Applying Solar Energy for Water Heating – a Case Study at a Secondary School in Croatia

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Abstract: The paper describes an example of solar energy usage for water heating. Solar energy is suitable for application in Croatia, considering a number of sunny days and high average temperatures in Croatia. Described weather conditions results in high efficiency of heating systems based on solar energy. The most important advantage of solar energy heating, in comparison to other heating systems, is in environmental sustainability. Solar system, applied for water heating, can save an average of 50–60 % annual energy needs. During almost all the year (except winter conditions with extra low temperatures), additional conventional water heating systems work on a minimum power, thus eliminating harmful emissions (CO_2), which occur as a by-product from burning conventional fuels. By transforming solar energy to water thermal energy, considerable financial resources are saved. Investment's repayment of this solar heating 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.

Key words: solar thermal energy, heating system, savings, emissions

1. Introduction

There are many energy sources applied by mankind but renewables are our future. Solar energy is one of the base points of renewables because of its natural transformations in other renewable energy sources indirectly used by engineers to produce applied energy, such as wind energy, water energy, biofuels, energy of tide, sea currents and waves. Also, solar energy is directly transformed to produce electricity (PV distributed generation) and heating energy. Today, climate changes have reached concerned level caused by burning of fossil energy sources which produce harmful emissions of greenhouse gas (CO_2). Mankind vision of possible ways to lead out of this crisis is based on returning to use less detrimental energy sources.

The main energy sources during last two centuries were non-renewable energy sources such as coal and petroleum.

The main problems of non-renewable energy sources are their limited quantity and great amount of environment pollution which very likely causes global temperature increment on the Earth. Renewable energy sources are long term sustainable but with other technical problem – unbalance of energy generation and energy consumption time scheduling.

Renewable sources have an enormous potential, but the present technological development does not make it possible to rely only on these sources. Renewable energy, excluding hydropower, still meets a negligible share of total energy demand. In the near future, this share should be significantly increased due to the known reasons related to non-renewable sources. The Sun delivers to the Earth 15.000 times more energy than mankind's needs. Also, the world distribution of energy consumption is unequal – areas (continents) with high density of energy generation and consumption and areas with neglected energy consumption although there are energy needs. It implies that renewables can and must be better used and that our civilisation should not be depended only on fossil fuel energy. The development of renewables is very important for several reasons:

a) Renewables play an important role in the reduction of CO_2 emission into the atmosphere. This green policy has been accepted by the European Union and Croatia as well.
b) Increased share of renewables improves energy system sustainability. Also, it improves energy supply security by reducing dependence on imported energy resources and electricity.
c) It is expected that renewable energy sources to become economically competitive regarding the conventional energy sources in the medium to long term period.

Several technologies, especially wind energy, small hydro power plants, biomass energy, geothermal energy and solar energy are economically competitive by feeding tariffs usage. It guaranties to attract new investments in renewable energy sources development.

The intensity of solar radiation comprises consists of different wave lengths. The most part (99%) of the solar radiation are in range of wavelengths from 0,275 μm to 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 then 0,75 μm) represented by 49,5% of the global energy of solar radiation Knezevic–Zidar (n.d.). Due to the Earth spherical shape, its elliptical orbit around the Sun, the inclination against orbital plane and rotation around its own axis, energy coming from the Sun is not uniformly distributed on the surface of the Earth and it changes year-round and during the day. In fact, the Sun's altitude on the horizon is changed, which implies the change of the solar radiation angle on the ground, furthermore, the day length and finally the distance between the Earth and the Sun. As all these changes are well known, solar radiation could be calculated at any period of the day or at any position of the upper atmosphere boundaries. The total solar radiation on the Earth surface consists of direct, diffused and reflected radiation. The sum of these radiation components form the total radiation, presented on Figure 1.

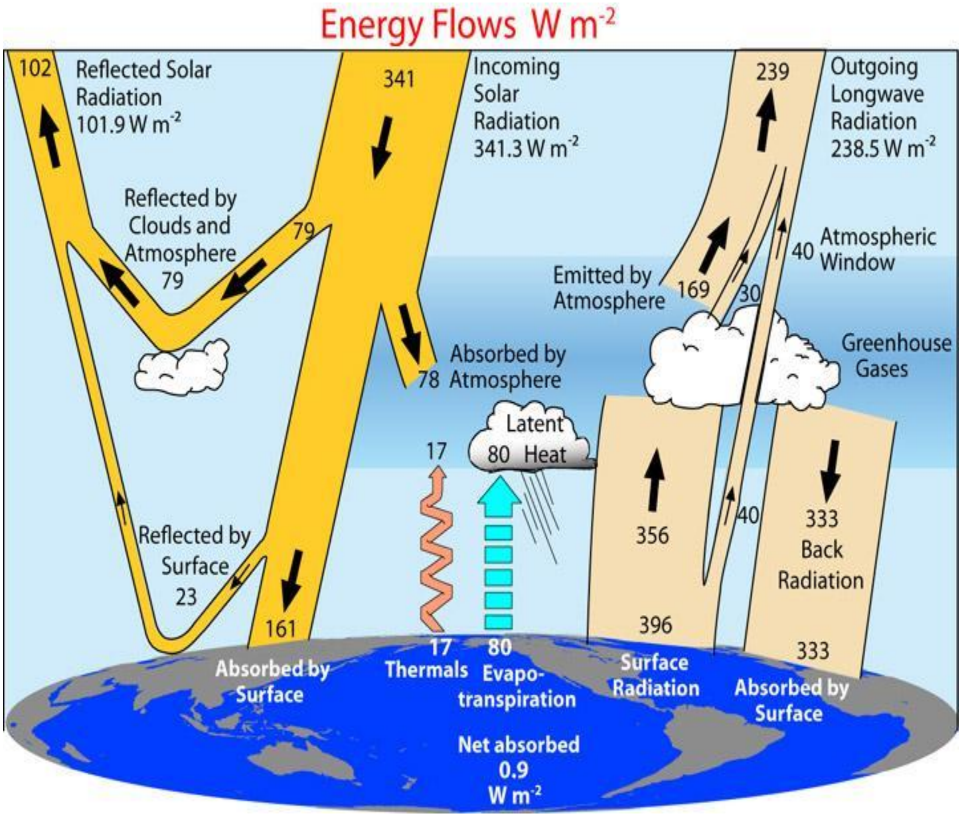

Figure 1. Solar radiation on the Earth (Google images…)

2. Solar radiation in the south east Europe (Danube Region)

Approximation of the available solar potential for a certain location is facilitated by the data bases (for example PVGIS, NASA, Meteonom database), which contain data on the solar radiation intensity, ambient temperature, average daily temperature etc.

All given data from data bases have been calculated based on satellite measurements of extraterrestrial radiation above the Earth atmosphere.

Most often used tool for cost-effective exploitation of solar energy is an irradiation maps, which show the level of irradiation of a certain areas on the Earth. Thus, by observing the irradiation map of south – east Europe (Figure 2), it is obvious that the total annual amount of solar radiation increases from the northwest to the southeast, which is in accordance with the latitude change. According to the PVGIS (Photovoltaic Geographical Information System) data, the optimal annual angle is also changed. It should be noted that the optimal angle changes day by day during the year due to a seeming Sun movement (PVGIS).

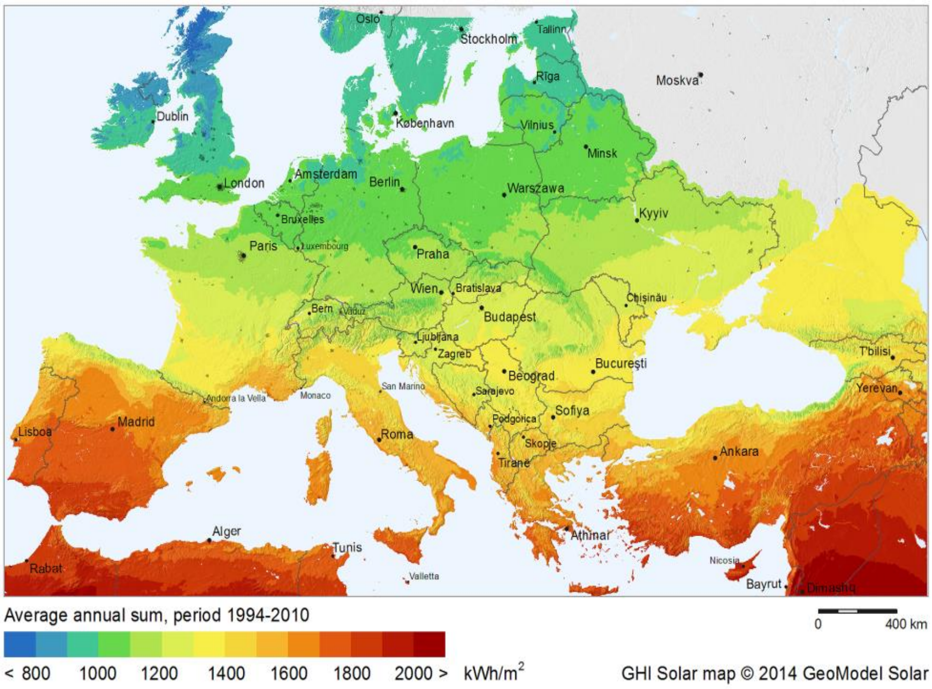

Figure 2. Total annual irradiation on horizontal plane (PVGIS)

3. Solar heating energy system

3.1. Collectors of solar radiation

Collectors that directly convert the energy of solar radiation into thermal 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 temperature of the operating medium up to 200°C, but usually it is bellow 100°C;
- high-temperature collectors – they use bigger surfaces for focussing 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

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 weeks without sufficient solar energy.

4. Application of solar energy system – case study

4.1. Secondary school 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 Table 1. The table presents gas consumption in the period of 2007 until 2009 (*Srednja*...).

Significant thermal energy consumption, as shown in Table 1, refers to gas consumption from 2007 to 2013. 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.

Table 1. Overview of natural gas consumption V (m^3) per months from 2007 to 2013 (*Srednja*...)
(The table does not provide gas consumption for metalworking in the workshop)

Month	Average	2007	2008	2009	2010	2011	2012	2013
	V (m^3)							
January	17,557.86	11,181	20,295	15,438	17,543	19,952	20,151	18,325
February	13,523.57	11,803	14,540	13,927	12,852	14,231	13,987	13,325
March	11,268.71	9,853	11,611	11,197	10,835	11,562	12,035	11,788
April	5,127.57	4,276	7,532	4,060	4,652	4,951	5,124	5,298
May	1,629.57	1,490	1,619	1,785	1,645	1,712	1,543	1,613
June	1,192.71	1,309	1,256	1,027	1,123	1,254	1,201	1,179
July	1,070.17		1,279	904	1,002	1,120	1,097	1,019
August	1,041.33		1,030	952	987	1,102	1,086	1,091
September	2,648.30	1,546	3,113	2,871	2,718	2,914	2,875	2,501
October	6,768.86	7,098	7,085	6,328	6,283	6,814	6,901	6,873
November	12,657.43	15,675	10,005	11,093	11,688	13,541	13,848	12,752
December	17,234.71	15,215	18,428	17,109	17,654	17,988	17,530	16,719

During the day, some real measurements were performed at school once per hour. Based on the results given in Table 2 and graphic presentation in Figure 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 consists of steel plate 200 × 300 × 18 mm, 2 pieces and digital thermometer Metalflex DT 850. There are 3 measurement points (dimensions of 400 × 500 × 180 mm): MP0, without cover glass; MP1, with single glass and MP2, with double glass. Here in Table 2, there are measured temperatures for two measurement points MP0 and MP2.

It is easy to see from Table 2 and Figure 3 that despite the clouds in the sky, a certain amount of energy input was received at the measurement points, which led to temperature rise.

5. Solar energy applied for heating

The secondary school must be heated in the long period (October – March at least) together with the gym and it causes significant costs for space heating and water heating during the school year. The present system of central heating, based on natural gas, meets the school needs. Installation of solar collector system applied for solar water heating and as a backup of present space heating system, could decrease consumption of conventional energy sources, namely natural gas, and decrease CO_2 emission into the atmosphere. Natural gas consumption varies during the year and it is significantly higher during winter period.

The solar heating system could be designed in such a way that solar energy is applied in summer months to meet demand for water heating (sport activities) and in transitional periods to meet demand for space heating and/or for solar water heating. During the winter period (shorter periods of solar radiation), solar thermal energy is insufficient, Therefore, it is necessary to use the conventional energy source (like natural gas) in order to meet demand for space heating and water heating. Of course, if solar heating system is additionally applied for apace/water heating, needs for natural gas decrease.

As an example, fluctuations in gas consumption during March are presented with the average temperature oscillations during the day. The solar heating system for heat water production is designed according to school daily needs for hot water (per single user). Hot water accumulation tank's volume (V_S) is calculated to be between minimum and maximum volume:

$$V_{S\min} = 1{,}5 \cdot W_h \quad (5.1)$$

$$V_{S\max} = 2 \cdot W_h \quad (5.2)$$

Table 2. Example of temperature measurements during the day, 18th April 2010

	Ambient temperature / °C	Weather conditions	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

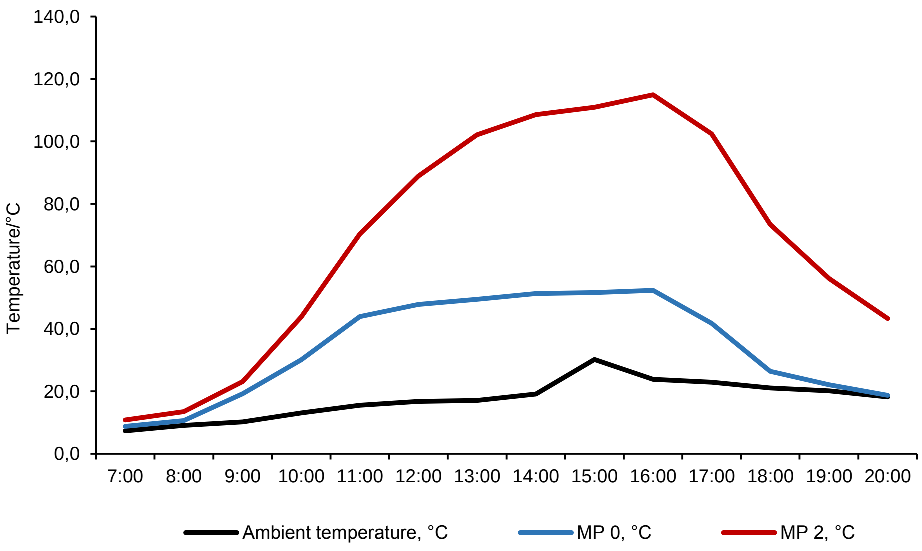

Figure 3. Comparison of measured temperatures during the day, April 18th 2010

Further on, total number of collectors depends on collector's surface P_k as a function of volume of hot water accumulation tank and it should be between minimum and maximum values:

$$P_{k\min} = 1{,}25 \cdot \frac{V_s}{100} \tag{5.3}$$

$$P_{k\max} = 1{,}65 \cdot \frac{V_s}{100} \tag{5.4}$$

Designed solar heating system consists of 30 m^2 solar collectors and heating accumulation reservoir of 1500 l. Design surface of solar collectors is increased to satisfy hot water demands during the winter and additional sport activities in gym which are not included in daily school hot water needs. Vacuum tube collectors has parameters: F_R (τα) = 0.76 and F_{Rk} = 1.6 W/m^2K. Vacuum tube collector is selected due to better performances during low solar radiation.

In the calculation performing, an assumption is adopted that thermal water consumption was 1500 l per hour and the initial water temperature was 20 ºC. Also, water temperature was 80 °C on leaving the reservoir. All calculated data were presented in Table 3 with notified changes during the day. In Table 4, the data for two 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 (Majdandžić 2008).

In order to make an easy comparison, the collector heat (Qk) was expressed as a gas equivalent in m^3 (fuel value of natural gas ranges from 34 to 38 $MJ/N{\cdot}m^3$) (Majdandzic 2008, *Seminar*…).

As the obtained data for energy needs of analyzed building in March, it is possible to do the same for the whole year (Hornung et al. 2010). Calculated data could be compared with the average gas consumption during 2007–2013 and expressed in percentages, as shown in Table 5 and in Figure 4, shows the coverage of natural gas consumption by equivalent solar energy.

If calculated data for the average gas consumption over the years (2007–2013) are analyzed, for the whole year (2008), an average of 91,720.8 m^3 of gas is spent. If solar energy were used to heat DHW and central heating backup, average of 91,720.8 m^3 of natural gas could be saved throughout the year, which in this example is 23.67%. In the same way, a comparison of energy demands for the same object located in several cities in Europe (Danube region) is made. The secondary school building in Valpovo (26 km from Osijek) is compared with the same object (geometry and energy demands) located in different cities of Europe.

Table 3. Water temperature in accumulation reservoir and equivalent of gas consumption during the day

Time	Q_k – collector heat / MJ	q_s – reservoir temperature / °C	Gas equivalent / m^3
8:00	25,6497	24,08	0,71
9:00	55,4480	28,82	1,54
10:00	93,0541	34,81	2,58
11:00	135,0478	41,49	3,75
12:00	178,1075	48,34	4,95
13:00	218,8039	54,81	6,08
14:00	253,8021	60,38	7,05
15:00	280,0535	64,56	7,78
16:00	294,8696	66,92	8,19
17:00	296,8712	67,23	8,25
18:00	288,0049	65,82	8,00

Table 4. Comparison of gas consumption in March

Time period	I (Gas + equivalent solar energy), gas / m^3	II (Gas) / m^3
Day	56.13 + 58.88	115.01
Week	392.87 + 412.17	805.04
Month	1,683.72 + 1,766.43	3,450.15

Table 5. Coverage of gas consumption by equivalent solar energy

Month	Consumed natural gas / m^3	Daily production / m^3	Weekly production / m^3	Percentage / %
January	17,557.90	13.98	433.29	1.62
February	13,523.60	28.14	787.86	4.80
March	11,268.70	58.88	1,825.31	11.18
April	5,127.57	73.97	2,218.97	23.99
May	1,629.57	91.43	2,834.34	159.02
June	1,192.71	96.00	2,880.01	213.06
July	1,070.17	102.60	3,180.55	237.09
August	1,041.33	100.41	3,112.78	278.16
September	2,648.29	67.74	2,032.21	64.12
October	6,768.86	46.38	1,437.78	17.26
November	12,657.40	21.31	639.41	4.74
December	17,234.70	10.66	330.49	1.23
Total	91,720.80		27,712.98	

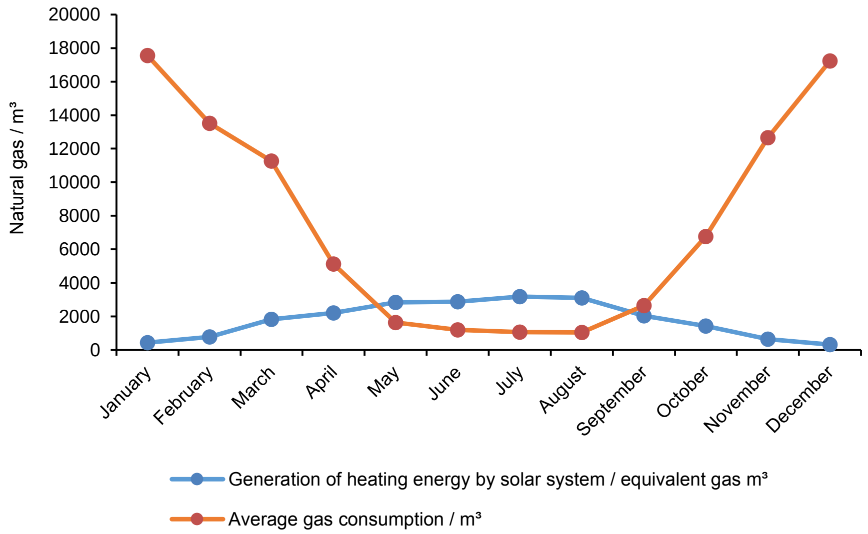

Figure 4. Coverage of gas consumption by equivalent energy production based on solar system

In Figure 5, energy savings are shown for one day in March with installed solar heating system. In Figure 6, there are calculated data of gas cumulative consumption for the same purpose (heating provided hot water) as comparison.

Solar system for domestic hot water (DHW) and / or central heating backup mainly consists of collectors, heat storage, radiator, or the corresponding heaters, automation and control system, as well as classic heater that provide heating energy when solar energy is not sufficient. The system also allows obtaining hot water by means of suitable heat exchangers. Conventional heating device must be sized to meet the needs when the solar contribution is insufficient.

6. Conclusion

Solar heating is suitable for climate area in Croatia, especially in south parts, with plenty of sunshine and relatively high average temperature, and results in greater efficiency of the heating system. The advantage of solar heating compared to other methods is its eco-friendliness, and also in its autonomy (this is applicable in areas without municipal infrastructure). The solar system for heating a building may save 50–60% annual energy needs of the object. During the summer months, the conventional system for hot water producing can be reduced to a minimum or completely shut down and thus remove the harmful emissions (CO_2), formed from the combustion of fossil energy sources. Significant savings of material resources can be achieved by thermal solar energy production.

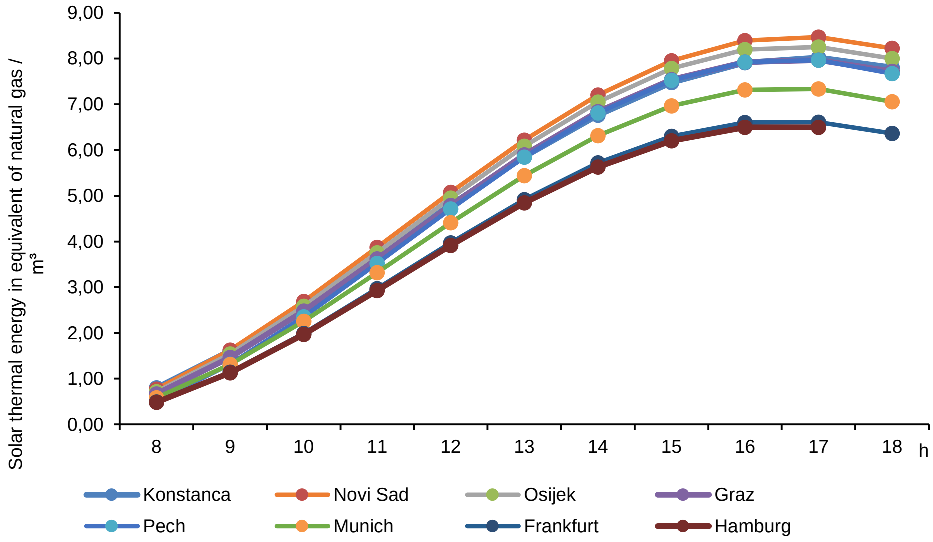

Figure 5. Generation of solar heating energy – equivalent of natural gas / m³

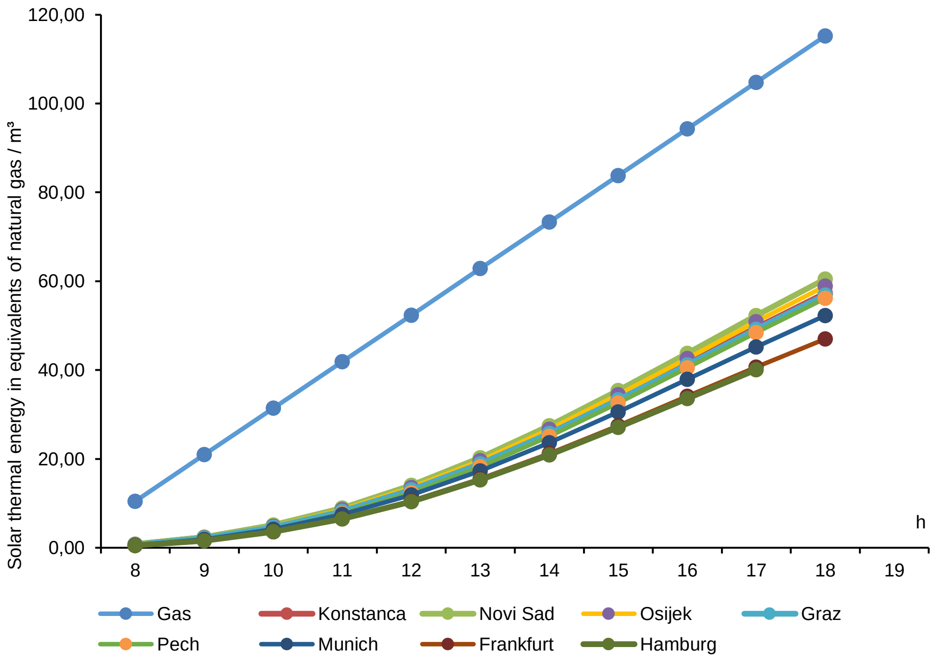

Figure 6. The required amount of natural gas and generation of heating energy of solar system in equivalent m³ of natural gas

Repayment of the solar system is made through the reduction of energy consumption (eg. natural gas) when DHW and/or energy for space heating. Proper size design and settings of the basic heating system, solar thermal energy can be used for partial or complete energy independence of the building. Designing of the solar thermal system should take into account day energy needs to determine the maximum installed heating power of the system, better to say day periods with direct usage of hot water and day periods with postpone usage of hot water (hot water accumulation storage tank).

Conflict of Interest

The authors declare no conflict of interest.

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