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

R&I recommendations to accelerate the development of seawater heat pump sector

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Purpose of this document

Purpose of the D.T3.3.1 R&I recommendations is the definition of specific recommendations focusing on Research and Innovation activities that will ensure the acceleration of incorporating heat pump technology in the building sector for heating and cooling.

The paper will give an overview of the seawater heat pump technology as well as its most significant flaws and possible solutions.

1 Introduction

The recent Heating and Cooling Strategy from Commission indicated that emissions related to energy used for heating and cooling of buildings could be significantly reduced with technologies which use renewable energy sources and have high efficiency. Taking this into consideration the SEADRION project aims to support the development of a regional innovation system for the Adriatic-Ionian area with the installation of 3 renewable energy facilities in the public buildings located in Greece and western and south part of Adriatic Croatia.

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 (SWHP) 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 ADRION region, science and technology cooperation between research institutions and enterprises,
- to enhance the innovation capacity of the heat pump sector to enhance their innovation skills, capacities and competencies and common strategy to enhance the use of seawater heat pump based heating and cooling in ADRION region.

In this Activity T3.3 Research to Innovation recommendation, the following are elaborated:

- the current state of the seawater heat pump technology (general, important parts of the SWHP system),
- the existing applicability of such systems (seawater heat pump potential, most representative examples in Adriatic-Ionian region),
- existing scientific work and innovations related to the SWHP technology,
- partner country projects related to the SWHP technology,
- research and innovation activities to promote the implementation of SWHP technology.

The main focus of the study is the technology of seawater heat pumps, especially the seawater intake system, and the problems in its operation. The study elaborates the most important parts of SWHP systems, the applicability of such systems and possible solutions to improve them.

2 Current state of the seawater heat pump technology

Seawater heat pump systems are systems in which the heat pump uses the seawater as a heat source or sink, i.e. a heat storage tank. In the heating mode, the system uses the heating energy of the seawater as a renewable heat source (Figure 1, right), while in the cooling mode it transfers the heat taken from the space to the seawater as a heat sink (Figure 1, left). Due to the seawater corrosivity, seawater does not transfer heat directly via a heat pump evaporator, but previously via a corrosion-resistant intermediate exchanger to freshwater which then flows to the evaporator. The heating energy on the evaporator is then transferred to the refrigerant and rises to a higher energy level, and then transferred to the heated space. The reverse process applies to the operation of the heat pump in cooling mode.

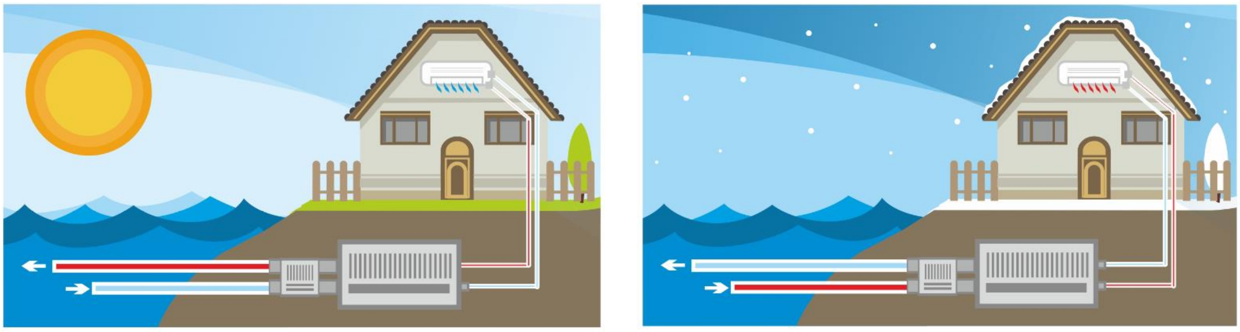

Figure 1: Seawater heat pump in cooling mode (left) and heating mode (right)

There are two versions of the heat pump system with seawater as a heat storage tank: open (Figure 2, left) and closed version (Figure 2, right). In the case of an open system, the seawater is pumped directly from a certain depth through a pipeline laid into the sea, which returns it. At the same time, in the closed version the glycol mixture exchangers are placed in the sea without seawater contact with the heat pump system. Both designs ensure equal system efficiency, but the closed version is initially more expensive because it involves more extensive installation work. On the other hand, the application of open versions is limited in areas with very cold climates as water freezing can occur, as well as the pipelines themselves laid in the sea.

Figure 2: Open (left) and closed (right) version of the seawater heat pump system [1]

In most cases, an open version of the system is used, which again has two possibilities of seawater intake, explained in more detail later in the paper.

Seawater as a heat source/sink

Most of the sun's solar energy coming to the Earth's surface is directly absorbed into the ocean and sea. A key feature that makes seawater a good heat source is its relatively constant temperature throughout the year. The thermal capacity of seawater is higher than the thermal capacity of air, which results in less intense heating and cooling of the water, i.e. its lower temperature change.

The target seawater intake depth for the operation of seawater heat pumps is 0 - 20 m. The higher the depth of the sea, the lower the annual water temperature changes. The considered depth of the sea is considered as the surface layer of the sea, and the temperature changes in this layer are called thermohaline properties of the sea.

Figure 3 shows the sea temperature profile, depending on the depth of the sea, for the Gargano - Split route in summer and winter months.

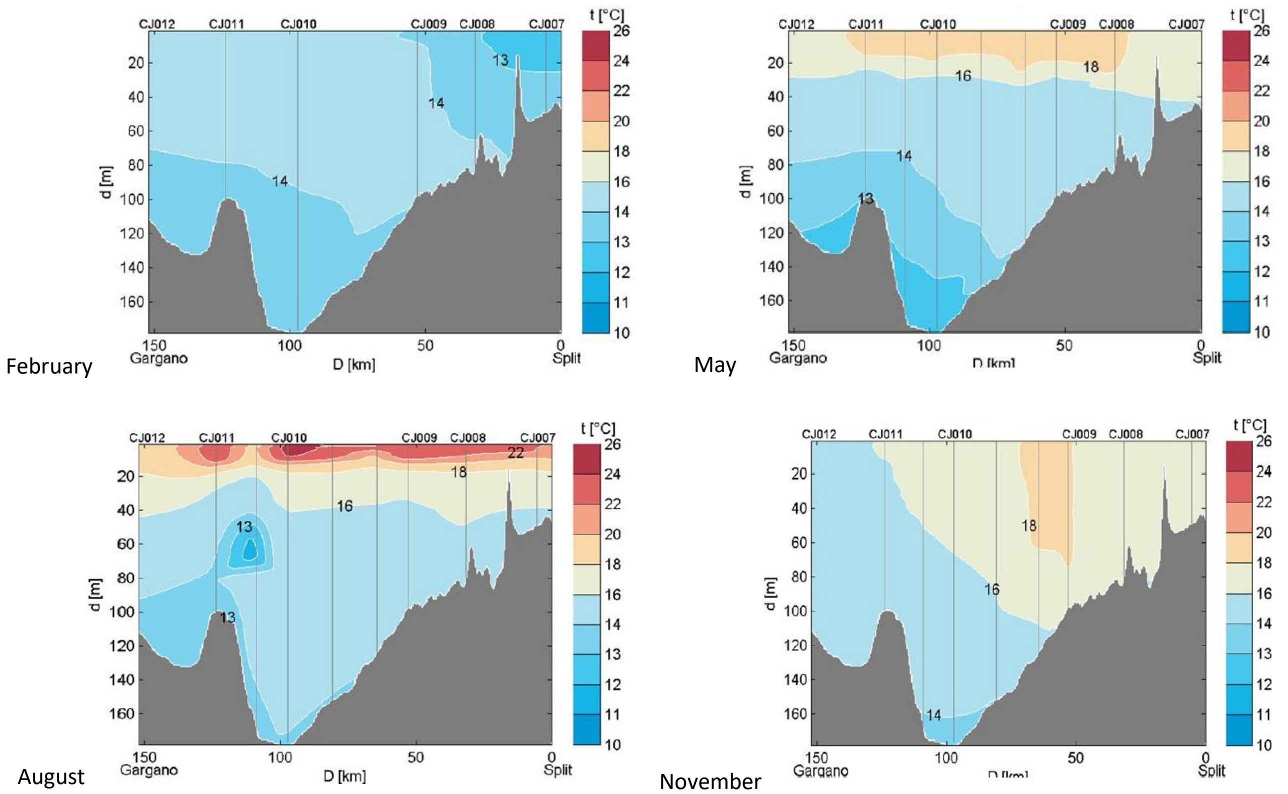

Figure 3: Gargano - Split sea temperature profile depending on sea depth in summer and winter [2]

At a depth of 20 m, the sea temperature varies from 13 to 20 ° C for the Split location, which is an annual temperature change of only 7 ° C.

From all of the above, it is evident that the temperature change of seawater as a heat source is very small and takes place on a seasonal, i.e. annual, level. Compared to heat pumps that use air as a heat source, seawater heat pumps have a higher and more constant heating factor depending on the change in the outside air temperature. Namely, the temperature of the ambient air as a heat source changes daily, since the air is heated and cooled more intensively, which makes the amounts of heating factors much more variable.

Figure 4 shows the dependence of the heat pump COP values with water and air as heat sources on the outside air temperature.

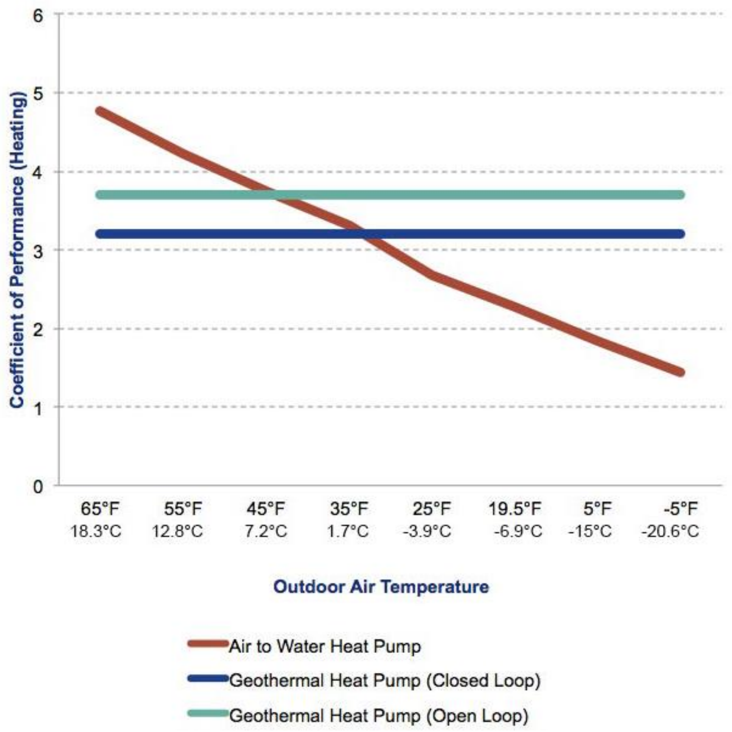

Figure 4: The dependence of the heat pump COP values with water and air as heat sources on the outside air temperature [3]

2.1 Important parts of the seawater heat pump system

Seawater intake

Seawater intake is one of the most important parts of a seawater heat pump system since the continuous and stable operation of the heat pump depends on continuous, stable and sufficient seawater inflow. The characteristic seawater intake system consists of a suction pipeline and its associated suction port and a protective grille around it, pumps and a return pipeline. Currently, there are two ways of seawater intake for the heat pump operation: direct seawater intake at a certain distance from the coast, and seizure of water from wells by the sea, i.e. on the coast itself.

Direct seawater intake

Direct seawater intake involves the intake of seawater directly from the sea at a certain depth and distance from the coast. It consists of a suction pipeline and its associated suction port and a protective grille around it, underwater pipelines that conduct seawater to the corrosive-resistant heat exchanger and back to the sea, pumping stations and a re-mixer of seawater, from which heat is taken over, with water in the sea. The seawater intake is carried out at a depth of 0 - 20 m and a sufficient distance from the coast, where the effects on the movement and temperature of the sea, due to the coastal movements of ships, people and discharges into the sea, are very small, i.e. insignificant. Figure 5 shows the characteristic scheme of a direct seawater intake system.

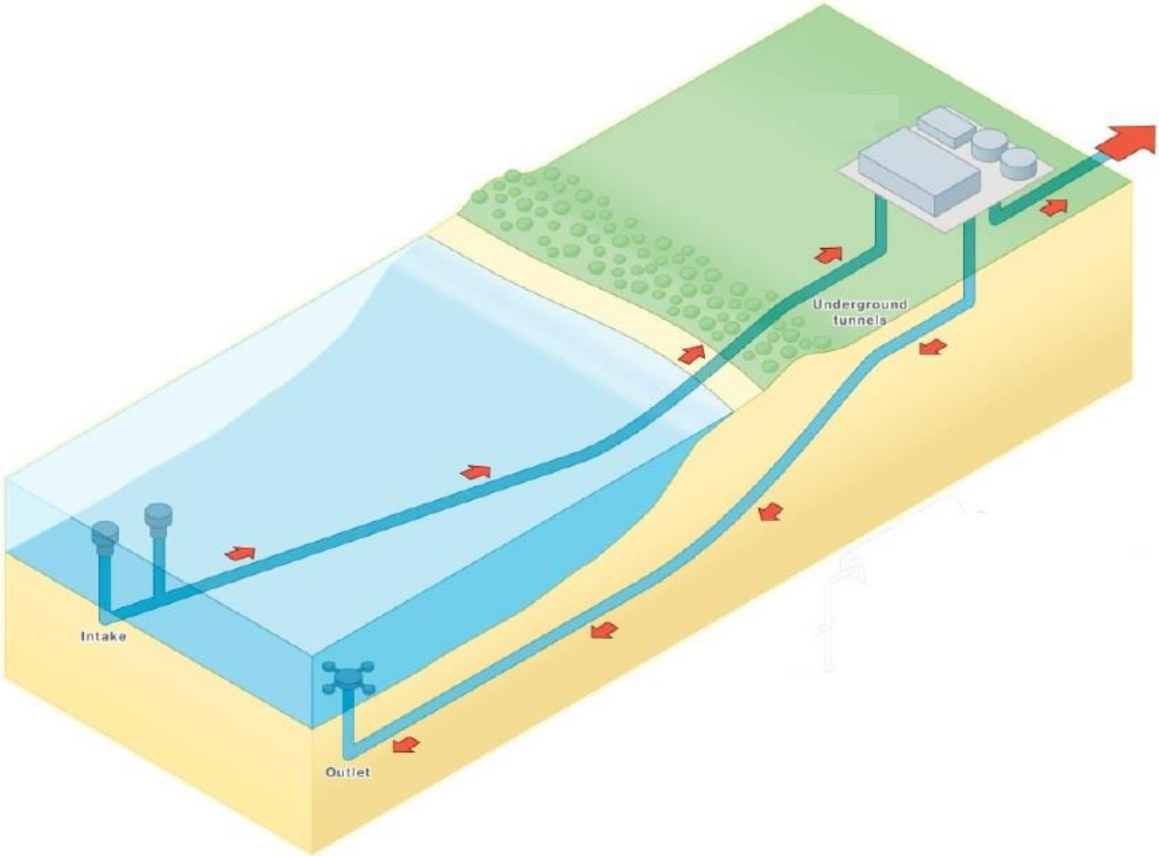

Figure 5: Characteristic scheme of a direct seawater intake system [4]

Since seawater has a pronounced corrosive property, the materials of the appliance, pipes and fittings in contact with seawater must be resistant to corrosion. Specifically, dissolved concentrated chlorides in seawater can cause pit and intercrystalline corrosion on materials such as stainless steels, carbon steels, and copper alloys.

Suction and return pipelines, which have been laid and floated in the sea, since the mid-1970s are constructed as HDPE (High-Density Polyethylene) pipes, i.e. high-density polyethylene pipes. As previously stated, metal pipes are susceptible to corrosion and are heavy and rigid to be laid in the sea. When pipes are laid on an uneven seabed, they must adjust to the outline of the seabed, which is impossible with metal pipes. HDPE pipes are resistant to corrosion and solar UV radiation, are flexible, durable and lightweight and have high thermal resistance. The relatively small mass of HDPE pipes allows them to be laid and floated in the water and easy to maintain. The high thermal resistance of HDPE pipes reduces the influence on the temperature of seawater in the pipes on the way to the heat exchanger, relative to the metal pipes (Figure 6). Also, HDPE pipes have a much smoother inner surface than steel or concrete pipes, which reduces line losses in the pipeline.

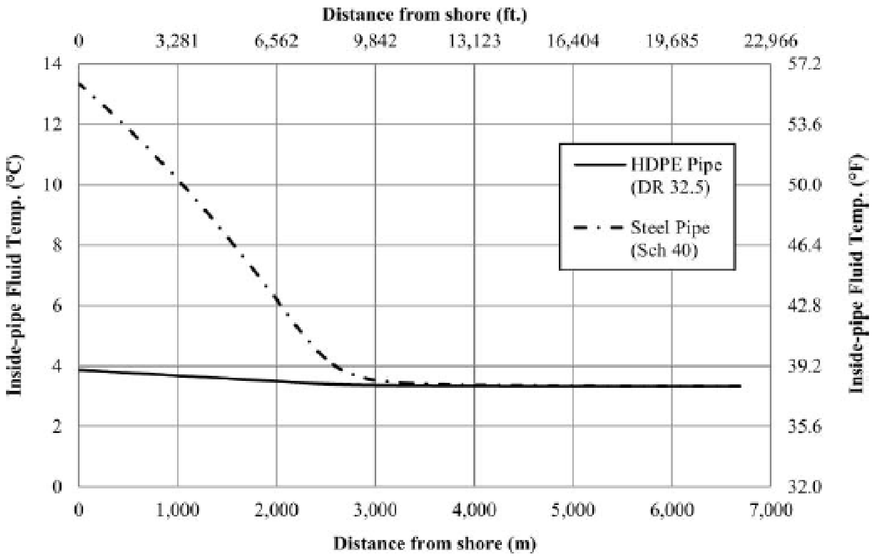

Figure 6: Influence of underwater pipe materials on seawater temperature in pipes [5]

Because the density of HDPE pipes is less than the density of seawater, HDPE pipes will float in the sea. While this is an advantage when laying a pipe in the sea, it can be a disadvantage while lowering the pipe to a certain depth of the sea and the operation of the system itself. Accordingly, it is necessary to attach reinforced concrete blocks to the pipeline, which will give stability to the pipeline during the influence of sea currents and waves. However, if metal tubes are used for certain reasons, it is recommended that they are coated with epoxy resin.

The next part that is in constant contact with seawater is the heat exchanger. In the 1970s and 1980s stainless steel, aluminium and copper alloys were considered as heat exchanger materials in contact with seawater. However, the life span of such heat exchangers was short due to corrosion. Since the 1980s, Titanium has been the most common material used to make heat exchangers in use with seawater as a working fluid. The pump material in the system must also have good corrosion resistance and depends on whether the pump is submerged or not. However, if metal materials are used in the manufacture of pumps or heat exchangers, it is obligatory to carry out cathodic protection of the same.

In the case of direct seawater intake, a major problem is the biological contaminants that accumulate in the pipelines and in the heat exchangers of the system, which result in irregular and poor system operation, and possibly a failure of the system. Seawater contains a large amount of micro - and macro-organisms that cause their accumulation problems such as reducing the efficiency of the heat exchanger, increasing the pressure drop in the pipes, clogging the filters and accelerating the development of local corrosion. The amount and magnitude of biological contamination depend on the nature, type and population of the organisms present in the seawater. To prevent and reduce the buildup of biological organisms such as algae and mussels in pipelines and on the exchanger, the dosage of seawater in the system with sodium hypochlorite, i.e. chlorine, is applied experimentally. Seawater chlorination is an environmentally friendly, inexpensive and effective way of controlling the growth of biological organisms in the system. When using a shell & tube heat exchanger, it is possible to permanently install a brush system that mechanically cleans the inside of the pipe to avoid seawater chlorination. Biological contamination is a big problem with the seawater heat pump systems, especially in higher-temperature seawater areas. Whether or not these measures apply, the system must also be manually cleaned. The annual number of cleanups depends on each system installed separately.

In addition to biological contaminants, direct intake of seawater should also pay attention to the input of larger organisms such as fish and molluscs and the withdrawal of sand from the seabed into the pipe. The suction port is designed with a protective grid, i.e. a cage, around it 2 - 3 m above the seabed to prevent sand from entering the seabed. The openings of the grille are 2 - 10 mm wide. The suction port and the associated protective grid should be designed so that the inlet velocity of seawater through the openings of the protective grid does not exceed 0.15 m/s to prevent the intake of fish and molluscs.

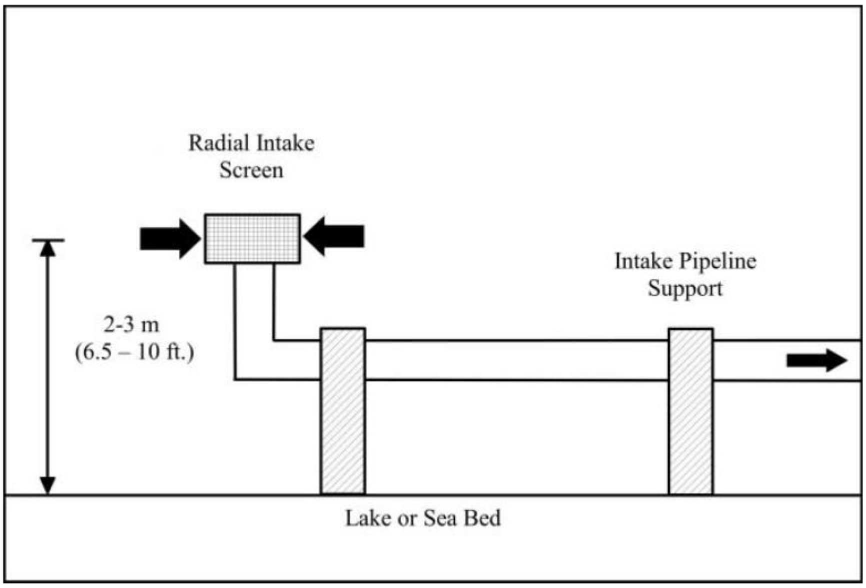

Figure 7: Suction port and associated protective grid for direct seawater intake [5]

Subsurface seawater intake from wells by the sea

Subsurface seawater intake from wells by the sea is groundwater abstraction from aquifers only a few meters below Earth's surface on or along the coast. This groundwater may be the result of infiltration of seawater through the sandy bottom to wells by the sea or mixing of fresh, inland water and infiltrated, saline, seawater.

Seawater wells are constructed as vertical or horizontal, depending on the heating and cooling requirements, i.e. the required amount of seawater (Figure 8).

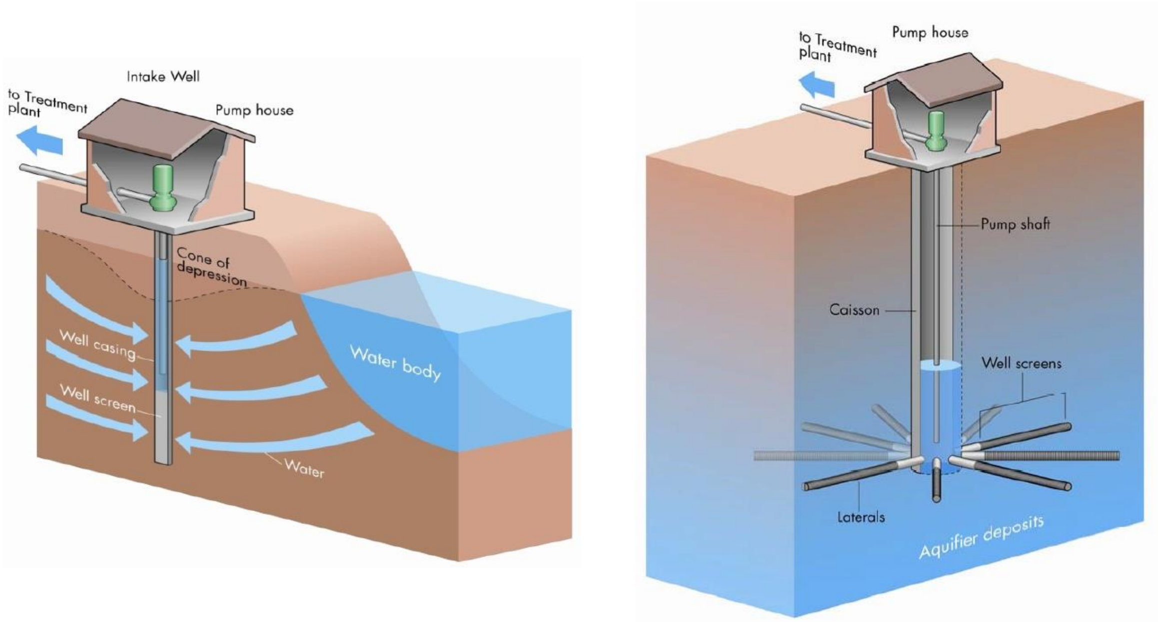

Figure 8: Shore seawater well designs: vertical (left), horizontal (right) [4]

In addition to water intake by vertical and horizontal wells, water collectors laid on the seabed, through which a sand filter layer is deposited, are applied which then prevents the entry of biological micro- and macro-organisms (Figure 9).

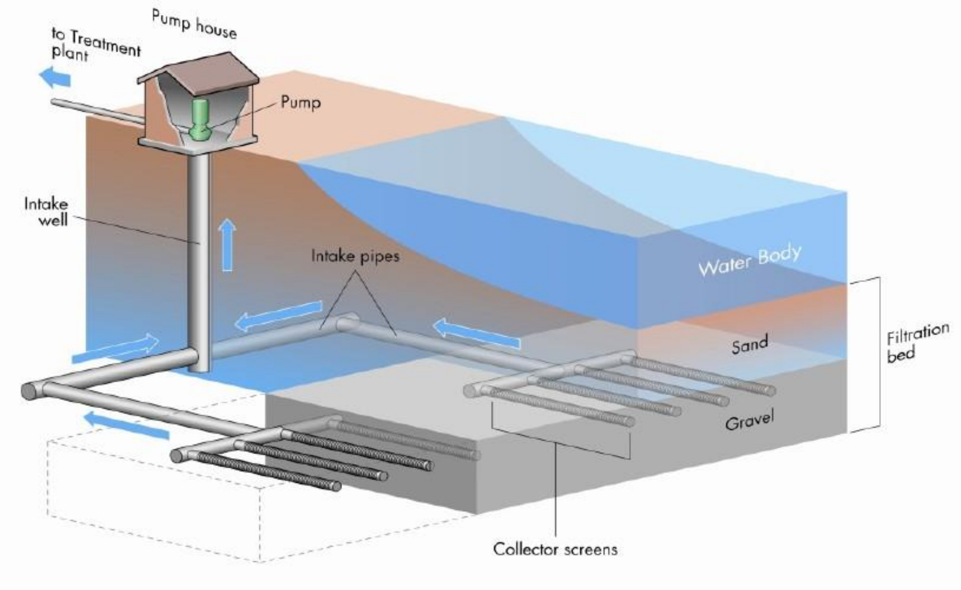

Figure 9: Seawater intake by infiltration through the seabed [4]

The subsurface seawater intake implies that this water contains less admixtures, oils and debris and biological micro - and macro - organisms, resulting in less biological contamination of pipelines and heat exchanger, and thus a more stable operation of the system. Also, such water has less salinity, which reduces the possibility of corrosion occurrence and development. The application of pump, piping and heat exchanger material is the same as for direct seawater intake. The measuring results of pilot plants with subsurface seawater intake show that such seawater intake enables more efficient operation of the seawater heat pump system since the temperature changes of such water are less than in the direct operation which, also, has a major impact on the system operation efficiency.

The disadvantage of subsurface seawater intake is a higher investment cost; however, the costs of maintaining the system due to biofouling are much lower.

2.2 The existing applicability of such systems

Seawater heat pump potential

Seawater heat pump potential depends on the seawater temperatures in a particular area. Since the heat pump coefficient of performance (COP) is determined by the temperature of the heat source, measuring the seawater temperature at different locations is of great importance for determining the locations that are suitable for the installation of seawater heat pumps and which are not.

The analysis of seawater temperatures showed that in most countries, the difference between air and seawater temperatures is higher during winter than during summer. All countries show the difference in air and seawater temperatures during winter, even on a monthly basis, raising the potential for seawater heat pumps. Some countries show the difference in air and seawater temperatures also during winter periods, but some countries have similar monthly seawater and air temperatures during summer. This would initially suggest that that the economic benefits of installing seawater heat pumps would be less, but if going deeper into the temperature data, it can be seen that on the hourly basis, air temperatures rise during the day up to 4 °C higher then the seawater temperatures and that is if the sea temperatures are measured on the surface. The deeper the seawater intake is, the more constant the sea temperature. Analysis of seawater over the air as a heat source/sink is discussed in detail in the previous section. Nevertheless, since the potential is higher for a heating period, further analysis was done for the heating regime.

The data gathered for buildings in partner countries where the seawater heat pumps can be implemented show that altogether heating demand is 4736.08 GWh/year for hotels and 496.73 GWh/year for public buildings. Exact heating demand per country can be seen in Figure 10, while heating demand per month can be seen in Figure 11.

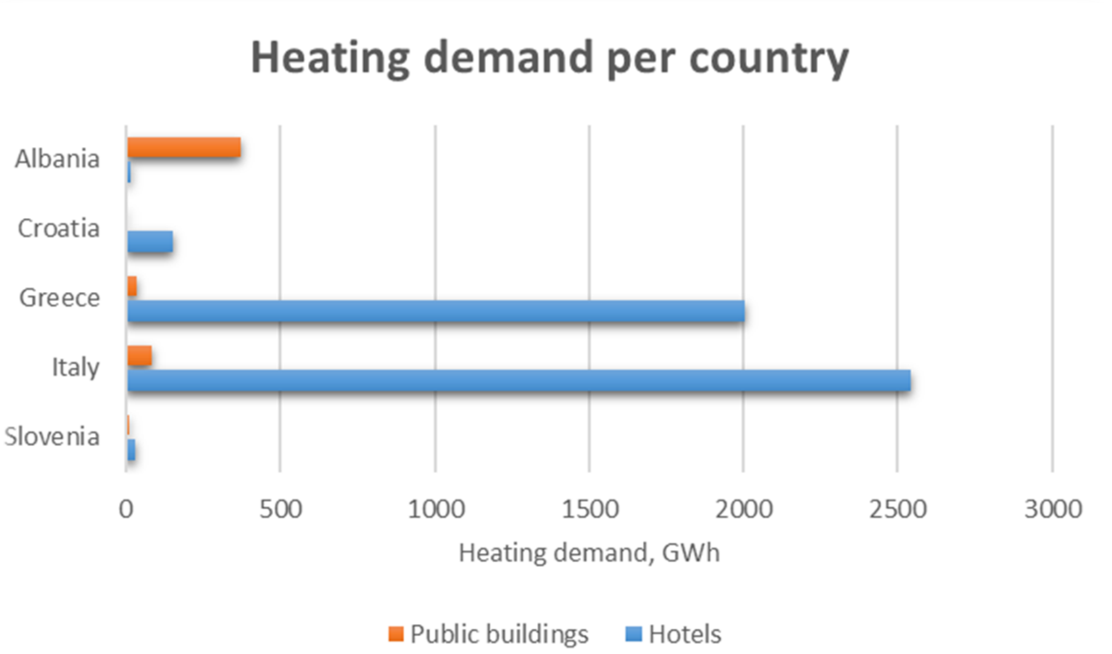

Figure 10: Heating demand per country

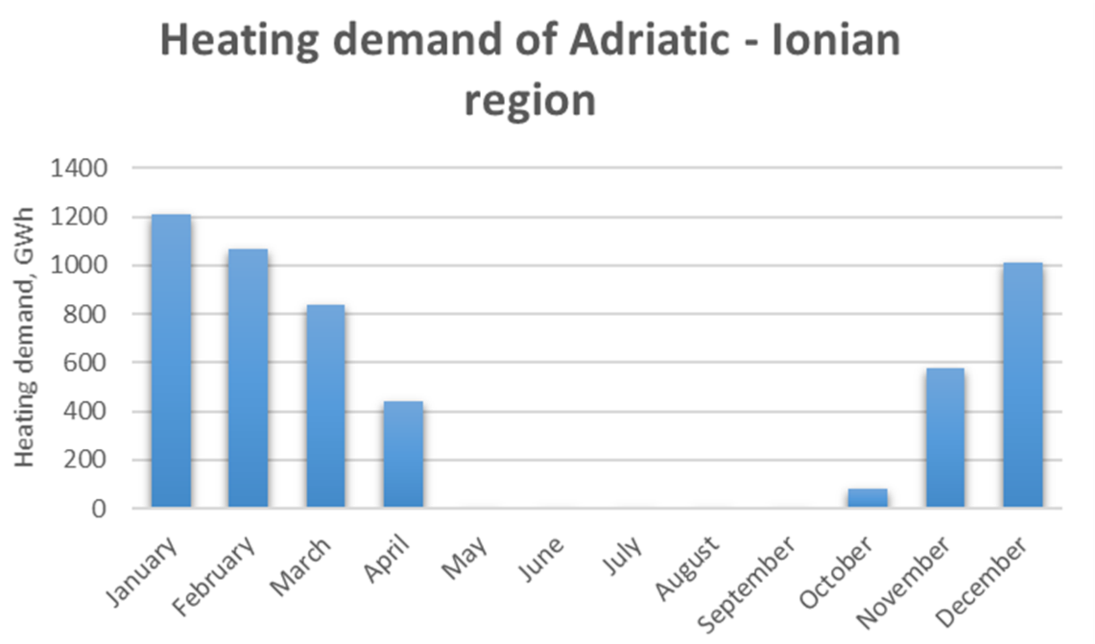

Figure 11: Heating demand of Adriatic – Ionian region per month

Further benefits of using seawater heat pumps for heating purposes is that thanks to their high efficiency, they lead to primary energy reduction and CO2 emission savings, as shown in Figures 12 and 13.

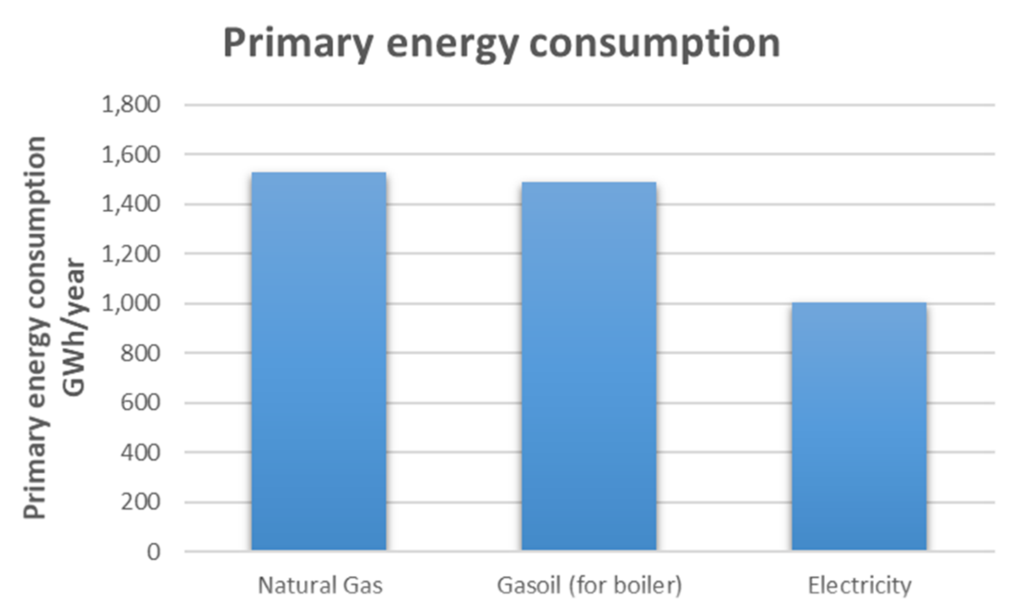

Figure 12: Primary energy consumption of public buildings close to the sea in Adriatic – Ionian Region if they would use natural gas boilers, fuel oil boiler or heat pumps for heating

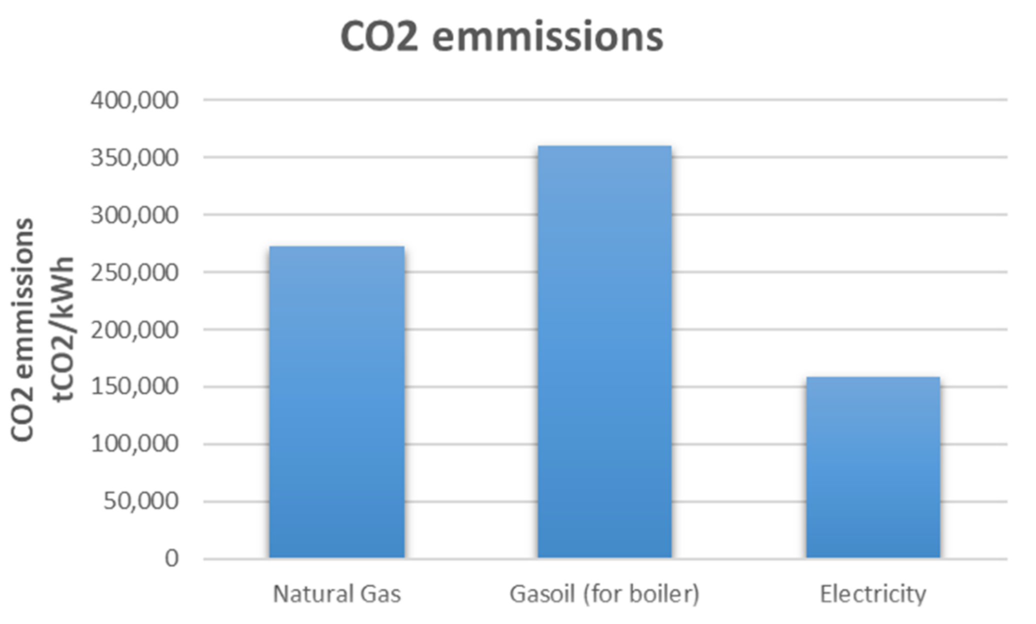

Figure 13: CO2 emissions of public buildings close to the sea in Adriatic – Ionian Region if they would use natural gas boilers, fuel oil boiler or heat pumps for heating

There are two mostly used methods of seawater exploitation. One is direct seawater intake from the sea, and the other is seawater intake from the subsurface wells as already explained in the previous section. For both cases, it is preferable that the building is as close to the sea as it is possible to reduce the length of the pipes that will need to be installed from the point of seawater intake to the heat pump, and the best would be if the building isn't more than 1000 m away from the sea.

Buildings with the greatest seawater heat pump potential are hotels that are generally very close to the sea and have high cooling needs. Furthermore, public buildings located close to the sea can also be considered. Below are data on hotels and public buildings along the coast of each partner country with seawater exploitation potential.

Slovenia

Table 1: Hotel data in Slovenia

Hotels	
Number of hotels	37
Minimum number of rooms in the hotels	16
Average number of rooms in the hotels	146
Maximum number of rooms in the hotels	276

Maximum number of rooms in the hotels	78%
Percentage of hotels with a maximum number of rooms than average	22%

Table 2: Public building data in Slovenia

Public buildings	
Number of public buildings	23
Average area of the building [m²]	3319
Specific Heat Consumption [kWh/m²]	101

Greece

Table 3: Hotel data in Greece

Hotels	
Number of hotels	9,604 hotels = 404,232 rooms, 782,463 beds
Average number of rooms in the hotels	42 rooms/hotel or 82 beds/hotel

Table 4: Data for public buildings in Greece [6]

Climate zone	Categories of buildings	Estimated annual average primary energy consumption of buildings (kWh/m²), for heating	Estimated annual average primary energy consumption of buildings (kWh/m²), for cooling	Average total floor area of a building	Number of buildings	Total floor area (m²)
A, B and C	Commercial	40.73	115.03	425.88	2	851.77
	Hospitals	154.24	141.04	3,839.75	191	733,393.17
	Temporary Residence	269.57	113.38	2,236.02	7	15,652.15
	Educational	98.53	14.03	1,487.68	773	1,149,979.55
	Sports Halls	154.66	215.95	973.58	227	221,003.73

	Prisons and Police Stations	276.08	151.19	7,724.41	11	84,968.48
	Offices	97.36	109.89	996.68	870	867,113.12
Total					**2081**	**3,072,961.96**

Croatia

Table 5: Data for hotels in Croatia

Hotels	
Number of hotels	520
Min. number of rooms in the hotels	2
Average number of rooms in the hotels	98
Max. number of rooms in the hotels	743
Percentage of hotels with a smaller number of rooms than average	67%
Percentage of hotels with a bigger number of rooms than average	33%

Table 6: Data for public buildings in Croatia

Public buildings	
Number of public buildings	320
Average area of the building [m^2]	1,826.5
Specific Heat Consumption [kWh/m^2]	107.78

Albania

Table 7: Hotel data in Duresi area, Albania

Hotels near the sea in Duresi Area	
Number of hotels	104
Minimum number of rooms in the hotels	15
Average number of rooms in the hotels	28

Maximum number of rooms in the hotels	120
Percentage of hotels with a minimum number of rooms than average	66 %
Percentage of hotels with a maximum number of rooms than average	34 %

Table 8: Hotels near the sea in Vlora Area, Albania

Hotels near the sea in Vlora Area	
Number of hotels	86
Minimum number of rooms in the hotels	12
Average number of rooms in the hotels	30
Maximum number of rooms in the hotels	100
Percentage of hotels with a minimum number of rooms than average	68 %
Percentage of hotels with a maximum number of rooms than average	32 %

Table 9: Hotels near the sea in Saranda Area, Albania

Hotels near the sea in Saranda Area	
Number of hotels	75
Minimum number of rooms in the hotels	14
Average number of rooms in the hotels	27
Maximum number of rooms in the hotels	90
Percentage of hotels with a minimum number of rooms than average	73 %
Percentage of hotels with a maximum number of rooms than average	27 %

Table 10: Hotels near the sea in Shengjin Area, Albania

Hotels near the sea in Shengjin Area	
Number of hotels	32
Minimum number of rooms in the hotels	18
Average number of rooms in the hotels	22
Maximum number of rooms in the hotels	85

Percentage of hotels with a minimum number of rooms than average	69 %
Percentage of hotels with a maximum number of rooms than average	21 %

Table 11: Public building data in Albania

Public buildings data, Albania				
	Durres	Vlora	Saranda	Shengjini
Number of public buildings	8	3	6	2
Average area of the building [m^2]	280	320	270	160
Specific Heat Consumption [kWh/m^2]	440	440	430	450

Additionally, seawater heat pumps can't be implemented at all locations in the Adrian - Ionian territory. Namely, at some location, Adrian and Ionian seas are too shallow, and the temperature of the seawater is too variable. Those locations would not be suitable for seawater heat pumps because their efficiency would drop significantly. Regarding the depths of the sweater, the most critical for the installation of seawater heat pumps is the north of Italy, where the sea is not deeper than 30 m, as can be seen in Figure 14.

The sea gets deeper on the south end of the Adriatic sea and towards the Ionian Sea, but as can be seen in Figure 15, the places close to the coastline still have shallow water. The depth of the seawater is important because the deeper the seawater intake is, the more constant the seawater temperature is.

Because of that, it is important to study the temperatures of the seawater at various locations to determine what places are suitable for the installation of seawater heat pumps and what are not, which was done detailly per country.

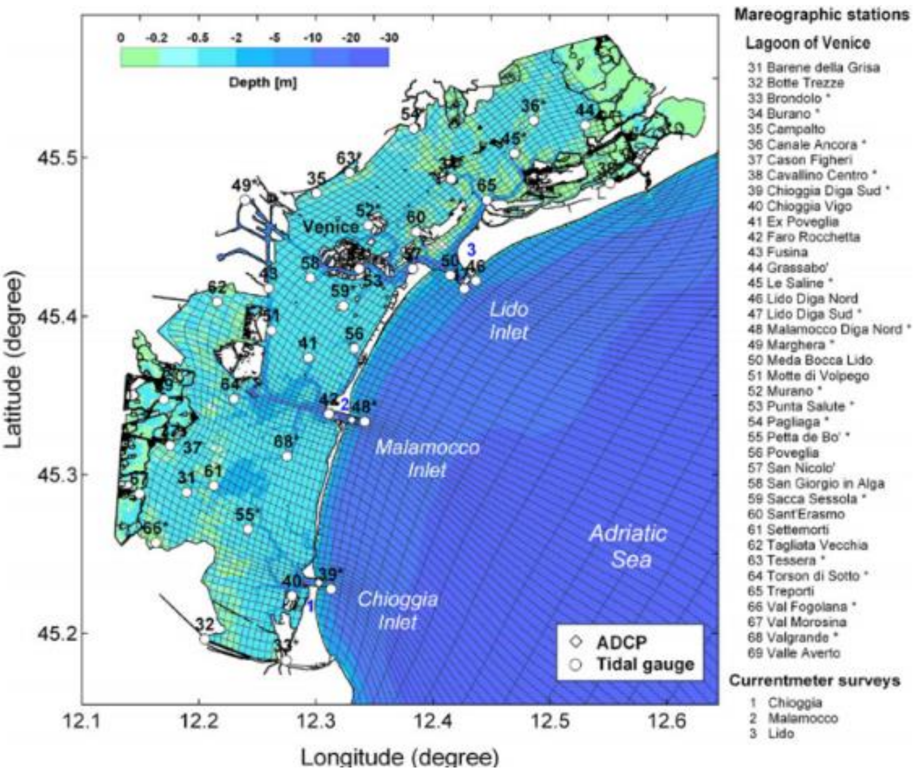

Figure 14: North Italy seawater depth [6]

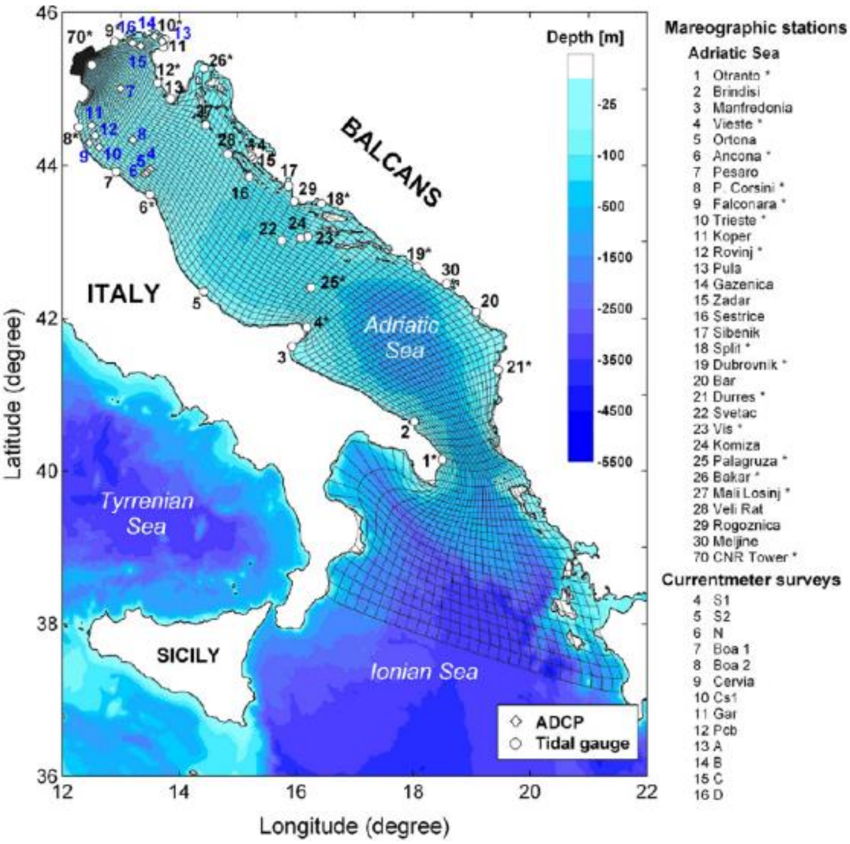

Figure 15: Adriatic-Ionian seawater depth [6]

Most representative examples in the Adriatic-Ionian region

Implementation of the seawater heat pump systems began in the 1970s and 1980s worldwide. With more than 180 large systems installed, northern Europe is at the forefront of implementing this technology, with Sweden and Norway among the largest users. In the Adriatic-Ionian region, such systems are also applied. Type and amount of buildings having SWHPs in each SEADRION partner country according to the responsible partners are presented in Figure 16.

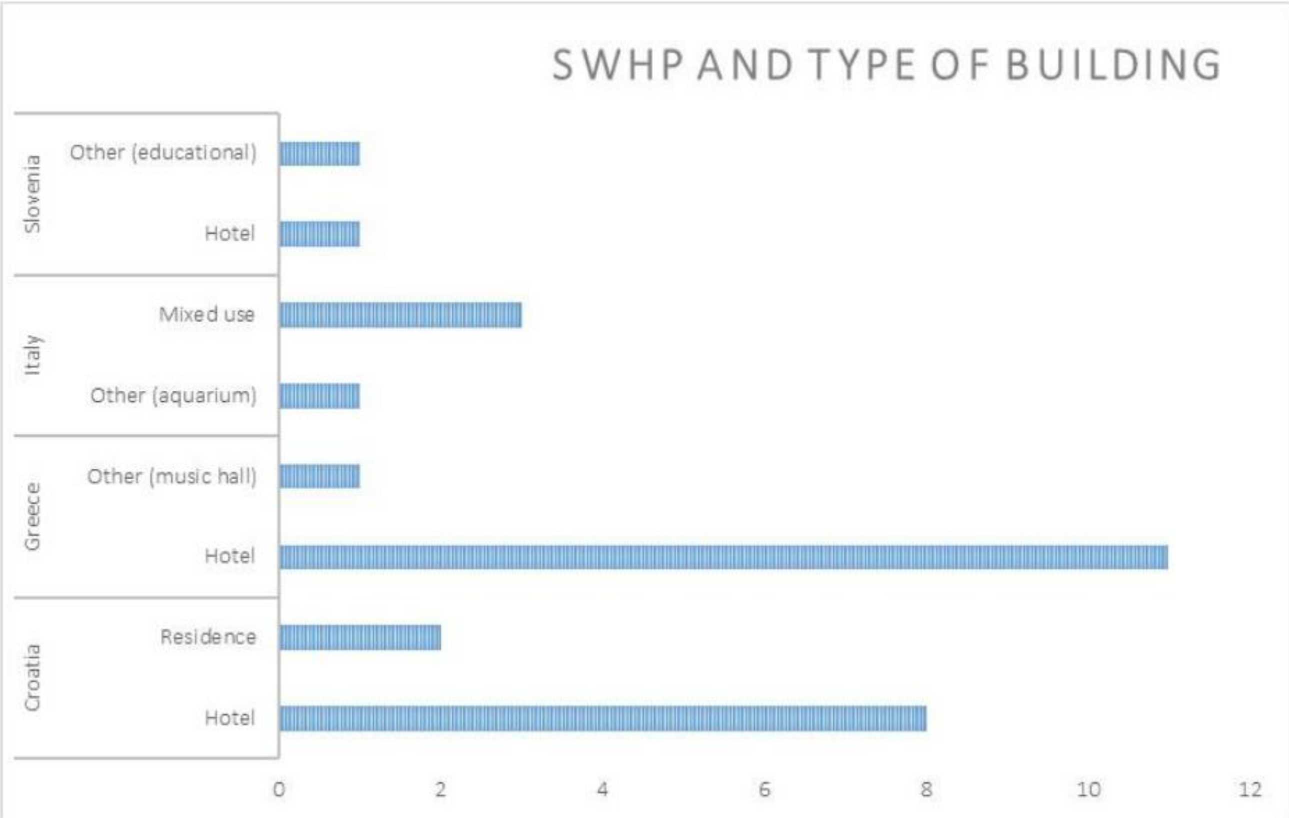

Figure 16: Type and amount of buildings having SWHPs in each country (no records are existing for Albania)

Some SWHP examples in the Adriatic-Ionian region are presented below.

➢ <u>Italy: Porto piccolo – Sistiana</u>

Porto piccolo – Sistiana, is a small village set in the Gulf of Trieste. Great attention to the protection of the environment has been given in the design and implementation of the project and entire complex construction, which uses solar and geothermal energy. Seawater is used for the covering of cooling and heating needs and also for DHW for the different buildings of the village (hotel, spa, residential units, commercial areas, etc.). Eighteen water-water heat pumps (3 MW overall) are installed at the site to produce hot and chilled fluids for indoor climate and hot water production. The village also uses solar energy for DHW needs with a total of 200 m^2 of solar panels. The village consists of 460 residential units, public and private beaches, parks, bars and restaurants, hotel, marina with 124 berths and a large spa make Portopiccolo a real city.

Table 12: Technical characteristics of Porto Piccolo – Sistiana SWHP system

Porto Piccolo – Sistiana		
Average air temperature (year)		1 °C to 28 °C
Average seawater temperature (year)		13 °C to 22°C
Type of appliance	**Nominal power heating/cooling**	**COP / EER heating/cooling**
Cooling and heating	18 Clivet heat pump water-water (3 MW overall)	COP 4,4 - 4,9
Other RES installed (technical data)	200 m^2 of solar panels for the production of domestic hot water	


Figure 17: Porto Piccolo – Sistiana village in the left and SWHP machine room in the right

- Italy: Aquarium of Genoa

The Aquarium of Genoa is the largest in Italy. Located in the old harbour area of Genoa, Italy, the 33,000-square-foot (3,100 m^2) aquarium is a member organisation of the European Association of Zoos and Aquaria (EAZA). It welcomes more than 1.2 million visitors each year. In 2007 the technological systems of the aquarium had been completely renovated in order to improve its functionality and efficiency.

The three Carrier 30HXC 375 refrigeration units (freshwater- or seawater-cooled chillers) that control the air conditioning of the rooms and provide heating and cooling of tropical fish and seal tanks are located in an underground room at level -2.

The plant consists of three refrigeration units that produce chilled water at a temperature of 6-7 °C for cooling the common areas and seal tanks.

The tempered water, disposed of during the condensation, is instead used for the air conditioning of the tropical fish tank at a temperature of 45-50 °C.

Heat exchangers are installed to guarantee the correct functioning of the refrigeration units ensure dissipation and complete the cooling cycle, while water distribution is entrusted to suitable circulators. An interesting technical note of the system is that the cooling units use water from the sea for the disposal of unused energy. In the face of this, special arrangements have been made in the plant plate exchangers designed for this particular operation.

Table 13: Technical characteristics of Aquarium of Genoa SWHP system

Aquarium of Genova		
Average air temperature (year)		6°C to 28°C
Average seawater temperature (year)		13°C to 23°C
Type of appliance	**Nominal power heating/cooling**	**COP / EER heating/cooling**
Cooling and heating	1,1 MW	3,04
Other RES installed (technical data)	-	

Figure 18: Aquarium of Genoa in the left and SWHP machine room in the right

- <u>Greece: Hotel Amalia in Nafplio</u>

Use of heat pumps for heating, cooling and sanitary hot water is widespread in the hotel sector in Greece. There are many installations using seawater as a heat source and a few using open-loop GSHPs exploiting saline water near the coast. One such example is the Amalia hotel in Nafplio, a building with around 9000 m² air-conditioned spaces. Hotel heating and cooling needs are covered by 4 GSHPs supplying 740 kW heating and 566 kW of cooling with fan-coils.

The GSHPs are fed through a heat exchanger by an open-loop geothermal doublet comprising one production and one reinjection well 60 m deep each, supplying 60 m³/h of groundwater at 18 °C. System SPF values are 4.77 in heating and 3.65 in cooling mode.

Table 14: Technical characteristics of Hotel Amalia SWHP system

Hotel Amalia in Nafplio		
Average air temperature (year)		17 °C (year 2017)
Average seawater temperature (year)		20 °C (year 2017)
Type of appliance	**Nominal power heating/cooling**	**COP / EER heating/cooling**
Cooling and heating	740 kW heating and 566 kW cooling	4.77 / 3.65
Other RES installed (technical data)	-	

Figure 19: Hotel Amalia in the left and its location in the right

➢ Croatia: Falkensteiner Family Hotels

The Falkensteiner Family Hotels have worked with international experts to implement a comprehensive system that helps to minimise its long-term ecological footprint. Choosing an ecologically sound construction method was at the core of the design process.

The sustainable seawater treatment plant provides the water that is required for everyday use and also generates energy for heating and cooling. Heat pumps are the only source of heating and cooling energy. Seawater intake is 300 m from the coast, at a depth of 15 m.

Table 15: Technical characteristics of Falkensteiner Family Hotels SWHP system

Falkensteiner Family Hotels		
Average air temperature (year)		16 °C
Average seawater temperature (year)		16.5 °C
Type of appliance	**Nominal power heating/cooling**	**COP / EER heating/cooling**
YORK, Water to water	3 x 1.2 MW	4.0 / 6.9
Other RES installed (technical data)	-	

Figure 20: Falkensteiner Family Hotels in the left and SWHP machine room in the right

2.3 Existing scientific work and innovations related to SWHP technology

Existing scientific work and innovations related to SWHP technology mainly relate to the seawater intake system and to the heat exchanger that exchanges heat between salty seawater and freshwater which then goes to the heat pump itself. Most problems in work are manifested in the previously mentioned parts of SWHP, and therefore most innovations, works and solutions focus on the same. Some of the common problems are corrosion, biological fouling, construction of seawater abstraction systems, etc.

As Northern European countries are at the forefront of SWHP technology in Europe, both in terms of installed capacity and technology development, most scientific papers and innovations are of that origin. However, worldwide, the great development of SWHP technology and the contribution through scientific research has been noticed in China and Japan. The US is also among the countries contributing to seawater technology; however, they are more focused on seawater desalination plants.

The seawater has the merit of inexhaustible and no charge but at the same time the demerit of the troublesome bio-fouling and intense corrosiveness. Problems of corrosion and bio-fouling of pipes and heat exchangers in contact with seawater can be seen in Figure 21.

Figure 21: Problems of corrosion and bio-fouling of pipes and heat exchangers in contact with seawater [7] [8]

Seawater intake system usually, if it is a direct seawater intake, consists of a suction pipeline and its associated suction port and a protective grille around it, underwater pipelines that conduct seawater to the corrosive-resistant heat exchanger and back to the sea, pumping stations and a re-mixer of seawater, from which heat is taken over, with water in the sea. On the other hand, if it is a subsurface intake of seawater from wells, there are no underwater pipelines laid in the sea. Each part of the seawater intake system that is in contact with seawater is subject to corrosion and biological fouling, i.e. underwater pipelines, heat exchangers and pumps specifically.

Underwater pipelines

One of the parts is the underwater pipelines, i.e. intake piping, are necessary to bring the seawater from a certain depth into a heat exchanger that exchanges heat between salty seawater and freshwater.

Different varieties of steel pipe lined with glass or concrete and jacketed with insulation or concrete have been used for underwater applications in the petroleum industry and sewage disposal systems for many years (Hirshman et al. 1975). These underwater pipelines were considered standard up until the mid-1970s when high-density polyethylene (HDPE) became widely accepted as an underwater pipeline material (Hirshman et al. 1975). Fibreglass pipe could also potentially be used for underwater pipeline applications (Ciani 1978; Hirshman and Kirklin 1979). VanRyzin and Leraand (1991) and Leraand and VanRyzin (1995) have documented several deep cold-water pipeline intakes for ocean thermal energy conversion (OTEC) research and direct surface water cooling DWSC systems. They cite HDPE as the intake material of choice because it is chemically inert, fusible, flexible, strong, and will float in water, which aids in pipeline installation. Also, HDPE has a low thermal conductivity (Yang 2007) and thus a high thermal conduction resistance relative to steel pipe. This high conduction resistance insulates the cold water taken from deep underwater and prevents it from warming significantly as the pipeline passes through upper layers of warmer water. HDPE intake pipes can be fused together in large sections, ends capped, and then floated into place. HDPE pipe is also much smoother than steel or concrete pipe, which will decrease frictional pumping losses (Hirshman et al. 1975).

Preventing the entry of biological organisms

To prevent the entrainment of biological organisms or other submerged debris, some form of screening or filtration is implemented at the water intake. A typical the intake structure and primary screening device are already shown in Figure 7. This type of primary radial screen is intended to draw water from one specific horizontal stratum deep underwater. This design is intended to leave undisturbed the warmer water layers above the intake, and to also leave the water near the sea or lake bed undisturbed to avoid entraining sediment particles.

Chien et al. (1986) discussed the use of a coarse stationary primary screen, followed by one or more stages of travelling band screens equipped with backwashing spray systems3 for SWHP system intakes in Hong Kong. This is the only known implementation of moving mechanical screens for DSWC or SWHP systems; however, this is due to the nature of the SWHP intake locations, which were all located just below sea level down to 4 m (13 ft) depth. Because plastic garbage, seaweed, and other floating debris will impact the performance of screening equipment, travelling band screens with backwash systems were implemented.

The screened surface area should be large enough to maintain face water velocity at an acceptable level. By limiting the maximum face water velocity, biological organisms such as fish or fish larvae are not drawn to the intake, which will minimise death by impingement and entrainment. Stefan et al.

(1986). Kavanaugh and Pezent (1990) suggest that a fine slot, high impact PVC(ASTM2011)well screen has been shown to work well as an intake filter for small residential SWHP systems with a submersible pump located at the pipeline inlet. Kavanaugh and Rafferty (1997) state that for residential systems, multiple stages of screening or filters may be required.

A sand filter has also been proven effective at cleaning intake water for residential open-loop SWHP systems. This system uses a sand filter—similar to what would be used as a pool filter, for cleaning the surface water for the heat pump system. The sand filter functions by passing the intake water through a fine medium, typically fine sand or some gradation of sand and other porous media. The filtered water is then pumped through the heat pump for space conditioning. Once a predetermined time, maximum differential pressure, or filter water level has been exceeded, the sand filter units then reverse flow direction, backwashing the debris from the filter back to the water source (Cusack 2012).

Another novel intake structure design, similar to the sand filter for residential systems, is that of using the lake or sea bed as a filter by horizontally drilling beneath the lake or sea floor and installing a perforated drill casing. This allows the lake or sea bed to naturally filter the water coming into the system.No intake screen or filters would be required provided the lakebed geology is suitable for such an installation. Implementation of this technology has been discussed for use in desalinisation plant applications (Fari ˜nas and L'opez 2006; Peters and Pint' o 2008).

Seawater pumps

For pumps, one of the most important questions that must be answered is that of material selection. The working fluid salt content will be the main parameter influencing pump material selection. Other water quality parameters, such as suspended solids, water temperature, and pH, will also affect pump material selection. Salt content will cause corrosion of the pump components by electrochemical corrosion process while higher water temperatures will accelerate this corrosion process. Suspended solids content will accelerate the erosion of high-velocity pump components, causing clearances to expand and pump performance to decrease.

Brackish water or seawater will present the strictest requirements for pump material selection while freshwater pumping material requirements can be more relaxed. This is due to the highly corrosive nature of seawater. The concentrated chlorides dissolved in seawater can cause pitting, crevice corrosion, and inter-granular corrosion in stainless steel (SS), carbon steel, and copper alloys. Stress corrosion cracking is also a problem for SS components when higher temperature seawater is involved, especially for the heat-affected zone at a weld site (Maehara 2007). Appropriate materials must be selected, or the pump will fail prematurely, causing system downtime.

In the late 1970s, pumps with a SS impeller housed in a lined concrete case were the recommendation when beginning initial cost estimates for seawater pump systems. Titanium and Monel are also resistant to seawater corrosion and have excellent resistance to erosion (Keens 1977). When discussing corrosion and erosion, Antunes et al. (1981) differentiate between different periods of operation when erosion and corrosion occur—namely, normal operating conditions and idle or low load operating conditions. During normal operating conditions, the pump must be resistant to cavitation and erosion-corrosion. In contrast, during idle or low load conditions, the pump is vulnerable to pitting or crevice corrosion, i.e., galvanic corrosion. For pump components with lower flow velocity, i.e., the suction bell, column, or discharge head, high-Nickel ductile iron and Nickel-Aluminum-Bronze are recommended because of their resistance to erosion for flow velocities up to 15 m/s. These materials are also resistant to galvanic corrosion. For pump components with higher flow velocities, i.e. impeller, shroud, and casing, the recommended material is SS 316L (Antunes et al. 1981). SS 316L is however vulnerable to pitting or other galvanic corrosion reactions when immersed in stagnant water. A solution to this is to couple the SS 316L components with a more anodic sacrificial material.

Seawater heat exchanger

SWHP systems using saltwater as the working fluid will be more affected by electrochemical corrosion than would freshwater systems. As was the case with pump material selection, it is very important to select the appropriate heat exchanger material to ensure the desired lifespan. Inappropriate material selection will result in premature failure of the heat exchanger and decreased efficiency or system shutdown.

Heat exchangers with seawater as the working fluid began have been studied extensively. As of 1978, Titanium was a candidate for the first generation of OTEC heat exchangers, and research was underway to qualify aluminium, AL-6X SS, and 90/10 cupro-nickel alloy for OTEC heat exchangers (Kinelski 1978). As noted by Keens (1977), carbon steel is not a suitable heat exchanger material for seawater applications. Copper alloys with various concentrations of: nickel, aluminium, zinc, and tin exhibit fair resistance to corrosion in seawater, but that their lifespan will decrease significantly if used in locations where flow velocities exceed 1–3 m/s. Stainless steel 316 was preferred over 304; however, stainless steel may be more suited for pump impellers than heat exchangers. Aluminium was not recommended due to the risk of galvanic corrosion. Titanium was ultimately recommended for heat exchangers with seawater as the working fluid.

For seawater applications, Titanium is the most widely used heat exchanger material in current DSWC and SWHP systems operation around the world (Fermb¨ack 1995; Leraand and Van Ryzin 1995; Newman and Herbert 2009; War 2011). Smebye et al. (2011) recommend Titanium for seawater systems and high alloy steel for freshwater systems.

Biological fouling

Another problem occurring in SWHP systems is performance degradation due to biological fouling. If not addressed, biological film, algae, slime, and/or molluscs could form in the system, which will increase the thermal resistance as well as the required pumping power. To control the growth of biological organisms, biocide dosing schemes have been implemented and reported for various freshwater and seawater system applications. Keens (1977) reviewed several different biocide types, of which only the oxidising agent sodium hypochlorite (chlorine) is acceptable for use in open systems due to environmental concerns regarding chemical discharge. Fava and Thomas (1978) studied biological fouling of heat exchangers and noted that corrosion rates increased as the chlorine dosage increased. Chien et al. (1986) state that for seawater applications, chlorination has proven to be the most cost-effective and efficient means of preventing biological fouling in SWHP systems.

Kavanaugh and Rafferty (1997) describe several other methods for coping with heat exchanger fouling that does not involve biocide application. Permanently installed brush systems are available for shell-tube heat exchangers which mechanically clean the inside of the tube surfaces. These work using a 4-way valve that is installed on the tube side heat exchanger piping. This valve reverses flow after a specified period of time which causes the brushes to travel from one end of the tube to the other. The brushes are held in place by special cradles installed at each end of the tube (WSA 2012). Disassembly and cleaning of bolted plate frame heat exchangers is also another maintenance option for fouling mitigation.

Return piping

SWHP outfall systems are used to return the warmer or cooler return water to the water source without creating a concentrated pocket of water that is significantly warmer or cooler than the water source. These outfall systems are also intended to be placed at a depth that will not cause significant nutrient enhancement of the outfall area (Davidson 2003; War 2011). Water taken from deep underwater may contain higher amounts of nutrients than surface water, so the outfall should discharge at a depth that will not promote the growth of algae. The outfall system works by mixing the system water with the source water body over a large enough area so that temperature gradients are minimal. It is also typically discharged near the sea bed instead of directly into the water column.

3 Partner country projects related to the seawater heat pump sector

Ongoing and completed projects in partner countries related to the SWHP sector, seawater technologies in general and technologies associated with those mentioned above will be mentioned in this section. Most of the identified projects are on a European level, either ongoing or completed.

The most important synergies with the SEADRION project are as follows:

- Enhanced planning and management: Elaboration of territorial energy planning and management, such as success criteria of sustainable management of energy use, including certification and technical standards. Risk mitigation: Identification of all possible risks in geothermal project development as well as their classification and compilation in a Risk Register.
- Public awareness (knowledge) and perception of geothermal projects: Empower society to participate in the development of geothermal projects using alternative financing schemes.
- Certification schemes: Courses and training materials concerning the regulation of shallow geothermal.
- Advanced systems and components: Advanced systems and materials to improve the performance and cost-efficiency such as new pipe materials, advanced grouting additives and concepts (in case of indirect water intake), advanced phase change materials (heat storage), hybrid heat pumps, Aquifer Thermal Energy Storage (ATES).
- Integration in an urban environment: Heating and cooling in retrofitting existing and historic buildings.
- Identification of competing technologies: investigating the actual market requirements (including requirements on costs) and identifying the competing technologies (including the business-as-usual as well as substitute technologies).
- Support for technology transfer and knowledge sharing.
- Pursue a smart, sustainable and inclusive growth by supporting and promoting Blue Energy deployment (including SWHPs).
- Provide services, tools and methods tailored to the needs of Small and Medium Enterprises (SMEs) and help highlight the actual obstacles and limitations to the development of the Blue Energy sector.

There are many other direct and indirect activities of other projects related to the activities of the SEADRION and SWHP technology as well as similar technologies relevant to the previous one. Some of the projects related to SEADRION that have been implemented or are still being implemented in the partner countries are listed in the table below.

Table 16: Ongoing and completed projects in partner countries related to the SWHP sector

PROJECT NAME	SHORT DESCRIPTION	RELEVANCE TO SEADRION
MAESTRALE	**Nov-2016-Nov-2019** The project Maestrale intends to lay the basis for a Maritime Energy Deployment Strategy in the Mediterranean. Based on a survey of existing and innovative technologies, hindrances and potentials in participating countries, it aims to widen knowledge sharing among scientists, policymakers, entrepreneurs and citizens and prompt effective actions and investments for blue growth. The main output will consist of the creation of Blue Energy Labs (BEL) to take place in each participating region. BELs will involve local enterprises, public authorities, knowledge institutions and citizens and will operate to support future blue energy policies and plan concrete strategies for blue growth. Several pilot projects will serve the purpose of raising awareness among local stakeholders, facilitating social acceptance, decreasing uncertainty and increasing feasibility of concrete interventions.	▪ Overview of regulations, opportunities, hindrances and benefits; ▪ State-of-art, survey of existing technologies, previous studies and (EU) projects; ▪ Online geo-database; ▪ Energy potential analysis, including a catalogue/roadmap of possible solutions.
PELAGOS	**Nov-2016-July-2019** PELAGOS aim is to establish a permanent Cluster of national HUBs in the Blue Energy (BE) sector, where technical experiences are shared. Permanent communication among actors is a crucial asset for the evolution and advancement of the project and its effective contribution to the Blue Growth of	▪ Support for technology transfer and knowledge sharing; ▪ Stimulation of the development of high-tech and sustainable infrastructures in cohesive investment areas, thus concurring to generate economic growth, to enhance the security of energy supply, to foster competitiveness, and to increase the demand of high-quality professionals in new sea careers;

	Mediterranean coastal, insular and offshore regions. The specific scope of PELAGOS is to facilitate the deployment of targeted technological solutions and products that are tailored to the characteristics of the Mediterranean environment.	▪ Provide services, tools and methods tailored to the needs of Small and Medium Enterprises (SMEs) and help highlight the actual obstacles and limitations to the development of the Blue Energy sector.
BLUE DEAL	Blue Deal aims to increase the transnational activity of innovative clusters and networks of the BE sector, develop links and synergies between SME's, public authorities, knowledge institutions and civil society and establish transnational and regional Blue Deal Alliances. This project will create a favourable environment for BE investments and sustainable development in the Mediterranean economy.	▪ Improve the production of renewable energy from marine sources in different MED regions; ▪ Promote BE development potential for smart blue growth, also through the empowerment of public institutions and SMEs.
COASTENERGY - Blue Energy in ports and coastal urban areas	**Jan-2019-June-2021** The overall objective of COASTENERGY is to foster the creation of a favourable environment for business initiatives in the Blue Energy sector and promote the realisation of coastal blue energy systems in the Programme area, particularly focusing on a wave and thermal energy converters to be integrated into structures such as breakwaters, marinas, etc. These initiatives must be informed and designed to guarantee the full preservation of marine ecosystems and the landscape, and also comply with the needs of other maritime activities such as fishing, aquaculture, tourism, and shipping. The project will adopt a participatory approach, gathering and involving Quadruple Helix actors in a multi-level network for the development of a common roadmap and the deployment of coastal blue energy systems in pilot	▪ Knowledge transfer and education of the local and translational Hubs, present examples of good practices of seawater heat pump systems and integrated energy solutions with projects of zero-energy buildings; ▪ Improve cooperation and knowledge exchange between public administrations, companies, research centres and citizens; ▪ Establishment of an Italian-Croatian observer on the coastal energy system and development of network databases where potential investors and the public will have all relevant data and data related to the possibility of investigation in Istria County and surrounding Mediterranean environments (scientific research, data on legislation and financing, technological information and guidance.

	areas.	
GeoPLASMA-CE	**June-2016-Sept-2019** GeoPLASMA-CE aimed to foster the share of shallow geothermal use in heating and cooling strategies in central Europe. The project created a web-based interface between geoscientific experts and public as well as private stakeholders to make the existing know-how about resources and risks associated to geothermal use accessible for territorial energy planning and management strategies in Central Europe.	Resources and risks associated with geothermal use accessible for territorial energy planning and management strategies, e.g. **Success criteria for sustainable management of shallow geothermal use** including basic **certification** that covers the whole range of working steps during the implementation of geothermal energy systems for: Design, Drilling and construction, Installation, Maintenance, Licensing authorities. **Technical quality standards** Analyses performed in this project show that the state of the art varies between the countries involved in GeoPLASMA-CE with respect to technical and ecological standards. For this deliverable, the GeoPLASMA-team aims at elaborating common minimum quality standards. Quality standards can be technical standards for installation and operation but also standards for the compliance with quality control measures (e.g. drilling reports and system monitoring). A detailed definition of these standards is beyond the focus and expertise of GeoPLASMA-CE.
GEOCOND	**May-2017-Oct-2020** Advanced materials and processes to improve performance and cost-efficiency of Shallow Geothermal systems and Underground Thermal Storage. The overall aim of the project is to reduce the costs by about 25%, leading to a substantial gain in competitiveness through the development of new pipe materials, advanced grouting additives and concepts, advanced phase change materials and system-wide simulation and optimisation.	Advanced materials and processes to improve performance and cost-efficiency, such as **new pipe materials, advanced grouting additives and concepts (in case of indirect water intake), advanced phase change materials (heat storage)** and system-wide simulation and optimisation, e.g. **Geothermal pipes with improved ageing resistance and customised thermal properties**– Several approaches to improve the efficiency of a shallow geothermal system such as: i) improve thermal conductive pipes by including carbonous particles in the plastic material, ii) reduce the thermal conductivities

		of the pipes by developing a pipe with a foamed internal layer. **New additive for grouting applications (indirect water intake):** i) Functionalised silica: Commercial silane coupling agents to develop a low-cost chemical route to create chemical bonds between silica and carbon particles which are graphite, expanded graphite and graphite-like particles having different thermal conductivity. Using these additives could improve the thermal conductivity of the grouting without increasing the amount of conductive additives and in consequence, reducing grout viscosity. ii) **Heat storage materials for district installations.** New low-temperature transition Shape Stable PCMs developed from paraffin leading to an increase in the **heat storage** significantly in order to enhance the performance of the groutings employed in geothermal facilities at the district level. **Environmental, standardisation and social impact monitoring.** Environmental, economic and social assessment will be carried out. All development in new materials needs to be checked against the needs for groundwater and soil protection, and if necessary, adapted during the development process.
GEO4CIVHIC	**Apr-2018-2022** The main goal of GEO4CIVHIC is to develop and demonstrate easier to install and more efficient GSHEs, using innovative compact drilling machines tailored for the built environment & developing or adapting HPs and other **hybrid solutions in combination with RES** for retrofits through holistic engineering and controls approach improving the return of investments.	Deployment of shallow geothermal systems for heating and cooling in **retrofitting existing and historic buildings.** Innovations: modular and innovative machines, new solutions for heat exchangers, new plug and play, hybrid, high-temperature heat pumps. Innovative Heat Pumps for Civil and Historical Buildings & NZEB.
CHEAP-GSHPS	**June-2015-2019** The proposal will focus on one hand on the development of more efficient and safe shallow geothermal systems and the	The potential of shallow geothermal energy and the synergies with other renewable energy sources is very large, but remains insufficiently tapped. Today, the main barriers for shallow geothermal use in heating and cooling of

	reduction of the installation costs. This will be realised first by improving an existing, innovative vertical borehole installation technology and the design of coaxial steel GSHE drastically and second, newly designed basket type GSHE's with novel installation methodologies will be developed.	buildings are the **high upfront capital,** the **low awareness of this technology and the diverse and changing regulations** in the different European countries. In this respect, a **Technical Manual**, prepared by the Cheap-GSHPs consortium, reports the results of this extensive research and innovation activities. The manual also supports the National training and dissemination workshops foreseen. The manual, as a reference document, intends to increase the awareness and acceptance of shallow geothermal energy overall stakeholders and end-users. **Finally, the manual is expected to strengthen the professionals' capabilities in the design and roll-out of shallow geothermal plants in civil and historical buildings.** The engineering and design of shallow geothermal plants require knowledge and expertise in several disciplines of the value chain covering (hydro) geology, drilling, building physics, heat exchanger design, heat pumps. To decrease the threshold of acceptance, increase the awareness and reduce the engineering costs, databases and design tools were developed and bundled in a software suite. The **first chapter** of the Technical Manual aforementioned includes the description of the geological mapping, the climatic databases and the building load calculation tools. The Ground Source Heat Exchangers (GSHE) represent the major cost of a shallow geothermal installation. Cheap-GSHPs has tackled these costs by improving drilling methodology, drilling machines/tools and heat exchangers design to increase the thermal exchange yield and to reduce installation time/cost. The research and developments focused on respectively very shallow basket type and coaxial heat exchangers. The **second and third chapters** cover the machine developments, heat exchanger designs, field test results and installation costs

		for heat basket and coaxial heat exchangers. The design tools to size the geothermal field were adapted in chapter four to include the innovations on heat exchanger design developed within Cheap-GSHPs. Heat pumps, an integral part of shallow geothermal systems, need to be appropriately selected. A purpose-built selection tool assists in this selection, as also explained in **chapter four**. That same chapter describes the development and improved performances of a **high-temperature heat pump. Such a heat pump avoids the costly change of high-temperature terminals in building renovations and historical buildings**. Finally, **chapter four** also provides schematic indications and costs on the integration of shallow geothermal with other renewable energy sources such as **solar thermal, photovoltaics and wind.** All the tools mentioned above and databases are feeding into an easy to use Decision Support System (DSS). This DSS performs a feasibility study with an economic evaluation of different plant set-ups in the function of the priority criteria set by the user leading to the selection and design of low enthalpy geothermal systems. **Chapter five covers** the architecture of the DSS and the links with the different tools, the user-friendly interface and the user instructions. Non-experts can use the system for feasibility studies while expert users can use the tools to design the plant, thereby reducing also the engineering costs. All these innovations have been demonstrated in six real cases studies, and the design tools are applied in ten virtual demonstration cases. The lessons learned from the installation and performance in the field of the different developments are described in chapter six. The reported results and the feedback from the demonstrations highlight which innovation aspects are ready for the market and which developments still need some more work. Furthermore, these demonstrations also build confidence in this

		technology and increase awareness from life examples in Historic buildings. **Chapter seven** addresses the Environmental impact, assesses the risk, evaluates the standards and regulations in the different countries and regions. A set of recommendations facilitates the deployment of the heat exchanger, drilling and heat pump technologies in the case study sites, but also ensures **transferability of these to other parts of Europe**. Moreover, the Life Cycle Analysis of the real case studies demonstrates the lower environmental impact offered by Cheap-GSHPs technologies. In **chapter eight,** possible exploitation plans are described to help **SMEs and industrial project partners to develop new strategies in their respective businesses,** focusing on the market segments where these innovations provide competitive advantages.
GEOTeCH	**May-2015-April-2019** GEOTeCH project aims to stimulate and promote greater utilisation of renewable heating and cooling using shallow geothermal GSHP systems through the advancement of innovative drilling and ground heat exchanger technologies that are significantly more cost-effective, affordable and efficient than current technology.	A **preliminary assessment of the European market** for the developed solutions carried out, in order to ensure that the developed systems will be received and used by one or more defined market segments (e.g. small residential buildings market segment, large tertiary buildings market segment). This task will aim at investigating **actual market requirements** in a first instance (including requirements on costs) and at identifying the landscape of the competing technologies (including the business-as-usual as well as substitute technologies, namely technologies that could constitute a valid alternative toward the proposed technologies due to fulfilling the same function). Accordingly, a detailed analysis of potentially competing systems and technologies will be carried out at large, focusing on the same market segments addressed by the developed technology. Moreover, an analysis of the **framework market conditions** will be carried out, which will also include the **preliminary identification of financing models for potential buyers, the identification of potential market entry barriers (including, e.g. missing standards)** which may impose limitations to the take-up of the developed technological solution. **The market**

		assessment will be a synthesis of research, field observations, and interviews with stakeholders with knowledge of local markets. The results of the study will draw some **recommendations for future developments**, to overcome the existing barriers and to enable market penetration of the system.
REGEOCITIES	**2012-2015** The project aims to remove and clarify the non-technical administrative and regulatory barriers at regional and local levels affecting the uptake of SGE systems. The overall objective of the project is, therefore, to address and overcome the non-technical barriers concerning the regulation of shallow geothermal resources and to simplify and clarify the administrative procedures.	**Analysis of the current regulative framework** **Recommendations for a regulative framework**, e.g. **Report on the current situation of the regulative framework for shallow geothermal in the participant countries,** including an overview of the market situation, the non-technical barriers affecting geothermal and the expectations of the NREAPs. **Certification schemes** **Courses and training materials concerning the regulation of shallow geothermal systems** targeting policymakers and administrative personnel from the targeted cities and regions, as well as professionals. This is **supported by an online helpdesk for local authorities.**
GEORISK	**Oct-2018-2021** Developing geothermal projects by mitigating risks. The project aims to develop financial schemes to mitigate the impact of the resource risk by spreading it in such a manner that project developers can accept their fair share of it. This mitigation of the risk through financial instruments allows lowering the financial exposure of developers in case of failure to develop a geothermal reservoir.	Identification of all possible risks in geothermal project development as well as their classification and compilation in a **Risk Register.** The register is based on the analysis of about 70 documents of previous projects and studies dealing with risks in geothermal. It identifies the roughly 50 main risks faced by project developers and operators. Each risk is characterised by a description, the corresponding project phases, types of consequences, and possible technical and financial (insurance) mitigation measures. An online version of the Risk Register is available as the so-called GEOriskREPORT at https://www.georisk-project.eu/register/. This online tool includes a list of the main risks to be faced by developers, the corresponding mitigation measure, the

		results of the GEORISK Risk Assessment and a downloadable risk assessment sheet. The GEOriskREPORT can thus serve as an **interactive risk mitigation guide** for project developers and can help to shape a project-specific risk management plan. Based on the risk identification, GEORISK performed a risk assessment via a survey in which each risk of the Risk Register was rated and ranked by geothermal stakeholders (drilling companies, research institutions, geothermal project developers, insurance companies, consultants) concerning the current market situation in the local context of the target countries.
CROWDTHERMAL	**Sept-2019-Aug-2022** CROWDTHERMAL aims to initiate a new form of public dialogue that allows the direct participation of citizens. By creating **new financial services** and **communication strategies**, CROWDTHERMAL will contribute to the increase of geothermal energy in the final gross consumption. The synergetic achievement of these specific goals will help create a level playing field for geothermal energy development in Europe, while fully addressing the needs **for public engagement and transparency concerning the management of environmental impacts.** A horizontal objective is to help transform the rather conservative image of this industry into a dynamic one that uses cutting-edge concepts in public engagement and has the full wealth of contemporary financial services at its disposal in realising geothermal projects.	Empower society to participate in the development of geothermal projects using alternative financing schemes Surveys regarding the following: **Assessment of case studies**: One first stage consists of the general characterisation of the project. It includes geographical, technical, socioeconomic (including finance) and environmental aspects. Surveys were tackling **public awareness (knowledge) and perception of geothermal projects.** Establishment of community projects: best practices around Europe
HEATSTORE	Thermal energy storage technologies need to be developed and become an integral component in the future energy system infrastructure to meet variations in	Reference to **AQUIFER THERMAL ENERGY STORAGE (ATES)** Most ATES systems worldwide are low-temperature (LT) systems

	both the availability and demand for energy. The main objectives of this project are to lower the cost, reducing the risks and to optimise the performance of high temperature (~25 to ~90°C) underground thermal energy storage technologies by demonstrating 6 distinct configurations of heat sources, heat storage, and heat utilisation. **Technical, economic, environmental, regulatory and policy aspects** will be addressed that are necessary to support efficient and cost-effective deployment in Europe. The project will stimulate fast-track market uptake in Europe, promoting development from demonstration phase to commercial deployment within 2 to 5 years on the European market and provide an outlook towards utilisation of full potential in 2050.	• Extensive LT-experience in the Netherlands • Low-temperature storage (< 30ºC) • Medium-temperature storage (30-60ºC) • High-temperature storage (>60ºC) • Known technology/well tested, good business cases for LT The operation of Aquifer Thermal Energy Storage (ATES) means that water is extracted from a well and is heated or cooled before it is re-injected into the same aquifer. So, the thermal energy is stored in the groundwater and in the matrix around it. There are usually several wells, for extraction and injection, and these are separated in order to keep the warm and cold water from mixing. ATES systems are large scale systems mainly for seasonal thermal energy storage, both heating and cooling. In many cases, the same ATES is used for both heating and cooling.
Desalination plant Vora (DPV)	**Feb-2020-Feb-2022** Based on this project, we conclude that most of the recent seawater desalination proposals in Albania appear to be premature. Among the exceptions, the desalination proposals are alternative water-management options have been substantially developed, explicit ecosystem benefits are guaranteed, environmental and siting problems have been identified and mitigated, the construction and development impacts are minimised, and customers are willing to pay the high costs to cover a properly designed and managed plant for Vlora power plant.	The desalination plant will keep once-through cooling systems in operation ▪ cooling systems will remain in operation solely to service desalination plants. ▪ Project desalination will be independent of the power plant due to uncertainty associated with the cooling system. ▪ Additional research is needed to determine whether there are synergistic effects caused by combining desalination's high salinity discharge with high temperatures and dead biomass in power plant discharge. **Related to SEADRION project: this process will be good proportional for future utilisation SWHP.**
WDSHP project	**March-2021-March-2023**	Seawater desalination capacities vary based on the desalination process employed. Feedwater volume requirements generally range from

	Purpose of this project will be for desalination plant of Shengjini with Objectives: ▪ Identify intake technologies and modifications with potential to reduce water problem and ▪ Reduce overall costs by using existing intake infrastructure	approximately two times the plant production capacity for reverse osmosis (RO) systems to more than ten times the distillate production of thermal processes that usually have both processes and cooling water requirements. The necessary feedwater will be available whenever a plant is operating if it is to meet productivity goals. **Related to SEADRION project: this process will be good proportional for future utilisation SWHP.**
WISP-D project	**Jan-2021-Dec-2022** Purpose of this project will be Water intake for a swimming pool to use high temperature of seawater. The primary water will be a quality health challenge, in typical order of public health priority, controlling clarity to minimise injury hazard, controlling water quality to prevent the transmission of infectious disease and controlling potential hazards from disinfection by-products. All of these challenges can be met through the combination of the following factors: treatment (to remove particulates, pollutants and microorganisms), including disinfection and filtration; pool hydraulics (to ensure effective distribution of disinfectant throughout the pool and removal of contaminated water); addition of fresh water at frequent intervals (to dilute substances that cannot be removed from the water by treatment); cleaning (to remove biofilms from surfaces, sediments from the pool floor and particulates adsorbed to filter materials); and adequate ventilation of indoor facilities.	Design and construction. People responsible for commissioning pools and similar environments, along with designers and contractors, should be aware of the requirements to ensure the safe and enjoyable use of facilities. Operation and management. Facility operators play a key role and are responsible for the good operation and management of the recreational water environment. **Related to SEADRION project: this process will be good proportional for future utilisation SWHP.**

4 Research and Innovation activities to promote the implementation of seawater heat pump technology

Since seawater heat pump technology is not very popular due to the problems that come with its application and operation (corrosion, biofouling, maintenance, etc.), it is necessary to work frequently to improve it in order to minimise these problems and thus thereby increasing the implementation and efficiency of such systems.

The following are definitions of specific recommendations with an emphasis on research and innovation activities that will ensure the acceleration of the integration of seawater heat pump technology in the building sector for cooling and heating.

4.1 Development of special material heat exchangers to increase system efficiency and reduce problems in the operation of the system

In the 1970s and 1980s stainless steel, aluminium and copper alloys were considered as heat exchanger materials in contact with seawater; however, the life span of such heat exchangers was short due to corrosion. Since the 1980s, Titanium has been the most common material used to make heat exchangers in use with seawater as a working fluid. However, for the last ten to fifteen years, the application of polymer heat exchangers in various technologies, including technologies that use seawater, has been investigated.

Due to their low cost, lightweight and corrosive resistant features, polymer heat exchangers have been intensively studied by researchers with the aim to replace metallic heat exchangers in a wide range of applications.

Since DuPont introduced the first polymer heat exchanger, many attempts have been made for promoting the commercial utilisation of polymer heat exchangers. The conventional heat exchanger manufactured in metal (such as stainless steel, copper and aluminium) has the disadvantages in terms of weight and cost. Also, specially treated metal heat exchangers are needed if the working fluids are corrosive. Given these considerations, it is desirable to find an alternative material for heat exchangers that can overcome these disadvantages and also acquire comparable heat exchange efficiency and be easily fabricated. This is where the use of polymer heat exchanger comes into play. With the advantages of greater fouling and corrosion resistance, greater geometric flexibility and ease of manufacturing, reduced energy of formation and fabrication, and the ability to handle liquids and gases (i.e., single and two-phase duties), polymer heat exchangers have been widely studied and applied in the field of micro-electronic cooling devices, water desalination systems, solar water heating systems, liquid desiccant cooling systems, etc. Most importantly, the use of polymer materials offers substantial weight, space, and volume savings, which makes it more economically competitive compared with exchangers manufactured from many metallic alloys. Moreover, the energy required to produce a unit mass of polymers is about two times lower than common metals, making them environmentally attractive.

Currently, the widely used polymer materials in heat exchanger applications are PVDF (polyvinylidene fluoride), Teflon or PTFE (polytetrafluoroethylene), PP (polypropylene), PE (polyethene), PC (polycarbonate), PPS (polyphenylene sulphide) and PPO (polyphenylene oxide).

Polymer heat exchanger technologies are very advanced. However, if we compare the thermal properties of polymers in Table 17 with those of metal alloys used in compact heat exchangers (listed in Table 18), big differences can be found. As shown in Figure 22, the most significant difference between polymer and metal materials is thermal conductivity. The thermal conductivities of most polymers listed are lower than 1 W/mK, which are around 100 times lower than those of most metals. Because of this, it might appear futile to pursue polymers for heat transfer application. However, if we consider the application of heat exchangers with corrosive fluids, seawater, in particular, the only possible metals will be Cu-Ni alloys and Titanium. Cu-Ni alloys offer good resistance to corrosion, polluted water, and deposit attack, but can be expensive. Recent advances in manufacturing technologies now permit the use of Titanium, which is highly resistant to corrosion and provides more flexibility in the design of heat exchangers due to its low density and high strength. However, as shown in Table 18, corrosion-resistant materials such as Cu-Ni alloys and Titanium have low thermal conductivities compared to copper and aluminium, (17 to 50 W/mK). To overcome this, the conductive thermal resistance of these materials is generally lowered by decreasing the thickness of the heat exchanger wall.

Table 17: Thermal properties of common heat exchanger polymers [12]

Polymer	Density, [g/cm^3]	Thermal conductivity, [W/m K]	Melting point, [◦C]
PC	1.2	0.2	NA
PPS	1.43	0.3	280
PP	0.94	0.11	160
PTFE	2.17	0.27	330
PVDF	1.78	0.19	160

Table 18: Thermal properties of metallic materials used in heat exchangers [12]

Material	Density, [g/cm^3]	Thermal conductivity, [W/m K]	Melting point, [◦C]
Aluminium 3003	2.71	169	629 - 652
Cu99.9	8.89	391	1083
Hastelloy A	8.8	17	1299

Inconel X	8.25	12	1393
Stainless Steel 304	7.92	52	1393
Stainless Steel 316	8.08	52	1371
Stainless Steel 446	7.47	57	1399
Titanium	4.51	17	1691
Cu-Ni 90/10	8.9	50	1100
Cu-Ni 70/30	8.95	29	1170

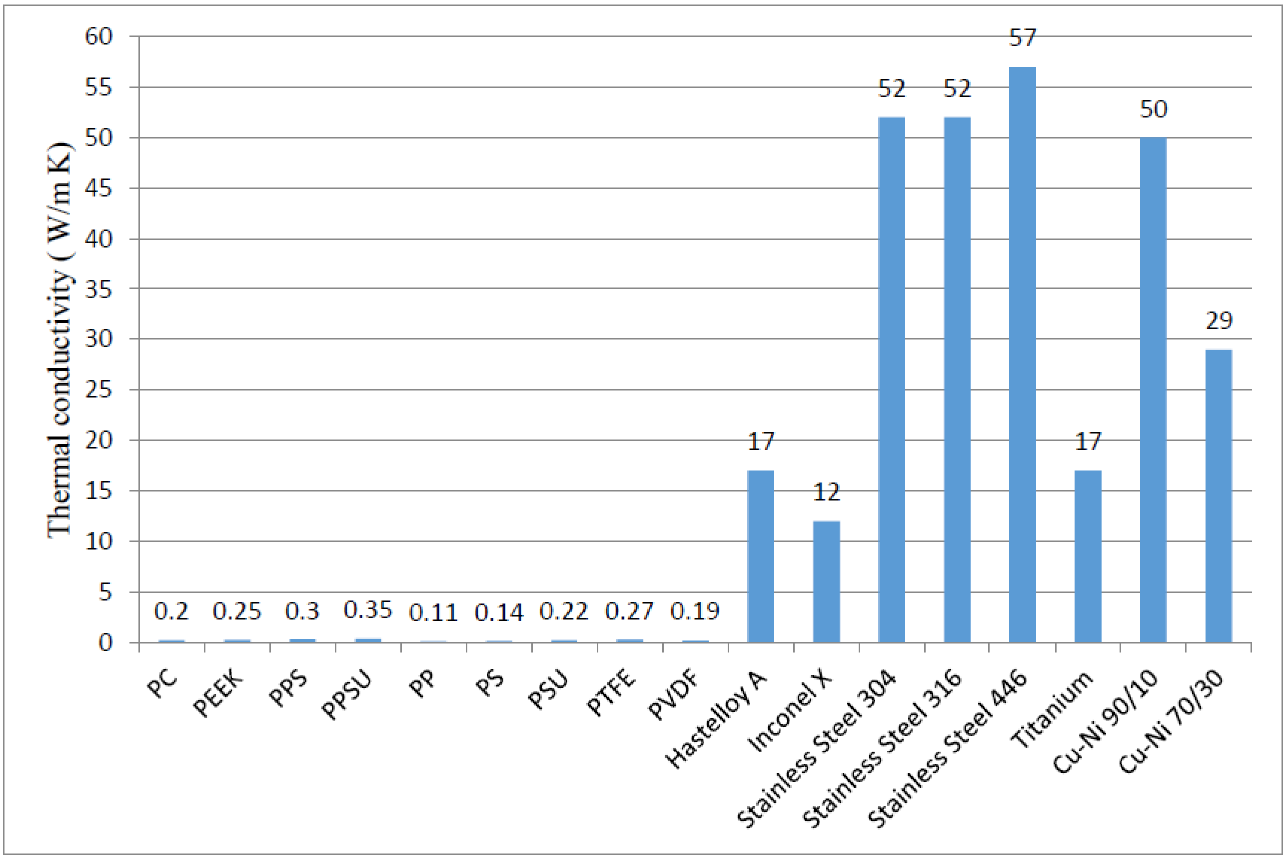

Figure 22: Comparisons of thermal conductivities for various polymers and metallic materials [12]

In order to quantitatively assess the differences between polymers and metal alloys for the applications in the heat exchanger area, it is worth considering the following three parameters together: heat transfer coefficient, the weight of the surface per unit of a heat exchanger and the costs of the materials. By comparing these three parameters, Zaheed and Jachuck concluded that by offering the same heat transfer rate, the heat exchanger manufactured using PVDF (polyvinylidene fluoride) would cost 2.5 times less than the Ni-Cr-Mo alloy unit. The cost advantage of polymers becomes particularly strong when competing with expensive, corrosion-resistant metal alloys. Moreover, by using thin-walled structures, the increased heat transfer resistance of the tube walls compared with metal tubes can be reduced significantly, making polymers a better alternative.

In terms of melting temperatures of polymers and metals showed in Figure 23, the polymers demonstrate relatively low heat deflection temperature (<300 °C), while metals have very high melting points (>1000 °C). But these numbers are not crucial for the heat exchanger design, as their melting temperature does not necessarily determine the operating temperatures of the heat exchangers.

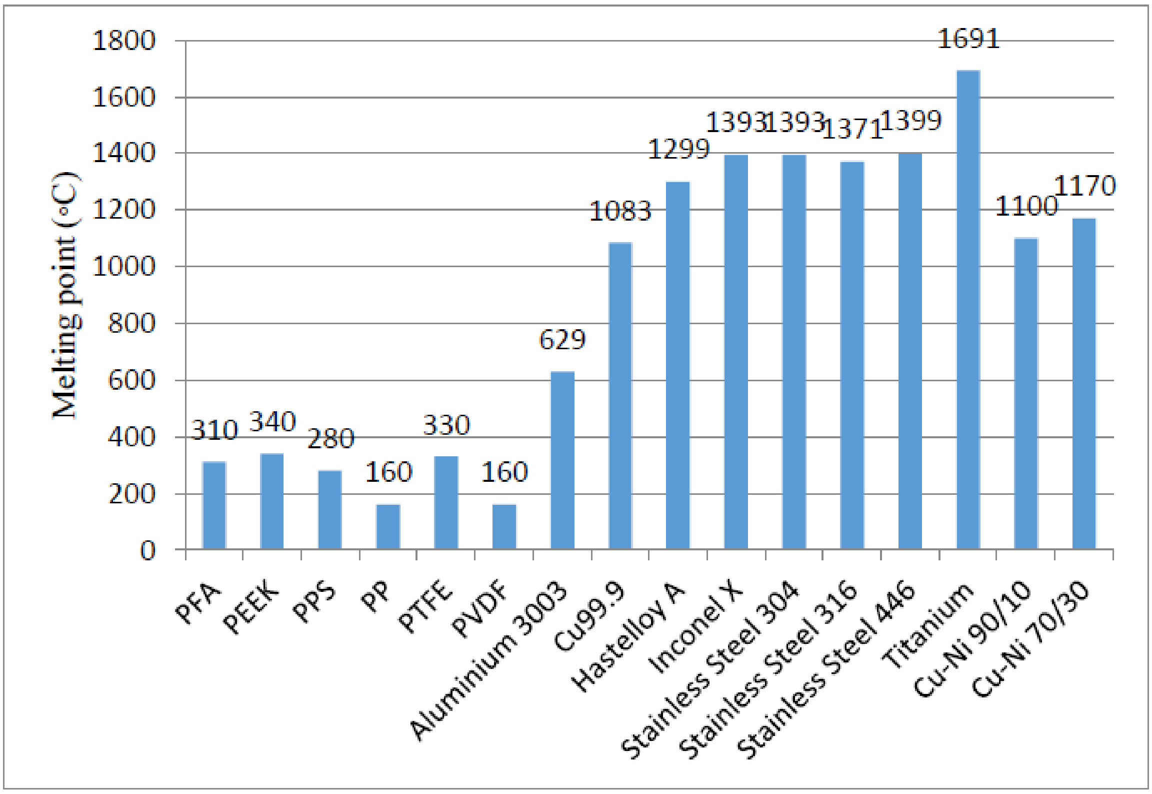

Figure 23: Comparisons of melting temperature for various polymers and metallic materials [12]

In heat exchanger applications the low thermal conductivity of basic polymers, at best 5% of that of metals, affects their attractiveness, but this can be alleviated by using polymer composite materials. The difference in corrosion resistance between polymers and metals are not presented in Tables 17 or 18; however, most of the polymer materials are resistant to chemical acids, solvents and corrosive fluids, whereas metals are susceptible to direct chemical dissolution. For polymers, long term exposure to seawater may only result in minor moisture-induced damage.

In terms of the environmental aspect of a polymer heat exchanger, polymers are easy to mould, and the energy required to process a specific shape is low. Unlike metal units, plastic heat exchangers can be easily contoured to fit available space. Also, most of the polymer materials are recyclable and can be reprocessed into a new product. Most importantly, the advantage of low weight reduces the handling and transportation emissions as compared to metallic heat exchangers.

In applications where seawater and other streams where fouling might occur, the use of polymers has added benefits due to their relative ability (a) to be cleaned, or (b) the characteristics of the polymer surface that inhibit foulants sticking. This has running cost benefits – lower cleaning costs and pumping power.

4.2 Development in dealing with pipe and heat exchanger biofouling due to seawater content

Marine fouling is an accumulation of microorganisms, plants, algae, and/or animals on wetted surfaces. These organisms form a fouling community, which can be divided into:

- Micro-fouling: Biofilm formation of bacterial adhesion. Appears as layers of bacterial slimes.
- Macro-fouling: Attachment of larger organisms (barnacles, mussels, seaweed, etc.).

Marine fouling (biofouling) of suction pipes and heat exchanger is explained in more detail earlier in the paper.

The impact of fouling in heat exchangers has been recognised since 1910, when the first research on the issue was conducted. Since then, there have been many developments from patented solutions to standard good practice, such as maintaining flow rates and carefully controlling temperatures. Fouling has a significant impact on heat transfer across the heat exchanger surface, and therefore on the overall operational performance and the economics of the process.

The following are some of the recent approaches that can reduce the fouling of suction pipes and heat exchangers, and thus contribute to more stable operation, i.e. better efficiency of the system.

Corrugated tubes in heat exchanger construction

When a fluid passes through a tube, several things affect how it moves, such as pressure, the nature of the fluid (how viscous it is), and the design of the tube wall. In a smooth tube, fluids generally follow a smooth path in which the particles which make up the fluid do not interfere with each other. This is known as laminar flow. However, where the smooth flow is disrupted, tiny whirlpool regions form in the fluid and turbulence occurs. Unsurprisingly, this is known as turbulent flow.

Turbulence makes tubular heat exchangers more efficient by preventing viscous (thick) materials sticking to the wall of the tube, where they can act as insulation and prevent efficient heat transfer (known as a boundary layer). It also prevents materials in suspension from dropping out of the carrier fluid and having a similar effect. This is the main benefit of corrugated tubes (Figure 24).

Because a corrugated tube has increased heat transfer rate compared to a smooth tube of the same length, the heat exchanger can be made smaller. For example, if corrugations increase the heat transfer by 10 per cent compared to a smooth tube, then the unit can be made 10 per cent shorter than an equivalent smooth-tube while delivering the same performance. The increased thermal efficiency – which can be up to three times that of a smooth tube heat exchanger – also means that less space is required to achieve the same level of heat transfer. Depending on the application, a corrugated tube heat exchanger can, therefore, be up to half the size of its smooth tube equivalent.

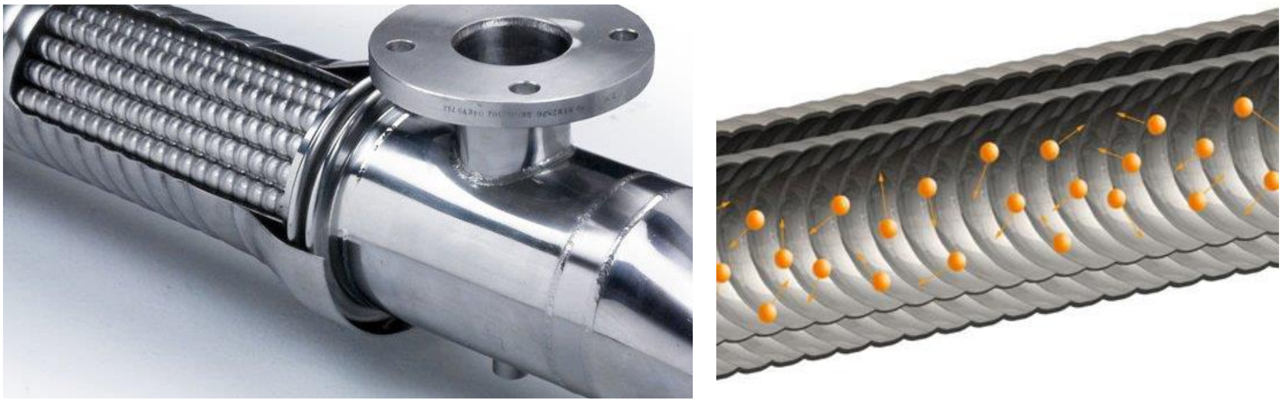

Figure 24: Corrugated tube heat exchanger [13]

Not only does preventing the formation of a boundary layer in the tube increase the thermal efficiency of the heat exchanger, but it also reduces the downtime needed to keep removing it. Therefore, the operational run-times between cleaning cycles are generally much longer with corrugated tubes than smooth ones, further increasing the overall efficiency of the process.

Control of marine biofouling on heat exchangers of vessels with ozone technology

The BIOFOULCONTROL European project has developed a new method for control of marine biofouling in cooling systems of vessels with the application of ozone. The project has been running for 27 months starting on 1 September 2009. It has been initiated by Normex AS, Norway in cooperation with four other small and medium-sized enterprises (SMEs) from 3 member countries. The consortium also consisted of 3 research and technological development (RTD) performers and one large shipping company. BIOFOULCONTROL has been funded by the European Union (EU)'s 'Research for the benefit of SMEs' Theme of the Seventh Framework Programme (FP7).

Despite huge expenditures used to clean fouled components of marine structures, no technology meets the need of the shipping industry to control settlement and growth of marine organisms on cooling systems that causes either blockage of inlet pipes of cooling water or hamper heat exchange. This results in the increased working temperature of engines and other heated appliances and possible shorter life or compromising of the vessel's safety.

Within the BIOFOULCONTROL project, an innovative ozone feeding system has been developed in order to attain efficient gas mass transfer of ozone into seawater. This enables enhanced dispersion of ozone in the cooling water and attains cost-effective inactivation of marine organisms that potentially settle in the cooling system. By this, the ozonation system enables minimised generation of by-products that are toxic to the marine environment. As part of the development work, the project has developed an intelligent process control unit for monitoring of process parameters and control of ozone dosage to attain optimum system operation.

The innovative components have been integrated into a pilot plant and subjected to four months of functionality tests in a real situation. The functionality trials demonstrated that ozonation is a promising technology that can efficiently mitigate marine bio-fouling cost-effectively without generating hazardous products to health, safety and the environment.

Electrolytic anti-fouling system

Cathwell has developed the CathFlow® anti-fouling system, which combats corrosion and prevents mussels, barnacles and similar organisms from establishing in seawater systems. The CathFlow® system works by releasing antifoulants (ions) in the seawater, forming an environment that mitigates corrosion and discourages organisms from adhering, growing and starting breeding.

The CathFlow® package for anti-fouling treatment usually consists of control panels and anodes in seawater intakes and filter houses. Copper and aluminium/iron anodes in pair are installed in the sea chests to treat the seawater before entering the seawater piping. As the anti-fouling effect gradually decreases through the piping system, complementary anodes may be required in separate dosing tanks or mud boxes for larger seawater systems.

Figure 25: MGPS and ICAF anodes mounted in sea chests to prevent fouling and corrosion (left); MGPS/ICAF anti-fouling anodes mounted at strainer lid (right) [16]

It should be noted that remotely installed anodes (sacrificial and anti-fouling anodes) located in sea chest or mud boxes, do not prevent galvanic corrosion caused by poor material quality or incorrect material combinations in the pipes. Such anodes can, however, be expected to provide local corrosion protection nearby the anodes. As a rule of thumb, anodes installed in pipes can be assumed to provide cathodic protection five times the pipe diameter inward the pipe.

4.3 Possibility of direct cooling in the coastal area

Many cities and buildings in the Adriatic-Ionian region are built in the coastal area. Thus, there is great potential for seawater to be used as a heat source or sink, while another way of using surface seawater to cool buildings is called direct surface water cooling (DSWC). These systems use deep ocean seawater where the water temperature is low as well as the flow temperature of the water in the heat pump chillers. Thus, DSWC systems bypass the heat pump and can save 90% of energy compared to conventional systems.

While DSWC energy savings are very good, there are many challenges in its application. One of the biggest challenges is that it is difficult to find surface seawater bodies with temperatures below 10 °C in the Adriatic-Ionian region. Although a seawater heat pump can use up to 26 °C surface water with fairly high efficiency in cooling mode, the question arises how to use the water range from 10 °C to 20 °C in DSWC mode without heat pump operation included.

To overcome this challenge, a hybrid SWHP-DSWC system could be implemented, taking full advantage of the energy-saving potential of using seawater as a heat sink as well as a natural cooler. The schematic diagram of the SWHP-DSWC system is shown in Figure 26.

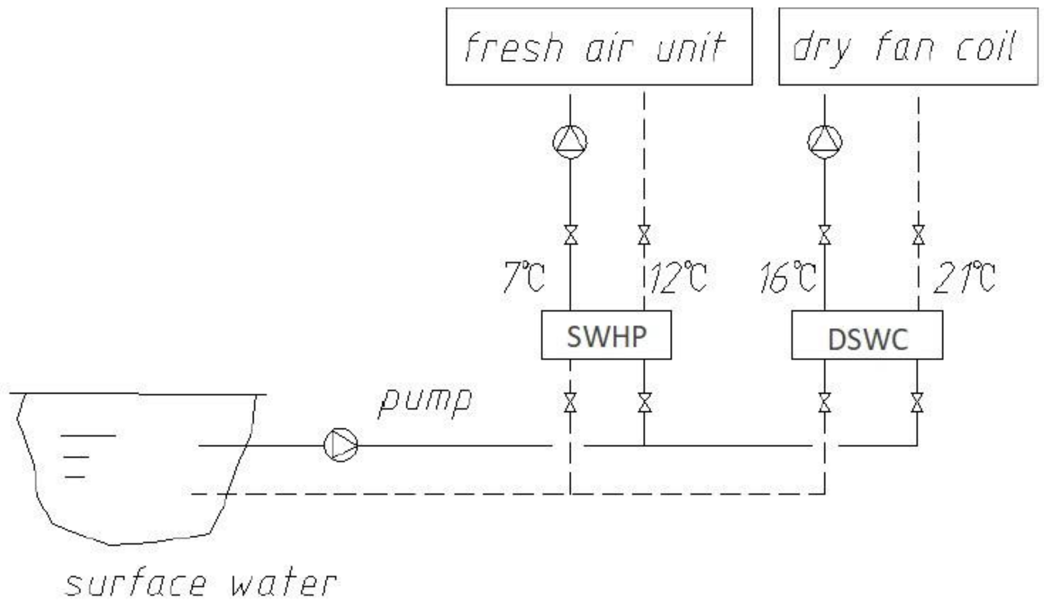

Figure 26: Schematic diagram of an SWHP-DSWC hybrid system [17]

In a hybrid SWHP-DSWC system, two water heat sinks with different temperatures (e.g. 16 °C and 7 °C) as well as temperature and humidity independent control system are required. High-temperature cooling water (16 °C) takes over most of the sensible heat load, i.e. cools the room air, while low-temperature cooling water (7 °C) takes over all the latent heat load and the remaining part of the sensible heat load, i.e. dehumidifies the room air.

The direct surface water is used as a high-temperature heat sink with its temperature of 16 °C. It is supplied to indoor devices such as dry fan coils to take most of the sensible heat load, while SWHP is used to prepare low-temperature chilled water with a flow temperature of 7 ° C, which is then fed to a fresh air treatment unit where the entire latent heat load and remaining part of the sensible heat load is taken over.

The annual operating costs of the SWHP-DSWC hybrid system are only 51% of the costs of conventional systems and 74% of the costs of the SWHP system, which proves that it fully exploits the energy-saving potential of natural low-temperature surface seawater.

5 Conclusion

Implementation of the seawater heat pump systems began in the 1970s and 1980s, and thus this technology has been continuously evolving since then. With more than 180 large systems installed, northern Europe is at the forefront of implementing this technology, with Sweden and Norway among the largest users. In the Adriatic-Ionian region, such systems are also applied.

The potential for the implementation of seawater heat pumps in the Adriatic-Ionian region is very large since a large number of public buildings, and especially hotel facilities, are located in the coastal area as well as on the islands. The data gathered for buildings in partner countries where the seawater heat pumps can be implemented show that altogether heating demand is 4736.08 GWh/year for hotel facilities and 496.73 GWh/year for public buildings which shows that investing in the further development of the considered technology is essential and important.

The most important and most demanding part of the seawater heat pump system is the seawater intake system, where the most operational problems occur, such as lower system efficiency due to corrosion and biological fouling, and the further development of technology is based. As Northern European countries are at the forefront of SWHP technology in Europe, both in terms of installed capacity and technology development, most scientific papers and innovations are of that origin. However, worldwide, the great development of SWHP technology and the contribution through scientific research has been noticed in China and Japan. The US is also among the countries contributing to seawater technology; however, they are more focused on seawater desalination plants.

Since the seawater intake system is the most sensitive part of the SWHP system, it is very important of which material the suction pipes and the heat exchanger between the salty seawater and the fresh tap water will be installed. Currently, HDPE (High-Density Polyethylene) leads as a material used to make suction pipes that are laid in the sea while Titanium leads in the making of heat exchangers that are in contact with seawater.

A major problem is also the biological contaminants that accumulate in the pipelines and heat exchangers in the system, the entry of large organisms such as fish and molluscs as well as sand from the seabed into the pipeline, which is why some form of screening or filtration is implemented at the suction port.

Many other ongoing and completed projects in partner countries related to the SWHP sector, seawater technologies in general and technologies associated with those mentioned above are dealing with the same or similar issues.

Since SWHP is not very popular due to the problems mentioned above that come with its application and operation, it is necessary to work frequently to improve it in order to minimise these problems and thus thereby increasing the implementation and efficiency of such systems. Some specific recommendations with an emphasis on research and innovation activities that will ensure the acceleration of the integration of seawater heat pump technology in the building sector for cooling and heating are elaborated in the paper such as the development of special material heat exchangers with the aim of increasing system efficiency and reducing problems in the system operation as well as development in dealing with pipe and heat exchanger biofouling due to seawater content.

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