THERMAL PERFORMANCE AND ECONOMIC EVALUATION OF A SOLAR HOT WATER SYSTEM IN TASHKENT

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ABSTRACT: In these days, with an increase in the standard of living, there is an increase in demand for energy, as well as increasing requirements for energy conservation and the use of renewable energy sources. The article presents the results of studying the possibility of using solar collectors in the small business sector, in particular, to meet the needs of hot water supply for a hotel located in Tashkent. The study used the f-method to determine part of the load on hot water covered by solar collectors. An economic analysis of the proposed system is carried out, the results of the study and their discussion are presented.

KEYWORDS: Solar collector, f-chart, domestic hot water, solar irradiation, solar heat, heat exchanger, net present value, investment.

Solar energy is an important renewable energy source offering potential benefits to all countries and especially in those with high radiation level. The solar thermal systems for hot water production in residential and hotel sector are the most accessible and promising energy saving options and the solar thermal market is now growing fast. This mature technology finds its way to market through engineers, experienced installers, manufacturers, and system managers. In recent years a number of hotels in several different countries have installed active solar system for hot water production. The reason is evident because the tourist hotels require large amounts of hot water and the solar hot water production is in phase with demand. Hiller and Johnson did some research on the water and energy consumptions in the hotel sector, and found that the domestic hot water system is one of the major end users of the energy and water [1]. A survey on the domestic hot water (DHW) usage in hotels revealed that the total hot water use was as high as 9.84 million liters for the business hotel, and 2.91 million liters for the travel hotel over a 13-month monitoring program.

However, the benefits of a solar water heating system cannot be realized unless it is properly designed and sized for its indented application. The sizing of a solar hot water system, however, is a complex problem because of the many different parameters that must be considered. These parameters are always associated with significant uncertainties [2]. For example, the usage pattern of the DHW system is strongly associated with the occupant behaviors, and therefore the usage is stochastic and highly time-diverse. Selecting the right input values for these parameters is usually tricky and confusing for designers and building molders, especially for those who don’t have much experience in this area.

Several methods of sizing solar heating systems have been developed to varying degrees of sophistication. The most accurate way of sizing a system is dynamic simulation by means of a computer model. Simulations, however, are not convenient because they require hourly meteorological data and are so complex to use that they are suitable only for computers. These have necessitated the development of simpler sizing methods as the f-chart and other methods. The f-chart method is one of the most comprehensive and widely used simplified methods, for predicting the monthly and annual solar fraction of active solar heating systems. Results from such methods are very helpful for solar system design since they allow one to learn about the complex interaction of a large number of variable in a short time, whereas experiments are time consuming and costly.

After all these we considered an active solar thermal system for hot water production installed in a hotel in Tashkent, in order to evaluate its thermal performance. The computer programme used has been developed at Renewable Energy Laboratory of Mechanical Engineering Department of University of West Attica in Athens, Greece, and is based on f-chart method. The developed software is a very fast and easy to use tool for predicting the monthly and annual solar fraction of active solar heating systems and to study its economic viability using the life cycle savings method.

Methodology

For the thermal performance evaluation of the proposed solar system, the developed software is based on f-chart method, while for the economic analysis is based on the Life cycle savings (LCS) method. The f-chart method is a correlation of the results of many hundreds of thermal performance simulations of solar heating systems. The conditions of the simulations were varied over appropriate ranges of parameters of practical system designs. Several assumptions were made, most of which tend to lead to conservative predictions of performance. One of the three standard system configurations for which the method has been developed is the domestic hot water heating using water heating collectors and an external collector-storage heat exchanger to transfer heat from the collector to storage Fig.1.

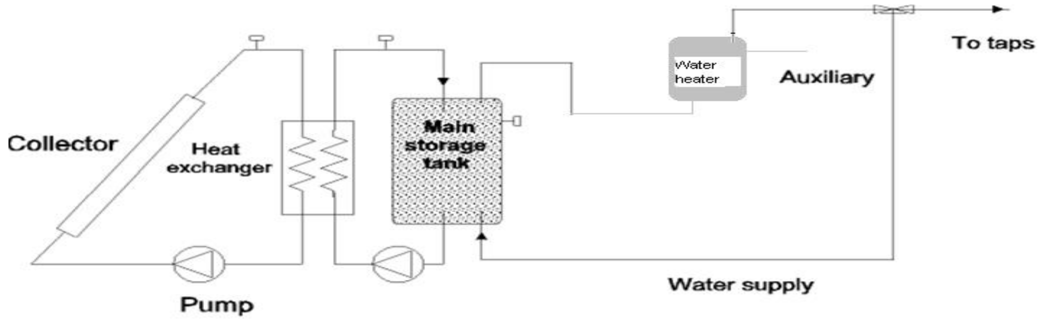

Fig.1.Standard system configurations by f-chart method for domestic hot water heating using water heating collectors.

The required input parameters by the developed program are entered by the user at the beginning of the program. The input parameters are divided in two main categories, one for the solar system and the load and the other for the system's economics. All input parameters can be saved on file and used again in another session. As far as climatic data are concerned, the program requires the monthly mean daily values of solar irradiance on horizontal per square meter, the ambient temperature and the mains water temperature. The outputs of the program related to thermal performance solar are the monthly and yearly system performance as, solar fraction, useful solar energy per square meter of collector, hot water load and pipe heat losses. Correspondingly, the outputs of the economic analysis are the net present value, internal rate of return, payback period, annualized total cost with solar and annualized energy cost without solar.

System configuration

The thermal solar system is designed to produce domestic hot water for a medium size hotel in Tashkent, Uzbekistan and based on the standard system configuration defined by f-chart method. It consists of liquid glazed flat-plate collectors, a single water storage tank and an external heat exchanger between solar collector and storage tank, a pump, tee-piece, flow diverter, controllers and insulated piping. Each solar collector has an aperture area of 1.306m^2. The technical specifications of the solar thermal system and load are shown in table 1and the monthly weather data for Tashkent are shown in Table 2 [3].

Table 1

The solar thermal system and load specifications

Collector parameter set	Value
Test slope parameter:	6.471 W/m^2 °C
Test intercept parameter:	0.674
Number of glazing:	1

Collector tilt:	40°
Collector - heat exchanger correction factor:	0.97
Storage capacity:	64 l/m^2
Piping parameter set	
Pipe length:	20 m
Piping heat loss coefficient:	0.5 W/m°C
Hours of daily operation:	16 h
Piping ambient temperature:	19 °C
Hot water load parameter set	
Occupants:	30
Daily consumption:	50 l/day·pers
Hot water temperature:	50 °C

The schematic of the active solar hot water system described above is similar to that of Fig.1.The collector used for the means of this study is a commercially available product which has been experimentally tested by an approved center for solar collector testing, in order to determine its thermal performance parameters according to standard test procedure EN-12975-2 [4]. The absorber of the collector is constructed of copper tubes, ultrasonic welded on a copper sheet. The collector is suitably insulated, with glass wool of 40 mm at the back and 20 mm at the sides, and enclosed in an aluminium box supporting the absorber plate. The transparent cover is a low iron tempered glass with a thickness of 4mm. The working fluid used in the closed loop of the collectors is a water-glycol mixture of 40% by volume to prevent freezing.An auxiliary heating unit is present as part of the system. It simply is a heater placed between the storage tank and the consumption in order to supply the auxiliary energy required to heat the water, if necessary. The orientation of the solar collectors is facing towards the true south, while its tilt angle is taken equal to the latitude of the city of Tashkent.

Table 2

Monthly weather data for Tashkent

Month	Ambient temperature, °C	Solar irradiation on horizontal surface, kWh/m^2	Mains water temperature, °C
Jan	0.5	54.3	11.5
Feb	2.3	75.8	11.2
Mar	8.6	110.8	12.4
Apr	15.1	164.8	15.1
May	20.5	217.0	18.4
Jun	25.3	236.0	21.5
Jul	27.7	237.7	23.5
Aug	25.4	213.2	23.9
Sep	19.8	164.5	22.6
Oct	13.3	110.5	19.9
Nov	7.7	62.5	16.6
Dec	3.4	46.8	13.5

Economic analysis

For the economic viability of the studied solar system, a simple economic analysis based on the Life Cycle Savings (LCS) method has been performed. This method is widely applied for determining energy systems economics. In this method, the net cash flow of all anticipated future costs and benefits between two alternative energy investments are discounted to their present values. As it is emphasized on costs, it is a suitable method for evaluating the economic feasibility of projects that realize their benefits primarily by reducing the consumption and cost of fuel. This method can also be used to find the economically optimum design of a given system. The estimation requires the synthesis of both the energy performance results and a number of economic parameters. Required energy performance data have been calculated using the developed software tool. The set of assumed economic parameters are shown in Table 3 and were obtained from the Electricity Authority of Tashkent [5] and one of the banks operating in Tashkent. The two energy systems compared in this study is a solar thermal system plus auxiliary energy and a conventional heating system. The fuel and electricity costs are being considered for each case and compared to each other. The conventional heating system is assumed to be a natural gas-fired boiler and an electrical respectively.

Table 3

Economic parameters

Economic parameter set	Value
Area dependent cost	200 €/m^2
Fixed cost	350 €
Maintenance cost (MC)	30 €
MC inflation rate	6 %
Domestic electricity price	0.0425 €/kWh
Natural gas price	0.0035 €/kWh
Domestic electricity inflation rate	8 %
Heating oil price inflation rate	7 %
Heating gas price inflation rate	8 %
Bank loan interest rate	12 %
Loan lifetime	20 years
Economic analysis	20 years
Market discount rate	12 %
Furnace efficiency	0.85

Results

The calculations of the thermal performance for the active solar system considered were based on the developed tool at the Renewable Energy Laboratory of Mechanical Engineering Department. Using this software and taken into account the specification for this system, the program was run with the meteorological data of city of Tashkent and the results are shown in diagrams.The annual solar fraction and the useful solar heat output per unit collector area for different collector areas are shown in Fig.2. The annual solar fraction increases with solar collector area, while the useful solar heat output per unit collector area, which is the most important performance figure relating to a solar installation, decreases. The economic results in Fig.3, clearly shown that at current natural gas prices, and for the collector areas investigated, the solar system appears to be uneconomical.

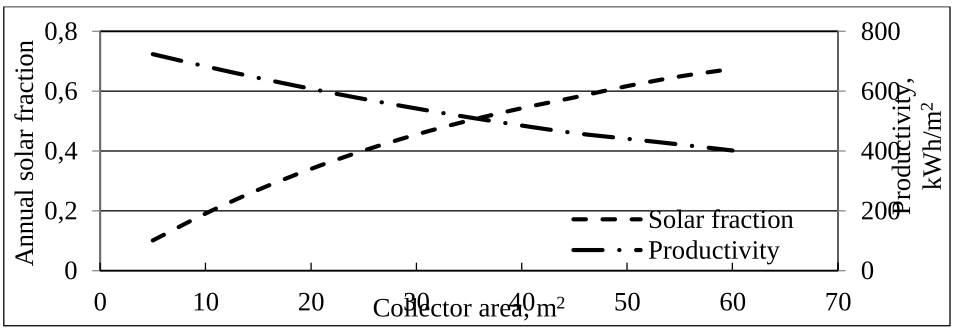

Fig.2. Variation of annual solar fraction and productivity at different solar collector area.

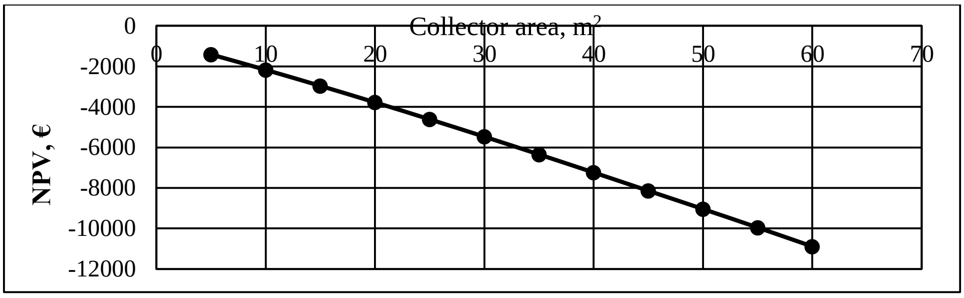

Fig.3. Variation of Net Present Value at different solar collector area.

However, it is interesting to examine the viability of a specific solar project at different natural gas prices and investment costs. Consequently, a sensitivity analysis has been performed in order to determine whether an increase in natural gas price or a reduction of the investment costs could turn economically viable a solar system.For this reason, an active solar thermal system for domestic hot water has been considered. The system consists of 40 m^2 collectors and covers 50% of annual total hot water demand of the examined hotel. The Fig.4 shows the values of profitability index, which is defined as the NPV/Investment cost (P.I.), at different natural gas prices. Points beyond the intersection of two lines indicate net system benefits. The profitability index for different investment costs are shown in Fig.5. The investment cost should be reduced enough for the curve to meet the straight line. The last two figures show clearly the effect of state intervention on the fuel prices and solar market.

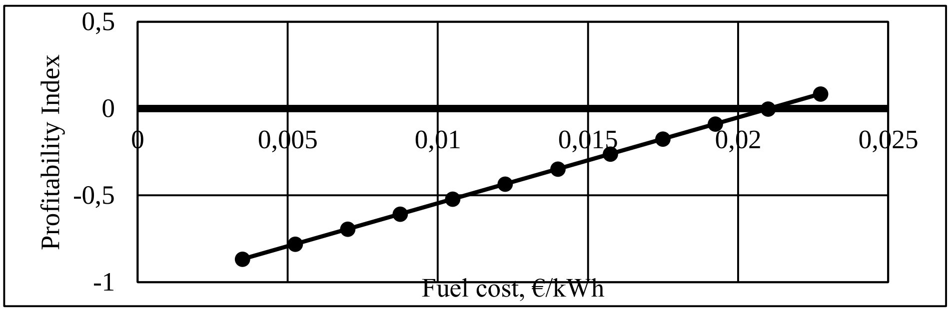

Fig.4. Variation of Profitability Index at different natural gas prices.

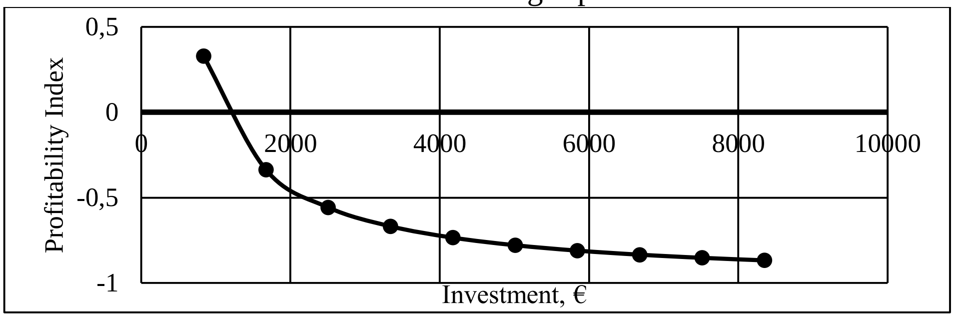

Fig.5. Variation of Profitability Index at different investment cost.

Conclusion

Considering the actual economic conditions in Tashkent, the proposed system seems to be an uneconomical investment and probablya state financial support is required to render it viable, as already applied in a number of European countries.

At present, incentives for investment in solar collector systems are provided on a national level, including direct contributions, low interest loans, income tax relief or reduced VAT. In the future, the collector systems have to be cost effective without monetary incentives. Also, in country it is implementing market stimulation programs, including measures such as government purchasing and financial support of manufacturers and buyers of solar systems, because is the only way for a sustainable development which can lead to a sustainable society.

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