

THE POTENTIAL OF LOW-TEMPERATURE SOLAR INDUSTRIAL PROCESS HEAT APPLICATIONS IN CYPRUS

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ABSTRACT

In this paper an overview of the potential of low-temperature solar industrial process heat applications is presented. The temperature requirements considered range from 60°C to 90°C. The characteristics of low to medium temperature solar collectors that can be employed are given and an analysis of the efficiency and cost of the solar systems is presented. Based on TRNSYS simulations, an estimation of the solar contribution of solar process heat plants operating in Cyprus are given for different collector technologies. The annual energy gains of such systems are from 745 to 994 kWh/m²-a and the resulting energy costs obtained for solar heat are from 0.025 to 0.043 Euro/kWh depending on the collector type applied. The costs will even be more favourable if the solar collectors become cheaper and renewable energy subsidies are considered.

INTRODUCTION

Beyond the domestic solar water heating applications there are several potential fields of application for solar thermal energy for low temperature level (60°C – 90°C). The most important of them are: heat production for industrial processes, solar cooling and air conditioning with absorption refrigeration, solar drying and seawater desalination. Large amounts of energy are spent for industrial heat generation in many countries. For example industrial process heat demand in the southern European countries is about 15% of the overall demand of final energy requirements (Schweiger, 2000).

Stationary collectors have been developed with a good relation of cost and performance at low to medium temperature. Recent developments in the field of medium temperature solar collectors are summarised and an overview of efficiency and cost of existing technologies is given. These include the flat-plate collectors, which are by far the most successful type of collector, and the evacuated tube collectors.

There is no commercial application of industrial process heat in Cyprus due to the “chicken and egg” theory, i.e., no entrepreneur will invest on research and development funds without a sizable market and there is no sizeable market until low-cost, proven technology units are available. Perhaps only Government or aid agencies could break this impasse.

The objective of this work is to investigate, based on TRNSYS simulations, the system energy yield of solar process heat plants for different collector technologies. For this purpose the climatic conditions of Cyprus will be employed by using the typical meteorological year (TMY) for Nicosia, Cyprus. Finally by using the obtained simulated performance data, an economic feasibility study is carried out in order to examine the viability of the systems considered.

THE INDUSTRIAL PROCESS HEAT DEMAND

From a number of studies on industrial heat demand, several industrial sectors have been

identified with favourable conditions for the application of solar energy. The most important industrial processes using heat at a medium temperature level are: sterilising, pasteurising, drying, hydrolysing, distillation, evaporation, washing and cleaning.

One type of industry that can use solar process heat is the food industry. The amount of money spent for fuels by the food, beverages and tobacco industries in 1996 is 2.06 million Cyprus pounds (C£) with a mean annual increase of 8.1% (Industrial statistics, 1997). This figure constitutes 3.5% of the total diesel oil sold in that year. Some of the most important processes related to food industry are given in Table 1. Particular types of industries, which can employ solar process heat, are the milk and cooked pork meats (sausage, salami etc.) industries and breweries. The temperatures required in these industries range from 60 to 90°C. Favorable conditions exist in food industry, because food treatment and storage are processes with high energy consumption and high running time (Kalogirou, 2001). In breweries solar process heat can be used in the bottle washer. Dairies are also very interesting applications for solar energy, because they are often work seven days a week, thus fully utilize the solar system compared to other industries which allow the system to be idle for two days per week. Due to their high constant energy demand, drying processes are promising. In the production, milk and whey are spray-dried in huge towers with air, which is heated from 60°C to 180°C. The drying process can have a

running time up to about 8000 hours per annum (Benz *et al.*, 1999). Therefore, the solar system in this case can be used to supply the total heat energy at the low temperature range or for preheating at the higher temperatures.

Large scale solar applications for process heat benefit from the effect of scale. Therefore the investment costs should be comparatively low, even if the costs for the collector are higher. One way to cause economically easy terms is to design systems without heat storage, i.e., the solar heat is fed directly into suitable processes (fuel saver). In this case the maximum rate at which the solar energy system delivers energy must not be appreciably larger than the rate at which the process uses energy. This system however cannot be cost effective in cases where heat is needed at the early or late hours of the day or at nighttimes when the industry operates on a double shift basis.

In a solar process heat system, interfacing of the collectors with conventional energy supplies must be done in a way compatible with the process. The easiest way to accomplish this is by using heat storage, which can also allow the system to work in periods of low irradiation and/or nighttime. Where feasible, collectors can be mounted on the roof of a factory especially when no land area is available. In this case shading between adjacent collector rows should be avoided and considered.

Table 1. Temperature ranges for different food industrial processes

Industry	Process	Temperature (°C)			
		60	70	80	90
DAIRY	PRESSURISATION	■	■	■	■
	CONCENTRATES	■	■	■	■
	BOILER FEED WATER	■	■	■	■
TINNED FOOD	PASTEURISATION	■	■	■	■
	COOKING	■	■	■	■
	BLEACHING	■	■	■	■
MEAT	WASHING, STERILISATION	■	■	■	■
BEVERAGES	WASHING, STERILISATION	■	■	■	■
	PASTEURISATION	■	■	■	■
FLOURS & BY-PRODUCTS	STERILISATION	■	■	■	■

SOLAR COLLECTORS CONSIDERED

There are many types of collectors that can be applied for industrial process heat. The most common and industrially matured systems are the flat-plate and evacuated tube collectors.

Cyprus began manufacturing of solar water heaters in the early sixties. The estimated collector area installed up today including central systems in hotels and hotel apartments is about 560,000 m² out of which 540,000 m² are installed in houses and flats. These units are exclusively used for water heating. Industrial application of solar energy is an area which has not been exploited so far.

Due to the introduction of highly selective coatings, standard flat-plate collectors can reach stagnation temperatures of more than 200°C. With these collectors good efficiency can be obtained at temperatures up to 90°C. Additional improvements in efficiency of flat-plate collectors and an extension of the range of possible working temperatures up to 150°C can be obtained by suppression of convection heat transfer by evacuation (evacuated tubes, evacuated flat plate collector), gas fillings with inert gases, convection barrier by an additional plastic foil or by honeycomb-type transparent insulation (TI) materials (Benz *et al.*, 1998).

Lately some modern manufacturing techniques have been introduced in the industry like the use of ultrasonic welding machines, which improve both the speed and the quality of welds. This is used for the welding of risers on fins in order to improve heat conduction. The greatest advantage of this method is that the welding is performed at room temperature therefore deformation of the welded parts is avoided.

A large number of evacuated tube collectors are on the market. Evacuated tubes with compound parabolic collector (CPC) - type reflectors are also commercialised by several manufacturers. One manufacturer recently presented an all-glass evacuated tube collector, which may be an important step to cost reduction and increase of lifetime.

Evacuated tube collectors have demonstrated that the combination of a selective surface and an effective convection suppressor can result in good performance at high temperatures. The vacuum envelope reduces convection and conduction losses, so the cylinders can operate at higher temperatures than flat-plate collectors. Like flat-plate collectors, they collect both direct and diffuse radiation. However, their efficiency is higher at low incidence angles. This effect tends to give evacuated tube collectors a day-long advantage over flat-plate collectors.

COMBINATION OF SOLAR WITH CONVENTIONAL SYSTEM

The central system for heat supply in most factories uses hot water at a temperature needed in the different processes. Typical maximum temperatures in the low temperature range are about 60–90°C. Hot water or low pressure steam at low temperatures (<90°C) can be used either for preheating of water (or other fluids) used for processes (washing, dyeing, etc.) or for steam generation or by direct coupling of the solar system to an individual process working at temperatures lower than that of the central steam supply. In the case of water preheating higher efficiencies are obtained due to the low input temperature to the solar system, thus low-technology collectors can work effectively and the required load supply temperature has no or little effect on the performance of the solar system.

The system considered is shown schematically in Fig. 1. It consists of an array of collectors, a circulating pump and a storage tank. It includes also the necessary controls and thermal relief valve, which relieves energy when storage tank temperature is above a preset value. The system is once through, i.e., there is no hot water return to storage, which is what usually happens in food industry applications. The used hot water is replaced by mains water. Mean monthly ground temperature values are used for the mains temperature in simulations.

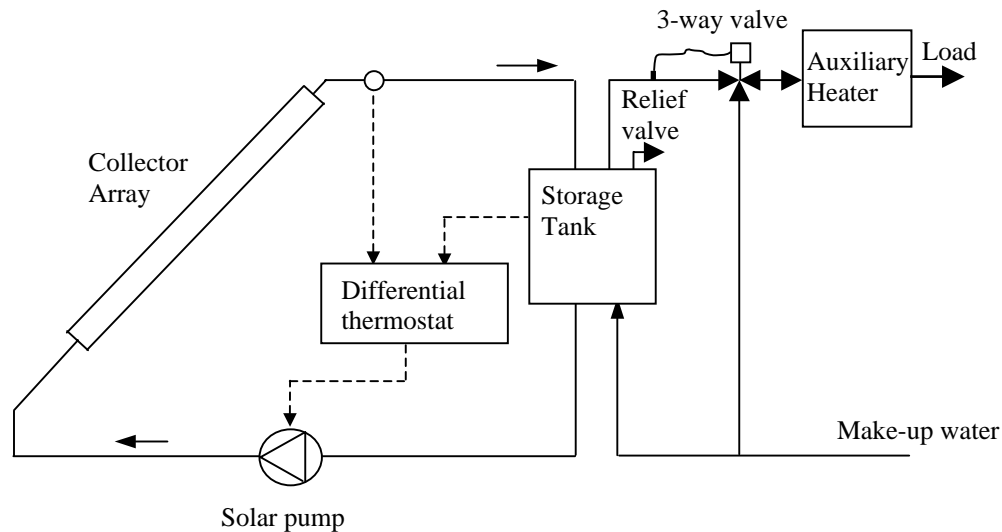


Figure 1. Possibilities of the combining the solar system with the existing heat supply.

When the temperature of the stored water is above the required process temperature, this is mixed with mains water to obtain the required temperature. If no water of adequate temperature is available in the storage tank its temperature is topped-up with an auxiliary heater before use.

For the modelling and simulation of the system the well-known program TRNSYS is employed (Klein *et al.*, 1994). TRNSYS is a modular transient energy simulation program. The program consists of many subroutines that model subsystem components. The mathematical models for the subsystem components are given in terms of their ordinary differential or algebraic equations. With a program such as TRNSYS which has the capability of interconnecting system components in any desired manner, solving differential equations and facilitating information output, the entire problem of system simulation reduces to a problem of identifying all the components that comprise the particular system and formulating a general mathematical description of each.

ANNUAL ENERGY GAINS

To estimate the solar energy gains TRNSYS-simulations were carried out using the typical meteorological year (TMY) for Nicosia, Cyprus (Petrakis *et al.*, 1998). Cyprus is located at the Eastern Mediterranean at 35°

north latitude. The climatic conditions of Cyprus are predominantly very sunny with daily average solar radiation of about 5.4 kWh/m² on a horizontal surface. In the lowlands the daily sunshine duration varies from 5.5 hours in winter to about 12.5 hours in summer. Mean daily global solar radiation varies from about 2.3 kWh/m² in the cloudiest months of the year, December and January, to about 7.2 kWh/m² in July. The amount of global radiation falling on a horizontal surface with average weather conditions is 1727 kWh/m² per year.

Three representative collector types were considered in this study:

- Flat-plate collector (FP).
- Advanced flat-plate collector (AFP). In this collector the risers are ultrasonically welded to the absorbing plate, which is also electroplated with chromium selective coating.
- Evacuated tube collector (ETC).

The collector characteristics are given in Table 2.

Table 2. Collector characteristics for the four collectors considered in this study.

Collector type	Optical efficiency (η_o)	Overall heat loss coefficient (U_L) [W/m ² K]
FP	0.79	6.67
AFP	0.80	4.78
ETC	0.82	2.19

The basic process considered is one where 2000 kg/hr of hot water are used at temperatures between 60 to 90°C (load). The load is required for the first three quarters of each hour. The industry is assumed to work on a single shift basis from 8.00 to 16.00. For the estimation of the annual energy supply to the above process, the following assumptions were made:

- The collector field has a gross area of 300 m² and the inclination of FP, AFP and ETC collectors is equal to the local latitude plus 5° (i.e., 40°). Mutual shading of collectors is considered.
- Heat losses of the piping are considered. It is assumed that the collector field is connected to the process with pipes 30 m long.
- The storage tank capacity is 25m³.
- Collector circuit flow rate is 4.5 kg/s.

The annual energy yield of the various collectors is shown in Fig. 2. As can be seen the energy yield at the low operating temperature (60°C) is lower. This is because at low load temperatures the water in the storage tank can satisfy most of the demand and as less water is replaced in the storage tank by make-up water the storage tank remains at increased temperature and thus the collectors are operating at higher temperature, hence the collector is less effective, which is reflected as lower energy yield.

The solar contribution or solar fraction, F , is defined as the ratio of the useful solar energy supplied to the system divided by the energy needed to heat the water when no solar energy is used. Therefore, F is a measure of the fractional energy savings relative to that used for a conventional system and is given by:

$$F = \frac{Q_{load} - Q_{auxiliary}}{Q_{load}} \quad (1)$$

The solar contribution F of the various collectors investigated is shown in Fig. 3. As can be seen the lower the load temperature the higher is the contribution of the system and vice versa. This is because at higher load temperatures more energy from the auxiliary is required to cover the load.

The collector with the higher energy yield and the higher contribution is the evacuated tube and the lower is the typical flat plate collector. This result is in agreement with the performance characteristics of the collectors shown in Table 2, i.e., a collector with better characteristics gives more energy and thus has a higher contribution and vice versa. It should be noted that the load is constant (same process) for all systems. This finding however has to be compared with the economics of the system in order to select the best collector for this application. The critical parameter for such an analysis is the cost of the collector.

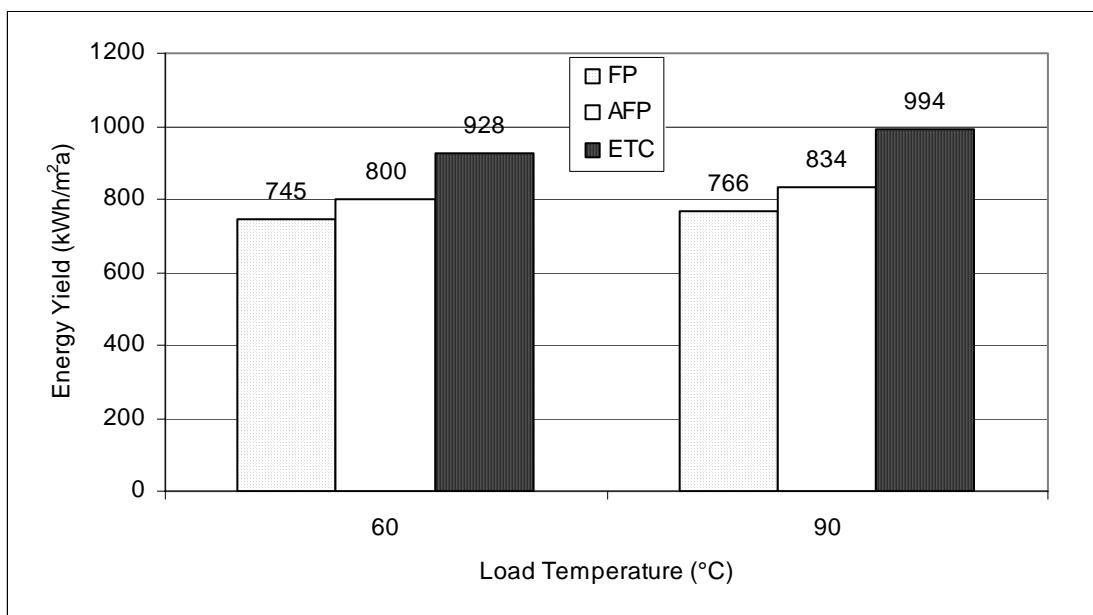


Figure 2. Annual energy yield delivered to the process.

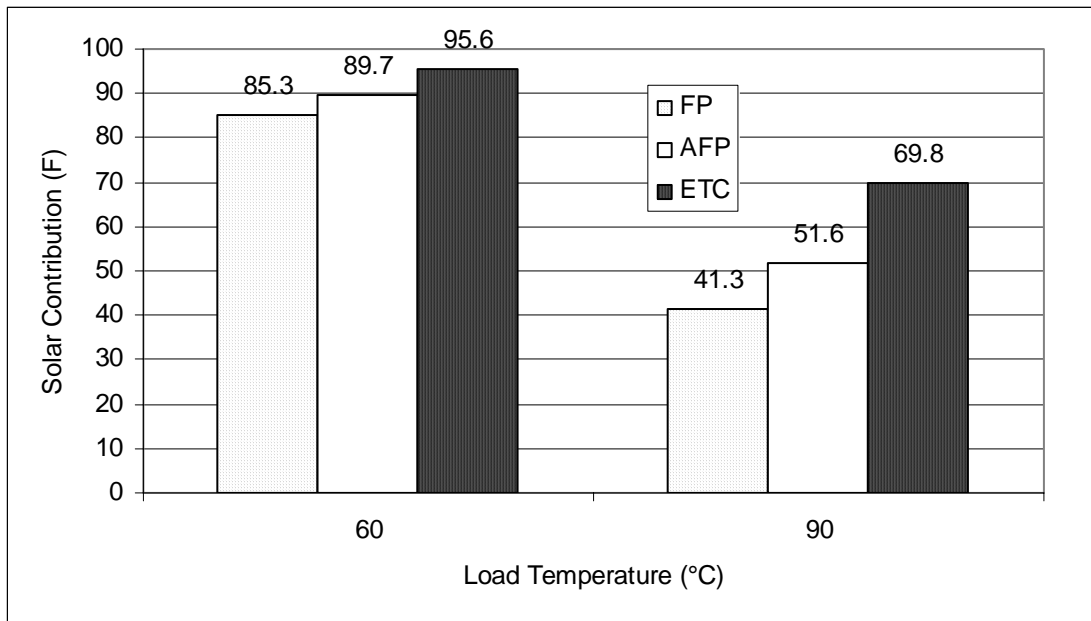


Figure 3. Solar contribution

ECONOMIC ANALYSIS

A life cycle analysis is performed in order to obtain the total cost (or life cycle cost) and the life cycle savings of the systems. Table 3 shows the estimated costs per square meter of the collectors considered. The economic scenario used in this project is that 30% of the initial cost of the solar system is paid at the beginning and the rest is paid in equal instalments in 10 years. The period of economic analysis is taken as 20 years (life of the system), whereas the inflation rates of fuel and electricity, used for pumps, are mean values of the last 10 years.

Table 3. Investment cost parameters for collectors considered in this study.

Collector type	Collector price (Euro/m ²)
FP	190
AFP	220
ETC	430
Prices include collector mountings and field piping.	

Maintenance and parasitic costs are also considered. Light fuel oil (LFO) is assumed to be used for a fuel-only system. From the addition of fuel savings incurred because of the use of the system and the tax savings the mortgage, maintenance and parasitic costs are

subtracted and thus the annual solar savings of the system are estimated which are converted into present worth values of the system. These are added up to obtain the life cycle savings. A detailed description of the method is given in (Kalogirou, 1996).

The total system cost is estimated by adding up the initial payment the maintenance and parasitic costs and the mortgage payments. From this figure the tax savings are subtracted and the result is divided by the number of years the system is operational (life of the system) and the total kWh produced by the system during its life, in order to obtain the heat price in Euros per kWh for each collector technology considered, for comparison purposes.

The heat price obtained from the economic analysis for all the collectors considered here are presented in Fig. 4 together with the current price of LFO. It should be noted that the price of LFO that was in effect about a year ago was heavily subsidised by petrol. This is removed due to EU regulations. For comparison though the heat price at the old fuel price is also shown in Fig. 4. As can be seen the cheaper the collector the better is its economic viability, i.e., a lower heat price value is obtained.

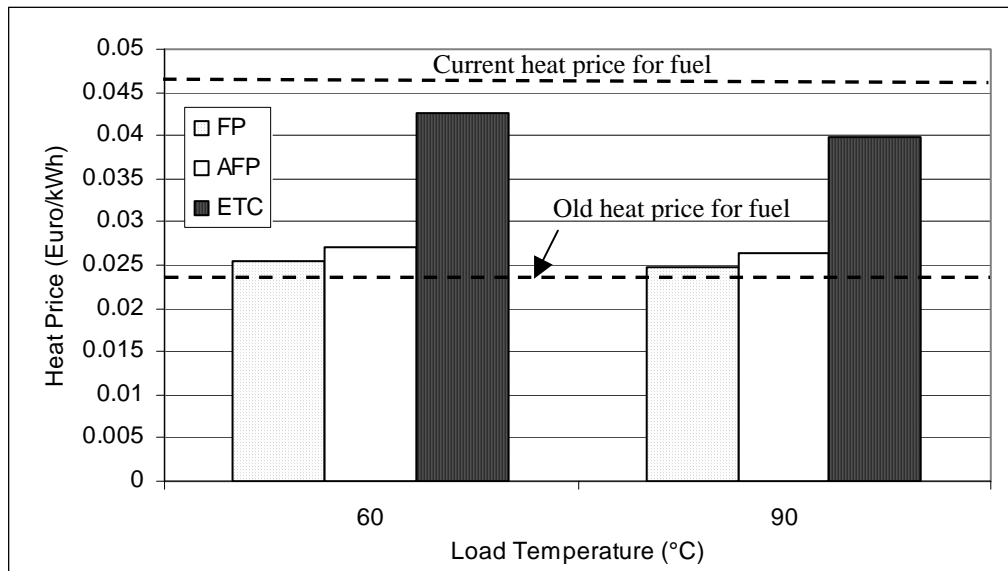


Figure 4. Heat prices as a function of load temperature

[Note: Current fuel price = 0.568 €/l (33.4 c/l) and old fuel price = 0.293 €/l (17.2 c/l). Both estimated at 85% boiler efficiency]

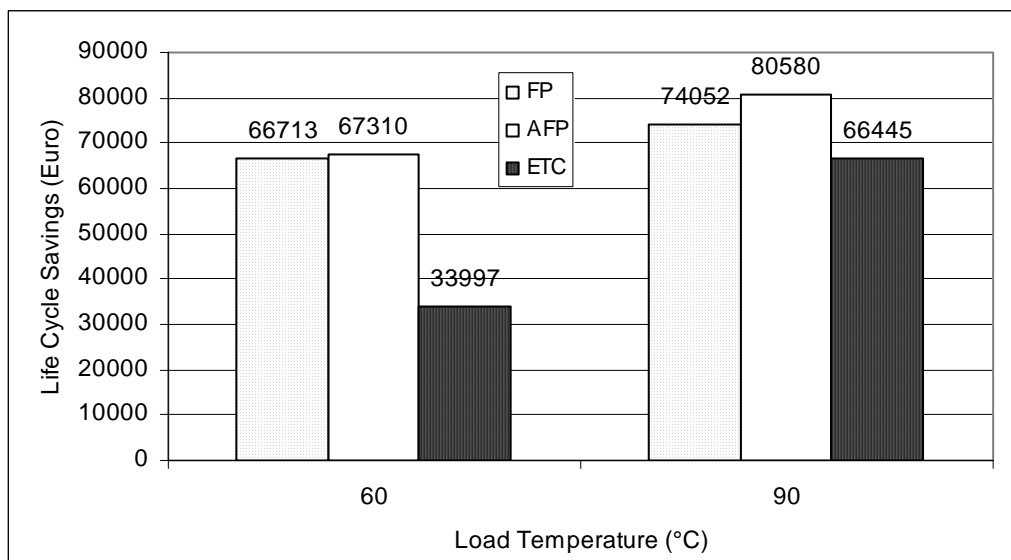


Figure 5 Life cycle savings as a function of load temperature for the various systems considered

As can be seen from Fig. 4 for the present application and for the current price of LFO all collectors are viable, whereas at the old fuel price no collector was viable.

The life cycle savings (LCS) of the different systems considered by using the current fuel price are shown in Fig. 5. Life cycle savings represent the money saved by installing the solar system instead of buying the fuel. The LCS of all cases examined are positive which means that all systems are viable. The best collector giving the higher life cycle savings is the AFP, which presents a good energy yield, compared to its cost. It can also be

concluded from the results presented in Fig. 5 that it is more advantageous to apply solar energy to higher temperature processes than to lower temperature ones as the savings incurred are much higher. It should be noted that the LCS of the systems at the old fuel price were marginal and even negative for the more expensive evacuated tube collector. Therefore the present situation clearly helps the spreading of solar energy systems as they now replace a much more expensive fuel.

From the above discussion it can be concluded that the viability of the systems depend on their initial cost and the fuel price.

None of these costs are stable but are changing continuously depending on international market trends and oil production rates. Finally it should be noted that the systems considered here should be optimised by trying a range of collector areas and storage volumes thus finding the best combination that gives the best life cycle savings.

A subsidisation scheme for renewable energy systems will be implemented in a few months time in Cyprus. With this scheme the Government will effectively pay a certain amount (up to 40%) of the initial investment of a system. Such a scheme will further increase the economic benefits of the systems.

It is believed by the author that solar energy needs to be exploited more and one area that can be developed is for industrial applications as outlined in this paper.

CONCLUSIONS

An industrial process heat system for the food industry is analysed in this paper both with respect to the energy yield and the resulting heat price for a number of collector technologies. The annual energy gains of such systems are from 745 to 994 kWh/m²-a. The resulting energy costs obtained for solar heat are from 0.025 to 0.043 Euro/kWh depending on the collector type applied. These results are applicable to any country with similar weather and economic conditions as Cyprus. As is proved in the analysis presented in this paper the economic viability of the systems depends on the initial cost of the solar systems and the fuel price. The costs will turn out to be more favourable when the solar collectors become cheaper and subsidisation of renewable energy systems is considered. At the design stage the solar systems to be considered need to be simulated and their economic benefits evaluated as indicated in this paper in order to select the best system for the particular application at the collector cost and fuel price applicable. It is believed by the author that solar energy should be given a chance especially now that the costs are very favourable. As the oil reserves are

depleted the oil prices will certainly increase and thus solar systems can provide real economic benefits. In addition the environmental advantages that the solar systems are offering should be forgotten.

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