THERMAL WATER UTILIZATION IN THE HUNGARIAN GREENHOUSE PRACTICE

by

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This article focuses on the usage of geothermic energy in greenhouses, its energy-, economic efficiency- and sustainability-related questions. The most notable cost greenhouses produce during operation is the usage of heat energy, which is why when planning a system for this purpose, the energetic analysis of the solution to be used is one of the most important factors. The presented analyses suggest that of the energy resources currently available and usable, geothermic energy has the lowest unit cost. In the case of greenhouse heating, this method turned out to be the most cost-effective among all solutions using any of the energy resources. Regarding the environmental aspect, the CO_2 emission rates of the various heating methods have been examined as well. Using the thermal water of the greenhouses before reinjection is an efficient way of energy utilization. Even though the firewood and pellet boilers look the most efficient forms for the first time, past experiences proved them to be the most expensive ones as well. Therefore, it can be stated that the utilization of geothermal energy is the best solution for greenhouse heating, from the perspectives of economic and environmental aspects as well.

Based on the previous observations in terms of environmental and economic efficiency this paper aims to discover the opportunities for high-scale thermal utilization in Hungary in order to meet its future renewable targets.

Key words: *geothermic energy, energy efficiency, environmental impact, cost-effectiveness*

Introduction

The Hungarian Government made the *Renewable Energy Action Plan of Hungary* for the 2010-2020 period in 2010. Its goal is: *increasing the gross share of energy produced from renewable sources in total energy consumption to 14,65% by 2020* [1]. The action plan aims for the continuous increase in renewable energy consumption, according to current international trends [2]. It proposed a mildly intensive ascending curve, and increase policy until 2015, but further intensified it from 2016.

The highest share of renewable energy consumption goes to heat production, which has two different kinds of basis:

– heat energy produced from combusting biomass, and
– geothermic energy.

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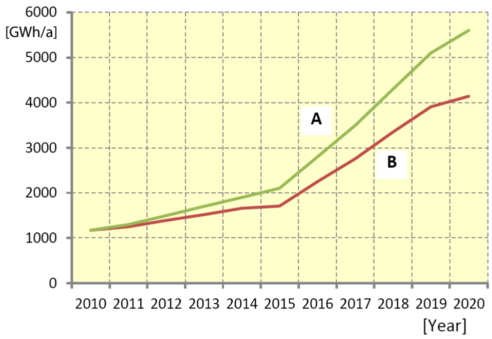

Figure 1. Development of geothermic energy usage (A – total geothermic energy, B – without heat pumping) [1]

Hungary has vast sources of geothermic energy. The main areas of usage for such sources are balneology, agriculture and the heating systems of buildings [3]. However, the increase the plan counts on is still substantial, as it is more than five times the potential of 2010, fig. 1.

The central area of the Carpathian Basin has an extremely rich potential compared to other geothermal areas. The average value of the heat-flow released from the depths of Earth is around 90-100 mW/m^2, which is about two times the continental average. Due to the previously listed geothermic attributes, the heat of the layer 1000 m underground reaches, and even surpasses 60 °C in Hungary. Isothermal heat analyses revealed substantial fields surpassing 100 °C, 2000 m under ground level [4]. The medium of geothermal energy is mainly thermal water in the Carpathian Basin, filling the porous – permeable zones of thick sedimentary rock beds, which can reach a thickness of up to 6 km. In Hungary, only the deep aquifer layers are utilized as contexts of geothermal energy, part of which are thermal waters, different from the rest of the sources due to their temperature. In Hungary, the definition of thermal water applies to layer water sources with a surface temperature above 30 °C. According to 2015 data, 951 of the existing 1300 thermal water wells are in operation.

Of which:

– 155 are used for energetic purposes,
– 214 are used as a drinking water source,
– 368 are used for supplying hot springs and spas, and
– 214 are used for other purposes (multiple usages, communal, industrial).

Hungary's thermal water usage has the deepest roots in balneological usage, in other words, balneotherapy, signified by the fact that 40% of the existing wells in spas are used for this purpose, and this is the area that has shown the most dynamic development in the last decade. Even compared to the global average, Hungary is in the lead from the perspective of agricultural usage, where a non-exhaustive list of implementation uses are 500.000 m^2 of greenhouse area, 1.200.000 m^2 of plastic tunnel area, dryers, husbandry farms, cleaning rag waste, *etc.* The mixture is also spiced by the heating of more than 5.300 flats, hospitals, and industrial halls.

Contrary to the previously explained facts, the share geothermic energy holds in the total energy production of Hungary is close to minuscule: 4.23 PJ (2010). Our capacity for utilizing thermal water for energetic purposes is far from ideal. The domestic indicators of directly utilizing thermal energy are sufficient even compared to global standards, but if we look at them from the efficiency perspective, there's much more to be done.

The reasons are as follows.

– The efficiency of the mainly seasonal heat usage is low, and the systems that utilize heat are old.
– The measurement methods of produced and utilized thermal water are not harmonized, heat utilization is often accompanied by wasting water.
– Successful examples of implementing a re-injecting procedure are scarce.

Geothermal energy is basically a never depleting cornucopia, but its usage is concentrated only in some areas even in Hungary, making it a local energy source.

Defining the problem

Legal regulations currently in effect, ruling on the procurement of a water legislation permit for using thermal water for energetic purposes, and the professional regulations and requirements of said permit are as follows:

- Regulations, governmental decrees touch on all important questions, thereby regulating, protecting this important natural resource, for us, and for the next generation as well.
- Thermal water produced explicitly for energetic purposes have to be re-injected, based on the ruling of a separate decree. However, Governmental decree 1002 of January 11, 2002 ruled that the requirement for re-injecting thermal water used for energetic utilization by agricultural production is no longer in effect.
- Production explicitly for energetic purposes has to be planned, installed, designed and operated in a way that its effects do not impair the yield and temperature of springs and karstic sources.

Based on the Act, those utilizing water bodies determined to be of sufficient quantity by the water collection and management plans are acquitted from the requirement of re-injecting by the December 22, 2020 at the latest (15. §). Directive 2000/60/EC of the European Parliament and of the Council called the Water Framework Directive (WFD) is the regulation directly affecting subterranean water bodies. Among its goals, it stresses the importance of averting the degeneration of water ecosystems, protecting and improving their quality [5, 6].

Based on this, the (non-exhaustive) list of duties Member States have are to:

- make arrangements to prevent or limit hazardous substances entering the subterranean water bodies, and
- protect, improve and rehabilitate the good quality of subterranean water bodies, and make sure a balance is struck between extraction and resupply.

Source and method

Greenhouse utilization

Greenhouse heating is considered a business activity, and as such, there is a competition on the market of energy resources. During our previous research, we analyzed these resources, and variants of heating technology applicable to winter heating greenhouses evaluated them by their respective pros and cons and took a look at their investment and maintenance costs as well. We also evaluated the specific energy yield costs of the various systems, fig. 2.

We successfully determined that using geothermic heat energy gained from thermal water would be the most economically sound decision (0.007 EUR/kWh). We also analyzed the specs of heat pumping already consumed heating water, its opportunities, pros, and cons.

Regarding the environmental aspect, we also examined the CO_2 emission rates of the various heating methods, fig. 3. Even though the firewood and pellet boilers look the most efficient forms, past experiences proved them to be the most expensive ones as well. Therefore, it can be stated that the utilization of geothermal energy is the best solution for greenhouse heating, from the perspectives of economic and environmental aspects as well.

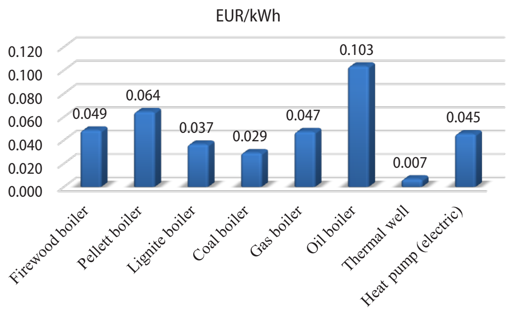

Figure 2. The price of 1.0 kWh heat energy where the system produces a 15-year return

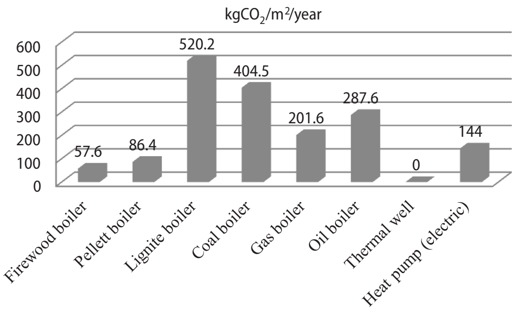

Figure 3. The CO_2 emissions of the certain fuels in a calendar year

The geothermic energy content of fluids is used in several stages within modern horticulture production systems while keeping sustainability in mind, fig. 4 and tab. 1.

The heat usage of the system, in case we also use a heat pumping before re-injecting:

$$Q_4 = -Q_8 - Q_{10} - Q_{12} - Q_6 + Q_{13} \tag{1}$$

where Q_4 is the heat content arriving in the heat exchanger/heat center of the main circuits, Q_8 – the heat content used for vegetation heating, Q_{10} – the heat content used for bud heating, Q_{12} – the heat content used for soil heating, Q_6 – the heat content used for heating social building, and Q_{13} – the heat content extracted and remixed by the heat pump.

Table 1. Heating context temperature values at the various points of the system

Signs of heating branches	Water temperature [°C]	Signs of heating branches	Water temperature [°C]
T1	80	T3	55
T1 backwards	25	T4	38
T1 backward/ heat pumping	10	T5	35
T2	75	T6	35
T2 heating/forwards	70	T7	25
T2 heating/backwards	40	T8	25
T2 after heating	35	T9	45

Analyses

Thermal water consumption via heat pumping

Releasing thermal water from wells onto the surface, fig. 5, and redirecting it (into lakes and rivers) poses environmental protection risks due to its high salt content (this is why an environmental load fee exists). Sequestration into thermal wells – the aquiclude – in the case of more shallow bands - also becomes a problematic factor, due to preserving water purity. However, these have to be utilized due to sustainability reasons. Siphoning heat energy from the high-enthalpy fluid via heat pumping before sequestration, or subterranean placement is definitely a viable option [7, 8].

Abbreviations on the illustration are [9]:

– temperature of the well fluid, Kf (60-80 °C),
– temperature of fluid leaving - released from - the heat exchanger, Ka (25-32 °C),
– temperature of heating water entering the greenhouse, $N1f$, and
– temperature of heating water returning from the greenhouse, $N1a$

Due to the theorem of energy conservation, we can define that the heat absorbed by the medium being heated equals the heat expended by the medium losing heat [10, 11] which is:

$$Q_K = \dot{m}_1 c(T_{Kf} - T_{Ka}) = \dot{m}_2 c(T_{N1f} - T_{N1a}) = Q_N \tag{2}$$

In other words, the heat successfully produced from the well is dependent on the difference in inbound and outbound temperatures, and the mass-flow volume of the fluid from

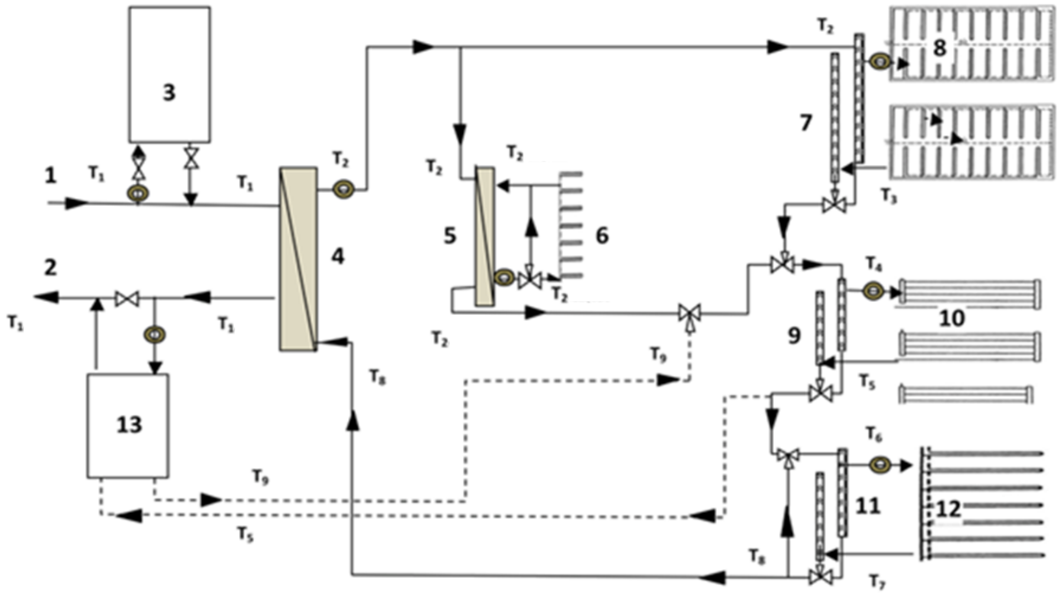

Figure 4. Theoretical heating system of a modern greenhouse; *1 – production well, 2 – exhaust well, 3 – buffer container, 4 – heat exchanger/heat center of main circuits, 5 – heat exchanger of social buildings, 6 – heating of social buildings, 7 – divider – collectors of vegetation heating, 8 – vegetation heating, 9 – divider-collectors of bud heating, 10 – bud heating, 11 – divider-collectors of soil heating, 12 – soil heating, 13 – heat pump*

the well. When determining the performance of the heat exchanger, the decisive factor is obviously the supported maximum mass-flow rate.

Heat supplied to the greenhouse is:

$$Q_N = \dot{m}_2 c(T_{N1f} - T_{N1a}) \tag{3}$$

Even with soil cooling, the temperature of water released in case of greenhouses is between 25-32 ºC [12, 13]. For such a lukewarm temperature, heat pumps can be operated with a high COP value (COP = 4-5). This is why heat pumping water before releasing it into open water or sequestrating it may be productive.

In this case, the heat exchanger on the heat pump's vaporizer side can be linked directly to the fluid to be sequestrated, but when the concentration of minerals is higher, operating it from an inserted heat exchanger, which also allows for mass-flow rate control might be preferable, fig. 6.

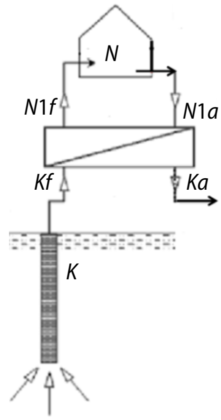

Figure 5. Heating greenhouse with released fluid (*N*-greenhouse)

Abbreviations:

– *Sf* (=*Ka*) – temperature of the fluid arriving in the inserted heat exchanger.
– *Sa* – the temperature of the fluid leaving the inserted heat exchanger, via releasing, or sequestration.

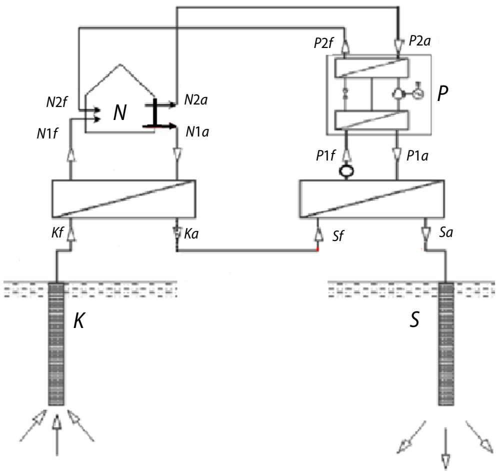

Figure 6. Installing the heat pump [14]

– The respective values of *P1f* and *P1a* are dependent on the ΔT value possible to realize on the heat exchanger, but even more dependent on the mass-flow rate set in this support circulation.
– The respective values of *P2f* and *P2a* are the temperatures of heating water leaving, and returning to the heat pump's capacitor. Their ranges are defined by the attributes of the heat pumps and the heat extraction of the greenhouse.

According to what was written until now, if we chose a vaporization temperature which is too low, thereby lowering the sequestration temperature, but disregard to do the same with the capacitor's temperature, the value of the COP will be worse. The same can be said about the capacitor side if we want to raise the heating temperature.

The need for sustainability

Domestic analyses and results (on porous sandstone soils)

The detailed measurements of the Geo-Log Ltd. [15] conducted in the areas of Szegvar and Szentes in 2008 refer to the effects of intensive extraction when compared to the measurements of VIKUV conducted in 1975. The measurements included 20 wells. The process of the measurements is quite complicated, however, detailed descriptions can be read in the introductory materials (presentations, articles, research reports) by Szongoth *et. al.* [16].

Usually, the goals of the periodic individual well evaluations are as follows [2]:
– Checking the well structure (lowest depth, diameters, state of the well body, location of leakage preventions, location of filters).
– Dynamic evaluations (flow and temperature readings, pressure readings: capacity evaluation, pressure increase, pressure gradient).
– Sampling and laboratory evaluation (water sample collection, gas separation, deep gas sample collection).

Moreover, they also stress the importance of the question: is the fluid extracted applicable to re-injecting into one of the given field's local wells, after it cooled down due to the usage for heating? Many consider that re-injecting into sandstone aquifers is impossible, due to the clogging of various filters and their direct proximity. Many experiments were conducted beginning in the 70's - on the Great Plains - related to re-injecting. Initial experiments proved to be unsuccessful. The first economically sound re-injecting well was built in Hodmezovasarhely, in 1998. Ever since then, millions of cubic meters of water were re-injected into the ground, with 3-5 bar pressure, fig. 7.

More recent domestic and international research suggests that while re-injecting into sandstone poses various problems if done adhering to proper criteria, may prove successful. Various German analyses also had to deal with the fluid re-injected into the ground having a differing chemical composition compared to the in situ reservoir's fluid. This is why they use a completely isolated system, and they do not allow the extracted water to come into contact with oxygen. The float contents of re-injected water are removed by using an 1.0 micron filter. Szanyi *et al.* [17, 18] pointed this out – that the clogging seen in the pores of the wells' filters, and the decrease in permeability can also be caused or influenced by not only the in situ molecules, temperature, pressure, salt content, velocity, and pH value, but molecules from an outside source as well (corrosion of pipes, bacteria, gas bubbles, suspended materials).

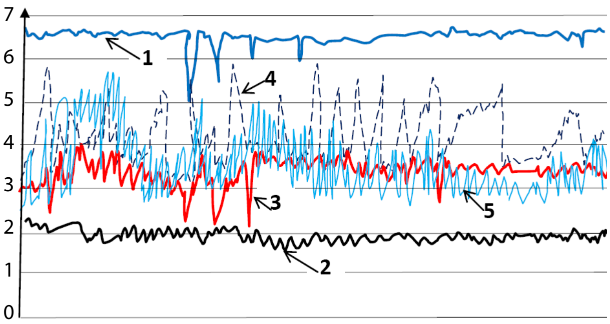

Figure 7. Re-injecting parameters of the well for the first quarter of 2006 [16]; *1 – water volume 100 l/min, 2 – absorption capacity by unit [lmin^{-1}], 3 – pressure of the well pump [bar], 4 – pressure before the filter [bar], 5 – water temperature 10 °C*

Geo-Log Ltd. conducted analyses [15, 16, 19, 20] first 20 wells in the area of the ARPAD AGRAR Inc., within the framework of the Jedlik Project until 2011. The area's source layer is sandstone. Beyond the generic evaluation of the 20 wells' conditions, they also evaluated numerous other factors, including making estimations for the theoretical possibility of using re-injection as well. They used many sensors and probes for the measurements, which were connected to the measurement data collector units in a trailer. Using the measurement system, they created laboratory conditions for the wells. Extraction was done at a rate close to the maximum yield, and the volume (pressure, temperature, *etc.*) flowing between the layers (filters) was measured, after which they sealed the well, and continued the measurements. This was done to observe the flow (inbound and outbound) between layers. Signs pointing to the flow between layers were marked for 5 wells seen in fig. 8 [15, 16]. Values show an equity between active layers almost everywhere.

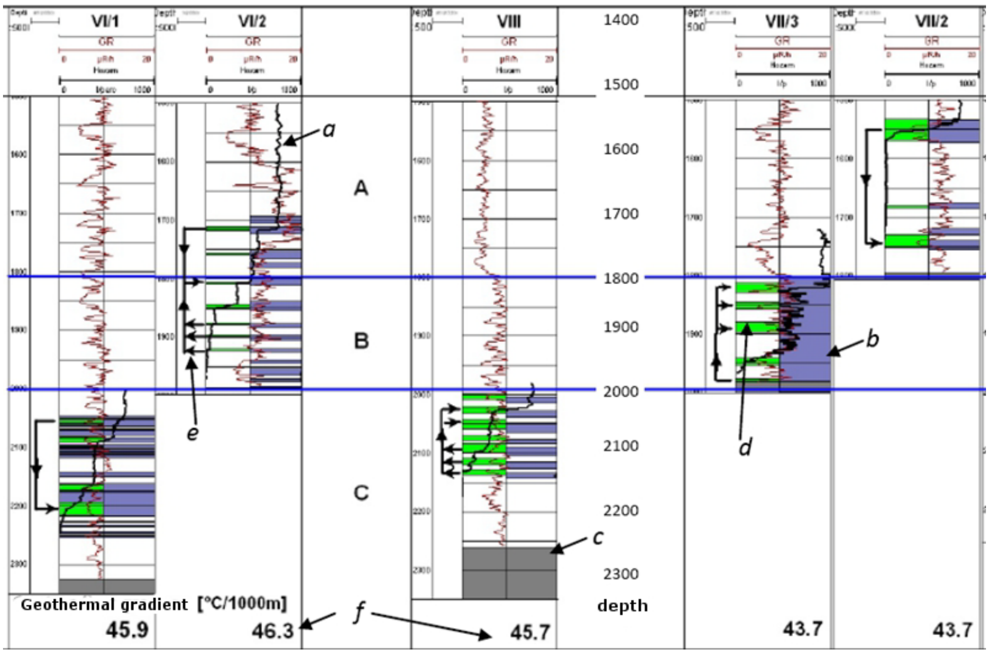

Figure 8. Internal cross-injection for wells of Szentes filtered in 6 different heights
(*for color image see journal web site*)

Curves on the fig. 8, based on colors:
- flow measurement curve (black)-a,
- filtered junctures (purple)-b,
- non-permeable junctures (grey)-c,
- active junctures (green)-d,
- the direction of cross-injections (black arrows)-e, and
- multiplicative inverse calculated for the geothermal gradient (bottom)-f.

The main conclusions are as folllows.
- During the detailed analysis of wells in perfect working order, and based on the results of prior measurements, we can state that the baseline water level decreased by 25-30 m during the last four decades, even though this can not be seen in the volume of production.
- During the wells' rest period, a situation where water layers exchange content between each other develops. Generally, the refilling process in the first phase of the rest period happens within the layer used previously, meaning flow can happen both upwards and downwards.
- Therefore, the measurement checks used for such extraction thermal wells is insufficient to determine the in situ state of aquifer layers. Only a monitoring well opened to the aquifer layer, equipped with filters can be used to determine the condition of an aquifer layer.
- The aquifer layers of the wells in the Szentes area show correlation (via various flow and temperature, and depth gradients), which signifies their effects on each other. This shows that used (trimmed enthalpy) water can be re-injected (which is further supported by the easily noticeable absorption layers).

Improving efficiency

Heat pumping before re-injection

The re-injecting moratorium currently in effect is only temporary, and once it is finished, re-injecting has to be solved somehow. The economic soundness of the investment for greenhouses is not only determined by governmental dues (taxes, fines, *etc.*) but the investment and operational costs (pumping, heat extraction, placement, *etc.*) as well.

In essence:
- the cost of energy procured by unit (kWh/EUR), and
- investment costs for creating potential for energy by unit (kW/EUR) are the decisive factors.

The cost of energy can also be influenced by the efficiency of heat usage achieved by the final consumer (heat exchangers, machinery and building insulation, heating units, *etc.*). While the investment cost for creating the potential for energy by the unit is mainly dependent on the costs of digging and maintaining wells. These two factors are obviously inseparable from each other, and affect each other, both are also substantially influenced by the technical system and the implementation. The extracted heat content for a set quantity of fluid is determined by the difference in temperature between the time of extraction (before usage), and the time after usage (release, before re-injection). By cooling the 32 °C fluid to 10 °C, we can get nearly as much performance as we would by using technological heat extraction directly from the well. What did we achieve (via re-injecting)? No need to dig new twin wells, which would require a 1.1-1.3 million EUR investment, further taxed by the need for plumbing to the location of usage.

However, the heat pump requires an investment of 220-250 thousand EUR. Naturally, the heat pump requires electric energy to operate. If we calculate with a COP value of 4, we get 4kWh/1kWh, which is – using a 0.063 EUR/kWh electric energy cost – $0.063 \cdot 4123/4 = 1031 \cdot 0.063 = 65.46$ EUR/h cost. If the extraction of the fluid in total is only 0.01 EUR/kWh, the surplus (4123·0.01, meaning 65.46 – 65.44) is approximation 0.02 EUR/h. If we calculate with an annual gross consumption of 2000 hours, the energy costs of the heat pumping are 26349 EUR a year. The life expectancy of the heat pump is 20 years, in which case 12698 EUR cost a year is deduced (to simplify matters, we disregard the maintenance and repair costs for the wells and the system). This makes the cost of heat pumping ~39000 EUR annually. Compared to the higher, one-time investment the twin wells require, and their 40-year life cycle, their value is reduced by 31746 EUR each year. Therefore, the operation costs do not increase the cost by a unit of the post-installed heat pump substantially. An important factor is that both the investment costs and the risks involved are lower, as we can not be too sure what results we can expect from the twin wells in advance. This system is especially advantageous in case we increase the size of our plantation, which results in the energy requirements increasing as well, but we do not want to realize a new geothermic investment.

Conclusions

In this article, we analyzed the respective costs of energy resources usable for the winter heating of greenhouses. We also examined the accessible energy resources in Hungary, and their annual costs for a 1 ha sized greenhouse. One of the main conclusions of the research was that geothermal heating proved to be the cheapest and the most environmentally friendly method. It can be said that if the COP value of the heat pumping system is higher than 3.8, it will be cost-effective in all cases, and it will operate on a low CO_2 emission level (only 30% compared to the emission rate of the gas boiler). Furthermore, using the thermal water of the greenhouses before reinjection is an efficient way of energy utilization. However, in the case of greenhouse heating, this method turned out to be the most cost-effective among all solutions using any of the energy resources.

According to the examination of the excellent sandstone water-based wells, and the results of the previous measurements, it can be stated that the static water level decreased by 25-30 m during the last 40 years. Still, this tendency can not be observed within the production performance. In Szentes, the water tables of the wells (the certain flow, temperature and depth gradients) show correlations which stand for their effect on each other. This makes it possible to re-inject used water (with reduced enthalpy). The presence of the absorbing layers implies the same result. We can conclude that the low-temperature reinjection of the fluid (still with a significant enthalpy) leads us to a slower water level decrease rate (in long-term) at the end of the greenhouse utilization. So the examined area is capable of sustainable geothermal energy usage.

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