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Investigating the Feasibility of Applying Integrated Photovoltaic and Solar Water Heating Systems in Residential Buildings

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Abstract. In this research, technical, economical and environmental feasibility study of applying integrated grid-connected photovoltaic and solar water heating systems in a typical 8-unit residential building for supplying the required electricity and hot water has been carried out. Considering geographical situation and climatic conditions of Tehran, the amount of it's electricity and natural gas demand and the required hot water, were investigated considering international prices of electricity and natural gas by using RETScreen software. The share of solar water heater in supplying the required energy for water heating is 53%. Likewise, 16.416 MWh/yr electricity is produced by installed photovoltaic panel (10kW). Taking into account the international prices for electricity and natural gas, the amount of annual natural gas saving, green house gases (GHGs) emission reduction, external costs diminution and normal payback period appear to be 4,777 m^3/yr, 14.6 tCO_2/yr, US$ 185 tCO_2/yr and 4.94 yr, respectively.

Keywords: Integrated Photovoltaic and Solar Water Heating Systems, GHG Emission Reduction, Residential Building, External Costs

1. Introduction

A theoretical examination of flat-plate solar collector with solar cells integrated into Hottel-Whillier model was conducted in 1995, in order to achieve high thermal and electrical efficiency through the integrated systems of solar thermal collectors and PV panels [1]. Most of the aforementioned works give experimental and modeling results regarding the performance of integrated systems of solar thermal collectors and PV panels with forced or natural circulations and heat removal fluid, while a few studies have been done regarding the required cost and energy for practical applications yet. Eventually, the performance of integrated PV panels and thermosyphonic solar water heating systems (BIPVW) was studied and a commercial thermosyphonic system was introduced to the market [2]. The recent researches imply that cooling PV systems can increase the output electrical and thermal efficiency of systems [3&4]. Efficiency of collector fin and quality of tube bonding have been identified as the key factors in designing integrated systems, and if the sheet and tube design is replaced by a flat box metallic thermal absorber design, the overall efficiency can be improved [5]. In this paper, technical, economical and environmental feasibility study of applying an integrated system including grid-connected photovoltaic panels and a forced circulation solar water heater for supplying the required electricity and hot water for a residential building has been carried out considering international prices of electricity and natural gas by using RETScreen software.

2. Materials and Methods

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Considering climatic conditions of Tehran, features of a typical four-floored 8-unit residential block situated in downtown Tehran with 25 residents, its electric energy and natural gas demand, and hot water supply, were investigated considering the international prices of electricity and natural gas by using RETScreen software. Total surface area of the building was 668 m^2, surface area of each unit was 82 m^2 and the basement was 173 m^2. The outer surface of the building at the north and the south wings was 261 m^2 each of which having 42.8 m^2 window made of one-layer glass. Energy carriers used in the building were electricity and natural gas which were provided by the national electricity grid and the national natural gas supply, respectively. Table 1 demonstrates features of electric energy consumption in the studied building.

Table 1: Features of Electric Energy Consumption in the Studied Building

Energy Systems	Systems Type	Total Power (kW)
House Appliances	Various Kinds of House Appliances	93
Light	Lamp	8
Cooler	Cooler	16

The highest amounts of electricity consumption occurs in August and September due to using the cooling system and the lowest amounts of electricity consumption occurs in April and May. Fig. 1 illustrates the electricity consumption profile for the monthly electricity needs (kWh) and Fig. 2 demonstrates the natural gas consumption profile for the monthly thermal energy needs (m^3).

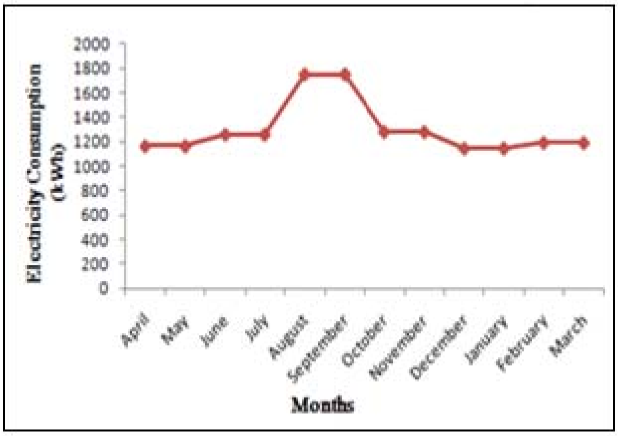

Fig. 1: Electricity Consumption Profile for the Monthly Electricity Needs (kWh)

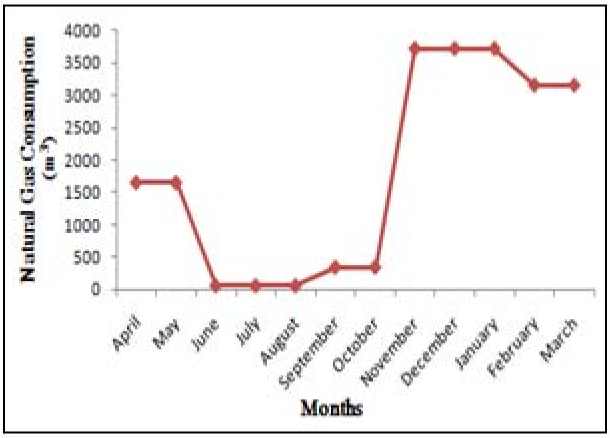

Fig. 2: Natural Gas Consumption Profile for the Monthly Thermal Energy Needs (m^3)

In the studied building, the electric energy is mainly used for light, house appliances and cooler, during the summer time. Method for estimating maximum electric charge depends on calculation of total implemented demand and inclusion of proper coincidence factor. Prediction of maximum amount of electricity demand, especially in terms of number of portable appliances, light, installed sockets and etc., depends on number of residents, their behavior (age, employment status, culture and etc.), and life style; electric appliances and their age; coincidence factor; climate of the region, building's surface area, construction method and interior design and etc. Coincidence factor can be calculated by Equation 1:

$$CF = \frac{SMD(kWh/day)}{\sum_{i=1}^{n} NSMD(kW)} \quad (1)$$

Where CF is coincidence factor (h/day); SMD is maximum demand used simultaneously (kWh/day); NSMD is maximum consumed demand of appliances at the building (kW); and n is number of building's electric appliances. Referring to table 1, the maximum consumed demand of studied building's appliances appears to be NSMD=117 kW., The maximum consumed demand of the building is 1,747 kW/month, or in average 58.23 kWh/day. Hence, the amount of coincidence factor in equation. 1 is:

$$CF = \frac{58.23(kWh/day)}{117\ kW} = 0.49h/day$$

The maximum demand that can be used simultaneously in the building, on the basis of controlling installation at the building entrance which is a single-phase 25-ampere fuse, is:

$$SMD = 25Am \times 220V \times 7day = 38,500Wh/day \Rightarrow 38.5kWh/day$$

$$\text{Maximum electric charge} = 0.49h/day \times 38.5kWh/day = 18.86kw$$

The required thermal energy in the building includes the energy for space heating, cooking and supplying hot water. The applied appliances are heater, stove and other gas-consuming ones with the efficiency of 75%. The highest amount of thermal energy consumption is dedicated to space heating during the cold seasons. The total consumed thermal energy of the studied building is 21,597 m^3/yr. Therefore, the total consumed thermal energy of the studied building is:

$$21,597m^3/yr \times 37,900kJ/m^3 \times 0.000278kWh/kj \times 0.57 = 170662.73kWh/yr$$

Maximum amount of natural gas consumption for the interest building is 3,714 m^3/month, thus, according to the above equation, the maximum amount of consumed thermal energy of the building is 29348.58 kWh/month. Also, minimum amount of natural gas consumption of the building is 58 m^3/month. Referring to the above equation, the minimum amount of consumed thermal energy of the building, is 458.32 kWh/month. As a result, the maximum thermal charge of the building will be:

$$29348.58kWh/month \times month/30day \times day/24h = 40.76kW$$

3. Results and Discussion

Feasibility of applying an integrated system including a grid-connected PV panels and a forced circulation solar water heater for supplying the required electricity and hot water of the studied building was investigated by using RETscreen software and considering the international prices of electricity (US$ 0.13) and natural gas (US$ 0.24) and selling price of renewable energies in Europe (US$ 0.57/kWh). Table 2 represents the required project investment costs and Table 3 shows the results of technical-economical and environmental feasibility of implementing the project and in Fig.3 the normal payback period has been presented.

Table 2: The Required Investment Costs

Integrated System			
Expenses of Investment for Solar Water Heater System	**Costs**	**(%)**	**Percentage of the Total Investment**
Installation (US$)	952	12.05	1.64
Plumbing (US$)	476	6.03	0.82
Transportation (US$)	114	1.44	0.20
Feasibility Study (US$)	95	1.20	0.16
Mechanical Design (US$)	190	2.41	0.33
Storage Tank (US$/L)	1,333	16.88	2.30
Pipe (US$/m)	572	7.24	0.99
Solar Collector Material (US$/$m^2$)	2,680	33.93	4.63
Building and Yard Construction (US$/$m^2$)	57	0.73	0.10
Circulating Pump (US$/W)	1,143	14.47	1.97
Collector Support Structure (US$/$m^2$)	286	3.62	0.5
Sum	US$ 7,898	100%	13.64%
Expenses of Investment for Photovoltaic System	**Costs**	**(%)**	**Percentage of the Total Investment**
Feasibility Study (US$)	95	0.19	0.16
PV System (US$/kW)	38,095	76.19	65.81
Inverter (US$)	11,430	22.86	19.74
Cable and Fuse (US$/km)	95	0.19	0.16
Base and Equipment (US$)	190	0.38	0.33
Transportation (US$)	95	0.19	0.16
Sum	US$ 50,000	100%	86.36%
Required Total Investment	**US$ 57,898**		

Table 3: Results of Technical-Economical and Environmental Feasibility of Implementing the Project

Features	**Amount**	**Features**	**Amount**
Number of Collectors	12	Annual Natural Gas Saving (m^3/yr)	4,777
Storage Capacity (L)	942	Solar Fraction (%)	53
Min and Max Water Temperature (°C)	12.2 & 21.8	Annual Solar Radiation-Horizontal (MWh/m^3)	1.91
Solar Collector Area (m^2)	21.36	Annual Solar Radiation-Vertical (MWh/m^3)	1.79
Electricity Pump (MWh)	0.1	GHG Emission Reduction (tCO_2/yr)	6.4
Temperature Coefficient (%/°C)	0.40	PV Array Area (m^2)	59
Number of Panels	44	Operating Solar Cell Temperature (°C)	45
Capacity Factor (%)	18.7	GHG Emission Reduction (tCO_2/yr)	8.2
Electricity Exported to Grid (MWh/yr)	16.416	Annual Solar Radiation-Horizontal and Vertical (MWh/m^3)	1.79 & 1.96
Normal Payback Period and Systems Expenses in Integrated Photovoltaic and Solar Water Heating Systems			
Earning Gained from Selling Electricity (US$)	9,357	Total Annual Costs (With Parts & Labor Costs) (US$)	848
Reduction of Consumed Natural Gas (US$)/($m^3$/yr)	1,146	Net Present Value (NPV) (US$)	35,243
GHG Emission Reduction (tCO_2/yr)	14.6	Normal Pay Back Period (NPBP) (yr)	4.94
Electricity Exported to Grid (MWh/yr)	16.416	Internal Rate of Return (IRR) (%)	26.14
Total Investment Costs (US$)	57,898	Reduction of External Costs (US$)/($tCO_2$/yr)	185

Fule Cost Escalation Rate, Inflation Rate 10%, Project life 25 yr, Dollar Exchange Rate to Rials is Considered 10,500 Rials.

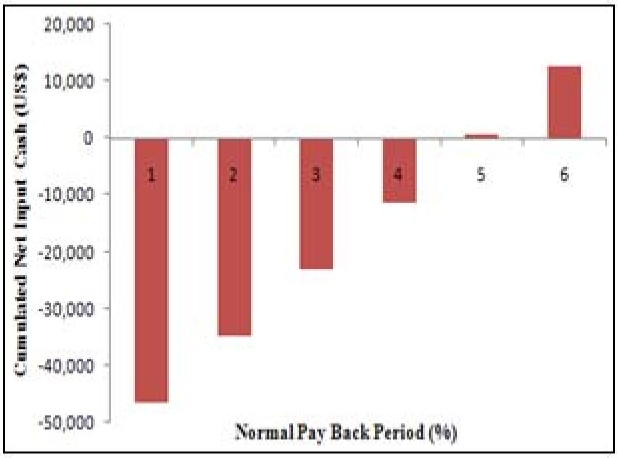

Fig. 3: Normal Payback Period

In the case of using integrated PV and solar water heating systems, the share of solar energy in supplying the required energy for water heating would be 53%. Considering the selling price of renewable energies in Europe, 16.416 MWh/yr electricity is produced per the installed PV panel (10kW). Considering the international prices for electricity and natural gas, annual natural gas saving is 4,777 m^3/yr, total investment costs is US$ 57,898, amounts of GHGs emission reduction (due to electricity consumption, natural gas saving and electricity supply required for the building) is 14.6 tCO_2/yr, amounts of external costs reduction, is US$ 185 tCO_2/yr and the normal payback period is 4.94 yr. Moreover, PV system sends 16.416 MWh/yr electricity to the national grid. Considering the discount rate of 15%, selling price of renewable energies in Europe and the international price of natural gas, the earnings and profits through installation and exploitation of the integrated systems is as presented in Table 4.

Table 4: Annual Profits and Earnings calculated by RETScreen software

Number	**Profits & Earnings**	**Costs**
1	Earning Gained Through Exporting Electricity to the National Grid (US$)/(kWh/yr)	9,357
2	Reduction of Consumed Natural Gas (US$)/($m^3$/yr)	1,146

3	Reduction in cost of Environmental Damages Attributed to GHGs (US$)/($tCO_2$/yr)	185
Sum		**US$ 10,688**

Normal payback period can be obtained by Equation 2. Where, NPBP is normal payback period (yr); A is annual natural gas saving (m^3/yr); C_0 is the initial investment (US$); and r is internal rate of return (%). Present net value is calculated using Equation 3. Where, NPV is present net value (US$); C_0 is initial investment (US$); TR_n is the income in n year; TC_n is the cost in n year; r is internal rate of return (%); and n is the year. Table 5 shows the internal rate of return.

$$NPBP = \frac{\log[A/(A - rC_0)]}{\log(1 + r)} \quad (2)$$

$$NPV = -C_0 + \frac{TR_n - TC_n}{(1 + r)^n} \quad (3)$$

Table 5: Internal Rate of Return for the Project

Discount Rate (%)	Net Present Value (US$)	Discount Rate (%)	Net Present Value (US$)
5	145,310	20	14,787
10	71,855	25	2,193
15	35,243	30	-6,193

4. Conclusions

In this paper technical, economical and environmental feasibility study of applying an integrated system

including grid-connected photovoltaic panels and a forced circulation solar water heater for supplying the required electricity and hot water for a residential building has been carried out by using RETScreen software. The share of solar water heater in water heating would be 53%. Considering selling price of renewable energies in Europe, 16.416 MWh/yr electricity will produced per installed PV panel (10kW). Moreover, the annual natural gas saving would be 4,777 m^3/yr, total investment costs would be US$ 57,898, amount of GHGs emission reduction would be 14.6 tCO_2/yr, amount of reduction in external costs would be US$ 185 tCO_2/yr and the normal payback period would be 4.94 yr. It will be cost-effective if the generated electricity is sending to the national electricity grid network at the selling price of renewable energies in Europe (US$ 0.57/kWh) and the international prices of electricity (US$ 0.13) and natural gas (US$ 0.24).

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6. References

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