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Preliminary Results of a Closed-Loop Sea Water Heat Pump: Application in Large-Scale Elderly Home Center for Heating and Cooling Load Coverage

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Abstract

As the plan for the building's sector energy transition proceeds, solutions of technology that exploit the primary resources available in each geographic location need to be advanced. In coastal regions, configurations such as heat pumps, which use nearby water as a heat sink to produce the necessary heating and cooling energy for the built environment, are widely used. Increasing research attention is given to these systems' integration, design, installation, and optimization. The main reason for this attention is the nearly stable water temperatures throughout the year, which occurs in certain depths in lakes and seas. The present study aims at designing such a system using a case study in Alexandroupoli, Greece. Key remarks for the design process are provided, especially in the proposed closed-loop seawater heat pump (CL-SWHP) configuration, while a novel approach toward dimensioning optimization for the system is introduced. The simulation is conducted during winter and summer scenarios to investigate the systems' load coverage capabilities. The results indicate that the system reached the setpoint temperatures for the heating and cooling scenarios and produced the necessary thermal energy for the load of the case study. The techno-economic approach concluded that the proposed system is more viable than the conventional system, as its Levelized Cost of Energy (LCoE) and operational costs were significantly cheaper. Its LCoE was 0.18 €/kWh, while the conventional system's 0.37 €/kWh. Further investigation is required for hybrid scenarios of the proposed system, where photovoltaic panels (PVs) will provide the necessary electrical energy to reduce the energy cost further.

Keywords: sea water heat pump, closed loop heat exchanger, surface waters, elderly facility, technoeconomic assessment

1. Introduction

The building sector is a significant energy consumer, with demands exceeding 35% [1]. The thermal and cooling energy demands are the main actors of that consumption, with a 75% share, while electricity accounts only for 25% [2]. So, in order to decarbonize the building sector as much as possible, it is essential to tackle the production, management, distribution, and consumption of heating and cooling energy. Some of the most widely used energy production assets are heat pumps, which exploit low-to-medium enthalpy fluids (water or air), to provide sustainable and cooling energy. They are widely applicable in buildings' heating systems, and the research focuses mainly on water-source heat pump (WSHP) applications. In that respect, alternative heat sinks are tested, the most prominent being the seawater application.

Figure 1 and Table I present the most prominent literature on surface water heat pump applications. Buyukalaca et al. were among the first to investigate the usage of lake water as a heat sink versus ambient air; for heat pump application. The authors' results suggested that the system's performance using lake-water as a heat sink outperformed the ambient air solution during heating and cooling seasons. There were no economic evaluation results in the study [3]. Chen et al., on the other hand, tested an open-loop lake-water heat pump for the coverage of heating and cooling needs and provided useful techno-economic features in their results. The system's performance was considered satisfactory, with a coefficient of performance (COP) for heating and cooling seasons significantly higher than air-sourced heat pumps. The authors' results included the system's environmental footprint, which was classified as acceptable, while the economic indicators, such as the payback period and return of investment (ROI), were fetching [4].

One of the most influential reviews on the topic of Sea Water Heat Pump (SWHP) was made by Mitchell et al. In the 2013 study investigated key design remarks such as distance from shore, pipe material/length, pump configuration and chiller design. The review's conclusions highlighted the absence of design directions for such systems despite their performance status. Design suggestions to the remarks mentioned above were given, but the need for further study and investigation of more case studies was highlighted [5].

Splitler et al., in the novel study on open-loop SWHP applications, investigated all the design parameters deeply. The application proposed in this novel study suggested that SWHP are appropriate solutions to large-scale building sector applications and district heating and cooling system designs [6]. Zou et al., however, focused on developing a model for accurately calculating the energy consumption of such equipment, which directly affects its economic feasibility. The study's findings indicated that energy consumption varied depending on water and ambient air

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temperature fluctuations both in winter and summer. The authors suggested replicating their method in more case studies, especially large-scale building applications [7]. Gaudard et al. tested the hypothesis of WHP applications in Switzerland. The study's results indicated that such systems provide a suitable and renewable solution for heating and cooling demand coverage while not significantly affecting surface water temperatures [8].

Table 1. The most highly cited research works on open and closed-loop surface water heat pumps.

Author	Year
Buyukalaca et al.	2003
Chen et al.	2006
Andritsos et al.	2011
Mitchell et al.	2013
Buhler et al.	2015
Splitler et al.	2016
Lund et al.	2016
Zou et al.	2017
Gaudard et al.	2019
Wang et al.	2019
Wu et al.	2020

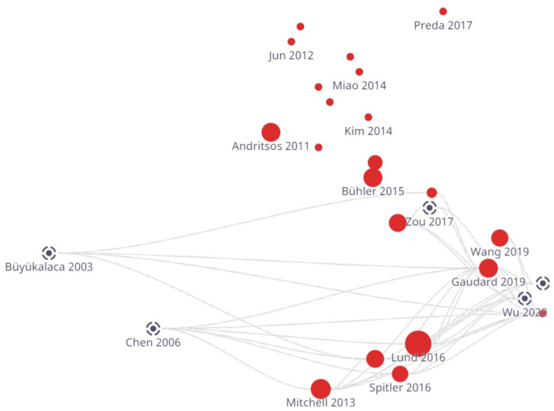

Fig. 1. Literature mapping of the most cited authors in the subject of SWHP (from the oldest to the most recent -x axis) (Table 1).

When comparing the air heat pumps and the SWHPs, studies suggest that the latter systems are more efficient and economically viable. Such a study was by Zheng W. et al., who even examined degradation phenomena in these systems, such as ice formation on the heat exchanger tubes. Their results suggest that the performance of these systems increases according to the sea water's temperature increase and that their performance coefficients are higher when compared to the air heat pumps' [9].

While such systems are employed to cover heating and cooling loads, a research debate is dedicated to their substitution by other renewable sources, such as solar power. Such is the work of Arabkoohsar A. et al., who investigated a solar-powered absorption chiller's economic and technical viability for large applications. Their results indicated that the system's performance returned revenue with a rate of over 5% for the first eight years of operation, describing it as viable. However, as stated by the authors, absorption chillers are affected by the fluctuating input temperatures of solar systems. A more stable thermal energy production system, such as a heat pump, might increase the system's overall performance [10]. In the following paper, the same authoring team investigated a multiple thermal energy input scenario, where a heat pump was included to ensure the stable output of thermal energy despite the intermittent nature of solar power [11].

The existing literature suggests that HPs, especially SWHP, are a promising field of study, not only because of their technological and economic feasibility but also because of their low environmental impact and renewable energy-based behavior. The works of Andritsos et al. differed from the areas mentioned above and focused more on another significant design aspect of SWHPs: mapping the low-enthalpy geothermal potential of the Greek territory. Buhler et al. and Lund et al. built upon the previous work and mapped Denmark's geothermal potential [13, 14]. The study's results implicated the undeveloped exploitation of geothermal energy in Greece, unlike the significant geothermal potential [12].

However, most research attempts focus exclusively on the configuration of the heat pump and the coverage of the load and not on matters of coil configuration, environmental impact, and economic feasibility, especially in Greece. Additionally, no significant attention is given to the dimensioning of such a system to comply with the demands of the respective case. The authors intend to evaluate the many technical aspects of SWHP, which according to [5–7], remain primarily unaddressed by designing a closed loop sea water heat exchanger to cover the heating and cooling needs of a case study in Alexandroupoli, Greece. Such a system will be presented, and its techno-economic feasibility will be addressed. They will also present a novel methodology for optimizing the dimensioning of several key elements of the proposed system, such as the circulating pumps of the sea heat exchanger, which to the authors' best knowledge, has not been approached in the literature.

2. Materials and Methods

In this section, the design methodology followed will be presented. The authors approached the system's design by exploring three well-established softwares, Sketch-Up, TRNSYS 18, and Matlab Simulink. The approach aimed to design the building's envelope and thermal zones in the Sketch-Up environment (Figures 2 and 3), then insert the model into TRNSYS's built-in building design outreach and perform the heating and cooling load analysis. The output data were then used in Matlab Simulink as heating and cooling loads to be met by the designed SWHP. By using a genetic algorithm, the aim is to dimension the proposed system's main pumps to produce the necessary energy to cover the load and be economically viable. Lastly, a MILP optimization was implemented for the optimal flow configuration between the sea water pump, the heat pump's working fluid circulation, and the building's pump.

Some of the most important design parameters for SWHPs are the choice of the placement location and the temperature characteristics that define the area (water temperature/simulation of the surface waters). Additionally, the depth of the tubes, the configuration and geometry of placement (e.g., spiral configuration, U-tube configuration, or other), the material of the pipes as well as the metallurgical procedure to ensure corrosion resistant operation. Regarding the depth of the placement, the choices are either the epilimnion (the surface where high-temperature profiles and a high degree of mixing are observed) or the thermocline region (the stratified layer under the epilimnion which also presents high temperatures and density gradients).

Applications, where open-loop configurations were chosen, are commonly inflicted by intermittent operation and high maintenance costs and may cause significant environmental issues to the ecosystem of the depths. Their costly installation and operation depend on the materials selected for the heat exchanger (most commonly titanium plates), the dimensioning of the filter before the heat exchanger (to ensure that algae and other biological organisms will not interfere with the hydraulic system and the pump's operation) and the maintenance of the piping, the circulation pump and the heat exchanger for corrosion resistance. Liu

Y. et al. focused more on the engineering design and installation variations depending on the tube diameter for SWHP systems. The results of their study indicated that the sea coil's tubes should not be greater than the DN600 pipe due to the heat losses and flow issues that may arise. Their study also suggested a vertical configuration for the sea coil to optimize the heat exchange according to the sea's different temperature gradients [15].

Thus, the research team selected a vertical, closed-loop configuration for their case study application. The essential design characteristics for such systems, according to [3, 6, 16] i) the heat exchangers depth configuration (partially buried solutions provide certain stability to the heat convection process), ii) the material selection for the pipework (typically used SDR11-HDPE, DN600), iii) a shell and tube heat exchanger, and iv) a back-up heating system to ensure that ice is not formed in the system.

A. Case Study Description

For a test case, an elderly facility home was chosen in Alexandroupoli, Greece. The selected building has a heated area of approximately 1700 m^2, including two floors and a basement. Although the construction of the building finished in 2016, it does not comply with Greece's latest national regulations for energy performance (KENAK) since the building permit was issued before KENAK was in force (2010). The construction is considered typical among other similarly sized buildings located in Greece and constructed between 1990 and 2010. The buildings' envelope includes thermally insulated walls with an average thermal coefficient of 0.8 W/m2K and double-glazed aluminum windows with an average value of 3.8 W/m2K. It has a flat roof has been thermally insulated to achieve a thermal coefficient of approximately 0.4 W/m^2K. The rooms for the elderly are on the first and second floor, having a south orientation.

Currently, the building is heated with a heating-oil boiler of 450 kW, which is connected to fan coil units (FCUs) through an extensive distribution network of insulated steel pipes. The cooling of the building is performed using a chiller of 350kW, which is connected to the same distribution network (2-pipe system). In addition to the FCUs, air handling units are connected to the same network delivering heat/cooling to specific building areas. The heating/cooling system is controlled by a building management system (BMS). The facilities' load fluctuation for a typical year, as evaluated using TRNSYS 18, is shown in Table 2.

For the implementation of the building on Sketch-Up, the orientation, and the building's openings were considered. The building was then separated into two adjacent thermal zones, the main areas and the basement. The research team made several attempts to configure more thermal zones, such as separating the main areas' northern and southern orientations. However, that significantly increased the computational intensity of the simulation, while the results were not entirely different (approx. 3%).

Table 2. Yearly heating and cooling loads for the elderly facility home of alexandroupoli, Greece.

Month	$Q_{h, mains}$ (kW)	$Q_{c,mains}$ (kW)
Jan.	167.5	0
Feb.	171.98	0
Mar.	108.51	0
Apr.	72.79	19.78
May	41.18	45.08
Jun	0	63.17
Jul.	0	65.05
Aug.	0	64.18
Sep.	0	48.04
Oct.	32.53	5.52
Nov.	72.09	0
Dec.	89.55	0

After the building's geometry setup, the model has imported to TRNSYS 18 Simulation Studio. Because of the software's dynamic-link library (DLL) architecture, it is possible to communicate information between similar software architectures, such as Sketch-Up and Matlab. In TRNSYS 18, some TRNSYS components are used to simulate the building's heating and cooling loads for a whole year. These are Type 15.6 (Weather), Type 56 (the Building Plug-in), and Type 15b (Online Plotter). For Type 15.6, the weather data were extracted from JRC Photovoltaic Geographical Information System [17]. This TRNSYS weather component uses typical meteorological year data (TMY) and the used data are: Date and time, Global horizontal irradiance, Direct normal irradiance, Diffuse horizontal irradiance, Air pressure, Dry bulb temperature, Wind speed, Wind direction (degrees clockwise from north), Relative humidity, and Long-wave downwelling infrared radiation.

Table 3. Thermal zone characteristics of the elderly facility home of alexandroupoli, greece (figure 3).

Zone	Area (m^2)	Volume (m^3)
Mains	1,689.2	5,336.8
Basement	1,525.58	9,763.71
Total	3,214.78	15,100.51

B. System configuration

The system's design is segregated into three main actors. The first is the closed-loop seawater heat exchanger (CL-SWHX) (Figure 4), while the second is the heat pump's typical layout (condenser, compressor, evaporator, and expansion valve). The third actor is the building's loads, as evaluated by TRNSYS 18. The CL-SWHX actor includes a sea coil where the heat convection takes place, a filter to prevent debris flow, a solenoid (electromagnetic) valve controlled by a Wheatstone bridge, and a diffuser to regulate the pressure at the intake nozzle of the suction side. Also, a screw pump for low noise operation and prevention of pulsatile flow, and a shell and tube heat exchanger to transfer the heat from the working medium of the sea coil to the refrigerant of the heat pump and is placed approximately 100m from shore.

The volume of the heat exchange area of the sea coil was assumed to be 50 m^3. The coil is fully submerged in water, and there is no ground contact. As a filter, a stainless steel choice was made for 200 microns size of debris. For the Wheatstone bridge, a 1 kOhm thermistor was considered for a reference temperature of 288.15 K. The screw pump's nominal head was considered 12 m, and the maximum capacity at zero head at 19.28 m^3/hr. Regarding the shell and tube heat exchanger, 240 shell passes were selected for relatively small geometry and maximal thermal conductance Figure 4.

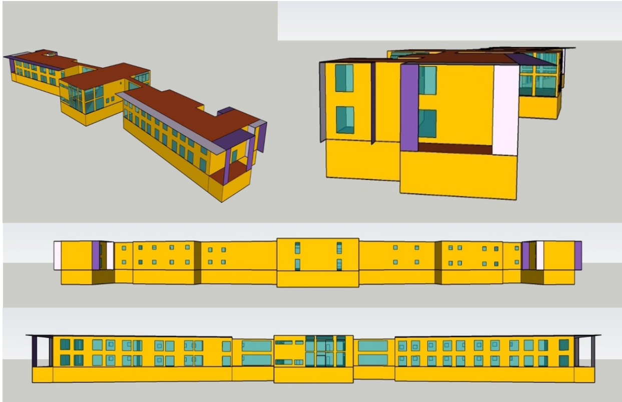

Fig. 2. Elderly home center of Alexandroupoli as developed in Sketch-Up software.

The evaporator's layout was considered a counter-flow heat exchanger for the heat pump configuration, while the refrigerant of choice is R245-Fa. The compressor's nominal speed is 10,000 rpm with a compression ratio of 26. As far as the condenser is concerned, a cross-flow configuration was considered with both fluids unmixed. In this case, one side is the heat pump's refrigerant, while the other is the circulating air from the fan coil system of the case study.

The rotation of the compressor is done by using a single-phase induction motor of 180 kW_e, which utilizes a Pulse Width Modulator (PWM), an H-bridge with an external power source, and an operation capacitor of 85 μF.

C. Multi-Integer Linear Programming (MILP)

MILP optimization techniques are used frequently in thermal energy systems' configuration, such as in [18, 19]. In order to dimension the circulation pumps' nominal capacity, head and flow, a MILP optimization algorithm was developed. The constructed problem aims to optimize the seasonal performance factor (SPF) of the designed system, minimize the cost of electrical energy required, and optimize the load coverage both for the cooling and heating situation.

1) Assumptions: As the worst-case load is the heating load, the proposed system's dimensioning has to cover the full load. According to Table II, the worst-case scenario is during February with 171.98 kW_{th}. In order to meet that load, the system has to extract a certain amount of heat from the seawater heat exchanger, exploit it in the heat pump according to its operational characteristics, and then deliver the desired amount to the building. A 15-20% loss is considered for the three separate heat exchange stages (seawater heat exchanger performance losses, seawater pump energy losses, heat pump losses, and pipework to and from the building losses).

The variables which need to be considered when optimizing a heat pump are the fan's power, the working fluid's flow rate, the air's temperature to and from the building, the pump's nominal capacity, which operates the working fluid, the seawater pump's nominal capacity (source), and the pump's nominal capacity, which transfers the hot/cold air to and from the building. According to the National Legislation on surface waters, and exploitation, the desired temperature difference between the intake and return loop should not exceed 8 ^oC. This significant environmental parameter is set due to its effect on the depth's ecosystem balance. So, assuming a maximum temperature difference of 7 *o*C meets the worst-case load without over-dimensioning the seawater pump. A 5 ºC temperature difference on average for the heat pump is considered, as mentioned in [3–5, 7]. As far as the building's circulation pump is concerned, a maximum of 6 ^oC was considered.

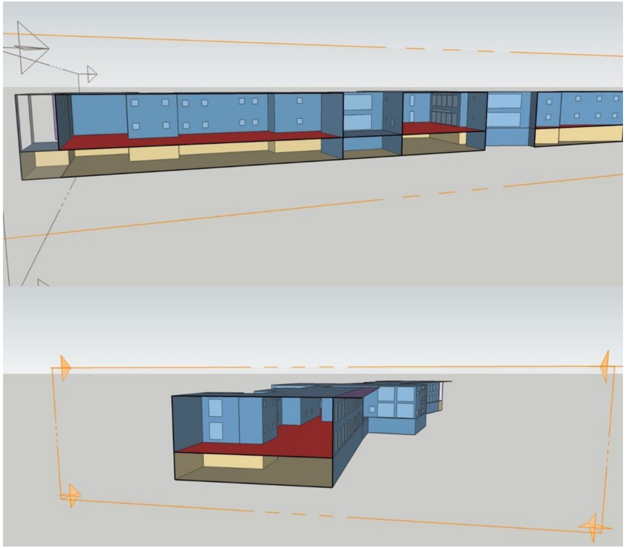

Fig. 3. Distinct thermal zones, main areas and basement, for the case study in Sketch-Up software.

To approach the problem's variables, the heat transfer equations were considered:

$$Q_{sw,p} = \dot{m}_{sw,p} \times c_{p,sea} \times \Delta T_{sw} \times 27 \times 10^{-5}$$
$$Q_{hp} = \dot{m}_{hp} \times c_{p,r245-fa} \times \Delta T_{hp} \times 27 \times 10^{-5}\ (kWh) \quad (1)$$
$$Q_{build} = \dot{m}_{build,p} \times c_{p,air} \times \Delta T_{build} \times 27 \times 10^{-5}$$

Where $Q_{sw,}$ is the energy delivered (or extracted) from the sea, $m_{sw,p}$ is the volumetric flow rate of the seawater via the seawater pump (m3/hr), ΔT_{sw} is the temperature difference (K) between the intake and return loop of the sea coil. The Q_{hp} is the energy delivered (or extracted) by the heat pump, m_{hp} is the volumetric flow rate of the heat pump's circulation (m3/hr), $\Delta T_{hp}$is the temperature difference (K) between the intake and return loop of the heat pump. The $Q_{build}$is the energy delivered (or extracted) by the system, $m_{build,p}$ is the volumetric flow rate of the hot/cold air supplied to the building through the FCUs (m^3/hr), and $\Delta T_{build}$is the temperature difference (K) between intake and return loop of the air handling units.

The nominal capacity of a centrifugal pump is given by Equation (2).

$$W = \frac{\dot{m} \times H \times \rho}{367 \times \eta} \quad (2)$$

Where m˙ is the volumetric flow rate, H is the nominal head of the pump, ρ is the density of the fluid, η is the pump's efficiency.

The problem consists of 3 objective functions: the SPF, the Cost, and the Load coverage.

$$SPF = \frac{Q_{hp} + Q_{back-up\ system}}{W_{hp} + W_{sw,p} + W_{build,p}} \quad (3)$$

Where $Q_{hp}$is the thermal energy produced (or extracted) by the heat pump, $Q_{back-up}$ system is the energy delivered (or extracted) by the back-up units if needed, W_{hp} is the nominal capacity of the heat pump's circulation pump, $W_{sw,p}$ is the nominal capacity of the sea water's pump, $W_{build,p}$ is the nominal capacity of the building's pump.

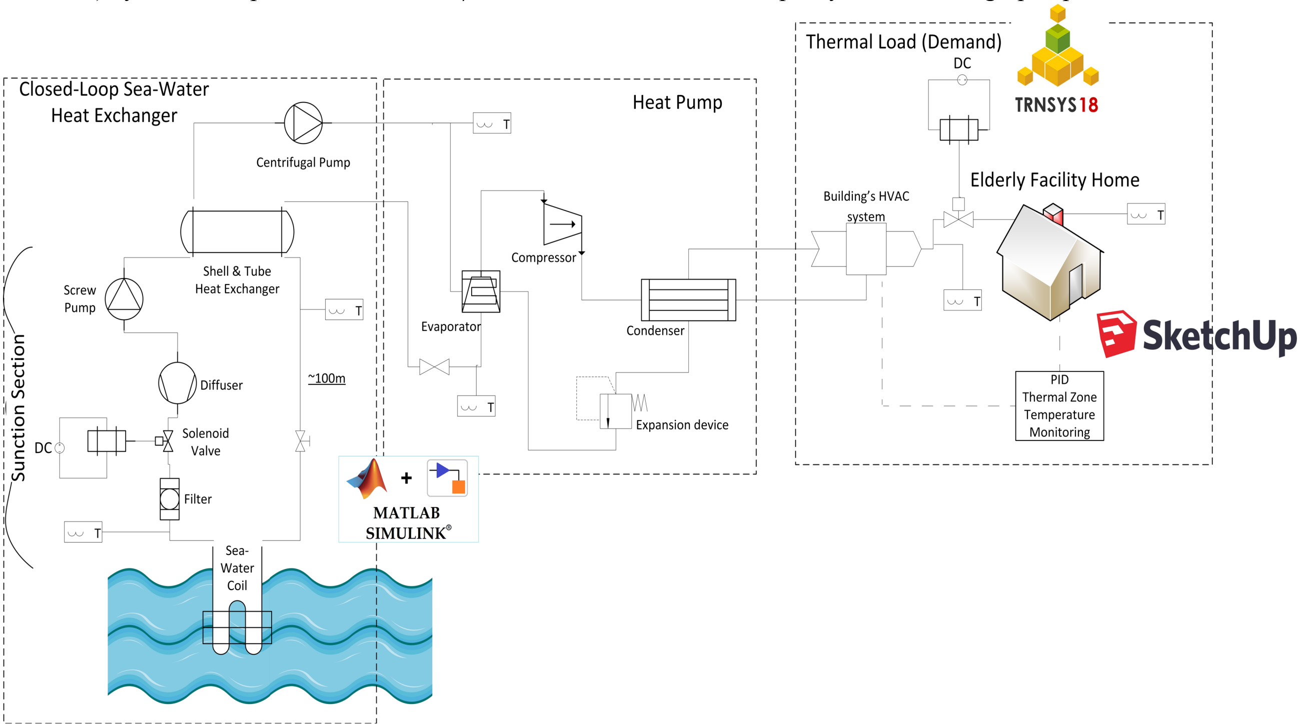

Fig. 4. Design methodology for the closed-loop sea water heat exchanger, heat pump, and heating/cooling load.

For the Cost:

$$C_{seasonal} = \left(W_{hp} + W_{sw,p} + W_{build,p}\right) \times t \times T \qquad (4)$$

Where t is the tariff of electrical energy consumed (€/kWh$_e$), and T is the time of operation of the system in the season (hours).

For the Load coverage (LC):

$$LC = \frac{Q_{build,p}}{Q_{load}} \times T \qquad (5)$$

Where $Q_{load}$is the heating or cooling load demand. The objective function, as described in Equations (3), (4) and (5) is:

$$\max(SPF, L.C)^T, 1260 \leq T \leq 1890$$
$$min(C)^T, 1260 \leq T \leq 1890 \qquad (6)$$

The genetic algorithm developed for the case aims to dimension the proposed system's circulation pumps according to SPF and LC optimization while minimizing operational costs. Figure 5 represents the 200 points of the Pareto front population, which are near-optimal solutions for the problem [20]. The authors further implemented TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) to configure the optimal solution. To implement TOPSIS, weights are needed to scale the solutions from best fit to worst. The operability and economic viability are the most important criteria for the research team, so the weights favored the SPF and Cost (80% combined), while the LC was at 20%.

The optimal solution according to the assumptions mentioned above is: for the circulation pump of the sea coil, the pump's flow is set at 19.28 m3/hr (nominal capacity 0.76 kW); for the heat pump's circulation, the flow is set at 0.2 m3/hr (nominal capacity 0.20 kW), and for the building's pump the flow is set at 17.3 m3/hr (nominal capacity 0.56 kW). By setting the flow rates at these values, the SPF is 93.5%, and the seasonal cost is 68,163.18 € (with a tariff of 0.46 €/kWh$_e$, as it was in March 2022).

3. Results and Discussion

The system's operation was simulated for the heating and cooling seasons, from December until February and June to August. The worst-case heating scenario (January) where the ambient temperature in Alexandroupoli reaches is -9 ^{o}C, while the worst-case cooling scenario is in July when the ambient is 36 ^{o}C. During those representative days, the heating load power was 172 kWth, while the respective cooling load was 65 kW$_c$. These worst-case scenarios are used to dimension the system, as any energy production system must cover the loads occurring on those days. Typically, a safety factor (between 10%-20%) is added to the dimensioning to cover possible district system losses and the inertia of the starting phase of the energy production system.

Figure 6 presents the mains' temperature fluctuation for the December, January, and February heating scenario. The thermostat's setpoint was set to 22 ^{o}C, and the proposed system was able to reach and maintain it for the whole heating season.

As seen in Figure 7, the proposed system covered the heating load. The system produced 554.82 MWhth during the heating period while it consumed 158.52 MWhe. In some circumstances, the thermal energy produced surpassed heating demand by 20%, which was expected due to lack of a compensation system in the simulation. The compensation system regulates the output temperature of an energy production system according to the heating demand and the ambient temperature to minimize the full-load operation of the production system. Thus, without a compensation system, the proposed SWHP sometimes operates in the full-load stage, while a part-load might be more appropriate.

Figure 8 presents the main areas' temperature fluctuation for the cooling scenario: June, July, and August. The thermostat's setpoint was 23 °C, and the proposed SWHP system adequately addressed the cooling needs.

Figure 9 presents the cooling load fluctuation and the cooling energy production for the summer months. For the cooling scenario, the system produced 194.68 MWhc and consumed 55.62 MWhe. The system responded to the cooling demand while presenting the regulation issues of the heating scenario. A compensation system should also be employed in the cooling case to regulate the output system's temperature according to the ambient conditions.

One significant metric of energy production systems is the COP. The COP is defined as the energy produced by the system compared to the energy consumed by the system (Equation (7)).

$$COP = \frac{Q_{prod}}{Q_{cons}} \tag{7}$$

where Q_{prod} is the thermal energy produced by the proposed SWHP system, and $Q_{cons}$is the electrical energy consumed.

For both scenarios, the system delivered the required thermal energy and the mean Coefficient of Performance (COP) was 2.34 for the heating case, while for the cooling 2.7. Regarding the Combined Energy Efficiency Ratio (CEER), the heating case was 5.4 and the cooling 5.62. The current draw for the operation of the heating scenario (which is the most significant load for the proposed system's operation) did not exceed 65 A, which is well within the operating characteristics of commercial 180 kW$_{th}$ heat pumps.

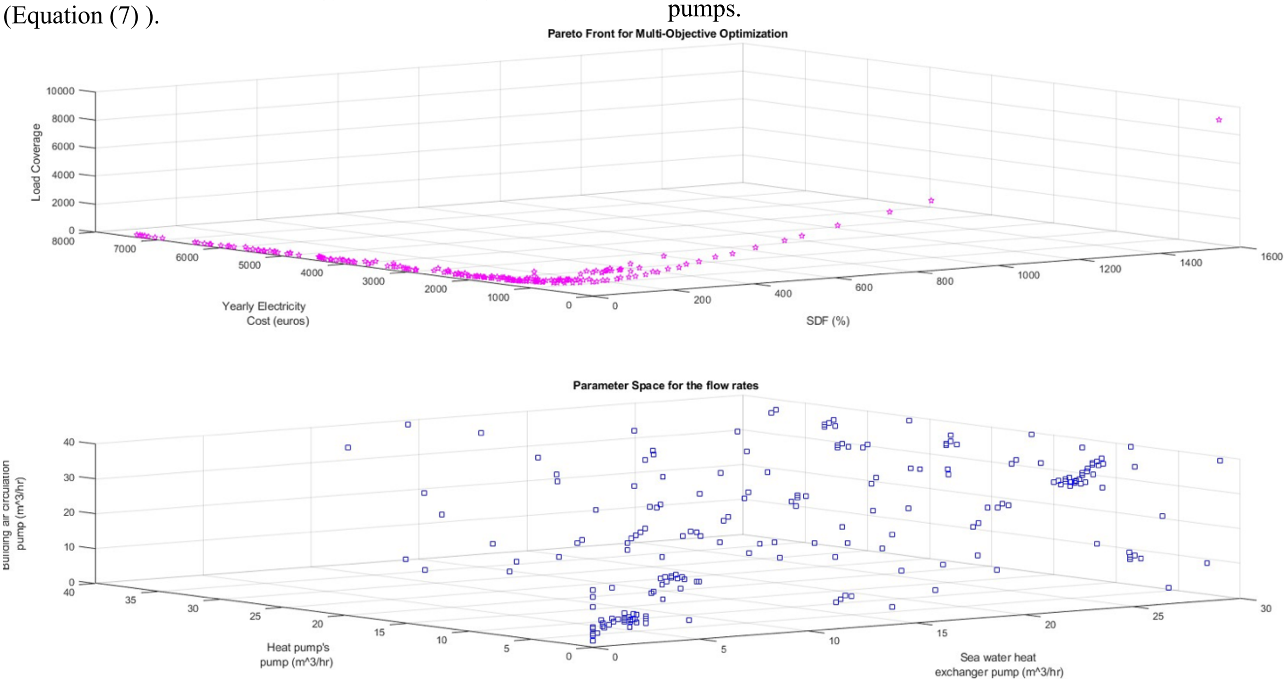

Fig. 5. Pareto frontier for the near-optimal solutions of the MILP developed.

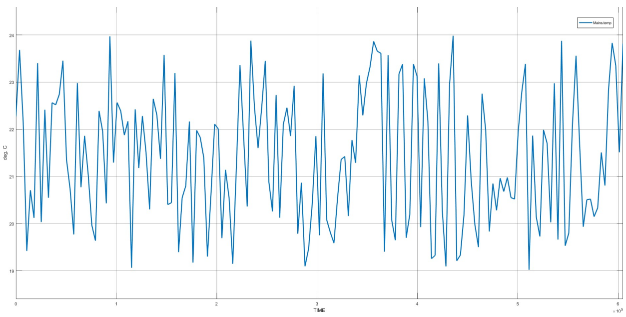

Fig. 6. Indoor temperature of the main areas for the heating scenario for the months December, January, and February.

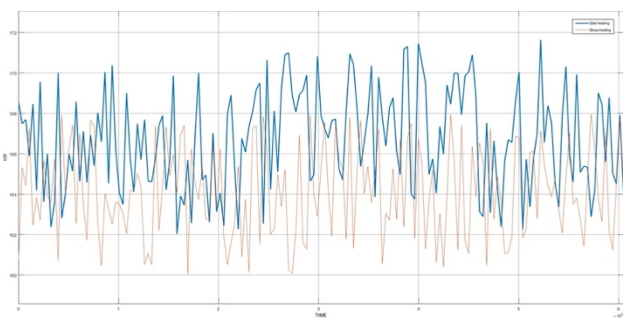

Fig. 7. Heating load and thermal energy delivered by the proposed SWHP system for the months December, January, and February.

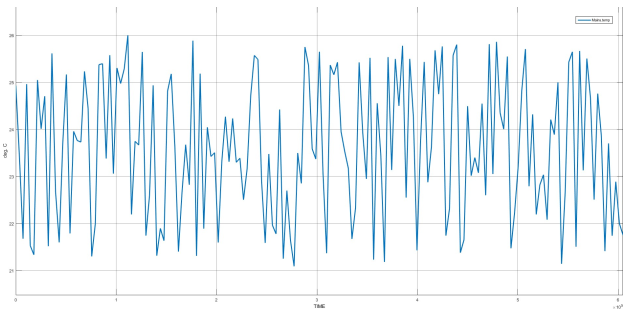

Fig. 8. Indoor temperature of the main areas for the cooling scenario for the months June, July, and August.

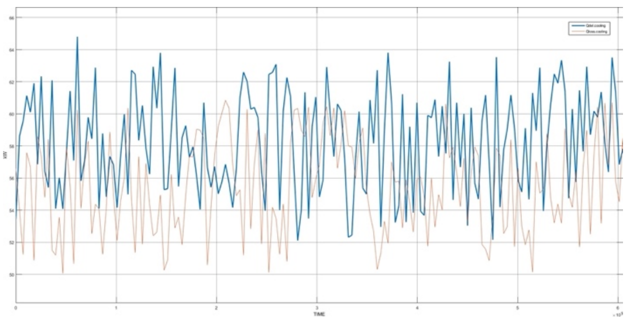

Fig. 9. Cooling load and cooling energy delivered by the proposed SWHP system for the months June, July, and August.

4. Techno-Economic Evaluation

The case study has an installed energy production system that consists of an oil boiler (450 kW_{th}) and a central cooling unit (350 kW_c), as described in Section 2.1. As Table IV shows, the existing system's total costs are significantly higher than those of the proposed system. Their yearly thermal energy production (heating and cooling energy combined) difference is marginal, while the primary energy consumed for the respective systems is significant. As for the capital expenditures, the oil boilers and the central cooling units are well-established technologies with many applications and significant market shares. The sea coils and the heat exchangers using seawater mediums are applied only in small-scale scenarios worldwide, with a low market share. Thus, their costs significantly differ, as observed by their Capital Expenditure values (Table IV). However, the fluctuating oil prices of 2021 and 2022 increased the conventional systems' operational costs [2].

Table 4. Techno economic comparison between the conventional and the proposed system for the case study of Alexandroupoli, Greece.

	Conventional System	Proposed SWHP system
Total yearly produced thermal energy	751 MWh	749.5 MWh
Total yearly consumed energy	672.09 MWh_{comb}	214.14 MWh_e
Capital Expenditure	109,687.5 € (oil boiler and central cooling unit)	42,002.40 €
Operational Expenditure	154,218.28 € (oil consumption and electrical energy)	92,082.22 €
Total Costs	179,714.08 €	138,284.86 €
LCoE	0.37 €/kWh	0.18 €/kWh
$CO2_{equiv.}$	434.07 kg	198.59 kg
	Utility costs	
Oil consumption	214.93 €	-
Electrical Energy	14,420 €	22,156 €
Maintenance Costs [21, 22]	2,193 €	840.04 €

The estimated Levelized Cost of Energy (LCoE) is 0.18 €/kWh for the case of the proposed system, while the respective conventional system has an LCoE of 0.37 €/kWh. The system needs further optimization to decrease the cost, as many design parameters have not been included yet, such as a compensation system for regulating the energy production output. The expected payback period for the system is 4 years, and the return on investment (ROI) is nearly 25%.

The results of the study, both technical and economical, are aligned with the findings of similar large-scale studies. The study by Chang S. et al. investigated the potential of seawater heat pumps in different locations in China. The key performance indicator system introduced helps quantify and analyze the relative advantages and disadvantages of existing heating/cooling systems. Quantitative evaluation results show that seawater heat pumps have higher techno-economic potential in northern Chinese coastal cities, while the southern cases require further study [23].

Another study compares various organic working fluids, such as R-32, R-290, R-407C, and R744, for their efficiency in generating electricity from ocean thermal energy. An LCOE analysis is also performed to compare the cost-effectiveness between different oceanic thermal energy combined systems using these working fluids, resulting in a cost of energy between 0.07 and 0.32 €/kWh [24]. Lastly, the study of Calise F. et al. shows that the proposed layout achieves significantly positive outcomes, with a primary energy saving and avoided greenhouse gas emissions equal to 133% and 134%, respectively. It also shows that the economic profitability of the system is limited, with a payback period of 15 years due to the high capital cost of setting up the plant [25].

5. Conclusions

The present study presented an attempt to design a novel CL-SWHP. The design methodology included using three different software, Sketch-Up, TRNSYS 18, and Matlab Simulink, while it also included a MILP optimization algorithm to optimize the system's seasonal performance and operational cost. The case study used to test the proposed method was an elderly facility home in Alexandroupoli, Greece. To test the system, the authors simulated the winter and summer thermal loads and tested the load coverage of their model using transient simulation software.

The proposed system included the design of the sea coil, along with the hydraulic layout (filter, pumping, actuation device), the heat exchanger, the heat pump with the respective components, the rotation device for the compressor (single-phase induction motor), and the thermal load of the building of the case study. The varying design parameters need thorough investigation, as they affect the system in many ways.

The results indicated that the system reached the setpoint for heating and cooling scenarios. The proposed SWHP system delivered over 550 MWh_{th} during heating and 194.6 MWh_c during cooling. The techno-economic evaluation of the system indicated an LCoE value of 0.18 €/kWh for the proposed system, which was cheaper than the existing system's (0.37 €/kWh). The proposed system also saves approximately 157 tonnes of $CO_{2equiv.}$ during its operation compared to the conventional. While this system has a higher initial investment cost, its operational expenditures are significantly lower than the conventional system's, making it a more viable solution.

Exploring the sea or lake water heat pump systems is a topic of high scientific significance. This study contributes to the field in the following way: the exploitation of seawater for large-scale installations is not researched thoroughly despite its viability and applicability in coastal areas; in the present study, a large-scale application is approached. The detailed planning of the system was improved using a genetic algorithm to optimize the mass flow rate of the individual circulation pumps. The closed-loop approach is less expensive than the more researched, open-loop system. This is due to the high maintenance costs of the seawater heat exchanger and the significant capital cost of the seawater circulation pump, the seawater heat exchanger, and the anti-corrosion pipework.

Further studies of the proposed methodology should incorporate hybrid layouts for the system, where the electrical loads of the heat pump are covered by rooftop PVs. Additionally, optimizing the dimensioning process should be explored in more detail, including more sensitivity analysis of the weights of the TOPSIS methodology.

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