PERGAMON

Renewable and Sustainable Energy Reviews
5 (2001) 157–173

RENEWABLE
& SUSTAINABLE
ENERGY REVIEWS

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Industrial solar thermal applications in Greece Economic evaluation, quality requirements and case studies

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Received 5 June 2000; received in revised form 26 June 2000; accepted 24 August 2000

Abstract

Industrial solar thermal installations of the 1980s had to face problems of poor quality and high maintenance requirements. During the 1990s the situation began to change and today in Greece there exist installations which are both economically attractive and offer significant energy saving and environmental benefits. Good potential for applications of solar thermal systems exist in sectors such as agrofood, textiles, chemicals and beverages. In this paper these systems are evaluated in economic terms in comparison with energy equivalent systems such as diesel, LPG, fuel 1500 and natural gas. The development of local solar thermal markets is described and eight successful applications of solar thermal systems in Greek industry are presented. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Solar energy; Industrial applications; Economic viability

Contents

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PII: S1364-0321(00)00012-5

1. Introduction

In Europe there is an urgent necessity to develop measures aiming at creating large projects harnessing renewable energy, promoting local and sectorial markets and developing business opportunities relevant to solar thermal SMEs. This is evident especially for regions like Spain and Portugal. Other Southern European regions, such as Greece, are considered to have a developed local market and business organisation. Nevertheless, in all the above countries and in specific markets such as the industrial process heating market, a sectorial policy for the promotion of solar thermal plants is rare [1].

As a part of a stimulation plan to raise solar thermal energy from a marginal to a significant energy source for industrial users, the Centre for Renewable Energy Sources (CRES), the Greek Solar Industry Association (EBHE), the Sociedad para el Desarrollo Energetico de Andalusia S.A. (SODEAN), the Sociedade Portuguesa de Energia Solar (SPES) and the Deutsche Fachverbande Solar Energie (DFS), implemented actions to:

- Increase local, public and industrial awareness of solar water heating technologies.

- Improve technical support to industrial designers, installers, craftsmen and users.
- Increase implementation of high quality solar installations in industrial applications.

The industrial solar thermal installation of the 1980s had to face problems of low quality and high maintenance requirements. During 1990s the situation began to change and nowadays in Greece installations exist which are both economically attractive and offer significant energy savings and environmental benefits.

This paper describes the development of solar thermal markets in Greece, by the reinforcement of the existing business infrastructure and the presentation of eight successful plants in Greek industry.

2. Industrial applications of solar thermal systems

The principal applications for large central solar thermal systems are: hot water production (domestic use: hotels, households, large residential buildings; large public and commercial buildings: hospitals, prisons, schools, sports centres; industrial applications and greenhouses: soil and space heating), space heating and cooling and desalination.

In industrial applications for solar hot water, five main industrial sectors can be distinguished, promising good acceptance of large solar thermal systems. These are industries with relatively low energy consumption, where the fraction of energy provided by the solar thermal system to the industry's energy load can be quite significant. Solar thermal systems are particularly effective in industries that require water temperatures in the range 40–80°C.

Five industries with good potential applications of solar thermal systems are [2]:

- Food industry (dairy products, cold cut and process meat factories, pastry and cake confectioneries, olive oil refineries, tinned goods, slaughterhouses).
- Agro-indusries (solar drying, horticulture–nursery greenhouses, slaughterhouses, meat processing, livestock landings).
- Textiles (tanneries, leather treatment, cloth, refineries, textile treatment workshops).
- Chemical industry (cosmetics, detergents, pharmaceuticals, wax, distilleries, breweries).
- Beverage industry (wineries, liquor and wine distilleries, breweries, soft drinks).

3. Economic evaluation of solar systems in industrial applications

Based on reports of existing projects built in the late 1990s and additional information on plants being presently built, the average total cost of a solar system for industrial applications in Greece is approximately 60,000 Drs/m^2 (180E/m^2), no VAT

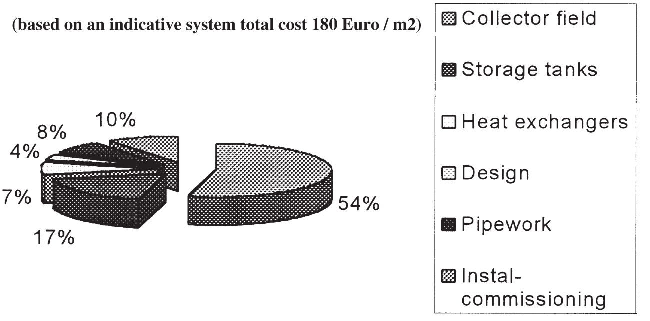

Fig. 1. Allocation of cost by system component.

Table 1
Economic evaluation of solar industrial plants

Fuel type	Fuel price 3/2000	No subsidies (180E/m^2)		Subsidies 50% (90E/m^2)	
		Payback (years)	IRR (%)	Payback (years)	IRR (%)
Diesel	0.628E/kg	3.6	26.7	1.8	55.1
LPG	0.540E/kg	4.2	22.6	2.1	47.2
Fuel 1500	0.295E/kg	7.7	9.7	3.9	24.9
Natural gas	0.02E/kWh	9.6	6.3	4.8	19.5

included. Fig. 1 shows the allocation of the system component costs as percentages of the total cost of the system [3].

The largest cost of the system (54%) is the collector, followed by the storage tank and heat exchanger (24%).

Tables 1–3 show the payback period of solar systems when they replace conventional fuels in the industrial sector. Column 3 of the tables displays the payback period of the investment cost of a solar system in an industrial application when

Table 2
Economic evaluation (common wisdom scenario, solar collector performance=640 kWh/year/m^2)

Fuel type	Fuel price 3/2000	No subsidies (180E/m$^{2)}$		Subsidies 50% (90E/m^2)	
		Payback (years)	IRR (%)	Payback (years)	IRR (%)
Diesel	0.628E/kg	4.6	20.7	2.3	43.9
LPG	0.540E/kg	5.2	17.2	2.6	37.5
Fuel 1500	0.295E/kg	9.7	6.1	4.8	19.2
Natural gas	0.02E/kWh	11.9	3.0	6.0	14.5

Table 3
Economic evaluation (pessimistic scenario, solar collector performance=640 kWh/year/m^2)

Fuel type	Fuel price (−20% reduction)	No subsidies (180E/m^2)		Subsidies 50% (90E/m^2)	
		Payback (years)	IRR (%)	Payback (years)	IRR (%)
Diesel	0.502E/kg	5.7	15.6	2.8	34.8
LPG	0.432E/kg	6.6	12.6	3.3	29.7
Fuel 1500	0.236E/kg	12.1	2.8	6.0	14.3
Natural gas	0.016E/kWh	14.9	0.0	7.5	10.3

replacing conventional fuels (diesel, LPG, heavy oil and natural gas) and column 4 of the tables displays the payback period when the system receives a 50% public subsidy. From the data in Tables 1–3 it is evident that the solar alternative is particularly appealing when replacing diesel fuel or LPG, especially if the system is subsidised. This is not the case for heavy oil and natural gas, where the solar alternative seems to be economically feasible. Diesel and LPG are common conventional fuels used in large market sectors (i.e. hotels, wineries, tanneries etc.) in Greece.

The assumptions used in calculating the data of Tables 1–3 are:

- Interest rate=8%.
- Boiler efficiency=0.8–0.85.
- Solar collector performance=800 kWh/year/m^2.
- Process coupling factor=0.8.
- Total investment cost of system=180E/m^2.

4. Quality requirements for solar systems in industrial applications

Solar energy system parameters are subject to design and material quality standards [4] in order to ensure durability of the product and satisfactory performance. The design standards include the drinking water standards (prEN 1717, prEN12897) (for the cases where the solar heated water comes into contact with drinking water), freeze resistance of the panels (EN 12975-2), overheating protection for materials (EN 12975-2), reverse flow prevention (EN 12975-2), pressure resistance and electrical safety of the system (EN 12975-2). The material quality standards include the solar collectors, supporting frame, circulation pumps, expansion vessels, heat exchangers, storage tanks, piping, thermal insulation, and control system (see Table 4).

The three most important components of an installation that must be analysed in depth regarding their minimum requirements in large solar installations are the solar collectors, storage tank and pipework.

Table 4
Solar system material component quality standards

Component	Standard number
System	PrEN 12977-1
Collector	PrEN 12975-1
Supports	ENV 1991-2-3, ENV 1991-2-4
Storage tanks	PrEN 12897, ENV 12977-3,ELOT 1181.1
Heat exchangers	EN 307
Pipework	ISO/TR 10217, prEN 806-1
Insulation	EN 253, prEN 12828
Pumps	EN 809, prEN 1151
Expansion vessels	–
Control system	ENV 12977-2

4.1. Requirements for the materials and the manufacturing of solar collectors

The collector box should be watertight to prevent penetration of rainwater. Condensed water must not accumulate in the collector. The materials of the collector components should be selected and constructed so that they can withstand the maximum temperature stresses that may occur at stagnation conditions and the thermal shocks they may be exposed to during the summer period. The materials of the collector should be resistant to exposure to incident and reflected UV-radiation.

Bushings and ducts in the collector casing should be constructed so that no leakage can occur due to thermal expansion. The design of the collector should be such that heat bridges between the collector casing and the absorber are avoided. The components and the materials should also be resistant to environmental stress from outdoor climate factors such as rain, snow, hail, wind, high humidity and air pollutants.

4.1.1. Absorbers

Absorbers should be made from suitable materials that meet the mechanical, thermal and chemical requirements of the application. The effect of the manufacturing processes such as cutting, brazing, soldering etc., on the properties of the absorber, should be considered.

Absorbers should be dimensioned with a design pressure equal to the permissible working overpressure specified by the manufacturer with a 1.5 safety factor. The wetted side of the absorber should withstand corrosion under normal operating conditions and taking into account the admixture of possible additives (i.e. glycol). Absorber coatings should retain their optical properties under high temperature, high humidity and condensation, and sulphur dioxide at high humidity. Common product absorber designs are tubes with fins, vacuum tubes, heat pipes, sandwich type and Integral Compact Systems. Common coating materials include black paint and TiNOx. Common coating manufacturing processes include selective deposition and scattering techniques.

4.1.2. Transparent covers

The transparency of covers should not deteriorate appreciably during the service life of the collector. Furthermore, the covers should be resistant to ultraviolet (UV) radiation, air pollution, high humidity and condensate as well as high temperatures, depending on the collector design.

The usual materials applied for industrial purposes are low iron glass and glass with antireflective coating.

4.1.3. Insulation materials

At the stagnation temperature no melting, shrinkage or outgasing of the insulation with consequent condensation inside the collector cover, or absorber performance reduction or corrosion of metallic surfaces, should occur to seriously reduce the collector performance. Water or humidity absorption by the insulation material may in the short term or permanently reduce the insulation performance of the material.

The usual materials applied for industrial purposes are: polyurethane, CFC-free polyurethane, rock wool and fibreglass.

4.2. Requirements for the materials and the manufacturing of storage tanks

If there are applications for drinking water, the storage tanks and parts of the storage tanks that are in contact with drinking water shall comply with the requirements in prEN 12897. Storage tanks of small custom-built systems should be tested following the ENV 12977-3 standard.

There is no existing standard for the amount and quality of insulation required in the solar system storage tanks for industrial applications of solar thermal systems.

Metal sheets are often used for the manufacturing of storage tanks for industrial projects. Their anti-corrosion protection can be achieved by the application of protective coating techniques, such as galvanisation, enamelling, thermally hardened resin coatings or metallic coatings.

Galvanisation provides weak protection at 60–70°C, whilst enamelling makes the tank expensive and more fragile and therefore presents a higher transportation risk. Also, metallic coatings are steel based and therefore not corrosion resistant. Thermally hardened resin seems a cost effective and viable solution but its manufacturing process is still not fully automated. In Greece this coating is made following the standard ELOT 1181.1. In industry, existing hot water storage tanks can be used as solar hot water storage tanks, for example, the steam condensate tank. The addition of accessories to the storage tanks, such as temperature sensors and flow meters will contribute to an optimised control of the storage tank operation, especially regarding hot water suction. The insulation of the storage tanks with polyurethane foams, even though expensive, seriously enhances the system's energy performance.

4.3. Requirements for the pipework

The pipe length of the system should be as short as possible. The pipes and fittings should be selected from materials that are compatible with the components included in each hydraulic circuit, according to the fluid of the circuit as specified in the ISO/TR 10217.

The piping for drinking water should comply with the requirements specified in prEN 806-1. The materials for pipes and fittings should be able to withstand the maximum operating temperature (stagnation conditions) and pressure. The piping should withstand thermal expansion without any damage or detrimental deformation. An open or closed expansion tank should be included. Venting of the system should be possible. No automatic vents should be placed in parts of the collector loop where vapour can occur (e.g. the top of the collector array), except if a manual valve is foreseen between the pipe and the automatic vent, which must be closed during normal operation of the system.

5. Hellenic case studies of solar thermal systems in industrial process heating applications

From the early 1990s to the present date, 10 successful solar thermal systems in industrial process heating applications have been in operation in Hellenic industries. Five of these installations have been monitored and their performance have thus been evaluated. The hot water requirements, technical description of the system and the technical problems encountered in all the systems will be explained in detail in the following sub-sections. The results from the five installations that were monitored [5] are shown in Table 5.

5.1. Achaia Clauss S.A. [6]

Achaia Clauss S.A. is a winery situated on the outskirts of the city of Patras. Its main industrial activity is the production of red, white and rose wine. Hot water (60–75°C) is required for the washing and sterilisation of the bottles in the bottling factory. The hot water consumption of the bottling process is 100 m^3/day. Originally, the hot water was provided by a steam boiler running on diesel fuel, which heated the water in two parallel, horizontal, 3000 l storage tanks (via a submerged heat exchanger) located in the boiler room of the plant according to the needs of the bottling process.

The solar system was installed in 1993 and consists of the following items: 308 m^2 sandwich-type, flat plate collectors coated with black paint located on the roof of the winery; closed-loop primary circuit with an open expansion vessel and two parallel, horizontal, 3000 l, closed solar storage tanks located on the roof of the winery. The water heated by the solar collectors circulates in a closed loop and heats the water in the solar storage tanks via submerged heat exchangers. Anti-freeze protection is provided in the closed loop on very cold winter days by activating the pump and circulating the water when the temperature drops below 5°C. The hot water leaving the solar storage tanks is fed to the two original storage tanks where auxiliary heating of the water is provided by the steam boiler. A re-circulation branch has been included which consists of a hydraulic branch connecting the solar storage

Table 5
Monitoring results from five installations on a typical day's operation

1. Company	2. Activity	3. Hot water consumption (m^3/day)	4. Solar energy used (kWh/day)	5. Total energy load of company (kWh)	6. % of energy load provided by solar energy (=Column 4/Column 5)	7. Incident solar energy (kWh/day)	8. System performance (%) (=Column 4/Column 7)
Kastrinogiannis S.A.	Textiles	6.466	229.2	–	–	1354	16.92
Kozani Greenhouses S.A.	Greenhouse	–	141.8	102.1	100	534.3	26.5
Achaia Clauss S.A.	Winery	80	464.1	3153	14.72	1973	23.52
Tripou-Katsouri S.A.	Tannery	6.731	165.4	–	–	2269	7.3
Allegro S.A.	Textiles	1.399	59.9	893	6.7	370	16.19
Madrekas S.A.	Dairy	0.494	7.58	230.38	3.3	–	–

tanks with the original storage tanks. When the water in the solar storage tanks exceeds the temperature of the water in the original storage tanks a pump is activated, which circulates the hot water from the solar to the original storage tanks. In this way, hot water produced by the solar collectors during the hours that the factory is not operating is utilised and energy is saved in the early hours of operation of the plant as the auxiliary heat required from the steam boiler is reduced.

The system operated for 6 years yielding a mean performance of 300 kWh/year/m^2. Due to administrative and financial difficulties of the company, the necessary maintenance work on the system was not carried out and this inevitably led to corrosion problems and inefficient operation of the system. Today, the system has been shut down due to the severe corrosion problems encountered by the system (25% of the collectors have either cracked glass covers or deformation of the plastic collector frame or rusting of the absorber plates). According to the monitoring results, a large amount of heat was lost from the solar storage tanks during the night hours due to poor insulation of the tanks. Also, due to this fact, the impact of the re-circulation branch was minimal.

The installation was financed with a Guaranteed Solar Results (GSR) contract, whereby the user paid no money for the installation of the system, but paid the manufacturer the amount of energy supplied by the system on a monthly rate, based on a fixed rate per kWh decided upon before the installation of the system. A third, independent party, in this case the Centre for Renewable Energy Sources (CRES) undertook the monitoring of the system, which determined the energy supplied by the system. When the user paid the initial investment of the system back, the system became the exclusive property of the user.

5.2. Allegro S.A. [5]

Allegro S.A. is children's clothing industry situated in the municipality of Metamorfosis, in the city of Athens. Its main industrial activity is the processing of imported children's clothing (washing, ironing, sorting and folding). Hot water (40–90°C) is required for the washing machine of the factory. The hot water consumption of the washing process is 0.7 m^3/day. Also, the steam presses of the factory require steam for ironing the clothes. Originally, steam was provided by a steam boiler running on diesel fuel, which was fed cold water from a 500-l storage tank located in the boiler room of the factory. The water requirements of the steam boiler are 1.4 m^3/day.

The solar system was installed in 1993 and consists of the following items: 55 m^2 sandwich-type, flat plate collectors coated with black paint, located on the roof of the factory; closed-loop primary circuit with an open expansion vessel and one horizontal, 1500 l, open solar storage tank located on the roof of the factory. The water heated by the solar collectors circulates in a closed loop and heats the water in the solar storage tanks via a submerged heat exchanger. Anti-freeze protection is provided for in the closed loop on very cold winter days by activating the pump and circulating the water when the temperature drops below 5°C. The hot water leaving the solar storage tanks is fed either to the washing machine of the factory where the auxiliary heating of the water is provided for by an internal electric resistance or to the original storage tank feeding the steam boiler. In this way, the solar system pre-heats the water entering the steam boiler.

Today, the system is operational although the lack of necessary maintenance to the system has resulted in minor corrosion problems and reduced efficiency of the system (10% of the collectors have either cracked glass covers or deformation of the plastic collector frame or rusting of the absorber plates). During the first years of operation of the system, the open solar storage tank encountered severe corrosion problems and was replaced by a closed, vertical tank with a closed expansion vessel.

5.3. Alpino S.A.

Alpino S.A. is a dairy situated on the outskirts of the city of Thessaloniki. Its main industrial activity is the production of dairy products (butter, cheese, butter milk, etc.). Steam is required by the various dairy processes of the plant (pasteurisation, sterilisation, evaporation and drying) and for the operation of the Cleaning in Place (CIP) machine of the factory, which is used to clean and disinfect the utensils and machinery of the factory. Originally, steam was provided for by three steam boilers running on heavy oil, which were fed cold water from the water supply grid. The water requirements of the steam boiler are 40 m^3/day.

The solar system was installed in 2000 and consists of the following items: one collector branch with 324 m^2 tube-fin, flat plate collectors coated with black paint, located on the roof of the factory; closed-loop primary circuit with a closed expansion vessel and one vertical, 15,000 l, closed solar storage tank located in the boiler room of the factory. The water heated by the solar collectors circulates in a water–glycol closed loop and heats the water in the solar storage tanks via submerged heat exchangers. There is also a second collector branch with 252 m^2 tube-fin, flat plate collectors coated with black paint, located on the roof of an adjacent building; closed-loop primary circuit with a closed expansion vessel and one vertical, 10,000 l, closed solar storage tank located in the boiler room of the factory. The water heated by the solar collectors circulates in a water–glycol closed loop and heats the water in the solar storage tanks via a submerged heat exchanger. The hot water produced by both branches of the solar system is used to pre-heat the water entering the steam boilers of the factory.

The system has just commenced operation and therefore no operational results are available. The system was funded with a Guaranteed Solar Results (GSR) contract, whereby the manufacturer guarantees a minimal performance of the system otherwise he does not receive the full amount due to him.

5.4. Kastrinogiannis S.A. [7]

Kastrinogiannis S.A. is a textile industry situated on the outskirts of the city of Heraklion, on the island of Crete. Its main industrial activity is the dyeing and finishing of textiles. The dyeing machinery of the plant requires steam [8]. Originally, steam was provided for by steam boilers running on heavy oil, which were fed cold water from water storage tanks located on the roof of the factory. The factory originally had no access to the water supply grid and water tankers to the factory transported water. The water requirements of the steam boiler are 10 m^3/day.

The solar system was installed in 1993 and consists of the following items: 180 m^2 tube-fin, flat plate collectors with a selective paint coating, located on the roof of the factory; closed-loop primary circuit with a closed expansion vessel and two horizontal, parallel, 5,000 l, closed solar storage tanks located on the roof of the factory. The water heated by the solar collectors circulates in a water–glycol closed loop and heats the water in the solar storage tanks via submerged heat exchangers. The hot water produced by the solar system is used to pre-heat the water entering the steam boilers of the factory.

Today, the system is operational and in excellent working order. Nevertheless, over the years there have been significant changes to the factory and the solar system, which have altered and improved the solar system. According to the monitoring results, the water stored in the cold-water storage tanks on the roof of the factory was heated up by the sun's radiation. This resulted in an increased entry temperature of the water to the solar storage tanks and a reduced efficiency of the system. In 1995, the factory finally gained access to the water supply grid and this problem was therefore overcome. Also, according to the monitoring results, the solar storage tanks were insufficiently insulated and exposed to the elements. This resulted in a large heat loss from the tanks to the environment during the night hours. This problem was overcome through the application of a significant amount of external insulation and the construction of a simple shed in which the tanks were placed. Furthermore, according to the monitoring results, it was noted that the surface area of the submerged heat exchanger in the solar storage tanks is too small and reduces the efficiency of the system.

5.5. Kozani Greenhouses S.A. [5]

Kozani Greenhouses S.A. is a complex of greenhouses situated on the outskirts of the city of Kozani. Its main activity is the growing of indoor decorative plants and flowers. The ideal room temperature required for the growing of these plants is 19°C. The greenhouses and the soil are heated by an on-floor and under-floor piping system whereby water at 45°C is circulated through the pipes thereby heating the soil and environment. Two water boilers driven by heavy oil originally provided hot water. The water requirements of the water boilers depend exclusively on the outdoor weather conditions.

The solar system was installed in 1994 and consists of the following items: 80 m^2 tube-fin, flat plate collectors coated with black paint located on the ground adjacent to the complex of greenhouses; closed-loop primary circuit with a closed expansion vessel and four parallel, vertical, 1100 l, closed solar storage tanks located in a specially constructed room adjacent to the greenhouse boiler room. The water heated by the solar collectors circulates in a water–glycol closed loop and heats the water in the solar storage tanks via submerged heat exchangers. The hot water leaving the solar storage tanks is fed to the water boilers where possible auxiliary heating of the water can take place.

Today, the system is operational and in very good working order, although a fire which broke out in a neighbouring farm spread to the site of the greenhouse complex and burnt nine collectors. The effective area of the solar system is therefore now only 62 m^2. Also, there are serious heat losses from the piping of the solar primary circuit due to the fact that the pipes have not been insulated.

5.6. Mandrekas S.A. [5]

Mandrekas S.A. is a dairy situated on the outskirts of the city of Korinthos. Its main industrial activity is the production of dairy products (yoghurt, milk, cream, etc.). Steam is required by the various dairy processes of the plant (pasteurisation, sterilisation, evaporation and drying) and hot water is required to maintain the yoghurt at 45°C during its maturing process and for the factory's WCs [9]. Steam is provided for by a steam boiler running on liquid propane gas (LPG), the cold water being supplied by the water supply grid, and hot water is provided by the solar system. The hot water requirements of the factory are 15 m^3/day.

The solar system was installed in 1993 and consists of the following items: 170 m^2 tube-fin, flat plate collectors coated with black paint located on the roof of the factory; open loop circuit and two parallel, horizontal, 1000 l, closed solar storage tanks located in the boiler room of the dairy. The water from the water supply grid enters the solar storage tanks and from there is fed to the solar collectors where it is heated and returned to the solar storage tanks. The hot water leaving the solar storage tanks is either fed directly to the factory's WCs or is fed to the yoghurt maturing process and then returned to the tanks. Any auxiliary heating required by the yoghurt maturing process is provided via a heat exchanger, which receives steam from the steam boiler.

Today, the system is operational and in very good working order. According to the monitoring results, the hot water requirements of the yoghurt maturing process are much smaller than the amount of hot water produced by the solar system and therefore the system has been oversized. Also, due to the low hot water requirement of the yoghurt maturing process, the steam heat exchanger is heating the solar storage tanks thereby reducing the efficiency of the solar system.

5.7. Mevgal S.A. [10]

Mevgal S.A. is a dairy situated on the outskirts of the city of Thessaloniki. Its main industrial activity is the production of dairy products (butter, cheese, butter milk, etc.). Steam is required by the various dairy processes of the plant (pasteurisation, sterilisation, evaporation and drying) and hot water is required for the operation of the Cleaning in Place (CIP) machine of the factory, which is used to clean and disinfect the utensils and machinery of the factory. Originally, steam was provided for by steam boilers running on heavy oil, which were fed cold water from the water supply grid. The water requirements of the steam boilers are 150 m^3/day.

The solar system was installed in 2000 and consists of two solar thermal systems. The first system consists of: 216 m^2 tube-fin, flat plate collectors with a black paint coating, located on the roof of the factory office building connected in series with 111 m^2 CPC collectors with a black paint coating. The closed-loop primary circuit of system 1 has a closed expansion vessel and two vertical, parallel, 2500 l, closed solar storage tanks located in a specially designed room adjacent to the boiler room of the factory. The water heated by the solar collector system 1 circulates in a water–glycol closed loop and heats the water in the solar storage tanks via flat-plate heat exchangers. The hot water produced by the solar system is used to pre-heat the water entering the steam boilers of the factory. The second system consists of: 398 m^2 tube-fin, flat plate collectors with a selective paint coating, located on the roof of the cheese factory. The closed-loop primary circuit of system 2 has a closed expansion vessel and two horizontal, in series, 2500 l, closed solar storage tanks located on the roof of the cheese factory. The water heated by the solar collector system 2 circulates in a water–glycol closed loop and heats the water in the solar storage tanks via flat-plate heat exchangers. The hot water produced is used to either feed the CIP machine or the solar storage tanks of system 1.

Today, the system is operational and in excellent working order. A potential problem to the future operation of the system is the increased amount of soot in the exhaust fumes of the steam boiler, which result in the deposition of soot on the collector surface and a reduction in efficiency of the collector.

The installation was financed with a Third Party Financing contract, whereby a Third Party (CRES) financed the installation of the system and the user had no initial investment. The user (Mevgal S.A.) will pay the amount of energy supplied by the system on a monthly rate, based on a fixed rate per kWh decided upon before the installation of the system. The amount of energy supplied will be determined by monitoring procedures undertaken by CRES. Once the user pays back the initial investment of the system back, with interest, the system will become its exclusive property.

5.8. Plektemboriki S.A.

Plektemboriki S.A. is a textile industry situated on the outskirts of the city of Heraklion, on the island of Crete. Its main industrial activity is the production of olive oil nets. Hot water (90°C) is required in the treatment of the net fibres in special treatment tanks. Electrical resistances in the bottom of the treatment tanks originally heated the water.

The solar system was installed in 1999 and consists of the following items: 50 m^2 tube-fin, flat plate collectors with a black paint coating, located on the roof of the office building; closed-loop primary circuit with a closed expansion vessel and two horizontal, parallel, 1000 l, closed solar storage tanks located on the roof of the office building. The water heated by the solar collectors circulates in a water–glycol closed loop and heats the water in the solar storage tanks via submerged heat exchangers. The hot water produced by the solar system is used to pre-heat the water in the fibre treatment tanks. The electric resistances provide any auxiliary heating required.

Today, the system is operational and in excellent working order. The roof of the office building was not the ideal location for the installation of the system due to its small distance from the ground and its vicinity to adjacent buildings. All these factors contribute to the shading of some of the collectors from the factory building and adjacent buildings during various hours of the day.

5.9. Sarantis S.A.

Sarantis S.A. is a cosmetics industry situated on the outskirts of the city of Inofita. Its main industrial activity is the production and trade of cosmetics products. The solar system is used for the space cooling of the stock warehouse of the factory. The temperature of the warehouse must be 27°C and this is maintained by silica-gel adsorption chillers located in the boiler room of the factory. Water source chillers located on the roof of the boiler room provide for any auxiliary cooling.

The solar system was installed in 1999 and consists of the following items: 2700 m^2 tube-fin, flat plate collectors with a selective paint coating, located on an area especially set aside for the collectors; closed-loop primary circuit with a closed expansion vessel and one horizontal, 2000 l, closed solar storage tank acting as a buffer for the start-up of the adsorption chillers located in the boiler room of the factory. The water heated by the solar collectors circulates in a water–glycol closed loop and is fed to the regeneration chamber of the adsorption chillers.

The system has just commenced operation and therefore no operational results are available. The system was funded with a GSR contract, whereby the manufacturer guarantees a minimal performance of the system otherwise he does not receive the full amount due to him.

5.10. Tripou-Katsouri S.A. [5]

Tripou-Katsouri S.A. is a tannery situated in the municipality of Tavros, in the city of Athens. Its main industrial activity is the production of leather. Hot water (40–90°C) is required for the various processes of the tannery. The hot water consumption requirements of the various processes are 15 m^3/day. Originally, the hot water was provided by a steam boiler running on natural gas, which heated the water in three parallel, horizontal, in series, 1200 l, closed water storage tanks (via submerged heat exchangers) located in the boiler room of the plant. The hot water produced in these storage tanks was then fed to two, parallel, horizontal 3800 l, closed water storage tanks located in the boiler room of the factory where auxiliary heating was again provided by the steam boiler (via submerged heat exchangers) before going towards consumption.

The solar system was installed in 1993 and consists of the following items: 308 m^2 sandwich-type, flat plate collectors coated with black paint, located on the roof of the factory; closed-loop primary circuit with an open expansion vessel and two horizontal, parallel, 6750 l, open solar storage tanks located outdoors on the ground floor of the factory. The water heated by the solar collectors circulates in a closed loop and heats the water in the solar storage tanks via submerged heat exchangers. Anti-freeze protection is provided for in the closed loop on very cold winter days by activating the pump and circulating the water when the temperature drops below 5°C. The hot water leaving the solar storage tanks is fed to the three parallel, 1200 l water storage tanks.

The system operated for 4 years. Due to administrative and financial difficulties of the company, the necessary maintenance work on the system was not carried out and this inevitably led to corrosion problems and inefficient operation of the system. Today, the system has been shut down due to the severe corrosion problems encountered by the system (30% of the collectors have either cracked glass covers or deformation of the plastic collector frame or rusting of the absorber plates). The collectors were situated next to the exhaust stack of the factory and this led to the large amount of soot deposition on the collector surfaces, resulting in a significant decrease in the efficiency of the system. Also, the floats of the open solar storage tanks frequently malfunctioned, creating an overflow of water and creating significant problems to the operation of the system.

5.11. Monitoring results [5]

Table 5 shows the monitoring results for a typical day of operation of the solar thermal installations of Kastrinogiannis S.A., Kozani Greenhouses S.A., Achaia Clauss S.A., Tripou-Katsouri S.A., Allegro S.A. and Mandrekas S.A.

6. Conclusions

The solar thermal energy systems in industrial process heating applications are becoming more cost effective due to the increase in the price of liquid fuels (especially in the cases where diesel oil or LPG is used). However, most of the solar thermal plants installed in the early 1990s in Greece presented technical inadequacies related to insufficient maintenance. The aforementioned inadequacies seem to have been overcome in the recent solar thermal systems due to:

- Better quality products and spare parts.
- Better design.
- Better financing prospects.
- Guaranteed Solar Result (GSR) systems.

Acknowledgements

The authors would like to thank the DG XVII for Energy of the European Commission, which supported a relevant ALTENER project entitled ‘Solar thermal process heating in industrial applications. A stimulation plan' (contract number 4.1030/Z/98-205). The paper was developed based on the experience of the authors during the realization of the above project.

References

[1] Centre for Renewable Energy Sources, PROCESOL, ALTENER Project, Contract No. 4.1030/Z/98-205, Interim Report, 2000, pp. 2–7.
[2] Karagiorgas M, Lamaris P. Guaranteed solar results in industrial installations in Greece. In: Proceedings of the Conference C72 of the Solar Energy Society. Cardiff: University of Wales, 1998:13–4.
[3] EBHE, Technical and Economic Report on the Applications of Solar Thermal Systems in the Dairy Industry, Athens, 2000, pp. 13–17.
[4] CEN, European Committee for Standardisation, Thermal Solar Systems and Components. Custom Built Systems. Part 1: General Requirements, Final Draft, prENV-12977-1, 1999, pp. 1–20.
[5] SPA European Commission Programme, Active Solar Systems, 1993.
[6] SOLE S.A., Technical Description and Operational Results of the Solar Installation in the Achaia Clauss Winery, 2000.
[7] VALOREN Programme, A Study for the Installation of a Solar Thermal System in the Textile Dyeing/finishing Plant, E. Kastrinogiannis S.A, for the Pre-heating of the Plant's Process Water, 1993, pp. 41–63.
[8] European Commission, Review of Energy Efficient Technologies in the Textile Sector, Thermie Programme Action No. I 150, Final Report, 1995.
[9] European Commission, Review of Energy Efficient Technologies in the Dairy Industry Sector, Case Studies Provided Through the OPET Network, 1992.
[10] PEPER Programme, A Study for the Installation of a Solar Thermal System Used to Pre-heat the Water Entering the Steam Boilers of the MEVGAL S.A. Dairy, 1997.