up to 45^0C and is blown at a rate of 4 cubic metres per minute, per bag of 45kg of dried grains. The bags should be turned once to allow exposure of both the sides of the bag.
2. Bin dryers
   A bin dryer consists of a bin to hold the grains and the bottom of this is perforated to allow hot air to enter the bin. Hot air generated in the burner is pushed through the bin by means of a blower till the moisture content is

reduced to the required level. The depth of the grain level is kept below 1.8 metres to reduce power requirements and reduce grain deterioration at the top due to deposition of moisture by the moving air.

(ii) Continuous dryers

Continuous flow driers can be divided into mixing type and non-mixing type. These driers have large capacity. The grain is usually fed from the top and flows down through the drier by gravity. The rate of discharge is regulated mechanically at the bottom. Drying is accomplished by forcing heated air through the grain as it flows downwards. Some of the continuous driers are

1. Louisiana State University (LSU) dryer.
2. Cup and cone dryer.
3. Rice Process Engineering Centre (RPEC) re-circulatory dryer.
4. Taiwan Drier

(iii) Conduction dryers.

1. IRRI – heated-sand rotary dryer.
2. TNAU – heated sand dryer.
3. Sand roaster.

Hullers are presently using the various dryers given above and each dryer is characterised by certain advantages and disadvantages. Nowadays most of the modern rice mill owners opt for a drier locally known as Taiwan Drier and one of the industries manufacturing it SUNCUE industries. More details about this drier is described in the later chapters. The major drawback in mechanical drying is the huge investment and running cost, which cuts into the profit.

A.3) Chemical drying

Researchers at the Paddy Processing Centre, Tiruvarur (Tamil Nadu) has developed a process for drying using common salt. This when applied either in dry or as solution withdraws water from paddy without entering the kernel. They have reported a reduction in moisture content from 29% to 14.5% after 4 days of treatment. The major problem encountered with chemical drying is corrosion of parboiling vessels.

B) ENERGY CONSUMPTION

Modern rice mills consume a large quantity of energy in various forms as electrical energy, thermal Energy and manual energy. A look at the energy consumption of milling sections of different types of rice mills in Orissa during 1993 – 94 is given in Table 3.1 which provides a clear picture of the energy utilisation of rice mills. The total energy requirement for processing 1 tonne of paddy is 10,72,229 kJ, which is distributed as 3,59,789 kJ for soaking, 1,38,221 kJ for gelatinisation and 5,74,213 kJ for drying (4). This shows that drying consumes around 50% of the energy requirement.

Table 3.1 Energy consumption of Rice mills in Orissa, 1993-94

Type of Rice mill	Total power of installed motors (kW)	Period of operation		Electrical energy consumption $\times 10^8$ MJ	Manual energy consumption $\times 10^6$ MJ	Total energy consumption $\times 10^8$ MJ
		Days	(h/day)			
Huller	55711.28	295	8	4.733	7.889	4.812
Sheller-cum-huller	10135.16	320	12	1.401	5.115	1.452
Sheller	8593.92	320	12	1.188	1.928	1.207
Modern mills	5908.32	320	12	0.8168	1.938	0.8362
Total	80348.68			8.139	16.87	8.307

[source 4]

Parboiling of paddy consumes considerable energy. Sehgal (1987) has proposed that, in parboiling the average energy consumption in parboiling is around 2529 MJ/tonne of paddy (9), taking into consideration the manual energy input too. The energy requirement for drying one tonne of paddy is provided in Table 3.2. Most of the modern rice mills in Tamilnadu use Taiwan driers (locally called name) for drying their products. The capacity and fuel consumption of the various models of Taiwan drier for paddy drying is listed in Table 3.3. A schematic of the Taiwan drier by SUNCUE industries is provided in Figure 3.1. This drier is operated by burning kerosene or premium diesel in the burner and has a oil tank capacity of 90 litres.

Table 3.2 Drying details for one tonne of paddy

Product	Details		Values
Paddy raw	Moisture content	Initial %	22-24
		Final %	11
	Maximum drying temperature (^{0}C)		50
	Water to be removed (Kg/Tonne)		195.4-252.9
	Energy required 10^6 kJ/tonne		0.252-0.298
Paddy parboiled	Moisture content	Initial %	30-35
		Final %	13
	Maximum drying temperature (^{0}C)		50
	Water to be removed (Kg/Tonne)		195.4-252.9
	Energy required 10^6 kJ/tonne		0.398-0.516
Rice	Moisture content	Initial %	24
		Final %	11
	Maximum drying temperature(^{0}C)		50
	Water to be removed (Kg/tonne)		146.1
	Energy required 10^6 kJ/tonne		0.298

(Source: 9)

Table 3.3 Capacity of the various models of Taiwan Drier

Model	Capacity (Kgs)		Fuel consumption Litre/Hr. (max)
	Min.	Max.	
NEW PRO-60-36	2500	3600	6.7
NEW PRO-60-48	2500	4800	6.7
NEW PRO-60	2500	6000	9.0
NEW PRO-60-72	2500	7230	9.0
NEW PRO-60-85	2500	8450	9.0
NEW PRO-60-100	2500	9650	9.0
NEW PRO-120-110	2800	10800	13.5
NEW PRO-120	2800	12000	13.5

(Source: SUNCUE operating manual)

C) SCOPE OF SOLAR AIR HEATING SYSTEM IN PADDY DRYING

As explained earlier, the most widely used practice of paddy drying is through open sun drying. Since open sun drying is uncontrolled and non-uniform, sunburns occur in paddy and hence it cracks. This is due to the difference in moisture level within the grain created by over drying in sun. A drying temperature of 60^0 C is sufficient to dry the wet paddy to a moisture content of around 13 %. Hence the feasibility of incorporating SAHS in modern rice mills exists. This can save energy (both manual and fuel consumption) with the added advantage of uniform controlled drying of paddy. India is a tropical country and receives good radiation through out the year and hence the SAHS can be operated successfully. The insolation levels across the country given in Table 4.1 prove this.

Chapter 4 SOLAR AIR HEATING

A. Introduction to Solar Heating

Solar energy comes from thermonuclear reactions occurring in the core of the sun. It is non-polluting and inexhaustible unlike the fossil fuels. All objects that are warmer than their surroundings lose energy by radiation. Very hot objects, like the sun, radiate mostly high energy waves with short wavelengths. Therefore, most solar radiation is short wave. When the radiation strikes a material, it reflects or passes through or is absorbed. The absorbed fraction usually causes the material to heat. With proper combination of materials, it is possible to build a solar collector to collect this heat. Objects only slightly warmer than surrounding temperatures, such as absorber plates in solar collectors, radiate or emit lower energy waves with long wavelengths (also called thermal or infrared radiation). There are two basic types of solar systems - passive and active.

Passive Systems

In passive solar systems, the working fluid moves with little or no pump or fan power. Natural convection and radiation distribute the collected solar energy. Passive solar systems can be simple and can provide heat at low operating and maintenance costs. Disadvantages include poor temperature control, wide temperature fluctuations in the heated space, and fading and deterioration of fabrics exposed to direct sunlight.

Active Systems

In active solar systems, pumps or fans move the working fluid. Some applications require extra pumps or fans, but others - like preheating grain drying air or livestock building ventilating air - use existing fans. The pressure drop in the solar collector reduces system airflow and increase energy input to the fan motor.

B) INSOLATION LEVELS.

The intensity of solar energy, or solar radiation, decreases with increasing distance from the sun. The sun is not at the centre of the earth's orbit, so the earth's distance from the sun varies during the year and so does the intensity of the radiation reaching the earth. About 1353 W/m^2 the solar constant reaches a surface facing the sun and just outside the earth's atmosphere, 24 hr/day. Only a fraction of this energy is available to solar collector surface depending on time of the day, the time of year, the weather, the latitude of the collector site and the collector's tilt angle. Table 4.1 gives the details of location and inclined surface Insolation levels for various stations in India.

4.1 Insolation levels at various stations in India (Slope = Latitude)

Sl No.	Station	Latitude	Longitude	Elevation (MASL)	Average Sum of Global Solar Radiation per day, G_t (kWh/m^2)	
					Horizontal Surface	Inclined Surface
1.	Ahmadabad	23.07 N	72.63 E	55	5.786	6.323
2.	Allahabad	25.45 N	81.73 E	98	5.121	5.755
3.	Bangalore	12.95 N	77.63 E	897	5.357	5.511
4.	Baroda	22.30 N	73.25 E	34	5.828	6.387
5.	Bhopal	23.27 N	77.42 E	503	5.758	6.157
6.	Bhubaneshwar	20.25 N	85.87 E	26	5.725	6.163
7.	Calcutta	22.65 N	88.45 E	6	4.971	5.385
8.	Coimbatore	11.00 N	77.00 E	431	5.699	5.812
9.	Cudappah	14.48 N	78.83 E	130	5.514	5.711
10.	Hyderabad	17.45 N	78.47 E	545	5.741	6.047
11.	Jaipur	26.82 N	75.80 E	390	5.720	6.449
12.	Jammu	32.67 N	74.83 E	367	5.507	6.484
13.	Kodaikanal	10.23 N	77.47 E	2345	5.579	5.677
14.	Kottayam	09.53 N	76.50 E	73	5.643	5.742
15.	Leh	34.15 N	77.57 E	3514	5.881	7.157
16.	Lucknow	26.75 N	80.88 E	128	5.565	6.185
17.	Nagpur	21.15 N	79.12 E	311	5.443	5.930
18.	Patna	25.50 N	85.25 E	52	5.592	6.217
19.	Pune	18.53 N	73.85 E	563	5.669	6.025
20.	Vishakapatnam	17.72 N	83.23 E	3	5.626	5.958

(*Source: Solar Radiation Over India – Annamani & Rangarajan.*)

C) Flat Plate Collectors.

A solar collector is one which

- Intercepts radiation from the sun;
- Convert this solar energy into thermal (heat) energy;
- Transfer the heat energy to a fluid;

The basic types of solar collectors are flat plate collectors and concentrating collectors. A flat plate Collector with reflectors has characteristics of both plate and concentrating collector. The concentrating collector and flat plates with reflectors are more efficient than the flat plate collectors, as they enclose a larger area. But the economic indicators point flat plate collectors to be more feasible than the other two. An added advantage of flat plate collector is that it can be integrated with the existing roof itself. Since we are concerned with the economical aspect we will restrict our discussion to flat plate collectors. Flat plate collectors can collect both direct and diffuse radiation and can make small amount of heat even on overcast days.

The Solar Air Heating Systems (SAHS) using flat plate collector traps the solar energy and converts the same into useful energy. Since our discussion is centred on the application of Flat plate collectors, an introduction about the same will be briefed. An energy flow diagram of the flat plate collector is provided in the figure 4.1. The important components of flat plate collectors are

C.1. Absorber

This forms the important part of the flat plate collector. The absorber is essentially flat, but can also be perforated, corrugated, finned or crimped. It absorbs solar energy, heats up and then transfers the heat to the fluid moving over or through it. They collect both direct and diffuse radiation, so they may produce small amounts of heat even on overcast days when all solar radiation is diffuse.

A good absorber in a solar collector:

- Absorbs a high percentage of incoming solar radiation.
- Loses minimum energy to the collector's surroundings.
- Efficiently transfers absorbed energy to the collector fluid.

It can be made up of copper, aluminium or GI sheets. Dark surfaces have high absorptance and hence collector absorbers should be black painted if they are not naturally dark. "Selective surfaces" have both high solar absorptance and low long-wave emittance. Most of them are special factory-applied coatings and can be quite costly. Selective surfaces can reach higher temperatures because they lose less energy by radiation.

Well-weathered galvanised metal with a rough, dull grey surface is a natural mildly selective surface. Painting the metal flat black increases the solar absorptance, but destroys the selective surface—the unpainted surface is probably more cost effective.

C.2. Cover

Solar collectors are covered by covers or glazing which are fitted to

- Reduce convection heat losses by shielding the absorber from the wind;
- Admit solar or short-wave radiation to the absorber;
- Reduce radiation heat losses by preventing the escape of long-wave radiation from the collector.

Adding cover layers reduce energy losses from a collector, but also reduces the radiation transmitted to the absorber. Glass is most common on collectors with re-circulated working fluids. It has excellent transmittance that does not change over time. The biggest disadvantage of glass is its brittleness. Fibreglass reinforced plastics (FRP) are one of the most efficient cover materials for low-temperature agricultural collectors.

Other cover materials include polyester, polycarbonate and poly-vinyl fluoride. Polyester and polyvinyl fluoride are cheaper than FRP and have higher solar transmittance, but they also have higher long-wave transmittance, are less durable than FRP, and are harder to work with. Polycarbonate has good transmittance and can withstand ultraviolet radiation better than FRP, but it has high thermal expansion and is very expensive.

C.3. Insulation

In addition to losing heat by radiation, absorbers in solar collectors lose heat to the side and back plates by conduction, natural convection in liquid-type collectors, and forced convection in air-type collectors. The inside walls of the collector warm up and the heat is conducted through them to the outside, where it is carried away by the wind, Insulation reduces these heat losses. Some of the insulators used are rockwool, polyurethenes, polystyrenes etc.,

C.4. Efficiency

Converting solar energy from radiation to heat is not cent percent efficient. Efficiency shows how well a collector converts available solar energy into useful heat energy. The efficiency of the collector is determined by the following formulae

Collector Efficiency = Useful energy/ Energy incident on the collector.

The performance equation of the flat plate collector is given by

$$\eta = F_R\,[(\tau\alpha)_n - U_l(T_{av} - T_a)/I_T]$$

Where

η **--** Efficiency

$\tau\alpha$ **--** Transmittance -Absorptance product.

U_l -- Overall heat loss coefficient of collector (W/m^2K)

F_R -- actual collected useful energy/useful energy collected if whole collector surface were in inlet temperature.

I_T -- Intensity of solar radiation (W/m^2)

C.5. Types of Flat Plate Collectors

There are different modes by which the fluid is passed through the collector to get optimum heat out of it. It is based on the flow of the fluid with the absorber as the reference point. The various modes of fluid flow are

(a) Flow above the absorber

In this, the fluid is allowed to pass through the spacing between the cover and the absorber. This is the cheapest mode of flow as there is no additional cost involved other than the cover, absorber plate and insulation. The top loss in this mode of operation is more than the other flow patterns.

(b) Flow below the absorber:

In order to reduce the heat losses, the flow below the absorber model was developed. In this model, the fluid flows below the absorber plate and thereby removing heat. Since the area between the cover and absorber has cold air, the losses are minimised. But this set-up will require another plate between the absorber and the insulation, which increases the cost.

(c) Suspended absorber:

Another model is the suspended absorber in which the fluid flows first through the space between the cover and the absorber and then through the spacing below the absorber. This two-pass model is too costly.

Roof integrated solar air heating system is an economic alternative to the costlier solar heating systems. The advantage of roof integrated system lies in its simplicity, cost effectiveness, longer life and requires no extension of the existing processing area. The concept of the roof integrated solar air heating system is well explained by the Figure 4.2.

D) Modular Design of SAHS for Paddy drying

In the following paragraphs, the details of the solar air heating system that is proposed for paddy drying will be dealt with.

D.1. Location

The Ram singh Rice mill is located in Theni in Tamilnadu. This area is located at 10^0N Latitude and 77^0E Longitude with an altitude of 125 MASL. The climate experienced in this part of the country is Tropical with moderate rains during the North east monsoon. The Clear Sky Radiation (CSR) data for the location (Theni) for all the days in a year obtained by simulation is given in Annex- I.

D.2. Operating parameters

The industry is processing raw paddy to parboiled rice. The capacity of the mill is processing 12tonnes of parboiled rice per day. The paddy is soaked in cold water for 8-16 hours in cement tanks depending on the atmospheric temperature. Soaked paddy is then steamed for about 8 minutes in a conventional cooking chamber. Parboiled paddy is subjected to preliminary drying in open yard and then is dried in a Taiwan drier for 7-8 hours and is send to the milling section. In the Taiwan drier, paddy is dried at 60^0C at an airflow rate of 12,000m^3/hour. A photograph of the Taiwan drier installed in the mill is given in Figure 4.3. The fuel consumption by the drier for drying paddy is 96 litres of diesel/batch.

Figure 4.3 View of the Taiwan Drier

D.3. Calculation of area requirement

The basic step in going for the SAHS is the calculation of the solar panel area required to trap the thermal Energy required for the drying operation. The drying operation is carried out in Taiwan drier. The energy requirement for drying twelve tonnes of paddy is found to be 852.24 kWh. With the hot air requirement of 12,000m^3/hour and the temperature required at 60^0C the solar panel area required for providing this energy is 212m^2.

D.4. Panel fabrication and installation

The 212m^2 solar panel is divided in to 4 panels, each with an air outlet of 3000m^3/hr. The panel is of three partition and four passes with inlet opening at one end and outlet opening on the opposite end. Each panel is of dimension

7.3mx7.3m. The absorber is of round corrugated aluminium sheet that is painted with a dull solar black paint. The absorber is fastened to the purlins through the insulation.

D.5. Insulation

Proper insulation is to be made below the G.I sheet to prevent heat losses. An insulator, rock wool is placed below the asbestos sheet throughout the area to be brought under the solar panel. The other area on which insulation is to be cladded is the duct carrying hot air. Once the ducting work is complete, they are insulation cladded.

D.6. Support

The glass cover needs support so that it provides the necessary gap for the air to pass through. The air gap is determined by the airflow rate required by the drier. The supports of fixed sizes are made and these are placed in locations of equal intervals and connected to the roof Purlins running beneath the roof. Aluminium extrusions are fastened on the supports to hold the glass cover.

D.7. Glass cover

Toughened solar glass of 4mm thickness is used as the cover material. The SAHS to be installed is a single cover, flat plate collector, which provides the required energy at a lower cost. These cover glasses available are made into manageable pieces and are placed on the aluminium supports. In order to have airtight cover, rubber beading is provided at the edges. A good sealant is also used to seal the air gaps. Railings can also be provided in the top to allow inspection of the panel.

D.8. Ducting

Ducting is necessary to convey the hot air from the solar panels to the drier. The hot air from the individual outlets of the solar panel is collected in a common plenum chamber. This air is routed through the duct and taken to the blower to be supplied to the drying section. A total ducting length of 40m is required for the industry. The ducting is usually done using G.I sheets and insulated. This completes the SAHS system.

D.9. Project Implementation Time

The project implementation timetable is give below.

Description of the work.	Time
a) Drawing and other preliminary works	1 weeks.
b) Making the roof ready	2 weeks.
c) Material Purchase	3 weeks.
d) System fabrication	5 weeks.
e) Commissioning work	2 weeks.
f) contingency	1 weeks.
Time required for installation and commissioning of 212 m^2 SAHS for paddy drying	14 weeks.

D.10. Controlling the temperature

The SAHS will have dampers connected to the ducting through canvass connection, which can be used to control the temperature. The dampers act as valves where in air can be allowed into the duct or send out. Large variations in airflow rates can be detrimental to the blower (in case of axial fan) and result in its damage. Exhaust dampers are also to be provided for the solar panel.

D.11 Operation Schedule

The paddy to be processed is to be steeped in water during the previous night to provide it time to get soaked. It should be then steamed in the morning and allowed to drain the condensing water. This paddy with a moisture content of about 30%(w.b) should be loaded into the Taiwan drier and allowed to dry. Since the drying time is around 8 hours, the entire operation can be done in the time having good insolation so that the system can operate as a Full Energy Delivery (FED) system and the savings can be optimised.

Chapter 5 ANALYSIS OF THE MODULAR DESIGN

The various operating parameters that are involved in the design of the SAHS are subjected to a simulation program to find out the efficiency of the design since actual performance is not available. The simulation program will provide the characteristics of the solar air heater, which are required for the successful operation of the SAHS.

A) PERFORMANCE CURVES

The various operating parameters that are involved in the design of the SAHS are subjected to a simulation program to find out the efficiency of the design since actual performance is not available. The simulation program will provide the optimal working parameters of the solar heater, which are required for the successful operation of the SAHS. The various performance curves based on the performance equation that are required to assess the efficiency of the SAHS planned are provided in the Figures 5.1 to 5.9. Among these the following plots show the long-term performance of the collector.

i) η Vs $(T_{av} - T_a)/I_T$

ii) η Vs $(T_i - T_a)/I_T$

iii) η Vs $(T_o - T_a)/I_T$

All the parameters that affect the smooth functioning of the collector are simulated in these plots. The efficiency of the collector plotted against global radiation at various airflow rates is provided in Figure 5.4. The airflow rate did not effect any appreciable increase in the efficiency and hence the required flow rate can be used and an average efficiency of 50% is anticipated. Figure 5.5 shows a linear increase of the energy gain by the collector with increase in global radiation and increasing flow rate. This is because at higher flow rates and global radiation the rate of heat removal will be more due to increased volume flow. Figure 5.7 discusses the effect of temperature raise with global radiation at various airflow rates. The effect of airflow rate has a pronounced effect on the temperature raise. Figure 5.8 showed a marked drop in overall loss coefficient with increase in airflow rate. This is because of the rapid increase in heat transfer rate with the increasing temperature. The heat removal factor plotted in Figure 5.9 against global radiation for the airflow under consideration is around 0.75 and this result is quite satisfactory.

B) Extrapolation of the results

The expected results that are obtained by the simulation of the operating parameters are extrapolated to other parts of the country. The results are made by the assumption that the parameters recorded in this selected mill will be similar in the other mills located in other parts of the country. The extrapolated results of the average insolation levels during the various months and the fraction of energy delivered by the SAHS are given in Annex-III. On an average 65 –70 % of the energy required for drying 12 tonnes of parboiled paddy can be provided by solar air heating system in most parts of the country. These results suggest that the states of Uttar Pradesh, Bihar and Orissa appears to be more attractive in the application of solar heating to take care of the drying needs as these areas receive more insolation. The leading rice producing states, Punjab and Tamil Nadu receive 72% and 68% of their energy from solar air heating respectively. The system can also be implemented in other states and the returns are on the average of about Rs. 2.4 lakhs. The north-eastern parts provide only 60% of the energy requirement.

Chapter 6.Economics of solar heating

The feasibility study has shown that the SAHS can operate as a FED system to take care of drying paddy. The maintenance cost involved with the SAHS is the cleaning of the glasses, which can be taken care by the labourers themselves. The life of the system is estimated to be around 15 – 18 years. The system is to be repainted once in five years, which costs around Rs. 20,000.

A. Cost of the modular Design

The split up of the cost involved in the construction of a 212m^2 solar air heating system to provide hot air for drying paddy is given in the Table 6.1.

Table 6.1 Cost for installation of SAHS

Sl.No.	Description	Cost (Rs)
1.	Aluminium Extrusion	1,51,889.00
2.	Rubber Materials	25,014.00
3.	Glass and absorber materials	1,03,253.00
4.	Insulation	54,984.00
5.	Blower and other accessories	49,886.00
6.	Ducting materials	1,05,155.00
7.	M.S angles and G.I sheets	63,052.00
8.	Labour charges	
	(a) Panel fabrication	1,56,941.00
	(b) Ducting & Cladding	1,15,638.00
9.	Design, Drawing charges and over head	50,000.00
	Grand Total	**8,75,812.00**

B. Energy and Cost savings by the SAHS

A theoretical feasibility study of Installing Solar Hot Air Systems at various locations in India including Economics for drying Paddy is given below,

Assumptions

Thermal Energy spend in drying 12 tonnes of parboiled paddy = 852.24 kWh

Normal Efficiency of Solar Air Heating System (SAHS) = 50%

Area of the Collector to be installed = 212 m^2

Daily hours of operation = 8hours

Period of operation = 300 days per year

Cost per kWh (based on diesel price) = Rs. 1.30/-

Table 6.2 Cost savings in various states of the country

S.No	Location	State	Fraction of energy supplied by SAHS	Cost saved per year (Rs.)
1.	Ahmadabad	Gujarat	0.71	2,40,078.00
2.	Bhubaneshwar	Orissa	0.77	2,58,684.00
3.	Calcutta	West Bengal	0.61	2,08,672.00
4.	Chandigarh	Haryana	0.72	2,42,921.00
5.	Chennai	Tamilnadu	0.68	2,30,213.00
6.	Lucknow	UttarPradesh	0.77	2,59,317.00
7.	Mangalore	Karnataka	0.61	2,05,657.00
8.	Nagpur	Madhya Pradesh	0.68	2,28,771.00
9.	Patna	Bihar	0.76	2,55,973.00
10.	Pune	Maharashtra	0.69	2,34,283.00
11.	Trivandrum	Kerala	0.68	2,28,457.00
12.	Visakhapatnam	Andhra Pradesh	0.69	2,31,322.00

Radiation data- source [1]

C. Environmental Savings

One of the major advantages of SAHS is the reduction in Green House Gases (GHG) particularly CO_2 due to fuel saving and therefore reduces the risk of global warming. The savings of fuel expected from the industry under consideration is 96 litres of diesel per day and this fuel consumption can be extended to similar rice processing units. The total production of paddy in India is 84.3 million tonnes and on an average 60% of the paddy is parboiled. Assuming 50% of this parboiled paddy being processed through modern rice mills, the fuel saved per annum is 21.252×10^6 litres of Diesel and this saving will reduce the CO_2 (GHG) load in the atmosphere by $61.631 \times 10^{3\,+}$ tonnes per annum. To achieve these advantages the collector area required is 259.099×10^2 m^2. This area is going to occupy the existing roofs of these industries and no additional roofing is to be done.

D. Government Incentives**

The cost incurred in setting up the SAHS is around 4100 Rs/m^2. The Government of India is disbursing loans to the extent of 75% of the total cost at a lower interest rate of 8.3% (for profit oriented industries) through Indian Renewable Energy Development Association (IREDA). Only 25% of the investment cost is to be borne by the investor. Since the payback period (including cost invested by the investor) is around 2 years, this is a profitable venture, which can start returning profits after the pay back period. The government also provides 100% depreciation of the first year of installation, which saves as corporate tax of about 40% of the investment. For the soft loan provided by the government a moratorium of 2 years is allowed and repayment can be made within the next 8 years.

[+] The Carbon content of Diesel is 84.2 Wt. % and the specific gravity is 0.9

E. Pay back Analysis

Table 6.3 Pay back analysis chart

Returns			Investment		
Period (years)	Details	Amount	Details	Amount	Surplus (Rs. in lakhs)
0			Capital	8,75,812.00	
I	Due to 100% depreciation, savings in corporate tax(40%)	3,50,324.00	Interest for 75% of capital@8.3% Interest for investment [+]by investor@18%	54,519.00 39,411.00	
	Fuel savings*	3,78,624.00	Maintenance and parasitic cost (5% of capital)	43,790.00	
	Total	7,28,948.00	Total	10,13,532.00	
Balance				2,84,584.00	(- 2.84)
II	Fuel savings	3,78,624.00	Interest for 75% of capital@8.3% Interest for investment [+]by investor@18%	17,715.00 12,806.00	
			Maintenance and parasitic cost	43,790.00	
	Total	3,78,624.00	Total	3,58,895.00	
Balance				19,729.00	(+ 0.19)

+ 25% of the total investment since 75% of the investment is provided by IREDA as soft loan with 8.3% investment with a moratorium of two years and a repayment of ten years.
* Fuel savings for a period of 290 days by SAHS at 50% efficiency.

** Source IREDA Guideline

Chapter.8 Benefits of SAHS

A. Advantages

The inherent advantages in using solar air heating for drying operations are given below with examples taken from our case study and experience in the particular field.

A.1 Fuel Conservation

For the drying operations, the most widely used fuels are diesel and furnace oil. Both being fossil fuels, they are to be conserved as the resources are depleting at a fastest rate due to increasing demand. With the demand on the curb of over exploitation of fossil fuels raising, the search for alternative energy sources is being done on a fast pace. The conservation of fossil fuels can be done easily substituting the energy requirements during the daytime with solar energy thereby reducing fuel consumption. For drying parboiled paddy the temperature requirement is around 60^0 C and hence the installation of solar air heater fits the bill perfectly. It will save the user the quantity of fuel that is used in the conventional furnace (96 Liters per day in this particular case) by acting as a Full Energy Delivery system (FED). Since the roof integrated flat plate collector can also work by using the diffuse radiation more heating (preheating) can be done beyond the specified period of operation.

A.2 Increased Efficiency

An increased efficiency can be experienced when the solar air heating system is installed. Normally all furnaces operate with an efficiency of around 40% for diesel fired systems and a much lower efficiency of 10-15% for fuelwood burnt systems. The SAHS normally operates at an instantaneous efficiency of 50% which when working with SAHS can yield increased overall efficiency. An advantage of using the solar air heating system is its lowest cost coupled with integrated roofing. The payback period for the system is the least and has less maintenance costs as compared to conventional energy sources. An efficiency of 53% is obtained in the operating systems, which by itself is a greater achievement. Currently work is being carried out to boost the efficiency to a higher level at a lower cost at PEN.

A.3 Environmental Benefits

With the states making a stringent posture on the pollution control measures, the solar air heating system stands out as an exemplary model of being nature friendly in providing a cleaner atmosphere. Since the system harness solar energy, it never gives out any harmful chemicals thereby helping these industries adopting this system to get international environment certification (ISO 14001). This cleaner technology can also aid in a better quality management to receive the ISO certifications (ISO 9001 & ISO 9002) which are a prerequisite to compete globally. This is achieved as the products are processed in a hygienic manner. The other major environmental benefit is the reduction of CO_2-a green house gas largely by substitution for fossil fuels.

A.4 Quality of product

With the implementation of SAHS coupled with the backup, the hot air temperature will be maintained constant throughout and hence uniform drying can be achieved. Uniform drying will decrease wastage due to breakage during milling and increases the shelf life of the product thereby rendering better quality.

B. Disadvantages

One of the problems that ail the SAHS system is its need for a backup heater to heat air when SAHS is not working. This problem arises when clouds as rain block the natural solar energy or the operation is prolonged beyond the sunshine hours. During such time, the conventional systems alone can help. The other situation arises when the solar SAHS could not deliver the required temperature. More over the initial investment cost of the system is also another deterrent in this system being adopted by the Small Scale Rice mill owners as they find it difficult to put in the additional investment cost.

OVERCOMING THE DISADVANTAGE

To overcome these problems, the SAHS is coupled with the conventional heating source such that the heating system never fails during the process as the operator can rely on conventional heater (auxiliary heating unit) when the SAHS is not under operation. In existing plants, the SAHS works coupled with the existing heater as that could get a backup at no more extra capital investment. This does not involve any complex design and is simple in installation and operation. The Plan outlay (Annex B) shows the mode by which the integrated system of SAHS and the conventional heater (backup) are operated. Since the SAHS is a Full Energy Delivery (FED) system, the auxiliary heating system supports the SAHS only when temperature is not sufficient.

A temperature indicator in the drier hot air flow duct can help in the detection of any change in the temperature and this can work as a indicator as to whether the backup system should be used or not. All states go through a lean phase in solar radiation for two months. During these months (see radiation chart) the back up heater can provide the necessary hot air for drying.

The initial investment cost can be made up by the industries by utilising the incentives provided by the Government of India through various schemes listed out in section D of Chapter 7.

Chapter 8 Conclusion

This project report explored the possibility of utilising the enormous energy liberated from the sun to the betterment of drying Paddy. Since paddy drying is a process practised throughout India, this project can be implemented on a large scale and can aid in reducing the post-harvest losses, which are in alarming proposition in the country. The elaborate study conducted as part of this project suggest that SAHS is an economically viable option present before the rice mills to do substantial gains in terms of fuel savings. The illustration presented has dealt in detail about the technical feasibility of installing a SAHS in a rice mill for its hot air requirement for drying paddy. SAHS can act as a FED system for about 6-8 hours a day. By operating for 8 hours required for drying in a day the quantity of fuel saved is 27,840 litres/annum. The cost savings due to this fuel saving is estimated to be 3,78,624.00Rs/annum. With this saving by installation of SAHS, the pay back period for the initial investment is Two Years along with the interest existing in the market. With such savings and technical feasibility the installation of SAHS can aid in considerable fuel saving and can increase the profit margin of the modern rice mill owners.

RECOMMENDATIONS

1) Rice being produced and processed through out the country, the installation of this roof integrated solar hot air technology would save the government a considerable amount of fossil fuel and the dependence on fossil fuel imports.
2) Mass utilisation of this technology will reduce the cost of production of required equipment and hence the initial investment of the same.
3) Installation of a model SAHS in a rice mill will go a long way in perfecting the system for drying paddy. The data generated from the collector will help in improving the performance of the system.
4) Spreading the advantages of the system through mass media will help in educating the millers about SAHS.
5) The Government can provide brochures about this system whenever a new application for modern rice mill is being made.
6) Small subsidies can encourage the utilisation of SAHS by SSIs.

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Figure 4.1 Schematic of Taiwan Drier