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ORIGINAL ARTICLE

Operation performance of a ground source heat pump system in the mediterranean climate zone. First results

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Abstract This paper presents the configuration and performance of a Low Enthalpy Geothermal System successfully installed and utilized in the Mediterranean climate zone. Additionally, it examines the performance of different types of Ground Heat Exchangers (GHE), all installed in the same System. The Ground Source Heat Pump (GSHP) of the system consists of vertical ground heat exchangers (GHEs) in five different configurations, one double helicoidal coil in a well and an open loop (well) system. The entire system is constantly monitored by a Building Management System (BMS) that records the energy, volume flow, incoming and outgoing temperature at critical points of the system. Based on the recorded values, the performance of the System was analyzed in a heating and a cooling working mode, after examining the power flows in and out from critical points of the System. Results show higher heat exchange values inside the open well, both in heating and cooling mode suggesting the usage of this type of GHE, where applicable. Additionally, the electric power consumed by the chillers which are the largest electricity consumers within the System, is approximately five times lower than the power placed in the building by the Geothermal System (SCOP between 4.5 and 5). In terms of primary energy savings, we can say with confidence the GSHP systems working under Mediterranean climate zone conditions, can be consider as high efficiency solutions, verifying the theoretical efficiency given by the manufacturer of the GSHP.

Keywords Ground source heat pump · Coefficient of performance · Ground heat exchanger · Open well · Helicoidal coil

Nomenclatures

ASHP	Air Source Heat Pump
AWHP	Air-to-Water Heat Pump
COP	Coefficient of Performance (ratio of the total amount of heat/cooling delivered to the electrical energy used by the heat pump)
COPsys	System Coefficient of Performance (ratio of the total amount of heat/cooling delivered to the total electrical energy used by the system (compressor, ground heat exchanger circulating pump, pumps and fans related to the handling system))
GHE	Ground Heat Exchanger
GSHP	Ground Source Heat Pump

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HP	Heat Pump
SCOP	Seasonal Coefficient of Performance (ratio of the total amount of heat or cooling delivered to the total amount of energy consumed over a heating or cooling period)

Introduction

Unlike fossil fuels, renewable energy sources emit little to zero greenhouse gases and in most cases are cheaper than coal, oil or gas (UN, n.d.). These clean and sustainable alternative energy solutions include solar energy, hydropower, wind energy, geothermal energy, biomass energy, and so on. Such forms of energy can be used in the collective effort toward giving solutions to major issues arising from the energy crisis Europe is now facing.

Due to this century's energy crisis, the European Union (EU) has developed energy strategies in order to become more resource-efficient and to ensure that greenhouse gas emissions are generated at a minimum. It has also invested in new technologies in the energy sector and developed legislation that can lead to higher energy efficiency of buildings (Massarotti et al., 2021). Additionally, relevant technologies developed for the exploitation of this free type of energy are getting more important, as heating and cooling represents 50% of EU's final energy consumption (ReGeoCitie Project, 2015) (2015 figure). Currently, in EU the residential sector is responsible for more than one quarter of the total primary cooling energy demand (Founda et al., 2019) and buildings are responsible for approximately 40% of total EU energy consumption, in spite of the fact that EU Commission has established a set of standards for the energy performance of buildings, called EPB standards (Energy EC Europa EU, n.d.). This still leaves a large untapped research potential with regard to using renewables and improving energy efficiency of systems. One manifestation of the latter is the installation of Geothermal energy systems (mainly Ground-Source Heat Pumps—GSHPs) for space heating and cooling in residential and commercial buildings, which has become increasingly popular in the last decades as compared to the more common air-to-water or air-source heat pumps (AWHP or ASHP) (Christou et al., 2024). Geothermal energy systems give an opportunity to achieve significant energy, environmental and at the same time economic benefits, if well applied (Atam & Helsen, 2016). In comparison with ASHP systems, for each kWh electric, GSHPs can produce (or remove) 50% extra thermal energy (Zhang et al., 2018). In particular, a vertical GSHP system for heating and cooling in typical conditions of the European Mediterranean coast consumed in average up to 43 ± 17% less primary energy than the alternative ASHP system (Urchueguía et al., 2008). Even if ASHP systems can be slightly more financially attractive for a short period, GSHP systems can offer significant savings for a longer design life (Lu et al., 2017). Studying the thermal performance of a hybrid solar GSHP system, the efficiency of the ground heat storage (in a water tank) mode can reach 47.9%, depending on the collector area and the number of GHEs (Yang et al., 2018). Moreover, a ground water GSHP was shown to lead to a primary energy consumption reduction of 42.9% compared to an original mainstream system (Zhu et al., 2015), while a GSHP system was shown to lead to CO2 emissions reduction of 36.7% and 28.9%, compared to an ASHP system and a natural gas system respectively (Kapıcıoğlu & Esen, 2022).

To this end, as other EU countries, Cyprus has adopted the EU Directives 31/2010/EC and 27/2012/EC, and in order to support, among other goals, the reduction of energy consumption and the increase of the energy efficiency in the building sector (Cyprus Bar Association, 2006), three financial subsidy schemes were launched in December 2014, March 2015 and March 2018 respectively. Moreover, Cyprus had adopted the EU Directive 2009/28/EC regarding geothermal energy development and, as a result, the Government was obliged to establish certification schemes for GSHPs installers. The GSHP system is one of the most well-known types of geothermal systems and renewable energy technologies for heating and cooling buildings due to its high efficiency and its environmental friendliness. GSHPs make use of GHEs, which are designed to meet the energy demand both in summer and winter (Ma et al., 2019).

In the case of any space air conditioning geothermal installation, the purpose is to cover the needs of the summer and winter air conditioning of a building according to its use. In recent years, applications for the utilization of shallow geothermal energy have been successfully developed in Cyprus. In particular, previous studies have performed measurements of ground temperatures in Cyprus that can be used for ground thermal applications (Pouloupatis et al., 2011), as well as measurements and analysis of thermal properties of rocks that can be used for the compilation of geothermal maps of Cyprus (Stylianou et al., 2016). Also, a methodology for estimating the ground heat absorption rate of GHEs in Cyprus (Stylianou et al., 2017), a parametric analysis of the factors affecting the efficiency of GHEs in Cyprus (Pouloupatis et al., 2017) and the effect of groundwater in modeling GHEs in Cyprus (Stylianou et al., 2019), have been addressed. The design of a geothermal system and the methodology used for estimating the ground heat absorption rate of GHEs (Stylianou et al., 2017), both play a vital role for low energy consumption, whereby reducing the amount of energy required and, hence, maximizing the efficiency (Michopoulos, 2020). Note that, for maximum efficiency, an equally important role is played by the ground thermal properties (Stylianou et al., 2016), which is an issue beyond the scope of this study though. Once the system geometry is established, the working temperature profiles must be set. If the velocity of the heat carrier fluid stays constant, then the hydraulic and thermal problems can be uncoupled. This allows performing the calculation of the energy balance and solve problems of temperature distribution.

Naranjo-Mendoza et al. (2019) used subsurface as an Earth Energy Bank and calculated the whole system's performance assessed through calculating the energy fluxes involved in it. The obtained results showed that after 19 months of operation the system performed well with a COPsys of 2.51 and covered the space heating requirements of the building in winter. Liu et al. (2023) went into more detail as it was required to keep all winter time the temperature of a greenhouse constant at 25°C. So, the general energy balance of the geothermal system was calculated as the net heat input rate equal to network output rate, if it is assumed that there are no significant changes in kinetic or potential energy, and no heat or work transfers (Ozgener & Hepbasli, 2005).

Cooling or heating performance of a GSHP system is represented by the Coefficient of Performance (COPsys), as opposed to the COP of the HP and the seasonal COP (SCOP) (Man et al., 2012). It should be emphasized that HP performance depends on the temperature of the fluids exchanging heat at the evaporator and the condenser stages. Therefore, different climatic conditions like the Mediterranean climate zone and different demand scenarios over a season can lead to large variations in the overall efficiency of the machine.

Concerning existing studies of GSHP systems that have been conducted in the last decade, just a few of them concentrate on the practical operation performance of the GSHP systems, as most of them are focused on theoretical and simulation models.

Hwang et al. (2009) presented the actual cooling performance of a GSHP system installed in Korea, based on specific dates where temperatures were the highest of the year. With the help of these computational measurements the COPsys was found to be 5.9 at 65% of partial load conditions. Man et al. (2012) presented comprehensive data concerning the GSHP experimental rig installed in the Hebei University of Engineering, China. The GSHP system, used for both cooling and heating, was analyzed in intermittent and continuous mode, based on experimental data. It was found that the performance of the system was affected by its operation conditions and modes. In more detail, the system operated in intermittent mode possesses higher COP compared to that operated in continuous mode by 11.57% after 40 h of operation for cooling provision, and by 9.47% after 100 h of operation for heating provision. The advantage of intermittent mode over continuous mode increases as operation time increased.

Luo et al. (2015) examined the thermal performance of a GSHP system installed in an office building in Nuremberg, Germany. A 4-year continuous monitoring of the heating and cooling performance led to a COP of 3.9 for a typical winter day and a COP of 8.0 for a typical summer day (when the HP is shut and only water circulating pumps are in operation).

In the geographic area of the Mediterranean climate zone, Emmi et al. (2017) investigated the energy behavior of two case-studies in the environment of Venice and Florence, where GSHP systems were compared to ASHP systems and to common systems consisting of condensing gas boiler and air-to-water chiller. The obtained results showed that the GSHP was the best solution in terms of primary energy savings. In more detail, the results of the simulations were calculated in terms of the seasonal energy efficiency where the seasonal coefficient of performance

(SCOP) and seasonal energy efficiency ratio (SEER) of the HP were assumed as the ratio between the annual energy need for heating and cooling and the annual electrical energy demand for the two operation modes. The mean SCOP of the GSHP system was found to be 3.5, compared to the AWHP system, which was 2.5, and the condensing boiler coupled with an air-to-water chiller system, which was 0.95, for the Mediterranean climate of Venice and Florence. Simulations were executed for a 10-year period. The issue of heat dissipated to the ground, especially in the case of highly insulated buildings, was also addressed as this could lead to long-term, ground temperature shifts, resulting in a reduction of the COP in cooling mode.

Esen et al. (2006) analyzed the energy performance of a low enthalpy GSHP system. The study case was located in the hot climate of Turkey were the annual COPsys and the HP COP reached 2.82 and 3.42. Another study in Turkey by Pulat et al. (2009) tested the performance of a GSHP system with horizontal GHEs. As the system was tested in heavy winter, it displayed a COPsys of 2.58 and a considerably higher SCOP of 4.18 for the HP unit. As for different installation configurations of GHE, Esen et al. (2017) showed that the COPsys and SCOP were 2.88 and 3.55 respectively for horizontal slinky-type GHEs, while the COPsys and SCOP reached 2.34 and 2.91 respectively for vertical slinky-type GHEs.

García-Cespedes et al. (2020) focus on methods to characterize the efficiency losses in existing GSHP installations under partial-load conditions. The closed-loop system consisted of 10 vertical BHEs with an average drilling depth of 140 m. The efficiency losses of the GSHP were identified and quantified by analyzing key parameters measured and recorded by its monitoring system. The methodology was based on the EN-14825 standard and the literature. However, in order to obtain significant results, minute-resolved data acquired over time periods with almost constant thermal load (quasi-steady state conditions) proved to be necessary. The analysis yielded a value around 9% for the maximum partialization losses due to cycling operation. On the other hand, overall heating and cooling capacity reductions in the GSHP were observed. An overall 20% reduction was determined for the cool season (heating) and a 24% reduction for the warm season (cooling). The obtained SCOP for summer and winter were 3.14 and 3.09, respectively. These values are below what is expected in such heating/cooling facilities, where SCOP can easily exceed a value of 3.5 (Kim et al., 2012; Pospísil et al., 2018).

Lim and Lee (2021) experimented on the performance of standing column wells (SCW) used in a geothermal project and proposed the cross-mixing balancing well heat exchanger method. Measurements showed that using this technique in operation from a regular SCW-type heat exchange system to a well-intersected heat exchange system, not only improved the COPsys, but also ensured a stable supply of geothermal sources. The COPsys had an improvement of 23% and 12% during the cooling and heating operations, respectively, yielding values of 3.76 and 3.27 respectively.

Michopoulos et al. (2016) presented a theoretical feasibility analysis for the installation of GSHP systems in Cyprus, referring to two different types of buildings, a single and a multifamily one. The energy demand of the buildings for heating and cooling in the climate conditions of Cyprus was calculated. The authors performed a comparison of conventional heating and cooling systems (ASHP) that are widely used in Cyprus and a GSHP system consisting of a vertical GHE and water-to-water HPs. Significant reductions in primary energy use for both types of buildings were observed upon installation of the GSHP system. From an economic point of view, the geothermal system compares favorably with the conventional systems in many cases, having SCOP for the heating and the cooling mode, range between 4.0 and 4.5 and 5.0 and 5.5 for both building types.

Mahmoud et al. (2024) studied the advantages/disadvantages between the different types of GSHPs with highlights on the GSHP's performance in coloration with its geometry and the construction cost. Published results showed that the COP is mostly affected by the GHEs' depth and borehole spacing.

For comparison reasons, regarding ASHP systems, such a system installed in Woodbridge, Ontario, Canada performed well in the cooling mode with a SCOP average at 5.2, but in heating mode, the SCOP turned out to be only 3.4 (Safa et al., 2015).

Finally, in Table 1 a summary of real case studies regarding GSHP systems installed in various countries is given, with the respective COP, SCOP or COPsys.

Table 1 COP, SCOP or COPsys of GSHP systems in various countries

Area Installed	Working mode	System	Ambient Temp in project (°C)	COP, SCOP or COPsys	Year/ Ref
Bursa, Turkey	Heating	Horizontal GHEs	4.5 mean	2.5–2.6 (COPsys)	2009/(Pulat et al., 2009)
Nuremberg, Germany	Heating	Vertical GHEs	–9 to 1	3.9 (COP)	2015/ (Luo et al., 2015)
	Cooling	Vertical GHEs	up to 28	8.0 (COP)	(Luo et al., 2015)
Venice and Florence, Italy	Heating	Vertical GHE U-type	2.3 to 24.4	3.5 (SCOP)	2017/(Emmi et al., 2017)
Elazığ, Turkey	Heating	Ground & Solar horizontal GHE slinky type	–8 to 6	2.9 (COPsys)	2017/ (Esen et al., 2017)
	Heating	Ground & Solar vertical GHE slinky type	–8 to 6	2.8 (COPsys)	(Esen et al., 2017)
	Heating	Horizontal GHE	–8 to 6	2.8 (COPsys)	(Esen et al., 2017)
	Heating	Vertical GHE	–8 to 6	2.4 (COPsys)	(Esen et al., 2017)
Tremp, Spain	Heating	Vertical GHEs	down to –1.2	3.09 (COPsys)	2020//(García-Céspedes et al., 2020)
	Cooling	Vertical GHEs	up to 28.5	3.14 (COPsys)	(García-Céspedes et al., 2020)
Korea	Heating	Standing column well	15 to 16 (yearly underground heat sources)	2.9 (COPsys)	2021/ (Lim & Lee, 2021)
	Cooling	Standing column well	15 to 16 (yearly underground heat sources)	3.1 (COPsys)	(Lim & Lee, 2021)
	Heating	Standing column wells with cross-mixing balancing	15 to 16 (yearly underground heat sources)	3.3 (COPsys)	(Lim & Lee, 2021)
	Cooling	Standing column wells with cross-mixing balancing	15 to 16 (yearly underground heat sources)	3.8 (COPsys)	(Lim & Lee, 2021)
Cyprus (theoretical)	Heating	Vertical GHEs	8.5–13.2 (mean in January)	4.0–4.5 (SCOP)	2016/ (Michopoulos et al., 2016)
	Cooling	Vertical GHEs	25.7–29.7 (mean temp in summer)	5.0–5.5 (SCOP)	(Michopoulos et al., 2016)

The purpose of the current study is to present the hybrid configuration and the practical operational results of the GSHP system used for space air conditioning at the building where the library of Cyprus University of Technology (UMLL) is housed. In particular the goal is to estimate the efficiency of the system in relation to the specific area conditions, and to make the comparison with the theoretical efficiency given by the manufacturer, thereby assessing the success and usefulness of the system's employment. Section "Methods and Materials" presents the Methodology, containing the case study presented, the GSHP system operation and the associated Building Management system. In Section "Results" the results and their discussion are presented both for heating and cooling mode of the system operation. Finally, we conclude with Section "Discussion".

Methods and materials

The study presented here is a case study of a GSHP system installed in a relatively large building in the city of Limassol at the coastline of the Mediterranean island of Cyprus. In the sequel, the case study itself, the GSHP system operation and the associated Building Management system are all addressed in detail.

Case study

In late 2018, as part of the renovation of the historical building of the University Municipal Library of Limassol (UMLL), a GSHP system was installed as a new alternative way to cover the heating and cooling needs of the building. The building is located in the seaside city of Limassol, in the island of Cyprus. Cyprus is the third largest island in the Mediterranean Sea and lies in the north-east corner covering an area of 9251 km^2. The climate is Mediterranean, with long, warm, dry summers from June to October and mild winters, with occasional rain, lasting from December to April (Meteorological Service of the Republic of Cyprus, n.d.a).

Table 2 presents the characteristics related to the GSHP system with regards to the employed HP and GHEs and the building under consideration and the power and energy consumption.

For applying best practices, a Building Management System (BMS) was installed to monitor temperatures and flow volumes in various key points of the system (Christodoulides et al., 2023, 2024). Two different procedures were followed, one for cooling the building and one for heating. The decision for the installation of the BMS was taken as it offers the ability to control all the functions of the geothermal system from one central point and provides through its various functions better monitoring of the system in a user-friendly environment. It helps to reserve energy and save money though the tools that are available for the control and supervision of the performance of each part separately. Also, the BMS ensures high reliability in system operation with timely notifications in case of fault via emails and text messages (SMS) and it keeps records of the temperature readings, volume flow and energy for each point of the whole system every 15 min.

As the study case is in an area with long, warm, dry summers with high humidity from June to October the required energy from the geothermal system in the UMLL is increased in the summer months. Based on the data records kept by the Meteorological Service of the Republic of Cyprus (Meteorological Service of the Republic of Cyprus, n.d.a), July 2021 was the sixth July in a row with higher-than-normal average daily maximum temperatures in several areas in Cyprus; it actually ranked as the second warmest July since 1983 (Meteorological Service of the Republic of Cyprus, n.d.b). On the other hand, in March 2022 the average daily minimum temperature in Limassol was the lowest average daily minimum temperature recorded since 1976 (Meteorological Service of the Republic of Cyprus, n.d.c). The abovementioned info points to the need of more energy required both for cooling and heating. Under these climatic conditions, GHEs have high potential to be used together with GSHPs for the heating and cooling of the buildings.

Table 2 Characteristics of the GSHP system

Building type	Multi-use
Heating load peak (kW) of the month examined	110
Cooling load peak (kW) of the month examined	135
Ground Heat Exchangers (GHEs)	8 × Vertical GHEs; 1 × double-helix; 1 × complex open well;
Model and technical characteristics of heat pump	NECS-WN model 0352
Manufacturer's COP heating of GSHP	approximately 5
Manufacturer's COP cooling of GSHP	approximately 5
Electricity consumption yearly (kWh)	22300
Electricity consumption of heating for peak month (kWh)	700
Electricity consumption of cooling for peak month (kWh)	2700

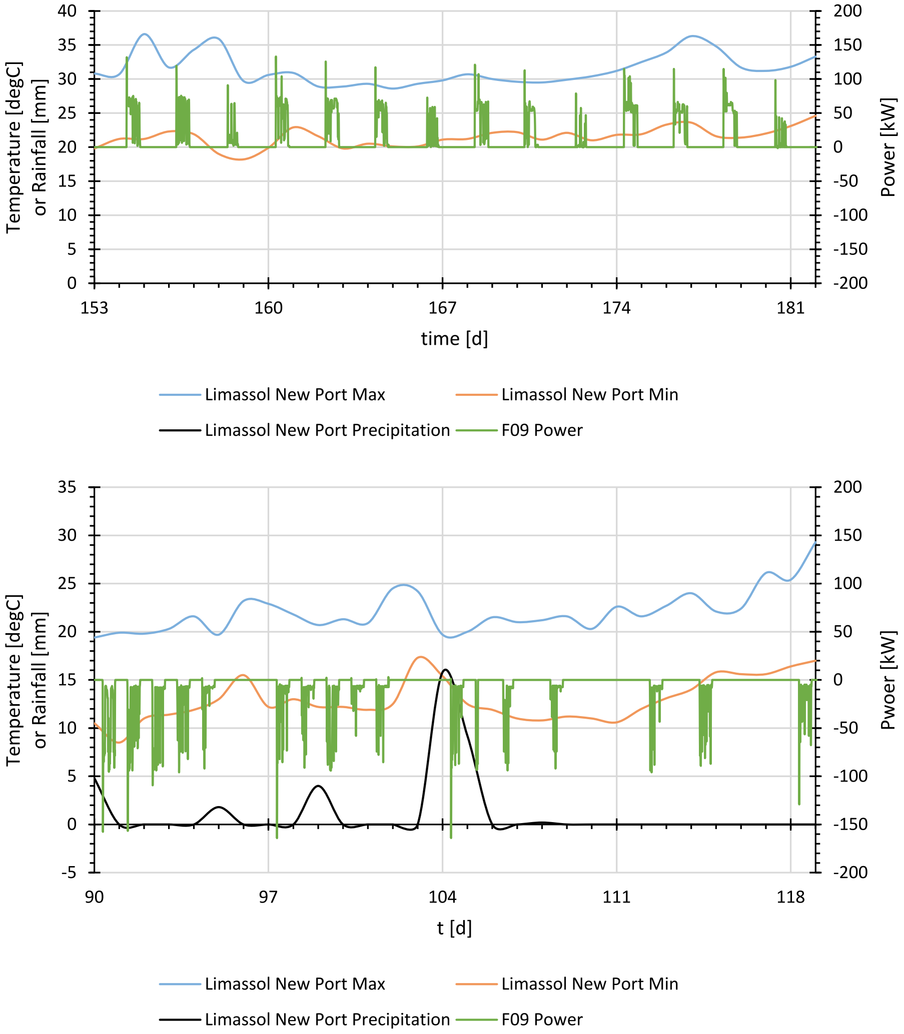


Fig. 1 Minimum and Maximum Temperatures and Precipitation in Limassol for the months of June (top) and April (bottom) 2019, and the power delivered or extracted to or from the UMLL building

In Fig. 1, the meteorological data, namely the max and min temps per day and the daily precipitation of the months examined, April and June, corresponding to heating and cooling working modes of the system, are shown. Also shown in the figure is the power delivered or extracted to or from the building, recorded in timesteps of 15min, during the chiller's functioning. As the temperature difference between max and min per day is around 10^{O}C (and actually less during the operational hours of the Library), the delivered/extracted power is rather constant. Note that April and June were chosen for the current study as they exhibited the most reliable and complete data recorded by the BMS.

GSHPs are divided into three main groups based on the use of ground water from wells, surface water or directly coupled with the ground by the use of ground heat exchangers (ASHRAE, 2015). In our case study, a combination was used as the GSHP system installed at the UMLL building includes five boreholes with different GHEs U-tube configuration, one GHE of helicoidal configuration in a well and open well as follows:

(i) one single vertical of 100 m depth and Φ25mm (diameter),
(ii) four single vertical of 100 m depth and Φ32mm,
(iii) one single vertical of 100 m depth and Φ40mm,

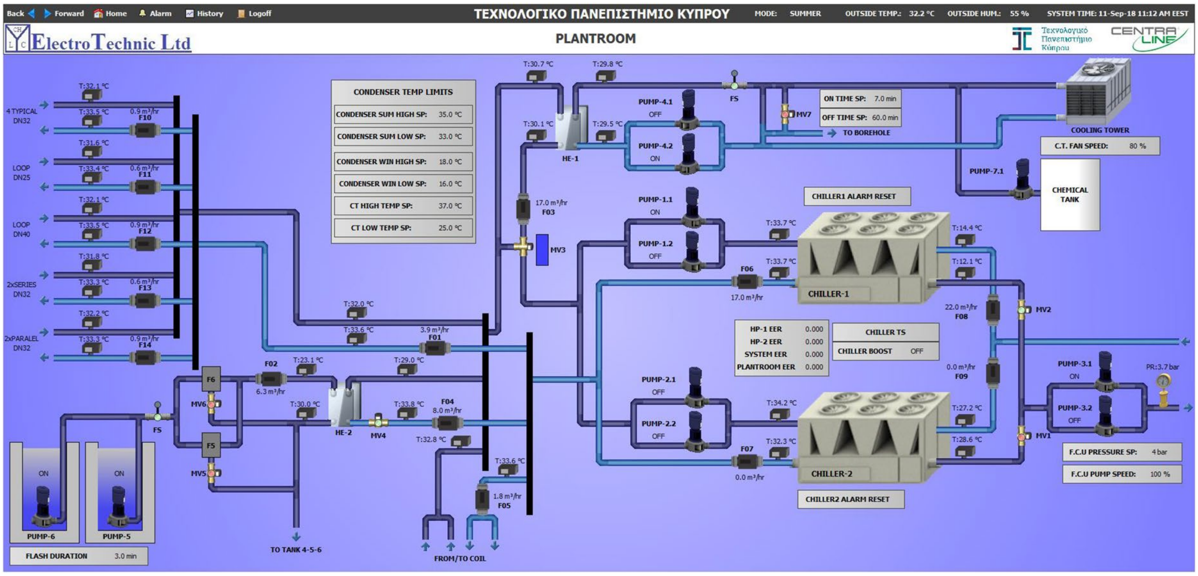
(iv) one double vertical of 100 m depth and Φ32mm, connected in series,

(v) one double vertical of 100 m depth and Φ32mm, connected in parallel,

(vi) one double helicoidal configuration in a well with coil of 6 m (around 10 m) length and Φ32mm, and corresponding diameters of 60 cm and 80 cm, and

(vii) one complex of open wells, consisting of one well for extracting water and three wells for dropping water, each of 16 m depth and 1 m diameter.

The GSHP system was separated into fourteen regions numbered from F01 to F14 (see Fig. 2, and Table 3 for definitions). In Fig. 2 one can view the system diagram with all features illustrated: the vertical GHEs in the top left side; the open wells in the bottom left side; the helicoidal coils in the bottom middle; the cooling tower (used as a back-up



MODE: SUMMER
OUTSIDE TEMP.: 32.2 °C
OUTSIDE HUM.: 55 %
SYSTEM TIME: 11-Sep-18 11:12 AM EEST

CONDENSER TEMP LIMITS
CONDENSER SUM HIGH SP: 35.0 °C
CONDENSER SUM LOW SP: 33.0 °C
CONDENSER WIN HIGH SP: 18.0 °C
CONDENSER WIN LOW SP: 16.0 °C
CT HIGH TEMP SP: 37.0 °C
CT LOW TEMP SP: 25.0 °C

ON TIME SP: 7.0 min
OFF TIME SP: 60.0 min

C.T. FAN SPEED: 80 %

HP-1 EER 0.000
HP-2 EER 0.000
SYSTEM EER 0.000
PLANTROOM EER 0.000

CHILLER BOOST OFF

F.C.U PRESSURE SP: 4 bar
F.C.U PUMP SPEED: 100 %

FLASH DURATION 3.0 min

Fig. 2 Diagram of GSHP System of the UMLL (screenshot)

Table 3 Definition of building management system's (BMS) labels

Label	Description
F01	Total circulating flow from all 5 types of vertical GHEs (see F10 to F14) (part of F03)
F02	Inlet flow of HE2 coming from the open wells
F03	Total flow coming from all GHEs and the open wells going as inlet to the chillers
F04	Outlet flow of HE2 contributing to the inlet of the chillers (part of F03)
F05	Flow in the Φ32 helicoidal GHEs (part of F03)
F06	Flow of the GSHP system to Chiller 1
F07	Flow to the GSHP system to Chiller 2
F08	Outlet flow of Chiller 1 going to the building (A/C units)
F09	Outlet flow of Chiller 2 going to the building (A/C units)
F10	Flow in each of four Φ32 vertical GHE
F11	Flow in the Φ25 vertical GHE
F12	Flow in the Φ40 vertical GHE
F13	Flow in the Φ32 double vertical GHE in series
F14	Flow in the Φ32 double vertical GHE in parallel

system) in the top right side; and in the “middle” the two chillers (HPs) that deliver the cooling/heating into the building in alternate days. It can be observed that the water from the wells is not delivered directly into the GSHP system but exchanges heat through a heat exchanger (HE-2), while the cooling tower exchanges heat with the system via HE-1.

The general aim was to evaluate the performance of each of these groups separately through an analysis of data obtained by the BMS system, regarding energy, flow volume, incoming and outgoing temperatures in the system, which are automatically recorded in the BMS. The data, recorded every 15 min, can be used for the evaluation of the performance for each unit of the system, using appropriate mathematical formulas (see below) in the Microsoft Excel tool. For this study, recorded values were extracted for F01, which represents the boreholes (vertical GHEs), F04, which represents the open wells and F05, which represents the helicoidal GHE.

The heat flow rate (power) estimated $\dot{Q}$ (in W), transferred to or from the system in each region F, is calculated from the equation:

$$\dot{Q} = \dot{m}c_p(T_{in} - T_{out}) \tag{1}$$

where $\dot{m}$ is the mass flow rate in kg s^{-1}, c_p the specific heat of the circulating liquid in J kg^{-1} K^{-1} and $T_{in} - T_{out}$ is the difference between the input and output temperatures of the circulating fluid in K.

System configuration and operation

The Library’s GSHP system operates with two chillers, which are working alternately day by day. Each chiller is a NECS-WN model 0352, water to water indoor unit for the production of chilled water with hermetic rotary scroll compressors. It has a braze-welded plate-type exchanger and thermal expansion valve and, concerning its structure, comes in galvanized steel with paint finish and external panels in pre-clad sheet steel (simil-Peraluman). The range includes the single-circuit two-compressor versions and the dual circuit four-compressor versions. The NECS-W are units designed with a range of integral accessories in mind for operation with total water loss (well, groundwater, etc.), and can adopt a dry cooler or cooling tower for satisfying all service system and installation requirements (Total versatility integrated hydronic module on cooler, condenser side integrated condensation´s control, n.d.). Units are available in the Class A Version, with CA efficiency levels in the HP mode according to the Eurovent performance tables. These units exceed the minimum winter mode efficiency requirements assuring a COP of ≥ 3.2 (INTEGRA unit for 4-pipe systems, n.d.).

In the summer the chiller mode changes to the cooling function. Every morning, the BMS will choose to first start the chiller with less hours of operation and try to balance the operation times. This means that the chillers alternate per day. If for some reason one of the chillers has a fault, the BMS will keep operating the other one until the fault has been restored. After two minutes the chiller will be enabled once the motorized valve on the user side is opened. Once the temperature in the inlet of the condenser reaches $35^{O}C$, which is though adjustable, the submersible pumps in the open wells are activated. When any of the submersible pumps is in operation, the corresponding motorized valve will be opened to maintain the inlet temperature between $26^{O}C$ and $35^{O}C$. The only limitation is that the temperature shown on the inlet of the condenser should not go below $26^{O}C$. If for some reason the temperature is still rising above $35^{O}C$, the cooling tower pump will be activated, cooling the water with heat exchanger HE-1 (HeatFlow Group mechanical construction company, n.d.) (see Fig. 2 for more details).

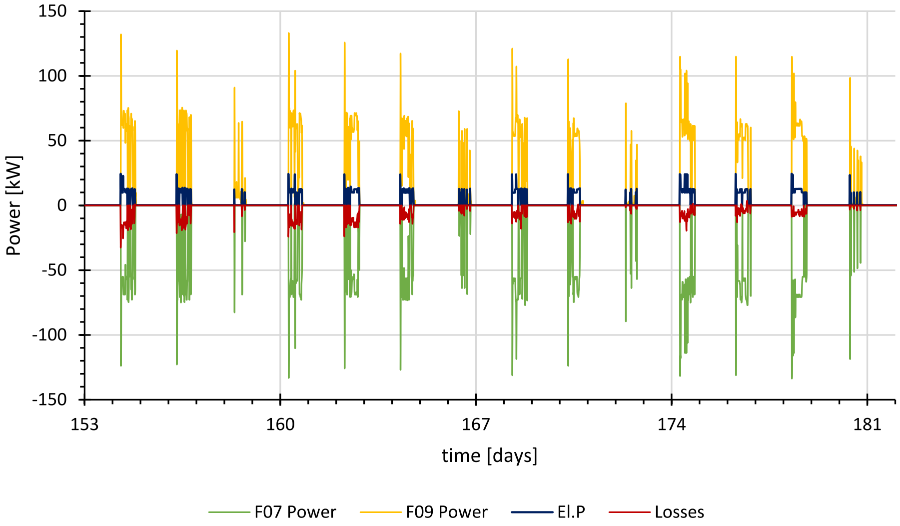
In winter, the chiller mode changes to the heating function. Then, the whole process is similar to the cooling function (see above). When the temperature in the inlet of the condenser reaches $12^{O}C$, the submersible pumps are activated one after the other. When any of the submersible pumps is in operation, the motorized valve will be opened to maintain the inlet temperature between $12^{O}C$ and $20^{O}C$. The temperature shown in the inlet of the condenser should not go below $12^{O}C$ (HeatFlow Group mechanical construction company, n.d.).

Building management system

The BMS system that monitors the GSHP system is a generalized and integrated geothermal data management system developed by Electro Technic Ltd.

In a geothermal system with no remote monitoring, the maintainers must visit the place frequently to

Fig. 3 Power entering and exiting the GSHP system (F07: GHEs Load (loss), Losses: losses to the environment, F09: Building load, El.P: Electric Power consumed)



carry out on-site inspection work, which could result in high charges and maintenance costs, jeopardizing the sustainability of such a system. Instead, installing a remote BMS that records basic parameters of the geothermal system, offers the ability of identifying a fault problem in a short time and proceeding to a solution. Also, with the installation of sensors at key points, the maintenance team will immediately be informed via the web, by mail or SMS (Industries et al., 2015).

The access to the BMS system is done through the webpage of the library and to access it, one needs to be an authorized user. The system stores the data of the temperatures in and out, the flow volume and the energy used by the system. Those data can be easily accessed through the "History" button in the BMS platform, after selecting the required time range.

Instead of using the BMS platform itself for the data processing, the platform also gives the option of selecting a "part" of the System through a list, i.e., from F01 to F14, and export all the corresponding measurements in different type of files, including.csv format for further processing.

Results

The data used for the preparation of graphs in the sequel, were collected through the BMS platform tools. Then using MS Excel, the efficiency of each part F (recall Table 3) was calculated separately. In order to confirm the calculated results, measurements were also manually taken directly from the Plant room.

As mentioned above, the UMLL GSHP system operates with two chillers, which function in alternating days. Here chiller 2 is studied.

Cooling mode

As a basis for the calculations, the GSHP system is considered as a closed system in which energy enters and exits in equilibrium as follows:

$$\begin{aligned}&\text{GHEs load (loss)} + \text{losses to the environment}\\&= \text{Building load} + \text{Electric Power consumed}\end{aligned} \tag{2}$$

The specific power in each of the components of the GSHP system is shown in Fig. 3 as a function of time, where time is the calendar day (from day 153 to day 181 of year 2019, i.e., June 2019, which is in the summer season). During the cooling mode operation, the evaporator of the unit (F09), which absorbs the building load, has a flow between 14 and 20 m^3/h, with a temperature difference of about 4 °C. The condenser that rejects heat to the ground (F07) has a flow between 12 and 17 m^3/h, with a temperature difference of about 4 °C. Recorded data are in agreement with Eq. (2).

Figure 4 shows the electric power consumed by chiller 2 (F09) (blue color) and power absorbed

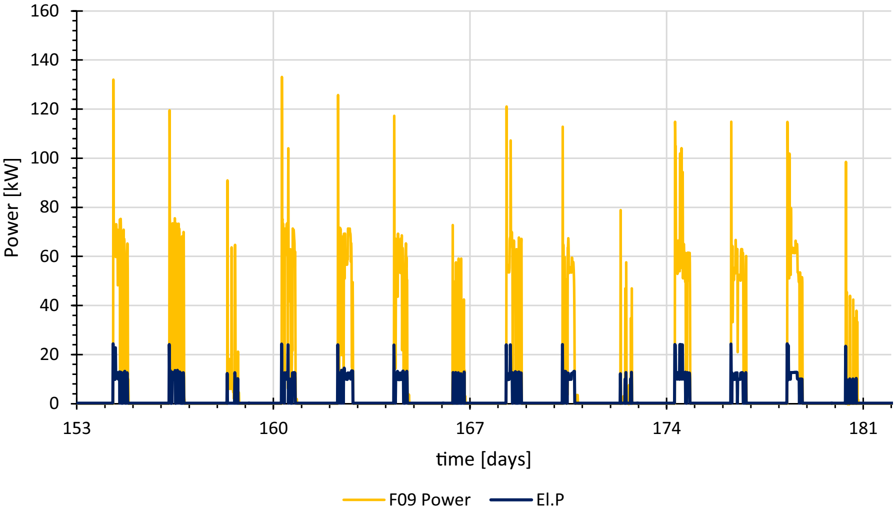


Fig. 4 Electric power in chiller 2 (El.P) and power adsorbed by the GSHP system due to building load (F09 power) in June 2019

from the building by the system (yellow color). The peak cooling load was estimated at 135 kW and the peak demand from the chiller at 25 kW.

In general, chillers are among the largest energy consumers within a building, and this has a large impact on operational costs. Therefore, if it is assumed that the electric power consumed by the chiller is equal to the total electric power consumed by the system and, based on Fig. 5, the SCOP can be estimated (see Fig. 4 for the month of June 2019). It turns out that an estimated mean SCOP value for June is 5.0.

Figure 6 shows the power rejected to the ground in June 2019 by the GHEs, namely F01 that represents the sum of the boreholes, F04 that represents the well, F05 that represents the helicoidal coils in the well and F07 that represents the sum of these three sources. As shown in the graph the highest power, between 60 and 80kW, is exhibited by the open well, followed by the sum of the boreholes, which is between 40 and 60kW. The helicoidal coils in the well reject a smaller amount, between 10 to 15 kW, because of their limited size. The total power rejected to the ground by the GHEs is between 70 and 138 kW.

Heating mode

As a basis for the calculations, the GSHP system is considered as in the summer to be a close system in which energy enters and exits in equilibrium as follows:

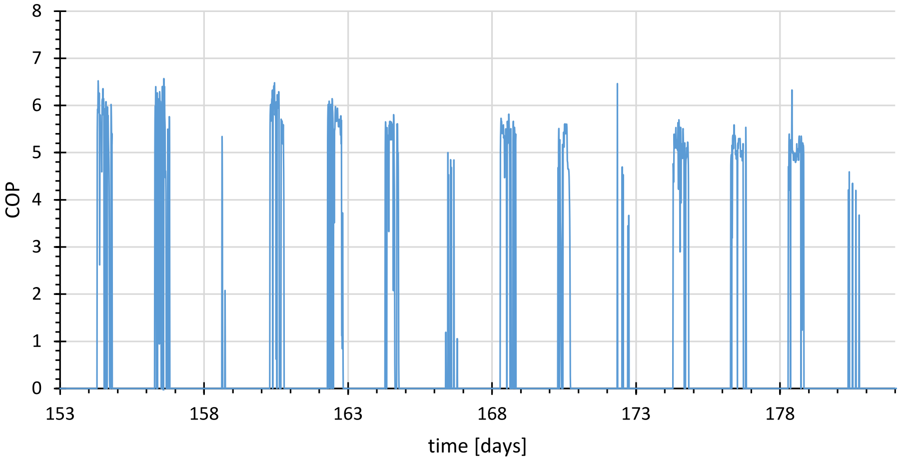


Fig. 5 Coefficient of Performance of the system when chiller 2 is in operation for June 2019 (cooling mode)

Fig. 6 Power rejected to the ground by the GHEs in June 2019 (mean daily values during operational time) (F01: boreholes, F04: open well, F05: helicoidal configuration in a well, F07: total power rejection, equal to the sum of F01 + F04 + F05)

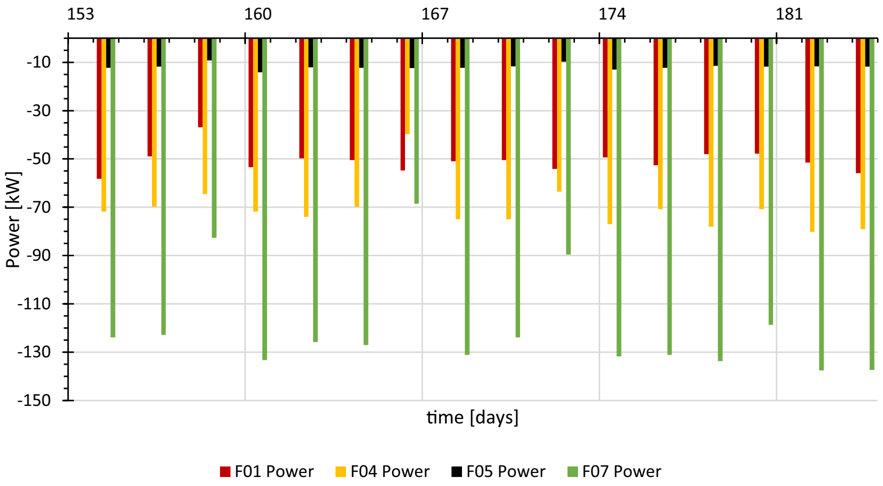
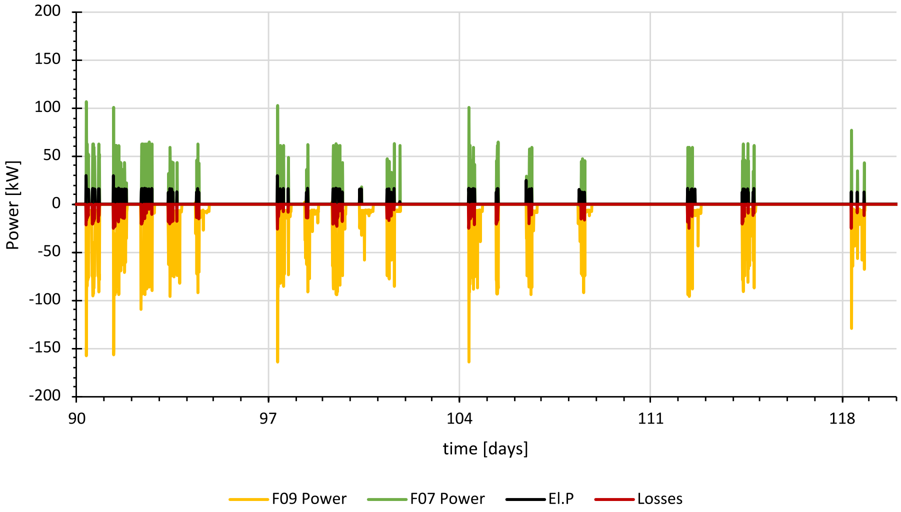


Fig. 7 Power entering and exiting the GSHP system (F07: GHEs Load (gain), Losses: losses to the environment, F09: Building load, El.P: Electric Power consumed



$$\text{Electric Power consumed} + \text{GHEs load(gain)} = \text{losses to the environment} + \text{Building load} \tag{3}$$

The specific power in each of the components of the GSHP system is shown in Fig. 7 as a function of time, where time is the calendar day (from day 90 to day 118 of 2019, i.e., April 2019, with the GSHP in heating mode. During the heating operation, the condenser of the unit (F09), which offers the building heat load has a flow between 14 and 19 m^3/h, with a temperature difference of about 4 °C. The evaporator that absorbs heat from the ground (F07) has a flow between 12 and 18 m^3/h, with a temperature difference of about 3 °C.

Figure 8 shows the electric power consumed by chiller 2 (red color) and power rejected to the building by the system (black color) as a function of time. Time is the calendar day, from day 90 to 119 of 2019, i.e. April 2019, period where the system was working in heating mode.

Figure 9 shows SCOP in April 2019, when chiller 2 is in operation, which has a mean value of 4.7 as derived from the values shown in Fig. 8.

Finally, in Fig. 10 are shown the values of power absorbed from the ground in April 2019 by the GHEs (i.e., F01: boreholes, F04: open well, F05: helicoidal configuration in a well, F07: total power rejection, equal to the sum of F01 + F04 + F05), for the system in heating mode. As shown in the graph the power absorbed by the open well is about the same as that of the sum of the boreholes, between 15 and 50 kW. The helicoidal coils in the well absorb a smaller amount, between 5 to 10 kW because of their small size.

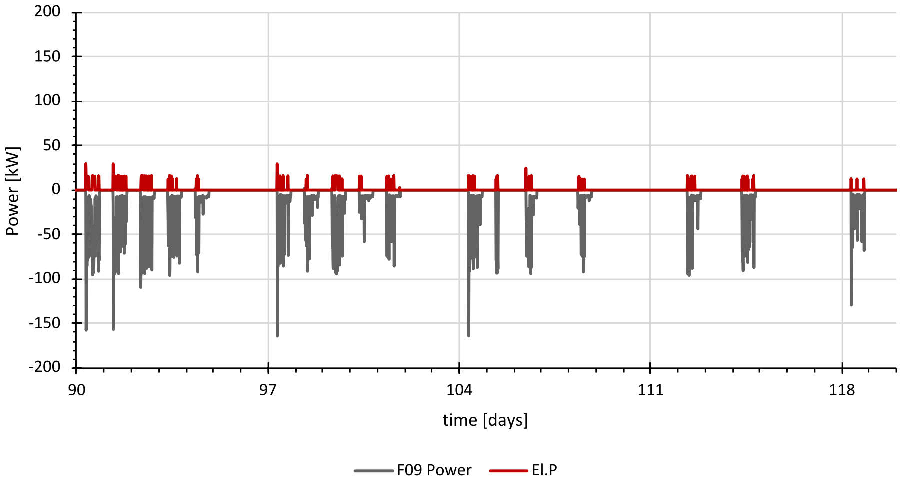


Fig. 8 Electric power in the chiller 2 (El.P) and power rejected by system for the building heating load (F09) in April 2019

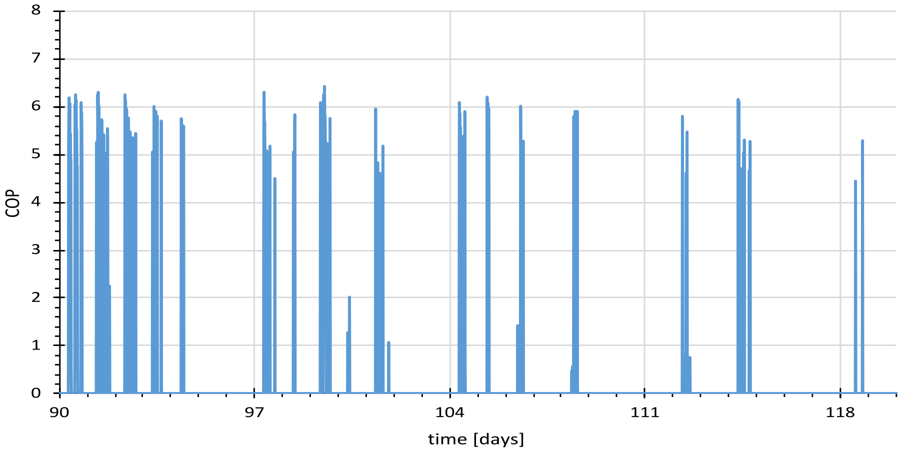


Fig. 9 Coefficient of Performance of the system when chiller 2 is in operation for April 2019 (heating mode)

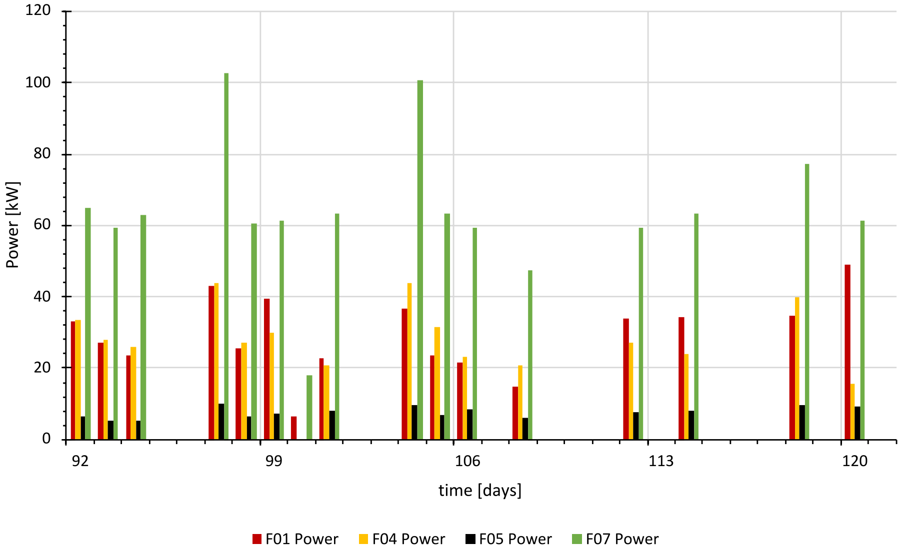


Fig. 10 Power absorbed by the GHEs in April 2019 (mean daily values during operational time) (F01: boreholes, F04: open well, F05: helicoidal configuration in a well, F07: F01 + F04 + F05)

Discussion

With regard to the GHE type, the analysis presented above has shown higher heat exchange values, especially in summer, inside the open well, compared to the boreholes and the helicoidal coils.

The chillers' operation was also examined as it has a great impact on operational costs by being the largest electricity consumer within the System. The chillers' operation was monitored through the SCOP and by analyzing the results one comes at the conclusion that chillers in a GSHP system working in Mediterranean climate zone are more efficient in cooling mode than it heating mode for the tested case; this is probably due to the specific choice of April.

The obtained SCOP values (4.7 for heating, 5.0 for cooling) compare well with all reported values for similar real case studies (recall Table 1). Actually, the obtained SCOP values for the current case study are higher than most of the reported cases, whether these are concerned with boreholes in Germany (Luo et al., 2015), Italy (Emmi et al., 2017), Turkey (Esen et al., 2017), Spain (García-Céspedes et al., 2020), or other GHE types in Turkey (Esen et al., 2017; Pulat et al., 2009) or Korea (Lim & Lee, 2021). This can be attributed to the Mediterranean weather conditions of the coastline city of Limassol, a climate well suited for geothermal installations. In addition, the experimental results obtained here verify the theoretical values as suggested by Michopoulos et al. (Michopoulos et al., 2016) for close weather conditions and geographical location. Of note is that previous numerical studies, validated using borehole data in various locations in Cyprus led to a positive conclusion about the suitability of geothermal systems in Cyprus, as they can lead to efficient use of GSHPs, as performance is not affected by the ambient conditions (Florides et al., 2012, 2013; Pouloupatis et al., 2017). The results obtained here indeed verify this conclusion.

Measurement errors can have significant effects on the accuracy and reliability of experimental or observational results. Inaccurate measurements lead to inaccurate results by introducing deviations from the true values of the quantities being measured. These can lead to inconsistencies or difficulties in the reproducibility of results. Measurement errors therefore can undermine the validity of conclusions drawn from the data. Researchers might make incorrect assumptions or interpretations about the phenomenon under study due to the presence of measurement errors. To avoid these errors measurement instruments should regularly be calibrated to ensure their accuracy and reliability, implement quality control measures during experiments or observations to identify and correct errors and through replication to conduct multiple measurements or experiments to assess the consistency of results and reduce the impact of random errors. It is important to recognize that complete elimination of measurement errors is often not feasible, but a systematic approach to minimizing and managing these errors can improve the overall quality and reliability of scientific research and experimentation. In order to eliminate errors in the case study we would recommend temperature readings to be recorded with an increased accuracy (0.1^{o}C instead of 0.5^{o}C) and monitoring the system and reporting results for much longer periods (whole year/s).

Conclusions

The overall aim of this paper was to present the practical operational results of a GSHP system used for space air-conditioning installed in the Mediterranean climate zone. Another goal was to compare different types of GHE, as the system consists of five different types of GHEs U-tube configuration, one GHE of helicoidal configuration and a complex of open wells. The evaluation of the collected data was done both for heating and cooling operation mode.

Regarding heat exchange value, in cooling mode, the open well had values between 60 and 80 kW, which are higher than the heat exchange achieved by the sum of the boreholes (between 40 and 60 kW) or the helicoidal coils in the well (between 10 and 15 kW). Regarding the chillers' performance, analysis of the SCOP lead to the finding that the chillers in a GSHP system working in cooling mode were more efficient than working than in heating mode (SCOP values 5.0 for cooling versus 4.7 for heating). In both modes one could conclude that the electric power consumed by the chillers is approximately five times lower than the power placed in the building by the Geothermal System. The estimated efficiencies indeed match the theoretical manufacturer's efficiencies.

It is crucial to recognize that the ranges for COP can fluctuate due to variables such as the specific ground temperature and the geological characteristics of the region, the level of installation quality, the design temperatures of the system, the type of ground loop implementation, as well as the indoor and outdoor air temperature and humidity. Still, the good results in terms of energy performance confirm that the GSHP systems located in Mediterranean climate zone are high efficiency solutions in terms of primary energy savings.

The next step in the GSHP under consideration performance assessment is to re-test the system with present day data, where the Library was in full operation after the Covid19 pandemic years. Before doing that the whole BMS system should be re-calibrated in line with the mechanical system. This points to the limitations of the current study, the most important of which is the lack of data related to the additional energy consumed by the handling system, i.e., ground heat exchanger circulating pumps, pumps and fans related to the handling system (to be used for COP-sys). However, as a very first verification of the high SCOP obtained for the year 2019, come some preliminary results for the year 2023 (the first post-Covid19 year with full operation of the UMLL), with calculated respective SCOP values of 5.2 and 5.1 for summer and winter. Moreover, the present-day data (with the library in full operation) will also enable a complete analysis of the performance of all ingredients of the mechanical system, as well as a cost analysis.

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Data availability Data are available upon request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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