Fostering diffusion of Heating & Cooling technologies using the seawater pump in the Adriatic-Ionian Region

Pilot plants comparative report

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1 Introduction

The SEADRION project **aims** to support the development of a regional innovation system for the Adriatic-Ionian area by installing three renewable energy facilities in public buildings located in Greece and the western and southern part of Adriatic Croatia. These facilities are seawater heat pumps, an innovation system that uses the thermal energy contained in a reservoir (sea) to achieve the cooling and thermal energy in the buildings close to the sea.

The main **objective** of the SEADRION is to identify benefits and barriers associated with the use of this technology and to find a system solution designed to improve the use of the seawater heat pump technology and to make the building's energy self-sufficient and independent of fossil fuels.

The main **outputs** of the SEADRION project are transnational seawater heat pump network:

- to support sustainable development in the ADRION region, science and technology cooperation between research institutions and enterprises,
- to enhance the innovation capacity of the heat pump sector with the aim to improve their innovation skills, capacities and competencies and common strategy to enhance the use of seawater heat pump based heating and cooling in the ADRION region.

2 Pilot plants general information

2.1 CRIKVENICA

UNIZAG FSB within the SEADRION project proposed the installation of a high-temperature seawater heat pump in a public building to ensure the non-profit character of the pilot project.

In particular, UNIZAG FSB proposed a special hospital Thalassotherapia in the City of Crikvenica, which is located a few meters from the sea. The pilot project involves the installation of a high-temperature seawater heat pump to meet thermal needs in the summer and winter period in the Thalassotherapia, Crikvenica.

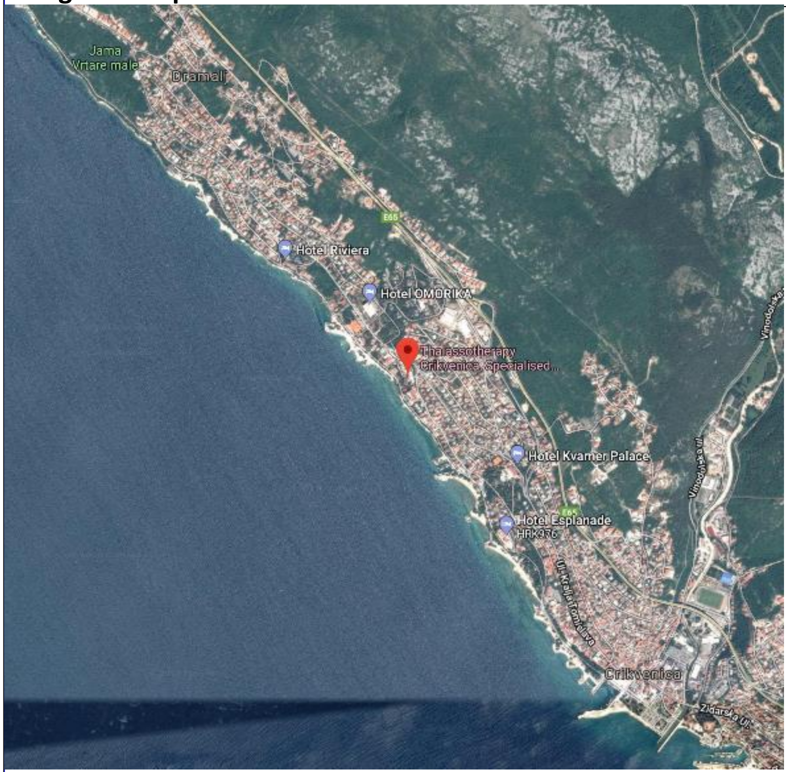
The heat pump will have two circles, the seawater circle and glycol circle used to heat the pool and thermal baths in the building. For this reason, well depth 3m built previously in the mull for the pool needs will be used for seawater intake to have enough water and an easy collection point for the seawater. This property was preferred due to its proximity to the sea, a prerequisite for the project's needs, as the heat pump's operation will be tested for a high temperature, which is not a typical installation in the ADRION region.

2.1.1 General description of the building

The Thalassotherapy Crikvenica is located at Gajevo Šetalište 21 in the Municipality of Crikvenica. It is a rehabilitation building, built-in 1970 and has a year-round operation, with approx. 50 occupants per day. The average yearly air temperature is 15.3 °C and air humidity in the summer months is 54.9%.

Figure 1. Thalassotherapia Crikvenica

3. Location of the building		
Address	Gajevo Šetalište 21	
Postcode	51260, Crikvenica	
Location (available from Google Map)	**Latitude**	**Longitude**
	45°11'09.3"N	14°40'39.4"E
Google Earth photo		



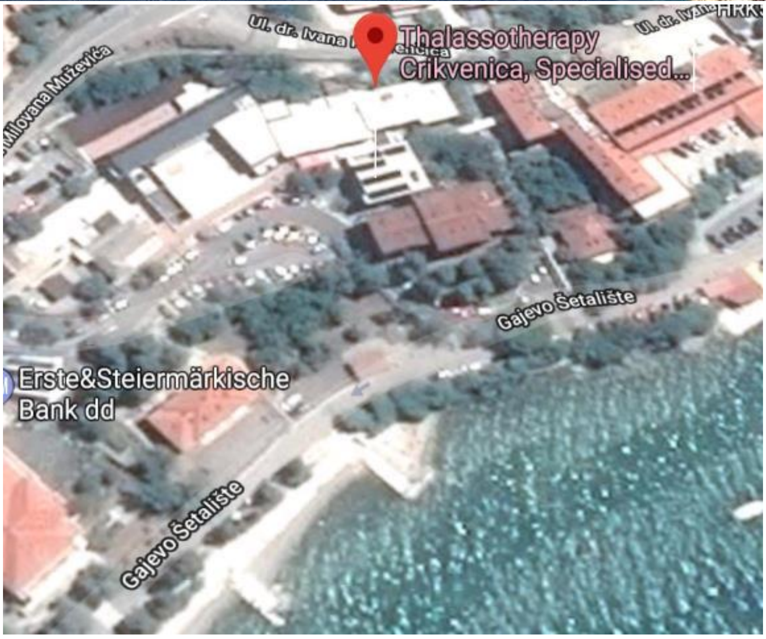


Figure 2. Location of the pilot plant in Crikvenica

2.2 DUBROVNIK

Within the SEADRION project, partner DURA proposed the installation of a pilot plant and, in particular, a seawater heat pump in a public building to ensure the non-profit character of the pilot project.

In particular, DURA proposed the Rectors Palace, which is located a few meters from the sea. The pilot project involves the installation of a heat pump to meet thermal needs in the summer and winter periods for complex buildings.

2.2.1 General description of the building

The Rector's Palace is located in the City of Dubrovnik, Pred Dvorom 3, Croatia.

Figure 3. Pilot plant location in Old Town Dubrovnik

The Rectors Palace – The historic multipurpose building is located in street Pred Dvorom 3 in the Municipality of Dubrovnik. It is a cultural protected building from the 14th century including a Museum, Townhall, theatre and cinema and has a year-round operation, with approx. 100 occupants per day.

It is a UNESCO World Heritage Site, and no modern reconstruction is allowed on it.

Figure 4. The Rector's palace in Old Town Dubrovnik

2.3 GREECE

Project partner CERTH proposed the installation of a geothermal heat pump in a public building to ensure the non-profit character of the pilot project.

In particular, CERTH proposed a sports facility (sports hall) in the Municipality of Alexandroupolis, which is located a short distance from the sea (around 50m). The pilot project involves the installation of a geothermal heat pump to meet thermal and cooling needs in the Municipal Stadium "Fotis Kosmas".

2.3.1 General description of the building

The Municipal Stadium of Alexandroupolis "Fotis Kosmas" is located at 1, Apolloniados street in Alexandroupolis.

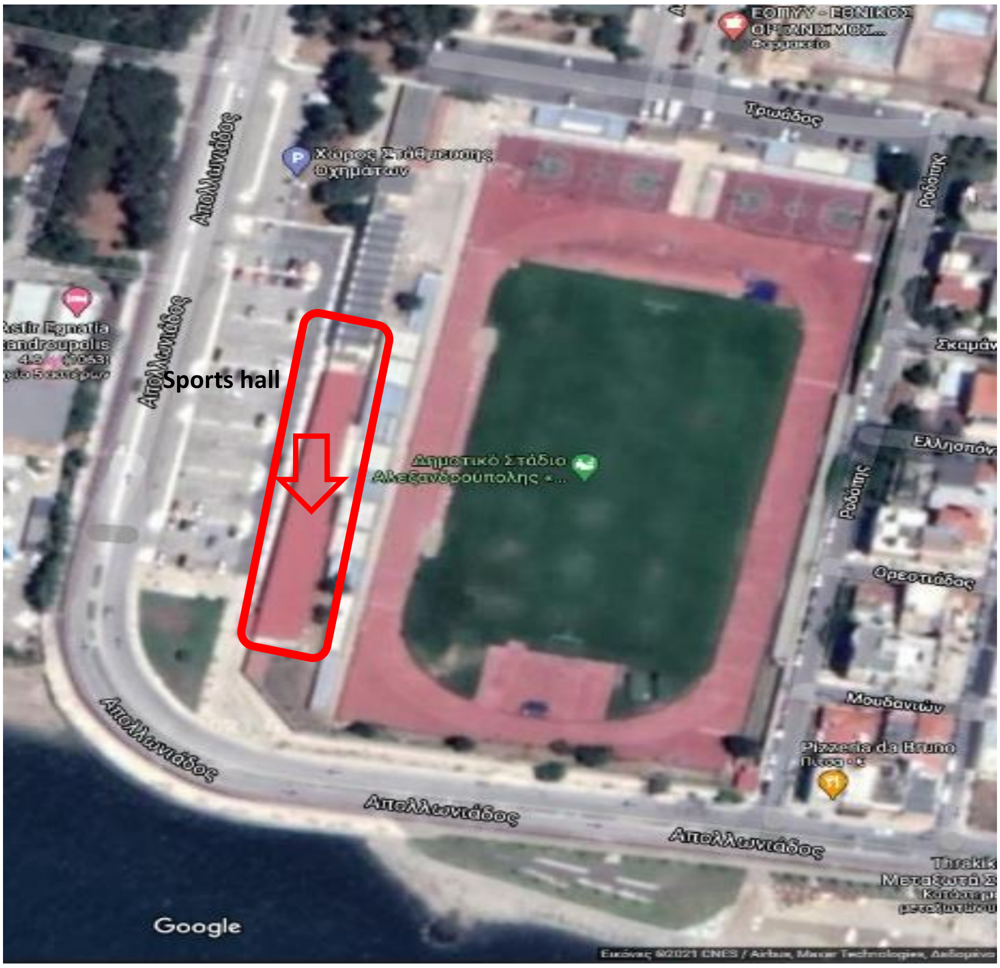


Figure 5. Situation of Municipal Stadium of Alexandroupolis "Fotis Kosmas"

2.3.2 Building

The sports hall of Fotis Kosmas Stadium is located on the NW side of the stadium and was built before 1950. It is designed and constructed as a non-residential, free-standing building as part of the stadium facilities. It has a year-round operation, with approx. 20 occupants per hour.

Figure 6. Sports hall of Fotis Kosmas Stadium

The values of the building's outer shell and floor parameters are given below.

- Ground floor/single storey building
- Surface ca. 85m x 9m, walls with a sloping roof whose maximum height is 6.40m and a minimum of 4.40m.

3 General description of pilot plants

The general characteristics of the buildings and service system are presented below.

Table 1. General characteristics of the buildings

Characteristics	CRIKVENICA	DUBROVNIK	GREECE
Floors	4	3	1
Total heated area [m^2]	2243	8928	678
Gross heated volume [m^3]	8755	31248	3655
Type of windows	Double glazing - Aluminium frame	Single glazing-wooden frame	Single glazing - Aluminium frame
Building material	Concrete, semi-massive construction	Stone, massive construction	Concrete, bricks, massive construction
Thermal insulation	Yes	No	No

A summary of the most important parameters calculated within the energy analysis is depicted below:

Table 2. Calculated parameters

	CRIKVENICA	DUBROVNIK	GREECE
Total demand [kWh/year]	114,364	489,544	237,847
Total consumption [kWh/year]	127,071	494,489	317,129
Primary energy consumption [kWh/year]	139,778	798,105	348,842
CO_2 emissions [kgCO_2/year]	36,901	210,700	92,094

4 Technical description of SWHP facilities

4.1 CRIKVENICA

4.1.1 Seawater intake well

The pilot plant located in the Thalassotherapia will use existing well for the intake of the seawater. The existing well is used to deliver water to the rehabilitation pool and have enough capacity to install additional pipes for intake and disposal of seawater. In this way, the overall investment cost will be reduced.

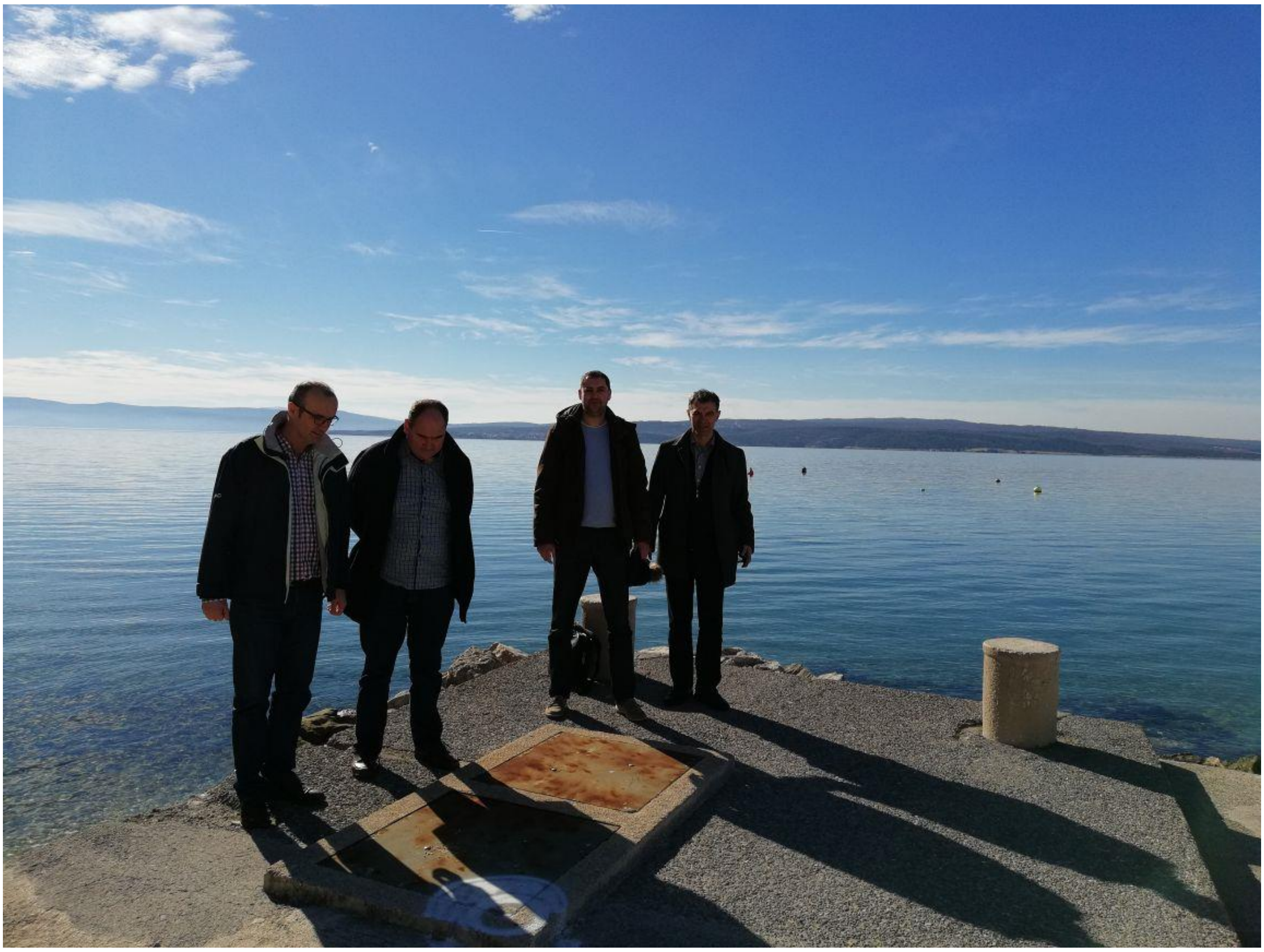


Figure 7. Seawater intake well in the Thalassotherapia pilot plant location

4.1.2 Seawater Heat Pump

The electric heat pump is designed to maximally meet the pool's heating and hot water requirements throughout the year. The engineered heat pump is a high-temperature LG heat pump type: ARWB200LAS4, which is combined with two high-temperature LG hydro type heaters: ARNH08GK3A2 and whose individual heat output is 25.2 kW. The heat pump is designed to operate at 65/55 °C. An internal high-temperature "hydroxy" for heating and domestic hot water preparation consists of two separate circuits of working substance that work in a cascade with a maximum hot water flow to consumers of 80 °C. The first functional group comprises the secondary circuit of the substance. This circuit raises the water temperature to the required level. These include the plate heat exchanger of two R410A and R134a workpieces; additional screw compressor, electronic expansion valve, 4-way valve, cooling battery, protection components and valves for secondary circuit servicing. The system is pre-filled with R134a working substance. The second functional group includes the R134a-water heat exchanger and other consumer water circuitry, including a frequency pump, expansion vessel, safety group, filling and discharge valve and flexible hoses for connection to the heating system.

4.1.3 Seawater heat exchangers

A titanium plate heat exchanger is selected to ensure its resistance to salty water. The technical characteristics are shown in Table 3. The counterflow heat exchanger will be at an operating pressure of 10 bar (primary-secondary) at a maximum operating temperature of 100 °C. The pressure drop on the exchanger will be less than 50 kPa (0.5 bar). Thermometers will be placed on all the inlets/outlets. A manometer device will also be installed to control the heat exchanger's clogging.

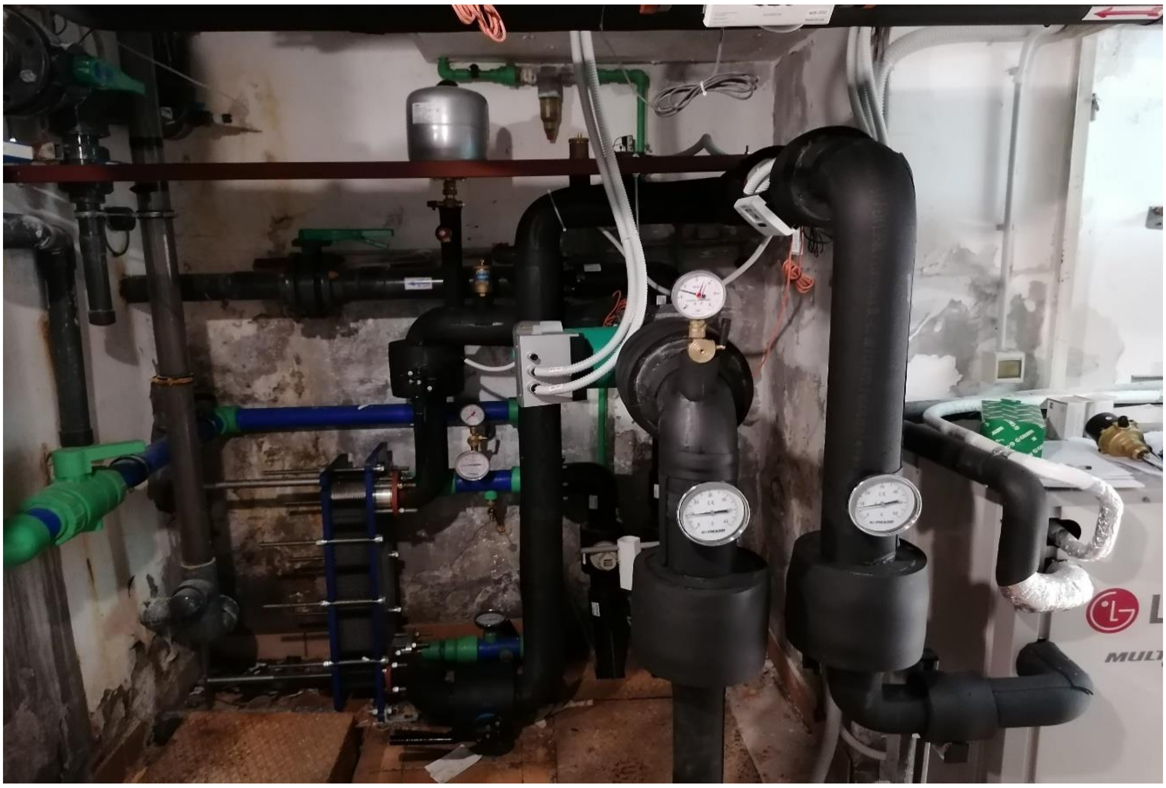


Figure 8. Heat exchanger with equipment

In addition, due to the existence of the water's salinity, a gradual reduction of the exchanger's efficiency is expected. For that reason, a special pump to avoid blocked or clogged piping will be installed, accompanied by special chemical liquids used for the cleaning of the heat exchanger as well as a neutraliser.

4.2 DUBROVNIK

4.2.1 Seawater intake well

The pilot plant will use the existing water intake of the seawater. In this way, the overall investment cost will be reduced. Water intake is located in the City Port near the building complex.

Figure 9. Old Town port

4.2.2 Seawater Heat Pump

There are six heat pumps in the engine room from DT1 to DT6. The heat pumps operate in a cascade, where the DT1 is set as a master while the other units are set as slaves. The master unit communicates with the slave units via internal bus communication. The setpoints of DT operation are determined by the project and are entered by the service technician during commissioning.

The heat pumps' start/stop and heating/cooling mode are set from the touch panel, while the mode can be set manually with a switch on the door of the SCADA cabinet.

Modbus connect all heat pumps, and all their parameters can be monitored via SCADA.

Figure 10. Engine room

4.2.3 Seawater heat exchangers

There are two seawater heat exchangers. Both on the seawater side and the heat pump side. The only connection between the SCADA and the heat exchanger is the pressure sensors connected to the inlet and outlet of the heat exchangers. Pressure sensors allow monitoring and alarm via SCADA. A graphic alarm is set to appear on the SCADA if the differential pressure rises above a certain value on the seaside or the heat pump side.

4.3 GREECE

4.3.1 Seawater intake well

The new installation of the seawater heat pump refers to an open-loop geothermal system application to cover the sports facility's heating and cooling needs.

Two boreholes (1st productive and 2nd re-injection) with a depth of 50 m each were constructed near the geothermal engine room located in a storage area adjacent to the boiler room of the sports hall. The amount of water pumped should be around **10 m^3/h**.

Figure 11. Grouting works and sensors' installation in extraction (up) and re-injection boreholes (down)

The heat exchanger, the geothermal heat pump, and all the mechanical and electrical equipment for optimum system operation were installed inside the engine room.

4.3.2 Seawater Heat Pump

The geothermal heat pump was a water-to-water type from Aermec S.p.A. (WRL model) with an R410A working medium, an internal reversible cooling-heating operation and an appropriate operating system to achieve the optimum efficiency depending on the fluctuations in the building's heat loads. It has two SCROLL type compressors in a common refrigeration circuit. The operation characteristics of the GSHP are shown in Table 3.

Table 3. Technical characteristics of the Geothermal Heat Pump

Heating operation	
Power (thermal)	**>95 kW**
Electrical power	**22 kW**
Efficiency (COP)	**>4.3**
Temperature evaporator	**13°C-8°C**
Temperature condenser	**45°C-40°C**
Cooling operation	
Power (cooling)	**>80 kW**
Electrical power	**17.1 kW**
Efficiency (EER)	**>4.7**
Temperature evaporator	**7°C-12°C**
Temperature condenser	**25°C-30°C**

Figure 12. Geothermal Heat pump - water storage tank – heat exchanger

4.3.3 Seawater heat exchangers

A titanium plate heat exchanger was selected to ensure its resistance to the sea / brackish water. The technical characteristics are shown in Table 4. The counterflow heat exchanger will be at an operating pressure of 10 bar (primary-secondary) at a maximum operating temperature of 100 °C. The pressure drop on the exchanger will be less than 50 kPa (0.5 bar). Thermometers are placed on all the inlets/outlets. A manometer device is also installed to control the heat exchanger's clogging.

In addition, due to the presence of the corrosive environment, a gradual reduction of the exchanger's efficiency is expected. For that reason, a manometer to record the pressure drop and a special submersible pump was installed, consisting of stainless steel components to ensure high corrosive resistance, bearings with sand flush channels that minimise wear, and a suction interconnector a strainer to prevent large particles from entering the pump.

Furthermore, the system is accompanied by special chemical liquids and neutraliser used to clean the heat exchanger.

Table 4. Technical characteristics of the titanium plate heat exchanger

Heating operation	
Drilling side	**Supply** 10 m3/h – **Temperature** Tin/Tout 18°C/9,5°C
Geothermal heat pump	**Supply** 17 m3/h – **Temperature** Tin/Tout 8°C/13°C
Cooling operation	
Drilling side	**Supply** 10 m3/h – **Temperature** Tin/Tout 18°C/26,5°C
Geothermal heat pump	**Supply** 17 m3/h – **Temperature** Tin/Tout 30°C/25°C

Figure 13. Heat exchanger, filters and circulation pump (primary loop)

5 Performance analysis of the SWHP plants

5.1 CRIKVENICA

5.1.1 Coefficient of performance (COP)

The monitoring activity of the HVAC plant of the special hospital Thalassotherapia in the City of Crikvenica, based on a seawater open-loop heat pump, revealed very high electricity consumption for the operation of three pumps. In total, 50% of electricity consumed is used for the operation of pumps and because of that overall efficiency of the system is lovered.

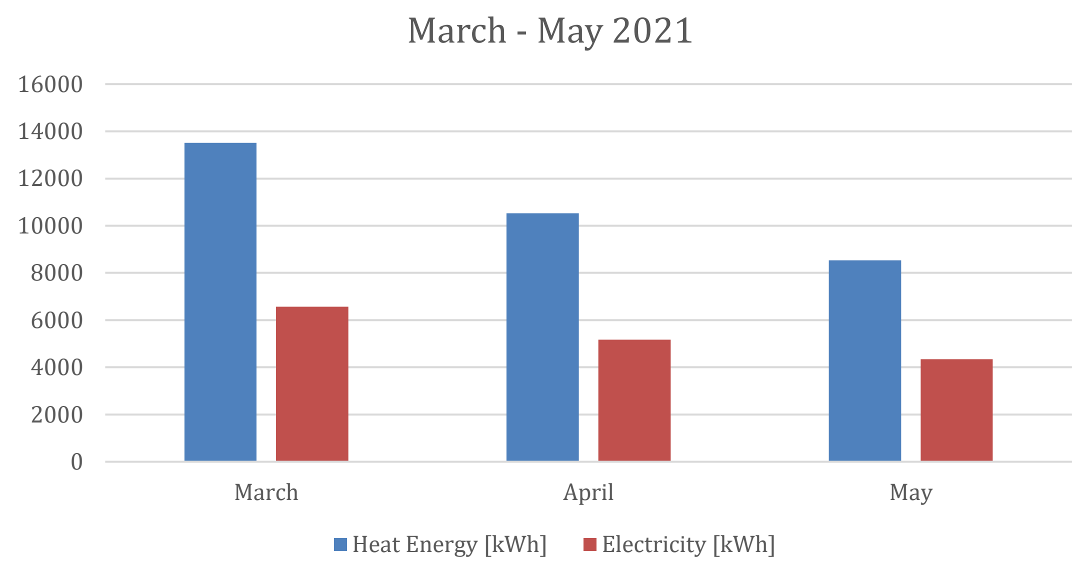


Figure 14. Delivered Heat energy and Electricity consumption [March – May]

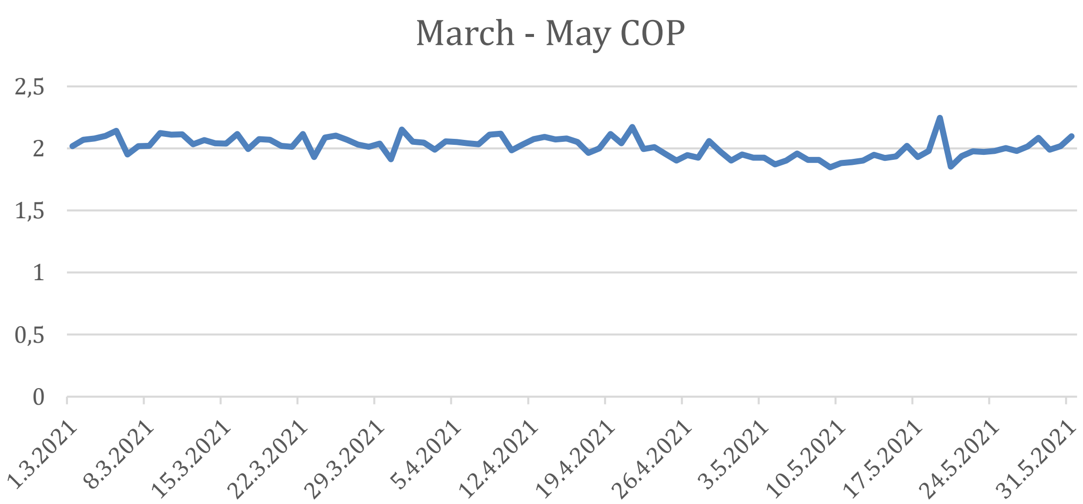


Figure 15. March-May COP in Crikvenica SWHP

Table 5. COP, Heat energy and Electricity consumption [March – May]

Date	COP/EER, [-]	$Q_{H/C}$, [kWh]	E_{el}, [kWh]
HEATING SEASON			
March	2,057684205	13510,60387	6565,926801
April	2,038776651	10532,24799	5165,964594
May	1,96334916	8536,647726	4348,002841
SCOP: 2,02			

Next table shows the meaning of each symbol mentioned in the table above:

COP/EER	[-]	Coefficient of performance / Energy efficiency ratio
E_{el}	[kWh]	Consumed electric energy
$Q_{H/C}$	[kWh]	Generated heating/cooling energy

Figure 15. and Table 5. show how COP was changing throughout the three months of 2021. It shows that the best results were in March when the outside air temperature was lowest and demand for heating energy was highest, leading to the best COP of the heating season.

5.1.2 Electric energy consumption

The electricity consumption presented in Figure 16 represents the system's overall consumption, which includes a Heat pump and three water pumps needed for the system operation. Conducted analysis indicated that 50% of consumed electricity is used for the operation of water pumps.

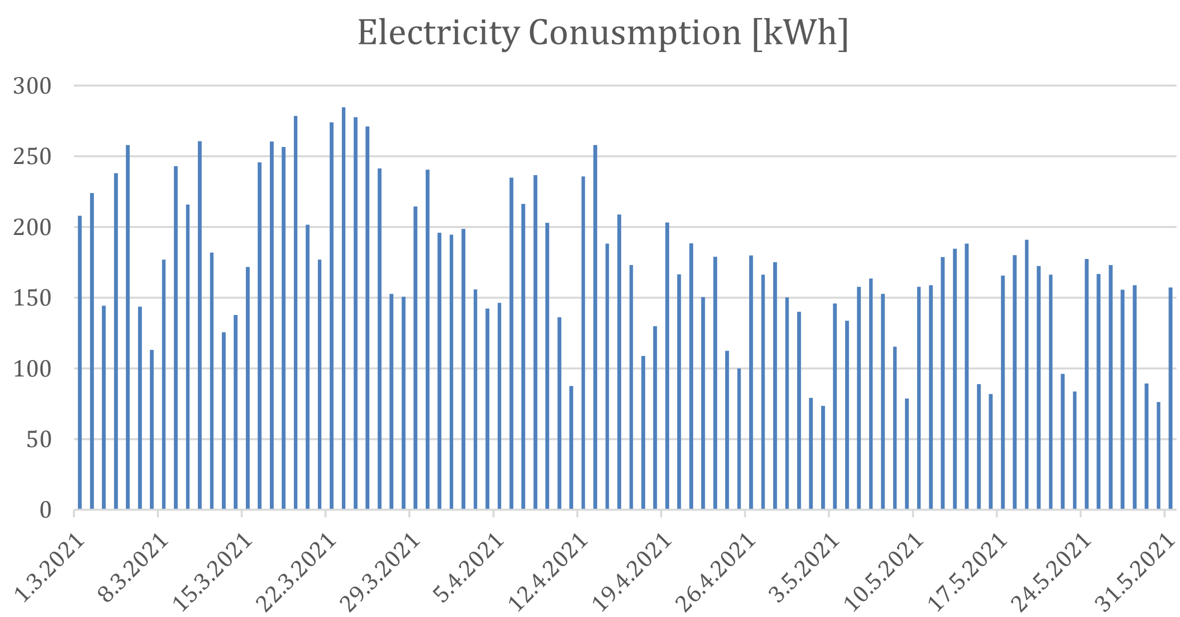


Figure 16. Electricity consumption [March – May]

5.2 DUBROVNIK

5.2.1 Coefficient of performance (COP)

The monitoring activity of the HVAC plant of the Rector's Palace in Dubrovnik, based on a seawater open-loop heat pump, revealed very poor energy performance with respect to the design. The main reason was an inefficient control logic. As mentioned before, due to the pandemic, demand for produced heat is drastically lower, with only 70 kW out of 422 kW calculated heat demand, while consumption of electric energy was stable and around 400 – 500 kWh.

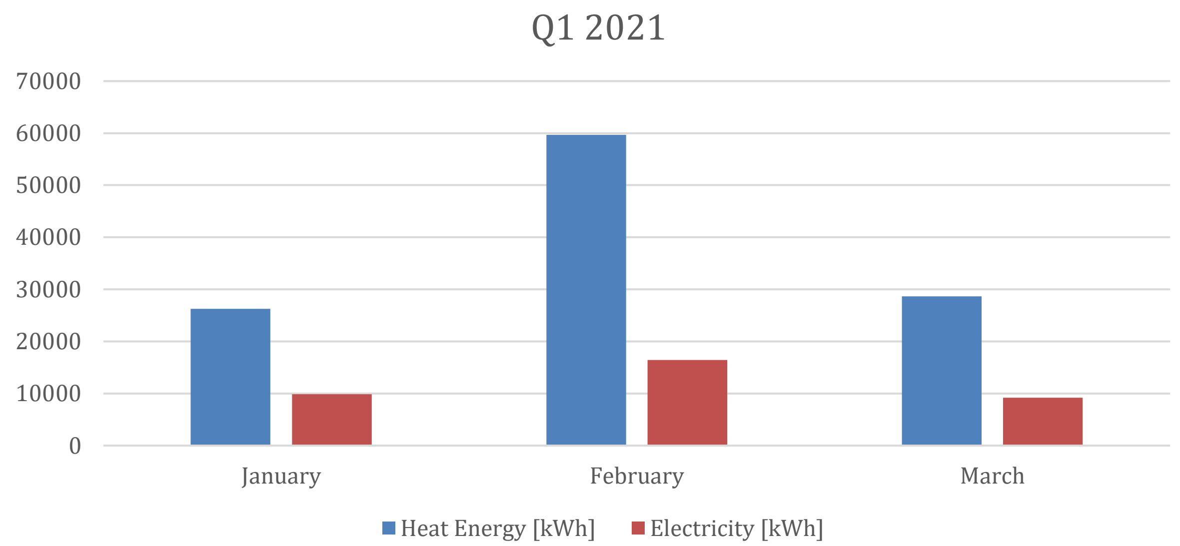


Figure 17. Delivered Heat energy and Electricity consumption in Q1

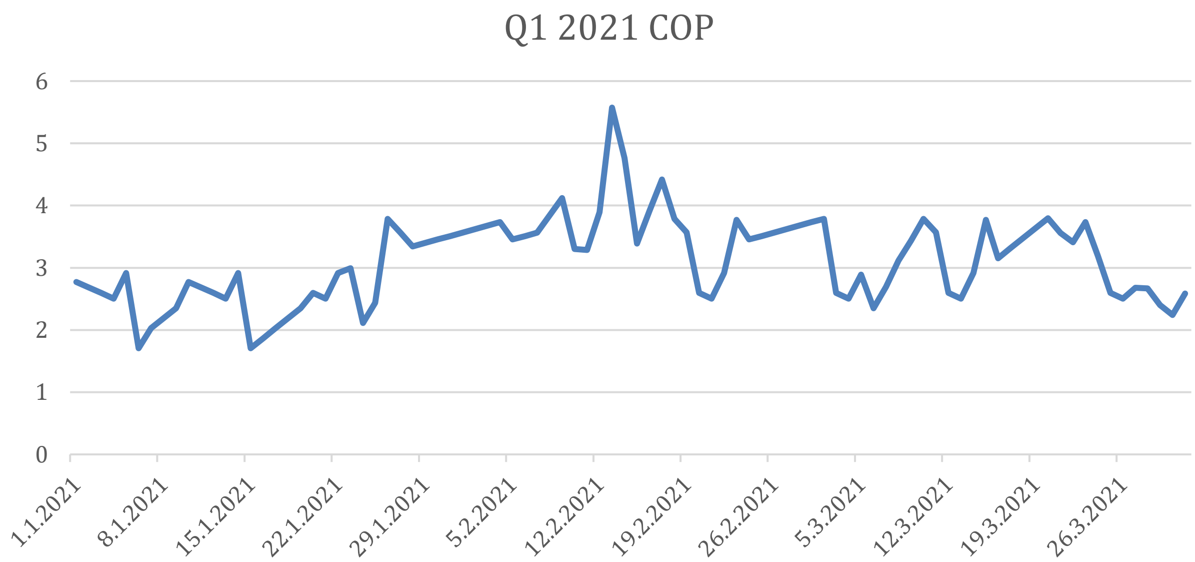


Figure 18. COP of Dubrovnik SWHP in Q1

Table 6. COP, Heat energy and Electricity consumption in Q1

Date	COP/EER, [-]	$Q_{H/C}$, [kWh]	E_{el}, [kWh]
HEATING SEASON			
January	2,658612	26267,08464	9880
February	3,637496	59682,2115	16407,5
March	3,10732	28649,49047	9220
SCOP: 3,134			

Next table shows the meaning of each symbol mentioned in the table above:

COP/EER	[-]	Coefficient of performance / Energy efficiency ratio
E_{el}	[kWh]	Consumed electric energy
$Q_{H/C}$	[kWh]	Generated heating/cooling energy

5.2.2 Electric energy consumption

Electricity consumption is for the overall system composed of heat pumps and water pumps needed for the system's operation.

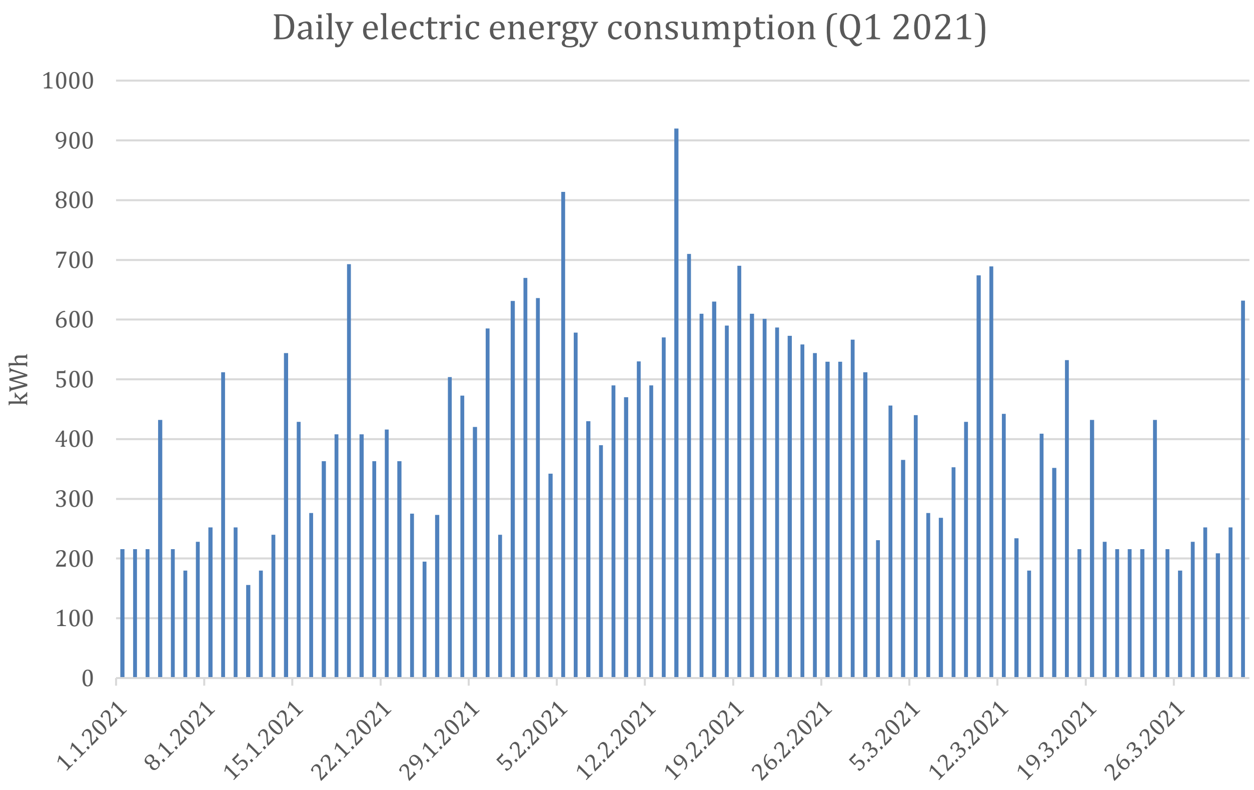


Figure 19. Electricity consumption in Q1

5.3 GREECE

During the heat pump system installation at the sports hall of the Fotis Kosmas Stadium, a monitoring system was also built-in. The system consists of various sensors and meters to measure temperature, thermal and electric energy, and pressure, along with transmitters, communication cards, PCs, and software necessary for its full operation.

The start of operation of the installation took place on 14.10.2020. The data were collected for a period from 11.11.2020 to 30.04.2021. They concern only about the heating period, and their recording was done on an hourly basis.

The internal temperature in the building is set at 20 °C and remains constant throughout the 24 hours.

It should be noted that despite the efforts of CERTH to change the radiators, the municipal authority did not succeed in replacing the existing panel radiators with new fan coils during the project's lifetime. The result is the inefficient distribution of heat inside the building.

Finally, the heating system has low efficiency because the sports hall is in fairly poor condition in terms of thermal insulation and frames. We estimate that with a refurbishment of the building, which will lead to a general energy upgrade of the sports hall, the desired thermal comfort will be provided to the users of the building.

5.3.1 Delivered heat on seawater heat exchanger

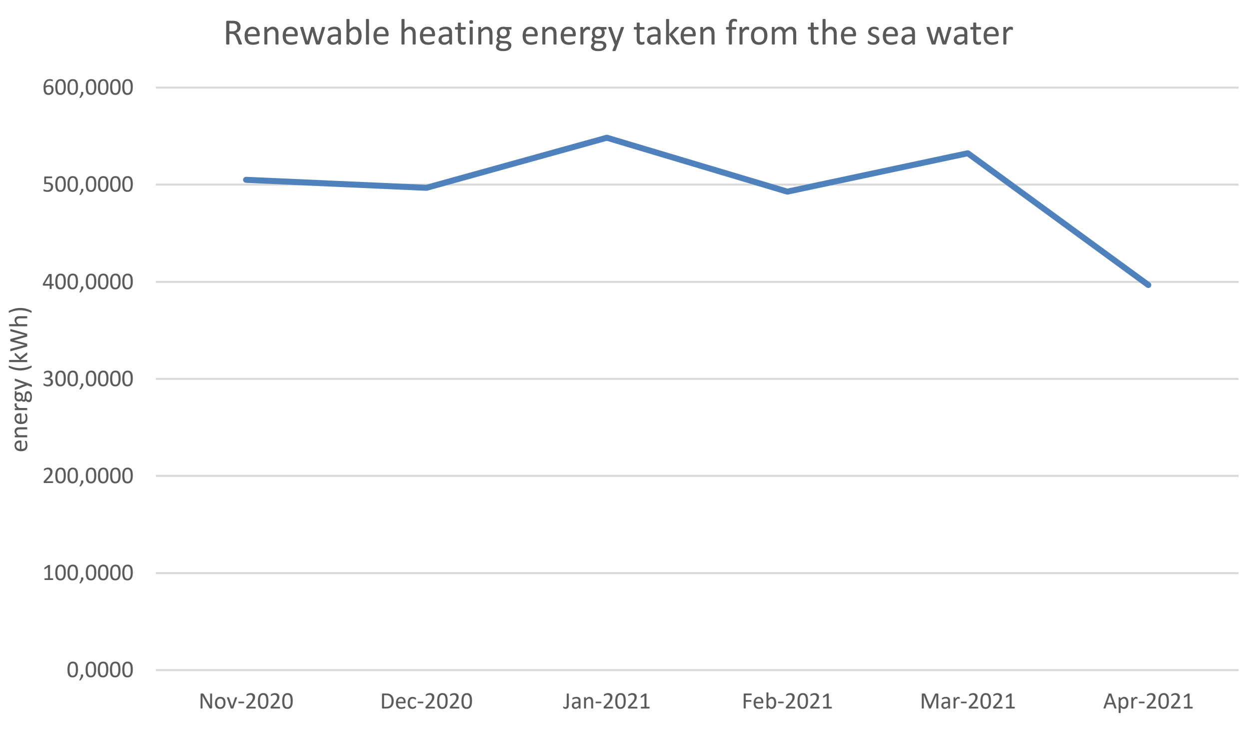


Figure 20. Renewable heating energy Greece SWHP

5.3.2 Coefficient of performance (COP)

The monitoring system of the installation simultaneously calculates and gives the values of the energy input as well as the heat output. The values, which are shown below, refer to:

- Coefficient of performance / Energy efficiency ratio, COP/EER
- Consumed electric energy, E_{el} [kWh]
- Generated heating/cooling energy, $Q_{H/C}$ [kWh]
- Renewable heating energy taken from the seawater, $Q_{H;renew;in}$ [kWh]

The following is a summary table with the monthly average of the above parameters and subsequently follows the summary diagram of these values.

Table 7. Monthly average

Date	COP_{sys}, [-]	COP_{HP}, [-]	$Q_{H/C}$, **[kWh]**	$E_{el\ HP}$, **[kWh]**	$E_{el\ pumps}$, **[kWh]**	$Q_{H;renew;in}$, **[kWh]**
Nov-2020	3.3881	4.1392	630.0000	143.4950	32.2750	505.0000
Dec-2020	3.5782	4.3772	648.3871	152.5935	34.1516	496.7742
Jan-2021	3.5765	4.3759	706.4516	158.3742	35.2000	548.3871
Feb-2021	3.5675	4.3528	625.0000	159.3107	34.6857	492.8571
Mar-2021	3.5593	4.3508	680.6452	153.9355	34.0194	532.2581
Apr-2021	3.5700	4.3600	496.6667	115.7733	24.7567	396.6667

Symbol meaning

COP_{sys}	Coefficient of performance (system)
COP_{HP}	Coefficient of performance (heat pump)
$Q_{H/C}$, [kWh]	Generated heating/cooling energy (heat pump)
$E_{el\ HP}$ [kWh]	Consumed electric energy (heat pump)
$E_{el\ pumps}$ [kWh]	Consumed electric energy (pumps)
$Q_{H;renew;in}$ [kWh]	Renewable heating energy taken from the seawater

The results showed that for the period of operation from **November 2020 to April 2021** and for an **average ambient temperature of 10°C** the COP of the HP was around 4.3 and that of the system around 3.6.

5.3.3 Electric energy consumption

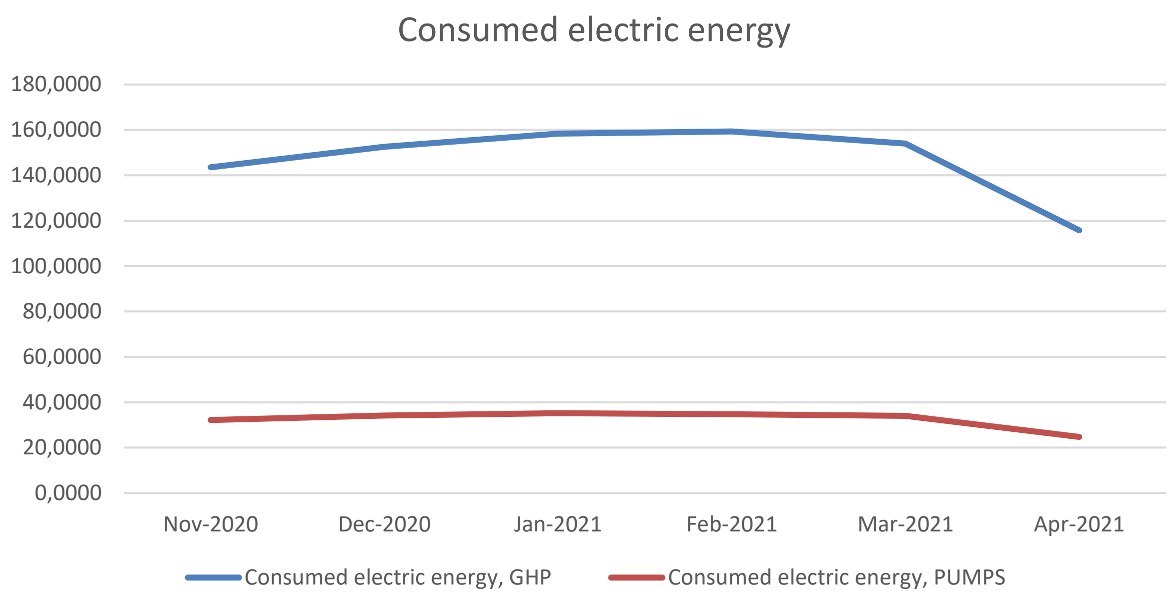


Figure 21. Monthly average of consumed electric energy

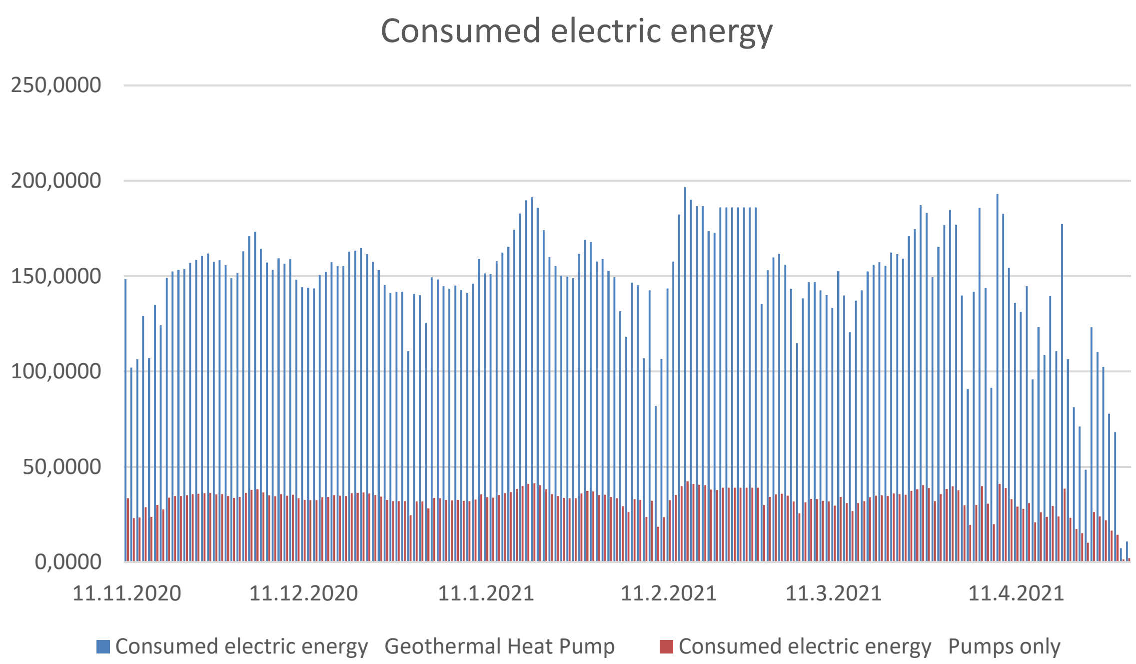


Figure 22. Daily average of consumed electric energy

6 Comparison of COP of installed SWHPs

A comparison report of three pilots installed in the frame of the SEADRION project is presented in Figure 23. Presented results show that the pilot plant's overall operation installed in Greece is very good compared to two pilot plants installed in Croatia. Analysis of results from a pilot plant in Croatia indicated that the overall electricity of water pumps is very high, and because of that, the COP of the system is very low. In the case of a pilot plant installed in Crikvenica, 50% of electricity is consumed to operate water pumps. Because of this, further analysis are ongoing on the installed pilot plant. The first step is to optimise the operation of water pumps to reduce overall electricity consumption and, in that way, to increase the efficiency of the system. The second step is shifting heat pump operation in the night mode and reducing the cost of electricity by working during the lower price of electricity.

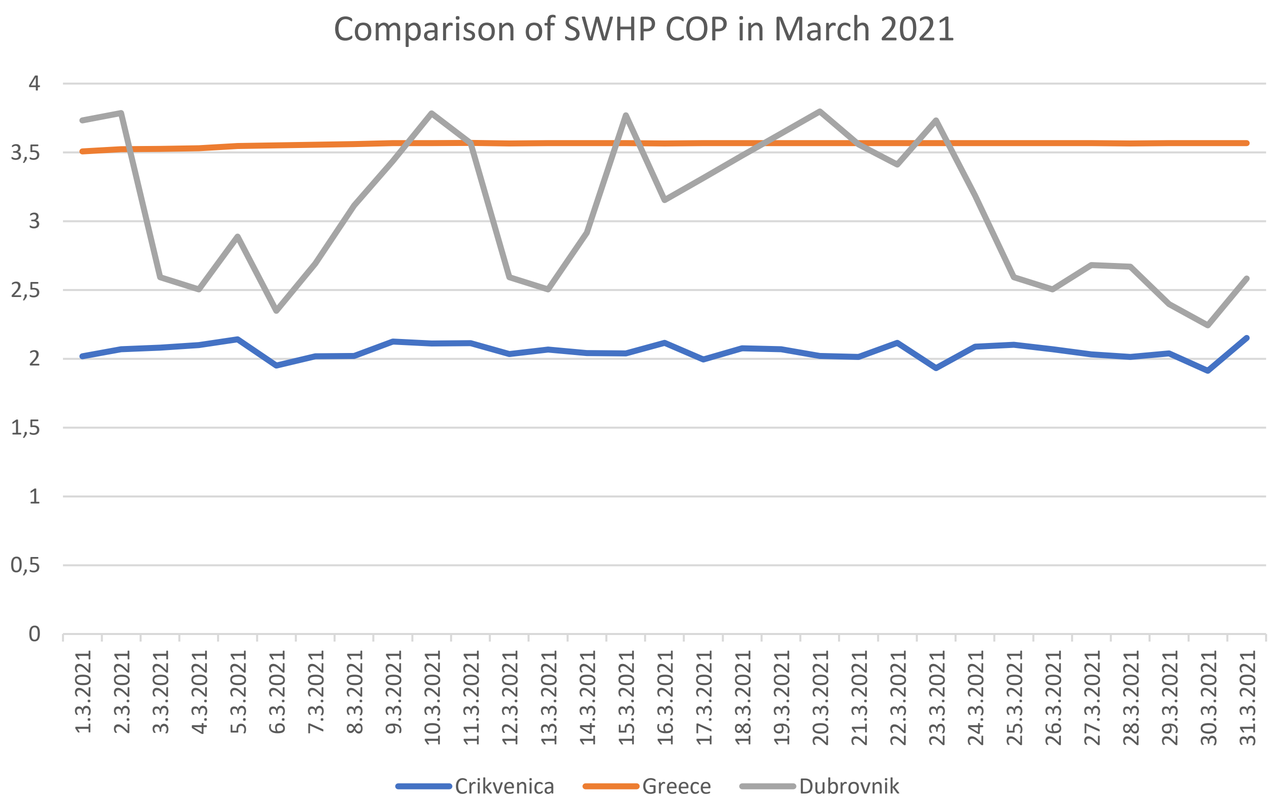


Figure 23. Comparison of SWHP COP in March

7 CONCLUSION

The purpose of this document was to compare three different SWHP pilot plants installed in Croatia and Greece. Initially, the outdoor climate parameters for the three regions were considered as inputs. Even though all three pilot plants share the same seawater, the temperatures of seawater and ambient air are different from place to place. The most important concern is to provide thermal energy to the buildings using seawater as a sustainable energy source.

In addition, although all three pilot plants share the same sea water-water heat pump technology, they operate in three different modes, so it was challenging to compare them. The pilot plant in Crikvenica is only used in heating mode, while pilot plants in Dubrovnik and Greece are used in both heating and cooling mode. Another significant difference was in temperature regime used in pilot plants – Dubrovnik and Greece SWHP are low temperature (50°C/45°C) while SWHP in Crikvenica is using high-temperature regime (70°C/60°C).

The best way to compare these three pilot plants was to choose one month where all three pilot plants were working in the same mode (heating mode in March 2021) and compare them by daily COP. Figure 23. shows that comparison of system COP – best results were in Greece where COP_{sys} was constantly above 3.5, while Dubrovnik pilot plant shows great volatility in daily COP, with values ranging from 2.5 – 3.8. The lowest COP_{sys} was in Crikvenica. The main reason is that the electricity consumption of water pumps is very high, and the overall COP of the system is reduced compared to the other two pilot plants. Furthermore, the seawater heat pump built in Thalassotherapia, Crikvenica, is phase 1. of the pool heating project in Crikvenica. Phase 2 is the installation of sollar collectors and phase 3 is installing a pool cover to prevent evaporation. By installing all of these elements, the overall COP of the system will be increased, and benefits will be much higher for the user. At the moment, the seawater heat pump allows Thalassotherapia to shut down fuel boilers during summer and increase the heating system's overall performance.

To sum up, it should be noted that the seawater source heat pump technology has been widely applied. Seawater heat pump units can reduce consumption by up to 30% compared with air-source heat pump units. It is a technique of high stability. With seawater, the all-the-year-round temperature change is relatively balanced, fluctuation is not big, and seawater temperature constant characteristics determine the seawater source heat pump units concerning the matter of running stability, at the same time making sure that the unit operation is efficient and economical.

It can provide heating, cooling, hot water, etc. It is a green and pollution-free technology. It uses a small amount of electrical energy to convert seawater's energy into thermal or cooling energy.

As a renewable energy utilisation technology, it has the significance of energy conservation and environmental protection.