THE USE OF SOLAR ENERGY IN LEISURE FACILITIES[1]

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Abstract

The study concerns the analysis of a solar energy system to meet the domestic hot water demands of 16 villas with private bathrooms, each equipped with a 30 litre water heater, fitted with a 1.5 kW electric heating element. The work highlights the electricity savings resulting from use of the system for producing domestic hot water by means of solar panels, with the consequent absence of CO_2 emissions.

Riassunto

Lo studio effettuato concerne l'analisi di un impianto solare termico finalizzato al soddisfacimento del fabbisogno di acqua calda sanitaria di 16 villini con servizi privati, dotati ciascuno di scaldacqua elettrico da 30 litri, equipaggiati con resistenza elettrica da 1,5 KW. Il lavoro pone in evidenza il risparmio di energia elettrica derivante dall'utilizzo di impianti per la produzione di acqua calda sanitaria attraverso i pannelli solari con conseguente assenza di emissione di CO_2.

Introduction

The use of ecoefficient technologies for the production of energy is of increasing interest to the sector of the tourism industry associated with leisure facilities.

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Technology using solar energy to produce heat has become so developed and reliable as to make it among the most rational and clean methods for the production of hot water or warm air for domestic and manufacturing applications. Despite its low density, solar radiation remains the most abundant and cleanest energy source on the surface of the planet with a potential of 19,000 GTOE irradiated from the sun annually, compared with a global primary energy demand of 12,000 MTOE in 2009, with the trend predicting an increase to 15,500 MTOE by 2020 and 28,000 MTOE by 2050 (1).

Current technologies allow an increase of 30% with respect to the yield from the panels used in the previous decade, and hence the various applications in the construction, service and agriculture sectors have become increasingly competitive from the economic viewpoint.

There are three types of technologies used to produce heat from solar energy: low, medium and high temperature.

1) **Low temperature** technologies include systems using a flat or vacuum-filled solar collector to heat a liquid or air. The aim is to capture and transfer solar energy in order to produce hot water or heat buildings. The name “low temperature” refers to heated fluids less than 100 °C (on rare occasions, the temperature can reach 120 °C).

2) The most common of the **medium temperature** conversion applications is represented by the solar furnace.

These are devices requiring the concentration of solar rays in order to reach temperatures in excess of 250 °C: in particular, in Italy they occupy a niche market in the hobby sector, while they can find widespread application in countries where lack of energy resources is an everyday problem. Other, but much less common applications of this type, are related to heat for industrial processes.

3) The component at the heart of **concentration (high temperature)** solar heat technologies and systems is a “concentrator collector”, namely a device capable of harvesting and directing solar radiation towards a receiver. The receiver may be thermal in nature, but also photovoltaic or thermophotovoltaic (2).

With regard to the geometry and the layout of the concentrator with respect to the receiver, there are linear parabolic concentrators, towers with central receivers and point or disk parabolic concentrators.

Recent technological advances predict renewed application of this technology, both for the generation of electricity, and for the production of industrial process heat.

In order to analyse the production potential of low temperature systems, normally used for the production of domestic hot water, the saving in energy and CO_2 production, with regard to a single family (4 persons) replacing an **electric water heater, with a nominal power of 1.5 kW using** 7.74 kWh (electricity)/day, has been estimated. In Italy, considering the electricity power plant energy mix, the production of one kWh results in the atmospheric emission of 0.58 kg of carbon dioxide (CO_2), one of the main gases responsible for the greenhouse effect (2). Hence, the electric water heater in question is indirectly responsible for the atmospheric emission of:

0.58 kg CO_2/kWh (electric)×7.74 kWh (electric)/day =
4.5 kg CO_2/day

This means that, just for the production of domestic hot water, using an electric water heater, a family of four is responsible for the release of 4.5 kg of CO_2 into the environment each day (with a per capita mean of 1.125 kg CO_2/day). In the case of a natural gas boiler, combustion produces 0.25 kg of CO_2 for each thermal kWh; the same family of four thus gives rise to the following daily carbon dioxide production:

0.25 kg CO_2×6.97 kWh (thermal) =
1.74 kg CO_2/day with a per capita mean of 0.435 kg CO_2/day

In the case of **solar/gas hybrid systems**, namely solar plants integrated with a gas boiler, guaranteeing the same level of comfort throughout the year, in the case of solar radiation in relation to the city of Rome, it is possible to save 60% of gas consumption: the same family would thus produce 0.69 kg CO_2, with a per capita mean of 0.174 kg CO_2/day.

The reduction in CO_2 emissions obtained with the hybrid system is significant, particularly with respect to the former scenario: the value of 1.125 kg of CO_2 released per capita in the case of use of an electric water heater becomes 0.174 kg of CO_2, with a percentage reduction of 80%. In the case of using a natural gas boiler and integrating this with collectors, an absolute per capita reduction of 0.33 kg of CO_2 is observed, while if the electric water heater is used in conjunction with solar energy, the reduction is 0.675 kg of CO_2 (3-4).

In order to conduct a detailed evaluation of the production of heat for heating domestic hot water, the application of solar thermal technology to a camp site has been investigated in order to identify the best technological solutions and correct proportioning, as a function of the effect of substitution with respect to a traditional energy source.

The production of hot water from solar thermal collectors

The most common application is the solar thermal collector used to heat domestic hot water.

Considering a flat solar thermal collector, this is generally composed of:

• a transparent sheet that filters the solar radiation, generally tempered high-transmittance glass (low iron content) of sufficient thickness to resist extreme atmospheric conditions (rain, snow, hail, extreme temperatures);

• solar absorber plate, generally copper but also stainless steel, coated with a layer of special high selective-capacity paint (titanium or chromium based) allowing the absorber to retain more of the sun's heat, at the same time reducing the reflection of sunlight. A circuit of copper or steel tube collectors (typically welded by ultrasound) with circulating thermo-convector fluid, is applied to the plate;

• heat insulation made from rock wool, polyurethane foam or the like, impeding the dispersion of heat;

• casing, normally made from aluminium or stainless steel, enclosing all the components.

A thermoconvector fluid (normally an aqueous solution of non-toxic propylene glycol, which can resist temperatures of −30 °C at the correct concentrations) is introduced into the circuit of tube collectors fitted to the absorber plate.

Warmed as a result of the heat released by the absorber, the fluid becomes less dense and hence lighter, and thus tends to naturally flow upwards, conveyed through the circuit towards the tank for the water to be heated, and there releases its heat by means of a special heat exchanger.

One square metre of flat solar collector can heat between 40 and 300 litres of water to 45-60°C in one day depending on the efficiency, which can vary, depending on the weather conditions and collector type, between 30% and 80%.

Heat exchange between the solar collector and the water tank may be facilitated by natural or forced circulation.

In the former case, the thermoconvector fluid, which tends to naturally flow upwards when warmed, circulates without the aid of a circulation pump if the water accumulation tank is raised with respect to the collector.

On the other hand, in the latter case, circulation between the collector and the water collection tank, positioned lower than the solar collector, requires a circulation pump to force the thermoconvector fluid downwards.

Operation of the circulation pump is controlled by an electronic control unit which activates the pump when a specific difference in temperature between the fluid contained in the solar collector and the water in the tank is reached (Table 1). (2,5)

TABLE 1

NATURAL CIRCULATION AND FORCED CIRCULATION SOLAR COLLECTORS: MAIN DIFFERENCES

	Natural circulation collector	Forced circulation collector
Tank	Must be positioned above the collector	Located in the most convenient point
Electric pump	absent	necessary
Electric control unit	absent	necessary

Proportioning criteria forsolar plants for civil use

The first step in correct proportioning of a solar thermal system consists of estimating the daily hot water requirement.

In a dwelling, the domestic hot water demand remains more or less constant and depends on the number of people living in the house. Normally, the daily per capita consumption of 45 °C water is between 35 l (person/day) and 75 l (person/day) (2,5).

On the other hand, in buildings with a tourist-leisure function, the calculation of demand is more complex. In order to correctly proportion a solar thermal system, the daily hot water demand should be evaluated for the mean occupancy during the period of maximum leisure activity.

In order to verify the aforementioned considerations, a licensed leisure facility (camp site) operating seasonally from April to October, and hosting up to 1,152 guests in accommodation ranging from tents to small villas with bathrooms, has been studied (Table 2).

TABLE 2

DISTRIBUTION OF GUESTS WITHIN THE LEISURE FACILITY ACCORDING TO ACCOMMODATION TYPE

Type of vlodging	**N° with bathroom**	**N° without bathroom**	**Total number of lodgings**	**Accommodation capacity – N° of guests**
Bungalow	4	8	12	48
Small villa	11	0	11	44
Chalet	2	0	2	4
Room	-	9	9	18
Caravan	-	12	12	38
Tent plot	-	89	89	1,000
Caravan/ camper plot	-	37	37	
	TOTAL ACCOMMODATION CAPACITY			1,152

As may be observed, the facility has 17 dwellings with private bathrooms and can host up to a maximum of 70 persons, while the various other types of accommodation have access to a special area with communal toilet facilities and 16 showers with hot water.

The period during the year with the greatest recorded number of guests is the month of August, when the camp site hosts up to 870 holiday makers, over 70% of the potential capacity.

During this period, the consumption of domestic hot water is essentially determined by use of the hot water showers available in the villas and in the communal areas, since the bathroom toilets are only connected to the cold water system.

Hence, the aim of the study has been the analysis of a solar energy system capable of meeting the domestic hot water demands of 17 small villas with private bathrooms, with the aim of replacing the 30 litre electric water heaters, each fitted with a 1.5 kW electric heating element.

Technical evaluation of the systems

The deliberate choice to adopt solar thermal technology to produce the domestic hot water required by the leisure facility basically takes into consideration the factors associated with the type and seasonal nature of the demand, and the architectural characteristics of the leisure facility.

With regard to the first two factors, the production of domestic hot water within the facility is essentially intended for use in the showers available in the villas and in the communal area, since the bathroom toilets are only connected to the cold water system.

Furthermore, the number of guests in the facility varies significantly throughout the 7 months of seasonal activity. While the 17 villas with private bathrooms are occupied almost constantly from May to September, the number of guests using the communal area services is subject to highly significant variability, from zero up to 870 for the month of August.

Furthermore, the study does not take into consideration the hot water consumption required for the kitchen and bar facilities, satisfied by 2 electric dish-washers.

Table 3 shows the domestic hot water consumption pertaining to the facility operating at capacity, calculating the per capita daily need for guests to be 20 litres of water at 45°C (Table 3).

TABLE 3

CONSUMPTION OF DOMESTIC HOT WATER FOR SHOWERS/DAY DURING THE MONTH OF AUGUST (SHOWER USAGE L/PER CAPITA DAILY WATER: 20 LITRES AT 45 °C)

	No. of showers/day	Hot water at 45 °C (l)
Communal facilities	800	16,000
In villas	70	1,400
TOTAL	870	17,400

Prior to this operation, domestic hot water for the showers in the communal facility was produced by a heat plant consisting of a 90,000 kCal gas boiler and a 1,500 litre 65°C storage tank, while the 17 villas with private bathrooms each had 30 litre water heaters. In terms of energy consumption, the seasonal bill could be subdivided into approx. 5,000 litres of GPL and approx. 11,000 kWh of electricity (Table 4).

TABLE 4

ENERGY CONSUMPTION FOR THE PRODUCTION OF DOMESTIC HOT WATER

	Boiler	**Water heater**
Energy supply	GPL	Electricity
Power (kW)	104 thermal	1.5 electric
Mean daily consumption	25 l	3.5 kWh
Seasonal consumption	5,250 l	11,200 kWh 2

(Notes: 1: consumption with reference to the mean values calculated from 210 days of seasonal activity. 2: consumption with reference to the use of 17 water heaters of equal characteristics, applied to the villas for 190 days out of 210. 3: here, for the purpose of uniformity with the bibliographic sources reported in the text, the Cal (and multiples thereof) will be used as the unit of measurement in place of j (and multiples thereof).

The study has taken into consideration the level of tree growth in the camp site, which does not permit a sufficiently sunlit surface for the installation of solar thermal panels.

Hence, during the preliminary study, it has been decided to only consider solar energy for the hot water for the villas with private bathrooms, located in unshaded areas of the camp site and with flat roofs of sufficient size to house the solar collectors.

Following the preliminary evaluations regarding the peculiarities of the leisure facility, the consumption demands and architectural and landscape restraints, 16 of the 17 villas in the study (one has been kept out of the project for technical reasons as a results of its location) have been subdivided into 5 groups of 3 and 4 units, giving a total of 12 users per group. As already mentioned, the daily hot water demand for each individual user has been assumed to be a standard consumption of 20 litres at 45 °C. In energy terms, assuming the temperature of the water drawn from the water main to be 15 °C, it is possible to calculate the per capita quantity of heat energy required Q:

$$\mathbf{Q = G \times cs \times (Tu - Ta) = 20 \times 1 \times (45 - 15) = 600\ kCal}$$

Where:
G, mass of water to be heated (l); **Tu**, usage temperature, equal to 45 °C; **cs**, specific heat capacity of water (kCal/l); **Ta**, temperature of the water from the water main (°C).

This means, calculating a seasonal villa occupancy rate of 90%, an overall energy demand of approx. 8,000,000 kCal, i.e. 9,300 kWh_{ter}, equal to 10,600 kWh_{el}.

Based on the data, for each group of villas, a solar thermal plant has been arranged with flat glazed collector technology with semiselective copper absorbent plate. In detail, each plant consists of 3 flat collectors with gross area of 2 m^2 each, giving a gross total capture surface of 6 m^2 and a net surface area of 5.5 m^2.

Heat exchange occurs by natural circulation with a 300 litre 860°C vitrified steel tank, with interspace heat exchanger 1.3 cm wide and a thermoconvector fluid capacity of 4 litres (Tables 5 and 6).

TABLE 5

TECHNICAL CHARACTERISTICS OF THE SOLAR COLLECTOR

Dimensions:	200×100×10 (cm)
Empty weight:	38 kg
Water content	2 litres
Net capture surface:	1.83 m2
Max. admissible pressure:	3 BAR
Optimal flow rate:	100 l/h
Loss of load:	1000 mm at optimal flow rate
Absorbent plate	Copper
Insulation:	Rock wool, 45 mm thick
Type of glass:	Tempered prismatic extralight, 3 mm thick
Paint:	Semiselective: absorbance 93%, emission 50%

TABLE 6

TECHNICAL CHARACTERISTICS OF THE COLLECTION TANK

Dimensions:	200×60 (cm)
Empty weight:	95 kg
Domestic hot water capacity:	300 litres
Material:	860 °C vitrified steel
Max. admissible pressure:	3 BAR
Heat exchanger:	Interspace, 13 mm wide
Exchanger capacity:	4 litres
Thermal integration:	thermostatically controlled 1.5 kW electric heating element

The choice of a system with this type of composition has been determined by the need to guarantee at least 90% of the domestic hot water requirement during the entire seasonal opening period of the facility, considering that the solar irradiation coefficient and the heat production of the collectors is maximum in peak tourism months (July and August) reducing in April – June and September – October (Figure 1).

Based on the efficiency characteristics of the various absorbent plate types, choice has been focussed on a semiselective plate collector, i.e. coated with a layer of black paint with inferior efficiency with respect to an analogous model coated with titanium or chromium selective paint.

Calculation of the seasonal thermal output of the collector has shown that the thermal power developed would have been sufficient to guarantee the objective in question, thus making it unnecessary to resort to the more costly and more efficient selective collector.

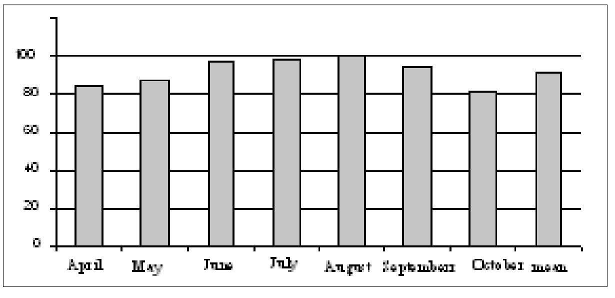

Fig. 1 - Share of domestic hot water production of the 6 m2 surface area natural circulation system in operation, with respect to the need of 12 people during the period April – October.

Conclusions

Energy efficiency is a subject of growing interest in leisure facility management: this is demonstrated by the ever increasing attention to the planning and construction of facilities utilising renewable energy sources.

In terms of CO_2 emissions avoided, the structured solar plant allows a saving of approx. 5 6 tons of CO_2 per season, considering the value of the energy mix in Italy – equal to 0.58 kg CO_2/kWh (3,5).

From the environmental viewpoint, the system has undisputed advantages, even if from the financial viewpoint, the initial investment might constitute an obstacle, despite the significant public subsidies.

These evaluations highlight the potential intervention of the financial institutions, which may offer structured financial products in order to assist the renewable energy sector.

Knowledge

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