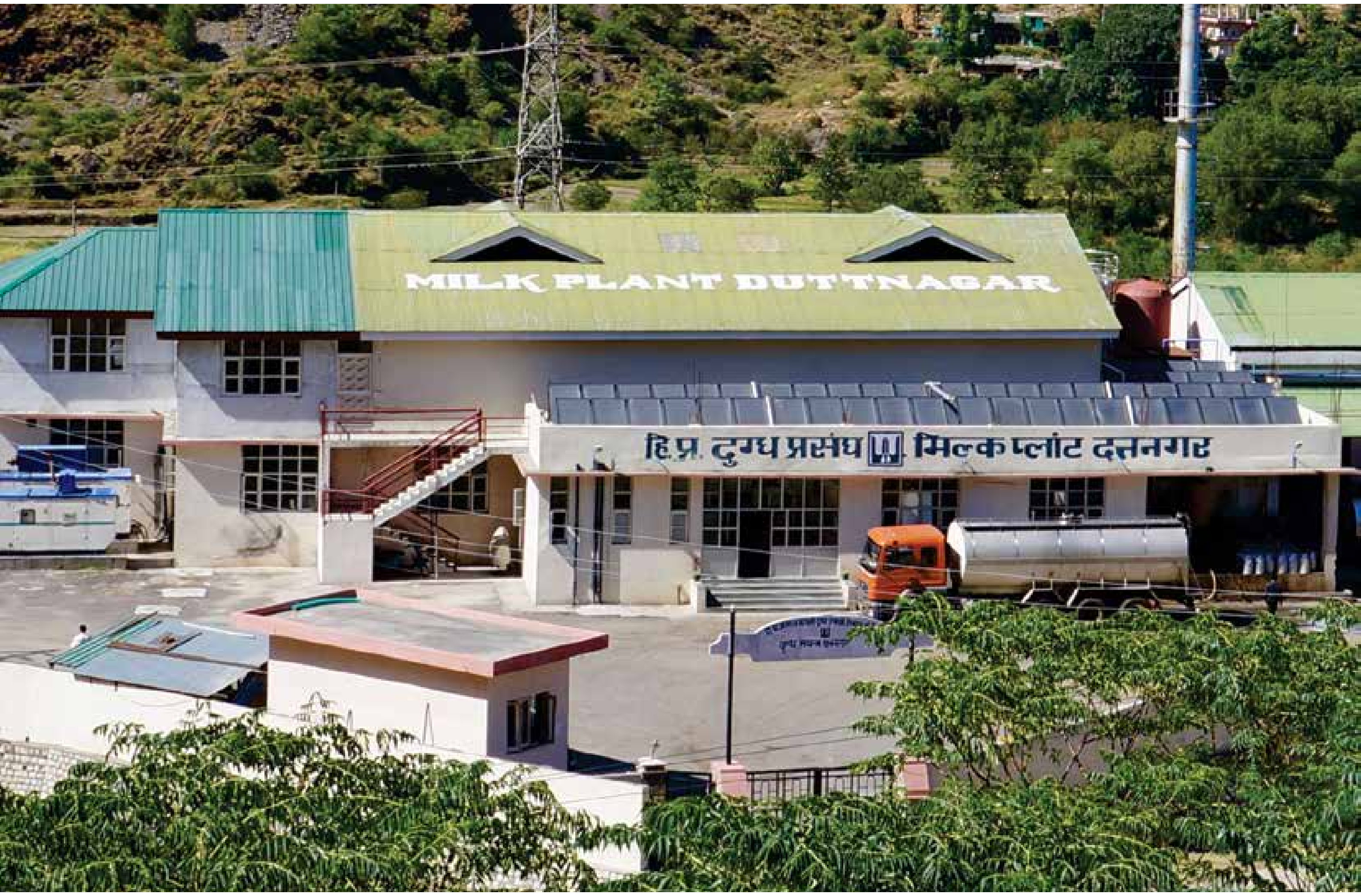
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of:
Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
of the Federal Republic of Germany

GOVERNMENT OF INDIA
MINISTRY OF NEW AND RENEWABLE ENERGY



Measuring Solar Heat Generation

Monitoring Results of a Solar Water Heating System for Process Heat
Case II – Himachal Pradesh Dairy, Food Processing Industry in Rampur, Himachal Pradesh

SoPro India
Solar Water Heating for Industrial Processes in India

Under SoPro India (ComSolar) Project

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Abbreviations

BMUB	German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
ComSolar	Commercialisation of Solar energy in Urban and Industrial areas
ETC	Evacuated Tube Collectors
FPC	Flat Plate Collectors
Fraunhofer ISE	Fraunhofer Institute for Solar Energy Systems ISE
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GSM	Global System for Mobile Communications
HC	Heat Counter
HP	Himachal Pradesh
IGEN	Indo German Energy Programme
kWh	Kilowatt Hour
MNRE	Ministry of New and Renewable Energy, Government of India
RO	Reverse Osmosis
R&D	Research and development
SHIP	Solar Heat for Industrial Processes
SoPro India	Solar water heating for industrial processes in India
SWHS	Solar Water Heating Systems

Introduction

The lack of reliable data of the energy output of Solar Water Heating Systems (SWHS) is one barrier for their deployment. Monitoring of SWHS shall on one hand show, how much fossil fuels and money can be saved by solar thermal energy and shall allow on the other hand to identify possible improvements of the technical concept and the way of operation of the monitored systems.

Within Solar water heating for industrial processes in India (SoPro) India – project under ComSolar, highly sophisticated monitoring systems, which are typically used by Fraunhofer ISE to do monitoring on a scientific level, are implemented to two SWHS to provide reliable data as a reference for further discussions. Based on these experiences, recommendations for a simple and cheap monitoring concept were derived, which can guide for designing monitoring systems for the Indian SWHS market.

Two SWHS were monitored within the SoPro India project, the SWHS utilising flat plate collectors at Himachal Dairy in Tehsil-Rampur Bushar, Himachal Pradesh, and the SWHS utilising evacuated tube collectors at Synthokem Labs in Hyderabad, Telangana. The result overview of the SWHS installed at Himachal dairy - a food processing company in Northern India - is presented and analysed in the following pages.

Monitoring system design

Monitoring system for the solar water heating system at Himachal Pradesh Dairy – Milk plant Duttnagar, Tehsil-Rampur Bushar district, Himachal Pradesh

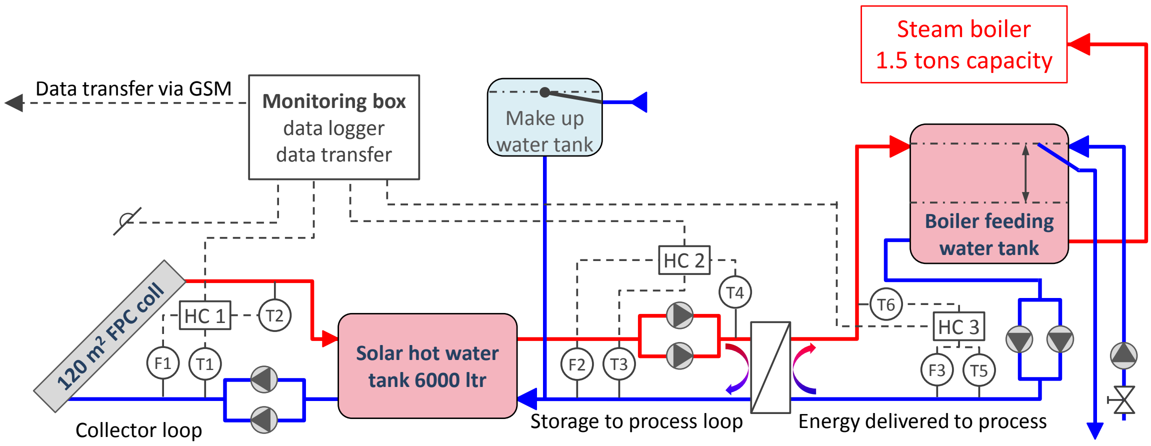

Figure 1 Scientific monitoring system to measure the yield of the solar water heating system and subsystems

Operation:

Each heat circuit has an own heat counter, which uses a flow meter F and the temperature difference between two temperature sensors T to calculate the thermal energy generated. Heat counter 1 measures the solar yield of the collector's fields delivered to the solar tank, heat counter 2 measures the thermal energy delivered from the storage to the heat exchanger and heat counter 3 measures the thermal energy delivered to boiler feeding water tank. The pyranometer is positioned in the same angle than the collectors and measures the intensity of the solar irradiation. So the efficiency of each step of the energy chain can be identified: solar irradiation / conversion to heat in the collectors / losses of the storage / losses of the heat exchanger.

Overview on the monitored performance of the SWHS

The HP Dairy SWHS is a non-pressurised, open system, composed of a Flat Plate Collector (FPC) field with 120 m^2 total collector gross area and a water storage tank with 6000 litre volume. The collectors are installed on the roof-top of the company building and the storage tank on the ground. The SWHS is used for pre-heating the feeding water of a steam boiler.

The system was monitored since 15 October 2014. Monitored data until 25 July 2015 are available and can be found under the tab "weekly results" on the project website www.soproindia.in. Further data are not available due to data transfer problems. Due to different reasons (broken sensors, failures in data storage or data transfer, etc.) monitored parameters are for several days or weeks not available. However, since the heat meters sum up their values continuously, the energy generated could be calculated for each month.

The monitoring results of the HP Dairy SWHS, available for the period of 15 October 2014 until 25 July 2015 (9 months), are extrapolated to annual data and shown in Table 1 and Table 2. Since the data of the summer period are missing, the real data can be expected up to 10% better than the presented ones.

Table 1 System performance values of the solar system (for the entire system with 120 m^2 collector gross area, 111 m^2 aperture area), annual values are extrapolated on measurements from Oct 2014 – July 2015.

Lines, formulas	Description of parameter	Annual values of the whole system	Average daily values of the whole system
(1)	Solar irradiation on collector area	155.9 MWh/a	427.0 kWh/d
(2)	Solar yield in the collector circuit	46.3 MWh/a	126.9 kWh/d
(3)=(2)/(1)	Solar collector efficiency	30%	
(4)	Solar energy delivered to process	30.4 MWh/a	83.4 kWh/d
(5)=(4)/(1)	Solar system efficiency	20%	
(6)	Water volume pumped in circuit to process	2,037 m^3/a	5.6 m^3/d
(7)=(4)/((6)*1.14)	Average temperature increase of water delivered to the process	13.1 °C	
(8)	Boiler efficiency assumed	70%	
(9)=(4)/(8)	Fuel saved (energy content 10.4 kWh/L)	43.4 MWh/a	119.0 kWh/d
(10)	Fuel saved (diesel)	4176 L/a	11.4 L/d
(11)	Total annual fuel demand (diesel)	3,03,000 L/a	830 L/d
(12)=(10)/(11)	Solar fraction	1.4%	
(13)	Fuel cost saving (52 ₹ per litre fuel)	2,17,000 ₹ /a	595 ₹ /d
(14)	Investment (total system costs)	₹ 1,667,000	
(15)=(14)/(13)	Simple pay-back time without subsidy	7.7 years	
(16)	Central Financial Assistance (CFA)/ Subsidy	₹ 792,000	
(17)	Investment costs minus subsidy	₹ 875,000	
(18)= (17)/(13)	Simple pay-back time including subsidy	4.0 years	
(19)	Carbon emissions saved (2.6 $kgCO_2e/L$)	11 tCO_2e/a	30 $kgCO_2e/day$

To ease the comparison of different solar systems with different collector areas, the values per square meter aperture collector area are shown in Table 2. The gross collector area is 120 m^2, while the aperture collector area (area without the collector frame, this means the area, where the solar irradiation can enter the collector) is 111 m^2.

Table 2 System performance values of the solar system (per square meter of collector aperture area)

Lines, formulas	Description of value	Annual values per square meter collector area	Average daily values per m^2 collector area
(1)	Solar irradiation on collector area	1,404 kWh/(m^{2}a)	3.8 kWh/(m^{2}d)
(2)	Solar yield collector circuit	417 kWh/(m^{2}a)	1.1 kWh/(m^{2}d)
(3)=(2)/(1)	Solar collector efficiency	30%	
(4)	Solar energy delivered to process	274 kWh/(m^{2}a)	0.8 kWh/(m^{2}d)
(5)=(4)/(1)	Solar system efficiency	20%	
(6)	Water volume pumped in circuit to process	18.3 m^3/(m^{2}a)	50.3 L/(m^{2}d)
(7)=(4)/((6)*1.14)	Average temperature increase of water delivered to the process	13.1 °C	
(8)	Boiler efficiency assumed	70%	
(9)=(4)/(8)	Fuel saved (diesel), energy content	390 kWh/(m^{2}a)	1.1 kWh/(m^{2}d)
(10)	Fuel saved (energy content 10.4 kWh/L)	37.6 L/(m^{2}a)	0.1 L/(m^{2}d)
(13)	Fuel cost saving (52 ₹ per litre fuel)	1,955 ₹ /(m^{2}a)	5.4 ₹ /(m^{2}d)
(14)	Investment (total system costs)	₹ 15,000 / m^2	
(15)=(14)/(13)	Simple pay-back without subsidy	7.7 years	
(16)	Central Financial Assistance (CFA)/ Subsidy	₹ 7,135 /m^2	
(17)	Investment costs minus subsidy	₹ 7,883 /m^2	
(18)= (17)/(13)	Simple pay-back including subsidy	4.0 years	
(19)	Carbon emissions saved (2.6 kgCO_2e/L)	98 kgCO_2e/m^2 a	0.26 kgCO_2e/ m^2 d

Description of parameters

The calculated solar irradiation (1) on the collector surface is about 1,400 kWh/m^2 per year, which corresponds to an average daily irradiation of 3.8 kWh/ (m^2 d) collector area. The average global irradiation is 4.8 kWh/ (m^2 d) on horizontal area given in literature. In the sloped angle of 45° it should be even slightly higher. There are three reasons for the lower value measured, firstly, the collector area is oriented in parallel to the long side of the building (see Figure 2), this means towards south-east 30° while the optimal orientation would be towards south. Secondly, the collectors in the morning and especially during

Figure 2 Orientation of the collectors towards south-east due to installation area

winter are shadowed by high mountains, since the dairy is located at the bottom of the valley. In addition, since the data of the summer months are missed, the real value can be assumed 10% higher than extrapolated.

Solar yield collector circuit (2) is the heat generated by the flat plate collectors, which is delivered to the storage tank. Due to the very limited roof area, the flat plate collectors are partly shadowed in the afternoon by parts of the building, which reduces the solar yield (see Figure 3).

Figure 3 Collectors partly shadowed in the afternoon

By dividing the solar yield by the solar irradiation, the solar collector efficiency (3) results as annual average, which is calculated with 30%. During winter time, the efficiency is lower than during summer time due to the lower ambient temperature and higher shadowing by the lower angle of the sun.

Most relevant is the solar energy delivered to the process (4) and the related solar system efficiency (5), this is calculated by dividing the energy delivered to the process by the solar irradiation. The HP Dairy solar system delivers about 30.4 MWh solar energy per year to the process (274 kWh/m^2), which results in a solar system efficiency of 20%.

Figure 4 Boiler feeding water tank (right side) with pipe from the solar system (blue) and the pipe to the boiler (red)

The solar heat is transported from the heat exchanger to the feeding-water tank by pumping 2,037 m^3 water through the circuit to process (6). The amount of solar energy transported by this water volume increased the water temperature in the average by 13.1 °C (7).

The temperature of feeding water in the boiler feeding-water tank is not known. A part of the solar heat is lost since the pipe to the tank and the water tank itself are not insulated (see Figure 4). These losses are not taken into account in the calculation, since their amount is not known.

Only a part of the energy content of the fuel is converted into heat due to the efficiency of the boiler (8), which is assumed with 70%. Therefore, the solar energy delivered to the process (4) must be divided by the boiler efficiency (8) to derive the energy content of the fuel saved (9). The volume of the fuel saved is given in (10) and the saved fuel costs in (13). The simple pay-back time without subsidy is calculated with 7.7 years in (15) considering the investment costs given in (14). The simple pay-back time is 4.0 years (18) if subsidy (17) is factored.

The carbon emissions saved are shown in (19).

Summary of the system performance

In each SWHS, only a part of the solar irradiation can be converted into useful heat. The amount of losses depends on the quality and efficiency of the components used, the design and operation of the system, which influences e.g. the temperature of the water which flows into the collector and the temperature of the water storage tank, the water temperature needed by the process (as higher the temperature, as higher the losses), the ambient temperature, the fraction of the total heat demand covered by solar energy, and the maintenance of the SWHS. Therefore, there is a broad range of possible solar system efficiencies and it is difficult to fix a typical efficiency. However, for a SWHS like at HP

Dairy a system efficiency of about 20% to 40% could be expected. This means that the performance achieved is with about 20% in the typical range, but there is room for improvement of the performance.

Discussion of the monitored performance

In the following, the monitoring results and possible reasons for the measured values are described. Figure 5 illustrates the measured efficiencies of the HP Dairy solar plant.

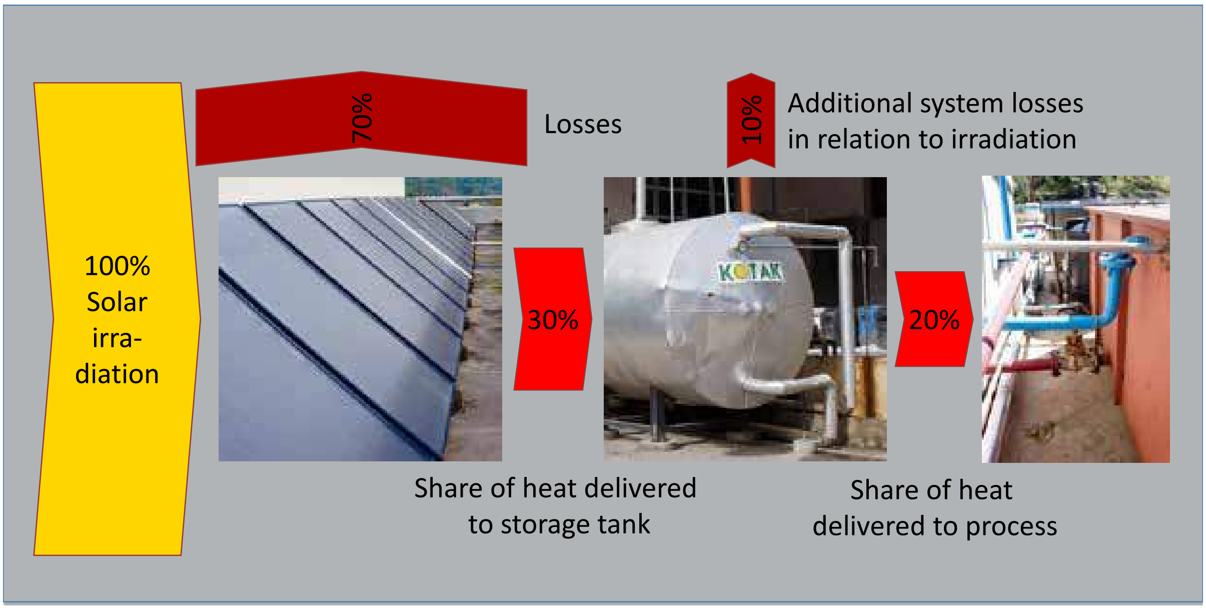

Figure 5 Measured energy flow and losses of the HP Dairy SWHS, percentages in relation to solar irradiation

Efficiency of the collector field and circuit

The typical maximum efficiency of flat plate collectors is 70% – 80%, depending on the transparency of the glass and the absorber coating used. With increasing temperature difference between the absorber and the ambient the thermal losses are increasing depending on the insulation of the collector and coating of absorber. On sunny days, e.g. on 24 April, the collector field delivers a temperature of about 70°C to the storage, the collector circuit efficiency reaches about 40% and the system efficiency about 35%. However, on colder days and less solar intensity, the efficiency is significantly lower.

Following causes could be responsible for the 70% of energy losses from the solar irradiation to the heat delivered to the storage tank:

1) At maximum, 70% – 80% of the solar irradiation is converted into heat, this means, that about 20% – 30% losses are caused by reflection and non-optimal transmission and absorption of the sunlight by the glass and the absorber. The collector glass is usually cleaned by rain. But if there is soiling on the collector glass, the so called "optical" efficiency can be lower than 70%.

2) The solar yield is lowered, if the collector or a part of it is shadowed by the collector row in front or by the building.

3) The absorber is heated by solar irradiation, but is increasingly loosing heat to the ambient with growing temperature difference between the absorber and the ambient. The losses depend on the type of coating of the absorber, the insulation at the back of the collector box, the tightness of the collector box and the ambient temperature.

4) Losses happen, if the collector field is not equally flown through by water, e.g. if air is trapped in some pipes, the water flow of parts of the collector field could be obstructed and this part of the collector field does not deliver heat to the storage or only a reduced amount.

5) Heat losses occur on the way from the collector to the tank, by improper insulated pipes and fittings.

6) The solar yield is also lowered if the collector circuit is not operated though the sun is shining, e.g. if the collector circuit pump is not switched on due to suboptimal controller parameter setting.

7) If the heat delivered to the storage tank by the collector field is not handed over to the process efficiently, the storage temperature remains higher than necessary. This leads to a higher collector inlet temperature, which results in a lower efficiency of the collector field.

Solar system efficiency

Additional losses of 10% (in relation to the solar irradiation) between the collector circuit and the heat demanding process are caused by:

1) Heat losses through the surface of the storage tank (taking into account, that the losses are already reduced by insulation).

2) Heat losses of the pipes and fittings, which are not well insulated.

3) Heat losses by unwanted circulation of the (hot) water from the storage to the collector field during night, due to natural convection by gravity.

4) Losses by heat exchanger. Since heat can only be transferred if a temperature difference exists, the heat exchanger leads to a higher temperature in the storage tank then the return flow from the process circuit. If the heat exchanger and the related pumps are not designed optimal (heat transfer capacity and/or mass flow through the heat exchanger too low), the heat cannot be transferred properly and an increased temperature results (which leads to a higher temperature in the fluid delivered to the collector field, which results in a lower efficiency).

Based on the measured data, it is not possible to identify which cause is responsible for which share of the losses. Some of the losses cannot be avoided, e.g. the reflection on the glass pane or the heat losses of the pipes and the storage tank, but losses can be reduced by a good quality of the products used. However, the effort to reduce the losses and increase the performance e.g. by using components with higher quality, is only reasonable, if the additional costs are lower than the cost savings which can be achieved by these measures.

Other losses can be avoided by a good operation and maintenance of the SWHS. A high performance requires that the fluid is pumped through the collector circuit whenever the temperature in the collector is higher than of the water to be heated in the storage. If an automatic controller is used like at the HP Dairy SWHS, the temperature difference between the collector outlet and the bottom of the storage tank (height of socket, where the pipe to the collector field is connected) is measured and if the difference is higher than e.g. 8°C the pump is switched on and if it falls again below e.g. 3°C, the pump is switched off. This hysteresis is necessary to avoid a permanent on-off-on-off operation as long as a stable operation mode is not achieved. However, it is important, that the temperature measurement is done properly, e.g. the sensors placed right, with sufficient accuracy and that the parameters of the controller are set correctly (not too high and not too low).

Figure 6 Collector outlet temperature sensor is located in the pipe close to the collector outlet.

As long as the collector circuit pump is not operated, the water heated by the collector, if the sun is shining, must be transported to the temperature sensor by micro-circulation. Therefore, it is important that the collector outlet temperature sensor is placed very close to the collector outlet or extends into the collector outlet tube, as it is at the HP Dairy System (see Figure 6).

Further it is important to prevent that air is encased in the collector circuits. This can be assured by the installation of vent valves at the highest points of the collector circuits. Especially, in non-pressurised systems they are important since they are usually open to the ambient. In the case of the HP Dairy SWHS, the collector circuit is not under pressure, however, it is also not emptied if the pump is not running. A vent valve is installed at the highest point, but there are other local points in the piping system, where air could be accumulated, without a valve. If air is encased in one of several parallel connected collector rows, it can hamper the circulation of the water in the related collector row so that its solar energy yield is not transported to the water storage tank.

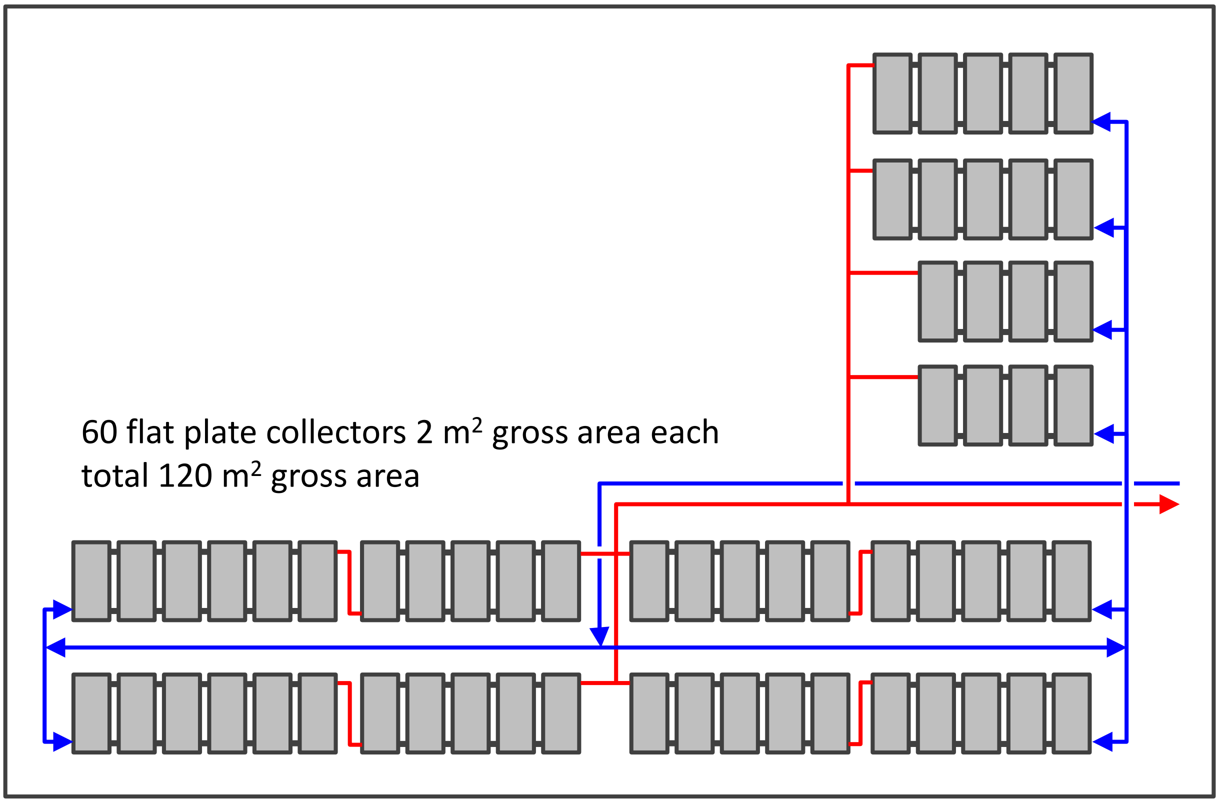

Figure 7 Hydraulic scheme of the collector field with 8 parallel connected collector rows

Also if the water flow through different parts of the collector field, which are connected in parallel, is not equal, due to different pressure drops, solar energy yield of parts of the collector field are not fully delivered to the water storage tank. Figure 7 shows the hydraulic scheme of the 60 flat plate collectors of the HP Dairy SWHS. Since 8 collector rows are connected in parallel with different number of collectors (and therefore different pressure losses), it can be assumed that the flow through the different collector rows is not equal. If in one or several collector rows air is encased, the water flow is hampered. This can be evaluated by comparing the temperatures of the pipes of different collector rows. Vent valves at the highest points of the circuit are necessary and should be checked regularly, to assure that they function properly.

Losses can also occur due to a suboptimal system design. The collector field should be designed in a way, that the pressure losses in each collector rows is equal. The design of an external heat exchanger is relatively costly and creates additional challenges to define the right dimension and run the pumps in both connected circuits with the right flow. How much the system efficiency could be increased by a different design cannot be assessed without additional investigation. However it can be stated, that the temperature at the bottom of the storage tank is with about 40°C higher than it should be. This is since the return flow from the storage to process loop, which defines the lowest water temperature in the storage, is typically at 40°C and should be lower. Since the bottom temperature of the storage tank determines the inlet temperature of the collector field, the collector efficiency is therefore reduced.

Further it should be stated, that the solar system is delivering heat to the feeding-water tank, which is not insulated. Since the solar fraction is with 1.4% very low, the resulting temperature increase of the feeding water by solar energy is rather low and therefore also the losses are rather low. However, the integration of the SWHS into the conventional heating system is not designed optimally.

Recommendations

The solar system is economical, since it is running with a system efficiency of 20% and a simple payback time of 4.0 years, taking into account the subsidies received. Therefore, there is no urgent need for changes in the system design.

However, the system performance could be increased by reducing the return flow temperature in the circuit of the storage to the process (this means to the heat exchanger), e.g. by optimising the flow on both circuits of the heat exchanger (see Figure 8). It should be proven as well, if the heat exchanger could be removed and the hot water of the storage tank could be directly pumped to the process feeding water tank, because then the cold temperature at the bottom of the feeding water storage tank would determine the temperature of the bottom storage temperature.

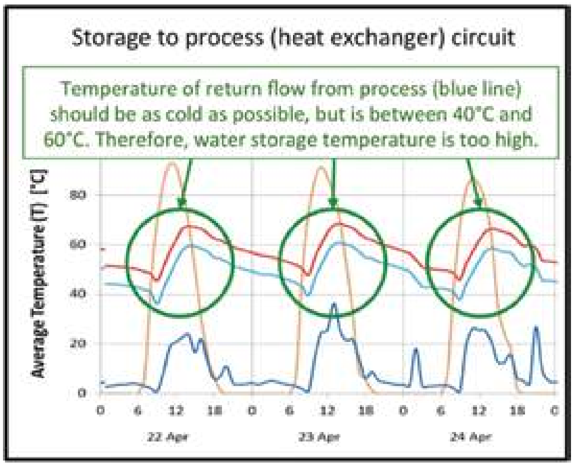

Figure 8 Temperatures of the storage to process circuit

The collector outlet temperatures measured in the collector circuit are typically between 50°C and 70°C, which is fine. But the collector inlet temperature is increasing immediately with the outlet temperature (see Figure 9). One would expect, that the inlet temperature stays longer at a lower temperature, because it reflects the low temperature at the bottom of the water storage tank, which should increasing slowly due to the volume. At least it should be at 40°C according to the return flow from the process (see above). Therefore the heat flow within the water storage tank should be evaluated.

It should be further evaluated, if the flow through the collector rows is equal. As part of this evaluation it should be checked, if air is enclosed in one or more parallel rows and, if necessary, missing air vents should be installed.

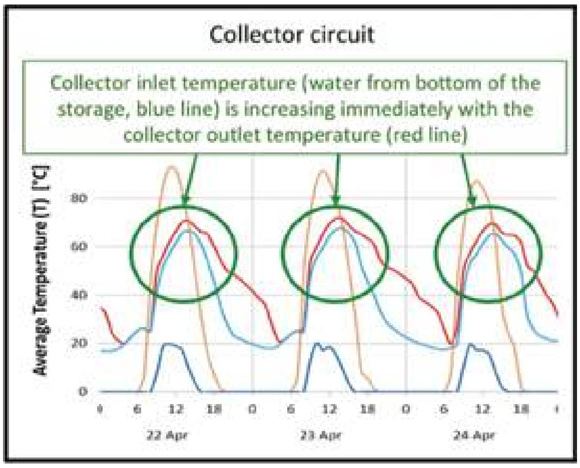

Figure 9 Collector inlet and outlet temperature curves

"We adopted solar water heating system as we had to pay very less upfront due to available subsidies. However, we are willing to pay for a system without subsidies because what matters to us is that the system should pay-back in its life-time. Having a meter which would let us know energy generated and thus fuel saved, would aid our investment decisions."

Mr AK Thakur,
Managing Director, HP Milkfed

"Solar water heating system is contributing to our energy savings. It is a maintenance free system and we haven't invested a rupee since the installation of system in 2013. We try to publicise this good, cheap and clean source of energy by taking our visitors to the roof-top and showing the system. It is being appreciated by the people, this enhances our brand value."

Mr Umesh Gupta,
Plant Manager, HP Dairy

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