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LARGE SCALE IMPLEMENTATION OF ACTIVE SOLAR SYSTEMS INTEGRATED IN PASSIVE BUILDINGS. POSSIBLE METHOD TO ACHIEVE THE TARGETS OF THE ROMANIAN ENERGY STRATEGY

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In this paper we propose a method which may diminish the cost of domestic hot water preparation. Romanian data is used for illustration. The method is based on the usage of active solar systems integrated in passive buildings. The method may be seen as a solution to the government's target of achieving by the year 2020 a level of 60 PJ for the thermal energy resulting from solar energy conversion.

Keywords: active solar energy system, passive building, annual energy cost, system efficiency

1. Introduction

AMVIC Ltd is the first Romanian producer for insulated concrete forms for low-energy and passive buildings. The AMVIC office building was built based on the rules of passive building design - German standard [1], developed by Passivhaus Institut in Darmstadt. Location is in Bragadiru, a city 10 km far from downtown Bucharest and it has 2086 square meters usable area [2, 3, 4]. In Reference 2, the thermal behavior of the AMVIC building is simulated by using the software Passive House Planning Package (PHPP). The results show that the building meets the criteria of a passive construction. The building has integrated many systems that are using energy from renewable sources, such as it is the active solar energy system.

In this paper we propose a strategy which may significantly diminish the cost of domestic hot water preparation in Romania. The main idea is the large scale implementation of active solar energy systems. Illustration is performed by using data related to the active solar energy system belonging to the passive building AMVIC. In Section 2 we briefly describe the active solar energy system of the AMVIC building. The solution proposed here is developed in Section 3. Section 4 contains the conclusions.

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2. Active solar energy system of AMVIC building

The AMVIC building is a mixed passive-active solar energy system. Part of the system, i.e. building's envelope, is passive since thermal energy is transferred as such from the sun through the windows system. The other part of the system is active, since moving the thermal fluid inside the collectors system and storage tanks requires pumps powered by electrical energy. The integrated active solar energy system of the AMVIC building is used to prepare hot water intended for consumption at the habitants located at the residential 5th floor and also for the offices areas, when necessary The technical room of the solar installation is located on the 5th floor. Its size is 7.1 m (length) by 1.56 m (width). The main components of the active solar energy system are: the solar vacuum collectors, the circulation pumps and two storage insulated tan

Next we present some details about the main components of the active solar system.

Fig 1: The AMVIC passive building: SC - solar vacuum collectors

In Fig. 1 can be observed the main facade of the building AMVIC with the solar vacuum collector placed above the roof.

2.1. Solar vacuum collectors

The system includes 10 flat-plate vacuum collectors, with flanged connections. A solar collector consists of a compact pressed metal casing, to which a safety solar glass is attached by a frame of noncorrosive aluminum profiles. The absorber, made of a specially shaped Al – Mg metal sheet with high-selective conversion layer, spans the copper pipe meander [5, 6, 7]. Figure 1 shows the solar vacuum collectors placed on the roof of the passive building AMVIC.

2.2. Storage tanks

The solar installation integrates two hot water storage tanks (one of 500 L and another one of 300 L, represented in fig. 2). The storage tanks are useful in case the solar installation cannot produce hot water at the required temperature level. This may happen when the level of incident solar radiation is low, for instance in case of more than 3 consecutive days of cloudy sky, or in case of raining or snowing for more than 3 consecutive days.

The tanks are insulated with aluminum coated polyurethane hard foam [6, 7, 8]. Both tanks are provided with double coils. The double coils for each tank are connected to enlarge transfer surface.

Fig.2 Picture representing the storage tanks

The storage tank of 500 L is provided with an electrical resistance of 2 kW. The storage tank of 300 L was missing in the initial scheme of the active solar system. It has been added later, to store the large amount of hot water supplied during summer, when it is operated manually.

2.3. Circulation Pumps

The active solar energy system has as components two circulation pumps, one placed on the primary circuit (solar vacuum collectors - double coils of the two storage tanks) and the other placed on the secondary circuit (storage tanks – users). Both pumps were bought from the company Grundfos [6, 7, 9]. These pumps are provided with a speed regulator with three levels. This allows to setting up the flow rate.

Fig 3: General view of the circulation pump (CP1) placed on the circuit solar vacuum collectors - double coils of the two storage tanks

Fig. 3 shows a general view of the circulation pump placed on the solar vacuum collector circuit - double coils of the two storage tanks.

3. Strategy and method

The Romanian Energy Strategy for the years 2007-2020 has been developed by the Romanian Government [10]. It proposed by the year 2020 a target of 60 PJ for the thermal energy resulting from solar energy conversion. Here we propose a strategy for achieving this target. It is based on the large scale implementation of active solar systems. We illustrate the method for the case of the active solar system belonging to the passive office building AMVIC. Note that this system was designed with the aim to provide heat for the flats at the four floor of the AMVIC building. Therefore, the solar collectors system of the AMVIC building can be implemented, with appropriate sizing, within residential buildings, too. The ideal assumption adopted here is that this system is implemented in the residential buildings, at national level. Also, the whole population of Romania is considered when the heating demand is evaluated. .

The method starts by evaluating how many solar installations would be required in each county of Romania to provide sufficient hot water for consumption. During calculations we take into account the population number in the county n_p [15]. Figure 4 shows the number of inhabitants in each county. This number is ranging between 200,000 and 900,000. Of course, in counties with more people the hot water consumption will be higher compared to counties where the population is lower.

Also, we assume that the active solar system was designed to provide sufficient hot water for 10 persons [11]. Then:

$$Ni = \frac{n_p}{10} \tag{1}$$

where N_i represents the number of installations necessary in each county to provide sufficient hot water for consumption. Figure 5 shows the number N_i for all counties of Romania. As expected, due to the variation of population in counties, the number of installations also varies. In counties with larger population, the number of installations is higher, due to the higher amount of hot water necessary for consumption.

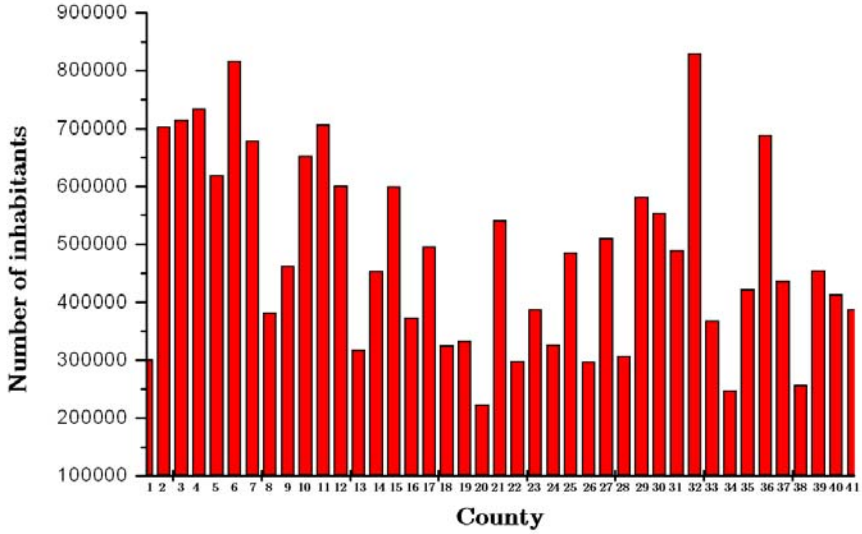

Fig.4: Number of inhabitants in each county, from year 2002 [15]: 1-Ilfov, 2-Cluj, 3-Constanta, 4-Dolj, 5-Galati, 6-Iasi, 7-Timis, 8-Alba, 9-Arad, 10-Arges, 11-Bacau, 12-Bihor, 13-Bistrita-Nasaud, 14-Botosani, 15-Brasov, 16-Braila, 17-Buzau, 18-Calarasi, 19-Caras-Severin, 20-Covasna, 21-Dambovita, 22-Giurgiu, 23-Gorj, 24-Harghita, 25-Hunedoara, 26-Ialomita, 27-Maramures, 28-Mehedinti, 29-Mures, 30-Neamt, 31-Olt, 32-Prahova, 33-Satu Mare, 34-Salaj, 35-Sibiu, 36-Suceava, 37-Teleorman, 38-Tulcea, 39-Vaslui, 40-Valcea, 41-Vrancea

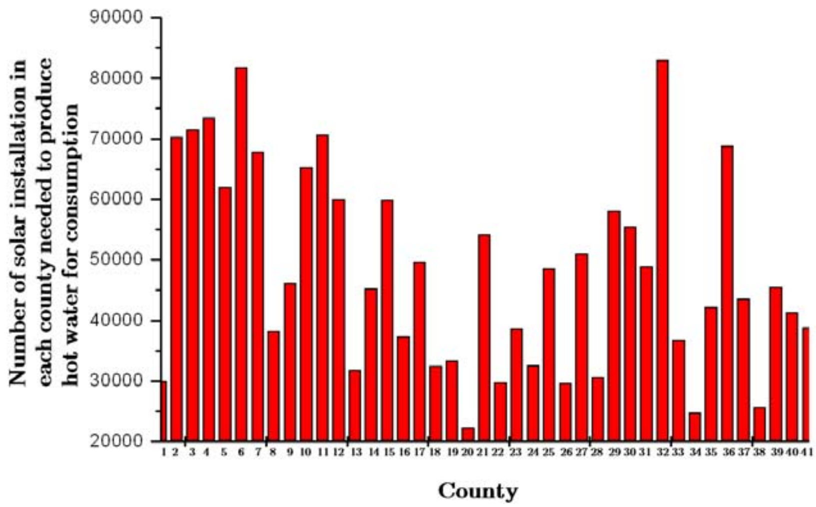

Fig.5: Number of solar installation in each county needed to produce hot water for consumption: 1-Ilfov, 2-Cluj, 3-Constanta, 4-Dolj, 5-Galati, 6-Iasi, 7-Timis, 8-Alba, 9-Arad, 10-Arges, 11-Bacau, 12-Bihor, 13-Bistrita-Nasaud, 14-Botosani, 15-Brasov, 16-Braila, 17-Buzau, 18-Calarasi, 19-Caras-Severin, 20-Covasna, 21-Dambovita, 22-Giurgiu, 23-Gorj, 24-Harghita, 25-Hunedoara, 26-Ialomita, 27-Maramures, 28-Mehedinti, 29-Mures, 30-Neamt, 31-Olt, 32-Prahova, 33-Satu Mare, 34-Salaj, 35-Sibiu, 36-Suceava, 37-Teleorman, 38-Tulcea, 39-Vaslui, 40-Valcea, 41-Vrancea

Note that the cost of solar systems implementation in existing block of flats is rather high. That is why we focused on residential buildings other than those in blocks of flats. The cost of solar components and the cost of the installation was taken directly from the manufacturer and from the owner of the particular building considered here (S.C. AMVIC SRL). Table 1 provides information about the costs related to the solar active system of the AMVIC building. We neglected the cost of the pipes and the cost of the solar panel support structure. However, these are rather low costs and they do not change significantly the results obtained here.

Table 1

The cost of the solar active system installation [5, 8, 9, 12]

	Symbol	Cost (Euro)
Solar collector cost	C_{SC}	3660
Storage tank cost	C_{ST}	3606.1
Expansion vessels cost	C_{EV}	96.5
Pumps cost	C_p	169.1
Installation cost	C_i	750
Total cost	C	8281.7

The total cost in Table 1 of the solar active system installation has been simply computed as:

$$C = C_{SC} + C_{ST} + C_{EV} + C_p + C_i \tag{2}$$

Next, we calculate the annual cost for a person to receive hot water for consumption, C_{ap}. We take into account the cost of 1Gcal, C_g, which is different from county to county (see Fig. 6). Since the values in Fig. 4 are expressed in Romanian currency (RON), the exchange rate RON – Euro is needed. On January 5, 2013, this rate was 1 Euro = 4.4251 RON [13]. In the following we are using the covering rate 1Euro = 4.5 RON. Another assumption adopted here is that a person consumes 2.5 Gcal/year [14]. Then, the annual cost per capita to receive hot water for consumption is:

$$C_{ap} = C_g * \frac{2.5}{4.5} \tag{3}$$

As seen in Fig.6, the cost of 1Gcal varies, depending on the county

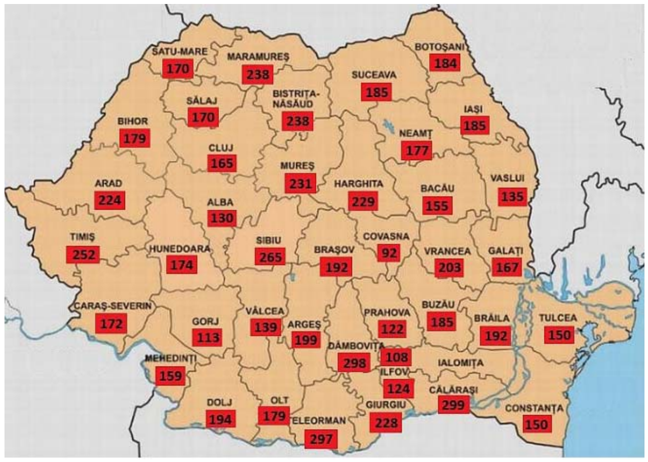

Fig.6: The cost of 1Gcal for all Romanian counties for year 2011, in Romanian currency (RON) [14]

As a consequence, the annual hot water consumption cost per capita depends on county (Fig. 7).

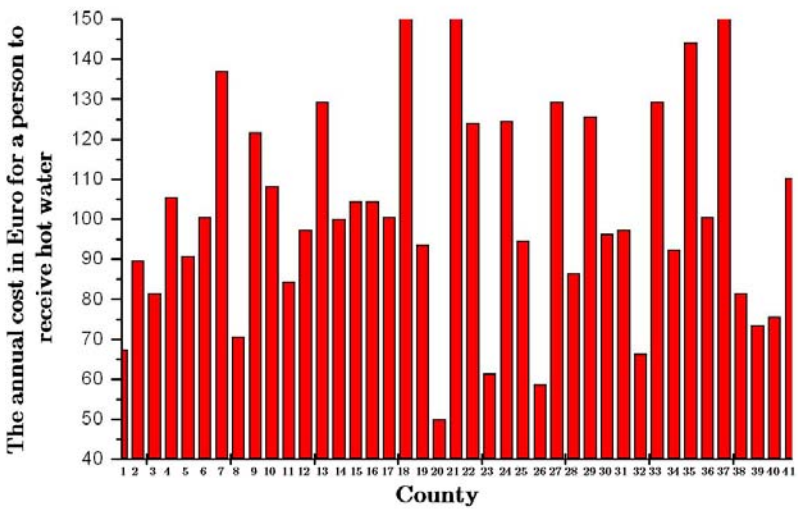

Fig.7:The annual cost (in Euro) per capita to receive hot water for consumption in each county of Romania: : Number of solar installation in each county needed to produce hot water for consumption: 1-Ilfov, 2-Cluj, 3-Constanta, 4-Dolj, 5-Galati, 6-Iasi, 7-Timis, 8-Alba, 9-Arad, 10-Arges, 11-Bacau, 12-Bihor, 13-Bistrita-Nasaud, 14-Botosani, 15-Brasov, 16-Braila, 17-Buzau, 18-Calarasi, 19-Caras-Severin, 20-Covasna, 21-Dambovita, 22-Giurgiu, 23-Gorj, 24-Harghita, 25-Hunedoara, 26-Ialomita, 27-Maramures, 28-Mehedinti, 29-Mures, 30-Neamt, 31-Olt, 32-Prahova, 33-Satu Mare, 34-Salaj, 35-Sibiu, 36-Suceava, 37-Teleorman, 38-Tulcea, 39-Vaslui, 40-Valcea, 41-Vrancea

The annual cost in Euro for 10 persons to receive hot water for consumption (C_{10ap}) is expressed as:

$$C_{10ap} = C_{ap} * 10 \tag{4}$$

Figure 8 shows the results of the values of C_{10ap} for all counties of Romania.

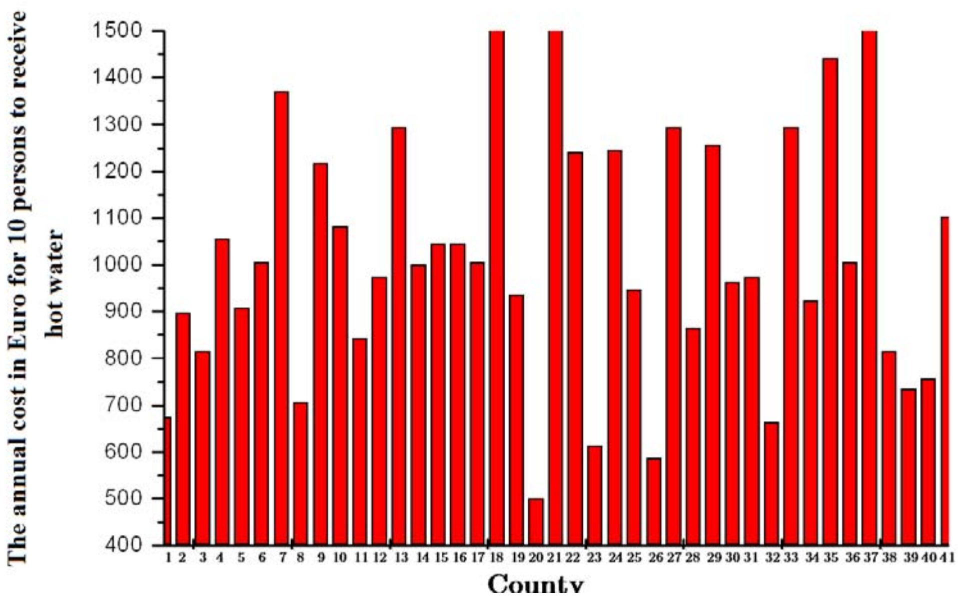

Fig.8: The annual cost (in Euro) for 10 persons to receive hot water, for all counties of Romania: 1-Ilfov, 2-Cluj, 3-Constanta, 4-Dolj, 5-Galati, 6-Iasi, 7-Timis, 8-Alba, 9-Arad, 10-Arges, 11-Bacau, 12-Bihor, 13-Bistrita-Nasaud, 14-Botosani, 15-Brasov, 16-Braila, 17-Buzau, 18-Calarasi, 19-Caras-Severin, 20-Covasna, 21-Dambovita, 22-Giurgiu, 23-Gorj, 24-Harghita, 25-Hunedoara, 26-Ialomita, 27-Maramures, 28-Mehedinti, 29-Mures, 30-Neamt, 31-Olt, 32-Prahova, 33-Satu Mare, 34-Salaj, 35-Sibiu, 36-Suceava, 37-Teleorman, 38-Tulcea, 39-Vaslui, 40-Valcea, 41-Vrancea

The AMVIC solar installation was designed for 10 people. Therefore, the annual cost to receive hot water is evaluated for 10 persons, too. The recovering period for the investments, A_p, (in years) may be computed by using Equations. (2) and (4), as follows:

$$A_p = \frac{C}{C_{10ap}} \tag{5}$$

Figure 9 shows results. The values A_p depend on county, as expected, since the cost of 1Gcal depends on the county, too.

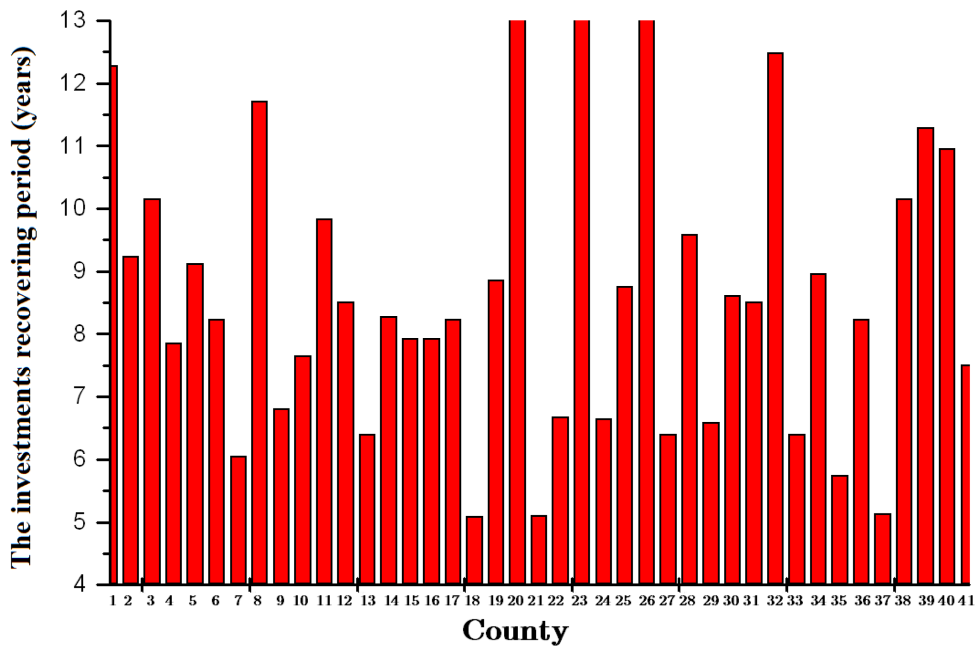

Fig.9: The investments recovering period (years) for each county of Romania: 1-Ilfov, 2-Cluj, 3-Constanta, 4-Dolj, 5-Galati, 6-Iasi, 7-Timis, 8-Alba, 9-Arad, 10-Arges, 11-Bacau, 12-Bihor, 13-Bistrita-Nasaud, 14-Botosani, 15-Brasov, 16-Braila, 17-Buzau, 18-Calarasi, 19-Caras-Severin, 20-Covasna, 21-Dambovita, 22-Giurgiu, 23-Gorj, 24-Harghita, 25-Hunedoara, 26-Ialomita, 27-Maramures, 28-Mehedinti, 29-Mures, 30-Neamt, 31-Olt, 32-Prahova, 33-Satu Mare, 34-Salaj, 35-Sibiu, 36-Suceava, 37-Teleorman, 38-Tulcea, 39-Vaslui, 40-Valcea, 41-Vrancea

Now, we assume that the strategy proposed here would be implemented by the year 2020. It may provide thermal energy for the population, which is expressed now as a percentage, P, of the target proposed by the Government (i.e. 60 PJ = 14340344.17Gcal). First, we estimate the total number of installations to ensure hot water all over Romania. Making the sum of all installations to ensure hot water in each county, the result is 1977082 installations. Next, we compute the thermal energy annual production, at national level, from all these solar installations. We remind that each installation produces hot water for 10 persons, i.e. 25Gcal/year. The result is 49427047.5Gcal/ year produced by all installations. Now, the percentage P is easily computed by:

$$P = 14340344.1 * \frac{100}{49427047.5} = 344.6\% \tag{6}$$

The cost of all the investments, C_V, involved by the implementation of this solution is:

$$C_V = 1977081.9 * 8281.7 = 16{,}373{,}599{,}170 \text{ Euro} \quad (7)$$

The results obtained here fit better to buildings of the size of the office building AMVIC, considered here. They may be used, as first approximations, for smaller residential buildings, located in urban or rural area. Better results are obtained when the water usage is adjusted, taking into account the specific location (i.e. rural or urban).

The annual efficiency of the active solar systems is considered now. Simulations have been done in Solar Water Module belonging to software RETSCREEN [7] for the capitals of all Romanian counties, taking into account the technical characteristics of the AMVIC active solar energy system. For more details how the simulation was done please read paper [7]. Figure10 shows the annual system efficiency obtained from the simulations. The system efficiency results are different, this aspect is normal because of the weather conditions which are specific to each city.

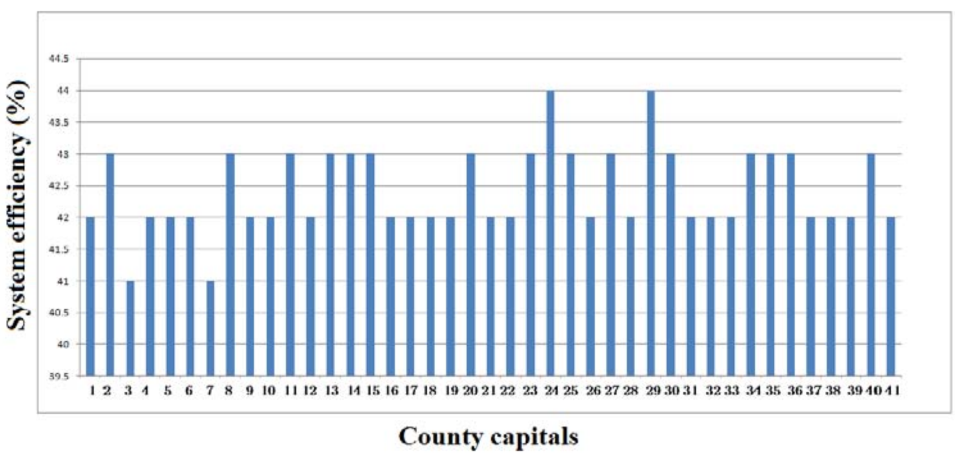

Fig.10: System efficiency (%) for the capitals of the Romanian counties: 1-Bucuresti, 2-Cluj Napoca, 3-Constanta, 4-Craiova, 5-Galati, 6-Iasi, 7-Timisoara, 8-Alba Iulia, 9-Arad, 10-Pitesti, 11-Bacau, 12-Oradea, 13-Bistrita, 14-Botosani, 15-Brasov, 16-Braila, 17-Buzau, 18-Calarasi, 19-Resita, 20-Sfantu Gheorghe, 21-Targoviste, 22-Giurgiu, 23-Targu Jiu, 24-Miercurea Ciuc, 25-Deva, 26-Slobozia, 27-Baia Mare, 28-Drobeta Turnu Severin, 29-Targu Mures, 30-Piatra Neamt, 31-Slatina, 32-Ploiesti, 33-Satu Mare, 34-Zalau, 35-Sibiu, 36-Suceava, 37-Alexandria, 38-Tulcea, 39-Vaslui, 40-Ramnicu Valcea, 41-Focsani

Now, we take into account the annual cost per capita to receive hot water for consumption, C_{ap}, as well as the efficiency of the active solar system, S_{ef}.

Then, the annual energy cost per capita to receive hot water, C_{um}, may be computed as follows:

$$C_{um} = C_{ap} - C_{ap} * \frac{S_{ef}}{100} \tag{8}$$

where: $C_{ap} * S_{ef} /100$ represents the annual energy cost of saving for a person to receive hot water.

Figure 11 shows the annual energy cost of saving per capita to receive hot water in the capitals of the Romanian counties after the implementation of the proposed method.

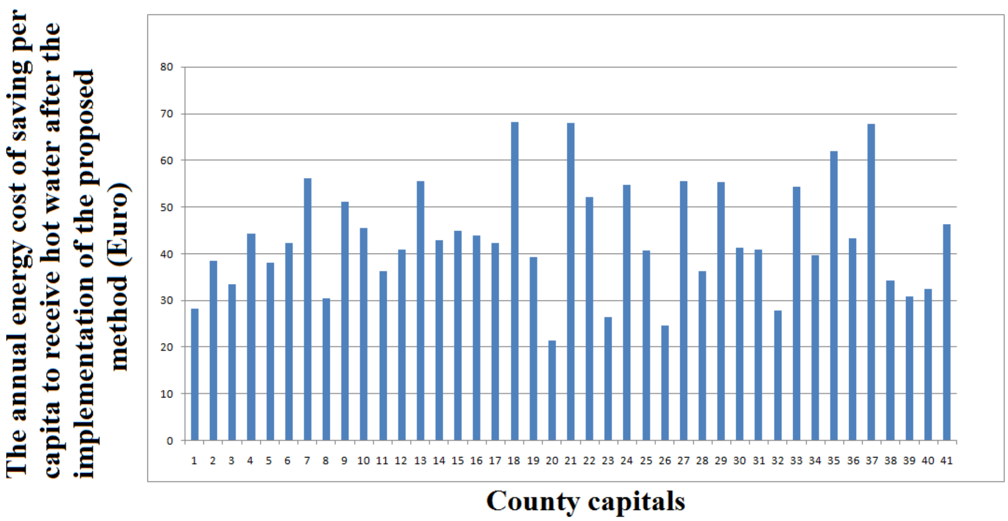

Fig.11: Annual energy cost of saving for a person to receive hot water in the capitals of the Romanian counties after the implementation of the proposed method: 1-Bucuresti, 2-Cluj Napoca, 3-Constanta, 4-Craiova, 5-Galati, 6-Iasi, 7-Timisoara, 8-Alba Iulia, 9-Arad, 10-Pitesti, 11-Bacau, 12-Oradea, 13-Bistrita, 14-Botosani, 15-Brasov, 16-Braila, 17-Buzau, 18-Calarasi, 19-Resita, 20-Sfantu Gheorghe, 21-Targoviste, 22-Giurgiu, 23-Targu Jiu, 24-Miercurea Ciuc, 25-Deva, 26-Slobozia, 27-Baia Mare, 28-Drobeta Turnu Severin, 29-Targu Mures, 30-Piatra Neamt, 31-Slatina, 32-Ploiesti, 33-Satu Mare, 34-Zalau, 35-Sibiu, 36-Suceava, 37-Alexandria, 38-Tulcea, 39-Vaslui, 40-Ramnicu Valcea, 41-Focsani

After the implementation of the proposed method result an annual energy cost of saving for a person to receive hot water. This annual saving cost varies because of the differences between system efficiency in the counties and the fluctuations of annual cost per capita to receive hot water for consumption in the counties. As a result of implementing the proposed method, the annual energy cost for a person to receive hot water in the counties of Romania decreases.

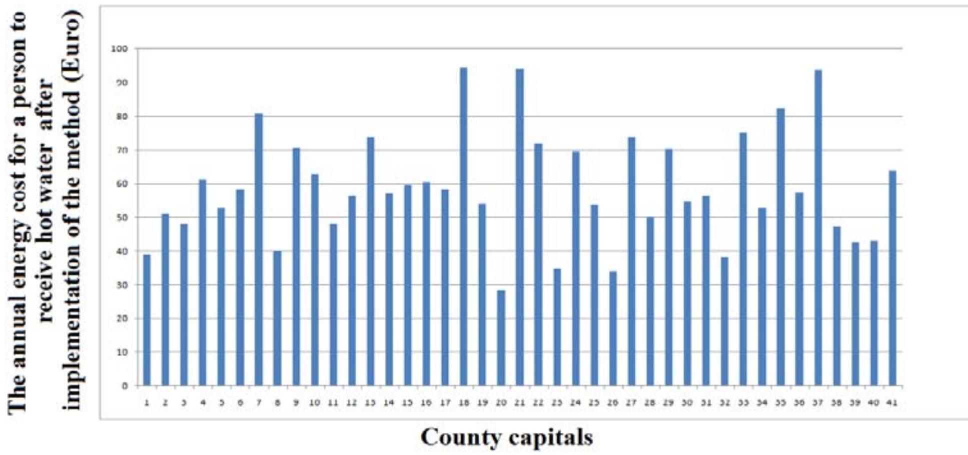

Fig.12: Annual energy cost for a person to receive hot water in the capitals of the Romanian counties after the implementation of the proposed method: 1-Bucuresti, 2-Cluj Napoca, 3-Constanta, 4-Craiova, 5-Galati, 6-Iasi, 7-Timisoara, 8-Alba Iulia, 9-Arad, 10-Pitesti, 11-Bacau, 12-Oradea, 13-Bistrita, 14-Botosani, 15-Brasov, 16-Braila, 17-Buzau, 18-Calarasi, 19-Resita, 20-Sfantu Gheorghe, 21-Targoviste, 22-Giurgiu, 23-Targu Jiu, 24-Miercurea Ciuc, 25-Deva, 26-Slobozia, 27-Baia Mare, 28-Drobeta Turnu Severin, 29-Targu Mures, 30-Piatra Neamt, 31-Slatina, 32-Ploiesti, 33-Satu Mare, 34-Zalau, 35-Sibiu, 36-Suceava, 37-Alexandria, 38-Tulcea, 39-Vaslui, 40-Ramnicu Valcea, 41-Focsani

Fig. 12 shows the annual energy cost per capita to receive hot water in the capitals of the Romanian counties after the implementation of the proposed method.

The results obtained here fit better to buildings of the size of the office building AMVIC, considered here. They may be used, as first approximations, for smaller residential buildings, located in urban or rural area. Better results are obtained when the water usage is adjusted, taking into account the specific location (i.e. rural or urban).

4. Conclusions

The paper is a theoretical study about the large scale implementation of solar collector systems in the residential area. However, all input data used are taken from real world. The results reported here provide a perspective about the potential of using the solar collector systems for domestic hot water preparation.

The strategy proposed here, based on thermal energy obtained from renewable resources, seems to be viable. This is also justified by the fact that the cost of 1Gcal increases year by year. Applying the methods set out in this paper, the cost recovering period for the installation ranges between 5 and 16 years. The recovering period depends on county, due to cost differences of thermal energy. The method could be extended beyond the year 2020. Indeed, implementation of this method to a quarter of Romania only may provide 60 PJ by the year 2020. However, one must be keep in mind that the solar installation does not provide hot water all over the year, because of the night-day cycle and also because the sky is not always clear. The Romanian Government may be involved in collaboration with local municipalities to implement this method. When such financial support is provided, the usage of solar collectors may become attractive even for the existing blocks of flats. Thus, for those who live in the blocks where the method is implemented, the local municipalities might put a modest fee, i.e. not exceeding 12.5 Euro/month. This fee would depend on the county, due to differences in costs of thermal energy. Implementing this method at national level, it might significantly reduce the money paid by the population for to receiving domestic hot water.

Acknowledgments

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