Aspects regarding using solar energy in heating systems and sanitary hot water

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Abstract: - Selection and sizing of heating and sanitary hot water solar system for a building always involves determining the optimal rate of heat provided by solar energy conversion. As this rate is higher, a greater amount of fossil fuels is saved and the pollutant emission and greenhouse gases emission decreases. But this may involve, during the summer, the producing of a quantity of heat, greater than heat demand of the building, resulting an excess of heat that involves additional energy management costs with negative impact on the annual energy efficiency of solar thermal system. In the final part of this article, it was presented a case study on the use of an solar system for indirect preparation of sanitary hot water and for supporting the space heating for a building for tourism.

Key-Words: heating systems, solar energy, solar collectors, participation level, energy efficiency, CO_2 emissions.

1 Introduction

From the perspective of current environmental policies and strategies, reducing non-renewable energy consumption and eliminating energy waste are among the main objectives of the contemporary world. Since heating systems are an important component among the energy consumers, (in the Eastern European countries they are the largest energy consumers), using solar energy for heating represents a clean alternative: low level of pollution, available, renewable and underused.

The radiant energy of sunlight is captured and converted into thermal energy through thermal solar collectors respectively through the heat exchangers integrated in the solar collectors. An active solar thermal system for indirect domestic hot water preparation and for supporting the space heating involves: the solar collectors, the thermal storage tank with integrated heat exchanger in the tank or external, the circulation pumps of the solar thermal agent (in the case of forced circulation) and the automation system for controlling, regulating and limiting the related parameters (temperature and pressure). The main element of the thermal solar system is the solar collector, (collector with a liquid heat transfer fluid), which can be plane or with vacuum tubes. For areas with lower solar radiation and for the solar applications of the space heating, it is recommended the use of the collector with vacuum tubes due to its advantage of capture an additional allowance of solar energy related to the diffuse radiation.

2 Working method

2.1 Mathematical modeling

One of the main indicators of energy performance of the heating system of the building is the participation quota of the non-conventional energy sources. Coverage of the heat demand through the solar energy can be expressed by:

- Participation level at the peak consumption, of the solar energy, (α_s^v):

$$\alpha_s^v = 100 \times Q_s^v / Q_î^v \quad [\%] \qquad (1)$$

where:

$Q_î^v$ is the thermal energy demand for heating (hourly heat demand at the consumption peak), in kW;

Q_s^v - thermal power supplied by solar energy at the consumption peak, in kW.

- Annual participation level of the solar energy, (α_s^{an}):

$$\alpha_s^{an} = 100 \times Q_s^{an} / Q_î^{an} \quad [\%] \qquad (2)$$

where:

$Q_î^{an}$ is the thermal energy demand for heating, in kW/an;
Q_s^{an} - annual supplied solar energy, in kW/an [5].

Since solar energy, although in unlimited quantity, has a variable feature, (it presents important daily and seasonal variations) and the possibilities of storing thermal energy thus obtained for the use in the heating systems are technologically limited, usual areas of operation of the solar systems, in bivalent mode, (in which, to cover the heat demand peak, alternative heating sources are provided), are:

- solar thermal system for sanitary hot water with low participation level (usually around 35 %);
- solar thermal system for sanitary hot water with high participation level (usually around 60 %);
- solar thermal system for sanitary hot water and for supporting the space heating [8], [9].

The first case is encountered in practice in situations where sanitary hot water consumption presents a highly variable nature and possibilities of accumulation of sanitary hot water are limited. The second case, most commonly encountered in practice, presume a relatively constant sanitary hot water consumption and the possibility of accumulating the sanitary hot water. The third case, system solar for both sanitary hot water and space heating support is a challenge in terms of dimensioning solar thermal system so that the oversizing to be avoided and the efficiency of the solar thermal system to be high.

2.2 The optimal value of participation level of the thermal energy provided through the converting solar energy for bivalent operation of the solar thermal systems

The selection and sizing of a solar system for such applications always involves determining the optimal rate of heat provided through solar energy conversion. The higher the participation level is, the more it saves a large amount of fossil fuel and consequently the pollutant emissions and the greenhouse gases emissions are decreasing. But this fact may involve an excessive heat production in the summer, an excess that requires additional energy costs. Consequently, annual operating thermal yield decreases along with the decreasing annual energy efficiency of the solar collectors:

- annual thermal yield of solar collector η_a [%] is defined as the percentage of the solar radiation that reach the collector surface annually transformed into heat output. The optical yield of the collector η_o [%] take into account additional losses by reflection and absorption of the primary solar radiation;
- annual energy efficiency of the solar collector [kWh/m^2 · an] is defined as a ratio between the annual amount of useful heat supplied and useful area collecting.

The solar thermal systems are mainly dimensioned, based on:

- the heat demand for sanitary hot water;
- the heat demand for space heating;
- the possibility of managing the excess heat during the periods with low heat demand.

In many cases, the heat demand for sanitary hot water is relatively constant throughout the year while the heat demand for space heating is greatest during the cold season when available solar energy is low. Sizing the system solely on base of heat demand for space heating can lead to a problematic oversizing of the solar thermal system.

It follows that the minimum level of annual participation of solar energy is given by the annual heat demand for sanitary hot water (in this case 50 - 60 %). Optimal annual participation level of solar energy (in relation to the total heat demand) represent the level calculated on base of sanitary hot water demand and percentage of the annual space heating demand with ensuring the possibility to take over the heat excess during the periods with low heat demand (during the warm season of the year).

There are a number of other factors that affect the sizing of the solar thermal collectors surface:

- limiting factors (for example the type and the size of available space for mounting the solar collectors, cost factors, et.);
- compensating factors (for example azimuthal orientations unfavorable, unfavorable mounting angles of inclination et.).

The compensating factors lead to increasing the useful surface of the field of solar collectors. It is obvious that the azimuthal orientations unfavourable and unfavorable mounting angles lead to the decrease of seasonal efficiency at the solar collectors. In the case of the annual energy efficiency, this fact depends on the share of heating energy and share of sanitary hot water preparation in total energy consumption. As a general rule, if it is not imposed by construction factors, (for example by the slope of the roof where the collectors are mounted), it is chosen the favorable angle of inclination for the warm season when the available solar energy is maximum.

ISBN: 978-960-474-352-0

3 Case study

3.1 Description of proposed solar thermal system

Next, we will refer to a solar thermal system for indirect preparation of the sanitary hot water and supporting of the space heating for a building for tourism (accommodation and leisure base).

The building has the following characteristics according to the rules in force in Romania:

- it is located in the climatic zone III, conventional exterior calculation temperature for winter is -18 ^oC according to SR 1907-1/1997, [6];
- it is located in the eolian zone IV, the conventional calculation speed of the wind is 4 m/s according to SR 1907-1/1997, [6];
- it is located in the insolation zone I according to the National Institute of Meteorology and Hydrology (INMH), the average annual solar radiation is 1150-1250 kWh/m^2 · year, [2], [7], [10];
- average annual duration of insolation is 2100-2200 h/year according to the INMH;
- the building has basement, ground floor and 5 floors and the total built volume is 37.190 m^3;
- class of importance is C (normal);
- category of importance is II.

Analyzed building is equipped with: indoor swimming pool with useful volume of the pool 330 m^3 and outdoor swimming pool with 520 m^3 useful volume. The boilers' room is equipped with boilers that operates with natural gases. In order to increase energy performance for heating system and to obtain conventional fuel economies, it was provided in addition, solar system with solar thermal collectors. Since it is about supporting the space heating in the cold season, solar collectors with vacuum tubes and forced circulation of solar thermal agent, (mix antifreeze/water - for operation at low temperatures -18…-30 ^oC), with optical yield η_o = 83,8 %, were mounted. These thermal collectors have the advantage of capture an additional energy share for diffuse radiation and they have the constructive capacity to reduce thermal losses by increasing thermal insulation. The installation of the solar collectors was made on the roof structure of the building. The slope of the solar field is given by the slope of the roof, 25 ^{o}.

The building has the following characteristics:

1. the annual heat demand for sanitary hot water is 131 MWh;
2. the annual heat demand for space heating is 959 MWh;
3. the annual heat demand for heating the water from indoor swimming pool is 34 MWh.

Hourly heat demand at the consumption peak during the cold season is 600 kW (it was taken into account the simultaneity in operation of the heat consumers). Hourly heat demand at the consumption peak during the warm season is 185 kW (it was taken into account the simultaneity in operation of the heat consumers).

The mode operation of the indoor pool is all year round at constant temperature (with superior limitation of the water temperature in the pool). The mode operation of the outdoor pool is during the months from May to September also with superior limitation of the water temperature in the pool.

Annual insolation %
Angle of inclination

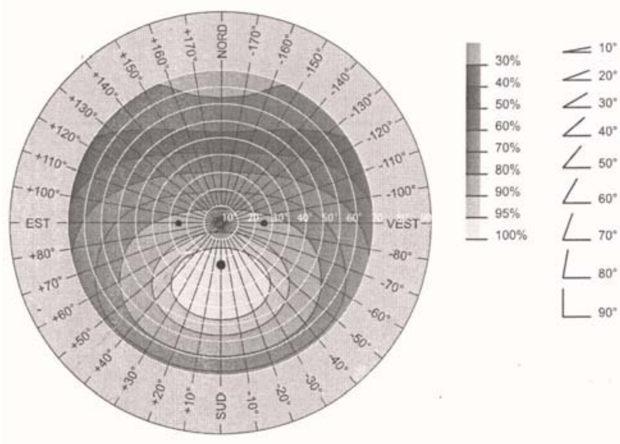

Fig. 1 - The impact of the direction and inclination of the solar collectors over the amount of captured solar energy, Perez Model, [1,3,4]

In case of southern orientation and angle of 25 ^{o}, solar collectors still capture 95 % of the optimum solar energy (according to fig. no. 1). The unfavorable angle of inclination of the solar collectors is compensated by proportionally increasing the solar collectors surface with 5 %. In case, the solar collectors would be mounted on the roof with east-west orientation, they capture 85-90 % of the optimum solar energy. In this case, the useful surface increases with 10-15 % if there is no possibility to independently rotating every tube collector to compensate the azimuthal disadvantage.

For sanitary hot water preparation are provided bivalent hot water storage tanks with lower coils (integrated heat exchangers in the storage tank) to connect to the thermal solar system.

For overtaking the heat demand for heating are provided heating water buffer tanks with lower coils (integrated heat exchangers in the storage tank) to connect to the thermal solar system.

The integration mode of the solar thermal system in the classic heating system has been made according to the drawings of fig. no. 2 and fig. no. 3:

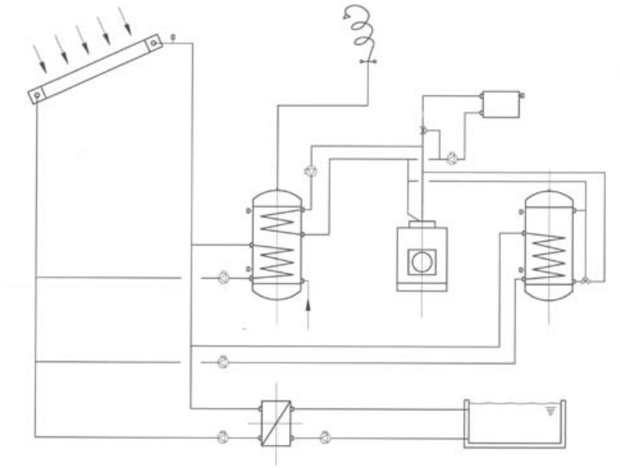

Fig. 2 - Solar system for sanitary hot water and for supporting the space heating

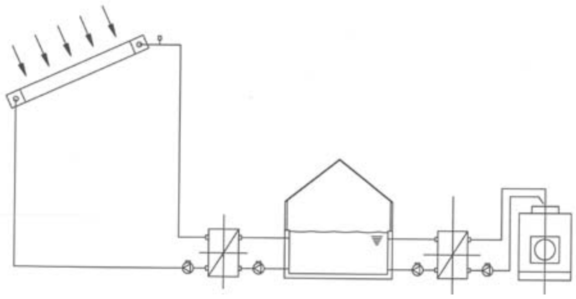

Fig. 3 - Solar system for heating the water of the indoor swimming pool

3.2 Results and discussion

For the situation analysed, the optimal constructive and functional data lead to the results from table no. 1:

Table 1 - Operating indicators

<table>
<tr><td>No.</td><td>Operating regime of solar system</td><td colspan="2">α_s^{an}</td><td>Annual saving of fuel gas</td><td>CO_2 emissions avoided</td><td>Annual energy efficiency</td></tr>
<tr><td>0</td><td>-</td><td colspan="2">%</td><td>m^3/an</td><td>kg/an</td><td>kWh/m^2 · year</td></tr>
<tr><td>1</td><td>Sanitary hot water preparation</td><td colspan="2">55,7</td><td>8.550</td><td>18.107</td><td>840</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">Sanitary hot water preparation and supporting of the space heating</td><td>DHW</td><td>60,3</td><td rowspan="3">18.440</td><td rowspan="3">39.000</td><td rowspan="3">845</td></tr>
<tr><td>heating</td><td>0,85</td></tr>
<tr><td>global</td><td>8</td></tr>
<tr><td>3</td><td>Heating the water of the indoor pool</td><td colspan="2">64</td><td>2.550</td><td>5.400</td><td>904</td></tr>
<tr><td>4</td><td>Total</td><td colspan="2">9,7</td><td>20.990</td><td>44.400</td><td>-</td></tr>
</table>

The highest energy efficiency of the solar collectors is obtained in the case of combined heat production for sanitary hot water and supporting the heating (table no. 1 and table no. 2).

Energy efficiency is negatively influenced by the variability of heat consumption. The indicator presents increases when profile of the heat demand is relatively constant in time.

Following the increase of annual coverage levels over the values in table no. 1, considerable savings by fuels and CO_2 emissions decreased were obtained, but the annual efficiency of the solar collectors has decreased (table no. 2).

ISBN: 978-960-474-352-0

Table 2 - Operating indicators

No.	Operating regime of solar system	α_s^{an}		Annual saving of fuel gas	CO_2 emissions avoided	Annual energy efficiency
0	-	%		m^3/an	kg/an	$kWh/m^2 \cdot year$
2	Sanitary hot water preparation and supporting of the space heating	DHW	65	24.721	52.276	812
		heating	2			
		global	9,6			
3	Heating the water of the indoor pool	64		2.550	5.400	904
4	Total	11,2		27.271	57.676	-

4 Conclusion

Following the centralisation and analysing the results, the following conclusions can be drawn:

- The annual participation level of the solar energy for the preparation of sanitary hot water and for the support of the space heating in bivalent heating systems is closely linked to the annual energy efficiency of the solar collectors. Not always, the increase of the the participation level leads to the increase of the collector energy efficiency. Contrary, the overcoming of the optimal level of participation, leads to the decrease of the efficiency of the solar collectors field, because of the long stagnation periods of the system and leads to the additional energy costs for managing the excess heat produced during the warm season, with overcoming the critical temperatures at the solar collectors and also with the premature wear of the heating system;
- The heat demand for sanitary hot water is relatively constant throughout the year while the heat demand for heating is highest in the cold season when available solar energy is low. Sizing the system solely on base of heat demand for space heating, although it leads to important fuel savings, it can also lead to a problematic oversizing of the solar thermal system. The bivalent system for sanitary hot water preparation and for supporting of the space heating is effective just if there is a consumer which takes over the excess of the heat produced in the summer (in this case the outdoor swimming pool);
- The optimal level of participation of the solar energy for coverage the relatively constant heat consumptions throughout the year, (the heat for sanitary hot water, the heat for heating the water in the indoor pool), is between 60 % and 64 %, in this study-case;
- The optimal overall level of participation of the solar energy (relative to the annual heat demand) is the calculated level based on the heat demand for sanitary hot water and on the heat demand for space heating with the ensure of the possibility of manage with minimal costs the excess of the heat produced during periods with low heat consumption (in this study-case 8 %).

The solution analysed in this article is applicable in the cases where it is desired the preparation of the sanitary hot water and supporting of the space heating in the cold season with solar energy input and there is the possibility to take over the excess of the heat generated in the warm season.

Finally, we can say that the analyzed data are sufficient for supporting, at the global level, the percentages highlighted in this article but also should be considered the fact that they may vary in each case studied.

Following the integration of the solar collectors in the classic thermal systems, significant savings of fossil fuels are achieved and therefore, significant reductions in emissions of greenhouse gases are achieved.

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ISBN: 978-960-474-352-0