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DOMESTIC WATER HEATING WITH SOLAR ENERGY AN ALTERNATIVE TO ENERGY INDEPENDENCE

BY

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Abstract. The analysis based on the climatic conditions of Cluj-Napoca - Romania for the solar collectors included in the study, may allow to conclude that the water heating using the solar energy is a viable solution that allows a family from Romania to ensure its required energy needs for the summer season, namely to secure its energy independence. In the present study a selection for the best options of the solar collectors based on their technical characteristics was performed that together with regional atmospheric conditions gave the global solar radiation intensity input. Later, the heat capacity was determined using 6 collectors, 2 from each category (flat solar collectors, thermal tube collectors and vacuum tube collectors) which was subsequently converted into an annual income - annual cash flow freed as a result of the energy production. By using the 6 solar thermal collectors an analysis of six investment projects including all the components required for a solar installation was performed. Total expenditures were established for each investment project by adding fixed and variable costs. Using the statistical indicators - average, variance, standard deviation and variation rate - the least risky and the highest risky projects were identified.

Key words: efficiency; risk; solar energy.

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1. Introduction

Changes in global climate and the dependence on energy of all States led to a series of worldwide debates related to energy efficiency, identification of new stable secure and competitive sources of energy, and incentives for producing local energy (Bolton & Timothy, 2015a, 2015b; Zakhidov, 2008).

To reduce energy consumption in the EU, leaders set a target of reducing annual Union consumption by 20% until 2020. This measure aims at reducing consumption besides itself and a number of items with a side effect: reducing greenhouse gas emissions, increase supply security, reducing import costs and promoting the competitiveness of European economies.

This European Council meeting on 20 and 21 March 2014 highlighted the role that energy efficiency can have on reducing energy costs and dependence on energy. However there are concerns for the efficient functioning of the energy market in the EU, there are a number of documents aimed at establishing a legal framework for promoting the interconnection of energy networks of the Member States. The concerned energy sources are fossil fuels and nuclear energy, as well as renewable energy sources (solar, wind, biomass, geothermal, hydro and tidal (http://eur-lex.europa.eu/legal-content/RO/TXT/ PDF/?uri=CELEX:12012E/TXT&from=RO; Directiva 2012/ 27/UE; COM (2014)).

Energy efficiency has become a national objective for Romania, which is regulated and updated by Law 121/2014 aiming at a reduction in energy consumption of up to 19% by 2020. At national level, the Energy Strategy of Romania for 2007-2020 provides guidelines for the encouragement and development of renewable energy sources up to 35% of gross domestic consumption of electricity by 2015 and up to 40% by 2020 (Legea 121/2014; http://www.minind. ro/energie/STRATEGIA_energetica_ actualizata.pdf).

The transition from conventional to renewable energy sources is not easy, it most often entail fundamental changes in the perception, preference and behavior among consumers. Success depends on how are they known and financially supported by national policy of incentives and how investments in sustainable energy are encouraged (Steg *et al.*, 2015; Murphy *et al.*, 2014; Liua *et al.*, 2015).

The efficiency of solar collectors using solar energy to obtain hot water has been studied by many specialists who demonstrated the influence of solar radiation absorbing surface, ambient temperature and temperature of the fluid in the solar collector (Lee *et al.*, 2014; Nan *et* al., 2012). Another study demonstrated that although irradiation on the vertical surface of the solar collectors is lower than on the horizontal surface, contributing to reducing solar radiation, vertical mounting of the solar collectors will result in optimal performance in winter of 20% compared to the other seasons and additionally eliminates overheating of solar collectors during summer due to low demand (Yongping *et* al., 2014).

Solar energy obtained through solar collectors required for domestic hot water is considered a viable solution that allows on one hand energy independence by providing power from own site resources and on the other hand reducing carbon emissions and greenhouse gases that have a global pollution effect (Nan *et* al., 2012; Tiwari & Tiwari, 2007; Hammarström, 2012). Although researches show this is an affordable solution, equipment costs are still high and the problem of energy storage obtained in warm periods to be used in colder periods is still unresolved. There are currently technical solutions but involving energy losses by up to half during storage (Fieducik & Godlewski, 2014; Axel *et al*., 2015).

Of a special importance for investment is the risk assessment, namely the decision to invest or not by taking eventually an alternative if there are more possibilities when we are in a position to decide which the best option is. Later question is if the investment is secure and if there are possible scenarios in which we can situate in the future, concerning the possibility of winning. Measurement of risk associated with an investment project, can be achieved through a deterministic or a rational approach. If in the first approach results depend mostly on the experience of the person who does the calculation, in the second, the risk involves performing mathematical calculations and considering several possible situations in which probabilities are associated manifestation (Ioniță, 2011). Rational approach is based on mathematical hope of winning requiring annual updates of financial cash flows for different possible situations and certain probabilities.

2. Material and Methods

In this study we analyze six investment projects capable of producing domestic hot water for a home hosting a family consisting of 4 peoples. We studied the possibilities and we have chosen the best solution considering the project investment costs required for implementing the investment, the financial cash flows that can be generated and the associated risks at each project depending on their likelihood of occurrence.

The study started from the calculation of solar global radiation intensity, which can be obtained when we use one of the variants of solar collectors that are part of a solar system, for preparing the domestic hot water and we observed the difference between one system and another. The months for which the specific heat is calculated and considered for this study's are from April to October, because was considered that during these six months there is enough solar energy that can be captured successfully by solar collectors and used for hot water in the regime of accumulation. We have chosen three types of collectors: flat plate collectors, thermal collector tubes and vacuum tube collectors from Viessmann and Termotechnology Bosch companies.

Monthly heat production calculations have been done for two collectors in each above mentioned category taking into account the individual technical characteristics and local geographical conditions. The data used for calculations were obtained from measurements made with two CMP3 type pyranometers from Kipp & Zonen Company in the Netherlands. They used data collected in a database with a transfer rate of 60 seconds, and the location where the measurement was conducted is the site of Technical University of Cluj-Napoca, Romania, Latitude, Longitude: 46 47.758 N 23 37 563. A pyranometer was used to determine the total solar radiation intensity and the other for determining the intensity of diffuse solar radiation.

Values of global solar radiation intensity and corresponding time points were obtained using the technical data specific to each solar collector: heat loss correction factor k_1, heat loss correction factor k_2, optical return for collectors in the study.

Subsequently it was calculated the monthly heat accumulated by each collector considered in the study, which is presented in Table 1.

Table 1
Annual Heat Type Solar Collectors, [kWh]

Month	Flat Collector Vitosol 100	Flat collector Buderus 4.0	Vacuum tube collector Vitosol 300 SP3	Vacuum tube collector Buderus Vaciosol CPC 12	Thermal tube collector 200-T tip SP2	Thermal tube collector Vitosol 200-T tip SP2
April	365.79	470.61	676.35	605.94	627.83	941.74
May	546.26	691.79	935.52	822.16	870.38	1,305.57
June	555.64	706.19	950.00	832.45	884.24	1,326.36
July	580.44	728.61	945.00	822.91	880.36	1,320.53
August	673.26	835.19	1,047.20	906.36	976.39	1,464.58
September	386.51	489.30	664.14	587.73	617.46	926.19
October	332.03	430.29	613.87	545.99	570.30	855.45
TOTAL	3,439.93	4,351.98	5,832.09	5,123.54	5,426.96	8,140.44

The heat load for domestic hot water was calculated with equation:

$$\dot{Q}_{\mathrm{DHW}} = \frac{n \times m \times c_w \times \left(t_b - t_r\right)}{\tau \times 3{,}600}, \tag{1}$$

where: Q_{DHW} is the thermal load of hot water, [kW]; n – the number of persons; m – the amount of hot water daily consumption considered as, [kg]; c_w – the specific heat of water quantity which varies with temperature, but which can be considered value c_w = 4,186 kJ/kg.K; t_b – the temperature of the cylinder, [°C]; t_r – the cold water temperature, inlet temperature, [°C]; τ – the period during heating hot water considered of particular importance for the amount of heat load, [h].

To determine the amount of prepared hot water we can use relationship:

$$m = n \times C_{zn} \times \rho, \tag{2}$$

where: m is the amount of hot water daily consumption considered as, [kg];

C_{zn} – the daily consumption of hot water, [m^3]; ρ – the density of water varies depending on the temperature and the indicative value calculations take 1,000 kg/m^3.

We used the following reference data:

a) daily consumption C_{zn} = 50 l = 50 × 10^{-3} m^3;

b) cylinder temperature t_b = 45ºC;

c) cold water temperature t_r = 10ºC;

d) duration of hot water τ = 8 h.

Specific heat (Q_{DHW}) required for domestic hot water is calculated with equation:

$$Q_{\text{DHW}} = \dot{Q}_{\text{DHW}} \times \tau_{zn},\ [\text{kWh}]. \quad (3)$$

To calculate the number of required collectors, depending on their type of heat production for domestic hot water it was used technical data given in Table 2.

Table 2
Technical Data

Month	Flat collector Vitosol 100	Flat collector Buderus 4.0	Vacuum tube collector Vitosol 300 SP3	Vacuum tube collector Buderus Vaciosol CPC 12	Thermal tube collector 200-T tip SP2	Thermal tube collector Vitosol 200-T tip SP2
Uniform thermal load, [W/m^2]	200	200	250	250	250	250
Area capture every collector, [m^2]	2.32	2.1	2.05	2.56	2	3

Knowing the number of collectors required to provide sufficient domestic hot water, it was expressed the value of the annual specific heat for each type of collector, starting from value of 1 kWh taken from the national power producer Company Electrica S.A. So the value in MJ was calculated for each month of the year and it was turned subsequent into kWh (1 kWh = using equivalent 0.15 € could be evaluated in monetary terms). We calculated the amount of energy produced over a period of 5 years, considering these to be years of exploitation for potential investment and we established the financial cash flow achieved for the total investment. Because in time money value is changing, to determine the real value of cash flows generated by an investment in a number of years, it is necessary to use a discount factor (r) that is intended to correct differences from year to year. This discount factor enables inclusion of all changes that might occur in the economy of a country and usually includes inflation, interest on bonds issued by state and a coefficient of stimulation due to the postponement of long-term use. Updating based on r

allows an amount which will be collected in the future to be known and calculated now.

It used eq. (4) to determine the total financial cash flows on during to exploitation of the investment project:

$$\mathrm{CF}_T = \sum_{i=1}^{n} \frac{\mathrm{CF}_i}{(1+r)^n}, \tag{4}$$

where: CF_T is the sum cash-flows possible for each project over a period of n years; CF_i – annual cash flow; i – operating year of the project, $i = 1,\ldots,5$ years; r – discount rate; because the time value of money is not the same from one year to another using a discount rate of 6% by value.

Since the investment made in the study may be affected by a number of varying climatic factors and these are reflected in energy production and financial cash flows we have taken into considerations three hypotheses that allow estimation of possible variations and the risk of these combinations.

Financial cash flow forecast for each of the six distinct projects was weighted for each hypothesis: pessimistic, medium and optimistic through the following relationship calculation:

$$\mathrm{CF}_{\text{assumption}} = \left(\sum_{i=1}^{n} \mathrm{CF}_i \right) \times f, \tag{5}$$

where: $\mathrm{CF}_{\text{assumption}}$ is the financial cash flow obtained tr a hypothesis given the associated weight to this hypothesis; f – weighting factor associated with a hypothesis that has allowed such values: $f_{\text{pessimistic}}$ = 60%; f_{mediuum} = 75% and $f_{\text{optimistic}}$ = 100%.

Weighting factor was later associated with each hypothesis of achieving cash-flows and has a probability coefficient calculated a weighted average representing the expected financial cash flow (expected value) calculation using the following relationship:

$$\overline{M} = \sum_{i=1}^{n} (\mathrm{CF}_i \times p_j). \tag{6}$$

Considering that the probabilities associated with each hypothesis value must meet the condition $\sum_{j=1}^{3} p_j = 1$ it was established a probability of realization of each hypothesis, where: p_j is the probability of occurrence of each hypothesis; j – proposed hypothesis of the three possible choices (pessimistic, optimistic and medium).

Dispersion was calculated using eq.:

$$\sigma^2 = \sum_{i=1}^{n} (\mathrm{CF}_i - \overline{M})^2 \times p_j. \tag{7}$$

It is believed that the higher the dispersion around the mean value (or spread type), the higher is the corresponding relative risk.

Standard deviation was calculated using the formula:

$$\sigma = \sqrt{\sigma^2} = \sqrt{\sum_{i=1}^{n} (\mathrm{CF}_i - \overline{M})^2 \times p_j}\,. \qquad (8)$$

Standard deviation is a probability, namely the weighted average deviation from the mean. It shows how much real value is higher or lower than the expected. Next indicator that was calculated is the variation rate that allows us to appreciate the level of risk associated with a project. The project with the lowest rate variation tells us that has the lowest level of risk.

The rate of relative variation, determining the extent of variation, was calculated using the formula:

$$\mathrm{RV} = \frac{\sigma}{I}, \qquad (9)$$

where: RV is the rate of relative variation; I – it is the investment of each project.

This factor shows if our project is less risky, enabling the differentiation of projects according to the value obtained. The lowest (nearest "0") allows us to conclude that the project is less risky while values close to "1" shows a higher degree of risk.

3. Results and Discussions

Specific annual heat obtained from measurements made with the two pyranometers used in the study period between the months of April to October is shown in Fig. 1. It was transformed from MJ to kWh to simplify following calculations.

Analyzing Fig. 1, we observe that annual value of specific heat varies from month to month due to both the weather conditions and technical features related to each collector. The highest value 1,465 kWh is obtained in August by heat pipe collector type Vitosol 200 T SP2 (3 m^2) while the lowest value of 332 kWh was recorded in October by flat collector Vitosol 100.

Analyzing the thermal load depending on the time of heating is found that this decreases as the number of hours to prepare the domestic hot water increased (Fig. 2).

The calculation shows that the thermal load required for hot water for 4 people for 8 h/day amounts to 1.017 kW = 1,017 W.

Knowing the thermal load required for hot water and capture area for each collector, the area capture and the number of collectors required were calculated and given in Table 3.

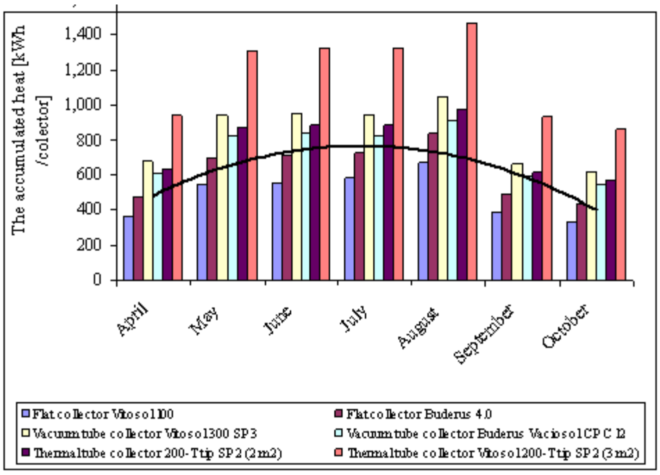

Fig. 1 – Heat accumulated in the types of collectors from April to October.

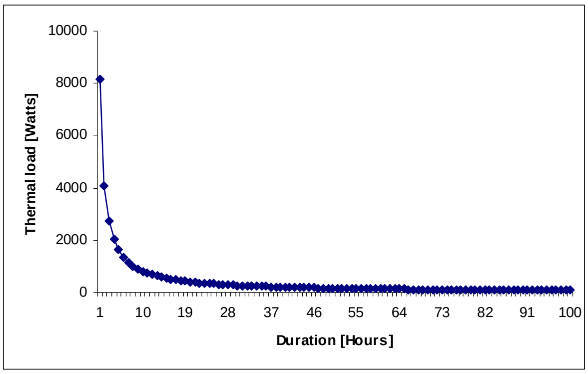

Fig. 2 – The influence of the heating on heat load.

Table 3

Set Number Solar Collectors

Type of collectors	Uniform thermal load W/m^2	Collector area needed m^2	Area capture for every collector m^2	Number of collectors
0	1	2 = Q_{DHW}/col.1	3	4 = 2/3
Flat collector Vitosol 100	200	5.085	2.32	2.19
Flat collector Buderus 4.0	200	5.085	2.1	2.42
Vacuum tube collector Vitosol 300 SP3	250	4.068	2.05	1.98
Vacuum tube collector Buderus Vaciosol CPC 12	250	4.068	2.56	1.59
Thermal tube collector Vitosol 200-T tip SP2 (2 m^2)	250	4.068	2	2.03
Thermal tube collector Vitosol 200-T tip SP2 (3 m^2)	250	4.068	3	1.36

*the termal load required for DHM = QDHW = 1,017 W

It was later obtained by mathematical calculation the required value of the construction of solar domestic hot water system, which includes fixed and variable costs specific to each project. The variable costs are determined by the number of required collectors and their cost. Fixed costs are determined by additional required equipment: bivalent boiler Buderus Logalux SM 300, AGS group Bosch solar pumping 5, automation system ground Bosch B-100, expansion tank for hot water Aquasystem VR8/8. In Romania an investment for obtaining energy from renewable sources is subsidized by the Romanian state through a grant depending on the type of renewable energy. Expenses related to each investment project were obtained by adding fixed costs to variable costs which subsequently decreased amount of subsidy that would be received from the Romanian state (Table 4).

Table 4
Cost of Solar System

No.	Elements of calculation	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6
1	Quantity solar collectors	2	2	2	2	2	1
2	Variable expenses per unit / type collector	656.86	931.13	1,417.64	1,593.00	2,520.87	3,770.82
3	Total variable costs for solar collectors	1,313.72	1,862.26	2,835.28	3,186	5,041.74	3,770.82
4	Fixed expenses	1,880.15	1,880.15	1,880.15	1,880.15	1,880.15	1,880.15
5	Total expenditure without any subsidies from the State	3,193.87	3,742.41	4,715.43	5,066.15	6,921.89	5,650.97
6	State subsidy value*	1,339.25	1,339.25	1,339.25	1,339.25	1,339.25	1,339.25
7	Total expenses subsidized by the State	1,854.62	2,403.16	3,376.18	3,726.90	5,582.64	4,311.72

* State Subsidy Programme "Green House" was calculated: 6,000 RON: 4.4801 RON/€ = 1,339.25 € (Ordinul nr. 948 din 19 iunie 2014; Ordinul 714 din 06 mai 2010).

Specific heat generated by a collector was multiplied by the number of solar collectors necessary and the cost of a kWh and thus was obtained the annual income or financial cash flow released from a solar installation for domestic hot water, according to Table 5.

Table 5

Annual Income Generated by Solar Collectors

Type of collectors	Annual specific heat kWh	Annual Income €
Project 1 - Installation solar flat plate collectors Vitosol 100	6,879.86	1,031.98
Project 2 - Installation solar flat plate collectors Buderus 4.0	8,703.95	1,305.59
Project 3 - Installation solar vacuum tube collector Vitosol 300 SP3	11,664.17	1,749.63
Project 4 - Installation solar vacuum tube collector Buderus Vaciosol CPC 12	10,247.08	1,537.06
Project 5 - Installation solar thermal tube collector 200-T	10,853.91	1,628.09
Project 6 - Installation solar thermal tube collector Vitosol 200-T	16,280.87	2,442.13

To see a period of five years which are cash flows unobstructed investment using a discount rate of cash flows 6%, taking into account inflation, interest rates and other influences which determine the change in value over time a money. Using the discount rate and considering that the revenue obtained is constant over a period of 5 years the total value of financial cash flows was calculated, according to Table 6.

Table 6

Annual Updated Income

Type of collectors	Annual income	Updated Cash-Flow					TOTAL updated Cash-flow
		Year 1	Year 2	Year 3	Year 4	Year 5	
Project 1	1,031.98	973.56	918.46	866.47	817.42	771.15	4,347.07
Project 2	1,305.59	1,231.69	1,161.97	1,096.20	1,034.15	975.62	5,499.63
Project 3	1,749.63	1,650.59	1,557.16	1,469.02	1,385.87	1,307.42	7,370.06
Project 4	1,537.06	1,450.06	1,367.98	1,290.55	1,217.50	1,148.58	6,474.66
Project 5	1,628.09	1,535.93	1,448.99	1,366.97	1,289.60	1,216.60	6,858.10
Project 6	2,442.13	2,303.90	2,173.49	2,050.46	1,934.40	1,824.90	10,287.14
discount rate use is 6%							

Total cash flow for the entire financial period of 5 years was calculated separately for each investment project for each of the 3 studied assumptions (pessimistic, optimistic and medium), Table 7.

To differentiate the investment projects and to choose the best investment project, we calculated the difference between financial cash flow (CF) and average financial cash flows (M), and dispersion associated with each project for each event separately (Table 8).

Table 7
Cash Flow Generated by Solar Collectors, [€]

Project type	Value investment	Possible hypotheses	Cash flow by hypotheses	Probability
Project 1	1,854.62	pessimistic	2,608.24	0.05
		medium	3,260.30	0.90
		optimistic	4,347.07	0.05
Project 2	2,403.16	pessimistic	3,299.78	0.05
		medium	4,124.72	0.90
		optimistic	5,499.63	0.05
Project 3	3,376.18	pessimistic	4,422.04	0.05
		medium	5,527.54	0.90
		optimistic	7,370.06	0.05
Project 4	3,726.9	pessimistic	3,884.80	0.05
		medium	4,856.00	0.90
		optimistic	6,474.66	0.05
Project 5	5,582.64	pessimistic	4,114.86	0.05
		medium	5,143.57	0.90
		optimistic	6,858.10	0.05
Project 6	4,311.72	pessimistic	6,172.29	0.05
		medium	7,715.36	0.90
		optimistic	10,287.14	0.05

Table 8
Cash Flow Generated by Solar Collectors, [€]

Project type	Possible hypotheses	CF-M	$(\text{CF-M})^2$	$(\text{CF-M})^2 \times p_j$
Project 1	pessimistic	–673.80	454,000	22,700
	medium	–21.74	472	425
	optimistic	1,065.03	1,134,293	56,715
Project 2	pessimistic	–852.44	726,659	36,333
	medium	–27.50	756	681
	optimistic	1,347.41	1,815,514	90,776
Project 3	pessimistic	–1,142.36	1,304,985	65,249
	medium	–36.85	1,358	1,222
	optimistic	1,805.66	3,260,425	163,021
Project 4	pessimistic	–1,003.57	1,007,158	50,358
	medium	–32.37	1,048	943
	optimistic	1,586.29	2,516,324	125,816
Project 5	pessimistic	–1,063.00	1,129,979	56,499
	medium	–34.29	1,176	1,058
	optimistic	1,680.23	2,823,184	141,159
Project 6	pessimistic	–1,594.51	2,542,453	127,123
	medium	–51.44	2,646	2,381
	optimistic	2,520.35	6,352,164	317,608

Using eqs. (6),...,(8) we obtained the values of variation rate for each studied investment project. Rate variation allows the measurement of risk associated with each investment project, this being calculated based on the standard deviation and expected value of financial cash flows. When the variation rate value takes values close to "0" we say that investment projects are less risky and vice versa, thus being able to differentiate investment projects (Table 9).

Table 9
Cash Flow Generated by Solar Collectors, [€]

Project type	Average $\overline{M}$	Dispersion σ^2	Standard deviation σ	Rate of variation RV
Project 1	3,282.04	79,839.83	282.56	0.15
Project 2	4,152.22	127,789.18	357.48	0.15
Project 3	5,564.40	229,492.63	479.05	0.14
Project 4	4,888.37	177,117.34	420.85	0.11
Project 5	5,177.86	198,716.40	445.78	0.08
Project 6	7,766.79	447,111.91	668.66	0.16

From analysis of the Table 9 we observed than the lowest risk for financial cash flows is associated with the investment project 5 and the biggest risk is associated with the investment project 6.

4. Conclusions

The study allowed the identification of the best project among the 6 possible investment projects that can be used for domestic hot water using the mathematical expectation for the annual financial cash flows update.

In this study were analyzed 6 investment projects for preparation of domestic hot water and we established than the investment project number 5, using heat pipe solar collectors Vitosol 200 T Type SP2 ($2m^2$), is considered the less risky compared to other projects. Investment projects number 4 and 3 are considered for 2nd and 3rd place, because for these the investment is less risky. Although the investment cost for project 5 is the largest compared to the others, finally it got the lowest risk.

The energy independence using the solar energy can be successfully ensured if the geographical conditions allow production of energy for domestic hot water using global and diffuse solar radiation. Although the cost of acquisition of such investment for preparation of domestic hot water using solar energy is relatively high, in the future we think there exists the premise to lowering the price for needed equipment that will allow access to a larger number of consumers. Another argument would be getting clean and safe energy that will prevent the user from future price fluctuations due to higher prices of energy from conventional sources.

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ÎNCĂLZIREA APEI CALDE MENAJERE CU ENERGIE SOLARĂ O ALTERNATIVĂ PENTRU INDEPENDENȚA ENERGETICĂ

(Rezumat)

Analiza realizată ținând cont de condițiile climaterice din localitatea Cluj-Napoca din România şi de colectorii solari luați în studiu a permis să concluzionăm că încălzirea apei calde menajere utilizând energia solară este o soluție viabilă care permite unei familii din România să-şi asigure necesarul de energie în sezonul de vară, respectiv să-şi asigure independența energetică. Alegerea celei mai bune opțiuni de colectori solari în studiul de fața s-a realizat plecând de la caracteristicile tehnice ale acestora care împreuna cu condițiile atmosferice zonale ne-au dat intensitatea radiației solare globale. Aceasta a ajutat la obținerea căldurii specifice acumulată de 6 colectori, câte 2 din fiecare categorie (colectori solari plani, cu tuburi termice şi cu tuburi vidate) care ulterior s-a convertit în venit anual respective flux financiar anual de numerar degajat ca urmare a producerii de energie. Prin folosirea celor 6 tipuri de colectori solari termici s-au identificat 6 proiecte de investiție care cuprind toate componentele necesare pentru realizarea unei instalații solare. S-au stabilit cheltuielile totale pentru fiecare proiect de investiție prin însumarea cheltuielilor fixe şi variabile. Folosind indicatorii statistici precum: medie, dispersia, abaterea standard şi rata de variație s-a identificat care este proiectul cel mai puțin riscant şi care este proiectul cel mai riscant.