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Solar Combi-Systems a New Solution for Space Heating in Buildings

[1]A. Ataei, [1]M. Kh. Assadi, [2]R. Parand, [1]N. Sharee, [3]M. Raoufinia and [1]A.H. Kani
[1]Department of Energy Engineering, Graduate School of the Environment and Energy,
Science and Research Branch of Islamic Azad University, Tehran, Iran
[2]Department of Energy Engineering, K.N. Toosi University of Technology, Tehran, Iran
[3]Department of Machine Building Technology,
National Technical University Ukraine, Kiev Polytechnic Institute, 03056 Kiev, Ukraine

Abstract: In the present study, the thermal load of a residential building is determined in two sample cities, Karadj and Hamedan. Then, the suitable solar combi-system and the underfloor heating system are designed for the units of the buildings. Furthermore, in response to the building energy demand and also by studying the expense-efficiency diagram, the efficiency of solar combi-system and the number of flat-plate solar collectors are determined. In continue, regarding the effect of the shade of the collector rows and the restriction of the roof space, a hybrid system is suggested. Finally, the annual energy saving in fuel consumption and reduction in social costs are studied and the payback period is determined.

Key words: Solar combi-systems, underfloor heating systems, energy saving, hybrid systems, solar collectors

INTRODUCTION

The solar systems which are used for providing consumptive hot water and a part of environmental heating energy are called solar combi-systems (Fig. 1) (Jäger, 1981; Lund, 2005; Bales and Persson, 2003). These systems are, in fact, derived from the combination of common heating systems with solar collectors. In these systems usually the highest thermal point is used for hot water output and the medium thermal point is used for heating the fluid in the underfloor heating system (Lund, 2005). For the enhancement of the system efficiency, there are twenty-one approaches proposed (Jäger, 1981). A thorough study shows that mostly increasing the number of heat exchangers, using two tanks and also using clarifying units and internal heat exchangers have had a lot of benefits for increasing the efficiency (Abrecht *et al*., 2005).

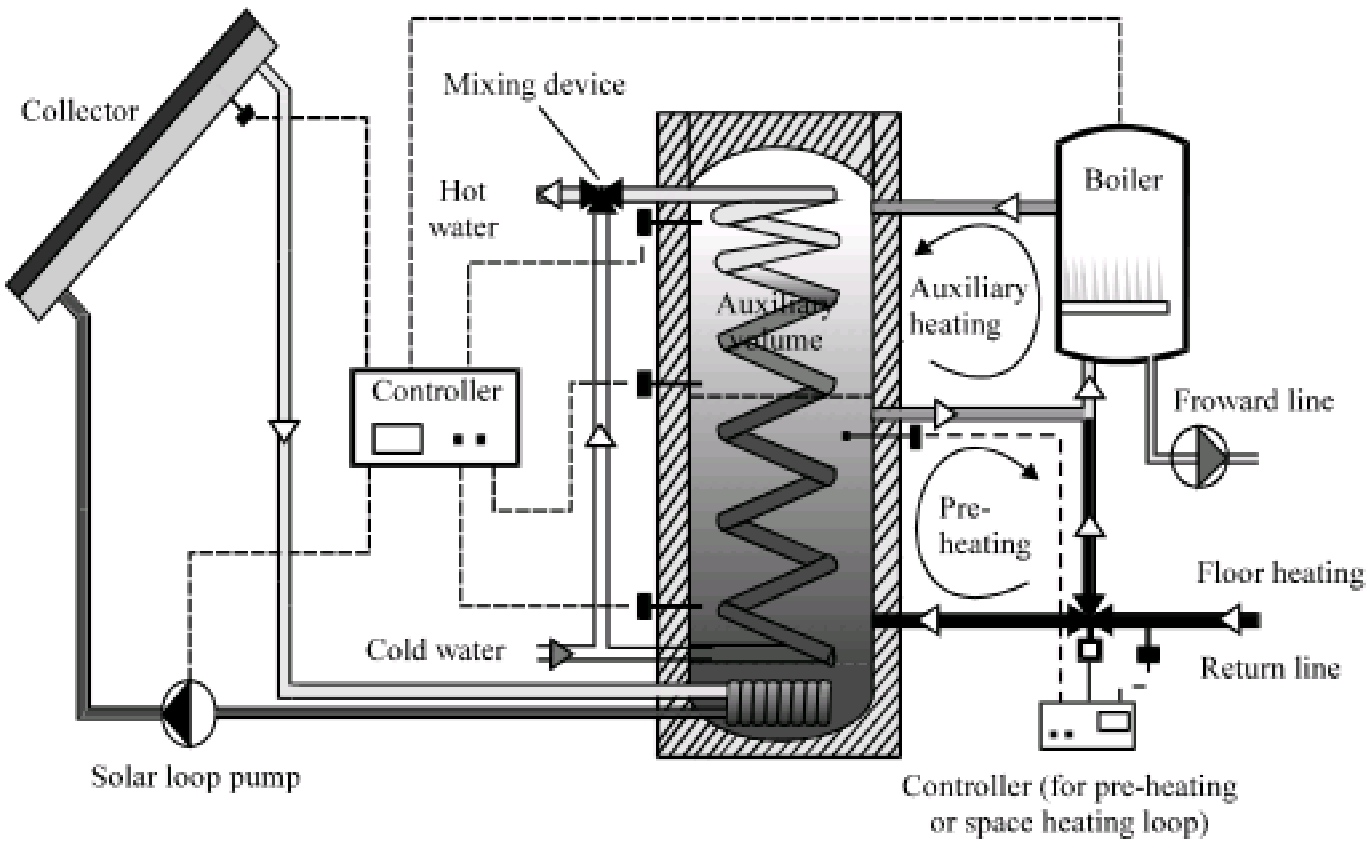

Fig. 1: A solar combi-system

Corresponding Author: Dr. Abtin Ataei, Department of Energy Engineering, Graduate School of the Environment and Energy, Science and Research Branch of Islamic Azad University, P.O. Box 14515-775, Tehran, Iran
Tel: 0098-912-5980104 Fax: 0098-21-44465383

Today with the development of the underfloor heating systems, solar combi-systems have been paid more attention due to the 30% reduction of energy consumption in the underfloor heating systems and the medium temperature level of the system provided by a flat-plate collector. According to the studies, radiation intensity on surface in our country is at least between 6-11.5 MJ m^{-2} (Roller and Goldman, 1967). Regarding the fact that residential sector takes up 40% of the national energy consumption and also the high level of the energy needed for hot water and heating which is 54% in Iran's residential units, the utilization of these systems can be noteworthy (Levermore, 2000; Keith, 2006). Using solar energy for heating was considered for a long time; with the development of the underfloor heating systems and the medium temperature level needed in the system, the efficiency of the solar combi-systems was paid more attention and different models were developed by Werner (2003), Pedersen (1993), Ucar and Inalli (2005) and Karacavus and Can (2009). Lund (1984) applied an optimization of a community solar heating system with a heat pump and seasonal storage. Lund and Östman (1985) investigated a numerical model for seasonal storage of solar heat in the ground by vertical pipes. Optimization of solar heating systems was discussed by Kulkarni *et al*. (2007). Ucar and Inalli (2007) proposed a model for a thermo-economical optimization of a domestic solar heating plant.

Some studies show that in spite of the low efficiency of the solar combi-systems, the payback time is acceptable due to the fairly high saving of fuel in cold climates (Lars and Gertzén, 2003; Duffie and Beckman, 2006; Lund, 2005; Bales and Persson, 2003).

Table 1: The result of installing hybrid systems

Country	Consumption rate	Solar energy share (%)	Payback time (year)
Sweden	High	30	2
Denmark	Medium	35	6
Germany	Low	60	15

It is predicted that in new future solar combi-systems comprise 40% of the collectors installed in Europe. Table 1 shows the result of installing such systems in three countries (Lund, 2005).

In this proposed plan, antifreezing solution enters collectors and absorbs the sun heat, then, enters the storage tank and pre-heats the input water by a heat exchanger. In the next phase, the returned water of the environmental heating circle (if the temperature is low) enters the tank and gains the required heat to some extent from the heat provided by the sun through a middle coil. Then it enters the supporting system (package) and exiting from that enters the storage tank with extra heat, the consumptive hot water is heated in the second phase, thus, the consumptive hot water required is gained from the highest thermal point, the water enters the environmental heating circle from the converter on top of the tank.

A suitable heating system for combining with solar system must be a system which not only decreases energy consumption but also provides comfort temperature at a lower thermal level. For this reason, the underfloor heating system is used (Parasons, 1997).

In underfloor heating systems with hot water circulation through the pipe grid, the heat is distributed slowly, smoothly and consistently; whereas, in traditional systems like radiators due to mal-distribution the local point is hot and the further environment is colder. It is noteworthy that the input water of the radiator is 75°C and in the underfloor system it is 40-50°C and the floor heat reaches a maximum of 29°C. The researches carried out have shown that, using the underfloor heating system not only provides more comfort in comparison to the radiator system but also decrease energy consumption by 30% due to lowering the temperature and transmitting heat by radiation (McQuiston *et al*., 2000; Drück *et al*., 2004; Frei and Sanger, 2002). Figure 2 shows Heat Distribution

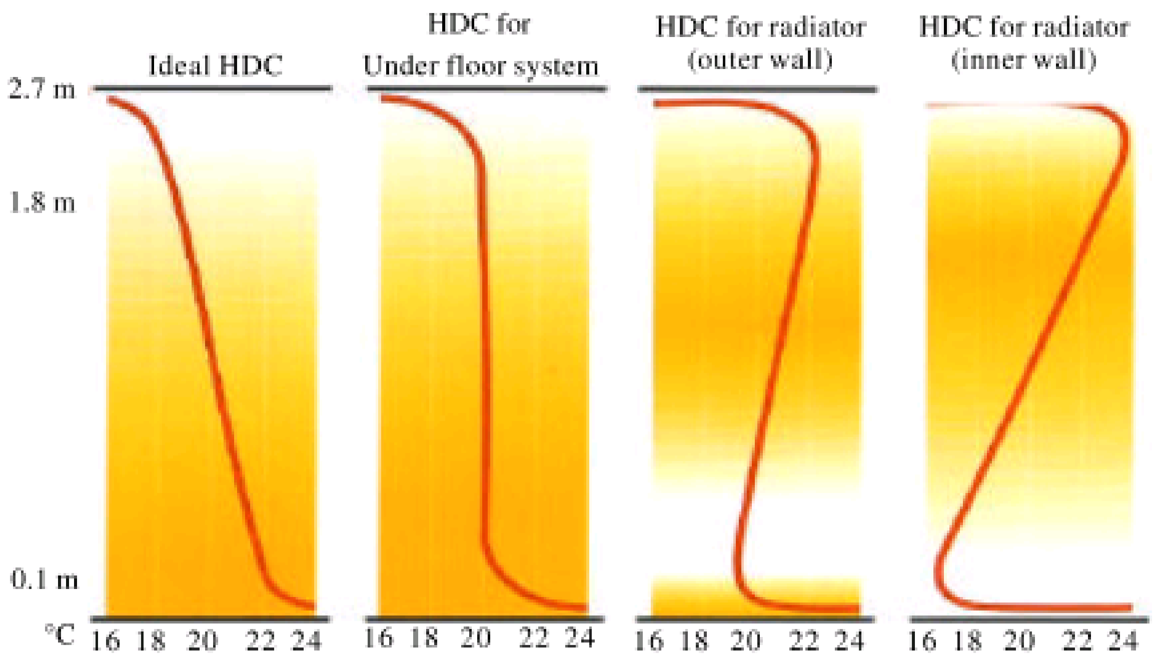

Fig. 2: Heat distribution curve for underfloor heating system and radiator

Curve (HDC) for underfloor system is more compatible with the ideal state than HDC for radiator.

In this study, solar combi-system is considered separately for any unit; therefore, its auxiliary heating system also must be separated. For this aim, a heating package is used.

According to the determined thermal load a 23-A package with a thermal capacity of 96296.4 kJ h^{-1} is used.

MATERIALS AND METHODS

For studying this plan, first, the map of sun radiation intensity in the country was examined. The cities were chosen which need high amount of thermal energy annually in addition to enjoying high radiation intensity. Thus, Hamedan in cold climates and Karadj in mild climates are chosen. The sample building in this study is a three storey building of six units totally with 90 square meter area per unit. A building plan is shown in Fig. 3.

According to the report of weather forecast bureau, the temperature 3.28°C and -12°C are chosen respectively for Karadj and Hamedan.

In the first situation according to the amendment 19 of National Building Regulation, building classification is determined according to different factors:

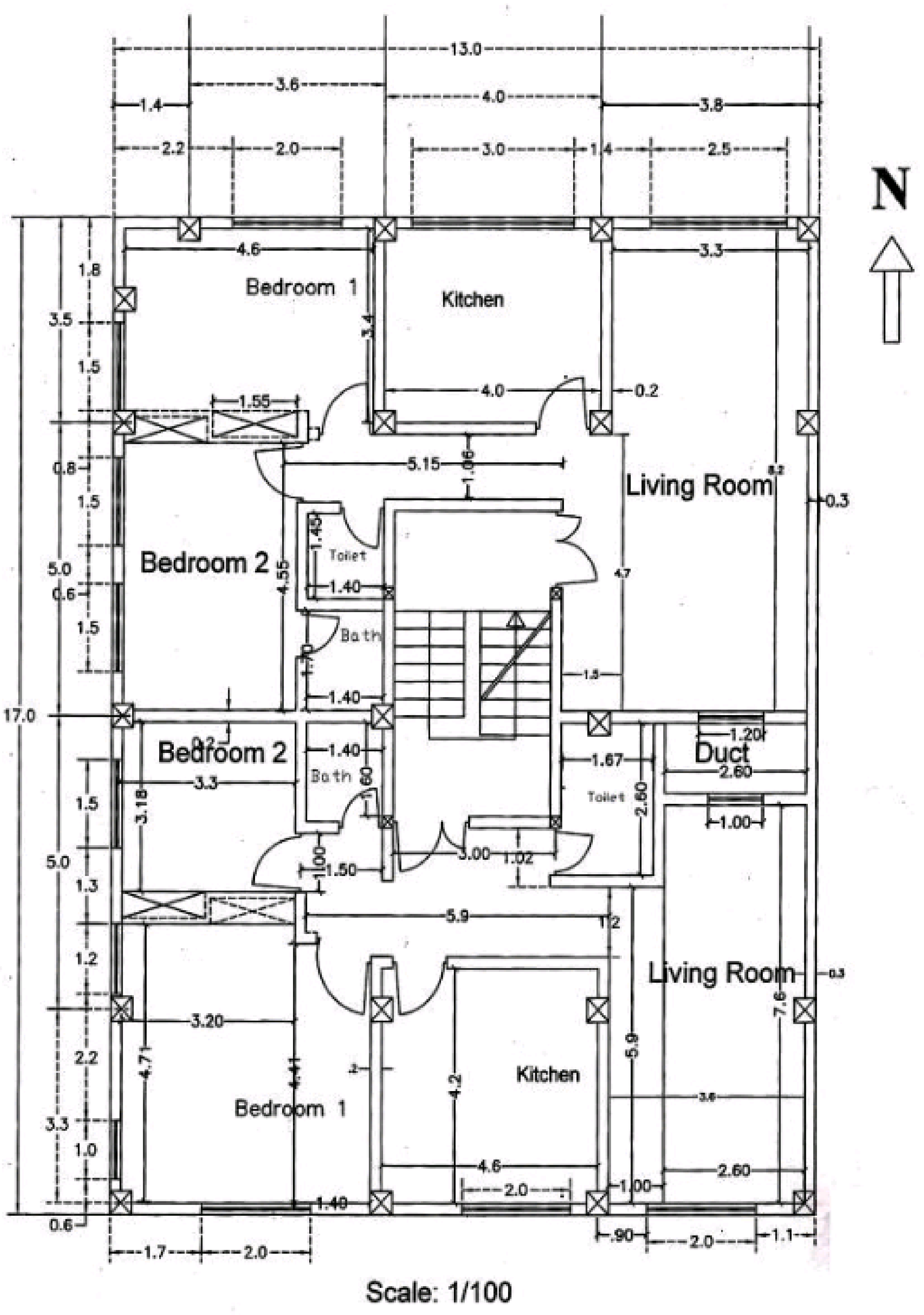

Fig. 3: Building plan

- The building is residential and categorized in group A according to building occupancy
- The annual thermal energy demand of Hamedan is estimated high and Karadj medium
- Hamedan is in the category of small towns and Karadj in the category of big cities
- The total area is less than one thousand square meter

According to the above factors, the sample buildings both fall into the category 2 (medium energy saving). Therefore, the conditions are the same.

Also the Prescriptive approach is chosen and the least thermal resistance of the walls, roof, floor and window types are determined according to the relevant table. Then the overall heat conductivity coefficient (Thermal transmittance), according to the construction materials, is calculated through following formula:

$$U = \frac{1}{\frac{1}{f_o} + R_1 + R_2 + ... + \frac{1}{f_i}} \quad (1)$$

Where:

R = Thermal resistance of the materials (h.Ft^2.°F/Btu)
1/f_o = External air film resistance (h.Ft^2.°F/Btu)
1/f_1 = Internal air film resistance (h.Ft^2.°F/Btu)

Then in order to calculate thermal loads for calculating coefficient heat conduction, first the required amounts from standard tables are extracted according to Table 2.

Thus with finding coefficients, the heat required for every unit is determined. Then the thermal load of the running hot water is calculated through the following method:

Assumptions: The temperature of the input water is considered 60 F and the output 140 F.

First, υ (the actual used hot water) is calculated considering the number of the residents, demand coefficient and the outmost hot water used for each individual.

Assuming each unit gives home to four people:

$$\upsilon = 4 \times 10 \times 0.6 = 24 \quad (GPH) \quad (2)$$

The volume of hot water tank:

Table 2: Heat conductivity coefficients for the amendment 19 (1) and usual materials (2)

Partition	U_1 (Btu/h.Ft^2.°F)	U_2 (Btu/h.Ft^2.°F)
Wall	0.126	0.30
Roof	0.058	0.18
Floor	0.097	0.26
Window	0.300	1.13

$$V = 24 \times 1.4 = 3.6 \quad (3)$$

Finally, the monthly energy needed is derived as followings:

$$Q(\text{monthly}) = V \times (60 - 15) \times n \times 1.1 \quad (4)$$

RESULTS AND DISCUSSION

Calculation of the annual heating energy needed: To calculate the annual heating energy, the number of heating degree-day should be determined; heating degree day is defined as the summation of the difference between a reference temperature and the average of the outside temperature during a long period of time and will be written as follows:

$$DD = \Sigma(T_b - T_a) \quad \text{Day-(°C)} \quad (5)$$

The amount of energy needed for a Degree-Day is determined as below:

$$\frac{Q}{DD} = UA \quad (\frac{Mj}{°C - Day}) \quad (6)$$

Degree-Day calculated in the previous step should be modified according to the calm temperature as bellow:

$$DD = [1 - K_d(65 - T_i + \frac{q}{UA})]DD_{65F} \quad (7)$$

$$K_d = 6.398 DD_{65F}^{-0.577} \quad (8)$$

Where:

$DD_{65\,F}$ = The annual Degree-Day based on 65 F as the reference temperature
Q = The internal energy sources of the building

Finally, the amount of monthly energy is determined as below:

$$\text{Energy(Btu)} = UA \times DD_{Mon} \times 24 \quad (9)$$

The average of the annual heating energy needed for Karadj and Hamedan has been shown in Table 3.

Table 3: The average of the annual heating energy needed for Karaj and Hamedan

City	Type of building	Annual heating energy (GJ)
Hamedan	Conventional	237.0
	Compatible to the nineteen chapter	120.0
Karadj	Conventional	94.5
	Compatible to the nineteen chapter	50.0

Solar combi-system design of building: Solar energy can be extracted from three sources:

The energy derived from the collectors: The angle between collectors and the horizon (β) is considered according to the latitude through the formula Ø+15 equaling 50 degree facing south.

In the next phase, the ratio of the radiation per hour on a flat surface of daily average (r_t) is determined through the following s:

$$r_t = \frac{I}{H} = \frac{\pi}{24}(a + b\text{Cos}\omega)\frac{\text{Cos}\omega - \text{Cos}\omega_s}{\text{Sin}\omega_s - (\frac{2\pi\omega_s}{360})\text{Cos}\omega_s} \quad (10)$$

$$\begin{bmatrix} a = 0.409 + 0.5016\text{Sin}(\omega_s - 60) \\ b = 0.6609 - 0.4767\text{Sin}(\omega_s - 60) \\ \left[\omega = (12 - M)\times 15, \omega_s = \omega \text{ of sun set}\right] \end{bmatrix} \quad (11)$$

With calculating (r_t), the ratio of the radiation per hour (I) is determined.

In the next phase, the ratios of dispersed and direct radiation are determined and the proportion between the direct and dispersed radiation on the pitched and horizontal surfaces (R_b, R_d) is determined through the formula 12, regarding the fact that in south facing collectors (γ) equals zero (γ = 0).

$$R_b = \frac{\text{Cos}(\phi - \beta)\text{Cos}\delta\ \text{Cos}\omega + \text{Sin}(\phi - \beta)\text{Sin}\delta}{\text{Cos}\ \delta\ \text{Cos}\ \phi\ \text{Cos}\ \omega + \text{Sin}\ \delta\ \text{Sin}\ \phi} \quad (12)$$

Where:

φ = Latitude

δ = Solar deviation angle the angular position of the sun at high noon with the equatorial plate

Finally, R (the proportion of radiation intensity per hour on the pitched surface with that on the flat surface) is determined through Eq. 13.

$$R = \frac{I_T}{I} = \frac{I_b}{I}\times R_b + \frac{I_d}{I}\times(\frac{1 + \text{Cos}\beta}{2}) + \rho(\frac{1 - \text{Cos}\beta}{2}) \quad (13)$$

Where:

ρ = Coefficient of the earth dispersed reflection

Figure 4 shows the annual energy derived from one square meter of collectors in Karadj.

Energy derived from south facing windows: In south facing windows also the same rule are applied. With only this difference that β = 90 and the ratio of light transition in one layer windows and two layer windows are, respectively 0.85 and 0.75.

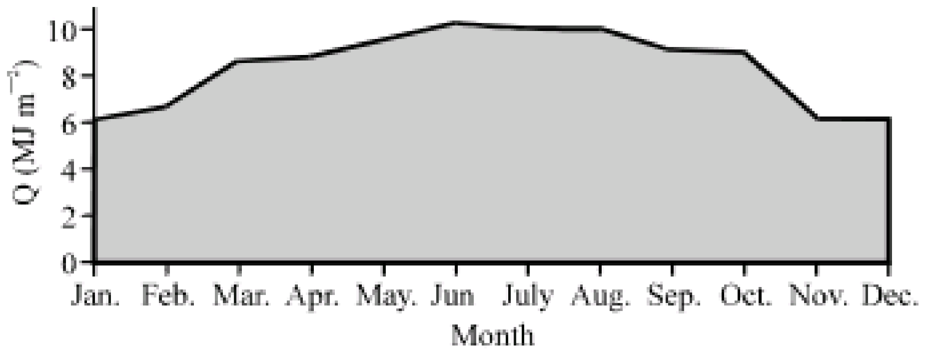

Fig. 4: Annual energy derived from one square meter of collectors in Karadj

Energy derived from west ward windows: In west ward windows the same rule is applied. With only this difference that γ = β = 90 and the ratio of light transition differs according to the radiation angle and the kind of window (one layer or two layers).

Determining the system dimensions: For providing the determined total thermal load from the solar energy considering the determined thermal load in the first phase and comparing the most thermal load (in January) with heating energy from the collectors and windows, the surface area for the collector required for providing the heating energy is determined.

$$A_c = \frac{((Q_{th} + Q_{DHW}) - Q_{win})}{q_C \times 31} \quad (14)$$

Where:

A_C = The required collector surface area

Q_{th} = The required energy for heating the environment

Q_{DHW} = The required energy for providing hot water

Q_{win} = Heat provided by the window

q_c = Heat provided by one square meter of collector

Optimized collector surface depends on elements like radiation, intensity, consumption rate and the increase in cost. The optimum situation is the point that two curves of Surface area-The extra capital and Surface area-Solar energy part coincide.

According to the calculated thermal load and the solar energy, Solar Conservation Factor (SCF), in any situation equals:

$$SCF = \frac{E_{co} + E_{win}}{Q_H + Q_{DHW}} \quad (15)$$

Where:

E_{co} = The energy derived from collector
E_{win} = The energy derived from the window
Q_H = Required heating energy for heating the environment
Q_{DHW} = Required heat energy for hot water consumption

Thus, the curve of surface area-solar conservation factor is determined. The cost of extra investment for the solar Combi-system in any situation is determined considering the discrepancy between the cost of the hybrid system and fossil system; consequently, the required curves and the optimum surface for collectors are determined in any situation as shown in Fig. 5.

For instance, in a building with common material a surface area of 38 (m^2) and 19 (m^2) in Karadj is determined (Fig. 5) optimum, but regarding the roof space and the question of the collector rows shading on one another, the necessity of observing distance between collector rows takes issue which is examined this way:

$$X = L \times \text{Sin}\beta \ \text{tg}(\varphi + 30) \tag{16}$$

Where:
X = The distance between collector rows
L = Collector panel length (2.15 m)
φ = The location latitude

Thus, with installing collectors on the surface of the roof, a surface area of about 10 m^2 of collectors is determined for any unit of the building. The volume of the storage tank considering the total amount of consumptive hot water and the required relative volume for heating water in the underfloor heating system is determined 300 lit.

Eventually, the part of solar system in any situation is determined. Figure 6 shows the share of solar energy in two buildings (one the normal building and the other amendment 19 of National Building Regulations) in Hamedan.

Economic analysis of the plan: A correct analysis of the economic justification for the derived energy from the solar systems can be made when the real international prices-not the subsidized prices of energy carriers are considered and also the environmental costs due to fossil fuels are taken into consideration.

Here, the payback time is determined through the Net Present Value (NPV).

$$NPV = I \times f(i,d,n) - C_0 - C_{OP}\frac{(1+d)^n - 1}{d(1+d)^n} \tag{17}$$

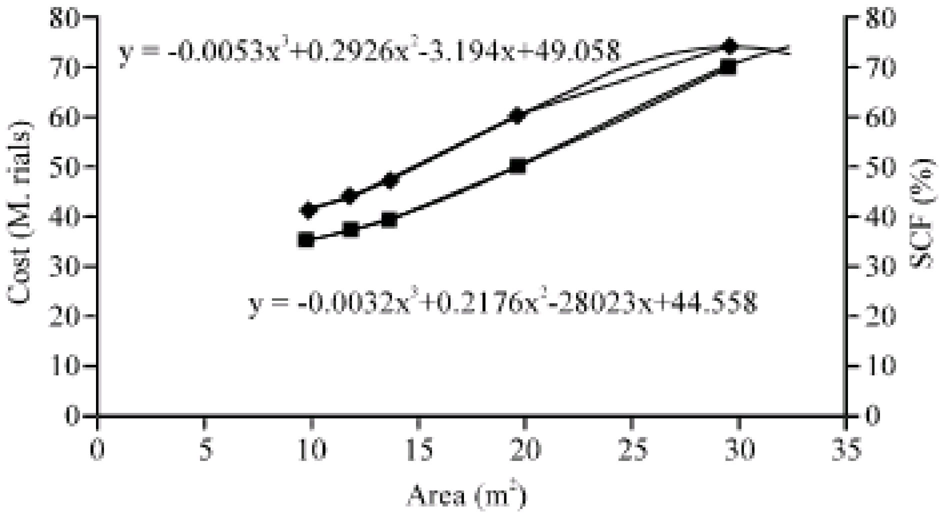

Fig. 5: Estimation of optimum surface area for the building in Karadj

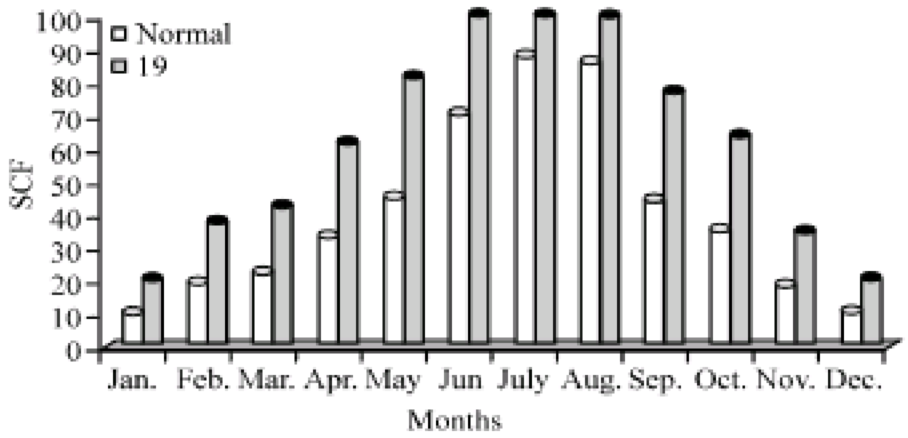

Fig. 6: Share of solar energy in two different kind of buildings in Hamedan

$$f(i,d,n) = \frac{P}{I} = \frac{i}{i-d}\left[\left(\frac{i+1}{d+1}\right)^n - 1\right] \tag{18}$$

$$P = I \times f(i,d,n) \tag{19}$$

Where:
P = Value of the total amount of the saved fuel
i = Inflation rate
d = Discount rate
C_0 = Extra investment for optimization
C_{OP} = Maintenance cost

For determining the payback time it is enough to solve NPV=0 for n which is done through trial and error.

Producing heat is accompanied by social costs which are mostly imposed on others who don't play any role in the production.

These costs are formed when the economic activities of one or some groups produce side effects of environmental damage (pollutants) and eco-system destruction. According to the National Energy Balance Sheet of 2006, the social cost of a ton of CO_2 equals 160000 Rials. The amount of CO_2 spread is made up of the fuel reaction of Oxygen.

Thus, the economic analysis of the solar system through the Net Present Value is made from two perspectives:

Table 4: Payback time estimation in Hamedan according to the first perspective

	Hamedan city			
Building type	Usual		Amendment 19	
Fuel	Natural gas	Gas oil	Natural gas	Gas oil
Payback time (year)	86	31	95	39

Table 5: Payback time estimation in Karadj according to the first perspective

	Karadj city			
Building type	Usual		Amendment 19	
Fuel	Natural gas	Gas oil	Natural gas	Gas oil
Payback time (year)	116	63.4	121	73.4

Table 6: Payback time estimation in Hamedan according to the second perspective

	Hamedan city			
Building type	Usual		Amendment 19	
Fuel	Natural gas	Gas oil	Natural gas	Gas oil
Payback period (year)	5.4	1.1	6.5	1.8

Table 7: Payback time estimation in Karadj according to the second perspective

	Karadj city			
Building type	Usual		Amendment 19	
Fuel	Natural gas	Gas oil	Natural gas	Gas oil
Payback time (year)	12.8	3.9	14.5	5.2

- The prices of the energy carriers are subsidized and the environmental costs are not considered
- The prices of the energy carriers are international and the environmental costs are considered

The results are shown in Table 4-7. It is obvious that with the subsidized fuel price the payback time is lengthy but if we consider the issue internationally and the fuel price -including natural gas and gas oil- considered equal to the export price the payback time reaches less than two years and is economically justifiable.

CONCLUSION

Solar Combi-system for a sample building in two cities Karadj (mild) and Hamedan (cold) according to national construction existing technology was chosen.

With studying the amount of the energy consumption decrease, it was determined that when the consumption is higher e.g., cold climates and the building is of common material and uses gas oil fuel, using solar Combi-system saves a lot of fuel and as it was mentioned this issue takes precedence when the international price of fuel (the export price) is considered with the comparison of the underfloor heating system with solar system and underfloor heating system with fossil fuel; in Hamedan there is 31 million Rials saving and in Karadj there is 5 million Rials saving annually. Another thing to mention is the environmental cost due to the pollutants. Using this system decreases fuel consumption, on social cost which makes the payback time less and provides comfort and environmental health. Taking into consideration the factors studied, the payback time for cold climates like Hamedan is 2 years and for mild climates like Karadj is 5 years.

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