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An Active Solar Energy System to Supply Heating Demands of the Teaching Staff Dormitory of Islamic Azad University Ramhormoz Branch

M. Talebzadegan, S. Bina, I. Riazi

***Abstract*—**The purpose of this paper is to present an active solar energy system to supply heating demands of the teaching staff dormitory of the Islamic Azad University of Ramhormoz. The design takes into account the solar radiations and climate data of Ramhormoz town and is based on the daily warm water consumption for health demands of 450 residents of the dormitory, which is equal to 27000 lit of 50-C° water, and building heating requirements with an area of 3500 m² well-protected by heatproof materials. First, heating demands of the building were calculated, then a hybrid system made up of solar and fossil energies was developed and finally, the design was economically evaluated. Since there is only roof space for using 110 flat solar water heaters, the calculations were made to hybridize solar water heating system with heat pumping system in which solar energy contributes 67% of the heat generated. According to calculations, the net present value "N.P.V." of revenue stream exceeds "N.P.V." of cash paid off in this project over three years, which makes economically quite promising. The return of investment and payback period of the project is 4 years. Also, the internal rate of return (IRR) of the project was 25%, which exceeds bank rate of interest in Iran and emphasizes the desirability of the project.

***Keywords*—**Solar energy, heat demand, renewable, pollution.

I. Introduction

THE application of renewable energies has been in focus in recent years. The scholars and government officials have recognized the significant role of these environment-friendly energies in human life. Residential buildings now consume more fossil energies for heating and cooling purposes than industrial facilities and utilizing solar energy properly can reduce fuel consumption by households. Solar energy can be supplied to buildings by two systems including active solar system vs. passive solar system. Using active solar system to provide cooling and heating demands is one of the most common systems in solar buildings. Demanding other kinds of energies by buildings is reduced using active solar system in warm and cold seasons. The absorption ventilating systems used to fulfill cooling and heating demands of buildings only gains thermal energy to produce heat in winter and cooling air in summer. Solar system is nothing more than the building itself in which constituting elements play double roles. Building walls act as an external enclosure and, at the same time, absorb, save and distribute thermal energy. Building architecture depends fully on the passive absorption. Saving energy by it while solar heating is active and requires solar gain and another energy source to supply and transfer the heated fluid into the building. Currently, the techniques used in the passive solar system include direct gain, greenhouse, swimming pool or plunge pool on roof, Tromb wall and water wall and thermal chimney [1].

M. Talebzadegan is with the Department of Engineering, Ahvaz Branch, Islamic Azad University, Ahvaz, Iran (corresponding author, phone: +986133348356; fax: +986133348356; e-mail: m.talebza@iauahvaz.ac.ir).

II. Heating Demands of the Ground Floor

Internal walls made of bricks and two inches' plaster with a heat transfer coefficient of U = 0.35 (Btu/hr.ft2.F). Building façade made of a 1.5 layer of bricks and 0.5 layer of sand, plaster and Bottle brick with a heat transfer coefficient of U=0.37 (Btu/hr.ft^2.F). Supply and return warm water temperature respectively are considered to be 40(F) and 60(F)

III. Heat Losses from Rooms Walls (Q_1)

$$Q_1=AU(To-T_i) \quad (1)$$

By replacing U, T_i, T_o and A with proper values in the relation above, heat losses from interior and exterior walls, doors, windows, floor and roof can be determined.

IV. Heat Losses by Air Conditioning (Q_2)

$$Q_2=V\times0.07949\times0.241\times(t_i-t_o) \quad (2)$$

The air density correction coefficient was obtained as 1.05.

V. Heat Demands of Warm Water (Q_3)

Table I shows consumable warm water in all floors that is equal and is determined based on the number of appliances.

TABLE I
Sanitary Equipment Warm Water Demand

Lavatory	Shower	Washing sink	Laundry sink	
10	200	20	30	Maximum Warm water demand (GPH)
12	15	4	10	Number

VI. Maximum Consumable Warm Water

$$(20\times4)+(200\times15)+(10\times12)+(30\times10) =3500 \text{ (GPH)} \quad (3)$$

Actual warm water consumed:

$$3500 \times 0.4= 1400 \text{ (GPH)} \quad (4)$$

For the purpose of calculations, the demand coefficient was taken as 0.4, reserve tank coefficient was taken 1, inflow water temperature to tank 60 (F) and outflow water temperature 40 (F). Using a safety coefficient of 10%, we will have:

$$Q_3=V\times8.33\times(t_2-t_1)$$
$$Q_3=1400\times8.33\times(140-60)\times1.1=1026256(Btu/hr \quad (5)$$

So, the total heat transfer becomes:

$$Q=(Q_1+Q_2)\times1.1+Q_3$$
$$Q=(513786.62)\times1.1+1026256=1591421.28\ (Btu/hr) \quad (6)$$

Considering the differences discussed earlier and the floors coefficients, the heating demand for the first, second and third floors are determined as:

$$Q_1=1608258.23(Btu/hr$$
$$Q_3=1924856.23\ (Btu/hr) \quad (7)$$
$$Q_2=1648464.69(Btu/hr)$$

The heat losses from ground floor do not affect heat demands of other floors, so it is deduced from total heat demands of all floors. In addition, heating demands of the roof of third floor is considered in calculating heat demands of the third floor itself. Hence total heat demand is:

$$Q=6604371.24\ (Btu/hr) \quad (8)$$

VII. Calculating Solar Energy

The building is considered to have walls with two concrete layers with an insulation of glass wool and double glasses window. The area of solar collectors was calculated to supply heat demands of the building. Due to the limited space of building roof, a combined solar-fossil energy system was proposed for the insulated building in which solar energy contribution to the system is 67%, Figs. 1 and 2. According to records, the daily consumption of warm water by 450 residents for health purposes is 27000 lit of 50 C° water. The heating has been calculated for an infrastructure of 3500 m². To determine the energy needed for cold seasons, heat demand of the coldest day of the year is multiplied by 90, the number of days of winter season, and approximately, half of the result is generalized as the heat demands in fall season. Then, the total heat demand for cold seasons of a year is calculated as follows:

$$14265441360+7132720680=21398162040\ (Btu/year) \quad (9)$$

VIII. Calculating Consumable Warm Water

The required warm water is determined by multiplying daily warm water consumption by the number of cold days of the year as:

$$24630144\times180=4433425920\ (Btu/year) \quad (10)$$

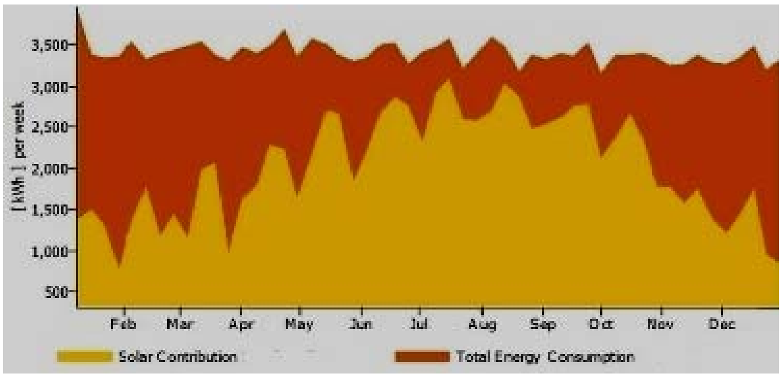

Fig. 1 Total energy required and energy produced by the solar system

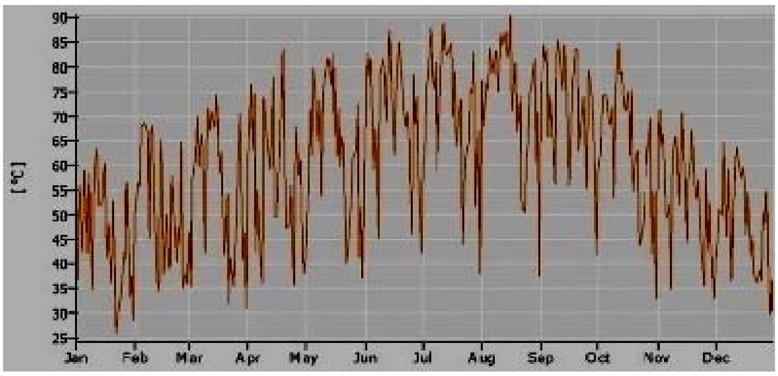

Fig. 2 The maximum temperature of the collector

IX. Calculating Total Energy Demanded for Cold Seasons

The total energy demanded is determined by summing up heat and warm water demands in cold seasons for the insulated building under study as:

$$21398162817+4433425920=25831587960(\text{Btu/year}) \quad (11)$$

X. Using Solar Water Heaters in the Building with Insulated Walls

Since the roof space of the building under study can be used for only 110 water heaters, the calculations are made to hybridize the solar water heating system with motor heating system. Each flat heater has an area of 2 m² or 21.5 ft². Since the collectable solar energy by each square foot of heater's area in Ramhormooz town in the coldest day of winter is 1500 (btu/day) and 1700 for the coldest day of fall, the solar gain by heaters is calculated as [2]:

$$21.5\times 1500\times 110\times 90=319275000\ (\text{Btu/year})$$
$$21.5\times 1700\times 110\times 90=361845000(\text{Btu/year}) \quad (12)$$

XI. Solar Energy Demanded by the Insulated Building Hybridized with Solar Collectors

Since the total energy demand by the insulated building for cold seasons of the year is 25931587960 (Btu/year) and, according to calculations, the energy gain from solar water heaters is 681120000 (Btu/year), the total heat demand by the insulated building is determined as:

$$25831587960-681120000=25150467960(\text{Btu/year}) \quad (13)$$

XII. Calculating Project Revenues

To determine the total revenues of the project, first total energy demanded by both ordinary and insulated buildings was turned into equal crude oil barrels, then, the value difference of energy in the insulated building with solar hybrid system and an ordinary building is calculated as project revenues for each oil barrel of 100 USD. Also, by determining air pollutions produced by both buildings and the differences each makes in removing such pollution, another revenue is recognized for the insulated building with hybrid solar system as:

Btu Conversion factors to barrels of crude oil is 172×10^{-9}

The demanded energy for the ordinary building equalized to the crude oil barrels is as below:

TABLE II
POLLUTION PER CRUDE OIL BARREL

Pollution(Kg)	NO_X	SO_2	CO_X
Emissions generated by each crude oil barrel per	2.01	3.59	10.65
Emissions generated per year for ordinary house	119.821	214.009	634.875
Emissions generated per year for insulated house	9.579	17.109	50.755

TABLE III
FIGHTING ENVIRONMENTAL POLLUTION

Pollution(USD)	NO_X	SO_2	CO_X	*Total*
Cost of pollution per ton in (USD)	10836	2232	48.8	
costs of fighting pollution per year for ordinary house in (USD)	1298.38	477.64	30.98	1807
costs of fighting pollution per year for insulated house in (USD)	103.799	38.187	2.476	144.4

$$4443\times 100=444300\$$$
$$3826\times 100=382600\$ \quad (14)$$

The emissions generated by each crude oil barrel per kg are given in Table II [3]. The costs of fighting such environmental pollution are given in Table III based on EPA statistics [4].

XIII. Total Cost

The total cost of removing environmental pollutions and supplying heat demands are as:

$$444300+1806.01=44107$$
$$382600+144.462=382744\$ \quad (15)$$

The difference in values above is equal to the annual revenues made by using the insulated building with solar collectors:

$$44107-382744=63363\ \$ \quad (16)$$

XIV. Calculating Differences in Initial Investments

The areas of exterior walls of the building and windows are 2000 m² and 300 m², respectively. The construction costs of the ordinary building walls with 20 cm thick bricks and single glass windows are totally 47,619.00 USD while for the building with concrete insulation with a wool layer and windows with two-layer glasses, the costs are estimated to be 154,761.90 USD, Fig. 3.

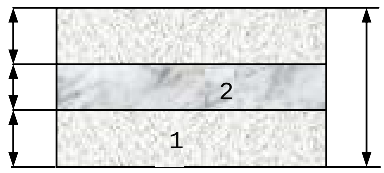

Fig. 3 Typical insulated concrete wall with glass wool

Additionally, the set-up cost of 110 solar water heaters was estimated to be totally 18,700.00 USD. Totally, the investment cost for the insulated building is 173,461.90 USD. The initial cost difference between the two schemes can be shown as:

$$173461.9-47619=125842.9\ \$ \quad (17)$$

XV. Economic Feasibility

First, all project cash flows were discounted by a reasonable rate. The results show that over three years, the present value of positive cash flows exceeds the present value of negative cash flows. In this case, the return period is three years and the project is reasonably acceptable. The NPV formula is [5]:

$$NPV = \frac{R_n}{(1+k)^n} - c \tag{18}$$

Alike internal rate of return (IRR) method, money has time value in NPV relation and project cash flows are a key variable in deciding project attractiveness.

XVI. Internal Rate of Return (IRR)

Internal rate of return is the interest rate at which the net present value of all the cash flows from the project equal zero. IRR for this project 25%, which is higher than bank interest rate, shows project profitability. Equation (19) was used to calculate IRR in which investment costs are shown by *C* and future revenues are represented by R1, R2,…,Rn. In addition, *r* is discount rate, which makes future revenues equal to initial investments [6].

$$\frac{R_1}{(1+r)^1} + \frac{R_2}{(1+r)^2} + \frac{R_3}{(1+r)^3} + ... + \frac{R_n}{(1+r)^n} - C = 0 \tag{19}$$

XVII. Conclusions

(19) shows the present value of positive cash flow exceeding the present value of negative cash flows, which emphasizes the project feasibility over three years. The IRR for this project was 25% which is higher than bank interest rate in Iran showing again the profitability of the project. The net present value of the hybrid system exceeds the present value of investment costs over its life; hence, the insulated building plan with hybrid solar system is economically cost-effective.

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