Widening the Thermal Solar Energy Exploitation by the Successful Models

WidetheSEEbySuccMode

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Impact Study on the Environment

Authors : Athanasios Kalogeras, Epameinondas Mitronikas, ISI

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1. Executive Summary

WidetheSEEbySuccMod has a stated goal to promote the usage of solar thermal technologies for domestic hot water appliances in the South East Europe area. Widening this market is supportive to European policies relevant to European independence from fossil fuels and to the promotion of the utilisation of Renewable Energy Sources.

The present report represents a study of the impact on the environment of the usage of solar thermal technologies. It is evident that solar energy is a clean energy, yet this report tries to evaluate what is the positive impact on the environment of the substitution of fossil fuel energy by solar energy for domestic hot water appliances.

At first the theoretical background is provided. The formulas relevant to the calculation of the energy consumption required for the production of hot water for domestic usage are given. Then the formulas relevant to the energy output of solar systems are given and formulas for the calculation of equivalent fossil fuel energy and avoided gas emissions are presented.

Based on the regional data for 14 sites of the SEE area, solar system characteristics for 6 different solar collector solutions, and fuel characteristics for light fuel oil and natural gas, calculations have been made.

The calculations show important savings of fossil fuel for each solar thermal system installed. The impact on the environment in terms of CO2 emissions avoided is also quite significant.

An extrapolation of the findings of the study to the 1% of the population of the 14 selected sites show energy savings equivalent to 20,8Mlts of light fuel oil or 15,6Glts of natural gas. CO2 emissions avoided amount to 58,9 Kilotonnes in the case of light fuel oil and 29,7 kilotonnes in the case of natural gas.

An extrapolation from the 14 site population of 11 million to the overall SEE area population or EU population show and from the 1% of affected population to higher percentages, shows that the actual impact on the environment could be huge.

2. Introduction

The Impact Study on the Environment intends to show the impact on the environment by the wider application of solar thermal energy, and more specifically Domestic Hot Water applications.

Chapter 2 provides the theoretical background for the extraction of this information. Chapter 2.1 provides the formulas for the calculation of energy consumption for the production of domestic hot water, while chapter 2.2 addresses the utilisation of solar power to produce the above energy.

Chapter 3 provides the variables that have been used for the application of the theory presented in Chapter 2 in the SEE area.

Chapter 4 provides the findings of the impact study.

Finally, chapter 5 provides a conclusion and discussion.

3. Theoretical Background

3.1. Calculation of energy consumption for producing hot water for domestic use

3.1.1. Domestic hot water volume requirement

European regulations (prEN 15316-3-1) provide an estimation for the volume of the domestic hot water (DHW) consumed by the residents of a typical building. According to the regulation, the volume of the required DHW can be calculated by:

$$V_W = \frac{\alpha \cdot N_U}{1000} \text{ m}^3\text{/day [1]} \tag{1}$$

where:
α is the unit requirement based on litres of water at 60°C/day
N_U is the number of units to be taken into account

According to the regulation, the values of a and N_U can be provided in a National Annex. If a National Annex is not available, regulation gives a calculation method for this values for domestic use[1]. In a dwelling:

N_U is the Floor area (m^2) of the house, and

[1] The meaning of values N_U and a can be expanded to more building purposes than dwelling, according to prEN 15316-3-1, Annex B

$$\begin{cases} \alpha = \dfrac{62 \cdot \ln(N_U) - 160}{N_U} & if \quad N_U > 30m^2 \\ a = 2 & if \quad 15m^2 \leq N_U \leq 30m^2 \end{cases} \quad [1] \tag{2}$$

The above values of V_W assume a hot water temperature of 60°C and a cold water temperature of 10°C. For different reference temperatures the following formula can be easily extracted:

$$V_{W\theta} = \frac{50}{\vartheta_{hot} - \vartheta_{cold}} \cdot \frac{\alpha \cdot N_U}{1000} \tag{3}$$

where
ϑ_{hot} is the hot water temperature
ϑ_{cold} is the cold water temperature.

3.1.2. Energy of delivered hot water based on required volume

According to prEN 15316-3-1 the energy content of the domestic hot water delivered to the user (Q_W) can be calculated as:

$$Q_W = 967.54 \cdot V_{W\theta} \cdot \left(\theta_{W,t} - \theta_{W,o}\right) \text{ [1]} \tag{4}$$

where
$V_{W\vartheta}$ is the volume of DHW delivered at specified temperature (m^3/day)
$\theta_{W,t}$ is the specified temperature of DHW at tapping point , °C
$\theta_{W,o}$ is the temperature of the inlet water , °C

3.1.3. Required energy of produced hot water

In order to take account of the unavoidable water thermal losses during standby and the piping losses, the produced hot water energy has been augmented using the mathematical formula:

$$Q_{WP} = \lambda_{stdby} \cdot \lambda_p \cdot Q_W \tag{5}$$

where
λ_{stdby} is the standby thermal losses coefficient.
λ_p is the piping thermal losses coefficient.

Typical values used in this study are λ_{stdby}=1.20 and λ_p=1.14.

3.2. Utilization of solar power to heat water for domestic applications

3.2.1. Solar energy potential

The calculation of the exact amount of solar energy radiated to the earth surface is a very complicated task, which requires efficient calculations of the sun activity and orbit, as well as meteorological information about cloud presence and atmosphere clearness at a specific area of interest. However, a wide variety of statistical data are available through the net, making the calculation of solar activity data a matter of lookup table indexing [2], [3]. Most of these data are based on orbit calculation models and do not take account of the clouding, which should be additionally introduced as a loss factor. Data for most places in the world, including Europe, are mostly available in the form of monthly irradiation. Irradiation is available as either horizontal irradiance or irradiation at an optimal angle, which depends on the local area latitude. Therefore, is essential that two more calculations can be made:

1. Transform of the horizontal irradiance or optimal angle irradiance to solar panel surface irradiance (taking account of the solar panel tilt).
2. Calculation of the daily distribution of the solar energy, in order to calculate more accurately the utilizable solar energy.

3.2.2. Solar radiation on a specific surface [4]

The power incident on a solar energy collector depends on the power contained in the sunlight, and also on the angle between the collector and the sun. When the absorbing surface (collector) and the sunlight are perpendicular to each other, the power density on the surface is equal to that of the sunlight (in other words, the power density will always be at its maximum when the collector is perpendicular to the sun). However, as the angle between the sun and a fixed surface is continually changing, the power density on a fixed collector is less than that of the incident sunlight.

The amount of solar radiation incident on a tilted module surface is the component of the incident solar radiation which is perpendicular to the module surface. If the horizontal surface of the earth is related to the sun beam which is guided to the surface, then the solar energy at the horizontal surface ($H_{horizontal}$) is related to the total sun energy ($H_{incident}$ which is also the optimal angle energy) according to the equation:

$$H_{horizontal} = H_{incident} \cdot \sin\rho \tag{6}$$

The utilizable solar energy at the collector surface is:

$$H_{\mathrm{mod}} = H_{incident} \cdot \sin(\beta + \rho), \tag{7}$$

where

β is the tilt angle of the module measured from the horizontal surface and

ρ is the elevation angle, given by

$$\rho = 90^o - \varphi + \delta \tag{8}$$

Where ϕ is the latitude and δ is the inclination angle, given as a function of the day of the year (*d*) by:

$$\delta = 23.4^o \cdot \sin\left[\frac{360}{365}\cdot\left(284+d\right)\right] \tag{9}$$

From the above equations it can be concluded that H_{module} can also be expressed as:

$$H_{\text{mod}} = \frac{H_{incident}\cdot\sin\left(\beta+\rho\right)}{\sin\alpha} \tag{10}$$

3.2.3. Calculation of the daily distribution of the solar energy [4]

In order to obtain a fair estimation of the utilizable solar energy, the distribution of solar energy during the day has to be calculated. It is again impossible to take account of all the parameters that affect the daily insolation, however it is possible to calculate the daily distribution based on the solar elevation angle.
Solar elevation angle is calculated as:

$$\gamma = Elevation = \sin^{-1}\left[\sin\delta\cdot\sin\varphi - \cos\delta\cdot\cos\varphi\cdot\cos\left(HRA\right)\right], \tag{11}$$

where the hour angle is given by

$$HRA = 15^o\cdot\left(LocalSolarTime - 12\right) \tag{12}$$

It is straightforward that in the energy calculations negative values for γ have no sense, therefore in the calculation of the elevation negative values are replaced with zero, resulting to:

$$\begin{cases}\gamma' = \gamma & if \quad \gamma > 0\\ \gamma' = 0 & if \quad \gamma < 0\end{cases} \tag{13}$$

Taking all the above into account, the hourly solar irradiance in a typical day of the year can be approximated(2) as a fraction of the acquired daily irradiance, according to:

$$H_{hourly} = \frac{\sin\gamma'}{\int_0^{24h}\sin\gamma' dt}\cdot H_{daily} \tag{14}$$

Note 2: In the case study that has been presented (excel sheet) solar irradiation distribution approximation has been realized assuming a day in the middle of each month as a typical day.

3.2.4. Calculation of the energy acquired by the solar system

The European Solar Thermal Industry Federation has proposed a simple methodology for calculation of the energy delivery of Solar Thermal systems. This methodology is based on manufacturer-provided efficiency parameters, which are:

Zero loss efficiency:	η_o
1st order heat loss efficiency:	a_1
2nd order heat loss coefficient:	a_2

The collector efficiency (η) can be expressed as a function of these parameters as:

$$\eta = \eta_o - \frac{\mathrm{a}_1 \cdot (\theta_m - \theta_\mathrm{a})}{H_\mathrm{mod}} - \frac{a_1 \cdot (\theta_m - \theta_\mathrm{a})^2}{H_\mathrm{mod}} \tag{15}$$

The instant solar power transferred through the collector is

$$P_c = A_c \cdot \left(\eta_o \cdot H_\mathrm{mod} - \mathrm{a}_1 \cdot (\theta_m - \theta_\mathrm{a}) - \mathrm{a}_2 \cdot (\theta_m - \theta_\mathrm{a})^2\right), \tag{16}$$

where

H_{mod} is the solar irradiation at the collector surface

ϑ_a is the ambient air temperature

ϑ_m is the collector temperature

A is the active collector area.

From these values, S_{mod} and ϑ_a are environmental data defined by the location.
ϑ_m is a value which is normally not known, except if a detailed simulation software is used. Its value depends on the weather, the load and design of the components of the solar system (collector area and efficiency parameters, storage capacity, heat losses, control) and also on the actual operating conditions at a given point time.
Things become simpler if ϑ_m is assumed constant. This equivalent constant value is dependent not only on the weather but also of the configuration of the solar system, but typical values range from 42^{o}C to 50 ^{o}C [(3)].

Having all the parameters the total energy aquired from the solar panels can be calculated as

$$Q_{collector} = \int P dt = \int \left[A_c \cdot \left(\eta_o \cdot H_\mathrm{mod} - \mathrm{a}_1 \cdot (\theta_{mconst} - \theta_\mathrm{a}) - \mathrm{a}_2 \cdot \left(\theta_{m,const} - \theta_\mathrm{a}\right)^2\right)\right] \tag{17}$$

Note 3: The first versions of the excel sheet that has been developed in order to provide an easy-to use tool for energy calculations (1.0, 1.2), use a constant estimated value of ϑ_m for all regions. An attempt for calculation of a value of ϑ_m using environmental data and utilising the data extractred by the simulations provided by ANATOLIKI has been made in version 1.4. In this version, the value is automatically calculated using from the equation $\theta_m = \theta_\mathrm{a} + 0.06 \cdot A_c \cdot H_\mathrm{mod}$, where the coefficient 0.06 has been extracted from the simulation data. This approach can be obtained if the collector temperature value is left blank and has been proven to give a more accurate approach for the calculation of the total solar energy aquired by the sun.

3.2.5. Calculation of the solar system output[5]

According to the proposed methodology of the European Solar Thermal Industry Federation, the energy content of the output of the solar system, taking into account the collector loop losses, can be calculated as:

$$Q_{out} = Q_{collector} \cdot f_{col-sys} \tag{18}$$

where actually the factor $f_{col-sys}$ represents the collector loop losses.

3.2.6. Calculation Fuel Savings[5] and avoided CO_2 emissions

According to the proposed methodology of the European Solar Thermal Industry Federation, the saved fuel energy (Q_{fs}) can be calculated from the output energy according to the following expression:

$$Q_{fs} = Q_{out} \cdot f_{ss}, \tag{19}$$

where f_{ss} is the fuel saving coefficient. Typical values for this coefficient are 1.38 if fuel savings are referred to relatively high efficiency oil heaters and 1 if electrical heating is considered. Alternatively, the fuel saving coefficient can be expressed as

$$f_{ss} = \frac{Q_{out} + Q_{stdby}}{\eta_{boiler} \cdot Q_{out}} = \frac{1}{\eta_{boiler}} + \frac{Q_{stdby}}{\eta_{boiler} \cdot Q_{out}}$$

Finally, the amount of fuel can be calculated using the net heating value of the corresponding fuel. Typical heating values and CO_2 emissions of currently used fuels are shown in Table 1

Table 1: Energy content of fossil fuels

Fuel	Energy content (kWh/m^3)	CO2 emissions (kg/m^3)
Light Fuel oil	10.745x10^{-3}	2830
Natural Gas	10.65	1.9

4. Impact Study Variables

4.1. Regional Analysis

The impact on the environment for different areas of South East Europe requires a regional analysis for these areas. The different project partners contributed regional data for the following areas.

Austria, Guessing

Austria, Guessing
47,07 ° North
16,32 ° East
225 m
45 degrees

No of Days	Daily irradiation @ optimal angle	Cold Water Temperature	Average Ambient Temperature	Monthly irradiation @ optimal angle	Monthly Irradiation @ Collector Surface	Monthly Irradiation @ Collector Surface	Useful energy
31	1270 Wh/m^2	10 °C	-2,7 °C	39,37 kWh/m^2	36,15 kWh/m^2	249,42 kWh	0,00 kWh
28	2160 Wh/m^2	11 °C	1,6 °C	60,48 kWh/m^2	58,32 kWh/m^2	402,41 kWh	60,97 kWh
31	3100 Wh/m^2	11 °C	4,6 °C	96,10 kWh/m^2	95,75 kWh/m^2	660,68 kWh	169,02 kWh
30	4200 Wh/m^2	12 °C	9,9 °C	126,00 kWh/m^2	124,97 kWh/m^2	862,27 kWh	289,67 kWh
31	5200 Wh/m^2	13 °C	14,6 °C	161,20 kWh/m^2	154,38 kWh/m^2	1065,24 kWh	401,37 kWh
30	5300 Wh/m^2	14 °C	17,9 °C	159,00 kWh/m^2	148,19 kWh/m^2	1022,54 kWh	378,05 kWh
31	5320 Wh/m^2	14 °C	19,2 °C	164,92 kWh/m^2	155,51 kWh/m^2	1073,03 kWh	409,57 kWh
31	4800 Wh/m^2	14 °C	19,4 °C	148,80 kWh/m^2	145,70 kWh/m^2	1005,34 kWh	392,27 kWh
30	3420 Wh/m^2	13 °C	15,8 °C	102,60 kWh/m^2	102,60 kWh/m^2	707,94 kWh	213,58 kWh
31	2150 Wh/m^2	12 °C	8,6 °C	66,65 kWh/m^2	65,27 kWh/m^2	450,38 kWh	61,48 kWh
30	1290 Wh/m^2	11 °C	5,3 °C	38,70 kWh/m^2	36,08 kWh/m^2	248,93 kWh	0,00 kWh
31	980 Wh/m^2	10 °C	0,6 °C	30,38 kWh/m^2	27,44 kWh/m^2	189,35 kWh	0,00 kWh
nual values	**3266 Wh/m^2**	**12,1 °C**	**9,6 °C**	**99,52 kWh/m^2**	**95,86 kWh/m^2**	**661,46 kWh**	**198,00 kWh**
365				**1194,20 kWh/m^2**	**1150,37 kWh/m^2**	**7937,53 kWh**	**2375,97 kWh**

Austria Vienna

Austria, Vienna
47,17 ° North
10,58 ° East
775 m
45 degrees

No of Days	Daily irradiation @ optimal angle	Cold Water Temperature	Average Ambient Temperature	Monthly irradiation @ optimal angle	Monthly Irradiation @ Collector Surface	Monthly Irradiation @ Collector Surface	Useful energy
31	1140 Wh/m^2	10 °C	-2,7 °C	35,34 kWh/m^2	32,42 kWh/m^2	223,72 kWh	0,00 kWh
28	1990 Wh/m^2	11 °C	1,6 °C	55,72 kWh/m^2	53,70 kWh/m^2	370,56 kWh	47,58 kWh
31	2980 Wh/m^2	11 °C	4,6 °C	92,38 kWh/m^2	92,03 kWh/m^2	635,01 kWh	159,50 kWh
30	4180 Wh/m^2	12 °C	9,9 °C	125,40 kWh/m^2	124,40 kWh/m^2	858,35 kWh	295,61 kWh
31	5280 Wh/m^2	13 °C	14,6 °C	163,68 kWh/m^2	156,84 kWh/m^2	1082,20 kWh	424,66 kWh
30	5340 Wh/m^2	14 °C	17,9 °C	160,20 kWh/m^2	149,41 kWh/m^2	1030,96 kWh	394,52 kWh
31	5230 Wh/m^2	14 °C	19,2 °C	162,13 kWh/m^2	152,97 kWh/m^2	1055,52 kWh	407,56 kWh
31	4750 Wh/m^2	14 °C	19,4 °C	147,25 kWh/m^2	144,24 kWh/m^2	995,22 kWh	395,49 kWh
30	3330 Wh/m^2	13 °C	15,8 °C	99,90 kWh/m^2	99,90 kWh/m^2	689,31 kWh	208,69 kWh
31	1990 Wh/m^2	12 °C	8,6 °C	61,69 kWh/m^2	60,39 kWh/m^2	416,71 kWh	48,58 kWh
30	1120 Wh/m^2	11 °C	5,3 °C	33,60 kWh/m^2	31,30 kWh/m^2	215,98 kWh	0,00 kWh
31	890 Wh/m^2	10 °C	0,6 °C	27,59 kWh/m^2	24,90 kWh/m^2	171,82 kWh	0,00 kWh
nual values	**3185 Wh/m^2**	**12,1 °C**	**9,6 °C**	**97,07 kWh/m^2**	**93,54 kWh/m^2**	**645,45 kWh**	**198,52 kWh**
365				**1164,88 kWh/m^2**	**1122,52 kWh/m^2**	**7745,36 kWh**	**2382,20 kWh**

Bulgaria, Varna

Bulgaria, Varna
43,2 ° North
27,92 ° East
56 m
45 degrees

No of Days	Daily irradiation @ optimal angle	Cold Water Temperature	Average Ambient Temperature	Monthly irradiation @ optimal angle	Monthly Irradiation @ Collector Surface	Monthly Irradiation @ Collector Surface	Useful energy
31	2278 Wh/m^2	10 °C	2,4 °C	70,62 kWh/m^2	66,58 kWh/m^2	459,40 kWh	15,99 kWh
28	2854 Wh/m^2	11 °C	4,2 °C	79,91 kWh/m^2	78,31 kWh/m^2	540,34 kWh	60,36 kWh
31	3802 Wh/m^2	11 °C	7,1 °C	117,86 kWh/m^2	117,84 kWh/m^2	813,12 kWh	156,50 kWh
30	4727 Wh/m^2	12 °C	11,6 °C	141,81 kWh/m^2	139,10 kWh/m^2	959,80 kWh	225,52 kWh
31	5568 Wh/m^2	13 °C	17,6 °C	172,61 kWh/m^2	161,58 kWh/m^2	1114,90 kWh	290,31 kWh
30	5627 Wh/m^2	14 °C	22 °C	168,81 kWh/m^2	152,85 kWh/m^2	1054,67 kWh	256,03 kWh
31	5883 Wh/m^2	14 °C	24,5 °C	182,37 kWh/m^2	167,48 kWh/m^2	1155,60 kWh	316,25 kWh
31	5785 Wh/m^2	14 °C	24,4 °C	179,34 kWh/m^2	172,74 kWh/m^2	1191,92 kWh	378,55 kWh
30	4943 Wh/m^2	13 °C	19,6 °C	148,29 kWh/m^2	147,93 kWh/m^2	1020,69 kWh	307,71 kWh
31	3983 Wh/m^2	12 °C	14,9 °C	123,47 kWh/m^2	122,33 kWh/m^2	844,08 kWh	210,61 kWh
30	2498 Wh/m^2	11 °C	9,5 °C	74,94 kWh/m^2	71,53 kWh/m^2	493,56 kWh	33,15 kWh
31	1962 Wh/m^2	10 °C	4,2 °C	60,82 kWh/m^2	56,58 kWh/m^2	390,38 kWh	0,12 kWh
nual values	**4159 Wh/m^2**	**12,1 °C**	**13,5 °C**	**126,74 kWh/m^2**	**121,24 kWh/m^2**	**836,54 kWh**	**187,59 kWh**
365				**1520,85 kWh/m^2**	**1454,85 kWh/m^2**	**10038,48 kWh**	**2251,11 kWh**

Croatia, Zagreb

Croatia, Zagreb
45,82 ° North
15,98 ° East
136 m
45 degrees

No of Days	Daily irradiation @ optimal angle	Cold Water Temperature	Average Ambient Temperature	Monthly irradiation @ optimal angle	Monthly Irradiation @ Collector Surface	Monthly Irradiation @ Collector Surface	Useful energy
31	1903 Wh/m^2	10 °C	1,1 °C	58,99 kWh/m^2	54,66 kWh/m^2	377,17 kWh	9,86 kWh
28	2753 Wh/m^2	11 °C	3,7 °C	77,08 kWh/m^2	74,76 kWh/m^2	515,83 kWh	83,92 kWh
31	3507 Wh/m^2	11 °C	8,2 °C	108,72 kWh/m^2	108,50 kWh/m^2	748,63 kWh	165,44 kWh
30	4363 Wh/m^2	12 °C	12,7 °C	130,89 kWh/m^2	129,42 kWh/m^2	893,00 kWh	237,85 kWh
31	5029 Wh/m^2	13 °C	17,9 °C	155,90 kWh/m^2	148,29 kWh/m^2	1023,22 kWh	285,56 kWh
30	5133 Wh/m^2	14 °C	21,4 °C	153,99 kWh/m^2	142,27 kWh/m^2	981,69 kWh	262,85 kWh
31	5623 Wh/m^2	14 °C	22,7 °C	174,31 kWh/m^2	163,06 kWh/m^2	1125,13 kWh	357,44 kWh
31	5228 Wh/m^2	14 °C	22,5 °C	162,07 kWh/m^2	157,94 kWh/m^2	1089,77 kWh	367,61 kWh
30	4507 Wh/m^2	13 °C	17,8 °C	135,21 kWh/m^2	135,17 kWh/m^2	932,67 kWh	304,02 kWh
31	3070 Wh/m^2	12 °C	13,9 °C	95,17 kWh/m^2	93,60 kWh/m^2	645,84 kWh	129,33 kWh
30	1763 Wh/m^2	11 °C	7,6 °C	52,89 kWh/m^2	49,71 kWh/m^2	343,00 kWh	1,42 kWh
31	1279 Wh/m^2	10 °C	2 °C	39,65 kWh/m^2	36,18 kWh/m^2	249,62 kWh	0,00 kWh
nual values	**3680 Wh/m^2**	**12,1 °C**	**12,6 °C**	**112,07 kWh/m^2**	**107,80 kWh/m^2**	**743,80 kWh**	**183,78 kWh**
365				**1344,87 kWh/m^2**	**1293,56 kWh/m^2**	**8925,59 kWh**	**2205,31 kWh**

FYROM, Skopje

Skopje, FYROM
42 ° North
21,25 ° East
240 m
45 degrees

No of Days	Daily irradiation @ optimal angle	Cold Water Temperature	Average Ambient Temperature	Monthly irradiation @ optimal angle	Monthly Irradiation @ Collector Surface	Monthly Irradiation @ Collector Surface	Useful energy
31	1680 Wh/m²	10 °C	1 °C	52,08 kWh/m²	49,45 kWh/m²	341,24 kWh	0,00 kWh
28	2430 Wh/m²	11 °C	3,3 °C	68,04 kWh/m²	66,95 kWh/m²	461,93 kWh	46,15 kWh
31	3430 Wh/m²	11 °C	7,1 °C	106,33 kWh/m²	106,33 kWh/m²	733,67 kWh	152,71 kWh
30	4200 Wh/m²	12 °C	13,4 °C	126,00 kWh/m²	123,05 kWh/m²	849,07 kWh	208,02 kWh
31	5110 Wh/m²	13 °C	18 °C	158,41 kWh/m²	147,09 kWh/m²	1014,92 kWh	287,77 kWh
30	6120 Wh/m²	14 °C	21 °C	183,60 kWh/m²	164,57 kWh/m²	1135,56 kWh	379,56 kWh
31	6220 Wh/m²	14 °C	24,1 °C	192,82 kWh/m²	175,43 kWh/m²	1210,50 kWh	427,31 kWh
31	5500 Wh/m²	14 °C	23,8 °C	170,50 kWh/m²	163,24 kWh/m²	1126,34 kWh	395,78 kWh
30	4070 Wh/m²	13 °C	19,3 °C	122,10 kWh/m²	121,59 kWh/m²	839,00 kWh	234,02 kWh
31	2750 Wh/m²	12 °C	12,7 °C	85,25 kWh/m²	84,69 kWh/m²	584,33 kWh	83,27 kWh
30	1680 Wh/m²	11 °C	8,3 °C	50,40 kWh/m²	48,41 kWh/m²	334,04 kWh	0,00 kWh
31	1340 Wh/m²	10 °C	4,5 °C	41,54 kWh/m²	38,95 kWh/m²	268,76 kWh	0,00 kWh
nual values	**3711 Wh/m²**	**12,1 °C**	**13,0 °C**	**113,09 kWh/m²**	**107,48 kWh/m²**	**741,61 kWh**	**184,55 kWh**
365				**1357,07 kWh/m²**	**1289,76 kWh/m²**	**8899,35 kWh**	**2214,59 kWh**

Greece, Patras

Greece, Patras
38,25 ° North
21,733 ° East
52 m
45 degrees

No of Days	Daily irradiation @ optimal angle	Cold Water Temperature	Average Ambient Temperature	Monthly irradiation @ optimal angle	Monthly Irradiation @ Collector Surface	Monthly Irradiation @ Collector Surface	Useful energy
31	1940 Wh/m²	10 °C	10 °C	60,14 kWh/m²	58,22 kWh/m²	401,71 kWh	0,00 kWh
28	2600 Wh/m²	11 °C	10,6 °C	72,80 kWh/m²	72,33 kWh/m²	499,05 kWh	15,74 kWh
31	3620 Wh/m²	11 °C	12,5 °C	112,22 kWh/m²	111,96 kWh/m²	772,50 kWh	97,42 kWh
30	4880 Wh/m²	12 °C	15,6 °C	146,40 kWh/m²	140,61 kWh/m²	970,22 kWh	202,18 kWh
31	5800 Wh/m²	13 °C	20,1 °C	179,80 kWh/m²	162,23 kWh/m²	1119,37 kWh	267,59 kWh
30	7080 Wh/m²	14 °C	24,1 °C	212,40 kWh/m²	183,82 kWh/m²	1268,39 kWh	373,48 kWh
31	6930 Wh/m²	14 °C	26,4 °C	214,83 kWh/m²	189,21 kWh/m²	1305,56 kWh	392,33 kWh
31	6200 Wh/m²	14 °C	26,7 °C	192,20 kWh/m²	179,99 kWh/m²	1241,92 kWh	380,73 kWh
30	4830 Wh/m²	13 °C	23,5 °C	144,90 kWh/m²	143,13 kWh/m²	987,59 kWh	247,78 kWh
31	3160 Wh/m²	12 °C	19 °C	97,96 kWh/m²	97,84 kWh/m²	675,09 kWh	70,63 kWh
30	2000 Wh/m²	11 °C	14,5 °C	60,00 kWh/m²	58,60 kWh/m²	404,35 kWh	0,00 kWh
31	1560 Wh/m²	10 °C	11,4 °C	48,36 kWh/m²	46,35 kWh/m²	319,80 kWh	0,00 kWh
nual values	**4217 Wh/m²**	**12,1 °C**	**17,9 °C**	**128,50 kWh/m²**	**120,36 kWh/m²**	**830,46 kWh**	**170,66 kWh**
365				**1542,01 kWh/m²**	**1444,28 kWh/m²**	**9965,55 kWh**	**2047,88 kWh**

Greece, Thessaloniki

Greece, Thessaloniki
40,22 ° North
22,97 ° East
35 m
45 degrees

No of Days	Daily irradiation @ optimal angle	Cold Water Temperature	Average Ambient Temperature	Monthly irradiation @ optimal angle	Monthly Irradiation @ Collector Surface	Monthly Irradiation @ Collector Surface	Useful energy
31	2362 Wh/m²	10 °C	5,6 °C	73,22 kWh/m²	70,21 kWh/m²	484,45 kWh	5,29 kWh
28	2959 Wh/m²	11 °C	7,4 °C	82,85 kWh/m²	81,94 kWh/m²	565,39 kWh	45,60 kWh
31	3825 Wh/m²	11 °C	10,4 °C	118,58 kWh/m²	118,51 kWh/m²	817,69 kWh	122,19 kWh
30	5070 Wh/m²	12 °C	14,8 °C	152,10 kWh/m²	147,46 kWh/m²	1017,45 kWh	224,03 kWh
31	5534 Wh/m²	13 °C	20,7 °C	171,55 kWh/m²	157,24 kWh/m²	1084,95 kWh	232,34 kWh
30	6289 Wh/m²	14 °C	25,5 °C	188,67 kWh/m²	166,44 kWh/m²	1148,43 kWh	281,59 kWh
31	6281 Wh/m²	14 °C	27,7 °C	194,71 kWh/m²	174,56 kWh/m²	1204,46 kWh	311,82 kWh
31	5915 Wh/m²	14 °C	27,3 °C	183,37 kWh/m²	173,82 kWh/m²	1199,39 kWh	341,97 kWh
30	5124 Wh/m²	13 °C	22,5 °C	153,72 kWh/m²	152,58 kWh/m²	1052,77 kWh	287,19 kWh
31	4185 Wh/m²	12 °C	17,6 °C	129,74 kWh/m²	129,28 kWh/m²	892,01 kWh	202,30 kWh
30	2799 Wh/m²	11 °C	11,6 °C	83,97 kWh/m²	81,34 kWh/m²	561,27 kWh	42,22 kWh
31	1645 Wh/m²	10 °C	6,7 °C	51,00 kWh/m²	48,34 kWh/m²	333,57 kWh	0,00 kWh
nual values	**4332 Wh/m²**	**12,1 °C**	**16,5 °C**	**131,96 kWh/m²**	**125,14 kWh/m²**	**863,49 kWh**	**174,71 kWh**
365				**1583,47 kWh/m²**	**1501,71 kWh/m²**	**10361,83 kWh**	**2096,54 kWh**

Greece, Xanthi

Greece, Xanthi
41,08 ° North
24,52 ° East
160 m
45 degrees

No of Days	Daily irradiation @ optimal angle	Cold Water Temperature	Average Ambient Temperature	Monthly irradiation @ optimal angle	Monthly Irradiation @ Collector Surface	Monthly Irradiation @ Collector Surface	Useful energy
31	2260 Wh/m^2	10 °C	3,4 °C	70,06 kWh/m^2	66,87 kWh/m^2	461,42 kWh	15,73 kWh
28	2920 Wh/m^2	11 °C	4,9 °C	81,76 kWh/m^2	80,67 kWh/m^2	556,62 kWh	69,09 kWh
31	3840 Wh/m^2	11 °C	7,4 °C	119,04 kWh/m^2	119,02 kWh/m^2	821,22 kWh	166,41 kWh
30	4970 Wh/m^2	12 °C	11,9 °C	149,10 kWh/m^2	145,08 kWh/m^2	1001,05 kWh	263,25 kWh
31	5360 Wh/m^2	13 °C	17,4 °C	166,16 kWh/m^2	153,28 kWh/m^2	1057,60 kWh	264,64 kWh
30	5710 Wh/m^2	14 °C	21,7 °C	171,30 kWh/m^2	152,31 kWh/m^2	1050,94 kWh	266,13 kWh
31	5900 Wh/m^2	14 °C	24,3 °C	182,90 kWh/m^2	165,17 kWh/m^2	1139,67 kWh	318,95 kWh
31	5600 Wh/m^2	14 °C	23,9 °C	173,60 kWh/m^2	165,38 kWh/m^2	1141,11 kWh	353,22 kWh
30	4850 Wh/m^2	13 °C	19,2 °C	145,50 kWh/m^2	144,67 kWh/m^2	998,20 kWh	298,37 kWh
31	3830 Wh/m^2	12 °C	14,5 °C	118,73 kWh/m^2	118,15 kWh/m^2	815,22 kWh	193,30 kWh
30	2510 Wh/m^2	11 °C	9,3 °C	75,30 kWh/m^2	72,66 kWh/m^2	501,33 kWh	37,84 kWh
31	1740 Wh/m^2	10 °C	4,8 °C	53,94 kWh/m^2	50,87 kWh/m^2	351,02 kWh	0,00 kWh
nual values	**4124 Wh/m^2**	**12,1 °C**	**13,6 °C**	**125,62 kWh/m^2**	**119,51 kWh/m^2**	**824,62 kWh**	**187,24 kWh**
365				**1507,39 kWh/m^2**	**1434,12 kWh/m^2**	**9895,40 kWh**	**2246,93 kWh**

Hungary, Budapest

Hungary, Budapest
47,43 ° North
19,18 ° East
114 m
45 degrees

No of Days	Daily irradiation @ optimal angle	Cold Water Temperature	Average Ambient Temperature	Monthly irradiation @ optimal angle	Monthly Irradiation @ Collector Surface	Monthly Irradiation @ Collector Surface	Useful energy
31	1527 Wh/m^2	10 °C	-0,3 °C	47,34 kWh/m^2	43,34 kWh/m^2	299,08 kWh	0,00 kWh
28	2427 Wh/m^2	11 °C	2,4 °C	67,96 kWh/m^2	65,41 kWh/m^2	451,36 kWh	42,98 kWh
31	3566 Wh/m^2	11 °C	6,7 °C	110,55 kWh/m^2	110,08 kWh/m^2	759,57 kWh	161,74 kWh
30	4785 Wh/m^2	12 °C	13 °C	143,55 kWh/m^2	142,48 kWh/m^2	983,14 kWh	285,24 kWh
31	5414 Wh/m^2	13 °C	18,4 °C	167,83 kWh/m^2	161,04 kWh/m^2	1111,16 kWh	324,52 kWh
30	5660 Wh/m^2	14 °C	21,4 °C	169,80 kWh/m^2	158,64 kWh/m^2	1094,65 kWh	321,98 kWh
31	6064 Wh/m^2	14 °C	23,1 °C	187,98 kWh/m^2	177,65 kWh/m^2	1225,78 kWh	409,05 kWh
31	5493 Wh/m^2	14 °C	22,8 °C	170,28 kWh/m^2	166,95 kWh/m^2	1151,96 kWh	393,28 kWh
30	4627 Wh/m^2	13 °C	17,9 °C	138,81 kWh/m^2	138,81 kWh/m^2	957,78 kWh	307,96 kWh
31	3337 Wh/m^2	12 °C	13,2 °C	103,45 kWh/m^2	101,18 kWh/m^2	698,11 kWh	156,30 kWh
30	1862 Wh/m^2	11 °C	6,6 °C	55,86 kWh/m^2	51,95 kWh/m^2	358,42 kWh	2,86 kWh
31	1163 Wh/m^2	10 °C	0,4 °C	36,05 kWh/m^2	32,47 kWh/m^2	224,03 kWh	0,00 kWh
nual values	**3827 Wh/m^2**	**12,1 °C**	**12,1 °C**	**116,62 kWh/m^2**	**112,50 kWh/m^2**	**776,25 kWh**	**200,49 kWh**
365				**1399,46 kWh/m^2**	**1350,01 kWh/m^2**	**9315,04 kWh**	**2405,91 kWh**

Italy, Teramo

Italy, Teramo
42,65 ° North
13,7 ° East
265 m
45 degrees

No of Days	Daily irradiation @ optimal angle	Cold Water Temperature	Average Ambient Temperature	Monthly irradiation @ optimal angle	Monthly Irradiation @ Collector Surface	Monthly Irradiation @ Collector Surface	Useful energy
31	1779,3 Wh/m^2	10 °C	5,1 °C	55,16 kWh/m^2	52,18 kWh/m^2	360,03 kWh	0,00 kWh
28	2636,2 Wh/m^2	11 °C	5,9 °C	73,81 kWh/m^2	72,47 kWh/m^2	500,06 kWh	43,70 kWh
31	3757,1 Wh/m^2	11 °C	9 °C	116,47 kWh/m^2	116,47 kWh/m^2	803,62 kWh	160,28 kWh
30	4936,9 Wh/m^2	12 °C	12,8 °C	148,11 kWh/m^2	145,00 kWh/m^2	1000,47 kWh	267,19 kWh
31	5962,3 Wh/m^2	13 °C	16,8 °C	184,83 kWh/m^2	172,39 kWh/m^2	1189,49 kWh	354,73 kWh
30	6508,7 Wh/m^2	14 °C	21,4 °C	195,26 kWh/m^2	176,00 kWh/m^2	1214,38 kWh	378,83 kWh
31	6414,4 Wh/m^2	14 °C	24 °C	198,85 kWh/m^2	181,84 kWh/m^2	1254,71 kWh	399,53 kWh
31	5474,2 Wh/m^2	14 °C	23,6 °C	169,70 kWh/m^2	163,02 kWh/m^2	1124,82 kWh	345,80 kWh
30	4259,5 Wh/m^2	13 °C	20,4 °C	127,79 kWh/m^2	127,38 kWh/m^2	878,92 kWh	218,22 kWh
31	3020,1 Wh/m^2	12 °C	15,1 °C	93,62 kWh/m^2	92,87 kWh/m^2	640,84 kWh	86,81 kWh
30	1884,1 Wh/m^2	11 °C	10,4 °C	56,52 kWh/m^2	54,11 kWh/m^2	373,37 kWh	0,00 kWh
31	1452,1 Wh/m^2	10 °C	6,6 °C	45,02 kWh/m^2	42,03 kWh/m^2	290,00 kWh	0,00 kWh
nual values	**4007 Wh/m^2**	**12,1 °C**	**14,3 °C**	**122,09 kWh/m^2**	**116,31 kWh/m^2**	**802,56 kWh**	**187,93 kWh**
365				**1465,13 kWh/m^2**	**1395,75 kWh/m^2**	**9630,70 kWh**	**2255,10 kWh**

Italy, Torino

Italy, Torino
45,18 ° North
7,65 ° East
506 m
45 degrees

No of Days	Daily irradiation @ optimal angle	Cold Water Temperature	Average Ambient Temperature	Monthly irradiation @ optimal angle	Monthly Irradiation @ Collector Surface	Monthly Irradiation @ Collector Surface	Useful energy
31	1915 Wh/m^2	10 °C	4,4 °C	59,37 kWh/m^2	55,25 kWh/m^2	381,25 kWh	0,00 kWh
28	3052 Wh/m^2	11 °C	6,4 °C	85,46 kWh/m^2	83,11 kWh/m^2	573,43 kWh	78,52 kWh
31	4591 Wh/m^2	11 °C	10,2 °C	142,32 kWh/m^2	142,13 kWh/m^2	980,67 kWh	259,09 kWh
30	4868 Wh/m^2	12 °C	12,8 °C	146,04 kWh/m^2	144,15 kWh/m^2	994,62 kWh	239,94 kWh
31	5089 Wh/m^2	13 °C	17,7 °C	157,76 kWh/m^2	149,51 kWh/m^2	1031,61 kWh	221,07 kWh
30	5832 Wh/m^2	14 °C	21,6 °C	174,96 kWh/m^2	160,89 kWh/m^2	1110,15 kWh	278,25 kWh
31	6256 Wh/m^2	14 °C	23,5 °C	193,94 kWh/m^2	180,64 kWh/m^2	1246,43 kWh	361,22 kWh
31	5956 Wh/m^2	14 °C	23,1 °C	184,64 kWh/m^2	179,46 kWh/m^2	1238,25 kWh	399,18 kWh
30	5154 Wh/m^2	13 °C	19,3 °C	154,62 kWh/m^2	154,52 kWh/m^2	1066,20 kWh	332,44 kWh
31	3700 Wh/m^2	12 °C	15,1 °C	114,70 kWh/m^2	113,03 kWh/m^2	779,93 kWh	163,74 kWh
30	2303 Wh/m^2	11 °C	9,1 °C	69,09 kWh/m^2	65,20 kWh/m^2	449,85 kWh	16,16 kWh
31	1214 Wh/m^2	10 °C	5,3 °C	37,63 kWh/m^2	34,51 kWh/m^2	238,11 kWh	0,00 kWh
nual values	**4161 Wh/m^2**	**12,1 °C**	**14,0 °C**	**126,71 kWh/m^2**	**121,87 kWh/m^2**	**840,87 kWh**	**195,80 kWh**
365				**1520,52 kWh/m^2**	**1462,39 kWh/m^2**	**10090,50 kWh**	**2349,62 kWh**

Romania, Miercurea Ciuc

Romania, Csikszereda
46,367 ° North
25,809 ° East
662 m
45 degrees

No of Days	Daily irradiation @ optimal angle	Cold Water Temperature	Average Ambient Temperature	Monthly irradiation @ optimal angle	Monthly Irradiation @ Collector Surface	Monthly Irradiation @ Collector Surface	Useful energy
31	1190 Wh/m^2	4 °C	-3,4 °C	36,89 kWh/m^2	34,05 kWh/m^2	234,93 kWh	0,00 kWh
28	2060 Wh/m^2	7 °C	-1,1 °C	57,68 kWh/m^2	55,80 kWh/m^2	385,04 kWh	16,30 kWh
31	3440 Wh/m^2	7 °C	2,4 °C	106,64 kWh/m^2	106,36 kWh/m^2	733,85 kWh	158,57 kWh
30	4460 Wh/m^2	10 °C	8,5 °C	133,80 kWh/m^2	132,48 kWh/m^2	914,13 kWh	274,11 kWh
31	5720 Wh/m^2	13 °C	14,3 °C	177,32 kWh/m^2	169,18 kWh/m^2	1167,36 kWh	435,98 kWh
30	6000 Wh/m^2	16 °C	17,6 °C	180,00 kWh/m^2	166,95 kWh/m^2	1151,99 kWh	454,89 kWh
31	6220 Wh/m^2	16 °C	19,4 °C	192,82 kWh/m^2	181,02 kWh/m^2	1249,02 kWh	520,71 kWh
31	5630 Wh/m^2	16 °C	18,7 °C	174,53 kWh/m^2	170,45 kWh/m^2	1176,09 kWh	503,71 kWh
30	3970 Wh/m^2	13 °C	13,6 °C	119,10 kWh/m^2	119,09 kWh/m^2	821,70 kWh	263,26 kWh
31	2820 Wh/m^2	10 °C	9,1 °C	87,42 kWh/m^2	85,82 kWh/m^2	592,18 kWh	111,10 kWh
30	1510 Wh/m^2	7 °C	3,4 °C	45,30 kWh/m^2	42,43 kWh/m^2	292,75 kWh	0,00 kWh
31	993 Wh/m^2	4 °C	-2,2 °C	30,78 kWh/m^2	27,97 kWh/m^2	192,97 kWh	0,00 kWh
nual values	**3668 Wh/m^2**	**10,3 °C**	**8,4 °C**	**111,86 kWh/m^2**	**107,63 kWh/m^2**	**742,67 kWh**	**228,22 kWh**
365				**1342,28 kWh/m^2**	**1291,60 kWh/m^2**	**8912,01 kWh**	**2738,63 kWh**

Romania, Iasi

Romania, Iasi
47,17 ° North
27,6 ° East
41 m
45 degrees

No of Days	Daily irradiation @ optimal angle	Cold Water Temperature	Average Ambient Temperature	Monthly irradiation @ optimal angle	Monthly Irradiation @ Collector Surface	Monthly Irradiation @ Collector Surface	Useful energy
31	1889 Wh/m^2	10 °C	-2 °C	58,56 kWh/m^2	53,73 kWh/m^2	370,71 kWh	0,30 kWh
28	2993 Wh/m^2	11 °C	0,8 °C	83,80 kWh/m^2	80,77 kWh/m^2	557,33 kWh	87,39 kWh
31	4164 Wh/m^2	11 °C	4,8 °C	129,08 kWh/m^2	128,59 kWh/m^2	887,31 kWh	220,54 kWh
30	4733 Wh/m^2	12 °C	11,8 °C	141,99 kWh/m^2	140,86 kWh/m^2	971,91 kWh	248,11 kWh
31	5801 Wh/m^2	13 °C	17,7 °C	179,83 kWh/m^2	172,32 kWh/m^2	1188,98 kWh	346,02 kWh
30	5826 Wh/m^2	14 °C	20,9 °C	174,78 kWh/m^2	163,01 kWh/m^2	1124,79 kWh	308,55 kWh
31	5955 Wh/m^2	14 °C	23 °C	184,61 kWh/m^2	174,18 kWh/m^2	1201,84 kWh	355,32 kWh
31	5997 Wh/m^2	14 °C	22,3 °C	185,91 kWh/m^2	182,10 kWh/m^2	1256,50 kWh	435,34 kWh
30	5103 Wh/m^2	13 °C	16,9 °C	153,09 kWh/m^2	153,09 kWh/m^2	1056,32 kWh	350,62 kWh
31	3850 Wh/m^2	12 °C	11,9 °C	119,35 kWh/m^2	116,84 kWh/m^2	806,20 kWh	206,20 kWh
30	2141 Wh/m^2	11 °C	5,4 °C	64,23 kWh/m^2	59,84 kWh/m^2	412,86 kWh	13,78 kWh
31	1575 Wh/m^2	10 °C	-0,4 °C	48,83 kWh/m^2	44,07 kWh/m^2	304,06 kWh	0,00 kWh
nual values	**4169 Wh/m^2**	**12,1 °C**	**11,1 °C**	**127,00 kWh/m^2**	**122,45 kWh/m^2**	**844,90 kWh**	**214,35 kWh**
365				**1524,06 kWh/m^2**	**1469,39 kWh/m^2**	**10138,81 kWh**	**2572,16 kWh**

Romania, Resita

Romania, Resita
45,18 ° North
21,53 ° East
258 m
45 degrees

No of Days	Daily irradiation @ optimal angle	Cold Water Temperature	Average Ambient Temperature	Monthly irradiation @ optimal angle	Monthly Irradiation @ Collector Surface	Monthly Irradiation @ Collector Surface	Useful energy
31	1889 Wh/m^2	10 °C	1,26 °C	58,56 kWh/m^2	54,50 kWh/m^2	376,07 kWh	0,00 kWh
28	2993 Wh/m^2	11 °C	1,8 °C	83,80 kWh/m^2	81,50 kWh/m^2	562,34 kWh	83,72 kWh
31	4164 Wh/m^2	11 °C	6,38 °C	129,08 kWh/m^2	128,91 kWh/m^2	889,46 kWh	217,74 kWh
30	4733 Wh/m^2	12 °C	12,24 °C	141,99 kWh/m^2	140,15 kWh/m^2	967,03 kWh	242,50 kWh
31	5801 Wh/m^2	13 °C	17,06 °C	179,83 kWh/m^2	170,43 kWh/m^2	1175,94 kWh	339,26 kWh
30	5826 Wh/m^2	14 °C	20,36 °C	174,78 kWh/m^2	160,73 kWh/m^2	1109,00 kWh	299,23 kWh
31	5955 Wh/m^2	14 °C	22,39 °C	184,61 kWh/m^2	171,95 kWh/m^2	1186,46 kWh	344,50 kWh
31	5997 Wh/m^2	14 °C	21,52 °C	185,91 kWh/m^2	180,69 kWh/m^2	1246,77 kWh	427,47 kWh
30	5103 Wh/m^2	13 °C	16,84 °C	153,09 kWh/m^2	152,99 kWh/m^2	1055,65 kWh	346,53 kWh
31	3850 Wh/m^2	12 °C	12,56 °C	119,35 kWh/m^2	117,62 kWh/m^2	811,55 kWh	202,88 kWh
30	2141 Wh/m^2	11 °C	6,1 °C	64,23 kWh/m^2	60,61 kWh/m^2	418,21 kWh	11,40 kWh
31	1575 Wh/m^2	10 °C	2,01 °C	48,83 kWh/m^2	44,77 kWh/m^2	308,91 kWh	0,00 kWh
nual values	**4169 Wh/m^2**	**12,1 °C**	**11,7 °C**	**127,00 kWh/m^2**	**122,07 kWh/m^2**	**842,28 kWh**	**209,60 kWh**
365				**1524,06 kWh/m^2**	**1464,84 kWh/m^2**	**10107,41 kWh**	**2515,22 kWh**

Slovenia, Ljubljana

Slovenia, Ljubljana
46,07 ° North
14,52 ° East
301 m
45 degrees

No of Days	Daily irradiation @ optimal angle	Cold Water Temperature	Average Ambient Temperature	Monthly irradiation @ optimal angle	Monthly Irradiation @ Collector Surface	Monthly Irradiation @ Collector Surface	Useful energy
31	1946 Wh/m^2	10 °C	1,2 °C	60,33 kWh/m^2	55,80 kWh/m^2	385,01 kWh	14,32 kWh
28	2706 Wh/m^2	11 °C	3,4 °C	75,77 kWh/m^2	73,40 kWh/m^2	506,47 kWh	80,48 kWh
31	3531 Wh/m^2	11 °C	7,8 °C	109,46 kWh/m^2	109,21 kWh/m^2	753,54 kWh	170,72 kWh
30	4440 Wh/m^2	12 °C	11,9 °C	133,20 kWh/m^2	131,79 kWh/m^2	909,35 kWh	251,56 kWh
31	4865 Wh/m^2	13 °C	17,3 °C	150,82 kWh/m^2	143,66 kWh/m^2	991,24 kWh	266,35 kWh
30	5135 Wh/m^2	14 °C	20,9 °C	154,05 kWh/m^2	142,59 kWh/m^2	983,84 kWh	266,06 kWh
31	5449 Wh/m^2	14 °C	22,3 °C	168,92 kWh/m^2	158,28 kWh/m^2	1092,10 kWh	335,79 kWh
31	5286 Wh/m^2	14 °C	22 °C	163,87 kWh/m^2	159,85 kWh/m^2	1102,95 kWh	378,87 kWh
30	4238 Wh/m^2	13 °C	17,6 °C	127,14 kWh/m^2	127,11 kWh/m^2	877,09 kWh	265,80 kWh
31	3114 Wh/m^2	12 °C	13,6 °C	96,53 kWh/m^2	94,87 kWh/m^2	654,57 kWh	137,66 kWh
30	2056 Wh/m^2	11 °C	7,6 °C	61,68 kWh/m^2	57,88 kWh/m^2	399,37 kWh	22,28 kWh
31	1421 Wh/m^2	10 °C	2,3 °C	44,05 kWh/m^2	40,11 kWh/m^2	276,79 kWh	0,00 kWh
nual values	**3682 Wh/m^2**	**12,1 °C**	**12,3 °C**	**112,15 kWh/m^2**	**107,88 kWh/m^2**	**744,36 kWh**	**182,49 kWh**
365				**1345,81 kWh/m^2**	**1294,54 kWh/m^2**	**8932,33 kWh**	**2189,88 kWh**

Ukraine, Odessa

Ukraine, Odessa
46,48 ° North
30,63 ° East
0 m
45 degrees

No of Days	Daily irradiation @ optimal angle	Cold Water Temperature	Average Ambient Temperature	Monthly irradiation @ optimal angle	Monthly Irradiation @ Collector Surface	Monthly Irradiation @ Collector Surface	Useful energy
31	1606 Wh/m^2	10 °C	-0,9 °C	49,79 kWh/m^2	45,91 kWh/m^2	316,80 kWh	0,00 kWh
28	2347 Wh/m^2	11 °C	0,8 °C	65,72 kWh/m^2	63,54 kWh/m^2	438,46 kWh	34,97 kWh
31	3470 Wh/m^2	11 °C	4,4 °C	107,57 kWh/m^2	107,27 kWh/m^2	740,14 kWh	149,80 kWh
30	4314 Wh/m^2	12 °C	10,9 °C	129,42 kWh/m^2	128,18 kWh/m^2	884,45 kWh	218,40 kWh
31	5601 Wh/m^2	13 °C	17,2 °C	173,63 kWh/m^2	165,77 kWh/m^2	1143,78 kWh	350,95 kWh
30	5679 Wh/m^2	14 °C	21,3 °C	170,37 kWh/m^2	158,15 kWh/m^2	1091,22 kWh	323,29 kWh
31	5826 Wh/m^2	14 °C	24,2 °C	180,61 kWh/m^2	169,67 kWh/m^2	1170,75 kWh	373,00 kWh
31	5699 Wh/m^2	14 °C	23,5 °C	176,67 kWh/m^2	172,61 kWh/m^2	1191,02 kWh	424,72 kWh
30	5073 Wh/m^2	13 °C	18,1 °C	152,19 kWh/m^2	152,18 kWh/m^2	1050,02 kWh	376,87 kWh
31	3475 Wh/m^2	12 °C	12,5 °C	107,73 kWh/m^2	105,72 kWh/m^2	729,45 kWh	177,15 kWh
30	1948 Wh/m^2	11 °C	6,5 °C	58,44 kWh/m^2	54,69 kWh/m^2	377,38 kWh	9,25 kWh
31	1315 Wh/m^2	10 °C	1,3 °C	40,77 kWh/m^2	37,00 kWh/m^2	255,31 kWh	0,00 kWh
nual values	**3863 Wh/m^2**	**12,1 °C**	**11,7 °C**	**117,74 kWh/m^2**	**113,39 kWh/m^2**	**782,40 kWh**	**203,20 kWh**
365				**1412,89 kWh/m^2**	**1360,69 kWh/m^2**	**9388,78 kWh**	**2438,40 kWh**

4.2. Solar Collector Characteristics

Different types of solar collectors have been used in order to address the different markets in the SEE area. The characteristics of the collectors that the partners contributed and which have been taken into account in the present study, are shown below.

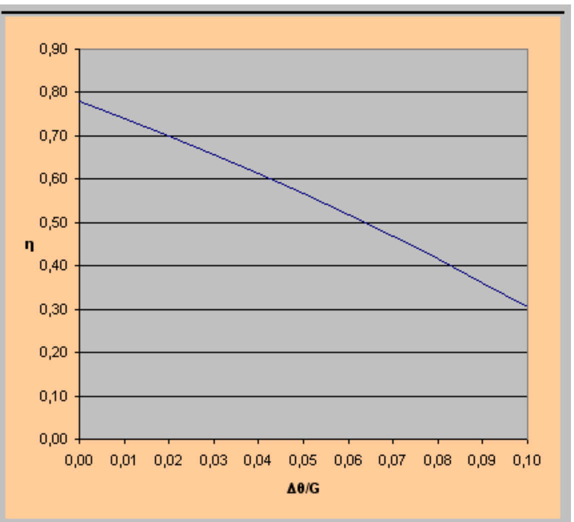
Solar Collector Data

Collector type:	Helional FPS 2.0	
Number of collectors:	3	
Tilt:	45 °	
Collector loop efficiency:	0,86	
Total active area:	5,46 m²	
Mean collector temperature (Enter temperature or 0 for automatic estimation):	48,80 °C	(Number in last line is used for calculations)

Calculated energy

Collector Surface Area Irradiation: 7429,39 kWh/year

Month	Acquired energy
1 January	14,18 kWh
2 February	70,49 kWh
3 March	184,36 kWh
4 April	248,52 kWh
5 May	371,36 kWh
6 June	346,15 kWh
7 July	387,80 kWh
8 August	427,80 kWh
9 September	370,60 kWh
10 October	200,99 kWh
11 November	42,73 kWh
12 December	0,75 kWh
Total energy ($Q_{collector}$)	2665,72 kWh



Collector type:	Helional FPS 2.0 Flat-Plate	
Active Area:	1,82 m²	
Efficiency at 800 W/m²:	η_o	0,78
	α_1	3,8
	α_2	0,012

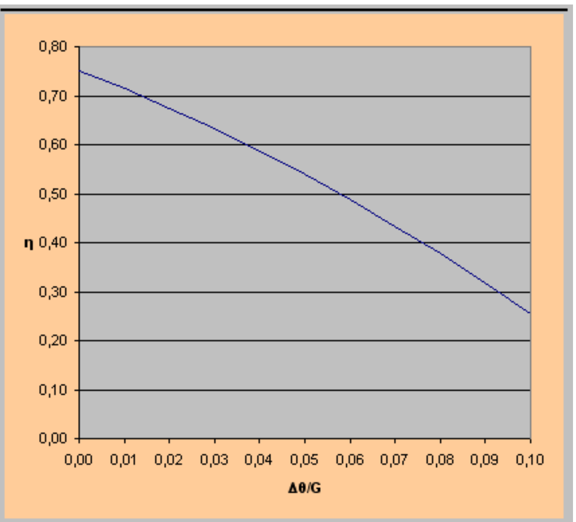
Solar Collector Data

Collector type:	Immergas CP2
Number of collectors:	3
Tilt:	45 °
Collector loop efficiency:	0,86
Total active area:	5,556 m²
Mean collector temperature (Enter temperature or 0 for automatic estimation):	49,45 °C (Number in last line is used for calculations)

Calculated energy

Collector Surface Area Irradiation: 7560,01 kWh/year

Month		Acquired energy
1	January	9,75 kWh
2	February	61,30 kWh
3	March	168,99 kWh
4	April	232,86 kWh
5	May	351,17 kWh
6	June	327,49 kWh
7	July	367,95 kWh
8	August	407,19 kWh
9	September	353,16 kWh
10	October	188,38 kWh
11	November	35,53 kWh
12	December	0,00 kWh
Total energy ($Q_{collector}$)		2503,77 kWh



Collector type:	Immergas CP2	
	Flat-Plate	
Active Area:	1,852 m²	
Efficiency at 800 W/m²:	η_o	0,752
	α_1	3,55
	α_2	0,0177

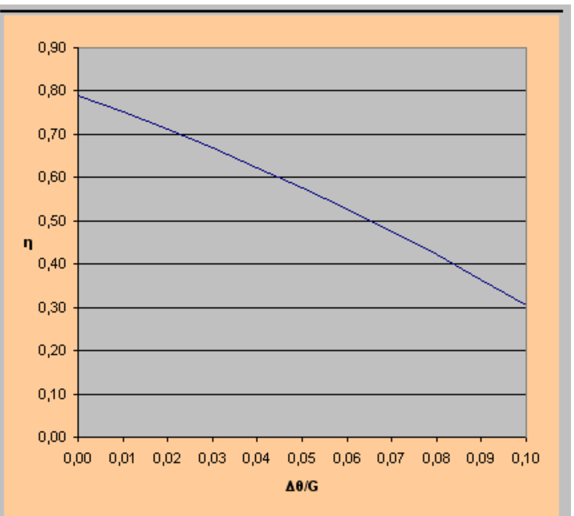
Solar Collector Data

Collector type:	Riposol RP 200 V
Number of collectors:	3
Tilt:	45 °
Collector loop efficiency:	0,86
Total active area:	11,1 m²
Mean collector temperature (Enter temperature or 0 for automatic estimation):	87,17 °C (Number in last line is used for calculations)

Calculated energy

Collector Surface Area Irradiation: 15103,70 kWh/year

Month		Acquired energy
1	January	0,00 kWh
2	February	0,00 kWh
3	March	1,03 kWh
4	April	35,34 kWh
5	May	150,28 kWh
6	June	115,15 kWh
7	July	169,72 kWh
8	August	255,70 kWh
9	September	222,39 kWh
10	October	24,00 kWh
11	November	0,00 kWh
12	December	0,00 kWh
Total energy ($Q_{collector}$)		973,59 kWh



Collector type:	Riposol RP 200 V	
	Flat-Plate	
Active Area:	3,7 m²	
Efficiency at 800 W/m²:	η_o	0,79
	α_1	3,72
	α_2	0,014

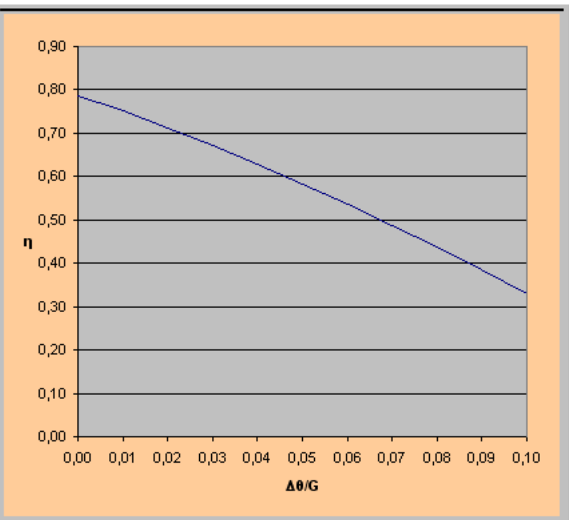
Solar Collector Data

Collector type:	Mea Quattro
Number of collectors:	3
Tilt:	45 °
Collector loop efficiency:	0,86
Total active area:	7,5 m²
Mean collector temperature (Enter temperature or 0 for automatic estimation):	62,68 °C (Number in last line is used for calculations)

Calculated energy

Collector Surface Area Irradiation:	10205,20 kWh/year

Month	Acquired energy
1 January	0,00 kWh
2 February	36,82 kWh
3 March	159,56 kWh
4 April	232,45 kWh
5 May	373,59 kWh
6 June	343,52 kWh
7 July	396,71 kWh
8 August	452,15 kWh
9 September	401,92 kWh
10 October	188,56 kWh
11 November	9,49 kWh
12 December	0,00 kWh
Total energy ($Q_{collector}$)	2594,78 kWh



Collector type:	Mea Quattro	
	Flat-Plate	
Active Area:	2,5 m²	
Efficiency at 800 W/m²:	η_o	0,787
	α_1	3,54
	α_2	0,013

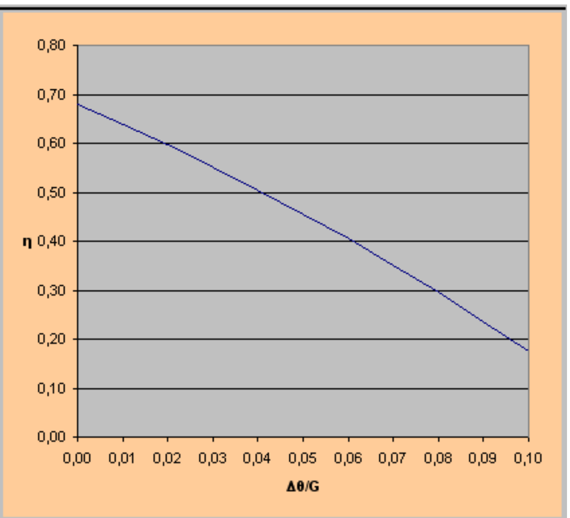
Solar Collector Data

Collector type:	ÖkoTech SolaWELL
Number of collectors:	3
Tilt:	45 °
Collector loop efficiency:	0,86
Total active area:	4,2 m²
Mean collector temperature (Enter temperature or 0 for automatic estimation):	40,22 °C (Number in last line is used for calculations)

Calculated energy

Collector Surface Area Irradiation:	5714,91 kWh/year

Month	Acquired energy
1 January	15,85 kWh
2 February	58,62 kWh
3 March	139,71 kWh
4 April	184,39 kWh
5 May	270,31 kWh
6 June	254,83 kWh
7 July	283,08 kWh
8 August	308,98 kWh
9 September	267,90 kWh
10 October	150,63 kWh
11 November	37,35 kWh
12 December	4,28 kWh
Total energy ($Q_{collector}$)	1975,93 kWh



Collector type:	OkoTech SolaWELL	
	Flat-Plate	
Active Area:	1,4 m²	
Efficiency at 800 W/m²:	η_o	0,679
	α_1	3,905
	α_2	0,014

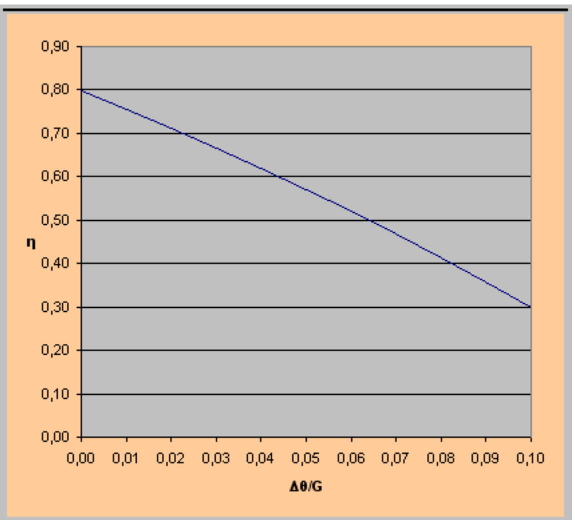
Solar Collector Data

Collector type:	Cordivari CS 2.5 V4
Number of collectors:	3
Tilt:	45 °
Collector loop efficiency:	0,86
Total active area:	6,9 m²
Mean collector temperature (Enter temperature or 0 for automatic estimation):	58,59 °C (Number in last line is used for calculations)

Calculated energy

Collector Surface Area Irradiation:	9388,78 kWh/year

Month	Acquired energy
1 January	0,00 kWh
2 February	34,97 kWh
3 March	149,80 kWh
4 April	218,40 kWh
5 May	350,95 kWh
6 June	323,29 kWh
7 July	373,00 kWh
8 August	424,72 kWh
9 September	376,87 kWh
10 October	177,15 kWh
11 November	9,25 kWh
12 December	0,00 kWh
Total energy ($Q_{collector}$)	2438,40 kWh



Collector type:	Cordivari CS 2.5 V4	
	Flat-Plate	
Active Area:	2,3 m²	
Efficiency at 800 W/m²:	η_o	0,798
	α_1	4,1
	α_2	0,011

4.3. Fuel Characteristics

Further to the specifications of different types of solar collectors for the production of Domestic Hot water, different types of fuel have been specified so that a comparison to the saved energy and CO2 avoided emissions could be obtained. The different types of fuel used in the impact study are shown below.

	Fuel Type	Fuel saving coefficient	Energy content (kWh/m^3)	CO2 emissions (kg/m^3)
1	Light fuel oil	1,89	1,07E+04	2830
2	Natural gas	1,39	10,65	1,9
3	Natural gas (Italy)	1,39	9,59	1,92759

4.4. Building Characteristics

Although the impact study addresses primarily the need for domestic hot water in SEE area, different types of buildings have been specified as shown below.

ID	Activity type	α	N_U	
1	Dwelling	1,1402	Floor Area	m²
2	Accomodation	30	Number of beds	beds
3	Health establishment without accomodation	10	Number of beds	beds
4	Health establishment without accomodation - without laundry	57	Number of beds	beds
5	Health establishment without accomodation - with laundry	90	Number of beds	beds
6	Catering, 2 meals per day. Tradiational cuisine	22	Number of guests per meal	guests
7	Catering, 2 meals per day. Self service	8	Number of guests per meal	guests
8	Catering, 1 meal per day. Tradiational cuisine	11	Number of guests per meal	guests
9	Hotel, 1-star, without laundry	57	Number of beds	beds
10	Hotel, 1-star, with laundry	71	Number of beds	beds
11	Hotel, 2-star, without laundry	78	Number of beds	beds
12	Hotel, 2-star, with laundry	92	Number of beds	beds
13	Hotel, 3-star, without laundry	100	Number of beds	beds
14	Hotel, 3-star, with laundry	114	Number of beds	beds
15	Hotel, 4-star and GC, without laundry	120	Number of beds	beds
16	Hotel, 4-star and GC, with laundry	135	Number of beds	beds
17	Sports establishment	103	Number of installed showers	showers

5. Impact Study Findings

The Impact Study builds on the theory described in chapter 2. It uses the different variables addressed in Chapter 3 in order to produce the environmental impact of the wider application of solar domestic hot water applications.

The parameters taken into account in this study are the following

- Dwelling type of building has been chosen with an area of 120 square meters as a typical example of a family house
- Different types of solar collectors may be used for the solar system installed in this house (see 3.2)
- A typical heater with a tank capacity of 300 lt, standby loss factor 1.12 and pipe loss factor 1.11 has been used
- Different areas may be addressed (see 3.1)
- Different conventional fuel may be used (see 3.3)

Based on the above parameters, the energy saving equivalent per house and per year has been calculated for two types of conventional fuel: light fuel oil and natural gas (or natural gas Italy for the Italian sites). Then the equivalent volume of saved conventional fuel per house and per year has been calculated. Finally, the CO_2 emissions avoided per house and per year have been calculated.

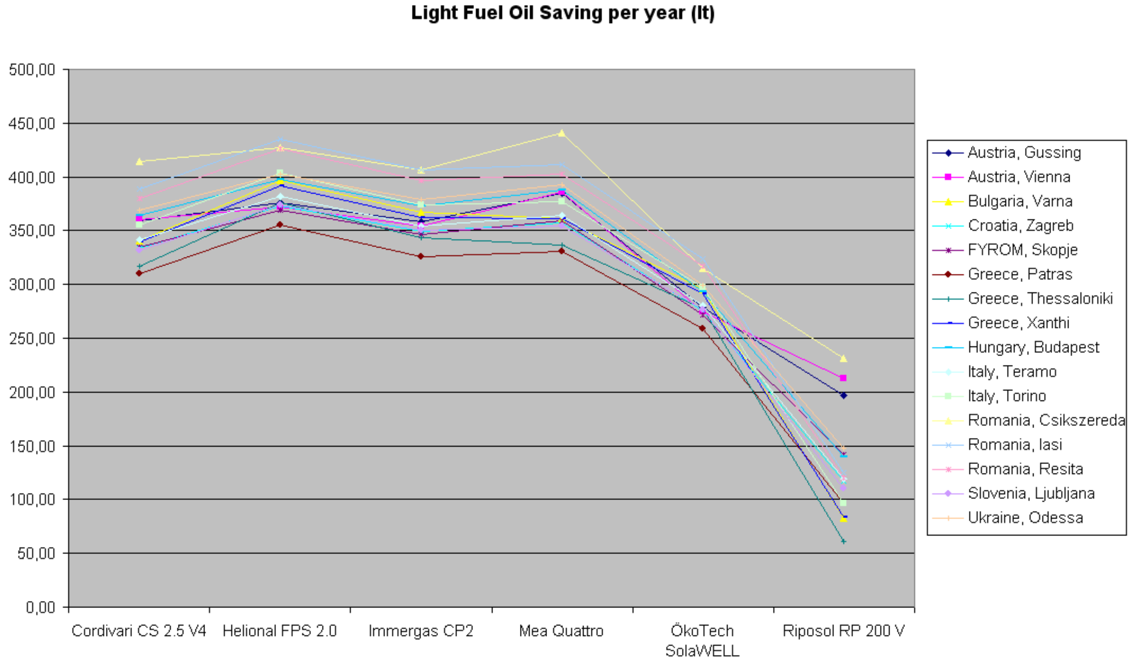
With reference to Light Fuel Oil energy saving equivalent per year, the results of the impact study are shown below depending on the site of the house and the type of solar collector utilized.

Light Fuel Oil Energy Saving Equivalent per year (KWh)

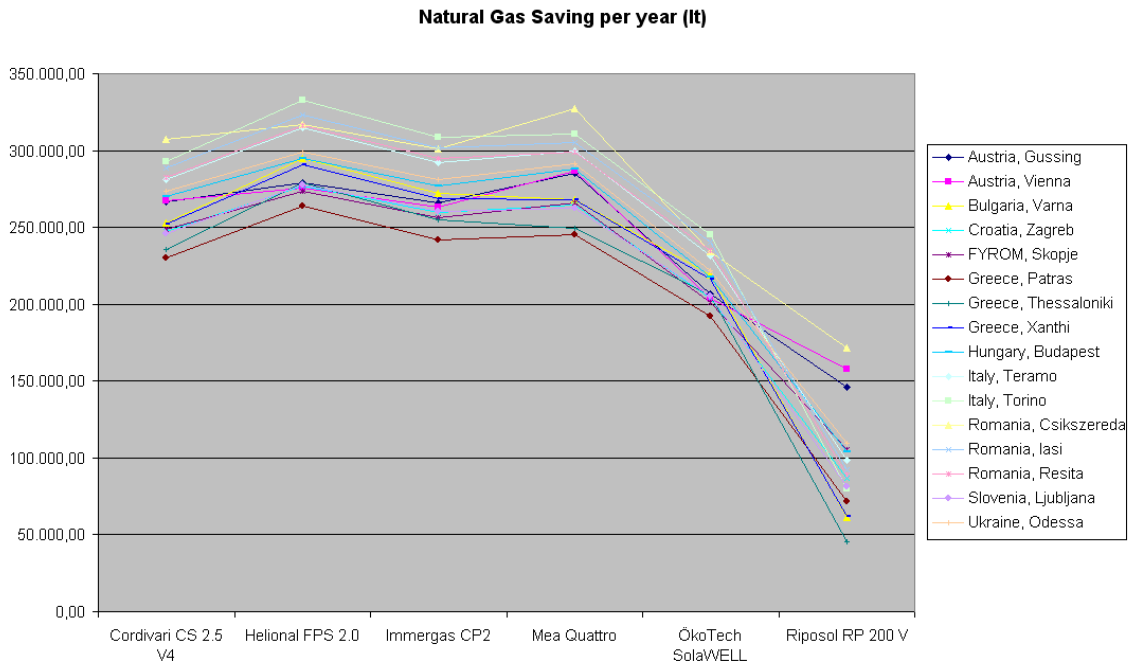
With reference to Natural Gas energy saving equivalent per year, the results of the impact study are shown below depending on the site of the house and the type of solar collector utilized.

Natural Gas Energy Saving Equivalent per year (KWh)

With reference to Light Fuel Oil savings per year the results of the impact study are shown below.

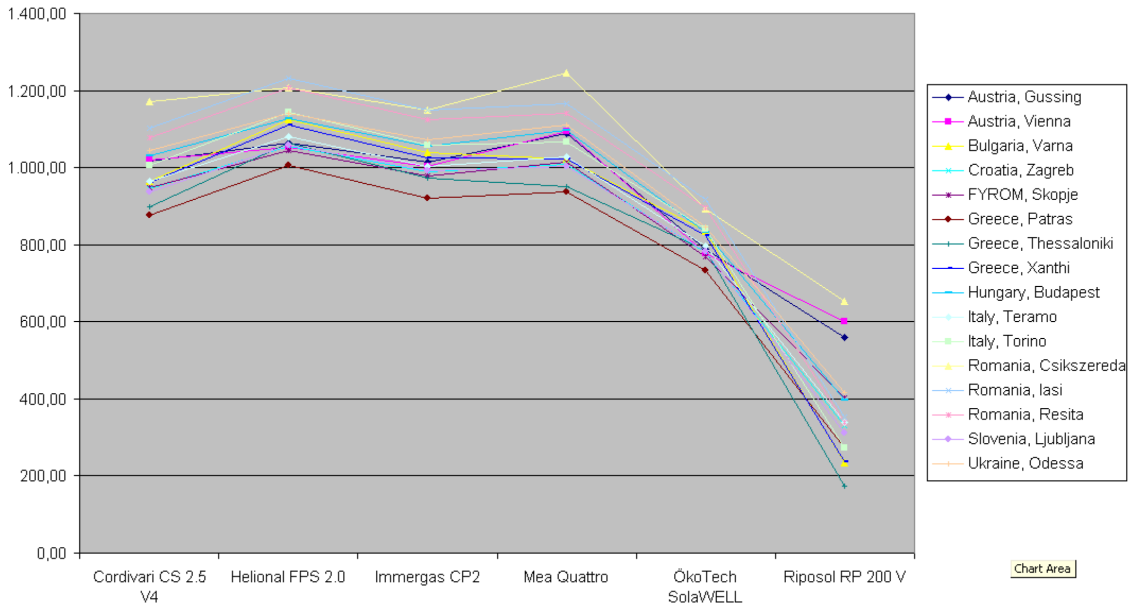


With reference to Natural Gas savings per year the results of the impact study are shown below.



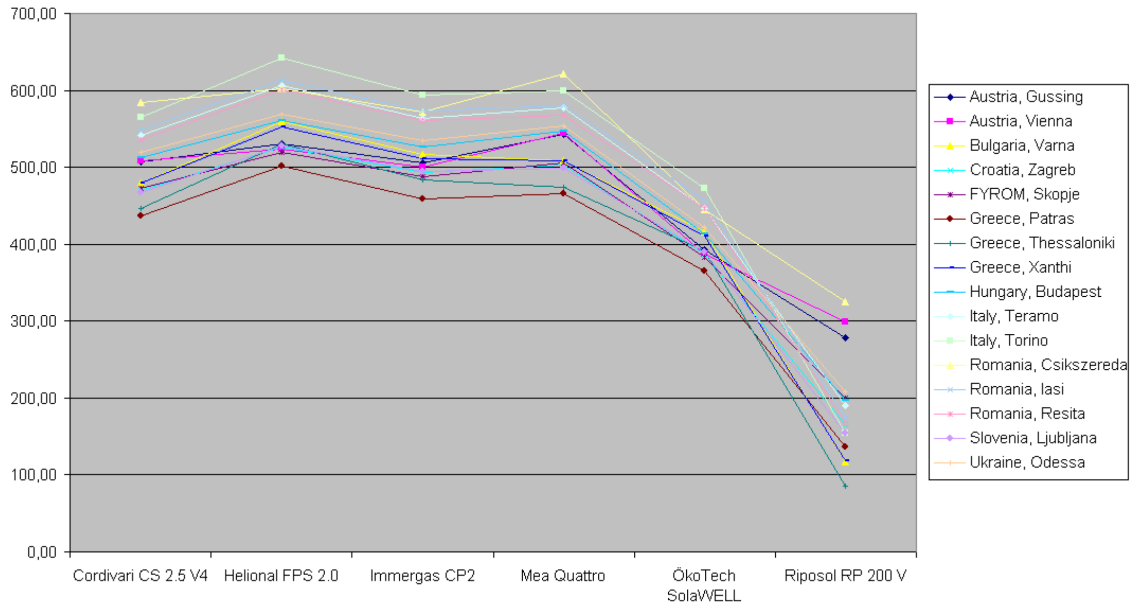
With reference to CO2 emissions avoided per year by the substitution of light fuel oil, the results of the impact study are shown below.

CO2 Emissions avoided per year (Light Fuel Oil) - Kg



Finally, and with reference to CO2 emissions avoided per year by the substitution of natural gas, the results of the impact study are shown below.

CO2 Emissions Avoided per year (Natural Gas) - Kg



6. Discussion – Conclusions

The application of the impact study shows that there is positive environmental impact through the utilisation of solar thermal technologies for domestic hot water applications. Taking as an example one type of solar thermal collector (Helional FPS 2.0), fuel savings equivalent per house and year range between 3.820,39 KWh in Patras, Greece and 4.675,93 KWh in Iasi, Romania if light fuel oil were used as conventional fuel or between 2.809,78 KWh in Patras, Greece and 3.438,91 KWh in Iasi, Romania if natural gas were used as conventional fuel (although this type of energy is not available in Patras, Greece). For the same example fuel savings range between 355,56 litres per house and year in Patras, Greece and 435,00 litres per house and year in Iasi, Romania for light fuel oil conventional fuel or between 263.828,73 litres and 332.869,57 litres of natural gas conventional fuel for Patras, Greece and Torino, Italy respectively (calculations for Italian cities are based on Italian natural gas). Finally, the same example shows that CO_2 emissions avoided by the substitution of light fuel oil with solar energy for domestic water heating range between 1006,23 Kg in Patras, Greece and 1.231,54 Kg in Iasi, Romania, while the relevant figures for natural gas are 501.27 Kg for Patras, Greece and 641,64 Kg for Torino, Italy.

There is strong influence of the area characteristics in the overall savings in energy and fuel as well as in CO_2 emission reduction that for the areas included in this study may result in 22% increase with reference to the minimum depending on the exact site. The geographical characteristics of the site, its irradiation as well as temperature all year long influence the anticipated environmental impact.

A quite important factor that is associated with the overall savings in energy is the solar collector utilised. Taking as an example one specific site (Guessing, Austria) and utilising different types of solar collector with the same panel characteristics leads to a range of energy savings (conventional fuel: light fuel oil) between 4.134,34 KWh and 2.119,93 KWh depending on the solar collector. This 95% increase depending on the collector also stands for fuel savings (between 197,29 lts and 384,77 lts) as well as for CO_2 emissions avoided (between 558,34Kg and 1.088,90Kg).

It would be interesting to extrapolate on the findings of the study in order to have a feeling of the impact on the environment at a larger scale. The overall population of the sites included in this study amounts to 12 million. It would be interesting to have an idea of what would be the impact on the environment of the widening of the solar thermal market in these sites. Although the different countries present different markets and different maturity levels with reference to solar thermal technologies, let us make an assumption that solar thermal market in all sites is widened by a percentage that affects 1% of their total population, i.e. that 119.139 inhabitants would be influenced. Taking into account that the average European household is of a size of 2,5 persons and with the assumption that average house area is about 100 square meters we will try to identify the total impact on the environment of this 1% increase.

City	Population
Austria, Gussing	27.199
Austria, Vienna	2.268.656
Bulgaria, Varna	358.724
Croatia, Zagreb	1.288.000
FYROM, Skopje	668.518
Greece, Patras	222.460
Greece, Thessaloniki	995.766
Greece, Xanthi	52.270
Hungary, Budapest	3.271.110
Italy, Teramo	55.106
Italy, Torino	910.188
Romania, Miercurea Ciuc	42.029
Romania, Iasi	315.649
Romania, Resita	86.383
Slovenia, Ljubljana	271.885
Ukraine, Odessa	1.080.000
Total	11.913.943

The figures in the case of light fuel oil are shown below (calculated for the Helional collector).

Type of Fuel: Light Fuel Oil			
City	Fuel saving energy equivalent per year (KWh)	Fuel savings per year (Lt)	CO2 emissions avoided per year (Kg)
Austria, Gussing	527.384,26	49.088,76	138.901,59
Austria, Vienna	43.505.925,37	4.050.912,15	11.458.527,72
Bulgaria, Varna	7.347.654,73	683.584,45	1.935.215,54
Croatia, Zagreb	24.773.618,69	2.306.035,20	6.524.843,14
FYROM, Skopje	12.714.923,56	1.184.079,08	3.348.825,94
Greece, Patras	4.079.546,28	379.669,27	1.074.464,03
Greece, Thessaloniki	19.312.618,69	1.797.158,48	5.086.532,05
Greece, Xanthi	1.056.776,91	98.350,57	278.332,12
Hungary, Budapest	67.123.805,25	6.249.128,54	17.678.910,26
Italy, Teramo	1.085.488,57	101.042,36	285.894,34
Italy, Torino	18.963.220,87	1.765.036,57	4.994.485,53
Romania, Miercurea Ciuc	925.144,70	86.100,02	243.663,05
Romania, Iasi	7.084.572,62	659.075,11	1.865.924,97
Romania, Resita	1.900.097,05	176.635,96	500.443,67
Slovenia, Ljubljana	5.246.945,48	488.087,95	1.381.928,38
Ukraine, Odessa	22.461.598,08	2.089.152,00	5.915.877,12
Total	238.109.321,10	22.163.136,48	62.712.769,45

The relevant figures in the case of natural gas are the following (calculated for the Helional collector).

Type of Fuel: Natural Gas			
City	Fuel saving energy equivalent per year (KWh)	Fuel savings per year (Lt)	CO2 emissions avoided per year (Kg)
Austria, Gussing	387.865,01	36.419.249,74	69.196,57
Austria, Vienna	31.996.408,63	3.004.357.618,26	5.708.279,47
Bulgaria, Varna	5.403.836,37	507.402.476,04	964.064,70
Croatia, Zagreb	18.219.734,33	1.710.773.176,91	3.250.469,04
FYROM, Skopje	9.351.208,39	878.047.585,63	1.668.300,04
Greece, Patras	3.000.301,23	281.718.425,25	535.265,01
Greece, Thessaloniki	14.203.472,67	1.333.659.405,44	2.533.952,87
Greece, Xanthi	777.206,30	72.977.117,18	138.656,52
Hungary, Budapest	49.366.142,19	4.635.318.515,13	8.807.105,18
Italy, Teramo	798.323,07	83.245.367,24	160.462,94
Italy, Torino	13.946.493,94	1.454.274.655,28	2.803.245,28
Romania, Miercurea Ciuc	680.397,43	63.887.082,22	121.385,46
Romania, Iasi	5.210.343,40	489.234.121,91	929.544,83
Romania, Resita	1.397.426,77	131.213.565,60	249.305,48
Slovenia, Ljubljana	3.858.867,18	362.334.946,94	688.436,40
Ukraine, Odessa	16.519.361,78	1.551.113.782,30	2.947.116,19
Total	175.117.388,70	16.595.977.091,06	31.574.785,99

The numbers are quite impressive as a widening of the market in the above sites leading to 1% of their population affected by solar thermal technologies could lead to energy saving equivalent of about 238,1 GWh in the case of light fuel oil or 175,1 GWh in the case of natural gas. Savings of fuel would be 22,1 Mlts in the case of light fuel oil or 16,6 Glts of natural gas. CO2 emissions avoided amount to 62,7 Kilotonnes in the case of light fuel oil and 31,6 kilotonnes in the case of natural gas. An extrapolation from the population of the selected sites (about 12 million) to the total SEE population or the total European population and an increase of the percentage of the population influenced gives the magnitude of change that projects like WidetheSEEbySuccMod could influence.

7. References – Literature

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