Using high-temperature seawater heat pump for pool heating and domestic hot water preparation in a special hospital

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***Abstract*—Heat pumps are recognized as energy efficient and environmentally friendly technologies for cooling and heating. The objective of this paper is to identify the economic and environmental potential of seawater heat pump installed in a specialized hospital on the Mediterranean coast. A seawater heat pump is operating in the heating mode throughout the whole year and it is used for pool heating and domestic hot water production. Energy demand was studied for a whole year, and the economic benefits, as well as primary energy savings and CO_2 emissions reduction, were analysed. The analysis showed that the seawater heat pump would lead to 25% lower costs, 52% primary energy savings and 63% of CO_2 emission reduction in comparison to fuel oil boiler.**

Keywords—seawater heat pump, pool heating, domestic hot water production, fuel oil boiler

NOMENCLATURE

$Q_{HD, refill}$	heating demand for the pool refill, kJ
m_w	mass of the heated seawater, m
c_w	specific heat capacity of the seawater, kJ/(kgK)
Tsw	temperature of the fresh seawater, °C
T_{pw}	temperature of the pool water, °C
$Q_{HD,maint}$	heating demand for the pool refill, kW
$\dot{m}_q$	filtered and disinfected seawater mass flow, kg/s
$\dot{m}_e$	evaporated water mass flow, kg/s
β	water transfer coefficient
R_D	specific gas constant for water vapour, J/kgK
T_m	arithmetic mean of water and air temperature, K
$p_{D,W}$	saturation pressure of water vapour at water temperature, Pa
$p_{D,L}$	water vapour pressure of the swimming hall air, in Pa
A_p	reference area/usable water area of the pool, m^2
Q_{vd}	evaporation heat loss, kJ
r	evaporation heat at pool water temperature, kJ/kg
Q_{DW}	heating demand of the domestic hot water, kWh
V_w	amount of spent domestic hot water, m^3
E	electricity demand, kWh
C_E	electricity costs, €
P_E	electricity price, €/kWh
FO	fuel oil demand, kWh
µ	boiler efficiency, %
C_{FO}	fuel oil cost, €
P_E	fuel oil price, €/kWh

I. INTRODUCTION

European Union (EU) is focused on creating European society as a competitive, safe and energy-efficient entity, ready to reach the long-term goal of reducing greenhouse gas emissions. Accordingly, the EU Strategy 2030 was introduced in 2014 with the goal to deliver a strong signal to the market by encouraging private investment in new energy infrastructure and low carbon technologies [1].

Heat pumps can help achieve that goal. They are energy-efficient and environmentally friendly technology for heating, cooling and hot water production. They can use energy stored in the air, ground or water as a heat source or heat sink. When the seasonal performance factor (SPF) is higher than 2.5 they can be considered a renewable energy source [2]. As the SPF does not differ in the case of small and medium heat pumps [3], they achieve the same efficiency no matter what type of building they are installed in. This means that even in buildings like hotels, heat pumps will significantly impact their energy efficiency and environmental impacts [4]. A study shows that hospitals are promising settings for heat pumps because of their year-round and often round-the-clock heating and cooling requirements [5]. An example of such system is NATO Military Hospital in Budapest, where the sewage water is used as a heat source for a heat pump which provides 3.8 MW of heating and 3.3 MW of cooling with the coefficient of performance (COP) 6.5 – 7.1 [6]. Another study recorded that annual cost reduction for integrating a water source heat pump in a hospital with an HVAC (Heating, Ventilation and Air-conditioning) system is $102,564 with a payback of 1.2 years [7]. Even if they are used only for the preparation of the domestic hot water, they will lead to significant energy savings and reduction of greenhouse gas emissions in hotels in the comparison to conventional boilers [8]. In case the building is close to the seawater, the best option is the use of seawater heat pumps since they show superiority in comparison with air heat pumps and conventional solutions [9]. Moreover, simulation results in [10] show that the annual heating performance of a seawater-source heat pump system can be improved by 8% or even more by the series operation.

Heat pumps are recognised as one of the most relevant power-to-X technologies for balancing of the power grids with a high share of renewable energy sources [11]. To be able to plan future energy systems, it is important to understand the behaviour of each technology in the system. Because of that, the operational characteristics of heat pumps are widely studied. Studies mostly focus on operation regulation analysis of heat pumps, and mostly for heating and cooling purposes as well as the preparation of domestic hot water. This paper is an addition to the previous heat pump studies but is focusing the attention on using the heat pump for simultaneous seawater pool heating and domestic hot water preparation in conditions where seawater heat pump does not always have high enough capacity to meet the demand.

In this paper, operating principles, together with the energy savings, operation costs and greenhouse gas emission reduction of a seawater heat pump system will be calculated and analysed. The paper will provide evidence that a heat pump is a good option and by using a storage tank, it can be beneficial even in cases when there is not enough electrical power during the peak demand. The study is made on a real case scenario on a special hospital Thalassotherapy, which will in close future install a high-temperature seawater heat pump with the help of the SEADRION project, and have it monitored to see the real data.

A. Seawater heat pump implementation

In comparison to conventional boilers, seawater heat pumps have lower operational costs, which is one of their biggest advantages. Furthermore, in general, heat pumps have lover CO_2 emissions and could also be CO_2 neutral if electrical energy would be produced from renewable energy sources. This doesn't always have to be the case since CO_2 reductions depend strongly on the CO_2 emissions of the energy sector. Furthermore, heat pumps are a safe technology that has a long lifespan, and in case of the well-designed seawater intake needs minimal maintenance. Another advantage is that they can be used for heating, cooling and domestic hot water preparation. On the other hand, they have high initial costs, the constructions itself is quite complicated and requires special licences, and not all refrigerants are sustainable.

For the implementation of seawater heat pumps, the execution of the seawater intake is one of the most important factors. In case the seawater intake isn't constructed with care, algae and mussels could get in the pipes which could lead to loss of efficiency or could even clog the pipes and stop the operation of the heat pump. There are three different executions of seawater intake: closed loop, open loop with direct intake from the sea and open loop with the intake from the well. Earlier specified problems with the seawater intake are mostly linked to the open loop with direct intake from the sea. Despite its disadvantages, such execution is still being used because it is the easiest and cheapest to implement. To prevent some of the disadvantages, various filters are used while the intake itself is risen from the seabed. The closed loop does not have problems related to the seawater intake itself, but it is a more expensive and complicated execution while cleaning the pipes from the outside still presents a problem. Lately, constructors are giving more and more attention to open loop with the intake from the well. Because of the need to drill a well, that execute requires somewhat bigger investment cost than the open loop with direct intake, but it can help to avoid all the beforementioned problems. Such execution rises the efficiency of the heat pump as well as the stability and reliability of the seawater heat pump, especially in cold areas with risks of the water freezing. A study made on the Liaodong peninsula in China showed that coefficient of performance (COP) of a heat pump with direct seawater intake was 2.99 while the one of the heat pump with the intake from the well was 4.66. The reason behind it were different seawater temperatures which were in the case of direct intake 5.83 °C, and in case of the well 12.85 °C [12].

Another barrier is the legal framework for the implementation of seawater heat pumps. For instance, in the Republic of Croatia, different intake methods acquire different permits. For the direct seawater intake, a concession for the special use of maritime goods is needed. On the other hand, in case a well is being used, one has to follow the Water Law [13].

II. METHODS

The seawater heat pump in Thalassotherapy will be used for pool heating and domestic hot water production. The pool contains seawater and is heated throughout the year on a temperature of 30 °C. Next to the pool, domestic hot water is used in large amounts because of whirlpool baths preparation. Heating demands for both the pool heating and domestic hot water production were calculated and were used to calculate and compare operating costs of the heat pump and light fuel oil, as well as primary energy and CO_2 emissions.

A. Pool heating

The seawater pool has a surface of 86.25 m^2 and a depth of 1.5 m. The temperature of the pool is 30 °C, and so is the temperature of the pool room meaning that there is no transmission heat loss to the indoor air. Once per month the pool is fully refilled during the 10 hours that it is not opened, and the rest of the time the water quality is maintained with 1500 kg/h of filtered and disinfected seawater. Water quality maintenance, as well as the air conditioning system is operating the whole day without stopping. Monthly heating demand of the pool consists of the pool refill, water quality maintenance, evaporated water and the evaporation heat loss.

Heating demand for a pool refill that is done once per month was calculated using (1), water maintenance, which is partly water quality maintenance and partly evaporation refill was calculated using (2). In accordance with VDI 2089 evaporated water was calculated using (3), and evaporation heat loss by using (4).

$$Q_{HD,refil} = m \cdot c_w \cdot (T_{sw} - T_{pw}) \tag{1}$$

$$Q_{HD,maint} = (\dot{m}_q + \dot{m}_e) \cdot c_w \cdot (T_{sw} - T_{pw}) \tag{2}$$

$$\dot{m}_e = \left(\frac{\beta}{R_d \cdot T_m}\right) \cdot (p_{D,w} - p_{D,L}) \cdot A_p \tag{3}$$

$$Q_{vd} = \dot{m}_e \cdot r \tag{4}$$

B. Domestic hot water production

At the moment, for heating and domestic hot water production, two fuel oil boilers are used that serve the whole complex. The main boiler has the capacity of 1400 kW. Besides the main boiler, there is also a supplementary boiler with the capacity of 1279 kW, which is only turned on in case of need. The boilers heat the water to a temperature of 74 °C. Later, the water is stored in storage tanks within each building. The temperature of the domestic hot water in the storage tank of the pool building is mostly around 66 °C.

To determine the heating demand of the domestic hot water, monthly data collected by the measuring equipment was used. Measuring equipment reported the amount of monthly spent hot water, and yearly energy spent on preparing the domestic hot water. The amount of spent domestic hot water can be seen in table 1, while yearly energy spent on preparing the domestic hot water amounts to 188,995.8 kWh.

TABLE I. MONTHLY SPENT DOMESTIC HOT WATER

Month	Domestic hot water, m^3
January	148,4
February	123,4
March	160,2
April	104,3
May	120,1
June	98,3
July	47,3
August	78,8
September	115,8
October	102,7
November	128,1
December	88,4
Year	1315,8

It can be assumed that the water is supplied at the same temperature throughout the whole year. With that assumption, it is possible to calculate monthly energy spent on the domestic hot water production using the (5).

$$Q_{DHW} = \frac{\sum Q_{DHW}}{\sum V_w} \cdot V_w \quad (5)$$

C. Seawater heat pump

The capacity of the installed seawater heat pump is 50 kW due to the high price of high-temperature heat pumps. This means that the heat pump won't be able to meet the heating demand for the whole year. During the colder months, the fuel oil boiler will need to meet part of the demand. The difference in the total heating demand and the heating demand met by the heat pump was calculated and analysed.

D. Techno-economic analysis

In the techno-economic analysis, efficiencies and operating costs of the heat pump and fuel oil boiler were compared. High-temperature heat pumps have lower seasonal performance factors (SPF) than the low-temperature heat pumps, which is why ideally the SPF of the heat pump will be 2.5, for the heat pump to be considered a renewable energy source. That SPF could also be achieved because the heat pump will be working the whole year in the heating mode, and it is expected that the coefficients of performance (COP) will be higher during the summer when the seawater temperature will be higher, as can be seen in Figure 1 [14].

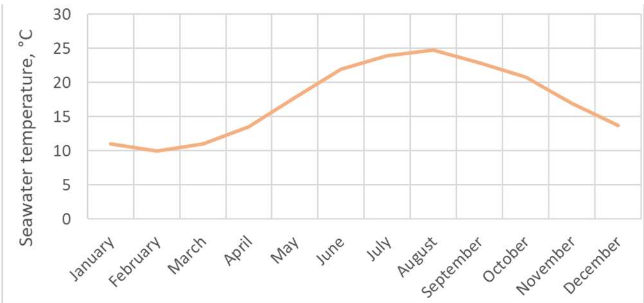

Fig. 1. Seawater temperature [14]

The electricity price is 0.13 €/kWh. Electrical energy spent by the heat pump is calculated using (6), while the cost of electrical energy spent by the heat pump is calculated using (7).

$$E = \frac{Q_{DT}}{SPF} \quad (6)$$

$$C_E = E \cdot P_E \quad (7)$$

The fuel oil boiler had initially higher efficiency due to the utilisation of condensing technology but was installed in 2005. It is assumed that current efficiency is not higher than 85%. The fuel oil price is 0.06 €/kWh [15]. Needed fuel oil is calculated using (8), while the cost of fuel oil spent by the boiler is calculated using (9).

$$FO = \frac{Q_{DT}}{\mu} \quad (8)$$

$$C_{FO} = FO \cdot P_{FO} \quad (9)$$

E. Primary energy and CO_2 emissions

For calculating primary energy and CO_2 emissions primary energy factors and CO_2 emissions factors for Croatia were used [16] as presented in table 2.

TABLE II. PRIMARY ENERGY AND CO_2 EMISSION FACTOR

	Primary energy factor	CO_2 emissions factor [kg CO_2/kWh]
Electricity	1,614	0,235
Fuel oil	1,132	0,3

F. Electric power

During the daytime, the hospital is using the maximum electric power of 240 kW, as can be seen in Figure 2. To shift the consumption from the peak load, a 1.5 m^3 storage tank will be installed. The energy stored in the storage tank will be used to meet the needs during the peak load, and the energy will be stored during the nighttime. Since the hospital has universal electricity price, this will not result with additional economic benefits and was thus not added in the analysis. Nevertheless, without the additional storage tank, it would not be possible for the heat pump to meet the heating demand during the peak load. Moreover, once the heat pump is installed, this data will be useful to monitor for the analysis of heat pump demand response behaviour.

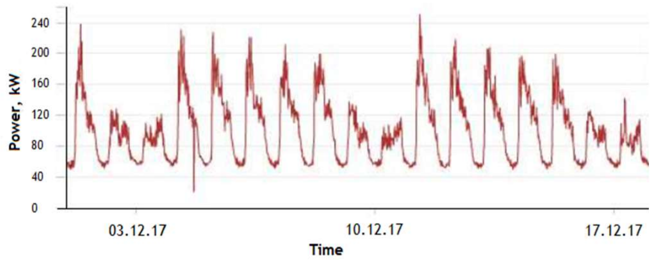

Fig. 2. Electric power consumption

III. RESULTS

Highest heating demand was the one for maintaining the pool water quality with fresh filtered and disinfected seawater as seen in Figure 3. The demand falls during the summer days because of the higher temperature of the seawater. Domestic hot water heating demand varies from month to month, depending on the occupants of the hospital, while evaporation remains the same from month to month. The energy needed for the full refill of the pool represents the lowest heating demand, but it is the time when the most heating power needs to be provided because of the fact that a big amount of water needs to be heated in a short period. The difference in the actual heating demand and the heating demand that was met by the heat pump is shown in Figure 4. It can be seen that the heat pump is able to meet the heating demands during most of the year, besides of the coldest winter months when the seawater temperature is the lowest.

Thanks to the higher efficiency of the seawater heat pump, heat pump consumes much less electrical energy than the boiler does fuel oil, as seen in Figure 5. This leads to smaller costs, although per kWh electricity is more expensive than fuel oil, as seen in Figure 6. This also leads to primary energy savings and CO_2 emissions reduction, as seen in figures 7 and 8 although primary energy factor is higher for electricity than for fuel oil. To be precise, using the seawater heat pump will lead to 25% lower costs, 52% primary energy savings and 63% of CO_2 emission reduction in comparison to fuel oil boiler.

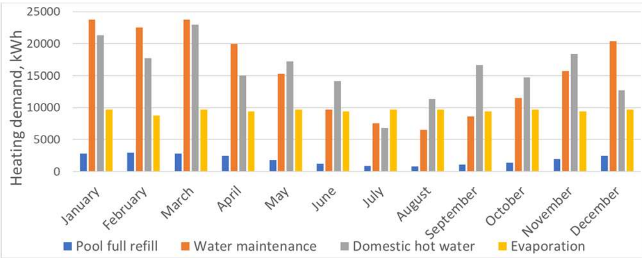

Fig. 3. Heating demand

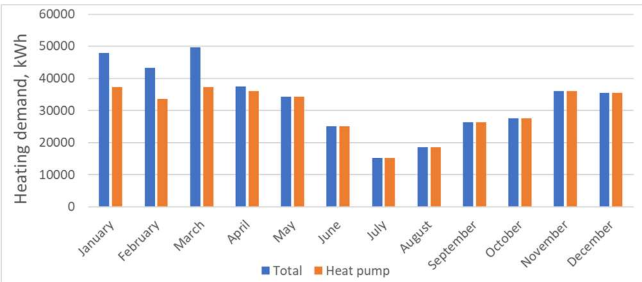

Fig. 4. Total heating demand and heating demand met by the heat pump

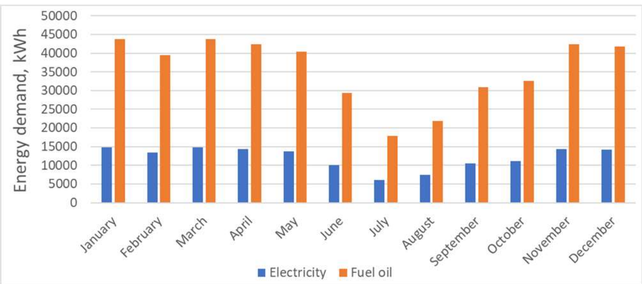

Fig. 5. Energy demand

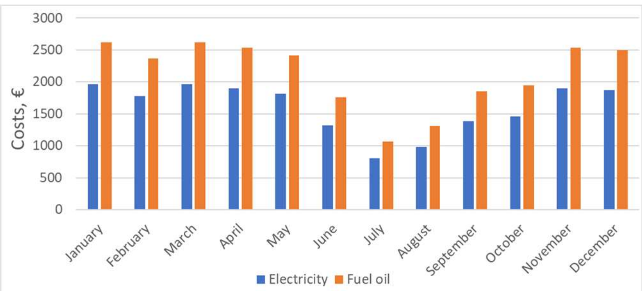

Fig. 6. Costs

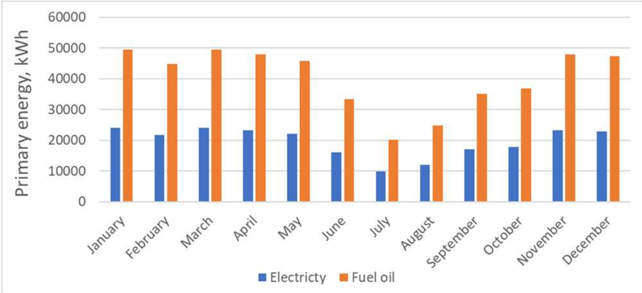

Fig. 7. Primary energy

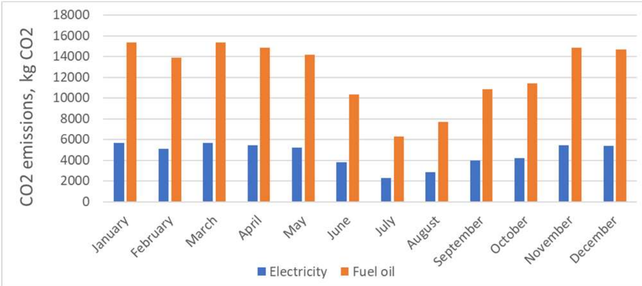

Fig. 8. CO_2 emissions

IV. CONCLUSION AND FURTHER WORK

This paper compared the use of fuel oil boiler and seawater heat pump for heating of the pool and domestic hot water production in a special hospital. Results showed that the highest heating is caused by constant water quality maintenance with 1500 kg/h of filtered and disinfected seawater. Moreover, due to limited capacity, the heat pump was not able to meet the heating demand on its own during the whole year. Nevertheless, using the seawater heat pump will lead to 25% lower costs, 52% primary energy savings and 63% of CO_2 emission reduction in comparison to the fuel oil boiler. In the future work, after the seawater heat pump will be installed, measurements will be collected, and a comparison with this analysis will be made.

V. ACKNOWLEDGEMENTS

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