GEOTHERMAL HEAT POTENTIAL – THE SOURCE FOR HEATING GREENHOUSES IN SOUTHESTERN EUROPE

by

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The paper presents economically evaluated solutions for heating greenhouses with geothermal potential, if the same greenhouse is placed in two different locations in Southeastern Europe, one in Slovenia and the other in Serbia. The direct geothermal water exploitation using heat exchangers is presented and the remaining heat potential of already used geothermal water is exploited using high temperature heat pumps. Energy demands for heating greenhouses are calculated considering climatic parameters of both locations. Furthermore, different constructions materials are taken into account, and energy demands are evaluated if the same greenhouse is made of 4 mm toughened single glass, double insulated glass or polycarbonate plates. The results show that the geothermal energy usage is economically feasible in both locations, because payback periods are in range from two to almost eight years for different scenarios.

Key words: *geothermal heat exploitation, greenhouses energy demands, high temperature heat pump, economic analysis*

Introduction

The greenhouse gas emissions from different sources present the problem that must be resolve to decrease air pollution and global warming [1]. Much effort regarding energy savings has been spent so far, due to large environmental problems [2] and because of limited energy sources [3-6]. From another point of view, according to the European Energy and Climate Change Policy and its targets for the year 2020, different options and solutions are searched in the way how to lower CO_2 emissions. One of the opportunities is exploitation of geothermal potential for different proposals, such as heating greenhouses [7].

The geothermal potential is very large in Southeastern Europe, especially in Slovenia, Hungary, Croatia, Bosnia and Herzegovina, Serbia, Bulgaria, *etc.* [8]. The solutions for heating greenhouses in which different plants are produced during the entire year are compared if the same greenhouse, made of 4 mm toughened single glass is placed in two different locations in Southeastern Europe. The first location is in north-east Slovenia and the second one is Macva district in Serbia. Furthermore, the study is based on regional climatic parameters for both locations and also on different geothermal potential, taking into account different economic conditions for each country. Energy demands are calculated and economic evaluation is done if different heating systems are implemented. Moreover, different scenarios are presented if the greenhouse roof is replaced with double insulated glass, or polycarbonate plates.

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Geothermal potential in Slovenia and Serbia

The geothermal potential in Southeastern Europe is very large [8, 9], that is way the comparison of the solutions for heating greenhouses are presented. The evaluation is done for the greenhouse in which vegetables are produced during the entire year if the same green-house is placed in two different locations.

Slovenia

The areas with geothermal potential are geologically younger structure at the north-east of Slovenia. Due to the latest data, there are 79 boreholes with aggregate flow of 1,500 L per s and total 140 MW_t of power. At the far north-east of Slovenia two geothermal sources are available:
– low temperature source (temperature 50 to 70 °C), and
– high temperature source (temperature 180 to 200 °C)

Geothermal water from the mentioned sources is used in spas, for district heating systems, greenhouses and in medical centres. The total flow is equal to 115 kg per s with 12 MW of power. The temperature distribution for different depth, 500 m (fig. 1a), and 3,000 m (fig. 1b) is represented for the north-east part of Slovenia.
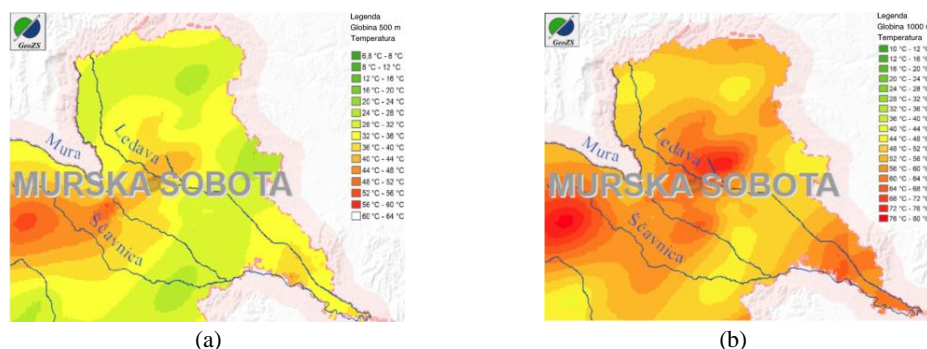

<div align="center">(a)   (b)</div>

Figure 1. Temperature distribution for different depths, 500 m (a) and 3,000 m (b) [10]

Serbia

The Macva region is placed at the western part of Serbia. The total area of this region is approximately 2,000 km^2. The area topology is mostly flatland with average altitude between 80 and 100 m. The Macva region is known for its geothermal potential and there are several boreholes available, their properties are presented at tab. 1.

Table 1. Geothermal properties of boreholes at Macva region [11]

Borehole	Location	Borehole depth [m]	Borehole capacity [s^{-1}]	Temperature [°C]
D1	Dublje	200	1.2	40
DB1	Dublje	400	10	50.5
IEDB1	Dublje	335	15	50.5
BB1	Bogatic	470	37.5	75.5
BB-2	Bogatic	618	60	78
BeB1	Belotic	450	20	34
MeB1	Metkovic	627	10	61
BZ-1	Zminjak	1,500	3	40

Characteristics of greenhouses

Ensuring suitable climatic parameters in the greenhouses is one of the basic goals for successful plants growing; consequently heat demands are extremely large. In order to adjust to the environmental temperature changes the heating system is automatically regulated. The location together with heating and cooling needs should be taken into consideration when construction material for greenhouse is chosen. In order to determine heat losses, the material properties have to be known, which are for specific materials presented in tab. 2.

The greenhouse annual energy consumption is strongly dependent on annual heating hours. The heating hour must be taken into consideration if outside air temperature is below 16 °C. In order to calculate annual heat demand of the greenhouse, following parameters should be considered:
– average month temperature (t_p),
– the daily increment of global emissivity (H_g),
– the amount of energy aimed for heating, and
– the greenhouse heat demand.

The monthly energy demands are calculated considering the heat flow, which leaves the greenhouse as the heat loss. The greenhouse with floor area of 43,920 m^2 is considered. The average month temperature is considered the lowest temperature. The minimal temperature of the greenhouse is 16 °C during all day, taking into consideration all days in the month. The energy of sun radiation together with heat demands of the greenhouse (GH) are represented for both locations in tabs. 3-6 only for those moths, where energy deficits (energy surplus are marked with minus) are.

Table 2. Material properties [12]

	Toughened single glass	Double insulated glass	Polycarbonate plate
Thickness of material [mm]	4	wall 4/16/4	16
Heat conductivity [Wm^{-2}K^{-1}]	5.8	1.1	3.1
Light transitivity	0.9	0.76	0.85
Price [EUR per m^2]	22.20	75.00	39.50

Table 3. The average month temperatures and amount of average solar irradiation

Month	Average month temperature – Slovenia [°C]	Average month temperature – Serbia [°C]	Average solar irradiation per month [h]	H_g [Whm^{-2}]
Jan.	−1.0	0.1	47	1,271
Feb.	1.8	2.7	95	1,860
Mar.	5.9	7.2	128	2,947
Nov.	5.8	6.5	56	1,453
Dec.	0.4	1.4	37	908

Table 4. Energy deficits for 4 mm thick toughened single glass

Month	Slovenian case				Serbian case			
	t_p [°C]	ϕ_s [kWh]	GH heat demand [kWh]	Energy deficit [kWh]	t_p [°C]	ϕ_s [kWh]	GH heat demand [kWh]	Energy deficit [kWh]
Jan.	−1.0	1,557,443	6,233,738	4,676,296	0.1	1,557,443	5,822,351	4,264,908
Feb.	1.8	2,058,618	5,218,603	3,159,984	2.7	2,058,618	4,871,334	2,812,716
Mar.	5.9	3,611,159	3,701,397	90,237	7.2	3,611,159	3,219,645	−391,514
Nov.	5.8	3,741,709	3,741,709	2,018,683	6.5	1,723,026	3,493,657	1,770,632
Dec.	0.4	5,702,350	5,702,350	4,589,715	1.4	1,112,634	5,364,129	4,251,495

Table 5. Energy deficits for double insulated glass

Month	Slovenian case				Serbian case			
	t_p [°C]	ϕ_s [kWh]	GH heat demand [kWh]	Energy deficit [kWh]	t_p [°C]	ϕ_s [kWh]	GH heat demand [kWh]	Energy deficit [kWh]
Jan.	−1.0	1,315,174	1,182,403	−132,771	0.1	1,315,174	1,104,372	−210,802
Feb.	1.8	1,738,389	989,854	−748,534	2.7	1,738,389	923,985	−814,404
Mar.	5.9	3,049,424	702,073	−2,347,350	7.2	3,049,424	610,696	−2,438,728
Nov.	5.8	1,454,999	709,720	−745,279	6.5	14,54,999	662,670	−792,329
Dec.	0.4	939,557	1,081,611	142,052	1.4	939,557	1,017,457	77,899

Table 6. Energy deficits for polycarbonate sheets

Month	Slovenian case				Serbian case			
	t_p [°C]	ϕ_s [kWh]	GH heat demand [kWh]	Energy deficit [kWh]	t_p [°C]	ϕ_s [kWh]	GH heat demand [kWh]	Energy deficit [kWh]
Jan.	−1.0	1,470,918	3,341,954	1,871,036	0.1	1,470,918	3,121,406	1,650,488
Feb.	1.8	1,944,251	2,797,732	853,481	2.7	1,944,251	2,611,559	667,308
Mar.	5.9	3,410,540	1,984,347	−1,426,193	7.2	3,410,540	1,726,076	−1,684,463
Nov.	5.8	1,627,302	2,005,958	378,656	6.5	1,627,302	1,872,976	245,674
Dec.	0.4	1,050,821	3,057,073	2,006,251	1.4	1,050,821	2,875,750	1,824,929

High temperature heat pump (HTHP)

HTHP [6, 13-15] are devices that ensure high added-values, and contribute to lower energy dependence. Their usages are possible in all industrial areas with low-temperature waste-heat sources of different fluids [16]. They ensure economically and environmentally effective usages of low-temperature energy sources, in order to improve specific energy usages in processes. Nonetheless, the emission of carbon dioxide is also decreasing because the fossil fuel usage is decreasing. The development of HTHP enabled the usage of low-temperature renewable and non-renewable energy sources for high-temperature heating or during the technological processes. The heat-pumps were used mainly for cooling purposes, whilst their usages for district heating systems were limited to low-temperature systems (up to 60 °C). Novel developments enabled usage of low-temperature heat sources (up to 55 °C), for high-temperature heating systems (up to 85 °C).
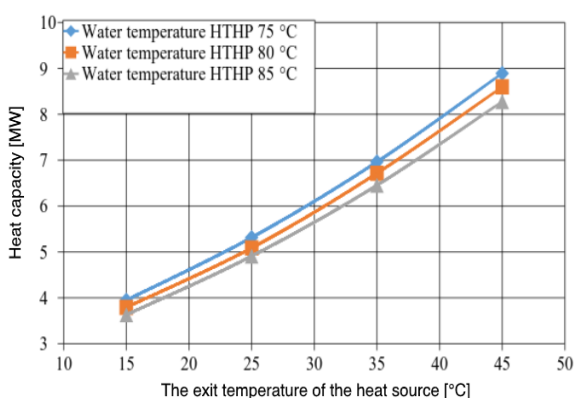

Figure 2. The obtained heat capacity of the high temperature heat pump *vs* the nominal rate of heat flow of 9.7 MW

The efficiency of HTHP is determined using coefficient of performance (COP), which represents the ratio of the produced heating energy and consumed energy for the compressor operation. The heat capacity of the evaporator shows how much energy is taken from a low-temperature energy source, whilst the heat capacity of the condenser shows the energy gained for heating systems. The electricity consumption of a compressor equals the energy needed for compressing the refrigerant, which is a substance with special physical characteristics [15].

Operating characteristics of 9.7 MW HTHP regarding the needed water tem-

perature and heat source temperature, are presented in fig. 2 and fig. 3, showing the results for various operating conditions using R717 (NH_3) working fluid, and a commercially available 50 bar screw compressor, for the hot water temperatures 75 to 85 °C. Other refrigerants proved to be less appropriate due to the lower enthalpy difference between the vapour and liquid phases, smaller heat-flow, and lower COP.

Greenhouse energy demands and preliminary economic evaluation

Figure 3. COP of the HTHP with the nominal rate of heat capacity of 9.7 MW

Two locations for the greenhouse heating system upgrade were compared in terms of economic performance. The following assumptions were considered during the economic analysis:

– both greenhouses already exist and are made of 4 mm toughened single glass,
– both greenhouses currently use gas boilers for heating purposes, with an efficiency of 0.95,
– the average solar irradiation is the same for both locations, and the whole is effectively utilized,
– the average solar irradiation is calculated on the ground plan of the greenhouse,
– prices of electricity and natural gas are 0.1 EUR per kWh, and 56.8 EUR per MWh, respectively for both locations,
– boreholes in Slovenia are 1,500 m in depth and price for drilling is 1,000 EUR per m; each exploitation borehole has a yield of 20 L per s of geothermal water with a temperature of 60 °C,
– boreholes in Macva region in Serbia are 700 m in depth and price for drilling is 700 EUR per m; the exploitation borehole has a yield of 37 L per s of geothermal water with a temperature of 80 °C,
– geothermal water is first used in a heat exchanger, where it is cooled to 45 °C; in order to exploit the remaining potential of the geothermal water (45 °C), it is used as the low-temperature heat-source in a series of high temperature heat pumps,
– the electricity consumption for geothermal energy utilization is neglected,
– the geothermal water has average composition and no specific material is needed,
– the specific CO_2 emission of natural gas is 0.2 kg per kWh [17], and
– the specific CO_2 emission from electricity market in Slovenia is 0.376 kg per kWh and in Serbia 0.666 kg per kWh [18, 19].

The needed heat demands that are dependent on the outside air temperature and solar radiation were calculated from the data in tab. 3-6. The heat consumption was calculated from the climatic data for both locations obtained from [11]. Different options were calculated for each material, depending on the location of greenhouse.

Slovenian case

The greenhouse made of 4 mm toughened single glass, which use the boiler system on natural gas for heating, was used for the comparison. The greenhouse floor area is
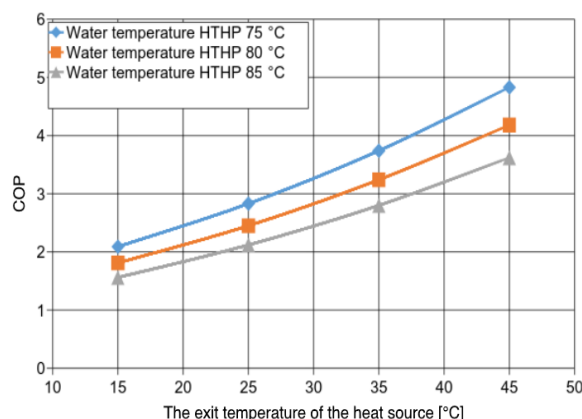
43,920 m^2, and it is assumed that the roof area is the same size. Heat demands for such greenhouse would be 17,735,289 kWh per year, and costs for heating at the current prices of natural gas would be 1,061,170 EUR per year. Nine different scenarios were calculated for example, if the heating system is changed and also if the greenhouse is constructed from different material. The scenarios were economically evaluated (tab. 7) and results are presented on fig. 4.

Table 7. Energetic and economic evaluation for different scenarios in Slovenia

	4 mm thick toughened single glass			Double insulated glass			Polycarbonate plates		
Number of HTHP	8	10	6	1	0	0	1	1	2
Price of HTHP [EUR]	1,000,000	1,250,000	750,000	125,000	0	0	125,000	125,000	250,000
Number of boreholes	3	3	3	2	2	0	2	3	2
Boreholes price [EUR]	4,500,000	4,500,000	4,500,000	3,000,000	3,000,000	0	3,000,000	4,500,000	3,000,000
Material price [EUR]	0	0	0	3,294,000	3,294,000	3,294,000	1,734,840	1,734,840	1,734,840
Total investment costs [EUR]	5,500,000	5,750,000	5,250,000	6,419,000	6,294,000	3,294,000	4,859,840	6,359,840	4,984,840
Total energy consumption [kWh]	17,735,289	17,735,289	17,735,289	3,868,128	3,868,128	3,868,128	7,270,185	7,270,185	7,270,185
Boiler [kWh]	219,240	108,358	455,108	0	96,117	3,868,128	509,782	25,931	136,039
HTHP [kWh]	5,680,689	5,791,571	5,444,821	96,117	0	0	1,221,502	103,100	1,595,244
Geothermal energy [kWh]	11,835,360	11,835,360	11,835,360	3,772,011	3,772,011	0	5,538,902	7,141,155	5,538,902
COP of HTHP	6.09	5.79	6.47	7.90			7.90	7.90	7.10
Electricity cost [EUR per year]	93,222	100,027	84,155	1,217	0	0	15,462	1,305	22,468
Cost of natural gas [EUR per year]	13,118	6,483	27,231	0	5,751	231,445	30,502	1,552	8,140
Savings [EUR per year]	954,830	954,659	949,784	828,508	823,974	598,280	783,761	826,868	799,117
Payback period [years]	5.76	6.02	5.53	7.75	7.64	5.51	6.20	7.69	6.24

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THERMAL SCIENCE: Year 2016, Vol. 20, No. 4, pp. 1061-1071
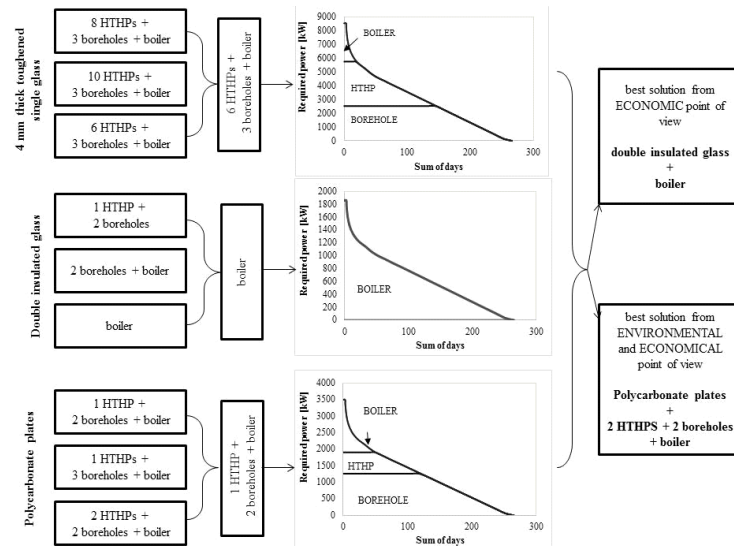
1067

Figure 4. Solutions for different scenarios – Slovenian case

Serbian case

The same evaluation as it was done for Slovenian case was also calculated for different scenarios in Serbia. Heat demands for such greenhouse in Serbia would be 19,263,772 kWh per year, and costs for heating at the current prices of natural gas would be 1,149,657 EUR per year. Different scenarios were calculated; economically evaluated (tab. 8) and results are presented on fig. 5.

Table 8. Energetic and economic evaluation for different scenarios in Serbia

|	4 mm thick toughened single glass			Double insulated glass		Polycarbonate plates	
Number of HTHP	0	3	1	0	0	0	0
Price of HTHP [EUR]	0	375,000	125,000	0	0	0	0
Number of boreholes	3	2	2	2	0	2	0
Boreholes price [EUR]	1,470,000	980,000	980,000	980,000	0	3,000,000	0
Material price [EUR]	975,024	975,024	975,024	3,294,000	3,294,000	1,734,840	1,734,840
Total investment costs [EUR]	2,445,024	2,330,024	2,080,024	4,274,000	3,294,000	4,734,840	1,734,840
Total consumption of energy [kWh]	19,263,772	19,263,772	19,263,772	4,201,495	4,201,495	6,394,601	6,394,601
Boiler [kWh]	0	241,772	620,463	0	4,201,495	0	6,394,601
HTHP [kWh]	0	825,590	446,898	0	0	0	0
Geothermal energy [kWh]	19,263,772	18,196,411	18,196,411	4,201,495	0	6,394,601	0
COP of HTHP		6.60	7.90				
Cost of electricity [EUR per year]	0	12,509	5,657	0	0	0	0
Cost of natural gas [EUR per year]	0	14,466	37,125	0	0	0	382,613
Savings [EUR per year]	1,152,625	1,125,650	1,109,843	901,233	901,233	901,233	518,620
Payback period [year]	2.12	2.07	1.87	4.74	3.65	5.25	3.35
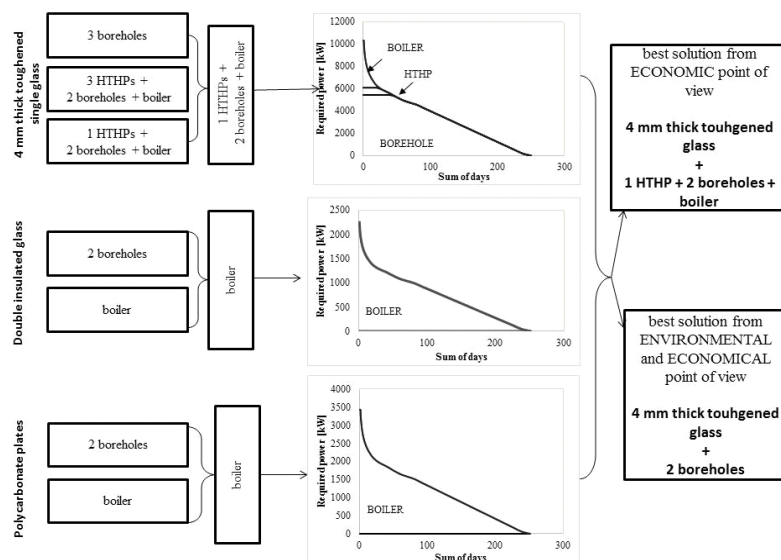
Figure 5. Solutions for different scenarios – Serbian case

Discussion

The monthly heat demands were calculated for Slovenian and Serbian greenhouse made of 4 mm toughened single glass with floor area of 43,920 m^2. Results are presented only for January, February, March, November and December, where the average month temperature and average daily increment of global emissivity were taken into account. The results in the tab. 4 show the needs for additional heating in each month for Slovenian case, while in Serbia the surplus of energy would be in March. According to tab. 4 and 5 energy demands are decreasing if better insulation material is used.

Furthermore, for each location different heating systems with different construction material were analysed (tab. 7 and tab. 8). The implementation of new double insulted windows and existed boiler system would be the best solution from economic point of view for Slovenian example, while the payback period would be 5.51 year. But according to environmental and economic aspects, where solutions with the lowest fossil fuels usage are searched, the best solution would be greenhouse with polycarbonate plates and heating system with two HTHP, two boreholes and boiler. The payback period would be slightly higher. The implementation of double insulated glass and heating system with one HTHP and two boreholes would be most environmental friendly solution for Slovenian case.

The results in Serbia are different (fig. 5) and the shortest payback time would be for the scenario with existed material and heating system with two boreholes and one HTHP, but from the environmental aspect the best scenario would be the implementation of three boreholes in existed greenhouse, where no additional heating would be needed. It could be concluded that Serbian area is more favourable for greenhouses with integrated geothermal energy due to lower drilling costs and higher geothermal heat potential.

The amount of CO_2 emissions is different for different scenarios (tab. 9 and tab. 10). According to the assumption that the greenhouse already exists and is heated by natural gas it is calculated that the emissions would be in the amount of 3,547 t CO_2 per year for Slovenian case study and 3,853 t CO_2 per year for Serbian case study.

Urbancl, D., *et al.*: Geothermal Heat Potential – the Source for Heating …
THERMAL SCIENCE: Year 2016, Vol. 20, No. 4, pp. 1061-1071

1069

Table 9. The amount of CO_2 emissions for different scenarios in Slovenia

	4 mm thick toughened single glass			Double insulated glass			Polycarbonate plates		
Number of HTHP	8	10	6	1	0	0	1	1	2
Number of boreholes	3	3	3	2	2	0	2	3	2
Boiler [kWh]	219,240	108,358	455,108	0	96,117	3,868,128	509,782	25,931	136,039
HTHP [kWh]	5,680,689	5,791,571	5,444,821	96,117	0	0	1,221,502	103,100	1,595,244
Geothermal energy [kWh]	11,835,360	11,835,360	11,835,360	3,772,011	3,772,011	0	5,538,902	7,141,155	5,538,902
COP of HTHP	6.09	5.79	6.47	7.90	0.00		7.90	7.90	7.10
CO_2 emissions from boilers [t]	44	22	91	0	19	774	102	5	27
Electricity for heat pumps [kWh]	932,216	1,000,271	841,549	12,167			154,620	13,051	224,682
CO_2 emissions from electricity production for HTHP [t]	351	376	316	5	0	0	58	5	84
CO_2 emission for the whole process [t]	394	398	407	5	19	774	160	10	112

Table 10. The amount of CO_2 emissions for different scenarios in Serbia

	4 mm thick toughened single glass			Double insulated glass		Polycarbonate plates	
Number of HTHP	0	3	1	0	0	0	0
Number of boreholes	3	2	2	2	0	2	0
Boiler [kWh]	0	241,772	620,463	0	4,201,495	0	6,394,601
HTHP [kWh]	0	825,590	446,898	0	0	0	0
Geothermal energy [kWh]	19,263,772	18,196,411	18,196,411	4,201,495	0	6,394,601	0
COP of HTHP		6.60	7.90				0.00
CO_2 emissions from boilers [t]		48	124		840		1,279
Electricity for heat pumps [kWh]		125,089	56,569				
CO_2 emissions from electricity production for HTHP [t]		25	11				
CO_2 emission for whole process [t]		73	135		840		1,279

Conclusions

The Southeastern Europe has great opportunities in the area of renewable energy sources, because the geothermal potential is available and it is very large in some regions. On the other hand different solutions for greenhouse heating are searched while on one side the demands for different plants are increasing through the entire year and on the other side the solutions for lowering CO_2 emissions are searched to achieve the target regarding reduced energy production from fossil fuels.

This study presents the comparison if the same greenhouse made of 4 mm toughened single glass is placed in Slovenia or in Serbia, where different options for geothermal potential exploitation are taken into account and also different climatic parameters are included.

The results show that Serbian region is more suitable for the assumed greenhouse type from economic and environmental point of view, as the payback period is much shorter than for the Slovenian case. The main reason for this is that the utilization of geothermal energy is much cheaper in Serbia, where the geothermal temperature potential is much greater at the depth of 700 m, compared to Slovenia's at the depth of 1,500 m. On the other hand according to Slovenian conditions the best solution from economic aspect would be heating system replacement with combination of HTHP, geothermal heat potential and boiler system only for covering peak values.

In this paper the case study is presented for two specific areas in Southestern Europe. Such calculations should be done for each specific area, while the climatic parameters are the same but the geothermal heat potential varies from region to region.

Nomenclature

A – greenhouse ground plan area, [m^2]
D – material thickness, [mm]
H_g – the daily increment of global emissivity, [Whm^{-2}]
t_m – number of days per month, [day]
t_p – average month temperature, [°C]

Abbreviation

COP – coefficient of performance

Greek symbols

ε – light transitivity, [–]
λ – heat conductivity, [Wm^{-2}K^{-1}]
Φ_{GH} – greenhouse heat demands, [kWh]
Φ_s – the heat flow from solar radiation, [kWh]
$\Delta\Phi$ – energy deficit, [kWh]

Appendix

The heat flow from solar radiation:

$$\Phi_s = H_g \times t_m \times A \times \varepsilon \tag{1}$$

Greenhouse heat demands for:
– toughened glass

$$\Phi_{GH} = 18,323.75\,\text{kWh/K} \times \left(16 - t_p\right) \times 20 \tag{2}$$

– double insulated glass

$$\Phi_{GH} = 3,475.6\,\text{kWh/K} \times \left(16 - t_p\right) \times 20 \tag{3}$$

– polycarbonate plate

$$\Phi_{GH} = 9,823.5\,\text{kWh/K} \times \left(16 - t_p\right) \times 20 \tag{4}$$

Energy deficit:

$$\Delta\Phi = \Phi_{GH} - \Phi_s \tag{5}$$

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