ISSN 1330-3651
UDC/UDK 620.91:697.7

NATURAL GAS SAVINGS USING SOLAR HEATING

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Preliminary notes

The paper presents the possibility of solar heating as a way of natural gas savings. Solar heating is ideally used in our climate area, considering a large number of sunny days and relatively high average temperatures in Croatia, resulting in higher efficiency of heating systems. The advantage of solar heating, compared to other methods (such as heating with natural gas), is in its environmental acceptability, and also in its partial autonomy, respectively in its applicability, without public utilities. Solar system, applied for one building heating, can save an average of 50-60 % annual energy needs. During the summer months a conventional heating system for hot water can work on a minimum energy needs or can be totally excluded, and thus eliminate harmful emissions (CO_2), which occur as a by-product of burning conventional fuels. Using solar energy to produce thermal energy makes it possible to save considerable financial resources. Repayment of this system can be observed through the reduction of energy consumption (e.g. natural gas) during the preparation of consumable hot water (CHW) and/or space heating.

Keywords: *renewable energy sources, solar energy system, thermal energy*

Ušteda prirodnog plina za grijanje uporabom sunčeve energije

Prethodno priopćenje

U članku je prezentirana mogućnost solarnog grijanja kao načina uštede prirodnog plina. Solarno grijanje je idealno za naše podneblje, s obzirom da velik broj sunčanih dana i relativno visoka srednja temperatura u Hrvatskoj, rezultira većom učinkovitošću sustava grijanja. Prednost solarnog grijanja u odnosu na druge načine (npr. grijanje prirodnim plinom) je u njegovoj ekološkoj prihvatljivosti, a također i u njegovoj djelomičnoj autonomnosti, odnosno primjenjivosti i tamo gdje nema komunalne infrastrukture. Solarni sustav za zagrijavanje jednog objekta može u prosjeku uštedjeti 50 – 60 % godišnje potrebne energije. Tijekom ljetnih mjeseci, konvencionalni sustav za zagrijavanja tople vode, može raditi na minimumu ili se potpuno isključiti te time ukloniti štetnu emisiju plinova (CO_2) koja nastaje kao nusprodukt sagorijevanja klasičnih energenata. Uporabom solarne energije za proizvodnju toplinske energije, mogu se s vremenom uštedjeti znatna materijalna sredstva. Otplata ovog sustava može se promatrati kroz smanjenje potrošnje energenata (npr. prirodnog plina) prilikom pripreme potrošne tople vode (PTV) i/ili za grijanje prostora.

Ključne riječi: *obnovljivi izvori energije, solarni sustav, toplinska energija*

1 Introduction
Uvod

The Earth life started millions of years ago and it has always been conditioned by suitable climate. Climate can be observed as a renewable source, which has the energy component, i.e. solar energy, and the material component, i.e. the oceans, as water containers. Climate changes have reached the point when we can talk about the climate crisis. The vision which leads out of this crisis implies harnessing of less detrimental energy sources. In the 20th century, the main energy sources were non-renewable, such as: coal, petroleum, natural gas and nuclear energy.

The problems relating to these sources include their limited quantity and environment pollution. Fossil fuel combustion releases an enormous amount of CO_2, which is a green house gas, and very likely the cause of the temperature rise. Nuclear fuels are not harmful to the atmosphere, but the products of nuclear reaction remain radioactive for years and they should be disposed of with great care. On the other hand, renewable sources are devoid of such problems. The most important renewable sources include:

- Solar energy
- Wind energy
- Bioenergy
- Water energy
- Waste energy and bio fuels
- Geothermal energy,
- Energy of tide, sea currents and waves.

Renewable sources have an enormous potential, but the present technological development does not make it possible to rely only on these sources. They provide only 1 % of the global energy requirements, without hydro energy. In the future, this share must be significantly increased due to the well-known reasons related to non-renewable sources.

The Sun delivers to the Earth 15 000 times more energy than humankind can currently utilize. However, the world distribution of energy consumption is unequal; namely, there are places on the Earth where energy consumption is much greater than needed or vice versa, significantly smaller than required.

The above said implies that renewable sources can and must be better exploited and mankind should not be concerned with running short of the fossil fuel energy. The development of renewable energy sources – wind, water, sun, and biomass – is important for various reasons:

- Renewable energy sources play an important role in the reduction of CO_2 emission in the atmosphere. This reduction policy has been adopted by the European Union and Croatia as well.
- Increased share of renewable energy sources enhances energy system sustainability. In addition, it improves energy delivery by reducing the dependence on the import of energy raw materials and electric power.
- Renewable energy sources are also expected to become cost-competitive regarding the conventional energy sources in the medium and long-term period.

Several technologies, especially wind energy, small hydro-electric plants, biomass energy, geothermal energy and solar energy, are cost-competitive. Other technologies

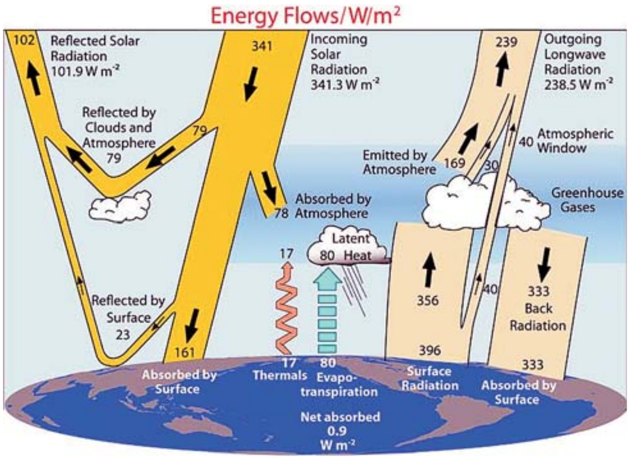

Figure 1 *Solar radiation on the Earth surface* [1]
Slika 1. *Sunčevo zračenje na površini Zemlje* [1]

depend on the market demand in order to become cost-effective compared to the conventional energy sources.

The intensity of solar radiation comprises various wave lengths. Most (99 %) of the solar radiation covers the spectrum of wave lengths from 0,275 - 4,6 μm. Radiation that reaches the Earth surface consists mainly of invisible ultraviolet range (0,12 - 0,4 μm) and it is represented by 9 %, of the visible range (0,4 - 0,75 μm) represented by 41,5 %, then invisible infrared range (greater than 0,75 μm) represented by 49,5 % of the global energy of solar radiation.

Due to the Earth spherical shape, elliptical orbit around the Sun, axis plunge against orbital plane and rotation around its own axis, the energy coming from the Sun is not uniformly distributed on the Earth and it changes year-round and during the day. Namely, what is changed is the Sun's altitude on the horizon, which implies the change of the radiation incidence angle on the ground, furthermore, the day length, i.e. the period of receiving solar energy and finally the distance between the Earth and the Sun. As all these changes are regular, solar radiation could be calculated at any period of the day or at any position of the upper atmosphere limit.

The global solar radiation on the Earth surface consists of direct, diffused and reflected radiation. The sum of these components denotes the total radiation. The components of the total radiation are presented in Fig. 1.

2
Solar radiation in the Republic of Croatia
Sunčevo zračenje na području Republike Hrvatske

Approximation of the available solar potential for a certain location is facilitated by the data bases (PVGIS, NASA, Meteonom database…), which contain information on the solar radiation intensity, ambient temperature, average daily temperature etc. It is important to emphasize that all information in the above mentioned data bases have been calculated due to satellite measurements of extraterrestrial radiation at the margin of the Earth atmosphere.

A good indicator of cost-effective exploitation of solar energy is an irradiation map, which shows the level of irradiation of a certain area on the Earth. Thus, by observing the irradiation map of Croatia (Fig. 2), it is easy to see that the total annual amount of solar radiation increases from the northwest to the southeast, which is in accordance with the latitude change. The biggest irradiation of the horizontal plane is observed in the Croatian south, namely the coastal area and the southern Dalmatian islands (1650 kWh/m^2 annually) [1].

According to the PVGIS (Photovoltaic Geographical Information System) data, the optimal angle for Croatia is between 33° in the north and 37° in the south. It should be noted that the optimal angle changes in the course of the year due to the seeming Sun movement [3].

3
Solar energy system
Sustav sunčeve energije

Basic elements of the solar energy system are collectors of solar radiation and thermal energy tanks.

3.1
Collectors of solar radiation
Prijamnici sunčevog zračenja

Collectors that directly convert the energy of solar radiation into thermal energy are presently the simplest and the most applicable devices for a wide-ranging usage from the technical, technological and economic standpoint. They could be roughly classified into two categories, depending on the temperature the operating medium could achieve:

- low-temperature collectors – this group includes all collectors, which have the operating temperature of the operating medium up to 200 °C, but very often it is bellow 100 °C.
- high-temperature collectors – they use bigger surfaces for focusing on a smaller surface whereby very high temperatures are achieved, depending on the construction, even up to several thousand °C.

Collector construction has resulted in various approaches, but basically the attempt is to obtain maximum exploitation of solar energy. The simplest device for conversion of solar energy into thermal is the flat-plate collector. The production technology for these collectors has been completely adopted, it has been used worldwide and many factories produce and sell these collectors commercially. Shapes, dimensions and positions of the parts are determined by installation, namely by conditions under which the collectors will function. In the same way the applied materials are determined by new knowledge and production technologies.

3.2
Thermal energy tanks
Spremnici toplinske energije

Thermal energy tanks should be chosen in accordance with the planned thermal energy consumption, based on the number of persons and their needs and/or based on the requirements of the heating/cooling system. Renewable energy tanks accumulate (store) heat because solar radiation varies during the day or year due to intermittent characteristic of solar energy.

Installation of accumulation tanks, thermal energy tanks, increases the efficiency of the solar energy system because they save thermal energy, collected during the day, to be used either at night or in the following few days or

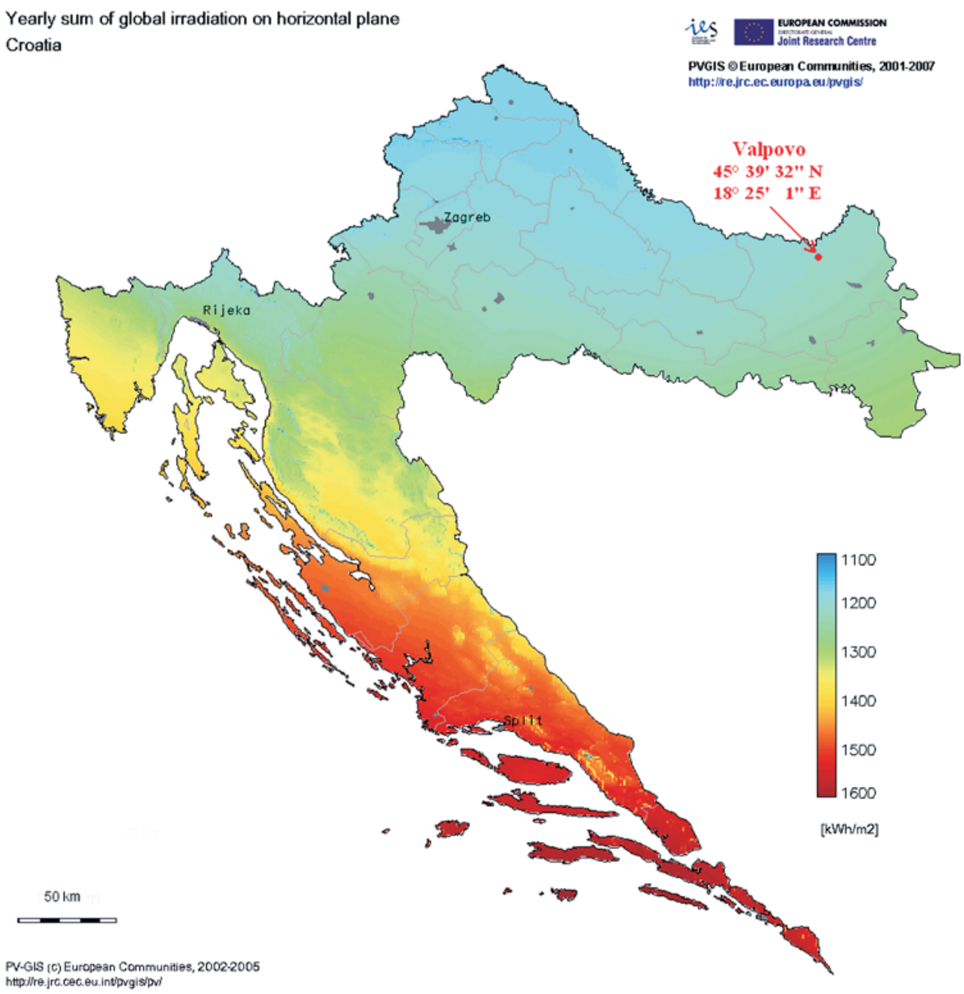

Figure 2 *Yearly sum of global irradiation on horizontal plane* [3]
Slika 2. *Srednja godišnja ukupna ozračenost vodoravne plohe* [3]

weeks devoid of a new flow of solar energy.

4
Application of solar energy system in the secondary school Valpovo
Primjena sustava sunčeve energije u Srednjoj školi Valpovo

The school building was built in 1967 and in 1992 it was modernized and enlarged. This provided optimal space conditions for the normal realization of an educational process.

Optimal layout of the school requires specific energy consumption and this means specific financial sources, as given in Tab. 1. The table presents gas consumption in the period of 2007 until 2009, and financial cost [4].

Significant thermal energy consumption, as shown in Table 1, refers to gas consumption from 2007 to 2009. Temperature changes, both monthly and daily, determine varied gas consumption used for school premise heating.

Usage of solar energy to obtain thermal energy is recommendable in transitional periods. In the winter, however, solar energy can be used as a backup power system, namely as a parallel energy source besides the major source, which is natural gas. There are various factors, which determine availability of thermal energy production by using solar energy: number and type of collectors, thermal energy tanks, possibility of adapting collector's direction etc.

During the day, some real measurements were performed at school once per hour. Based on the results given in Tab. 2 and graphic presentation in Fig. 3, it is possible to conclude that with minimum conditions and equipment, solar energy could be used for heating (water heating system and/or as a backup power system). The measuring equipment, used in this case, could be bought in any technical equipment shop without any problems, or personally made. Steel plate with a fixed temperature indicator, used for the measurement, was placed in an isolated chamber. The upper side of the steel plate was used to place in the glass plane. As two sets were made, simultaneous measurements for comparison of the different conditions were possible. During the measurement, one measurement set was used without glass and the other was used with double-isolated glass. Each time the ambient temperature was measured (in a shade, at 2 m height). Weather conditions were also recorded.

Equipment for temperature measurement:

- steel plate 200×300×18 mm, 2 pieces;
- digital thermometer Metalflex DT 850.

Description of measuring places:

- measuring place 0 (MP0), 400×500×180 mm, without cover glass;
- measuring place 1 (MP1), 400×500×180 mm, single glass;
- measuring place 2 (MP2) 400×500×180 mm, double glass.

Table 1 *Overview of gas consumption per months from 2007 to 2009 [4]*
(The table does not provide gas consumption for metalworking in the workshop)
Tablica 1. *Pregled potrošnje plina po mjesecima za razdoblje od 2007. do 2009.* [4]
(u tablici nije navedena potrošnja radionice za obradu metala)

OVERVIEW OF GAS CONSUMPTION /per months from 2007 to 2009						
Month	2007.		2008.		2009.	
	Consumption/m³	Cost/kn	Consumption/m³	Cost/kn	Consumption/m³	Cost/kn
January	11 181	21 279,68	20 295	38 625,44	15 438	35 596,94
February	11 803	22 463,47	14 540	27 672,53	13 927	32 112,88
March	9 853	18 752,23	11 611	22 098,06	11 197	25 818,04
April	4 276	8 138,08	7 532	14 334,90	4 060	9 361,55
May	1 490	2 835,77	1 619	3 081,28	785	1 810,05
June	1 309	2 491,29	1 256	2 390,42	1 027	2 368,06
July	/	/	1 279	2 434,19	904	2 084,44
August	/	/	1 030	1 960,30	952	2 213,11
September	1 546	2 942,35	3 113	5 924,66	871	2 024,81
October	7 098	13 508,90	7 085	13 484,17	6 328	14 710,70
November	15 675	29 830,76	10 005	19 041,52	11 093	25 787,90
December	15 215	28 957,19	18428	35 072,17	17 109	39 773,29
Total:	79 446	151 199,70	97 793	186 119,64	83 691	193 660,77

It is evident from Tab. 2 and Fig. 3 that despite the cloudy sky, a certain amount of energy input was received at the place of measurement, which led to temperature rise.

Also, it is easy to see almost neglecting influence of number of glasses above the sun collectors during morning hours but with important differences during afternoon hours, as presented in Tab. 3 and Fig. 4.

5 Thermal solar energy for heating
Toplinska sunčeva energija za grijanje

As the chosen object, the school, is spacious, it must be heated in the winter period, together with the gym, which means significant costs for heating and water heating, throughout the year. The present system of central heating, based on natural gas, meets the school needs. However, from the ecological and economic standpoint, solar system installation intended for solar water heating and as a backup power system to the present heating system, could decrease consumption of conventional energy sources, namely gas, and decrease CO_2 emission into the atmosphere.

Gas consumption varies throughout the year, but it is significantly higher in winter and during transitional periods.

The new system could be made in such a way that solar energy is used in summer and in transitional periods to heat premises and/or for solar water heating. During the winter period, when the days are shorter, solar thermal energy is insufficient, therefore, it is necessary to use the conventional energy source (like natural gas) in order to reach certain temperatures. In any case, if solar energy is additionally used for heating, less natural gas will be consumed to reach certain temperatures in the central heating system and for solar water heating.

In order to present fluctuations in gas consumption numerically, April was chosen as an example with the average temperature oscillations during the day. The solar system was chosen with a 30 m² collector possessing a 1500 l tank. There was an assumption that thermal water consumption was 1500 l per hour and the starting tank temperature was 20 °C. Water temperature was 80 °C on leaving the tank. All data were presented in Tab. 4 with notified changes during the day. In Tab. 5, the data for two

Table 2 *Temperature measurements on April, 18th, 2010*
Tablica 2. *Mjerenja temperature 18.04.2010.*

Time	Ambient temperature/°C	Weather	MP0/°C	MP2/°C
7:00	7,3	Clear	8,8	10,8
8:00	9,1	Clear	10,6	13,5
9:00	10,2	Clear	19,2	23,1
10:00	13,1	Clear	30,1	43,8
11:00	15,5	Clear	43,9	70,3
12:00	16,8	Clear	47,8	88,9
13:00	17,1	Cloudy/nimbuses	49,4	102,1
14:00	19,1	Cloudy/nimbuses	51,3	108,6
15:00	20,2	Cloudy/rain	51,6	110,9
16:00	23,8	Cloudy/nimbuses	52,3	114,9
17:00	22,9	Cloudy/rain	41,8	102,4
18:00	21,1	Cloudy/nimbuses	26,4	73,4
19:00	20,1	Cloudy/nimbuses/sunset	22,1	56,1
20:00	18,2	Cloudy/nimbuses	18,7	43,3

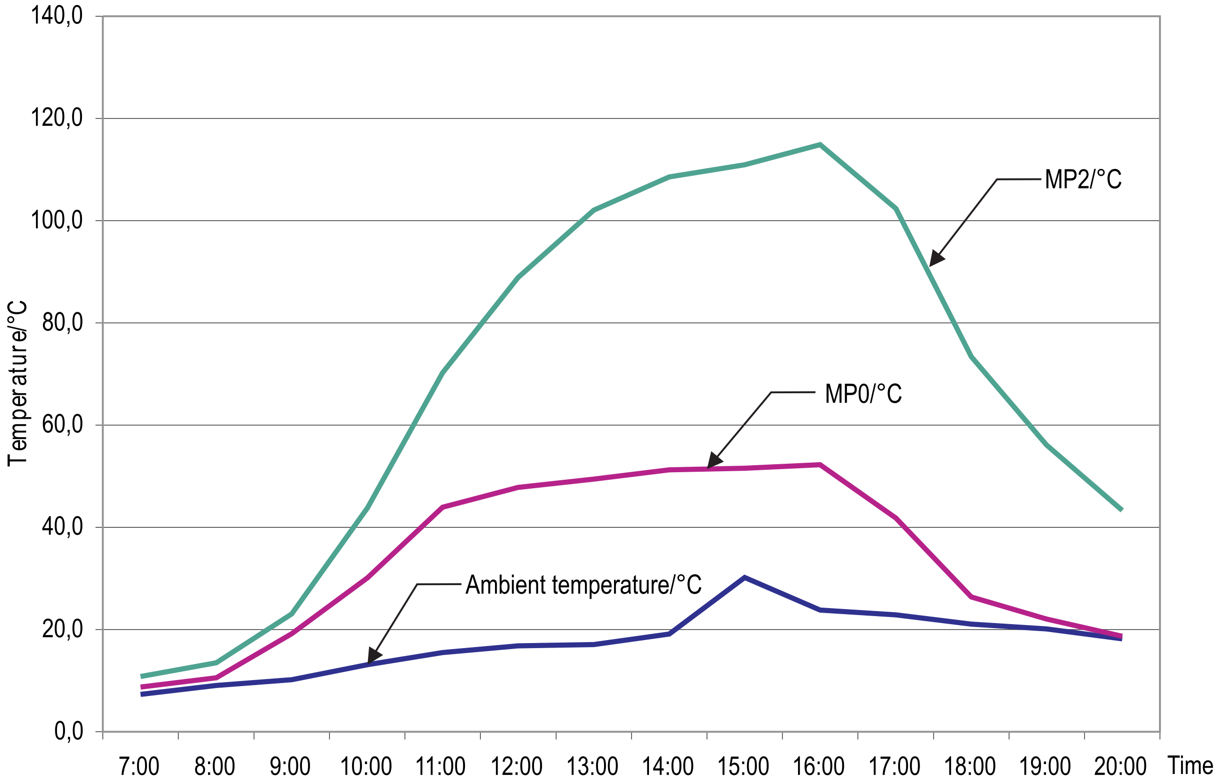

Figure 3 *Comparative presentation of temperature changes measured on April 18th, 2010.*
Slika 3. *Usporedni prikaz temperaturnih promjena, izmjerenih 18.04.2010.*

Table 3 *Temperature measurements on April 25th, 2010*
Tablica 3. *Mjerenja temperature 25.04.2010.*

Time	Ambient temperature/°C	Weather	MP1/°C	MP2/°C
7:00	15,1	Clear	15,1	15,0
8:00	16,5	Clear	16,6	15,5
9:00	17,8	Clear	19,8	18,9
10:00	19,9	Clear	24,8	23,7
11:00	22,2	Clear	32,7	32,0
12:00	24,2	Clear	72,8	71,9
13:00	25,1	Cloudy/strati	92,1	96,2
14:00	26,3	Cloudy/strati	108,2	116,4
15:00	29,3	Cloudy/strati	106,3	119,9
16:00	26,4	Cloudy/strati	86,9	103,2
17:00	26,1	Cloudy/strati	70,6	88,1
18:00	24,1	Cloudy/strati	51,8	67,8
19:00	22,3	Cloudy/strati /sunset	41,0	54,6

systems were compared in one day, week and month – the first system used a combination of gas and solar energy for solar water heating and as a backup to conventional heating, while the second used only natural gas [5].

In order to make an easy comparison, the collector heat (Q_k) was expressed as a gas equivalent in m^3 (fuel value of natural gas ranges from 34 to 38 MJ/m^3) [6].

It is possible to obtain data for the whole year, as it was done for April. Such data could be compared with the gas consumption in 2008 and given in percentages, as shown in Tab. 6. Fig. 5 gives the coverage of gas consumption by equivalent solar energy.

By observing measured consumption data during the whole year (2008), it is easy to see that 97 793 m^3 of gas was consumed. If solar energy had been used for water heating and as a backup to heating, 19 199,94 m^3 of gas could have been saved during the year, which is savings 19,63 % of total gas energy demand.

Solar water heating system or backup power system contains a collector, heat tank, radiator, adequate heating device, automation and regulation equipment, and classical heater which provide energy when solar energy is insufficient. The system also provides warm water by adequate heat exchangers. Conventional heating device has to be properly selected (nominal power) according to good engineering practices, so that it could meet the energy needs in periods when solar energy is insufficient.

6
Thermal solar energy for hot water supply
Toplinska sunčeva energija za opskrbu toplom vodom

Solar system used for hot power supply is designed according to hot water demand. It is assumed that hot water

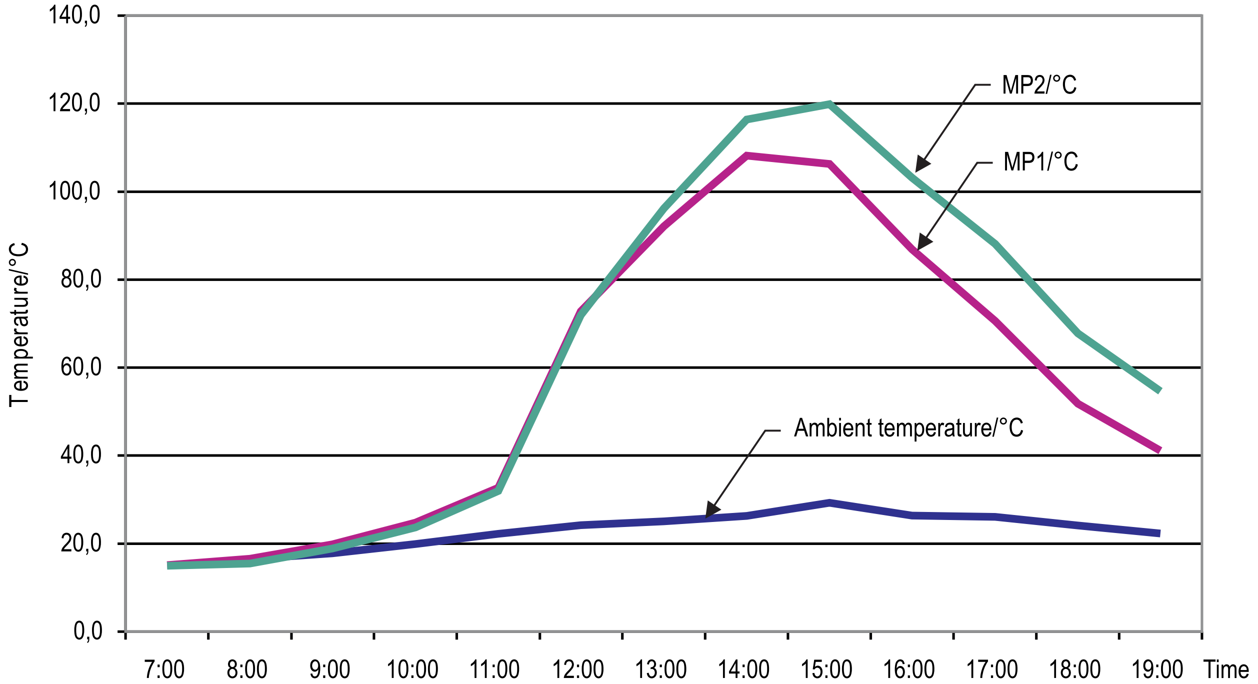

Figure 4 *Comparative presentation of temperature changes measured on April 25th, 2010.*
Slika 4. *Usporedni prikaz temperaturnih promjena, izmjerenih 25.04.2010.*

Table 4 *Water temperature in a tank and equivalent of gas consumption during the day (April 25th, 2010.)*
Tablica 4. *Temperatura vode u spremniku i ekvivalent potrošnje plina tijekom dana (25.04.2010.)*

Time	Q_k – collector heat/MJ	q_s – tank temperature/°C	Gas equivalent/m^3
8:00	12,0294	21,92	0,33
9:00	33,3418	25,32	0,93
10:00	61,0612	29,73	1,70
11:00	92,0514	34,67	2,56
12:00	123,2464	39,65	3,42
13:00	151,7254	44,19	4,21
14:00	174,6729	47,85	4,85
15:00	189,7077	50,24	5,27
16:00	194,8734	51,07	5,41
17:00	189,1326	50,15	5,25
18:00	174,1656	47,76	4,84

Table 5 *Comparison of gas consumption in April*
Tablica 5. *Usporedba potrošnje plina za mjesec travanj*

Time period	I (Gas + equivalent solar energy), gas/m³	II (Gas)/m³
Day	76,23 + 38,78	115,01
Week	533,59 + 271,45	805,04
Month	2 248,03 + 1 202,12	3 450,15

consumption is 50 – 60 liters per person. To heat the water takes up 50 – 70 liters per each square meter of collector with a water temperature of 45 – 60 °C.

During the designing and planning system for hot water generation, here mostly related to sports hall, it is necessary to take into account the large number of people – consumers of hot water. As in the case of solar collectors as support system for heating, it is necessary to plan a greater accumulation of heat energy – more reserve tanks (SEM-1) which would save thermal energy.

As for now, the solar system cannot completely replace the existing systems for hot water generation and heating support (applies to buildings built in the classical way), but also due to security of system function, herein several thermal solar systems for hot water generation are compared to each other in technical way.

In the principle of all solar systems, thermal energy collected by the collector is drained to the storage tank. For proper operation and maximum utilization of solar energy, it is necessary to measure temperature at several locations (tank, collector, etc.). Temperature differences are input variable to control function of pumps that will work only when the working fluid in the collector of higher temperature than the temperature in the storage tank to avoid cooling water in the storage tank.

During designing process of a solar system for hot water production and/or support for heating, it is very important to select at least minimum volume of the hot water storage tank to take all the heat from the collectors in the hottest days during the summer months.

It is possible to make a simulation model of the solar system for hot water generation, thus a review of data for

Table 6 *Coverage of gas consumption by equivalent solar energy*
Tablica 6. *Pokrivenost potrošnje plina ekvivalentnom solarnom energijom*

Month	Consumed/m^3	Daily production/m^3	Weekly production/m^3	Percentage/%
January	20 295	10,62	329,11	1,62
February	14 540	24,94	698,23	4,80
March	11 611	41,87	1 298,09	11,18
April	7 532	60,23	1 806,79	23,99
May	1 619	83,05	2 574,59	159,02
June	1 256	89,20	2 676,06	213,06
July	1 279	97,82	3 032,34	237,09
August	1 030	92,42	2 865,01	278,16
September	3 113	66,54	1 996,16	64,12
October	7 085	39,45	1 223,04	17,26
November	10 005	15,80	473,99	4,74
December	18 428	7,31	226,53	1,23
Total:	97 793		19 199,94	

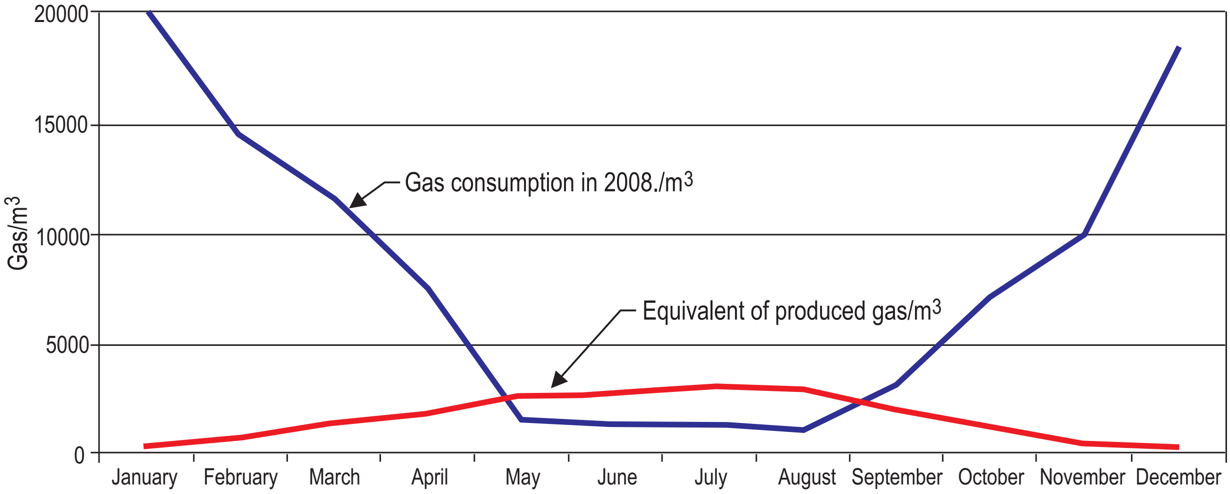

Figure 5 *Coverage of gas consumption by equivalent energy production based on solar system*
Slika 5. *Pokrivenost potrošnje plina ekvivalentom proizvodnje energije solarnim sustavom*

several systems (X/Y, X represents the area of the collector and Y amount of media that heats 1 m^2 collector) are presented in Tab. 7 and Fig. 6.

7 Conclusion
Zaključak

Solar heating is ideal for our region due to a great number of sunny days and relatively high average temperatures in Croatia, which results in higher efficiency of the heating system. The advantage of solar heating, compared with other types, lies in its ecological acceptability and independence (it is applicable in places without local infrastructure). Solar heating system of one object can save 50-60 % of annual energy needs, on the average.

During summer months, conventional water heating system could be put to minimum or totally switched off, eliminating thus harmful gas emission (CO_2), which is the result of conventional fuel combustion.

If solar energy is used for production of thermal energy, it yields significant financial savings. Therefore, loan repayment could be observed in terms of lower gas consumption used for water heating or school heating.

Thermal energy systems could significantly reduce energy consumption for heating sanitary water or school heating. Proper capacity evaluation and installation of solar energy system can provide partial or total self-sufficiency in energy consumption.

While determining the maximum power of the system, it is necessary to take into consideration the time of energy consumption – is it for immediate usage or is it necessary to store energy for later usage. Problems may arise with the heating system if energy accumulation is insufficient or energy tank inadequate. In that case, the collector temperature could rise beyond the acceptable limit.

Potential savings of natural gas are dependent on aspects of applied types of solar collectors (plate, vacuum etc.) and technology types of boiler fed by natural gas (for instance low, medium or high temperature) used for heating and it is the subject of further detailed analysis.

8 References
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Table 7 *Natural gas consumption and equivalent energy produced by solar hot water generation system* [4]
Tablica 7. *Potrošnja prirodnog plina i ekvivalentne energije proizvedene u solarnom sustavu za proizvodnju potrošne tople vode* [4]

Month	Natural gas consumption/m^3	System 20/50 ≈m^3 of gas	System 20/100 ≈m^3 of gas	System 30/50 ≈m^3 of gas	System 50/50 ≈m^3 of gas
January	20295	4600,21	5171,47	7411,72	11500,52
February	14540	7825,39	9126,74	12181,84	19563,48
March	11611	11633,25	13982,16	17776,63	29083,12
April	7532	16606,19	19974,03	24909,28	41515,47
May	1619	18539,09	23214,75	27808,64	46347,74
June	1256	19769,48	24785,11	29654,22	49423,70
July	1279	21791,00	27295,30	32686,50	54477,51
August	1030	20849,71	26057,05	31274,56	52124,27
September	3113	18489,97	22215,21	27734,96	46224,93
October	7085	14340,79	16501,72	21511,19	35851,98
November	10005	6709,35	7556,77	10064,02	16773,37
December	18428	3083,14	3467,45	4624,71	7707,85

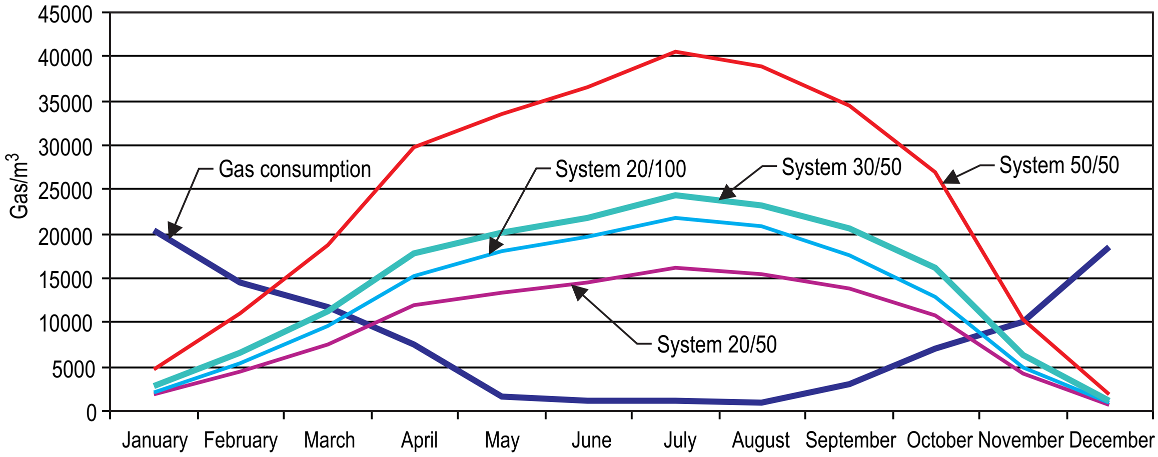

Figure 8 *Natural gas consumption and equivalent energy produced by solar hot water generation system* [4]
Slika 8. *Potrošnja plina i ekvivalentna energija proizvedena u solarnom sustavu za proizvodnju potrošne tople vode* [4]

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