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# Applied analysis of geocooling technology for a residential building in Lugano

Potentiel de geocooling d'un champ de sondes  
géothermiques pour un immeuble résidentiel à Lugano

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# SUPSI

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## Riassunto

Gli edifici residenziali possono essere raffrescati grazie al cosiddetto geocooling (chiamato anche più genericamente freecooling), che consiste nello scambio e trasferimento diretto di calore dall'edificio (solitamente tramite il sistema di distribuzione del calore a pavimento) con il terreno mediante sonde geotermiche verticali (SGV).

L'efficienza di questo tipo di sistemi è al momento poco conosciuta e troppo spesso stimata in modo approssimativo; dati e analisi applicate ad un caso reale possono quindi fornire interessanti indicazioni ai progettisti da un lato, ma anche a coloro che definiscono le strategie e le politiche energetiche. Inoltre, il ritorno di esperienza e la quantificazione del potenziale di raffrescamento a pavimento permette di apprendere aspetti e limiti essenziali per la corretta progettazione di impianti analoghi.

Partendo da queste premesse, questo studio ha voluto esplorare e determinare:

- l'efficienza e le potenzialità della tecnologia del geocooling,
- la reale quantificazione di una ricarica termica del terreno tramite il geocooling,
- l'assorbimento di calore (raffrescamento) dagli appartamenti,
- i limiti e l'efficienza ottenibile da un sistema di distribuzione del calore a pavimento mediante un vero e proprio caso di studio situato al sud delle Alpi.

L'opportunità consiste nello studiare in scala 1:1 un nuovo edificio residenziale a Lugano, abbinato ad un campo di 13 sonde geotermiche verticali. Il sistema è in grado di soddisfare i fabbisogni energetici di riscaldamento e raffrescamento, oltre che la produzione di acqua calda sanitaria (ACS) dei 46 appartamenti, il tutto attraverso l'energia geotermica.

Il concetto energetico durante l'estate consiste nello sfruttare la naturale differenza tra la temperatura dell'aria interna degli appartamenti (alta) e la temperatura del sottosuolo (bassa) senza la necessità di una pompa di calore reversibile (macchina frigorifera). Inoltre, iniettando calore nel terreno sottratto agli appartamenti durante i mesi estivi, è possibile "rigenerare termicamente" il campo geotermico (in inverno, infatti, le pompe di calore raffreddano il terreno estraendo il calore per riscaldare l'edificio, in estate avviene il contrario raffrescando gli appartamenti).

Questo studio intende dimostrare che il terreno può essere efficacemente rigenerato durante i mesi estivi dopo l'estrazione di calore dal terreno in inverno. Allo stesso tempo, intende verificare che gli appartamenti possono essere raffreddati raggiungendo un buon livello di comfort interno e con un bassissimo consumo di energia elettrica.

L'attività di monitoraggio è iniziata con la stagione estiva 2016 e si è conclusa con la stagione estiva 2019. Nei primi due anni di monitoraggio sono emerse alcune criticità operative, le quali sono state documentate e si è cercato di risolverle. In questo modo l'efficienza energetica e il comfort interno sono stati migliorati fornendo interessanti indicazioni anche per ulteriori e futuri progetti.



## Résumé

Les bâtiments résidentiels peuvent être rafraîchis au moyen de ce que l'on appelle le géocooling (également appelé freecooling). Ce système consiste à évacuer la chaleur d'un bâtiment (généralement par le plancher) et de la transférer dans le sol, au moyen de sondes géothermiques verticales (SGV).

Les données permettant d'évaluer l'efficacité réelle de tels systèmes sont cependant encore lacunaires, et l'efficacité n'est souvent estimée que de façon très approximative. Des données et analyses tirées d'un cas réel peuvent donc fournir des indications intéressantes aux constructeurs d'une part, mais aussi aux acteurs qui définissent les stratégies et les politiques énergétiques, d'autre part. De plus, le retour d'expérience, et la quantification du potentiel réel de rafraîchissement par le plancher, permettent de tirer des leçons sur les aspects essentiels et les contraintes liés à la conception correcte de systèmes similaires.

Partant de ces constats, cette étude a pour but d'explorer et de déterminer :

- l'efficacité et le potentiel de la technologie du géocooling,
- la quantification réelle d'une recharge thermique du sol par le géocooling,
- l'évacuation de la chaleur (rafraîchissement) des appartements,
- les limites et l'efficacité d'un système de distribution/évacuation de chaleur par le sol, en étudiant un cas réel situé au sud des Alpes.

La possibilité d'étudier un tel système à l'échelle 1:1 a été donnée grâce à la construction d'un nouveau bâtiment résidentiel à Lugano, combiné à un champ de 13 sondes géothermiques verticales. Le système étudié est capable de satisfaire les besoins de chauffage et de rafraîchissement, ainsi que de l'eau chaude sanitaire (ECS), des 46 appartements, le tout grâce à l'énergie géothermique.

Le concept énergétique consiste à exploiter, durant l'été, la différence naturelle de température entre l'air à l'intérieur des appartements (haute) et le sous-sol (basse), sans avoir besoin d'une pompe à chaleur réversible (machine de rafraîchissement). De plus, en injectant cette chaleur dans le sol pendant les mois d'été, il est possible de le "régénérer thermiquement" (en hiver, les pompes à chaleur extraient cette chaleur du sol pour chauffer le bâtiment).

Cette étude a pour but de démontrer, d'une part, que le sol peut être efficacement régénéré pendant les mois d'été, après l'extraction de la chaleur du sol pendant les mois d'hiver, et, d'autre part, que les appartements peuvent être agréablement rafraîchis en été, tout en ne consommant que très peu d'énergie.

Le monitoring a commencé avec la saison d'été 2016, et s'est terminé avec la saison d'été 2019. Au cours des deux premières années de suivi, plusieurs critiques liées à des aspects opérationnels ont été formulées par les habitants. Ces critiques ont été documentées et des solutions ont généralement pu être trouvées. L'efficacité énergétique et le confort intérieur ont ainsi été améliorés, et des informations intéressantes ont pu être recueillies, qui seront utiles pour des futurs projets.



## Summary

A way to cool residential buildings is with so called geocooling (i.e. freecooling), by a direct heat transfer from the building (generally by the underfloor distribution) into the ground through borehole heat exchangers (BHEs).

The efficiency of this kind of systems is usually poorly known and too often roughly estimated, while real data and analysis arise interesting indications to builders and to decision makers who define policy instruments and strategies. Moreover, field information feedback and quantification of the underfloor cooling potential allows us to know essential aspects and limits for the correct planning of similar installations.

Starting from these premises, this study aimed to explore and determine:

- the efficiency and potential of geocooling technology,
- the real quantification of a thermal recharging of the ground by geocooling,
- the related heat absorbed from apartments,
- the limits of the system and the efficiency achievable from a floor heat distribution system by studying a real case study located south of the Alps.

The opportunity to study on a scale 1:1 was provided by a new residential building in Lugano, coupled with 13 BHEs. The system studied can satisfy the energy space heating and cooling needs and domestic hot water production (DHW) of 46 apartments, all this through geothermal energy.

The system realized in the building exploits the natural difference between the indoor air temperature of the apartments (high) and the underground temperature (low) without the necessity of a reversible heat pump (cooling machine). In addition, by injecting into the ground the heat removed from apartments during the summer months through the underfloor circuit, it can “thermally regenerate” the geothermal ground field.

This study intends to demonstrate that the ground can be effectively regenerated during summer months after the extraction of heat from the ground during winter seasons. At the same time, it is intended to verify that the apartments can be cooled achieving a good level of internal comfort and with a very low consumption of electricity.

The monitoring activity started in the 2016 summer season and ended with the 2019 summer season. In the first two years of monitoring, some critical operational issues emerged. They have been documented and tried to be solved. In this way the energy efficiency and the indoor comfort has been improved providing interesting indications also for further and future projects.



## Non-technical summary

With summer temperatures rising inexorably, and more intense and frequent abnormal warm outdoor air temperature moments, the cooling needs of residential buildings have been growing considerably in recent years. This leads to the increasing use of cooling machines that are often low efficiency. The effects can cause large energy requirements on the electric grid. In fact, air conditioners operate by absorbing large amounts of electricity, which allows heat to be taken from inside buildings and poured out.

Finding alternatives that allow cooling with lower energy consumption becomes a priority in order to achieve the Energy Strategy 2050 and not to compromise residential building comfort.

Geothermal energy, which is the exploitation of ground temperature through borehole heat exchangers, can be a valid answer in this respect. In practice, the soil plays a role similar to that of a cellar, whose temperature remains very stable all year round, and in the summer, it is possible to take advantage of these lower temperatures. When it is used for cooling, without a cooling machine, this is generally called geocooling (sometimes also free-cooling).

This research, funded by the Swiss Federal Office of Energy (SFOE) and the Renewable Energy Fund of the Canton of Ticino (FER), investigated the effectiveness of a heating and cooling system through geothermal energy for a new residential building with 46 apartments in Lugano, Switzerland.

The objective of the research was to identify possible critical issues and verify the energy efficiency and comfort guarantee of the system studied, with a view to replicability.

The research was based on measurements through thermal and electrical sensors installed in the thermal plant and in one of the 46 apartments, on the collaboration with the technicians involved and on the administration of a questionnaire to the tenants of the building. The data collection period started in summer 2016 and finished in summer 2019.

During the first two monitored years, various problems emerged, including some comfort dissatisfaction in the apartments and other technical and system calibration questions from the energy efficiency point of view. Most of the critical issues were improved by optimizing the system regulation during summer 2018.

It has been demonstrated that geocooling makes it possible to cool the residential building studied with a very low consumption of electricity. In addition, underfloor cooling makes it possible to respect indoor comfort standards in terms of indoor temperature. However, high energy efficiency and correct indoor comfort are strictly linked and dependent on the correct implementation of technical regulation and management of the thermal plant equipment (in particular, the water circulation pumps). The improvement in efficiency and comfort in the last two monitored years, compared to the previous two, has shown how important it is to plan the systems optimally from the beginning phases. The improvements identified, and then solved, could in fact not be identified without this careful monitoring related to the research activity. This would have meant a more efficient system than the typical air conditioning systems, but with an underexploited potential, as well as possible problems for indoor comfort.

Moreover, the case study demonstrated through real data that, with geocooling, it is possible to thermally regenerate the ground in the summer months after heat absorption of heat pumps in winter. This allows the entire system to work properly over decades, as required by specific national and international standards and recommendations.

Finally, heating and cooling indexes have also been defined, and they allow quantification of the amount of annual energy a square meter of underfloor cooling can exchange. These indexes are applicable to similar buildings and climatic conditions (in this case high energy class residential buildings). This is an interesting result because it is potentially useful for designers and technicians in order to accurately assess the potential of an underfloor cooling.



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<b>Abbreviations</b>	
BHE	Borehole Heat Exchanger
COP	Coefficient of Performance
CLA	Coefficiente di Lavoro Annuo
DHW	Domestic Hot Water
FER	Renewable Energy Fund
GRT	Geothermal-Response-Test
HP	Heat pump
kW	Kilowatt
kWh	Kilowatt-hour
kWh/y	Kilowatt-hour per year
PMV	Predicted Mean Vote
SCOP	Seasonal Coefficient of Performance
SDD	Summer Degree Days
SFOE	Swiss Federal Office of Energy
SIA	Swiss society of Engineers and Architects
SSST	Scuola Specializzata Superiore di Tecnica
WDD	Winter Degree Days



# 1 Project objectives

The project aims to demonstrate the technical feasibility of a field of geothermal probes sized to heat and cool a residential building. The cooling needs are satisfied through geocooling technology and the project wants as well to verify the rational and efficient use of electricity to cool a building with residential apartments.

The project will quantify the potential and peculiarities of geocooling in southern Switzerland. In this context there are more critical climatic conditions compared to the rest of Switzerland. The realization of the "City Residence" in Lugano Besso, a Minergie® building with 46 apartments, represents a unique opportunity to study the geocooling technology in a real case.

The project also allows us to demonstrate the possibility of recharging the ground through geocooling technology. The expected feedback and the quantification of the geocooling potential, studied in this well-documented real case aim to provide the essential knowledge for the planning and dimensioning of future installations. The context and details that led to the realisation of this research project are described in Chapter 1.2.

To achieve these objectives, a series of sensors were installed in the thermal plants to monitor temperature levels and the flows of energies exchanged with the ground and with the building (described in Chapter 2.1). In addition, the air temperature and indoor humidity of an apartment were constantly monitored. In general, particular attention was paid to the concept of regulation and control of the thermal plant, and to the internal comfort.

The monitoring activity started in the 2016 summer season and ended with the 2019 summer season. In the first two years of monitoring, some critical operational issues emerged, and they are discussed in the first part of this report (Chapter 2.2). Chapter 2.3 describes overall results, integrating also temporally further results to the previous chapter and which can compare and confirm expected results.

## 1.1 Motivation and interest of the real estate promoter

SuissePromotion Immobiliare SA was the real estate promoter of the "City Residence" in Lugano Besso, while the contractor was HRS Real Estate SA. Together with Rezzonico Impianti SA (installer of the thermal system) and Studio Tecnico Mauro Micheli (thermal designer) they signed the declaration of intent as interested actors in the project. Every partner declared their intention to collaborate with SUPSI-ISAAC in this project.

SuissePromotion Immobiliare SA was already interested in the topic of geothermal projects to promote environmental and energy sustainability from the very beginning. It was also particularly attentive to geocooling technology, understanding its potential both in terms of investment, efficiency and indoor comfort. This interest on the part of SuissePromotion Immobiliare has contributed to increasing the sensitivity of the other involved partners, contributing to the submission of the project to the SFOE (CleanTech, P&D section) and to the FER (Renewable Energy Fund of Canton of Ticino).



## 1.2 Concept and initial planning

### 1.2.1 Background

“City Residence” is located in Lugano and is a Minergie® building with 46 apartments on 6 floors, whose apartments have been inhabited since 2014. A view of the object is shown in Figure 1a. The object is located about 1 km from Lugano railway station, in a high-density residential area (see Figure 1b).



1a

1b

Figure 1 – View of the building «City Residence» in Lugano – Besso (1a) and of the yard (1b).

The monitored and studied building has a BHE field that is dimensioned based on the winter needs covered by heat pumps. During winter seasons, the ground is thermally discharged and geocooling can recharge it. This solution makes it possible not to use traditional cooling machines in the summer since the temperature level is sufficiently low to permit cooling of the apartments. This solution can significantly lower summer electricity needs for cooling.

The heating power demand, calculated at 130 kW, is satisfied by 3 heat pumps coupled to a field of 13 BHE each 200 m deep. The partial thermal recharging of the ground, which is essential to ensure the proper functioning of the system in the long term [1], is carried out by means of geocooling that works on the same geothermal field. The underfloor heating circuit of the apartments is coupled to the geothermal circuit by a heat exchanger, allowing the apartments to be cooled in summer while at the same time improving internal thermal comfort.

A solar thermal plant (of about 100 m<sup>2</sup>) is designed and dimensioned to cover part of the annual domestic hot water needs and part of the space heating needs (for more details on the system see Annex 1). The thermal recharge of the ground must be entirely guaranteed by summer geocooling. Solar thermal excess heat is not injected into the ground to avoid unbalancing and penalizing the temperature levels of the geothermal field during geocooling mode.

### 1.2.2 National state of the art

At the level of Swiss standards, geocooling is treated and described with slightly different terminologies in SIA 384/6:2010, SIA 384/7:2015 and SIA 382/1:2014, without nevertheless going too much into details. The term “geocooling” is also used in combination with more generic terms like “freecooling” and “natural cooling”. In this study, reference is always made to the definition given by SIA 384/6:2010.

Regarding technical documentation, Hollmuller e al. in 2005 presents a state of the art for geocooling technology [2]. It summarizes some results from a dozen of realized and analysed buildings that integrate this technology. He concludes that these solutions must be studied and designed as an integral part of the whole building. He also points out that theoretical and technical knowledge is available, but practical applications are few. Pahud and al. in 2008 and 2011 studies in a theoretical way the geocooling potential for administrative buildings [3, 4]. Field information feedback of practical, measured and documented experiences is almost non-existent. Another national reference, but published in an international journal, is the one published by Pahud and al. in 2012 [5].



At international level, inspecting the Scopus scientific database, no other studies have been found concerning the geocooling technology, particularly applied to the residential level. Few studies concern phase change material (PCM) for thermal storage [6], or in general the cooling of buildings through direct cooling [7, 8]. Probably the disuniformity and differences in nomenclature can lead to fragmented and scattered sources, and are therefore also difficult to identify.

### 1.2.3 Preliminary feasibility studies and final design

In July 2011, SuissePromotion Immobiliare SA asked SUPSI-ISAAC to carry out a preliminary feasibility study (through numerical simulation tools accepted by SIA 384/6, and without a GRT) that consisted in analyzing and verifying the possibility of realizing a geothermal plant, with BHE, to heat and cool a residential building in Lugano Besso. Based on the preliminary thermal demands and geological literature data, 17 BHEs of 200m depth with an "L" configuration were evaluated. The importance of regeneration of the ground was shown and planned not to be less than 25%.

In May 2012, a Geothermal-Response-Test (GRT) was performed in-situ, showing excellent thermal characteristics of the ground.

In September 2012, a final dimensioning of the BHE field was requested from SUPSI-ISAAC, using redefined thermal demands and ground properties found by the GRT. It was then calculated that 13 geothermal probes, with a depth of 200 m each, allowed coverage of the building's thermal needs as defined by the designers. Those are here summarized:

Maximum thermal power for space heating:	100 kW
Annual thermal energy demand for space heating:	95 MWh/y
Maximum thermal power for DHW production:	30 kW
Annual thermal energy demand for DHW production (only HP):	60 MWh/y
Maximum thermal power for space cooling:	80 kW
Annual thermal energy demand for space cooling:	60 MWh/y

The geothermal system has been dimensioned with simulation tools validated and recognized by the SIA norm [1] that are EED [9] and PILESIM2 [10]. The sizing is also based on a geothermal response-test (GRT) for the determination of the thermal parameters of the ground. Figure 2 shows the position of the BHE, where most of them are positioned under the building.

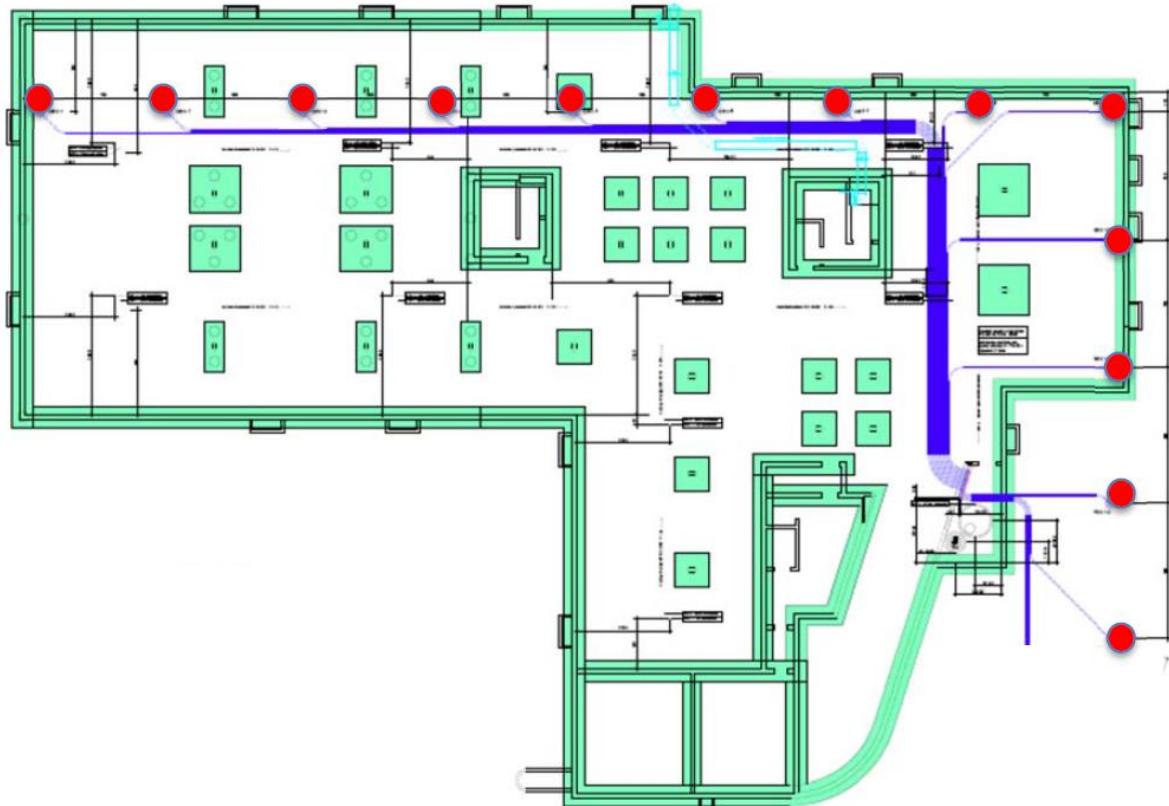


Figure 2 – Plan with the disposition of 13 BHE under the building.

The importance of maintaining the ratio between energy injected over energy extracted from the ground between a minimum value of 17% and a maximum value of 52% has been stressed for a good long-term operation of the plant. Not verifying the first condition (lower than 17%) would lead to an excessive extraction of heat from the ground compared to the injection, therefore to a rapid decrease in the temperatures of the fluid entering the ground (to below the limits imposed by the project). Not verifying the second condition (higher than 52%) would limit the expected potential for geocooling. Care has also been taken to try not to send water into the underfloor circuit of the apartments at a temperature lower than 21°C.

After the consultancy in 2012 previously described, SUPSI was no longer involved in the property until the building was fully operational and habitable (during winter 2013 – spring 2014).

Nevertheless, given the peculiarity and interest of this geothermal system, the real estate promoter agreed to proceed with a research project in order to evaluate the real energy performance of geocooling technology.

#### 1.2.4 Implementation of monitoring activities

In March and April 2015 both project funding confirmations from the SFOE and the FER arrived.

In the meantime, after the 2012 SUPSI study described above, the thermal system was nevertheless planned, designed and realised by the contractor and all the associated artisans. SUPSI was not involved in those planning phases, and the monitoring system wants to study an innovative but already existing thermal system.



Right from the start of the monitoring work, thanks to planning and discussions with the technicians involved, it was possible to develop a detailed data collection concept by contacting specific companies for the supply of sensors and measuring devices. However, due to some controversy over the delivery of the building to the apartment owners, SUPSI-ISAAC did not immediately obtain permission to access the technical thermal plant to carry out the installation works and proceed within the timing initially agreed (the plan was to start the monitoring in summer 2015). The necessary materials were decided on and purchased in order to proceed quickly once the authorization was obtained.

At the beginning of June 2016, Rezzonico SA was able to carry out the first hydraulic installation works (flow meters and thermowells).

On 18 June 2016, the building administrator provided to SUPSI-ISAAC with the access key to the technical thermal plant. SUPSI-ISAAC was thus able to begin its installation work (installation of sensors, data loggers, etc.), completing it in a few days.

On 21 June 2016 all the energy meters were in operation, while the winter-summer switchover could only take place on 26 June 2016, thus allowing monitoring of the whole summer season.



## 2 Work carried out and results obtained

### 2.1 The monitoring system

The devices and appliances that have been installed at the City Residence of Lugano-Besso are as follows:

- 1 technical cabinet with a data-logger inside.
- 5 volume flow meters.
- thermocouples cables (necessary to install 15 temperature sensors of about 10m each).
- 3 power-meters installed on the heat pumps.
- 3 power-meters on the circulation pumps dedicated to the geocooling and solar thermal circuits.
- 1 indoor weather station in one apartment (temperature and humidity).
- 1 outdoor weather station (Wi-Fi connection, without cables).

Below are the costs of the purchased materials:

*Table 1 – List and detail of costs for the installed material*

Material	Quantity	Unit costs (CHF)	Total costs (CHF)
Technical cabinet	1	488	488
Thermocouples	15	28	416
Flow meters	5	1'180	5'900
Power-meter for HP	3	188	563
Power-meter for circulation pumps	3	230	690
Data-logger (with multiplexer)	1	3'414	3166
Netatmo weather station (indoor air temperature)	1	205	205
WI-FI weather station (outdoor weather station)	1	133	133
Data communication (router, GPRS, etc.)	1	606	606
Taxes (TNT, FedEx, etc.)			316
Other (cables, net, chargers, etc.)			978
<b>TOTAL</b>			<b>13'460</b>

The purchase and the installation of the 3 power-meters for the electrical monitoring of all the circulation pumps dedicated to geocooling and solar thermal circuits, and the indoor weather station were carried out in autumn 2016.

It was not possible to install the outdoor weather station because the owner of the only garden with a north orientation never replied to SUPSI entry requests.

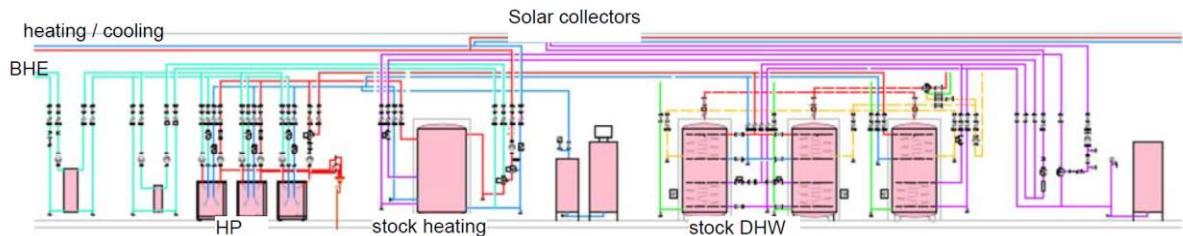


The installation of the energy counters (flow meters and thermowells<sup>1</sup> for thermocouples) was carried out by Rezzonico SA (plumber and installer of all the thermal and plumbing equipment of the building) for about CHF 10'000.

The total amount of the purchase and installation costs of the monitoring instruments was approximately CHF 24'000.

### 2.1.1 Description of the plant and of the dedicated installations

For reference, an extract from the hydraulic diagram is shown in the following figure (see Annex 1 for a larger and complete version of the figure).



*Figure 3 – Extrait du schéma hydraulique de l'installation (see also Annex 1).*

The heating power demand, calculated at 130 kW, is satisfied by 3 heat pumps coupled to a field of 13 BHEs each 200 m deep. The partial thermal recharging of the ground, which is essential to ensure the proper functioning of the system in the long term [1], is carried out by means of geocooling that works on the same geothermal field. The underfloor heating circuit of the apartments is coupled to the geothermal circuit by a heat exchanger, allowing the apartments to be cooled in summer while at the same time improving internal thermal comfort.

Different solar thermal collectors are designed and dimensioned to cover part of the annual domestic hot water needs, but excess heat is not injected into the ground to avoid unbalancing and penalizing the temperature levels of the probe field. The thermal recharge of the ground must be entirely guaranteed by summer geocooling.

The following simplified scheme provides a better understanding of the hydraulic system (see Annex 2 for a larger and complete version of the figure). In addition, the position and symbols of each sensor and meter are indicated.

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<sup>1</sup> In Italian: pozzetto termometrico ; in French: doigt de gant.

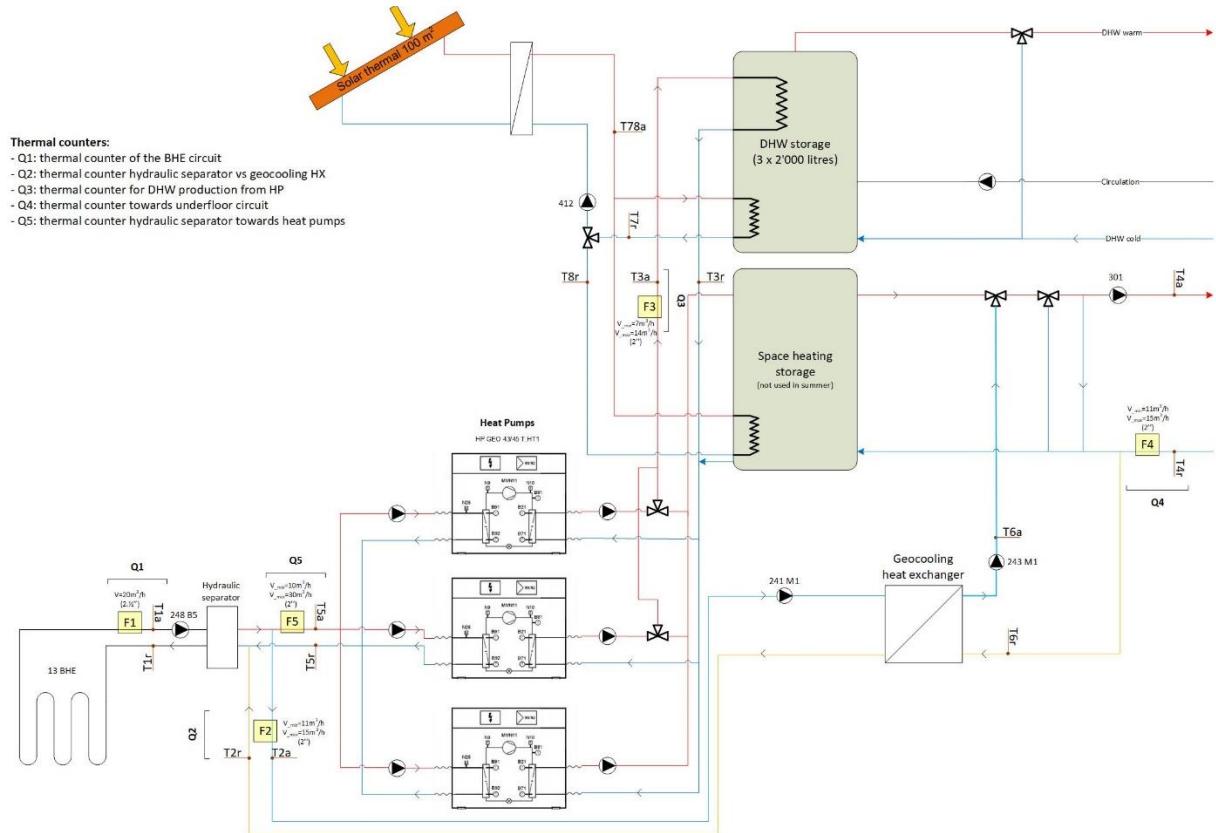


Figure 4 – Simplified scheme of the hydraulic system. Monitoring concept with positioning of the different sensors and meters (see also annex 2).

Referring to Figure 4, the energy meters installed in the technical room are listed and described as follows.

A total number of 5 heat meters (named "Q") have been installed, each composed by one electromagnetic flowmeter (named "F") and two temperature sensors (thermocouples, named "T").



Figure 5 – Heat meter, with 1 flowmeter (on the right) and 2 thermocouples (on the left).



The different heat meters are the following:

- Q1: heat meter of the BHE field. This is necessary for the monitoring of the thermal exchange with the ground. In this counter, water with glycol circulates;
- Q2: geocooling heat meter after the hydraulic separator and before the heat exchanger. In this counter, water with glycol circulates;
- Q3: heat meter after heat pumps, only for DHW production. In this counter circulates simply water;
- Q4: heat meter towards the underfloor heating (heating and cooling of apartments). In this counter simply water circulates;
- Q5: heat meter after the hydraulic separator towards heat pumps. In this counter flows water with glycol.

The main concept of the monitoring is to detect all heat flows inlet and outlet from the ground (F1) as well as those inlet and outlet from the hydraulic circuit of the underfloor circuit (F4). The F2 and F5 meters allow us, during summer operation, to exactly know the energy for geocooling or for DHW production. Due to the hydraulic separator, inserted to avoid creating imbalances in circulation pumps with different operating conditions, the flow rates can be different. For example, without the production of DHW, the heat output detected by F4 is equal to that of F2, but the flow rates and temperature differences (which depend on the setting of the circulation pumps) are not necessarily equal. During the summer period it is also possible to create a transit of thermal energy between F2 and F5, therefore not counted by F1 (there is a hydraulic separator<sup>2</sup> between them). The F3 meter has been positioned mainly to verify and quantify, during the summer period, the operation of the heat pump for DHW production.

The hydraulic separator consists of a vertical, empty vessel inside, equipped with 4 openings that allow the fluid inlet and outlet of geothermal circuit on one side, and fluid inlet and outlet to the heat pumps and geocooling circuits on the other side.



Figure 6 – Hydraulic separator (insulated to prevent condensing).

If the flow rate in one circuit is equal to the other one, the hydraulic separator does not perform any function, while if one of the two circuits has a different mass flow rate compared to the other one, thanks to the hydraulic separator part of this flow rate is recirculated. In this way all the circulation pumps work independently. However, in this case, if there is flow to the heat pumps in summer (DHW production), a part of the heat can also directly flow through the geocooling circuit, but without the possibility of managing the loads. Since the hydraulic separator does not have enough volume as a thermal storage could have, it does not allow management of the thermal power peaks: the thermal power necessary to

<sup>2</sup> In Italian: separatore idraulico; in German: Hydraulische Weiche



produce DHW is not equal to the one exchanged through the geocooling underfloor circuit. This can implicate heat transfer from Q5 to Q2, with consequent imbalanced and low temperature in the geocooling circuit. Given the short duration of these moments, the geothermal circuit pump is unable to react and compensate for this effect by enough increasing the flow rate. In summer, DHW production, although possible, is rare because of the solar thermal system.

The following figure shows a simplified scheme of the plant with the main hydraulic components, during the summer working period.

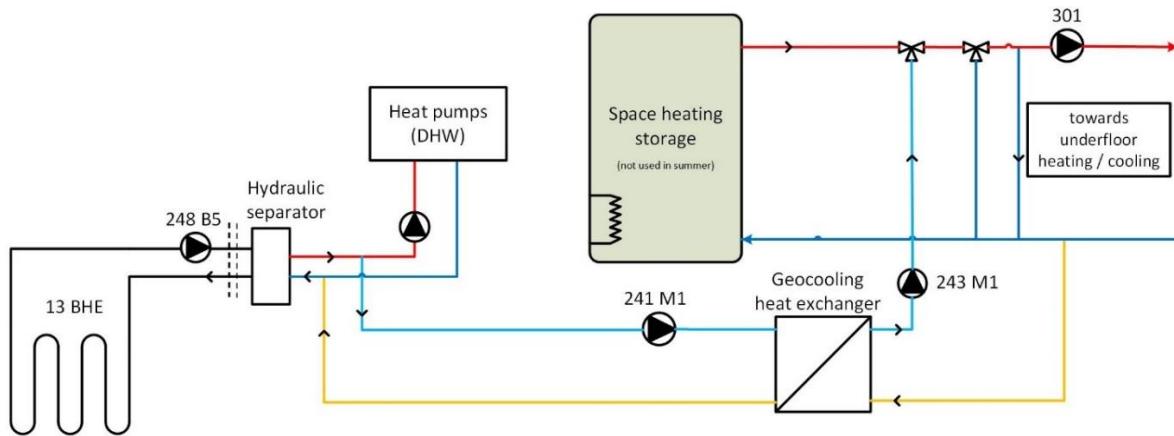


Figure 7 – Hydraulic scheme showing the summer cooling mode using geocooling.

Moving to the winter mode, the geocooling circuit is manually deactivated, the heat pumps charge the heat storage tank and the underfloor circuit allows heating of the apartments. The heat storage tank is not used during the geocooling mode and the water after the heat exchanger directly flows towards the underfloor hydraulic circuit.

For the different power meters, 5 circulation pumps were installed to monitor the electrical consumption. They are described below:

- Pump 248 B5: circulation pump of the BHE field. The operation of this pump is associated with the Q1 heat meter;
- Pump 241 M1: this pump, in geocooling mode, sends fluid from the hydraulic separator to the heat exchanger. The operation of this pump is associated with the Q2 heat meter;
- Pump 243 M1: this pump, in geocooling mode, sends fluid from the heat exchanger toward the underfloor circuit. This pump has two temperature measurements associated, but no flowmeter
- Pump 301: this pump sends warm water in winter and cold water in summer to the underfloor heating of apartments. The operation of this pump is associated with the Q4 heat meter;
- Pump 412: circulation pump of the solar thermal collector field. This power meter is necessary to evaluate, together with some temperature sensor, the operation of the solar thermal system. Three temperature measurements are associated with this pump (one for the forward temperature from the solar collectors, one for the return temperature from DHW storage, and one for the return temperature from space heating storage). No heat meter has been installed on the solar thermal circuit.

The four pumps dedicated to geocooling have been electrically monitored to permit evaluation and calculation of the efficiency of geocooling, as they are the only power consumption for floor cooling. The monitoring of the solar thermal pump is outside the scope of the study, however, it was considered interesting to have it in order to correct any possible malfunctions in the summer, so as to avoid operating the HP in the summer, thus further discharging the soil.



### 2.1.2 Information and description of the monitoring equipment

The data-logger is a Campbell (CR6 model), with an AM25T multiplexer for the connection of a total number of 15 thermocouples.

The thermocouples are T-type (copper-constantan) calibrated in-situ in a water bath. They have all been inserted in thermowells with inside a conductive paste to improve heat transfer.

The water flowmeters are electromagnetic types, in order to minimize the pressure drops in the pipes and keep them in place without creating any future inconvenience to the system (breakage of rotating parts, incrustations, etc.). These are Siemens SITRANS FM MAG 3100P flowmeters (diameters optimized to improve the accuracy, depending on the nominal flow rate).

The power meters are ICPDAS, model PM-3133-160-MTCP Modbus TCP (100A).

Data communication between the data logger and the database server is guaranteed by a SIERRA Wireless AirLink LS300 gateway module. This device communicates through the GSM/3G network via a dedicated SIM card with monthly subscription of about 20 CHF; an Antenna-wall-U (Net Module) has been installed outside the technical room due to the weak GSM/UMTS signal inside the room.

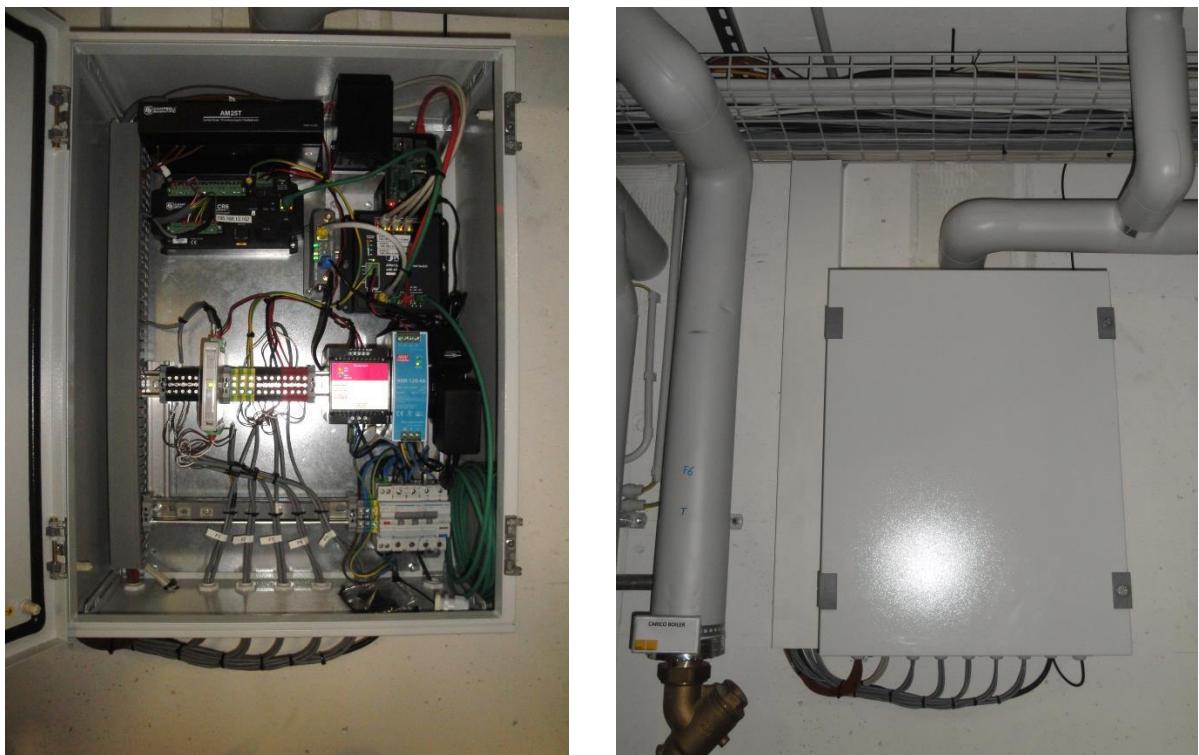


Figure 8 – Technical cabinet with datalogger, power-supply, communication, etc.

In addition to all costs relating to the systems and installers described herein, the internal costs of SUPSI personnel have not been listed. A lot of time was necessary for meeting and soliciting all the involved partners to obtain detailed and formal information.

All the system installations, except for the hydraulic works, were carried out by SUPSI technicians and engineers.



### 2.1.3 The system for data acquisition, visualization and supply

Thanks to the GSM Internet connection with a dedicated SIM card in-situ, the data were stored on a SUPSI server and can be viewed and downloaded via Grafana (that is an open source platform for the organization and graphic display of data).

The following image shows an example of data visualization on Grafana:



Figure 9 – Data display examples of 3 thermal energy meter (temperatures on the left, and volume flows on the right).

From the Grafana portal, it is possible to download data for further analysis. All the data collected have a sampling with a time interval of one second; depending on the needs, the portal allows downloading of data with different time samples (1 minute, 10 minutes, 1 hour, etc.).

An alarm system was also set up in the Grafana portal, which sent an email communication in case of:

- lack of internet communication
- hole during data acquisition
- exceeding of set limits of acceptance (e.g. temperature too much low or high).

These alarms allowed correction of any possible problem, resulting in almost no acquisition holes. They allowed reporting to the maintenance company some unexpected problems during the operation of the plant.



## 2.2 First two operation years (2016 – 2017)

The purpose of this data-analysis, which was done approximately in the middle of the monitoring project, was to discover and establish possible weaknesses of the thermal system, and therefore to propose improvements and optimizations. Following the results obtained from the analysis, some optimization measures on the regulation and control of the plant were proposed to the client.

### 2.2.1 First results and preliminary evaluations

The following diagram shows the extracted energy (red) and the injected energy (blue) from and to the ground through the BHE field, with a monthly resolution, during the analysed period.

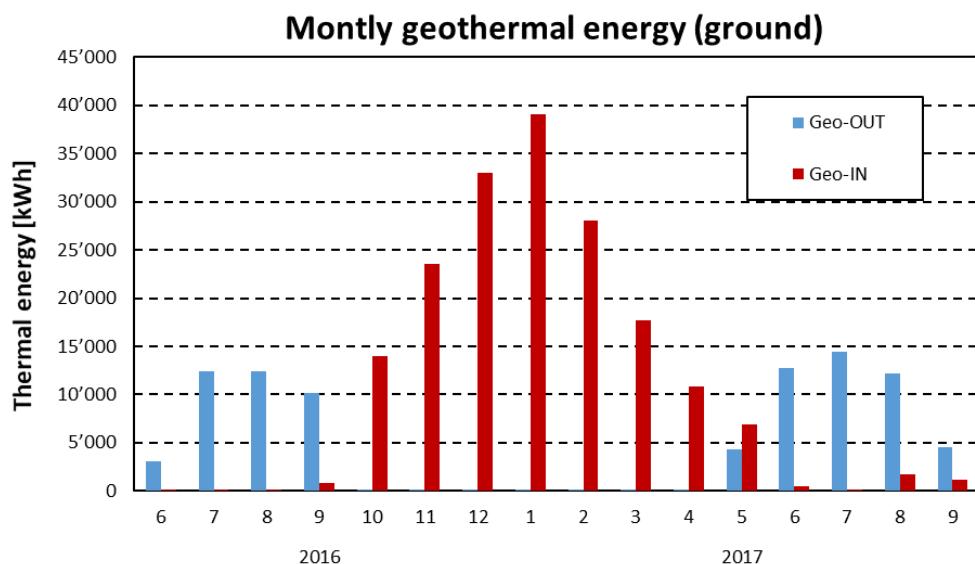


Figure 10 – Energy extracted and injected into the ground during the period June2016 - September2017.

During summer months there can also be also some heat extraction from the ground, due to two main factors:

1 - The graph shows monthly averages and the seasonal switching moment can occur in the middle of the month (usually September and June). In those months there can therefore be both a winter and a summer mode.

2 - Despite the installation of a solar thermal system, in summer, heat pumps can also produce DHW. If this is not all exchanged simultaneously with the geocooling circuit through the hydraulic separator (see Figure 7), then it is exchanged with the ground.

A comparison between the energy trend for the space cooling for summer 2016 and summer 2017 is shown in the following chart. The 2017 summer switching period started about one month in advance compared to the 2016-2017 switching period, and ended two weeks before.

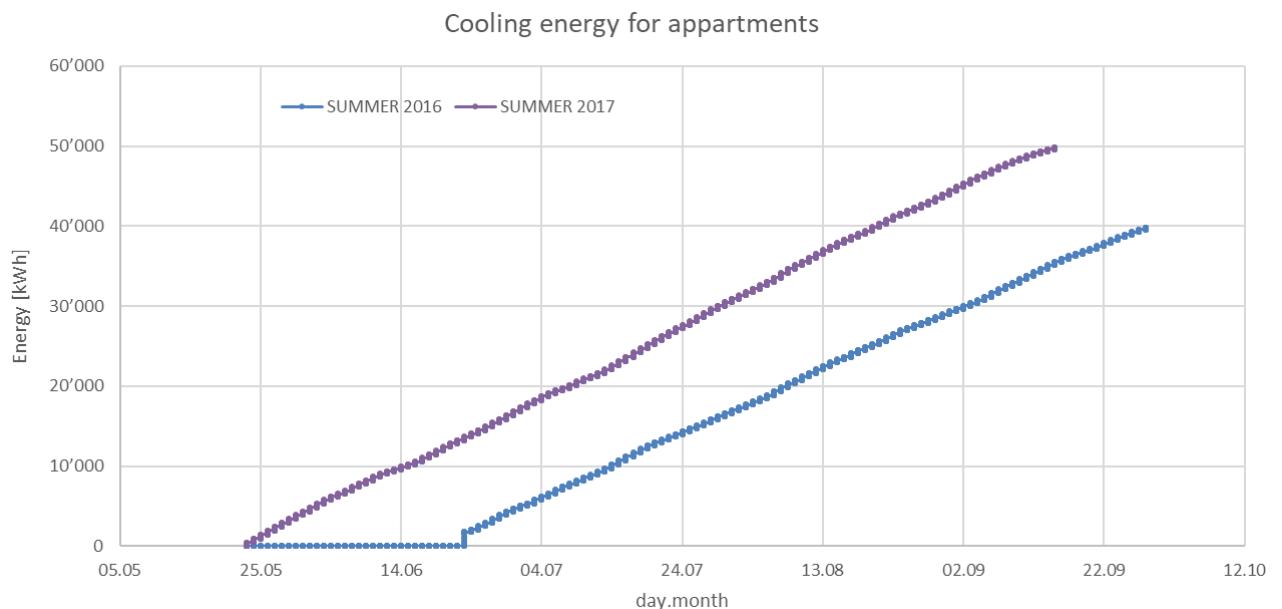


Figure 11 – Seasonal cooling energy for apartment (cumulative).

The power supply and the normal operating hours are almost the same for both years (parallel lines). Dividing the cooling energy by the hours of the circulation pump operation, an average power is obtained of about 22 kW<sub>th</sub> for two summers. This means that the lower energy of 2016 is mainly due to a delayed departure of geocooling (1'850 hours versus 2'200 hours).

For a detailed analysis of the temperature levels, a specific and typical moment was analysed with a maximum daily peak in the summer cooling. During this diurnal peak power of several hours and about 30 kW<sub>th</sub> (underfloor circuit) the temperatures levels are the following:

Indoor air temperature:	23.5 °C
Tset cooling up:	23.5 °C
Tset cooling down:	23.0 °C
Treturn cooling water:	21.9 °C
Tforward cooling water:	19.6 °C
Treturn ground fluid:	16.4 °C
Tout ground fluid:	14.7 °C
Tmean ground initial:	13.7 °C

Considering all the hydraulic circuit of the plant, considering the BHE, the underfloor and all the intermediate circuits, the forward-return temperature differences are rather low. One direct effect of the monitoring is to increase the relative error in the thermal energy metering. These small temperature differences are due to relatively large mass flows in the hydraulic circuits. All the circulation pumps of the system are modulating the mass flow, but these are not set to regulate their flows. Flows are set for a constant operation during the whole year, according to the logic of a winter regulation with fixed maximum power.

All temperature levels ranging from the ground to the air temperature in the apartment are shown in the following figure.

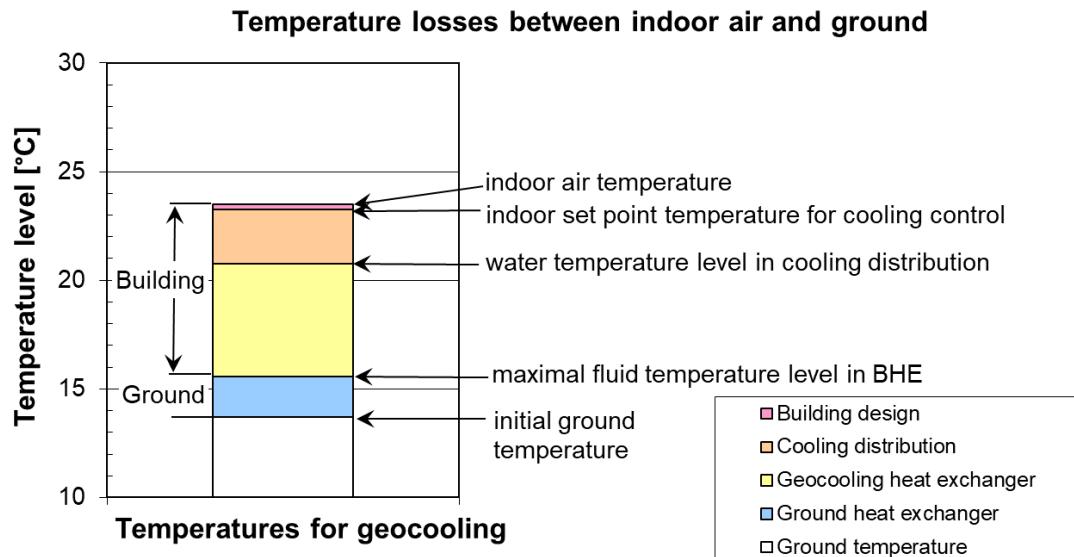


Figure 12 – Temperature levels – geocooling mode.

The greatest loss of temperature occurs at the level of the heat exchanger, while at the level of the apartment the operating range is rather small. This aspect and the direct consequence are explored and shown in the comfort-dedicated section (2.2.3).

The electricity consumption of the circulation pumps 241 (geocooling intermediate circuit), 243 (geocooling intermediate circuit), 248 (ground circuit - BHE), and 301 (underfloor circuit) during the "summer 2016" and "summer 2017" is summarized in the following table.

Since no power meters had already been installed in summer 2016, the electricity consumption of the circulations pumps has here been estimated based on the operation of the summer season 2017, in particular by imposing the linearity between the volume flow and the electric consumption.

Table 2 – Actual electrical consumption of the circulation pumps necessary for geocooling mode.

Circulations pumps	Consumption 2016 (estimation / real) [kWh <sub>el</sub> ] 23.06.16-28.09.16	Consumption 2017 (real) [kWh <sub>el</sub> ] 23.05.17-15.09.17
248, ground circuit (BHE)	966	1'133
241, intermediate circuit	212	237
243, intermediate circuit	87.8	120
301, underfloor circuit	1'135	1'435
<b>Total</b>	<b>2'402</b>	<b>2'925</b>

The geocooling system has been theoretically optimized assuming an increase in the forward-return temperature difference fixing a typical value of 3K for the BHE circuit (pumps 248 and 241) and of 5K for the underfloor circuit (pumps 243 and 301); theoretical electricity consumptions have been calculated and listed in Table 3. In the reality, to achieve these values, the different circulation pumps should modulate their flows and consequently modify their electricity consumption.



Table 3 – Minimum theoretical electrical consumption of the circulation pumps for geocooling mode.

Pump	Consumption 2016 (potential) [kWh <sub>el</sub> ] 23.06.16 - 28.09.16	Consumption 2017 (potential) [kWh <sub>el</sub> ] 23.05.17 - 15.09.17
248, ground circuit (BHE)	330	435
241, intermediate circuit	121	142
243, intermediate circuit	200	234
301, underfloor circuit	346	511
<b>Total</b>	<b>996</b>	<b>1'322</b>

Geocooling efficiency has been evaluated using the electrical consumptions of the circulation pumps necessary for the space cooling of the apartments during the summer period 2016 and 2017.

Geocooling efficiency of the building system is thus defined as the ratio between the thermal energy used for the space cooling of the apartments and the electrical energy used by the circulation pumps.

Table 4 – Seasonal geocooling efficiency (real).

	23.06.16 - 28.09.16 (real)	23.05.17 - 15.09.17 (real)
Thermal energy (geocooling) [kWh <sub>th</sub> ]	36'354	47'751
Circulation pump [kWh <sub>el</sub> ]	2'402 (estimated)	2'925
<b>Geocooling seasonal efficiency [-]</b>	<b>15</b>	<b>16</b>

On the other hand, the potential geocooling efficiency of this system, based on an optimization of the circulation pumps operation described before, is as follows:

Table 5 – Seasonal geocooling efficiency (potential).

	23.06.16-28.09.16 (optimized)	23.05.17-15.09.17 (optimized)
Thermal energy (geocooling) [kWh <sub>th</sub> ]	36'354	47'751
Circulation pump [kWh <sub>el</sub> ]	996	1'322
<b>Geocooling seasonal efficiency [-]</b>	<b>37</b>	<b>36</b>

These values are further detailed in Chapter 2.3 with the optimization measures (in particular, see section 2.3.7).

## 2.2.2 Evaluation of the measurement accuracy

The true real value of a physical phenomenon is never known, but it is possible to establish with some probability the interval within which it is located [11]. The measurement accuracy of a physical quantity (for example, in the case of energy that is a multiplication of temperature difference and flow rate) is determined by the uncertainty value of this result. The accuracy depends on the measurement methods, the temperature sensors, the data logger, and the measurement circuits used.

In this project the accuracy was calculated for the annual energies during the years 2016 and 2017. The aim was to evaluate the value of the acquisition and the feasibility of making energy results as reliable as possible.

The following table shows the margins of error that have been assumed, and fixed, on the reading of the data. These values arise both from the technical information made available by the sensors and the data logger, as well as from the experience acquired by other thermal data acquisition systems [12].



Table 6 – Errors and accuracies considered in the calculations.

<u>Thermocouples</u>	
Data-logger statistical error	0.04 K
Calibration statistical error (from 3°C to 60°C)	0.10 K
Statistical error of two different measurements	0.14 K
Error of the jumper (data logger element)	0.30 K

<u>Volume flow meter</u>	
Flow meter accuracy	0.2%
Calibration accuracy	2.0%
Transmission accuracy	0.2%
<b>Total accuracy of flow measurement</b>	<b>2.4%</b>

Due to the small temperature differences between the supply and return temperature of the circuit, large margins of uncertainty about the thermal measurements during the cooling period have been calculated. The accuracy of the measurements is around 10% for winter thermal energy (heating) and around 30% for summer thermal energy (cooling). These percentages state a precision; they represent therefore a statistical value (it means that, with a probability of 95%, the real value is placed within the range of 10% for heating energy or respectively 30% for cooling energy).

Also in order to improve the accuracy of the measurements, especially during summer monitoring, it was decided to propose some measures to optimize the plant to increase its  $\Delta T$  (temperature difference in meters, supply and return) during the summer season.

Some proposals for plant improvement are described in the following paragraph 2.2.4.

### 2.2.3 Summer comfort 2016 and 2017

It was possible to analyse the indoor temperatures of an inhabited apartment since one tenant agreed to install an air monitoring system in his living room.

These preliminary analyses cover the monitoring period 2016-2017, further analyses are presented in paragraph 2.3.9.

The following graphs show the internal temperatures as a function of the external temperature according to SIA 382/1 [13] and EN15251 [14].

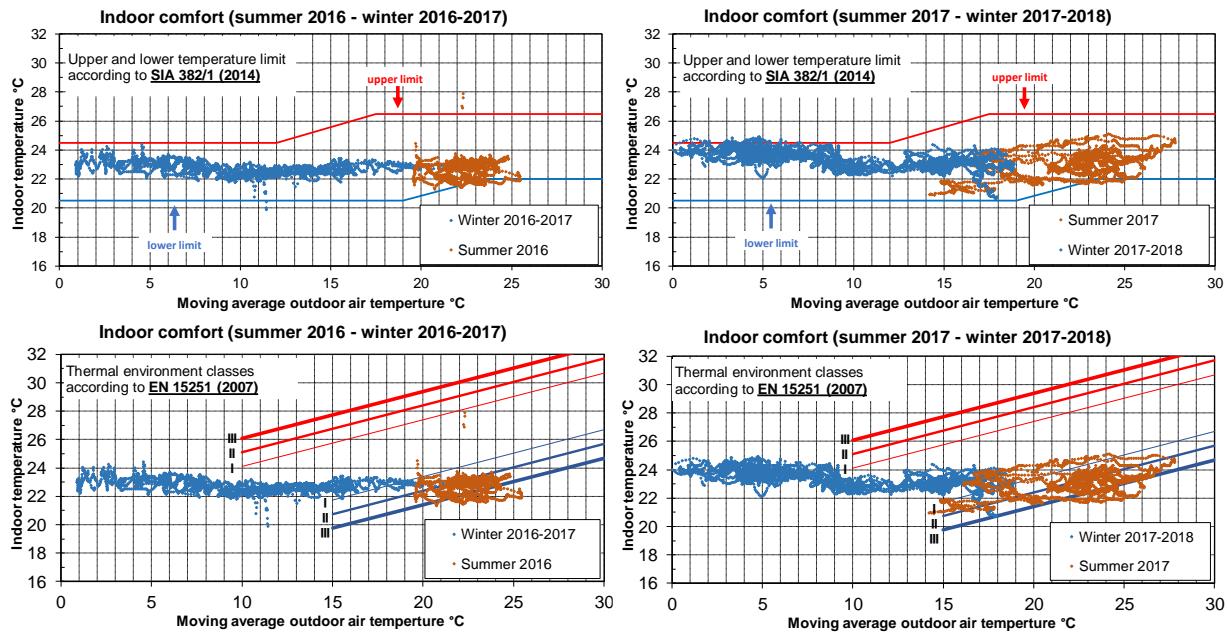


Figure 13 – Evaluations of the indoor comfort of an apartment compared to SIA 382/1 and to EN15251 (blue points winter seasons, orange points summer seasons). For larger graphs see Annex 4.

The standard SIA 382/1 (2014) indicates lower and upper limits that should not be exceeded (few exceptions are described in the standard).

The standard EN 15251 (2007) defines classes (named I, II, III, and IV) that relate outdoor and indoor air temperature to adaptive comfort and categories of PPD (Percentage of Persons Dissatisfied, that predicts the percentage of thermally dissatisfied people who feel too cool or too warm). The IV category has not been represented in the graphs.

Table 7 – Comfort classes following the EN 15251 (2007).

Categories	Overall thermal state of the body PPD %
I	< 6
II	< 10
III	< 15
IV	> 15

The space cooling seems to be sometimes quite excessive, and the actual indoor temperature is often arranged in the lower part of the diagrams.

Moreover, low air temperatures could cause several drawbacks with high relative humidity in the apartments. Since no dehumidification takes place with an underfloor cooling, the temperatures should be kept towards the upper limit of the graphs. Moreover, the mechanical and controlled Minergie® ventilation also contributes in summer to increase the relative humidity of the apartments by sending outside air, which in summer has a high level of relative humidity.



#### 2.2.4 Improvement proposals and implementations

During the summer season 2017 all the professionals involved were met, with the aim of showing and discussing the results of the project. The aim was to propose and implement some measures to improve the system. The proposals were verified by the technicians involved and, where possible, implemented by the various professionals responsible for the system.

From the research point of view, the aim was to reach as soon as possible an optimal situation of the system, and proceed with a monitoring that could give reliable results in line with the state of the art. The optimization measures were requested from the company that had implemented the system regulation in the past and the contractor company (HRS) paid for the work.

The proposed and implemented optimizations<sup>3</sup> are as follows:

- Flow rate regulation of the geothermal BHE circuit (underground circuit). During 2016 and 2017, there was a constant flow rate of the geothermal circuit. The system, designed to operate with a variable flow rate, was in fact configured with a fixed and rather high flow rate, especially during the summer. Adjusting the system, by varying the flow rate, reduces electricity consumption of the pumps and increases the efficiency of geocooling. It also improves the accuracy measurement of the Q1 thermal meter. To enable this adjustment, an additional temperature sensor was placed on the return pipe of the geothermal circuit, ensuring that the pump was able to adjust to a fixed temperature difference set at 3K. In the 248 B5 pump, a module was installed to modulate the flow rate following a 0-10V signal.
- Based on the operation of pump 248 B5, the intermediate circulation pumps (241 M1 and 243 M1) were also adjusted. All circulation pumps were equipped with signal modules to follow the operation of the first pump (248 B5) and provide the correct supply to the underfloor circuit pump (301).
- Flow regulation of the circulation pump 301 (underfloor circuit). A constant flow rate was found in the 2016 and 2017 seasons: technicians found a faulty pressure sensor in the plant. This pressure sensor is intended to reduce the flow rate when the apartment circuits are closed. After replacement, in autumn 2018 it was possible to check with the installers that the sensor was correctly working, however, the adjustment margin remained extremely small. It is not possible to control pump 301 by varying the flow rate and fixing the  $\Delta T$ . Since in the summer seasons 2016 and 2017 the  $\Delta T$  was smaller than 1K, it was therefore decided to reduce the flow rate in summer by maintaining the same prevalence, in order to obtain a temperature difference of at least 2K. A better regulation of this pump was not possible (and in any case this depends on the setting that the technician sets manually during each change of season).
- Increase the supply temperature of the geocooling circuit, with the aim of augmenting the temperature in the apartments and consequently reducing the relative humidity. With this hydraulic plant concept, it is not easy to set a summer temperature curve. Implementation of both of the above-mentioned measures were attempted: setting of the temperature difference  $T$  of the geothermal circuit (pump 248 B5 - geothermal probes) and decrease of the flow rate in the apartments circuit (pump 301).

All these proposals to improve the regulation of the thermal plant were made during 2017 and spring 2018, with the aim of being implemented during the next two operation years (2018 - 2019). It was therefore possible to see the effects of the new regulation in the period 2018 and 2019. All results are described in the Chapter 2.3.

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<sup>3</sup> Implementations have been made to optimize summer operation. However, the 248 pump works all year round, so this optimization also covers the winter period. Pumps 241 and 243 in winter operation are switched off. Pump 301 also runs all year round, however, as said it was not possible to optimize it.



## 2.2.5 Questionnaire to the tenants

It was agreed with the administrator to propose an anonymous questionnaire to all the owners/tenants to assess their satisfaction and how they used the indoor thermostat.

The questionnaire, sent out in autumn 2018 (so a few months after the optimizations implemented), included questions on basic knowledge of the temperature settings, possible comfort issues, and appreciation of how the cooling system functioned.

Out of the total of 46 apartments, only 7 correctly filled in questionnaires were collected. Nevertheless, the collected responses allowed us to draw some interesting considerations, shared by most of the respondents:

- indoor temperature was sometimes perceived as too cold (especially during the mid-season or summer days with lower temperatures);
- indoor temperature was sometimes perceived as slightly too warm (probably during very hot days);
- high humidity perceived inside the apartments (difficulty in drying damp cloths such as towels and bathrobes or difficulty in drying floors after washing);
- poor knowledge about the use of the internal thermostat;
- poor knowledge about the limitations (and advantages) of an underfloor cooling system.

The aim of the questionnaire was on the one hand to raise tenants' awareness of the features and limitations of geocooling, and on the other hand to collect useful feedback to confirm the first results and optimisations implemented.

## 2.2.6 Optimisation effects in summer 2018 and extension of monitoring

The new regulation of the thermal system (described in paragraph 2.2.4) was fully implemented in the first half of 2018. After the technical checks in spring 2018, temperature sensors on the circulation pumps and flow control modules on the circulation pumps (flow modulation to fix the  $\Delta T$ ) were installed in June 2018. July 2018 it was necessary to debug the software; it was in fact noticed that the modulation of the mass flow was in conflict with the opening of some valves that, instead of reducing the flow rate, produced a very frequent on-off of the circulation pumps. At the end of July this and other minor problems were solved.

August 2018 and September 2018 are therefore representative in showing benefits of the new regulations implemented.

SFOE and FER were asked to extend the contract in order to study also the 2019 summer season. The extension was accepted by both.

In June 2019, however, due to some system malfunctions, tenants complained that the apartments were not cooling down. The problem was caused by the closing of the valves in the apartments due to reaching of the dew point. It was then seen that this lowering of the flow temperature was linked to the momentary non-operation of the solar thermal system and therefore to the production of DHW by the heat pumps. The heat pumps lowered the temperature in the hydraulic separator to about 15°C and therefore also the underfloor temperature supply (the mixing valve was not set for this unforeseen event). Subsequently, the system control settings were changed again, which unfortunately led to the cooling being blocked several times during the 2019 summer season. SUPSI was not informed about what kind of and how many control changes were made<sup>4</sup>; analysing the acquired data, it can be assumed that the numerous arrests were always due to the approaching dew point in the apartments. Compared to the previous year, the mass flow in the underfloor circuit was increased and the supply temperature rarely exceeded 20°C.

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<sup>4</sup> As mentioned in the previous paragraphs, SUPSI did not supervise the design and installation of the thermal system (except by fixing the correct number of BHE). When the system was already working, SUPSI monitored its operation and suggested some optimization, which were validated and carried out by the technicians involved. Technicians take care of the maintenance of the hole system and collect requests or solicitations from the administrator or owners; they did not always inform SUPSI.



## 2.3 Overall and detailed results from summer 2016 until summer 2019

During the first two years (summer 2016 and summer 2017), the results were used especially to arrive at and suggest a series of useful optimizations to the plant and to the users.

In autumn 2017 a series of energy efficiency optimization measures were agreed with the technicians involved and the building administrator; these were fully implemented at the end of July 2018. August and September 2018 show representative results after the optimizations implemented. Summer 2019 was monitored to confirm the validity of these results.

The start and end dates of the summer and winter seasons are listed here. Switching is done manually by the person responsible for maintenance, and usually at the request of the administrator (there is no automatic control logic to switch from one mode to another).

*Table 8 – Table with start and end dates of the analysed seasons.*

<u>Season</u>	<u>Start date</u>	<u>End date</u>	<u>Season duration [days]</u>
Summer 2016	23.06.2016	28.09.2016	97
Winter 2016-2017	28.09.2016	23.05.2017	237
Summer 2017	23.05.2017	15.09.2017	115
Winter 2017-2018	15.09.2017	23.05.2018	250
Summer 2018	23.05.2018	03.10.2018	133
Winter 2018-2019	03.10.2018	04.06.2019	244
Summer 2019	04.06.2019	07.10.2019	125

With the aim of studying and verifying geocooling findings over several seasons, the whole monitored period from 2016 to 2019 has been studied in more detail, in order to obtain more detailed and aggregate results. In this paragraph, the results before optimization are also compared to those after optimization.

### 2.3.1 Ground and building thermal balance

The following diagrams show the monthly energy exchanged with the building through the underfloor circuit (corresponding to heat meter Q4, see Figure 4) during the entire monitored observation period (Figure 14) and the monthly energy exchanged with the ground through the BHE field (Figure 15). Thermal flows are calculated and distinguished with average time intervals of 10 minutes. Based on these, monthly energies have been evaluated.



### Monthly building demand (underfloor circuit)

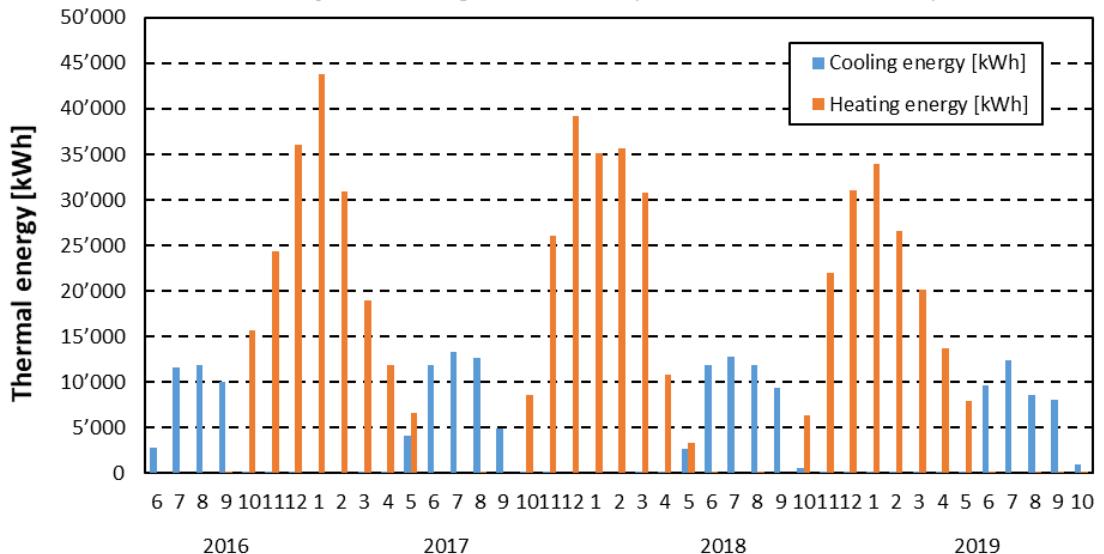


Figure 14 – Graph with monthly energy demands of the building (heat meter “Q4”) during the whole monitored period 2016-2019.

### Monthly geothermal energy (ground circuit)

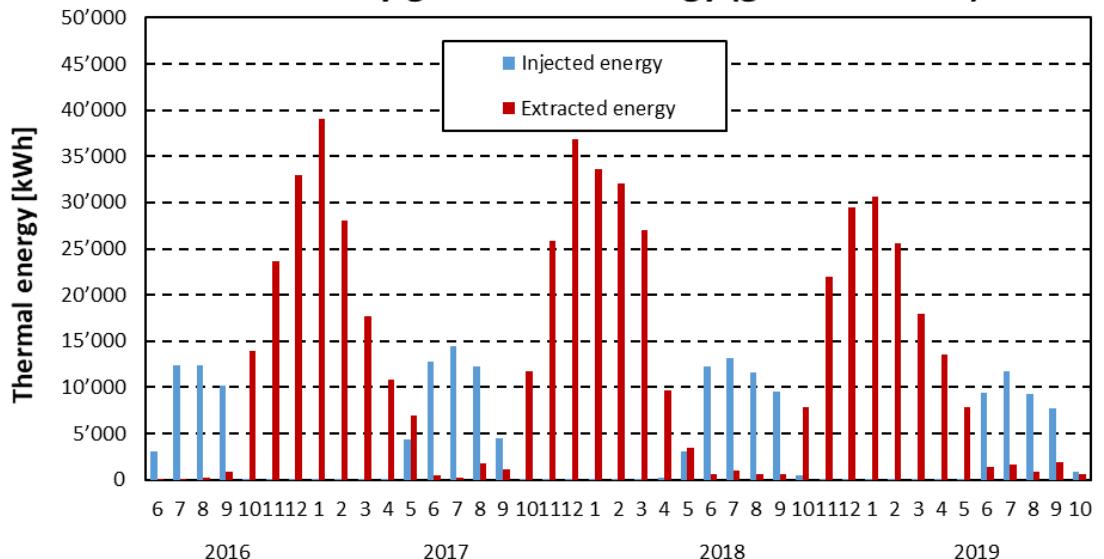


Figure 15 – Graph with monthly energy exchanged with the ground (heat meter “Q1”) during the whole monitored period 2016-2019.



To clarify the energy flows monitored, the following figures show the annual energies in the 2017-2018 winter season and 2018 summer season (flows are positive in the direction of the arrow).

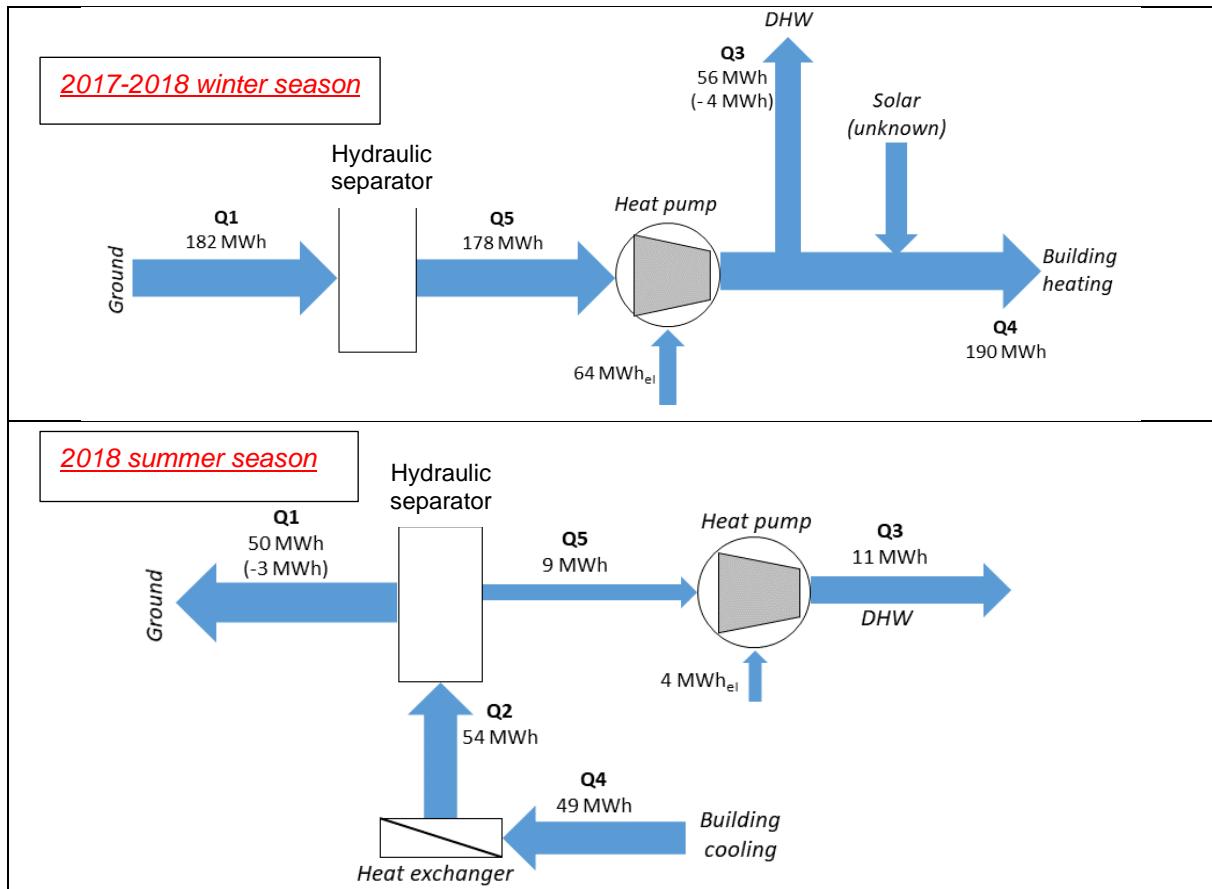


Figure 16 – Schemes with energy flows in the 2017-2018 winter season and 2018 summer season.

All the numbers shown in figure 15 are seasonal energies, calculated by adding together 10-minute average power values.

Negative values measured by heat meters mean heat flow inversions. In summer 2018, the  $Q_1$  measures a flow inversion when heat pumps produce DHW, in the absence of supply from solar panels. The heat meter  $Q_3$ , in winter 2017-2018, probably due to hydraulic short circuits, also measure some inversions of the thermal flow.

In addition, due to combined effects of thermal losses, instantaneous measurements, small hydraulic short-circuits and measurement technologies (see section 2.2.2), there are clear inaccuracies in the annual energy balances (especially in the hydraulic separator, heat exchanger, and heat pump).

Solar thermal panels can potentially contribute to cover apartments heating needs, as a second priority after DHW production. This contribution was only partially monitored through temperature sensors and without a mass flow sensor. By the way, according to the collected data, the energy contribution was minimal considering the overall and annual thermal balance.

Comparing the annual space heating energy consumption of the apartments to the building energy reference area [15] of 5'700 m<sup>2</sup>, the following specific values can be calculated:



*Table 9 – Table showing space heating consumptions at different monitored periods and the relative space heating consumption indexes.*

<u>Period</u>	<u>Space heating consumption</u>	<u>Space heating consumption indexes</u>
Winter 2016-2017	188.4 MWh	33.1 kWh/m <sup>2</sup> y (119 MJ/m <sup>2</sup> y)
Winter 2017-2018	190.2 MWh	33.4 kWh/m <sup>2</sup> y (120 MJ/m <sup>2</sup> y)
Winter 2018-2019	162.0 MWh	28.4 kWh/m <sup>2</sup> y (102 MJ/m <sup>2</sup> y)

Comparing the annual cooling energy absorbed from the apartments to the building energy reference area [15] of 5'700 m<sup>2</sup>, the following specific indexes can be calculated:

*Table 10 – Table showing space cooling consumptions at different monitored periods and the relative space cooling consumption indexes.*

<u>Period</u>	<u>Space cooling consumption</u>	<u>Space cooling consumption indexes</u>
Summer 2016	36.4 MWh	6.4 kWh/m <sup>2</sup> y (23 MJ/m <sup>2</sup> y)
Summer 2017	47.8 MWh	8.2 kWh/m <sup>2</sup> y (30 MJ/m <sup>2</sup> y)
Summer 2018	49.1 MWh	8.6 kWh/m <sup>2</sup> y (31 MJ/m <sup>2</sup> y)
Summer 2019	39.3 MWh	6.9 kWh/m <sup>2</sup> y (24.8 MJ/m <sup>2</sup> y)

In order to be able to better explain the annual difference in the calculated indexes, further and more in-depth analyses have been carried out in the paragraph 2.3.3, also to extend these indexes to similar buildings in terms of energy performances.

### 2.3.2 Thermal recharge of the ground

To evaluate the annual variation of thermal recharge of the ground, in terms of heat injection over heat extraction [4], it's necessary to consider complete years and calculate the value of this thermal recharge every entire year. In this evaluation it is necessary to set a starting season, therefore the first summer season 2016 has been eliminated in this analysis.



The annual recharges calculated are therefore as follows:

*Table 11 – Annual energy extracted and injected into the ground with the consequent thermal recharge.*

	Period	Extraction	Injection	Recharge [%]
1	Winter 2016-2017 + Summer 2017	173.3 MWh/y	44.6 MWh/y	25.7%
2	Winter 2017-2018 + Summer 2018	181.8 MWh/y	46.9 MWh/y	25.8 %
3	Winter 2018-2019 + Summer 2019	154.3 MWh/y	32.4 MWh/y	21.0 %

Concerning the annual quantities of heat injected into the ground, the part of the energy extracted by heat pumps for the DHW summer production has been subtracted.

On the other hand, to consider average and global values of thermal recharge "R" over the years, all the seasonal injected energies "I" (four summers) and all the seasonal extracted energies "E" (three winters) were taken into account.

According to the following formula, a global and average recharge value can be calculated as follows:

$$R = \frac{\frac{(I_1 + I_2 + I_3 + I_4)}{4}}{\frac{(E_1 + E_2 + E_3)}{3}}$$

By also considering a seasonal heat extraction during summer 2016 of 37.1 MWh/y, the average recharge of the ground during the whole monitored period is calculated at 23.7 %.

This value is important when taking into consideration a longer period of working exercise of the plant, because seasonal thermal effects implicate long-term dynamics behaviours [16]. Typical commercial and validated dynamic simulation programs in the field of geothermal design [9, 10] reproduce the same thermal needs every year, with trends that must comply with regulatory limits over a future period of decades. The real and effective thermal recharge must be verified and confirmed over the years, in order to eventually adapt to values defined during the planning initial phases. A large geothermal system, that usually has a huge extension of BHEs, should in this sense be planned and sized very carefully in this sense to avoid serious future malfunctions of the overall project (e.g. ground freezing, system shutdown).

### 2.3.3 Annual degree-days and specific climatic indexes

The annual heating and cooling requirements were compared to the summer and winter degree days, calculated for Lugano on the basis of the temperatures monitored [17] for each specific season. A degree day is computed as the integral of a function of time that varies with temperature. The function is truncated to upper and lower limits that vary by organism, or to limits that are appropriate for climate control. This computation can be done both for heating and cooling thermal needs. The daily average temperatures were calculated with a time step of 10 minutes.

In Switzerland, for the calculation of winter degree days (WDD), each individual heating day on which the daily average outside air temperature does not exceed 12 °C is taken into account, setting the indoor air temperature at 20 °C. These degree days are defined as WDD<sup>5</sup> 20/12 [18].

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<sup>5</sup> In Italian "GG" (gradi giorno)



There is no Swiss regulatory definition for the calculation of summer day grades (SDD). They have therefore been defined as the daily sum of the positive differences between the daily average outside air temperature ( $T_{m\_ext}$ ) during the summer season duration (n) and the indoor temperature with a set point of 25°C.

$$SDD = \sum_{m_{ext}=1}^n T_{m\_ext} - 25$$

In Tables 12 and 13 a relation between thermal needs (following the results in Tables 9 and 10) with external seasonal condition has been established.

*Table 12 – Annual indexes for winter space heating demand considering WDD.*

Period	<u>WDD</u>	Heating index Wh/m <sup>2</sup> /WDD
Winter 2016-2017	2279	14.5
Winter 2017-2018	2350	14.2
Winter 2018-2019	2041	13.9

*Table 13 – Annual indexes for summer space cooling demand considering SDD.*

Years	<u>SDD</u>	Cooling index Wh/m <sup>2</sup> /SDD
Summer 2016	73	87.9
Summer 2017	106	77.5
Summer 2018	112	76.7
Summer 2019	113	61.1

There is good coherence in the seasonal indexes for heating. This seems to be missing for the summer cooling. A particularly low index has been calculated for the 2019 summer season; this is probably due to the occasional shutdown of the system in some moment, due to the problems described in paragraph 2.2.6.

### 2.3.4 Comparison and analysis with dynamic simulations

Considering a longer working period of the plant, long-term thermal effects must be taken into account [16]. Typical simulation programs in the field of geothermal design reproduce the same thermal needs every year, with trends that must comply with regulatory limits over a future period of decades. In this paragraph, the monitored thermal fluxes from and to the geothermal field, have been reproduced for 50 years using the Pilesim2 program [10]. The real and effective thermal recharge has thus been verified in order to show and clarify long-term thermal effects.

The software uses hourly thermal energy values (thermal energy actually exchanged with the ground), and then calculates the respective fluid temperature over the years. During the first three years, the simulated supply temperature was compared with the monitored supply temperature.

The following two graphs show the trend of the minimum and maximum temperature of the fluid entering into the ground, with a trend over 50 years.

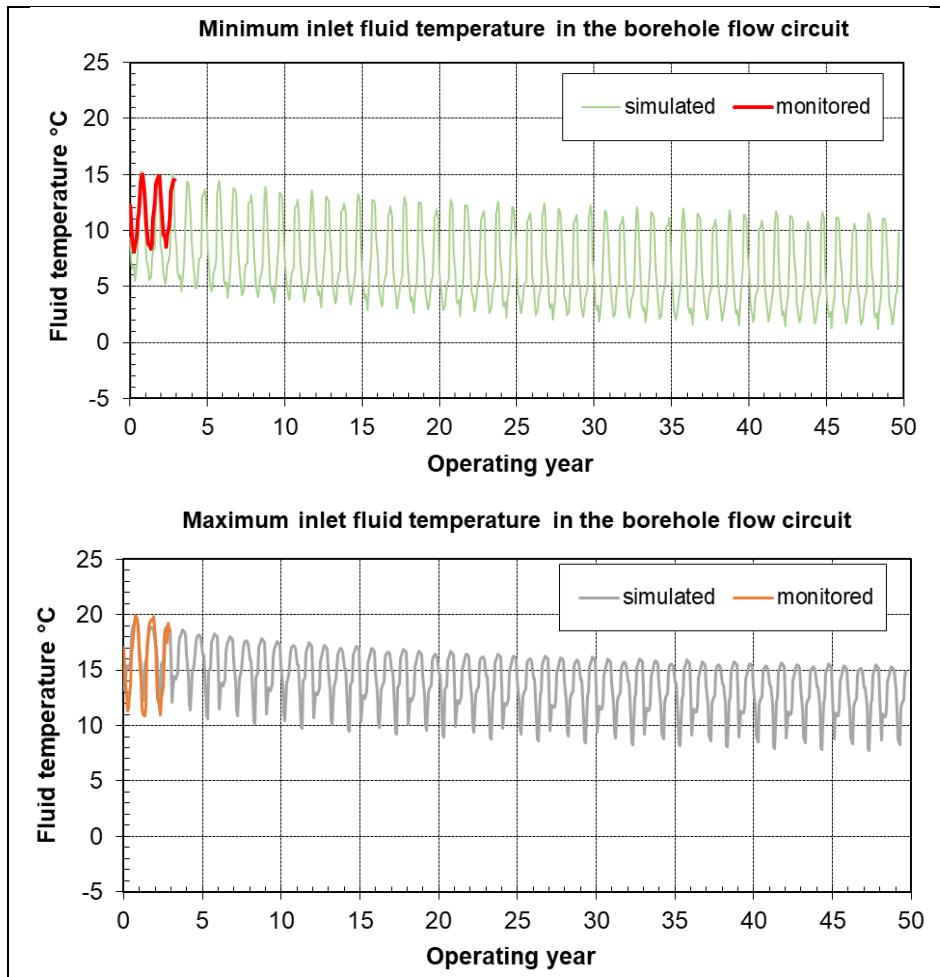


Figure 17 – Graphs with minimum and maximum inlet fluid temperature in the BHE circuit over 50 years (simulated and monitored values).

Similar to the previous graphs, the following two show the minimum and maximum fluid temperature entering into the soil, with a particular focus on the first three monitored years.

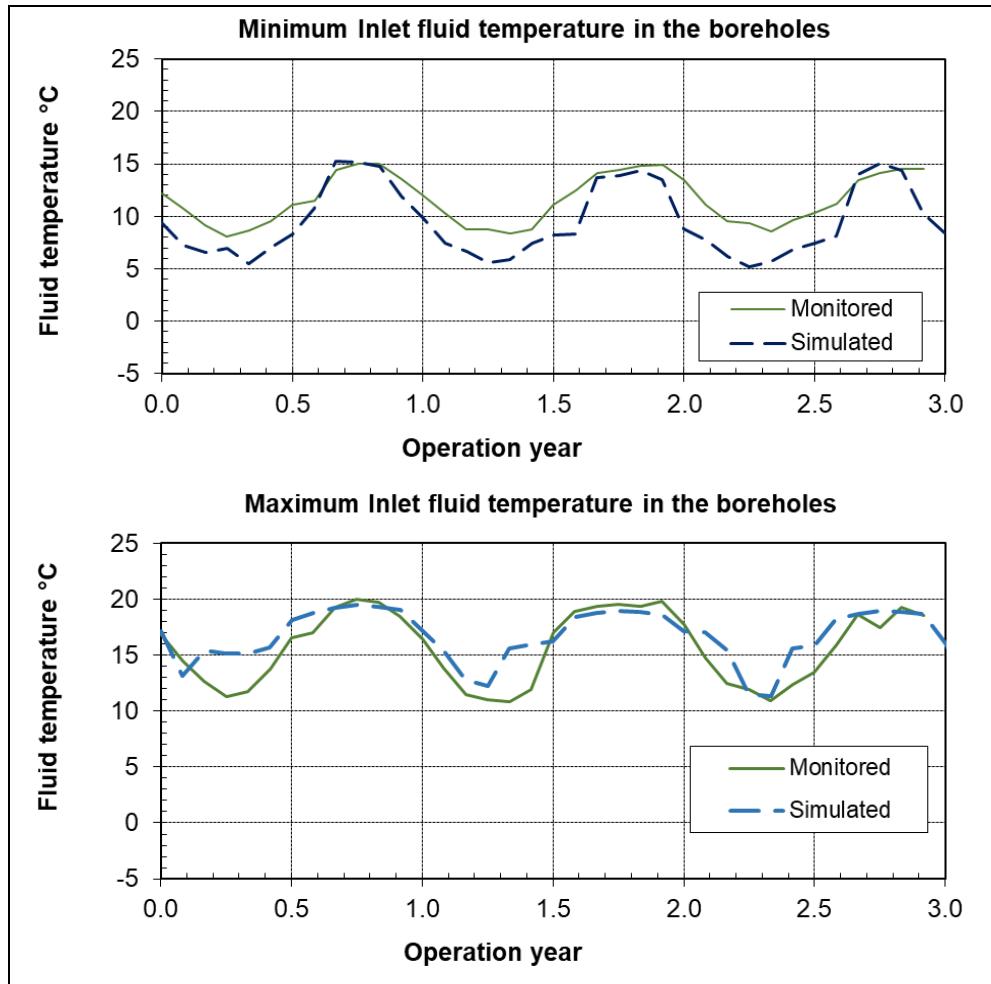


Figure 18 – Graphs with minimum and maximum inlet fluid temperature in the BHE circuit over 3 years (simulated and monitored values).

During winter periods, the temperature difference between simulated and monitored data is not enough correspondent. This is mainly due to the fact that the software always considers a constant  $\Delta T$  of 3K, but in reality (therefore from monitored data) a  $\Delta T$  of 5K can also be reached when there is simultaneous heating and DHW production. The energies exchanged are the same between monitored and simulated data, but the flow rates are therefore different (and consequently also the  $\Delta T$ ). Nevertheless, simulations are considered reliable since during summer periods the temperature difference is adequately correspondent. In this way the good correspondence between the simulated and monitored values during the summer periods strengthens and confirms the following results.

The previous analysis and its results aim to validate the simulation tool by comparing it with real data. Thanks to the simulation tool it is therefore possible to extend the analysis by making a sensitivity analysis that gives further results.

During the summer periods, the geocooling supply temperature (underfloor cooling) depends on the underground fluid temperature. The correct functioning of the geocooling depends on the correct setting of the thermal plant, the control system must adapt all the equipment to the thermal needs of the building (in term of correct supply temperature, mass flow variation).

The following analysis consists of a sensitivity study applied to this building, by means of simulations of the geocooling supply temperature using monitored thermal energies. For simplicity, the analysis does



not consider any temperature losses in the heat exchanger and in the intermediate circuit between geothermal BHE and underfloor cooling circuit. Below is a simplified diagram of the geothermal circuit and apartment circuit used in the model of the software, and used in the following simulation results. The thermal conditions of the hydraulic geocooling circuit fixed into the model of the software are:  $T_1=T_3$ ,  $T_4=T_2$  and  $(T_1-T_2=3K)$ .

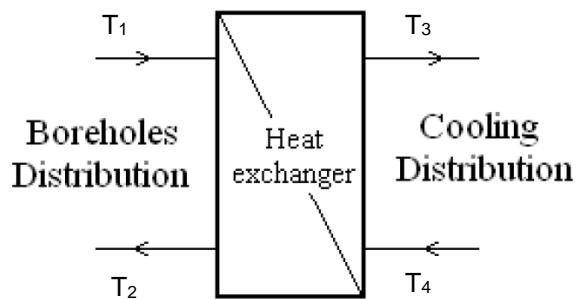


Figure 19 – Hydraulic scheme of the geocooling heat exchanger (simplified hypothesis).

The condition  $T_1=T_3$  is difficult to achieve due to the thermal efficiency of heat exchangers. Nevertheless, it is a simplification that allows, in the following analysis, a better understanding of the importance of temperature levels and the relevance of small variations on the potential extractable from the ground.

Several simulations have been carried out by setting different supply geocooling temperatures, thus looking at the effect on the cooling potential of the building.

The following graph shows results of the geocooling potential in terms of energy for apartment needs, and depending on different supply temperatures. 100% represents the total coverage of the monitored (therefore real) cooling needs of the building.

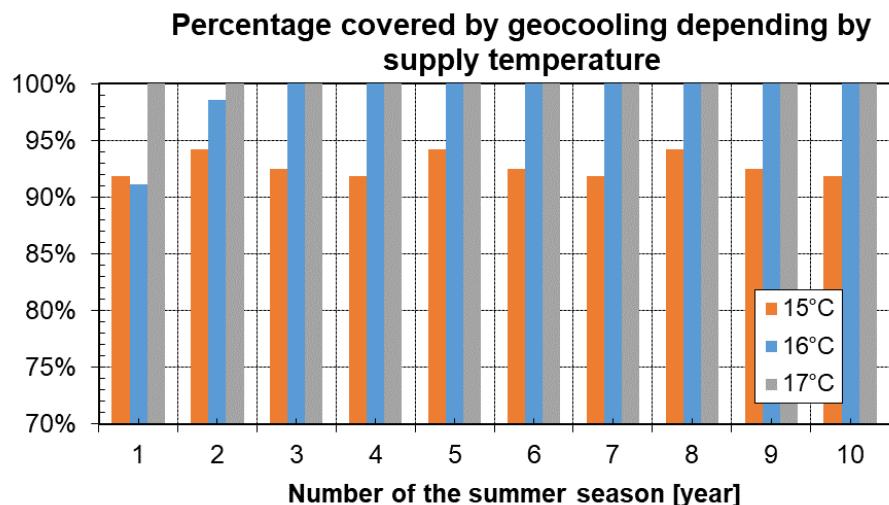


Figure 20 – Graph with annual trend covering cooling needs by geocooling, with different supply temperatures.

A temperature of 15°C that circulate in the ground (supply temperature, corresponding to  $T_1$  of Figure 19) would never completely satisfy the cooling needs currently required by the building. This temperature is too low and similar to the temperature of the ground, and the heat exchange between BHEs and the surround ground is not optimal (during the summer period, due to the geocooling thermal recharge, the ground temperature is increasing more and more, until it is impossible to exchange heat).

With a geocooling flow temperature of 16°C, it is possible to notice the effect of seasonal cooling of the ground. The heat extraction during winter, which is higher than the summer heat injection, in fact implies



a progressive cooling of the ground over the years; thanks to this effect it would be possible to cover the cooling needs only from the third operation year.

For all the higher supply temperatures ( $\geq 17^{\circ}\text{C}$ ), geocooling would cover all the building cooling needs. These simulations have the purpose of evaluating the potential of geocooling related to the supply temperature and does not consider the problems related to the apartment (such as different efficiencies of the underfloor circuit depending on the supply temperature, or the surface condensation of the floor and the humidity in the apartments).

### 2.3.5 Energy signature and temperature profiles

The energy signature is a diagram that shows the energy consumption of the building depending on the outside temperature [19]. The energy signature is represented in the Cartesian plan by some points (hourly or daily consumption versus outdoor air temperature) that are distributed along an interpolating line obtainable by linear regression. The result indicates average values in power, for given outdoor temperatures.

The graphs with summer and winter energy signatures and for all monitored years (from 2016 to 2019) are presented in Annex 3, with hourly and daily average values. In Annex 3 there are also diagrams showing the dependence of the supply and return underfloor temperature versus outdoor air temperature.

As an example, the graphs for the winter 2017-2018 and summer 2018 seasons are shown below, with average daily power values (the graphs for all seasons are in Annex 3).

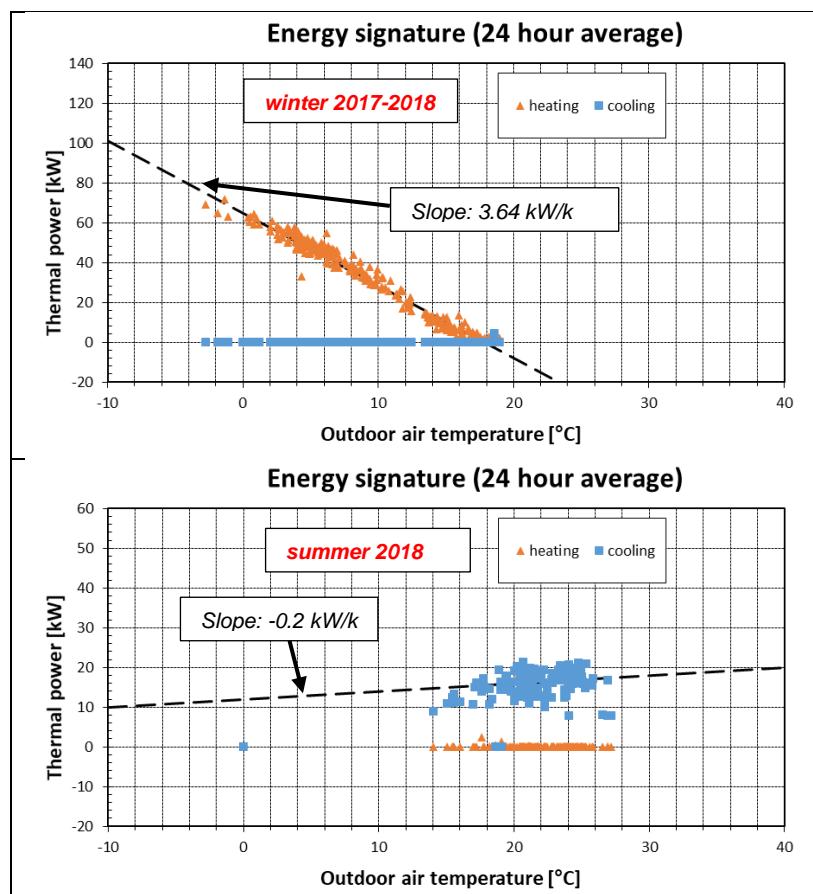


Figure 21 – Energy signature for winter 2017-2018 and summer 2018 (all seasons in Annex 3).

As result of the energy signature, there are winter thermal losses (slope of the interpolator line) of about 3.64 kW/K (Figure 21); the supply temperature trend also confirms this operational mode (Figure 22).



During summer there is a gradient of about  $-0.1 \text{ kW/K}$  for seasons 2016 and 2017 (see Annex 3) and about  $-0.2 \text{ kW/K}$  (see Figure 12) in the following 2018 and 2019 seasons. This increase in gradient, although reduced, could be partially explained by the optimizations implemented in 2018.

The graphs with the forward and return temperatures for winter 2017-2018 and summer 2018 are showed below (the graphs for all seasons are in Annex 3).

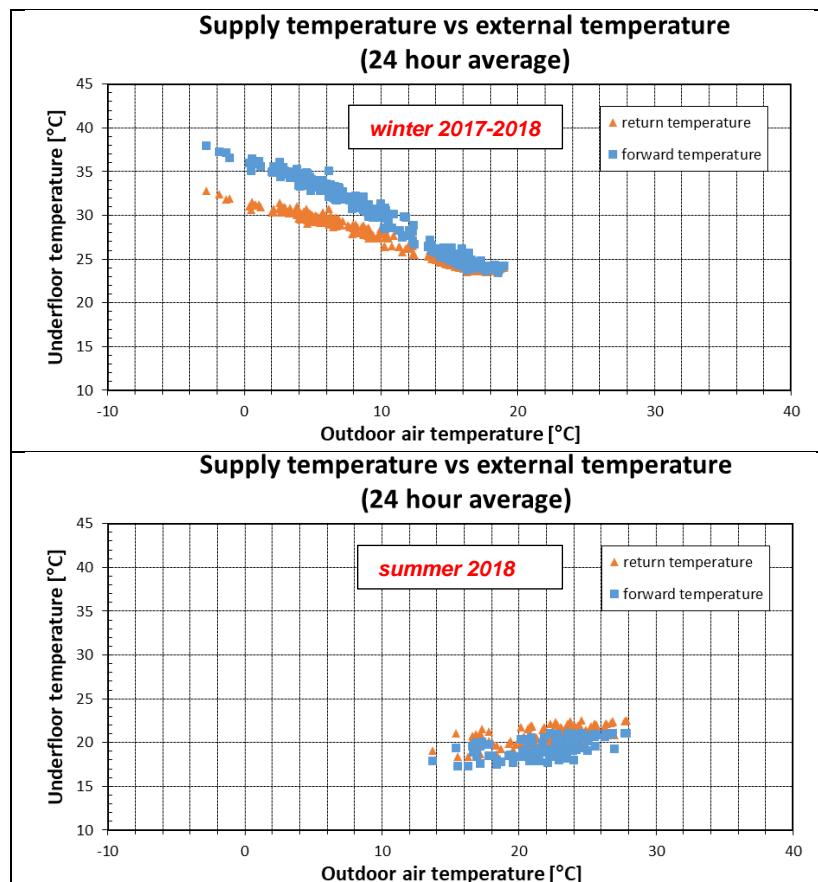


Figure 22 – Forward and return temperatures for winter 2017-2018 and summer 2018 (all seasons in Annex 3).

Following Figure 22, the trend of summer temperatures, with a maximum limit of around  $21^\circ\text{C}$  and a minimum of around  $17^\circ\text{C}$ , shows an almost non-dependence on the outside temperature except in the 2018 season. The 2019 summer season shows a decrease in the flow temperature with the increase in the external temperature, a phenomenon that leads to the probable closure of the valves in the apartments to reach the dew point and consequent cancellation of the heat exchange in the apartments (see comments paragraph 2.2.6).

As result of the energy signatures, the peaks in power exchanged in the apartments, are:

- About 120 kW for the winter heating (without DHW production)
- About 40 kW for the summer cooling

Following the space cooling and heating needs (summarized in Tables 9 and 10), and calculating the seasonal duration (duration of the heating or cooling season, in hours) and the working period hours of the plant (duration of actual heating or cooling, in hours – e.g. by removing the night-time switch-off of the system), the seasonal equivalent thermal power (kW) and the seasonal equivalent working hours (h) have been calculated.



The following formulas can clarify the concept:

$$\text{Seasonal equivalent thermal power [kW]} = \frac{\text{Space thermal consumptions [kWh/y]}}{\text{Seasonal duration [h]}}$$

$$\text{Seasonal equivalent working hours}^6[\text{h}] = \frac{\text{Thermal peak power [kW]}}{\text{Space thermal consumptions [kWh/y]}}$$

These two values make it possible to extend the energy and power values found in this study to other locations and, based on local climatic conditions, to make quick estimations of energy and cooling power.

The following tables show the results obtained for the summer and winter seasons:

Table 14 – Winter seasonal equivalent power and hours.

Seasons	Seasonal duration [hour]	Working period [hour]	Seasonal equivalent thermal power [kW]	Seasonal equivalent working hours [h]
Winter 2016-2017	5'664	4'523	41.7	1'570
Winter 2017-2018	5'808	4'637	41.0	1'585
Winter 2018-2019	5'880	4'737	34.2	1'350

Table 15 – Summer seasonal equivalent power and hours.

Seasons	Seasonal duration [hour]	Working period [hour]	Seasonal equivalent thermal power [kW]	Seasonal equivalent working hours [h]
Summer 2016	2'328	1'858	19.6	909
Summer 2017	2'760	2'203	21.3	1'174
Summer 2018	3'190	2'571	19.1	1'227
Summer 2019	2'952	2'378	16.5	983

This information can be extended to other geothermal systems and useful for switching from peak power to energy demands, as well as for correctly dimensioning the circulation pump for a required mass flow (to maintain a certain level and difference of the supply temperatures). These values could also be compared and related to the degree days presented in Tables 12 and 13.

### 2.3.6 Working operation of heat pumps

A realistic indication of energy efficiency over an entire year can be achieved by using Seasonal Coefficient of Performance (SCOP) of a heat pump. SCOP gives an indication of how efficiently a heat pump operates in different conditions. During summertime HPs must supply only DHW needs, at higher supply temperature compared to space heating needs during wintertime.

<sup>6</sup> In Italian: ore equivalenti a pieno carico; in French: heures équivalentes à pleine charge.



SCOP is defined as the ratio between the thermal energy produced and the electrical energy required.

Since we have the "Q5" heat meter before the heat pumps evaporators (see Figure 4), with the electrical monitoring of the HP compressors, it is possible to estimate the SCOP using the following formula:

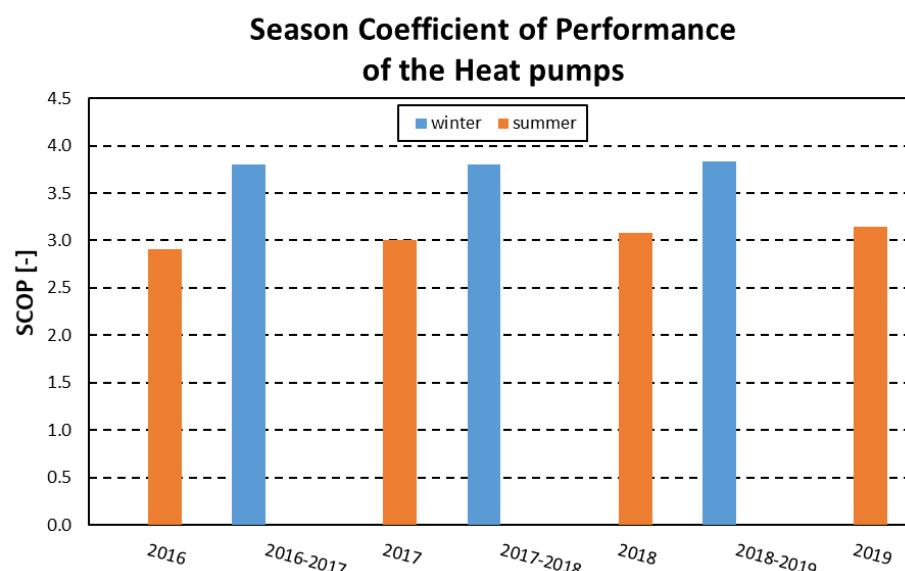
$$\text{SCOP} = \left( \frac{E_{th} \text{ evaporator } [\text{kWh}]}{E_{el} \text{ compressor } [\text{kWh}]} \right) + 1$$

The electricity absorbed by the circulation pumps and electrical devices has not been considered in the calculation of the SCOP (the electrical power meters of heat pumps measures the electrical consumption of the compressors).

*Table 16 – Calculation of the Seasonal Coefficient Of Performance (SCOP).*

Seasons	Evaporator thermal energy (HP) [kWh <sub>th</sub> ]	Compressor electric energy (HP) [kWh <sub>el</sub> ]	SCOP [-]
Summer 2016	1'695	887	2.9
Winter 2016-2017	167'306	59'741	3.8
Summer 2017	6'794	3'387	3.0
Winter 2017-2018	178'260	63'625	3.8
Summer 2018	8'705	4'186	3.1
Winter 2018-2019	157'069	55'517	3.8
Summer 2019	14'315	6'667	3.1

The following graph shows the SCOP for the winter and summer seasons starting from summer 2016 until summer 2019.



*Figure 23 – Graph with different seasonal values (summer and winter) of the SCOP.*



The operation of heat pumps in summer is exclusively due to the production of DHW when solar thermal is not sufficient, while in winter heat pumps produce both space heating and DHW.

It was not possible to perform the analysis that took into account the heat coming out of the heat pump (condenser) because there was no heat meter for every different energy flow (DHW, space heating and solar thermal flux).

These results are interesting for use in similar geothermal simulations in order to more correctly assess the amount of energy extracted from the ground by heat pumps (and thus better simulate long-term thermal effects).

### 2.3.7 Summer electricity balance and geocooling efficiency

In the 2016 and 2017 summer seasons, the flow rates of the circulation pumps and the temperature differences between flow and return in the various hydropower circuits were analysed. These showed a wide margin of energy optimization; in fact, most of the pumps were running at constant and high flow rates, resulting in high power consumption and small temperature differences.

In agreement with the owners and technicians, the circulation pumps were set to vary their flow rate while keeping the temperature differences fixed in accordance with the state of the art and regulations in force [20].

All the following graphs only show thermal and electrical energies during the summer periods (useful for geocooling efficiency calculation).

Referring to Figure 4 with the hydraulic scheme, the following table shows and compares the electricity monthly consumption of the pumps 241 (separator circuit), 243 (intermediate circuit), 248 (ground circuit) and 301 (underfloor circuit).

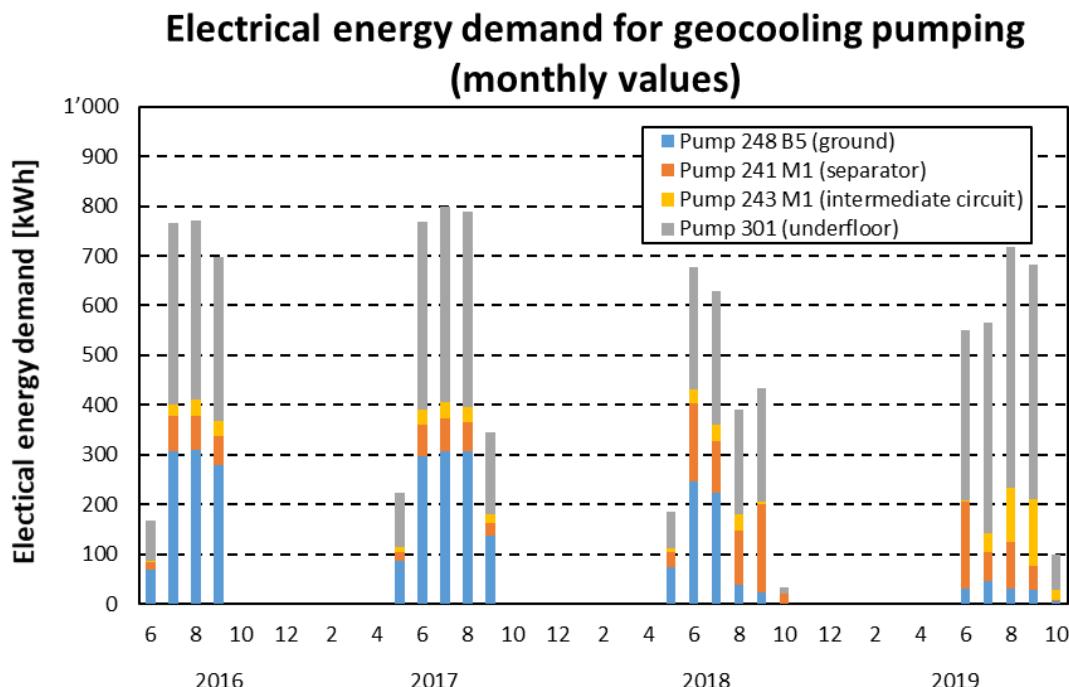


Figure 24 – Pumping electric consumptions during the summer periods from 2016 to 2019.

The implementation of the proposed optimization was completed in July 2018. In August and September 2018, the effects of the new circulation pump control and modulation system could be observed.

Since August 2018, the energy consumption of pump 248 has been appreciably reduced compared to the previous months and years. The intermediate pumps 241 M1 and 243 M1 could not be significantly



modified, except for pump 243M1, which was considered redundant and switched off. Due to construction, hydraulic regulation, and control software issues, it was not possible to modulate the operation of pump 301. In June 2018, its nominal flow rate was lowered manually, trying to reach a correct flow rate and plausible temperature differences.

The year 2019 was initially supposed to be useful to confirm the last two months of summer 2018. Nevertheless, in June 2019 there was a malfunction related to the failure of the solar thermal for the summer production of DHW. Heat pumps, forced to supply DHW needs, significantly lowered the water temperature on their evaporator side (ground side). This drop in temperature, down to levels of about 8°C, led to the blockage of the apartment underfloor circuit in order to avoid the formation of surface condensation. Due to this system malfunction, the technical company set new parameters, which led to a loss of part of the overall optimization achieved.

As described in paragraph 2.2.6, at the beginning of summer 2019, in order to solve some non-cooling moments of the system, the technical service modified some regulation settings by increasing manually the mass flow of the circulation pump 301 (underfloor circuit).

The exact modification(s) made is not exactly known<sup>7</sup>, but based on the monitored data, it is assumed that they concerned the operation of pumps 301 and 243. As mentioned, the 301 is the only pump that could not be automatically regulated since it is already provided with a self-regulating pressure sensor; the technical service can therefore easily modify its operation to increase the mass flow rate or the hydraulic head (given the increase in electrical consumption, it's possible to take this action). In summer 2018, pump 243 was considered redundant and it was decided to switch it off (seeing the new electrical consumption in summer 2019, it can be assumed that this pump has been switched on again). The change in the operation of these pumps has also affected the supply temperature levels, often leading to stopping underfloor cooling to avoid condensation on the floor.

All the previous considerations are quite visible in Figure 24. The effect was that, in addition to reducing the fluid temperature difference of the circuit, it also increased the electricity consumption. This has partly compromised the overall optimization by returning to an overall electricity consumption for pumping similar to the "pre-optimization" period.

Thanks to the electrical consumption of all the pumps needed to cool the apartments (such as the 248, 241, 243 et 301 showed in Figure 7), it's possible to evaluate the geocooling efficiency, that is defined as the ratio between the useful thermal energy (subtracted from the apartments) and the electrical energy used:

$$\varepsilon [-] = \frac{E_{th\_cool} [kWh]}{E_{el} [kWh]}$$

The following graph shows the monthly thermal energy and electricity consumption and the trend of geocooling efficiency.

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<sup>7</sup> As mentioned in the previous chapter, SUPSI did not supervise the design and installation of the thermal system (except by fixing the correct number of BHE). When the system was already working, SUPSI monitored its operation and suggested some optimization, which were validated and carried out by the technicians involved. Technicians take care of the maintenance of the hole system and collect requests or solicitations from the administrator or owners; they did not always inform SUSPI.

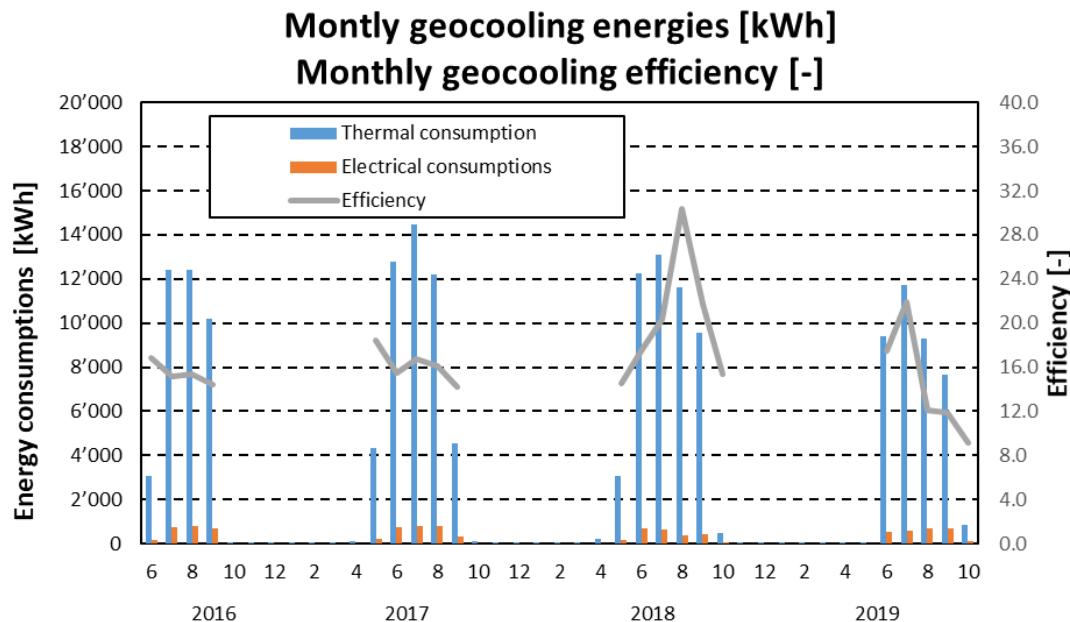


Figure 25 – Monthly cooling energy and electricity consumption and the related trend of geocooling efficiency.

It should be noted that an efficiency of 30 was achieved in August 2018. Nevertheless, in September 2018 the energy consumption remained almost unchanged, while cooling requirements were reduced. Without a better regulation of pump 301, it will probably not be possible to further optimize consumption, especially when cooling demand is reduced.

The 2019 summer season has shown how badly the entire system can be affected by misadjustments, with efficiency values even lower than in previous periods (in fact, efficiency values lower than 12 have never been achieved in the previous years).

Based on results obtained in August 2018, it can be stated that efficiency values of 30 are easily achievable. It has been then estimated that if there were the opportunity of regulating pump 301, it would be possible to increase the efficiency by a further 25%, thus reaching 35-40.

### 2.3.8 Temperature levels between ground and apartment during summer mode

The geocooling temperature difference potential is defined by the available temperature difference between the desired indoor air temperature and the initial ground temperature. This temperature difference is shared between the building, including its cooling distribution and the geocooling heat exchanger, and the ground coupled system [5].

The "before optimization" graph has already been shown in section 2.2.1 Figure 12, in order to suggest optimizations. The temperature levels, before and after the optimizations, are now shown in Figure 26.

The first temperature loss ("Building design") is necessary to keep some margin and anticipate the indoor air temperature increase due to internal and solar passive gains. It depends on building design and inertia of the distribution system. The second temperature loss ("Cooling distribution") is created by the cooling distribution system and the third one ("Geocooling heat exchanger") by the geocooling heat exchanger and all the intermediate hydraulic circuits. The sum of these 3 temperature losses is related to the building, whereas the remaining one, called ground temperature difference, is due to the heat exchange with the ground.

The "water temperature level in cooling distribution" is the average between the forward and return temperature in the underfloor circuit, while the "maximal fluid temperature level in BHE" is the average between the forward and return temperature in the underground circuit (maximal summer values).

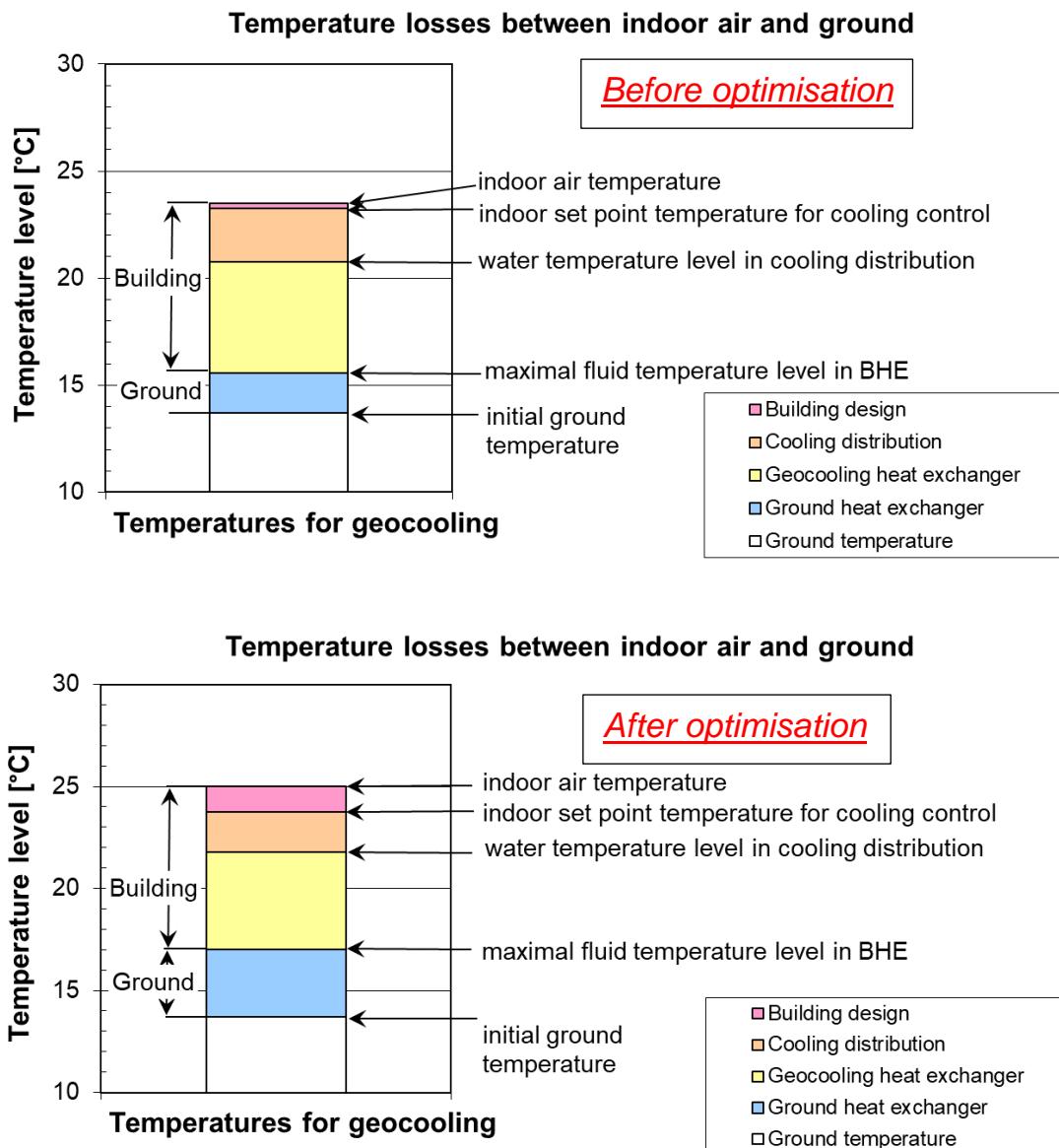


Figure 26 – Temperature levels and losses in the geocooling temperature difference potential (before and after optimization).

There has been an improvement in heat exchange, at the level of the building design and the ground heat exchanger.

The geocooling temperature difference potential is shared between the building and the ground. It is thus very important, when a geocooling system is designed, to have the possibility to modify and optimise to some extent both the building design and the cooling emitters.

Heat exchange between BHE and ground refers to these specific subsoil temperature conditions (see Annex 5).



### 2.3.9 Indoor comfort during the analysed seasons

The national and international standards related to building technology that encourage the improvement of building quality in terms of occupant comfort and reduced energy consumption are the SIA 382/1 and EN 15251, already mentioned in paragraph 2.2.3. The thermal indoor comfort of a living space is defined as the condition of satisfaction of the person regarding the thermal environment for which the indoor air is perceived as optimal by the majority of occupants. To avoid uncomfortable conditions inside buildings, the thermo-hygrometric variables (temperature and humidity) must be kept under control as they condition the thermal exchange between human beings and the environment. If the thermoregulation is balanced, there is a thermal neutrality feeling, otherwise there is a "warm" feeling or "cold" feeling defined as "discomfort". Too high or too low air humidity levels can cause as well uncomfortable situations.

At low temperatures, very dry air increases the feeling of cold, while air temperatures above 32 °C with relative humidity above 70% increase the feeling of warmth. The monitoring of the indoor parameters of one apartment during the summer and winter season allowed verification of their influence on the indoor thermal comfort and of whether the regulation of the thermal system was adequate.

In paragraph 2.2.3 the temperatures of the apartment were analysed before the optimisation, and with the aim of evaluating the best possible actions to modify the heating system. In this chapter the indoor comfort after optimisation is assessed. All data refer to measurements taken in one of the 46 apartments. All seasons monitored and their graphs, from summer 2016 till summer 2019, are shown in Annex 4. The graphs below (Figure 27) show the correlation between indoor and outdoor temperatures during winter 2017/2018 and summer 2018, subsequently elaborated on.

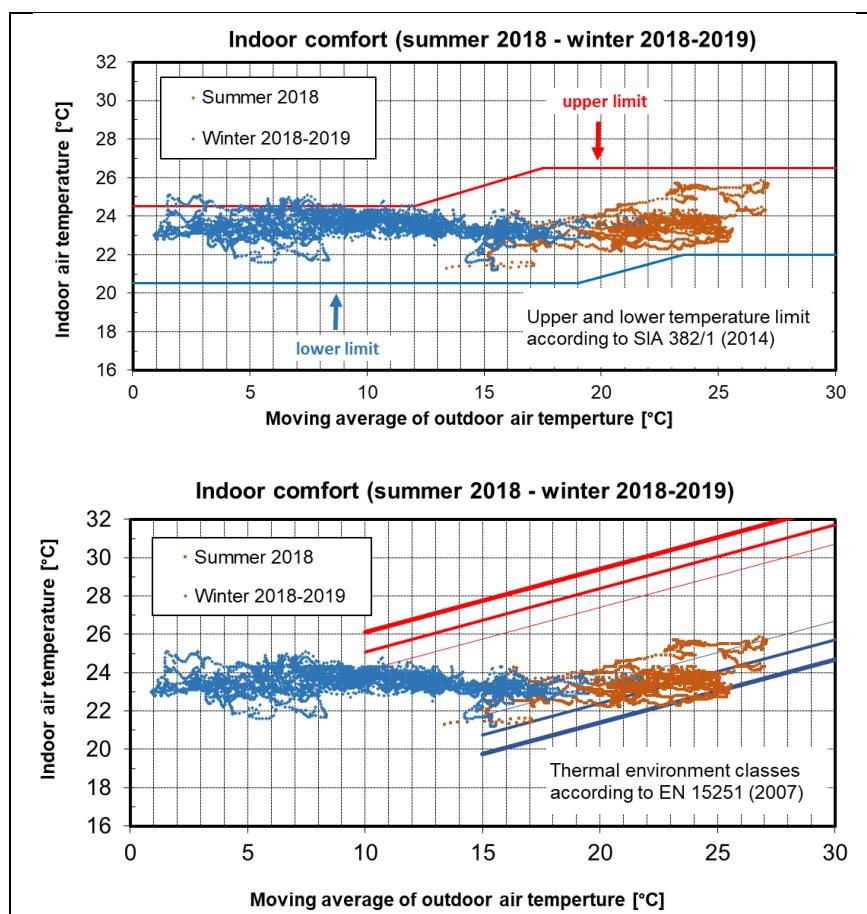


Figure 27 – Indoor and outdoor monitored temperature (hourly values) and comfort limits according to SIA 382/1 and EN 15251.



National and international standards dealing with indoor comfort do not explicitly consider indoor air humidity, a parameter also monitored in this project. In order to investigate this aspect, Terhaag's graph [21] was used, which correlates indoor air temperature with relative humidity, setting limits and determining the conditions of comfort (area delimited by the internal perimeter), acceptability (area delimited by the external perimeter) and discomfort for the occupants (areas outside the perimeters). Below are the Terhaag graphs with summer 2018 and winter 2017-2018 data (after optimization); all seasons monitored are shown in Annex 4.

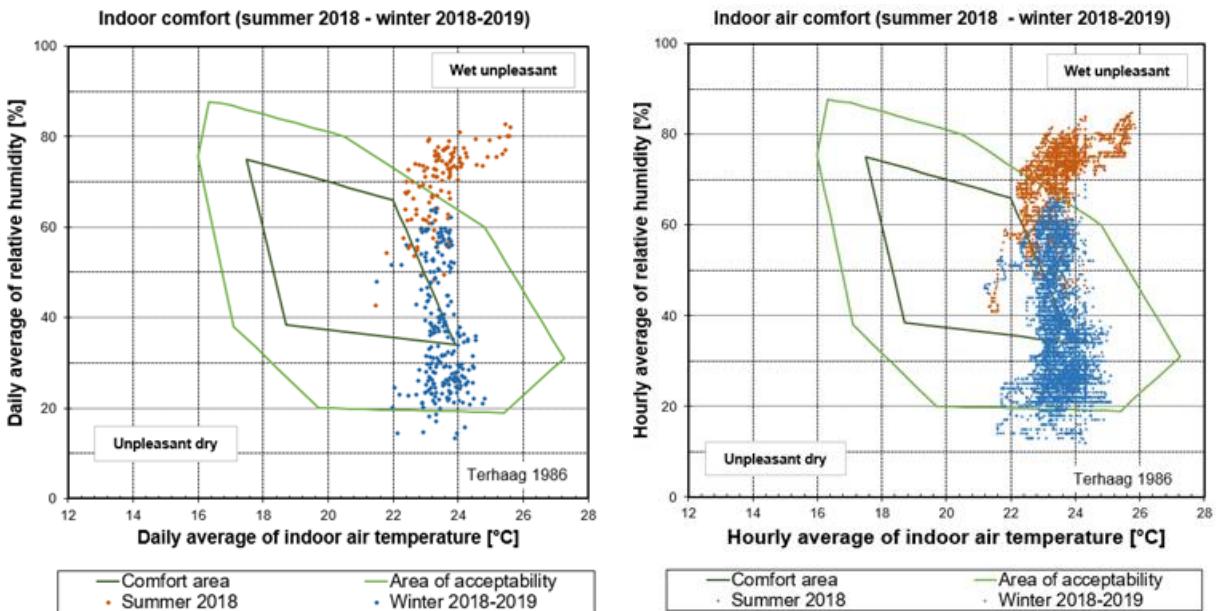


Figure 28 – Terhaag's graph. Hourly (right) and daily (left) values of indoor air temperature and relative humidity for the winter 2017-2018 and summer 2018 (all seasons in Annex 4).

There is a clear shift of points outside the comfort zone, with many points also outside the acceptability zone. The winter data also go beyond the comfort zone but are still well positioned within the acceptance zone. These considerations are also confirmed for all other seasons monitored (see Annex 4).

Particular attention has been paid to the summer season 2018, during which some system optimization measures have been implemented, with data breakdown before, during and after the system adjustment.

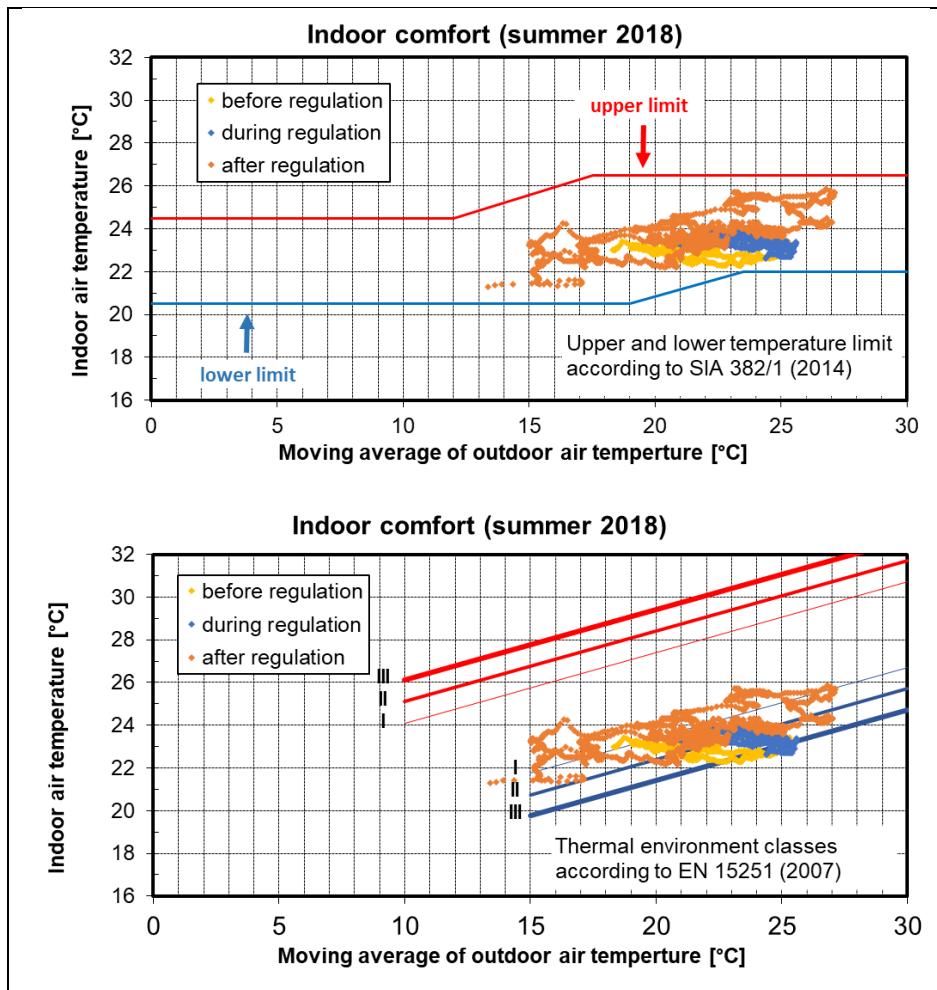


Figure 29 – Internal and external temperature monitoring and limits of SIA 382/1 and EN 15251, compared during the regulation performed in summer 2018.

In the period called "before adjustment" (yellow data) there is excessive cooling with data at the lower limit of comfort. Since no dehumidification takes place, the temperatures should be kept to the upper limit of the graphs to avoid a too high relative humidity in the apartments that leads not only to discomfort, but also to unpleasant situations such as surface condensation or blockage of the cooling system.

The so-called "during regulation" period corresponds to about one month during which, according to the instructions given to the tenant, the apartment thermostat has been set to 25°C (instead of the lower limit as in the previous period). During this phase, the system regulation has not yet been completely implemented, so the temperature increase is only related to the apartment setting.

The period called "after the regulation" corresponds to the end of July 2018 until September 2018, and was characterized by temperatures sent to the apartments higher than those of the previous period (about 21°C compared to the previous 19°C). During this period, the apartment thermostat was always set to 25°C.

It is found that "after regulation", the indoor temperature increased, showing a good correlation between increased outdoor temperature, and increased indoor temperature (adaptive comfort). However, the increase in indoor temperature still shows a good margin for improvement while remaining within the upper limits of the SIA 382/1 standard.



The monitoring carried out in the 2019 season could not fully confirm the merits of the optimizations in terms of indoor comfort, due to a new change of operating settings with the start of the 2019 summer season (see section 2.2.6). The data for the 2019 summer season are presented in Annex 4.

A digital sensor, showing relative humidity and temperature air inside all the apartments, could, in this sense, probably help make tenants more aware of how to better use the indoor thermostat.

### 2.3.10 Energy economic analysis

An energy economic evaluation was made to understand the value of a solution such as geocooling combined with conventional geothermal systems. In order to better understand the economic particularities related to the application of geocooling for a residential building, two distinct variants were analysed and compared:

**Variant 1 (heating only):** The geothermal system supplies heating needs through the heat pumps, but it is not planned to use the system in summer cooling mode. This creates a thermal regeneration deficit of the ground which, for correct long-term performance, can only be met by increasing the number of probes installed. The existing number of 13 BHEs each 200m deed, has therefore been increased to 14 BHEs each 200m deed (calculated and confirmed by commercial and validated simulation tools).

**Variant 2 (heating + cooling):** The geothermal system supplies heating needs through the heat pumps and cooling needs by geocooling technology. This variant corresponds to the case in question.

The following table summarizes the investment assumptions for the two analysed variants. The investment costs have been split into partial investments related to:

- heat pumps and thermal power plants: investments in thermal power plants related to the heating of residential spaces;
- recharging supplement: the part of the investment related to the summer cooling supplement (additional heat exchanger, additional pipes, additional circulation pumps, reversible thermostats in the apartments, sensors and additional control);
- geothermal drilling system : 13 BHE for the case in question with cooling (variant 2), 14 BHE for the case without cooling (variant 1).

*Table 17 – Investment costs for the two considered variants.*

	<b>Variant 1</b> <i>heating only</i>	<b>Variant 2</b> <i>heating + cooling</i>
Heat pumps and technical devices in the plants	250'000 CHF	250'000 CHF
Recharging supplement	-	20'000 CHF
13 BHEs <sup>8</sup>	-	240'000 CHF
14 BHEs <sup>9</sup>	258'000 CHF	-

The lifetime of the above listed categories, which with the consequent reinvestment for renovation, has been estimated according to experience and in accordance with SIA 480 (2004), are following summarized :

<sup>8</sup> This investment refers to drillings that took place in 2012, over the years these costs decreased by about 10%.

<sup>9</sup> This investment is a linear proportion of the previous price. Therefore, the same previous statement that the price decreases over the years is valid.



Table 18 – Lifetime of investments.

	Duration (years)
Heat pumps and technical devices in the plants	20
Recharging supplement	20
13 BHEs	50
14 BHEs	50

Although all the investment has already been made to this point, in this study average annual costs per kWh were calculated for both variants, assuming interest at 1% that consider the borrowed money and other missed investments (typical and current interest of a current fixed lien over several years). The analysis annually assesses the investments over the lifetime of the various components of the plant and the annual operating costs.

The following table shows the annual energy demand and related annual energy costs.

Table 19 – Energy demands, efficiencies and energy costs for the two considered variants.

	Acronym	Variant 1 heating only	Variant 2 heating + cooling
Heating energy (kWh <sub>th</sub> /y)	<b>E<sub>h</sub></b>	240'000	240'000
Cooling energy (kWh <sub>th</sub> /y)	<b>E<sub>c</sub></b>	0	45'000
HP annual energy efficiency	<b>CLA</b> <sup>10</sup>	3.2	3.2
Geocooling annual energy efficiency	<b>ε<sub>geo</sub></b> <sup>11</sup>	0	20
Heating Electric energy Cost (CHF/y)	<b>EC<sub>h</sub></b>	15'000	15'000
Cooling Electric energy Cost (CHF/y)	<b>EC<sub>c</sub></b>	0.0	450

(**E<sub>h</sub>**: heating thermal energy needs during one year; **E<sub>c</sub>**: cooling thermal energy needs during one year; **CLA**: yearly working coefficient of the heat pumps; **ε<sub>geo</sub>**: geocooling efficiency; **EC<sub>h</sub>**: electrical consumption (based on declared SCOP) to satisfy heating thermal needs; **EC<sub>c</sub>**: electrical consumption (based on declared **ε<sub>geo</sub>**) to satisfy cooling thermal needs).

Considering that any new heating system for a residential building would have adopted underfloor heat distribution, the following analysis excluded costs related to the heat distribution (underfloor pipes, collectors, etc.).

The annualized investment costs were divided into:

- **I<sub>part,h</sub>**: this is the partial investment for heating. It includes all the costs related to the heating system, without the necessary cooling components. Based on investment costs of Table 17, the **I<sub>part,h</sub>** is 17'837 CHF/y for variant 1, and 17'372 CHF/y for variant 2.
- **I<sub>part,c</sub>**: this is the partial investment for cooling components. It considers the extra cost for geocooling for the variant 2 (in Table 17 it is called "recharging supplement"). The additional recharging supplement corresponds to an investment for a heat exchanger for cooling, some additional pumps and pipes, increased system control and control. Based on investment costs of Table 17, the **I<sub>part,c</sub>** is 1'010 CHF/y.

<sup>10</sup> CLA in Italian, JAZ in German. In order to estimate the CLA value, the average SCOP calculate in section 2.3.6 has been reduced of 7% according to [22].

<sup>11</sup> Even if an efficiency of 30 has been reached in August 2018, a more conservative value of 20 has been used in this analysis.



A fixed cost ( $C_{fix}$ ) of 3'000 CHF/y including maintenance and insurance costs has been considered (this value is assumed as about 15% of the  $I_{part,h}$ ).

The first analysis wants to calculate the heating and cooling energy costs, defined as follows:

$$c_h = \frac{EC_h}{E_h}$$

$$c_c = \frac{EC_c}{E_c}$$

The results are as follows, and represents the cost of energy without considering investments and fixed costs:

*Table 20 – Heating and cooling energy costs for the two considered variants (without annual investment and fix costs).*

		Variant 1 heating only	Variant 2 heating + cooling
Heating energy cost	→ $c_h$ (cent /kWh)	6.3	6.3
Cooling energy cost	→ $c_c$ (cent /kWh)	0.0	1.0

In the second analysis, the heating and cooling energy costs were calculated together with the investment and fixed costs. These are named “partial” since the investment and fixed costs refer only to the thermal plant (and not consider other ones such as apartments devices, ventilation devices, etc.). They are defined as follows:

$$c_{part,h} = \frac{EC_h + C_{fix} + I_{part,h}}{E_h}$$

$$c_{part,c} = \frac{EC_c + I_{part,c}}{E_c}$$

*Table 21 – Heating and cooling partial costs for the two considered variants (with annual investment).*

		Variant 1 heating only	Variant 2 heating + cooling
Heating partial cost	→ $c_{part,h}$ (cent/kWh)	14.9	14.7
Cooling partial cost	→ $c_{part,c}$ (cent/kWh)	0.0	3.2

The annual cooling energy cost remains about six times lower than the annual heating energy cost (Table 20). It is interesting to observe the difference between these values and the heating and cooling partial costs in Table 21, which gives the weight of investment and fixed costs, and the energy costs; in the case of variant 2  $c_h$  is about a half of  $c_{part,h}$  and  $c_c$  is about a third of  $c_{part,c}$ .

The cooling and heating partial cost of Table 21 shows the cost for each of the thermal demands (heating and cooling), but they are not representative of the overall functioning. In order to have a realistic cost of total energy including the investment, it is necessary to consider all thermal energies involved (heating and cooling) within the same formula, related to partial investments and fixed costs. As an example, a borderline case is here shown: without cooling energy for variant 2, the  $c_{part,h}$  would not be affected by a lack of cooling, and so the investment  $I_{part,c}$  would not be considered.



To solve this issue, the following formula has been analysed:

$$c_{part,ener} = \frac{EC_h + EC_c + C_{fix} + I_{part,h} + I_{part,c}}{E_h + E_c}$$

The following results show the total energy cost (heating + cooling) called  $c_{part,ener}$  for both variants.

*Table 22 – Total energy cost for the two considered variants (with annual investment and fix costs).*

	<b>Variant 1</b> <i>heating only</i>	<b>Variant 2</b> <i>heating + cooling</i>
Total energy cost – $c_{part,ener}$ (cts/kWh)	14.9	12.9

The cost of the recharging supplement has been estimated at 20'000 CHF (Table 17), but with an investment of 150'000 CHF for it, the  $c_{part,ener}$  for variant 2 would be similar to the one for variant 1.

In this assessment, the interest in geocooling and its low operating costs in relation to the total cost are evident. However, it should be stressed that variant 1 considers a total energy demand of 240 MWh/a (heating only) and variant 2 of 285 MWh/a (240 MWh/a heating and 45 MWh/a cooling). The system therefore provides more energy at a lower cost. The total annual energy costs are 35'855 CHF/y (costs for heating only, variant 1) and 36'851 CHF/y (costs for heating and cooling, variant 2). The total energy cost ( $c_{part,ener}$ ) is therefore a cost that takes into account both heating and cooling energies supplied.

Geocooling proves to be not only an energy an interesting technology, but also very convenient from an economic point of view. This convenience is linked to the low operating costs, the reduced additional technical investment required (compared to heating only) and the considerable cooling energy that can be supplied. This is clearly only true under the conditions described above, and in particular if it is an addition, both in technical and investment terms, to the already necessary heating system.

In this case, geocooling technology can be considered as an addition (from the technical point of view) to conventional heating, which can therefore take advantages of the investment already necessary for heating.

In the analysis, the building surplus value (capital cost) equipped with a cooling system has not been considered, since more detailed real estate evaluations would be needed. This surplus value would certainly further increase the economic advantage related to a geocooling solution.



### 3 National collaboration and dissemination

Dissemination and communication of results are important when studying innovative systems and acquiring new knowledge that can enhance technical expertise on several levels. This allows the studies to be exploited and have direct effects on the territory. For this reason, SUPSI has paid attention to communication, information and training aspects during the years of the project.

Even if the FER (Renewable Energy Fund of Canton of Ticino) which co-financed the project, had not provided funds to support the communication and dissemination costs of the project, SUPSI decided to invest in these activities, both thanks to its self-financing and taking advantage of the mandate from the Geothermie-Suisse association (of which it is an antenna for Southern Switzerland).

Communication and dissemination activities concerning the project focused on the following areas:

- Training in schools (both at upper secondary school and university level) to reach future professionals in the technical plant engineering sector.
- Communication through the media and other dissemination channels (newspapers, online channels, brochures, participation in fairs, etc.) to reach the population and raise awareness of the issue.
- Sharing of results and collaboration with the public administration and associations interested in the topic (e.g. Energy-Schweiz, Ticino Energia, Associazione Professionale Pompe di Calore) in order to update the people involved in strategic energy planning and local energy policies on the state of the art and on the results.
- Scientific dissemination through scientific articles and participation in conferences.
- Collaboration with Geothermie-Suisse.

The following is a list of dissemination and training activities, by year:

2016

- 2016-12-01 and 2016-12-15 : Carrying out of two theoretical courses in class with SSST (Scuola Specializzata Superiore di Tecnica) in Trevano/TI. The school trains professionals in the field of thermotechnical engineering. The aim of the courses was to train and raise the awareness of students and teachers on innovative topics in collaboration with a teacher (Andrea Andreoli) expert in thermal systems and interested in the geocooling system studied. The teacher has then made himself available to discuss with planners and propose optimization solutions for the plant under examination.
- 2016-11-14 : "Open doors" morning with various SUPSI colleagues, administrator and some owners of apartments of the City Residence building. The aim was to promote the project by raising as much awareness as possible among the people involved in SUPSI education on the one hand and the residents of the building on the other.

2017

- 2017-01-25 and 2017-04-27 : Carrying out of two theoretical courses in class with students at SAM (Scuola Arti e Mestieri) and SPAI (Scuola Professionale Artigianale e Industriale) in Trevano/TI on various topics concerning energy in the building, including geothermal energy. They dealt with geocooling and the correct concept of plant construction, as well as the importance of a correct conception, planning and final realization.
- 2017-04-27 : Carrying out a theoretical course in class with students from SSST (Scuola Specializzata Superiore di Tecnica) in Trevano/TI dealing with geocooling and the correct concept



of plant construction. The importance of correct conception, planning and implementation, as well as continuous monitoring and assistance over time were addressed.

- 2017-04-01 : "Open doors" morning with SSST students (students and teachers). After the theoretical presentation in the classroom (previous point) the case discussed in class was visited. The invitation was also extended to the owners of the apartments.
- Throughout the year, continuous communication and dialogue with the technicians in charge of the heating system with the aim of proceeding with the correct plant regulation proposals to all the actors involved. The active and proactive role of the SSST teacher (Andrea Andreoli) was also fundamental. Collaboration continued for the teaching of students on this subject in order to transmit the knowledge to future professionals.

## 2018

- Throughout the year continuous dialogue and communication with the building administrator to convey the message to the apartment landlords about the limitations and advantages of geocooling. This activity is considered particularly important in order to make people aware of the peculiarities of the geocooling, but also in making the administrator aware of the management of other similar installations.
- 2018-06-26 : Radio interview with RSI on Rete 3 (program [Baobab](#) [23], name of the program "il freddo polare in estate") on the topic of geothermal energy, cooling and geocooling and the case study City Residence in Lugano.
- 2018-09-07 : Participation in the BRENET conference in Zurich, with an article entitled "Applied analysis of geocooling technology for a residential building" showing the first results of the data analysis until summer 2017 (before the optimization proposals). The conference also included the creation of a poster presented to the public during the dedicated poster section.
- 2018-11-12 in Gordola/TI: In the lifelong learning course dedicated to professionals on the use of SIA 384/6: 2010, the City Residence project in Lugano-Besso was also presented with the first available results.
- 2018-11-27 : To better understand the perception of the tenants to the geocooling system, a survey was submitted to the tenants of the building. In addition to the results that confirmed the statements that led to the implementation of some optimizations, the questionnaire was important to allow people to better understand the peculiarities, limitations and potentials of geocooling.
- 2018-11-07 and 2018-11-28 : Within some courses of CAS PEM (Certificate of Advanced Studies in Public Energy Management), in particular in the courses "Measurement and monitoring in buildings" and "Energy from infrastructures", the case City Residence in Lugano was described, presenting experiences, problems and results. The CAS PEM was attended by energy consultants, land planners, municipal employees and companies active in the energy sector.
- The geocooling concept and some results were presented in the "[Calendar of Sustainable Advent 2018](#)" [24], which is an online calendar supporting sustainable development. During the month of December, various aspects of sustainable development in Ticino can be discovered. The page on geothermal and geocooling technology recorded 5'500 views and 586 people took part in a quiz dedicated to the theme of geocooling.

## 2019

- Following a telephone interview with a journalist commissioned by the SFOE (Benedikt Vogel), a German-language article was written about geocooling and this specific project results. The article was subsequently adapted in several languages and published in different national newspapers. The article was also supervised in all languages by SUPSI and SFOE [25, 26, 27].



- Carrying out of a theoretical course in class with SSST (Scuola Specializzata Superiore di Tecnica) students in Trevano/TI. In addition to the theme of control and correct construction of the building sites, the topic of geocooling was also covered, with the relative monitoring and improvement of the plant. Results before and after the optimization were shown.
- 2019-11-07 in Gordola: As part of the lifelong learning course dedicated to professionals on the use of SIA 384/6: 2010, the City Residence project in Lugano was also presented.
- As in 2018, throughout the year there have been continuous communications with the technicians in charge for the heating system with the aim of proceeding with the correct plant regulation. The active and proactive role of the SSST heating system teacher was also fundamental. Thanks to this involvement, the collaboration for the teaching of students on this topic has continued to transmit the knowledge acquired to future professionals.
- As in 2018, throughout the year there was continuous communication with the building administrator to pass on information to the tenants of the apartments regarding the limitations and advantages of geocooling technology.

## 2020

- 2020-11-18 in Bellinzona/TI : In collaboration with the Energy-Schweiz Coordination Centre for Italian-speaking Switzerland, the project and its results will be presented during a conference at "Apéro-Energie ProKilowatt" 2020 in the autumn.
- In 2020 and in the following years SUPSI will continue its dissemination and promotion activities in lifelong learning courses, fairs, conferences and scientific articles.

### 3.1 Decommissioning of equipment and future perspectives

All data were collected and analysed until the end of the 2019 summer season. SUPSI technicians will take over the dismantling of some of the monitoring, data collection and transmission equipment. It was decided to leave some instruments on site; the flow meters and thermowells will remain installed without being removed to avoid excessive dismantling costs.

The administrator of the building, in agreement with the owners, asked SUPSI to leave the entire acquisition system installed during the 2019-2020 winter season and the 2020 summer season, taking charge of the monthly subscription of the internet connection. Since, during the 2019 summer season some system regulation problems had not been completely solved, it was considered useful to accept the request so that the technicians could use the system to correct and calibrate the system operation.

Moreover, on the research side, keeping some of the monitoring installations on site, allows the possibility of continuing to collect interesting data with a minimum expense even in the coming years (for example, cooling indexes and percentage of ground recharge, also in relation to any future adjustments of the plant).



## 4 Discussion and Conclusions

This project, funded by the Swiss Federal Office of Energy (SFOE) and the Renewable Energy Fund of the Canton of Ticino (FER), wanted to study and evaluate the effectiveness of a heating and cooling system through geothermal energy applied to a real case study: a new residential building with 46 apartments in Lugano, Switzerland.

As reported above, the main specific goals were to explore and determine:

- the efficiency and potential of geocooling technology;
- the real quantification of a thermal recharging of the ground by geocooling;
- the related heat absorption from apartments;
- the limits of the system and the efficiency achievable by an underfloor distribution system.

Thanks to the analysis of the data, collected between summer 2016 and summer 2019, and based on the measurement through thermal and electrical sensors installed in the thermal plant and in one of the 46 apartments, on the collaboration with the technicians involved and on a questionnaire filled in by the tenants of the building, we could arrive at the following main observations and results.

### Results:

- During the first two years of monitoring, some critical issues were found in the operation of the thermal system. These issues mainly affected the geocooling efficiency and summer comfort in the apartments. Therefore, some system optimizations were implemented, and they are described in section 2.2.4.
- Before regulation, the geocooling temperature levels were not considered optimal, not only from an energy point of view, but also from a comfort point of view. With the modulation of the circulation pumps, the temperature in the apartments was about 2K higher than in previous years (increasing from about 18°C to about 20°C of the supply fluid temperature).
- Geocooling efficiency through underfloor circuit (defined as the ratio between the thermal energy used for the cooling of the apartments and the electrical energy used by the circulation pumps) was calculated monthly and showed a maximum of 30 and a minimum of 12. It has been estimated that it is potentially possible to achieve a geocooling efficiency of around 40 optimizing the operation of all the circulation pumps. During 2018, together with all the technicians responsible for the system, a series of improvements in the regulation of the geocooling system was proposed and implemented, reducing the operation of some circulation pumps. The solution implemented and operational at the end of July 2018, showed an efficiency of 30 for August 2018.
- The circulation pump that sends warm/cool water to the apartments does not modulate the flow rate by fixing a temperature difference but by considering the pressure difference. A different control on this circulation pump would allow lower electrical power consumption and a better modulation of the flow temperature.
- In order to better understand the perception of cooling in the apartments and to educate tenants on the correct use of the thermostat in the rooms, a questionnaire was sent to the mailboxes. The results allowed a better understanding of the internal perception of cooling (see section 2.2.5). This information also supported the system regulation implementations (see section 2.2.4).
- The thermal recharge of the ground, defined as the ratio of the energy injected to the extracted, is about 24% over the monitored seasons (see section 2.3.2). The value (24%) follows the recommendations of the dimensioning report (see section 1.2.3). It is important to plan and respect the recharge ratio defined in the initial design phase. This is particularly important for large plants, since the seasonal storage effects are more and more important. If the planned thermal recharge of the ground cannot be achieved over the years, it is important to be able to modify the installation or its operation, since long-term thermal storage problems can seriously affect the whole system.



- As a strong cooling of the monitored apartment, at the limit of subcooling, has been noticed (see section 2.3.9), it can be hypothesized that the calculated recharging values (see section 2.3.2) are the maximum achievable ones for this building and in these boundary conditions (energy standard, solar gains, residential building, external weather conditions).
- Regarding the optimization of the system, the proposals made have demonstrated, for August 2018, the possibility of reducing the electrical consumption of some circulation pumps by increasing the efficiency of geocooling. However, it should be noted that there is still potential to improve the internal comfort (see section 2.3.9).

Recommendations:

- Even if the lack of experience and the complexity of these geothermal systems can limit the estimation of the possible amount of cooling exchanged with the apartments, this study indicates some interesting heating and cooling indexes that can be used for buildings similar to the one analysed. These indexes are presented in Chapter 2.3, Tables 9, 10, 12 and 13 give indexes with which it is possible to calibrate and estimate space cooling needs for residential building under different weather conditions. Tables 14 and 15 can be useful in estimating the cooling power, in term of peak and average thermal powers.
- The relatively high temperature levels used in underfloor cooling, compared to conventional cooling (e.g. air conditioning), require a meticulous planning of the hydraulic scheme and then an attentive management to guarantee its correct regulation. It is very likely that the system will need ongoing adjustments for several seasons. In this sense it is important to instruct the tenants and raise the awareness that underfloor cooling cannot be completely assimilated to conventional air conditioning. It is important to inform users about the potential and limitations of an underfloor cooling system since they often have less experience and sensitivity on the topic of building physics and thermo-hygrometry (study of humid air). Although it is possible to evacuate heat from the apartments through underfloor cooling, it must be borne in mind that latent heat cannot be evacuated (no removal of part of the absolute humidity by air condensation). Therefore, to avoid condensation problems, it is advisable to satisfy internal comfort trying to remain within the upper limits of the respective regulations.
- Loading a cooling storage with a subsequent mixture of the supply fluid can facilitate temperature regulation (and better exploitation of the summer operation of the heat pump for DHW production).
- In cases where there is a “condominium ownership”, it is difficult to implement all the optimization and management issues of the systems once the building site is finished and the construction is delivered to the owners. The initial planning phase, with the design of the thermal plant, is therefore very important. Once the thermal system is in operation, over the years it is important there is a responsible figure for its proper working performance. Contracts for management and control must be provided for both operation seasons (summer and winter) as the operating and boundary conditions are different, especially in term of temperature levels, mass flow, thermal needs, etc.
- From an economic point of view, geocooling is also extremely interesting. On the one hand, thanks to the benefit of the thermal regeneration of the ground, it allows saving of meters of drilling. On the other hand, with a low investment surcharge, it allows apartments to be cooled. The energy costs applied to this case study confirm this technology is of considerable interest (see section 2.3.10).
- The comments on the supply temperatures, indoor comfort and management of the thermal system, as well as the energy indexes found, can be extended to different buildings that also use the underfloor heating system also to cool apartments in summer, without dehumidifying the indoor air (elimination of latent heat).
- Geocooling is an interesting and extremely efficient technology that transfers heat between ground and building by means of circulation pumps. Nevertheless, geocooling is an active cooling system that consumes electric energy, and therefore the specific regulations on buildings and systems for the rational use of energy are always required and to be satisfied.



## 5 Acknowledgment

We thank SFOE and FER that supported our research with funding, without which the work could not have been accomplished. We also thank all the actors involved in the collection and processing of the measures, as without their active participation and their persisting search for optimised solutions the results presented in this report would not have been achieved.

We are also grateful to Barbara Antonioli Mantegazzini (professor at USI in Lugano) for her advice and suggestions for the energy-economic analysis.

Above all we hope that this research will be useful in an applied context, contributing to the diffusion of innovative systems that support energy efficiency while still guaranteeing residential building comfort.

In this sense, a special thanks goes to Andrea Andreoli (teacher at SSST in Trevano/TI), for his precious technical advices and for his continuous availability to realise the dissemination of the results through student courses, thereby transmitting the knowledge to future professionals.



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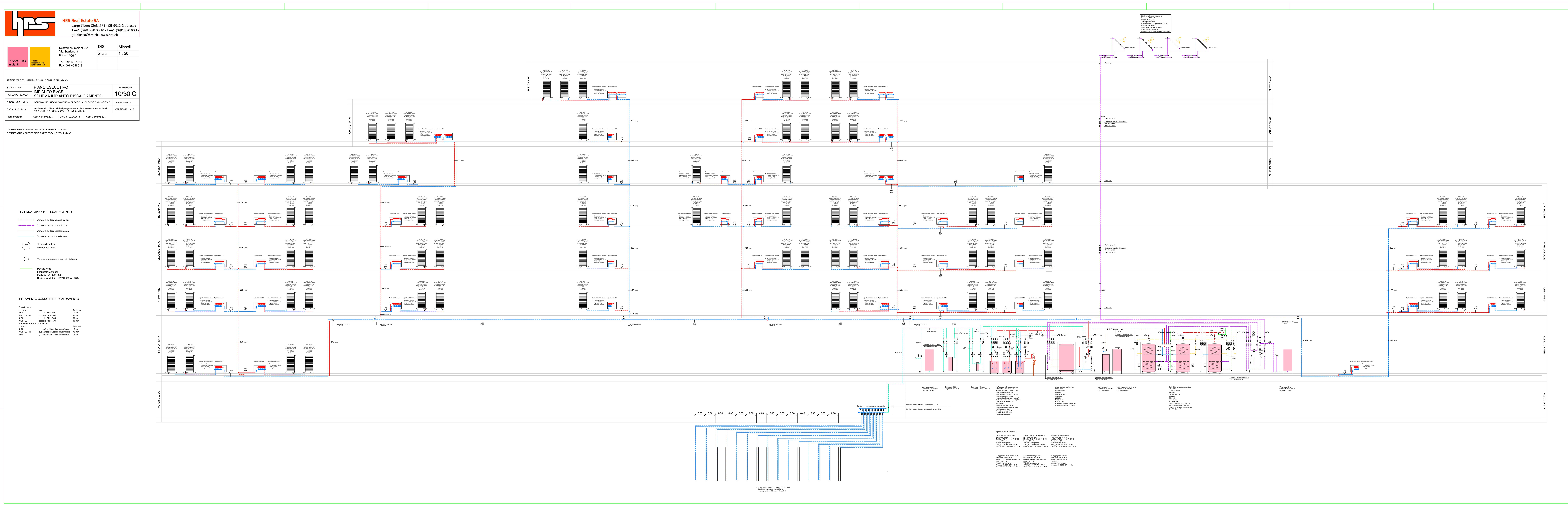


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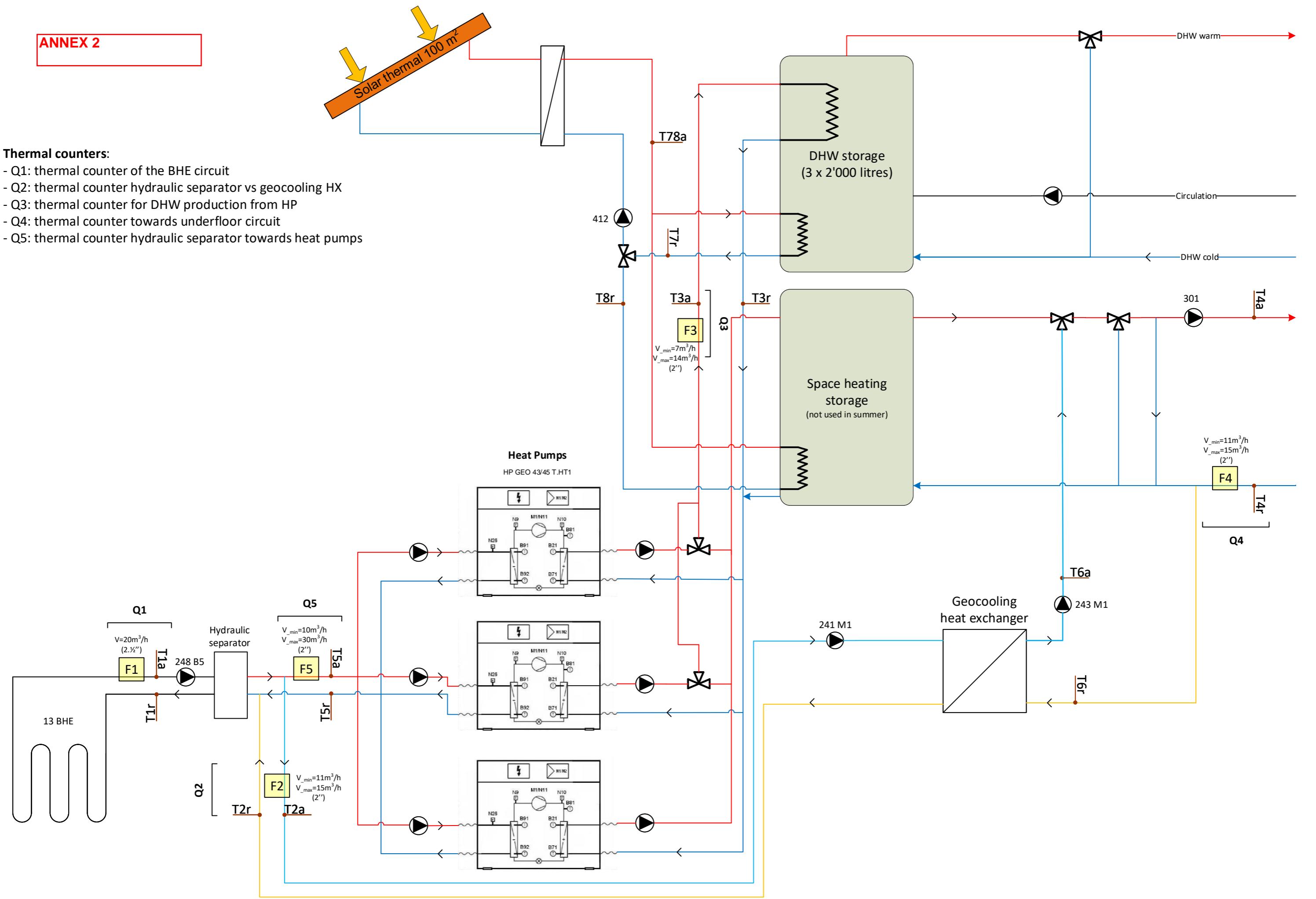


## 9 Annexes

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2. Annex 2: Position of the energy counters in the thermal plant
3. Annex 3: Graphs with seasonal energy signatures
4. Annex 4: Graphs with seasonal thermal comfort in an apartment
5. Annex 5: Thermal response test

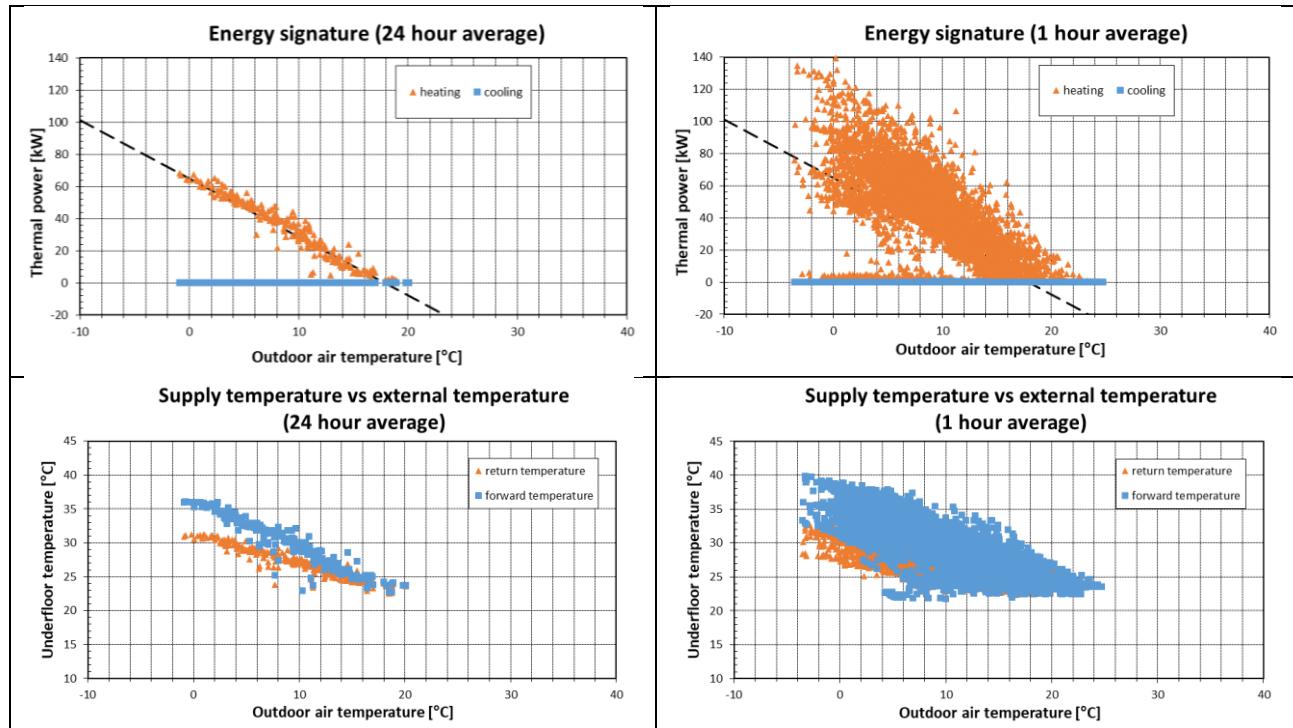


**ANNEX 2**

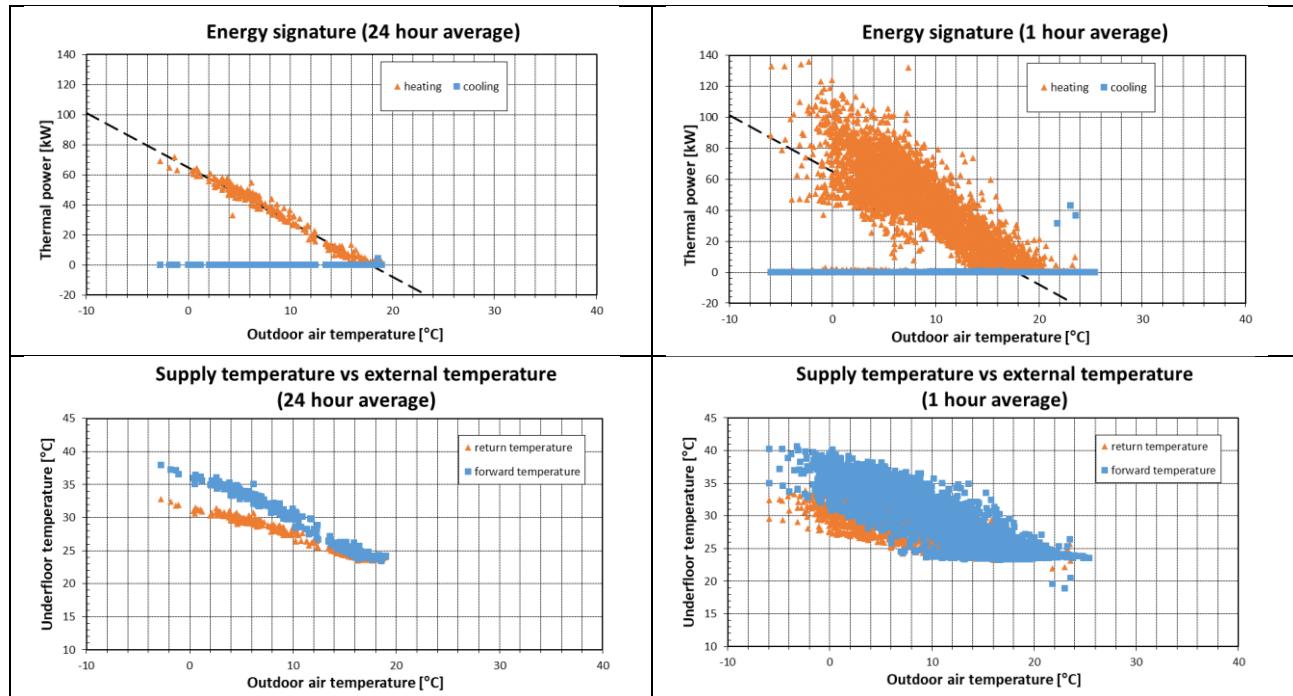


## ANNEX 3: Graphs with seasonal energy signatures

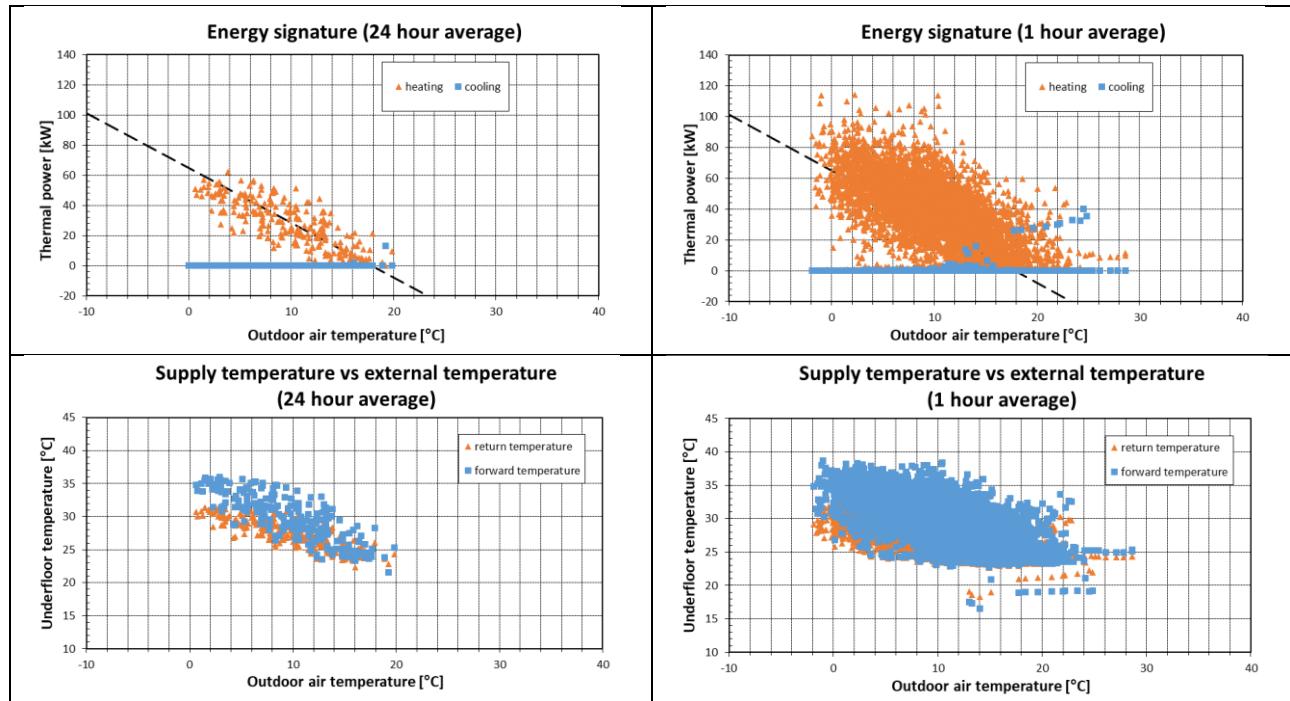
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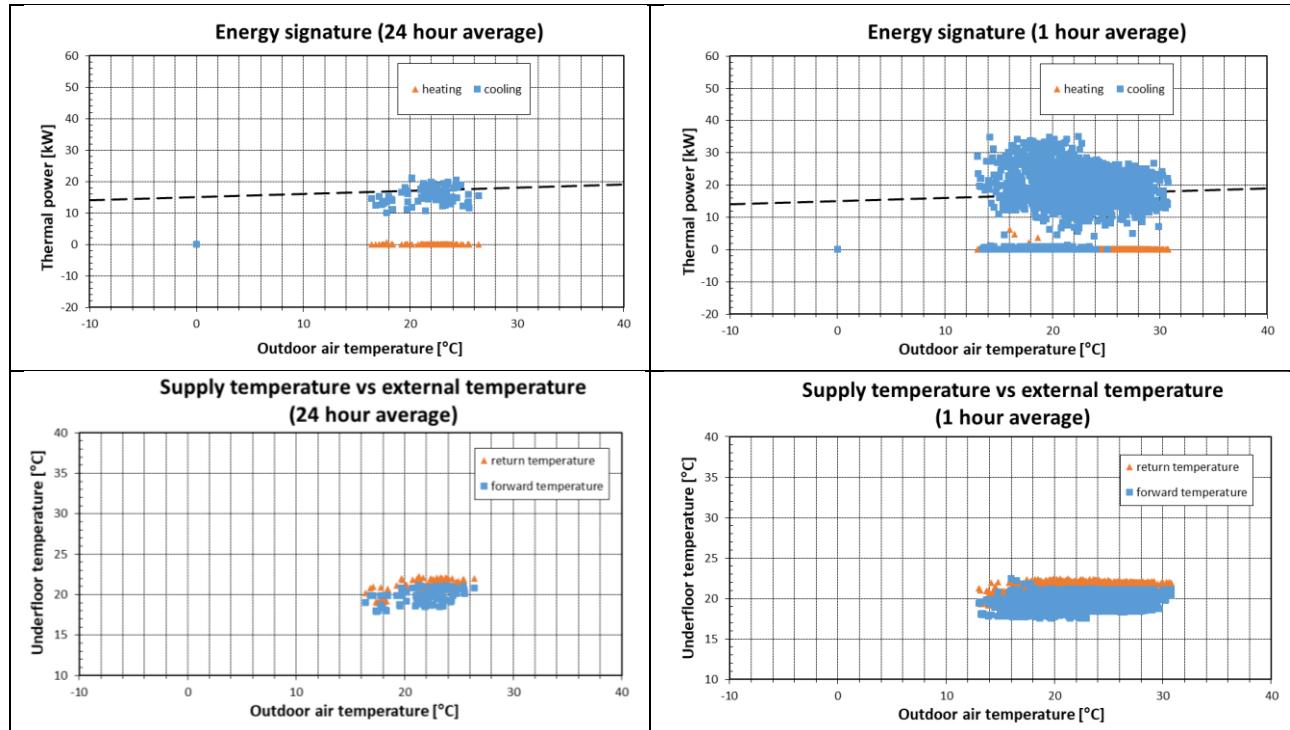
### Winter 2017-2018



### Winter 2018-2019

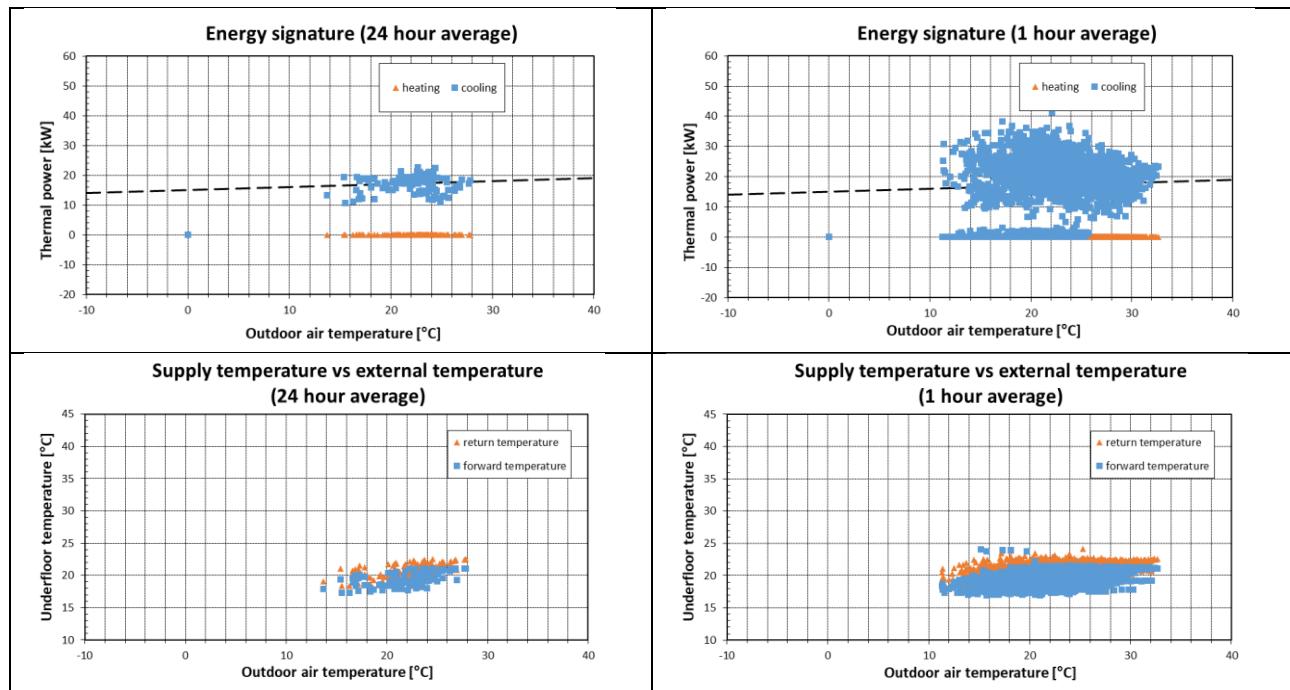


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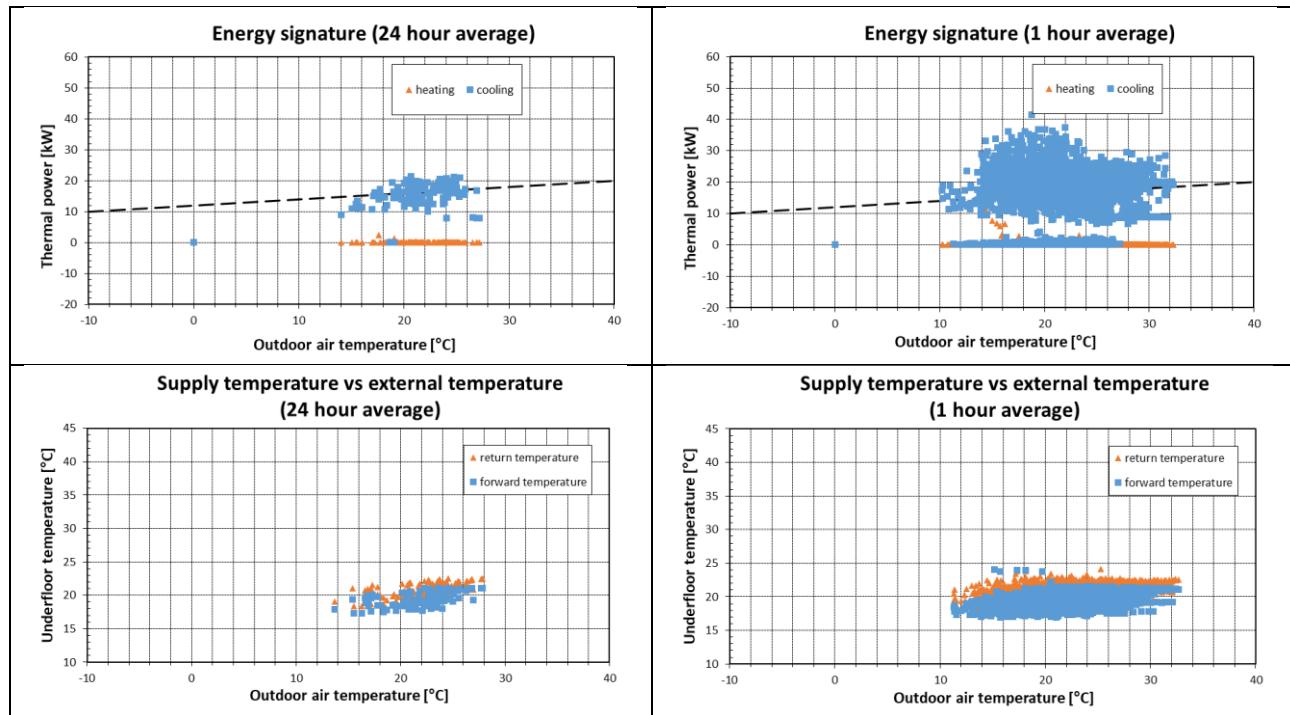


ANNEX 3: Graphs with seasonal energy signatures

### Summer 2017

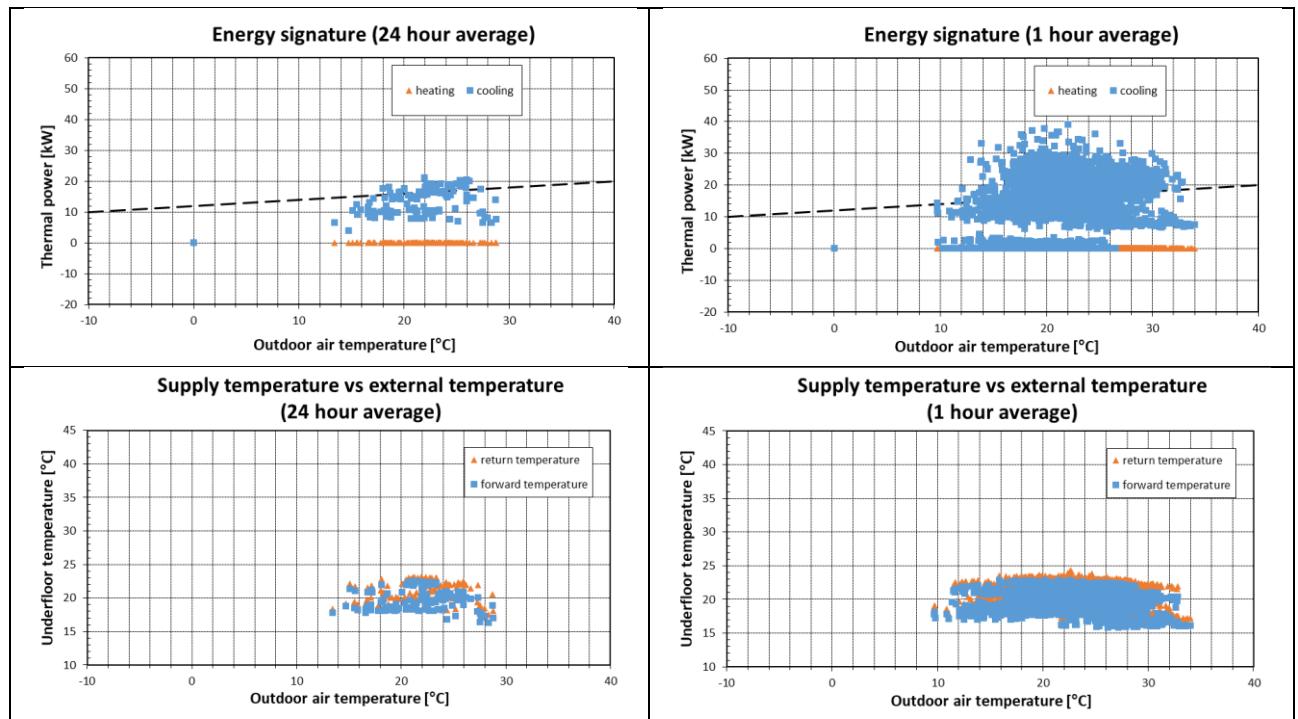


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ANNEX 3: Graphs with seasonal energy signatures

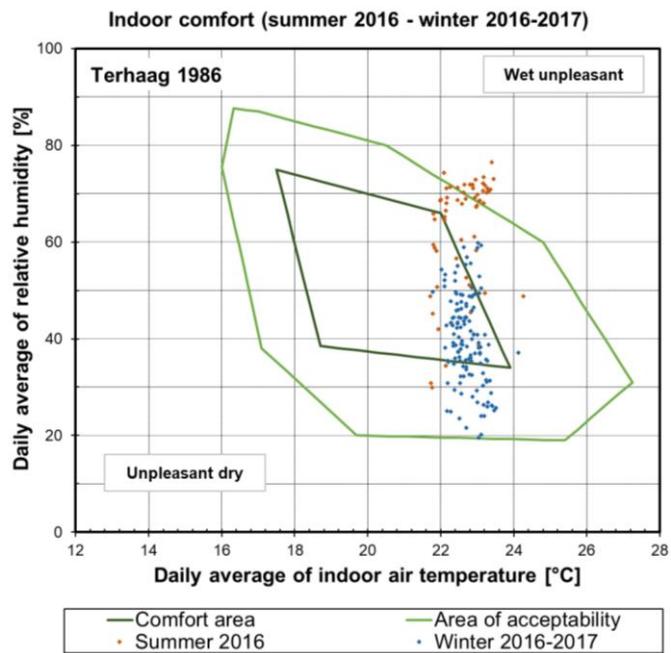
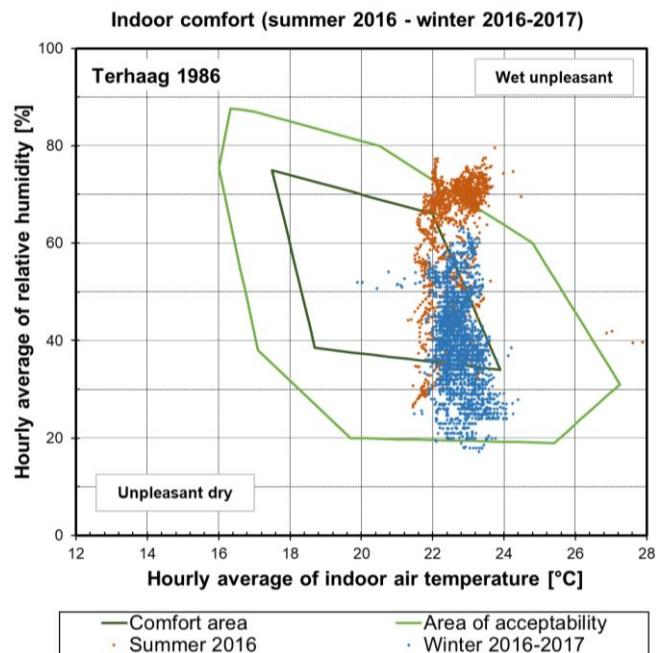
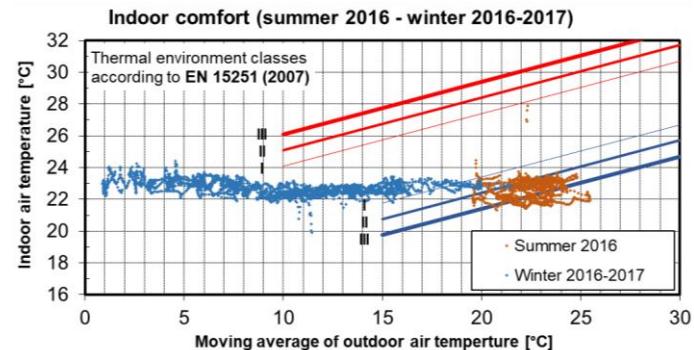
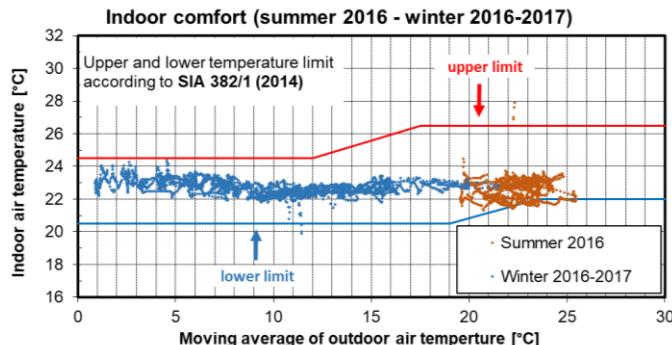
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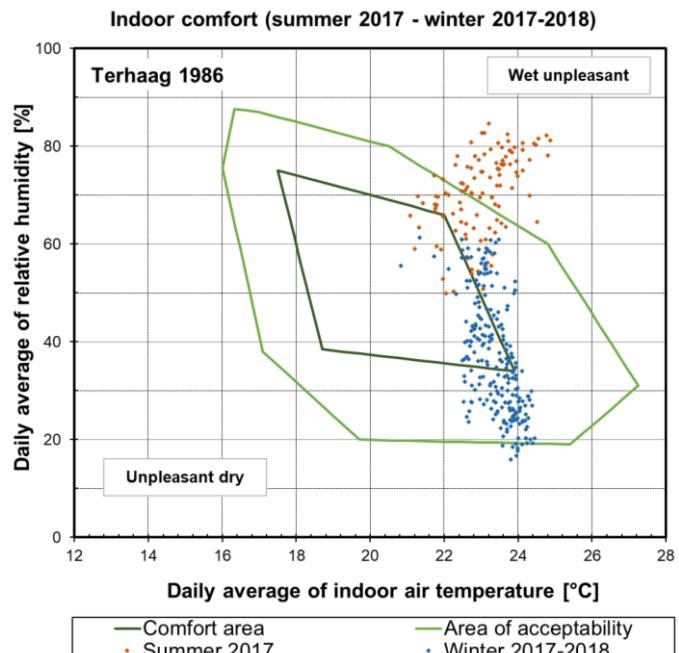
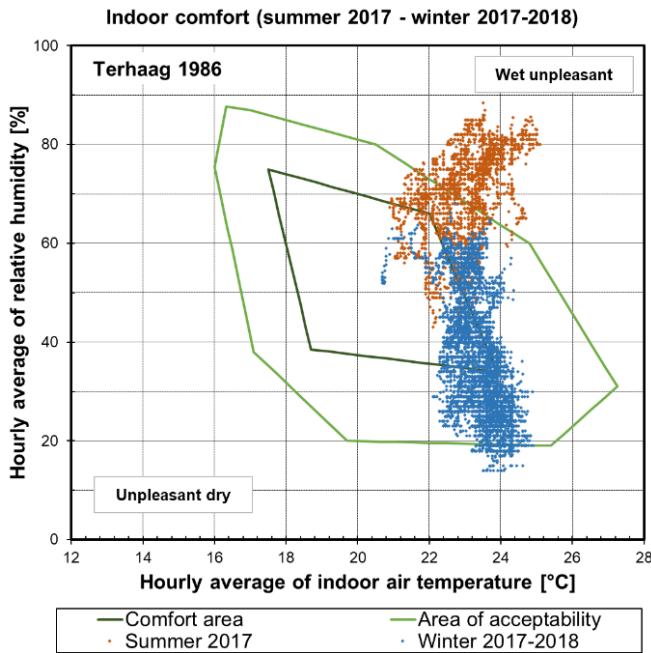
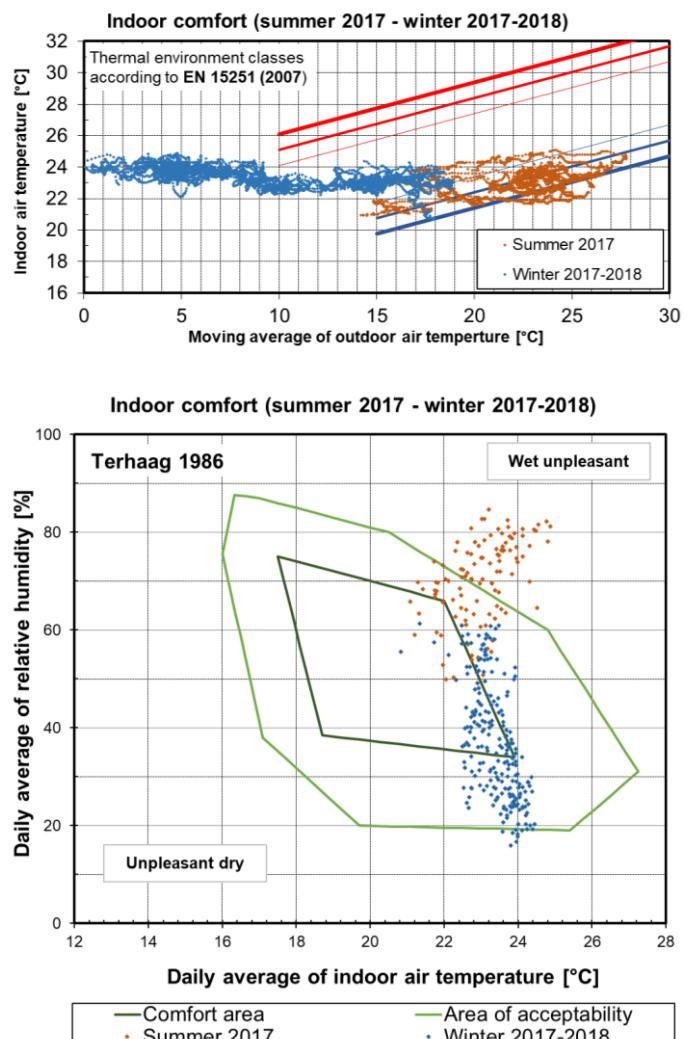
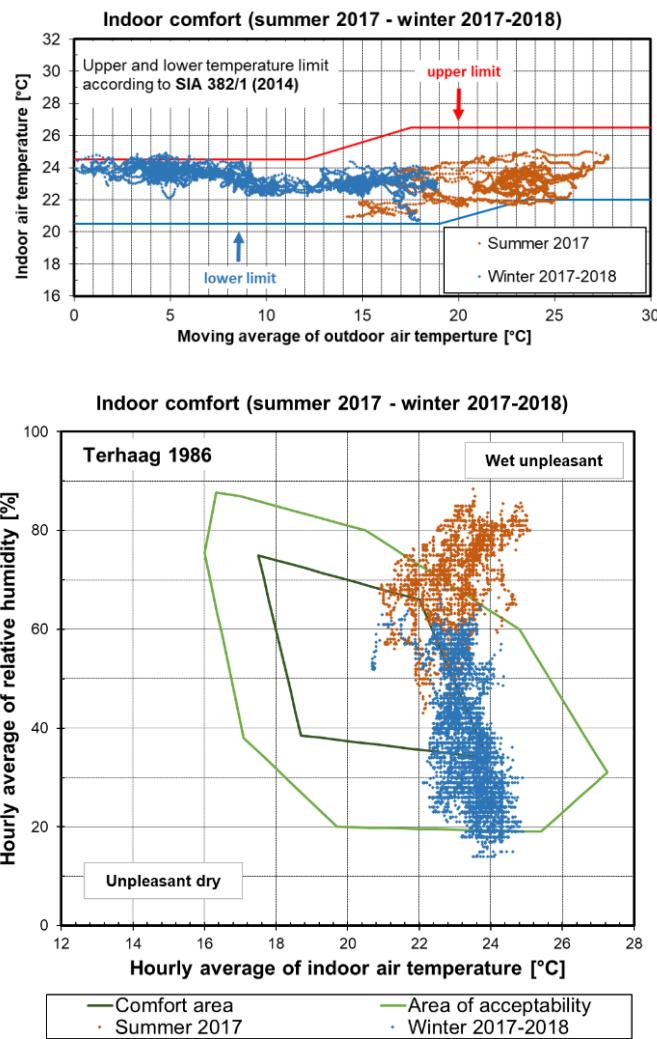
**ANNEX 3:** Graphs with seasonal energy signatures

## ANNEX 4: Graphs with seasonal thermal comfort in an apartment

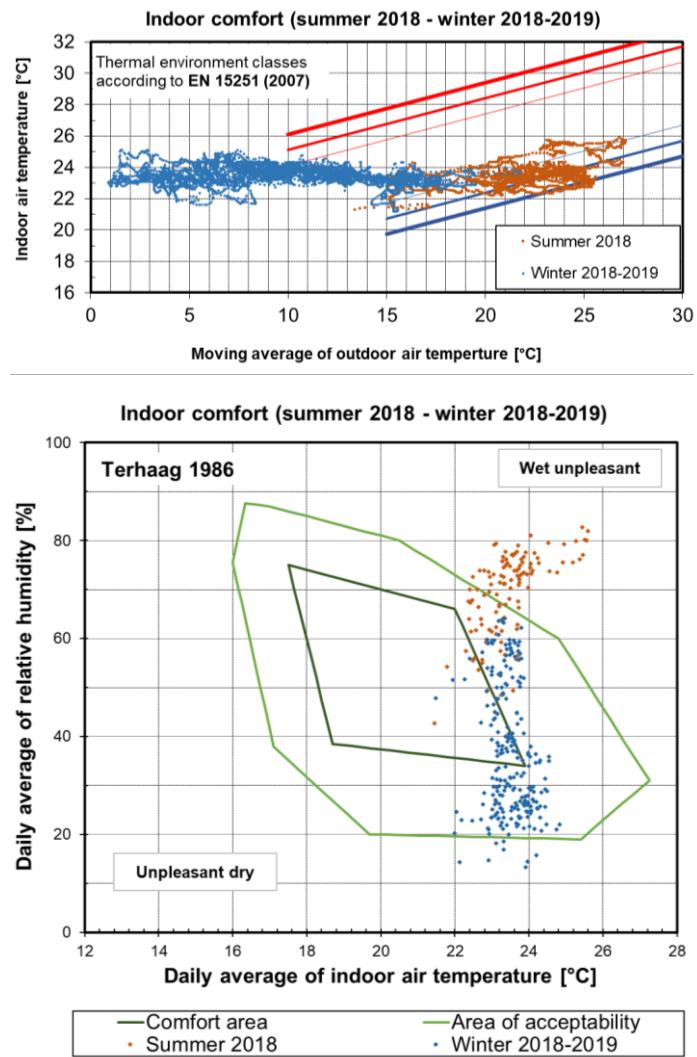
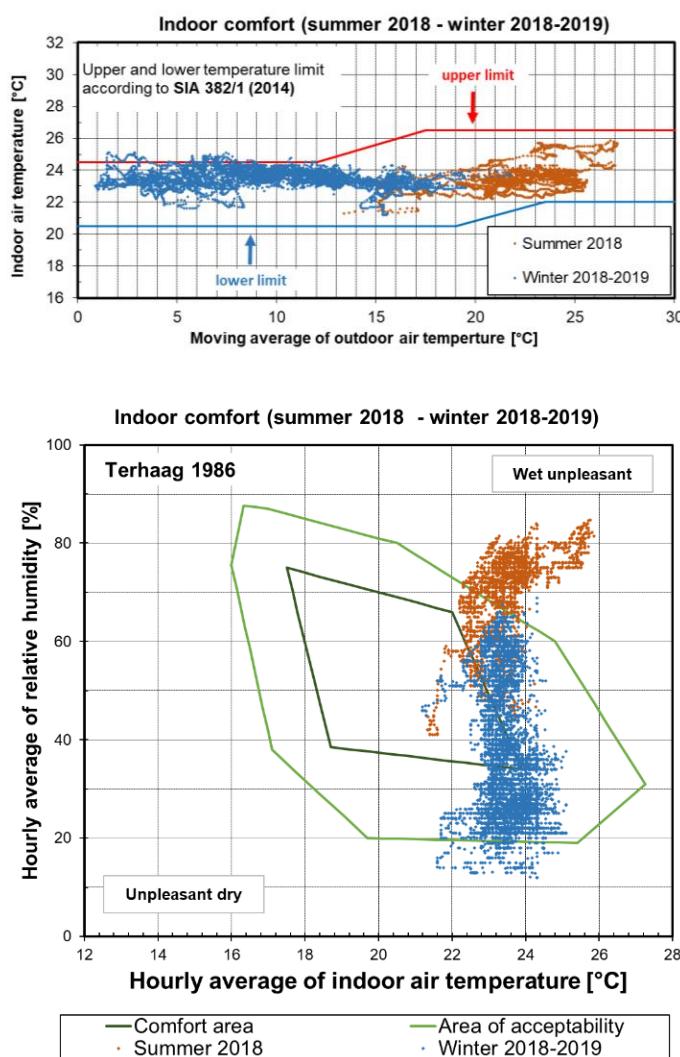
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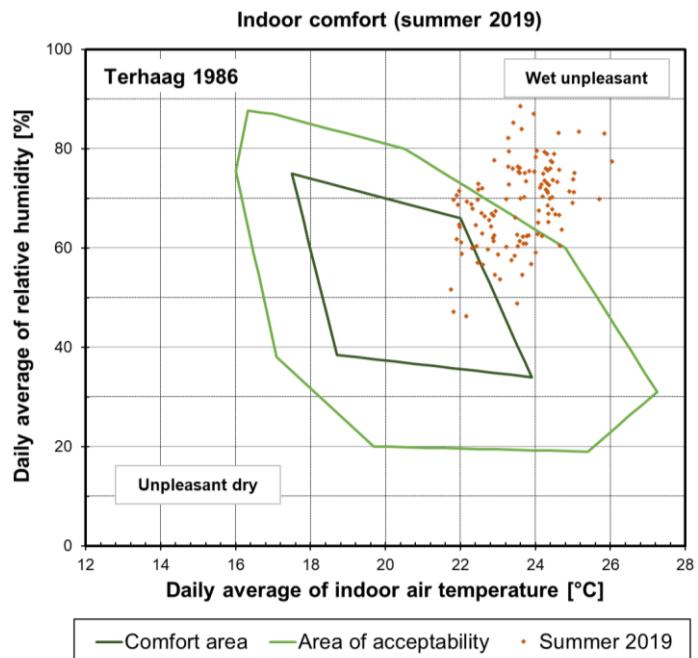
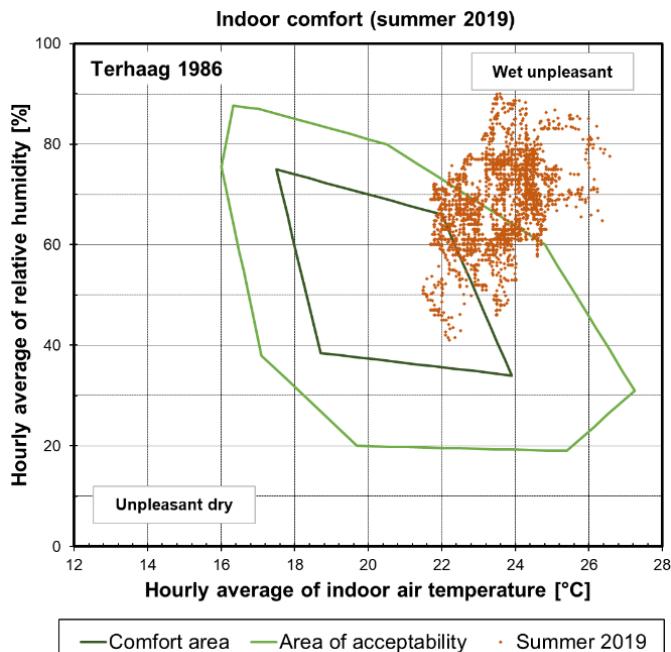
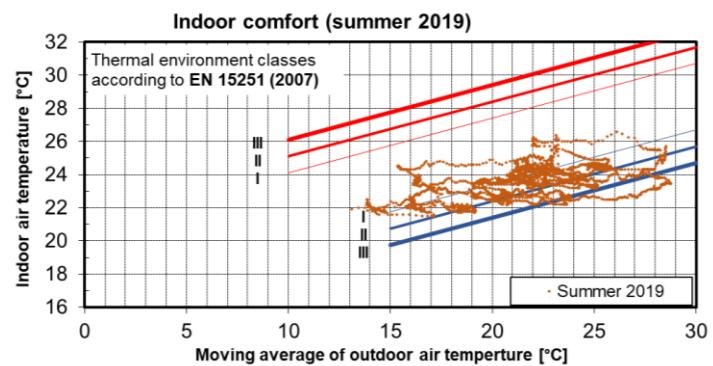
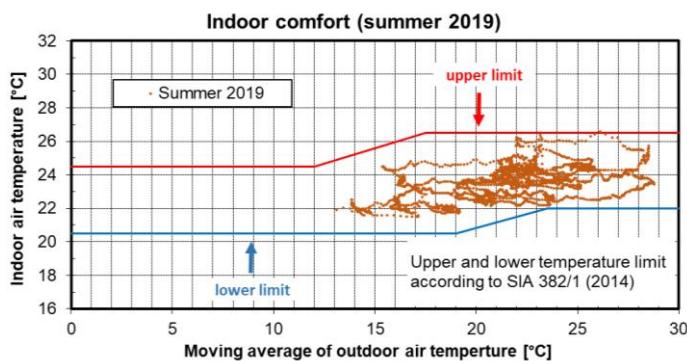
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- Summer 2018 - Winter 2018-2019



- Summer 2019



Base di pianificazione per impianti di sonde geotermiche secondo SIA 384/6

**Response test termico avanzato (eTRT) e misurazione della temperatura a Lugano-Besso, TI**

Rapporto del 23 maggio 2012

Su incarico di  
Luzi Bohr-Drilling AG  
Industriezone  
7408 Cazis

Ref. 1132 SS/RS/TM

Ordine: Per la pianificazione del campo di sonde geotermiche alla Via Guglielmo Canevascini a Lugano-Besso la Geowatt SA è stata incaricata il 11. aprile 2012. Lo scopo era di effettuare delle misurazioni del profilo termico e dei parametri termici del sottosuolo locale nella già installata sonda geotermica (incarico offerta del 4. aprile 2012).



Figura 0-1: Posizione della sonda geotermica (profondità 200 m) a Lugano-Besso.

Risultati: Per il dimensionamento del campo di sonde geotermiche progettato sono da inserire i valori dalla Tabella 0-1. Questi sono stati determinati dai valori misurati secondo la norma SIA 384/6 e sono validi per sonde geotermiche di 200 m di lunghezza in questa località. Per sonde più corte, i valori corrispondenti possono essere calcolati dai dati dei profili della conducibilità termica e della temperatura. Nel sottosuolo non sono presenti correnti di acque di falda di rilevanza.

Tabella 0-1: Caratteristiche del terreno per il dimensionamento secondo SIA 384/6

Temperatura media del sottosuolo sopra i 200 m di profondità	14.8 °C
Conducibilità termica media $\lambda$	3.35 W m <sup>-1</sup> K <sup>-1</sup>
Resistenza termica media del foro $R_b$	0.056 K m W <sup>-1</sup> *

\* Valido per le condizioni del TRT effettuato (flusso, temperatura del suolo, geometria della sonda).

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## 1. Verbale delle misurazioni

Tabella 1-1: Esecuzione delle misurazioni nella sonda test a Lugano-Besso.

3. Maggio 2012	12:30 - 13:36	Misuramento del profilo termico $T_0$
4. Maggio 2012	13:10	Circolazione senza potenza
4. Maggio 2012	14:46	Inizio del riscaldamento del sottosuolo
7. Maggio 2012	09:46	Fine del riscaldamento del sottosuolo
7. Maggio 2012	13:20 - 14:30	Misuramento del profilo termico $T_1$ con la sonda NIMO-T
8. Maggio 2012	14:14 - 15:06	Misuramento del profilo termico $T_2$ con la sonda NIMO-T

## 2. Misurazione della temperatura del sottosuolo

### 2.1 Misurazione

Per l'analisi del response test termico avanzato (eTRT) sono stati registrati 3 profili termici (sottosuolo non disturbato ( $T_0$ ), sottosuolo riscaldato - immediatamente dopo la fine della fase di riscaldamento ( $T_1$ )- e la fase di raffreddamento ( $T_2$ )). Le misurazioni dei profili della temperatura in funzione della profondità sono state effettuate con la sonda di misuramento di temperatura NIMO-T, sviluppata dalla Geowatt SA per misurazioni ad alta risoluzione e senza cavo in sonde geotermiche (per dettagli, vedi allegamento 1).



Figura 2-1: Piazzamento della sonda senza cavo NIMO-T per misurazioni della temperatura.

Sulla lunghezza totale della sonda geotermica di 200 m si ricava una temperatura del suolo media indisturbata ( $T_0$ ) di 14.8°C per questa località. Una temperatura in disturbata massima di 15.9°C è stata misurata al fondo della sonda.

Il sottosuolo mostra il profilo termico  $T_1$  ca. 2 ore dopo la fine del TRT. Dalla differenza da  $T_1$  a  $T_0$  si può dedurre la presenza di correnti di acque di falda rilevanti per la termica. I profili termici delle misurazioni effettuate con NIMO-T nella sonda sono mostrati in Figura 2-2.

## 2.2 Valutazione

L'evoluzione della temperatura tra 0 e 15 m di profondità è determinata dalla variazione annuale della temperatura in superficie. L'andamento delle differenze tra i vari profili termici non mostra una corrente di falda rilevante per la termica, la quale dovrebbe essere considerata nella pianificazione dell'accumulatore geotermico.

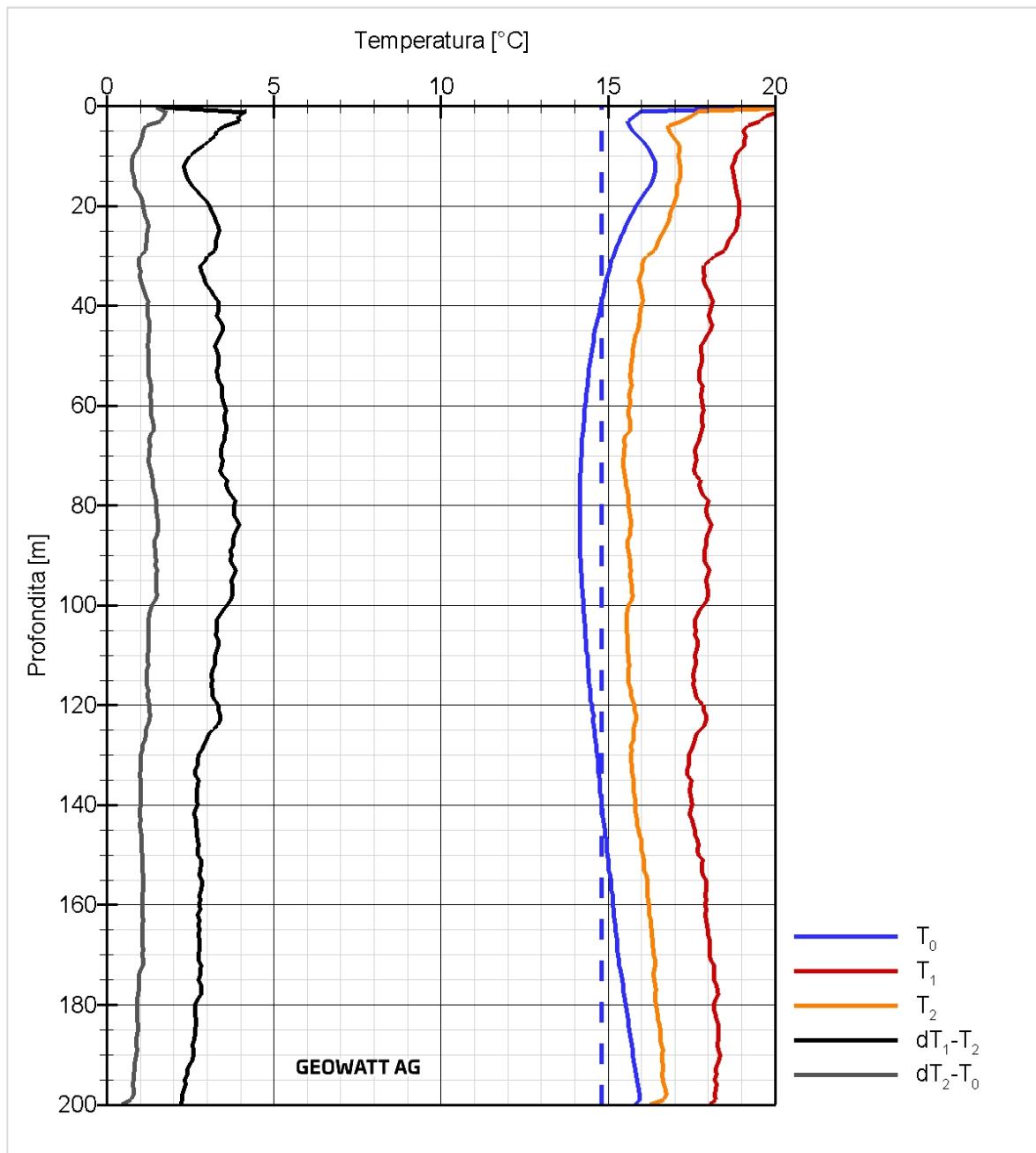


Figura 2-2: Profilo  $T_0$  del sottosuolo indisturbato, profilo  $T_1$  ca. 2 ore dopo la fine della fase di riscaldamento, profilo  $T_2$  ca. 24 ore in seguito a  $T_1$ , differenza tra  $T_1$  e  $T_0$ , differenza tra  $T_2$  e  $T_0$ , nonché temperatura media del suolo indisturbato di 14.8°C (linea tratteggiata).

### **3. Misurazione del profilo della conducibilità termica e della resistenza nel foro**

#### **3.1 Svolgimento della misurazione**

Per poter calcolare il comportamento termico dell'impianto di sonde geotermiche durante una iniezione di calore rispettivamente un' estrazione di freddo, è necessario conoscere sia la temperatura come anche la conducibilità termica del suolo lungo la lunghezza progettata della sonda. Il vantaggio di un "response test" termico avanzato (eTRT) rispetto a un TRT standard sta nel fatto che non viene determinato il valore medio della conducibilità termica nel suolo, ma bensì la sua variazione lungo la sonda test. Così, con una sola misurazione, si hanno a disposizione i dati corretti per la progettazione di diverse lunghezze di sonda.

Una potenza di riscaldamento regolata costantemente viene iniettata durante alcuni giorni nella sonda geotermica. In questo periodo, la temperatura del fluido viene misurata costantemente sia all'entrata che all'uscita dalla sonda. Prima e dopo l'iniezione di energia vengono misurati i profili termici lungo la sonda ( $T_0$ ,  $T_1$  e  $T_2$ ). Durante la procedura eTRT, l'intero svolgimento del TRT compresa la fase di ricovero termico, viene simulata con l'aiuto di un modello 3D. Il risultato delle simulazioni è il profilo della conducibilità termica, che accorda i profili termici misurati con i valori calcolati.

Un apparecchio di misura a regolazione di potenza della Geowatt SA è stato installato il 3 maggio 2012. Per minimizzare l'influenza atmosferica sui misuramenti, i tubi in superficie sono stati isolati, imballati in pellicola isolante e coperti con un copertone (vedi Figura 3-1). Le misurazioni sono state effettuate nel periodo dal 3 maggio al 8 maggio 2012. Lo svolgimento di prova delle misurazioni è raffigurato nella Tabella 1-1. I parametri del test sono elencati nella Tabella 3-1.

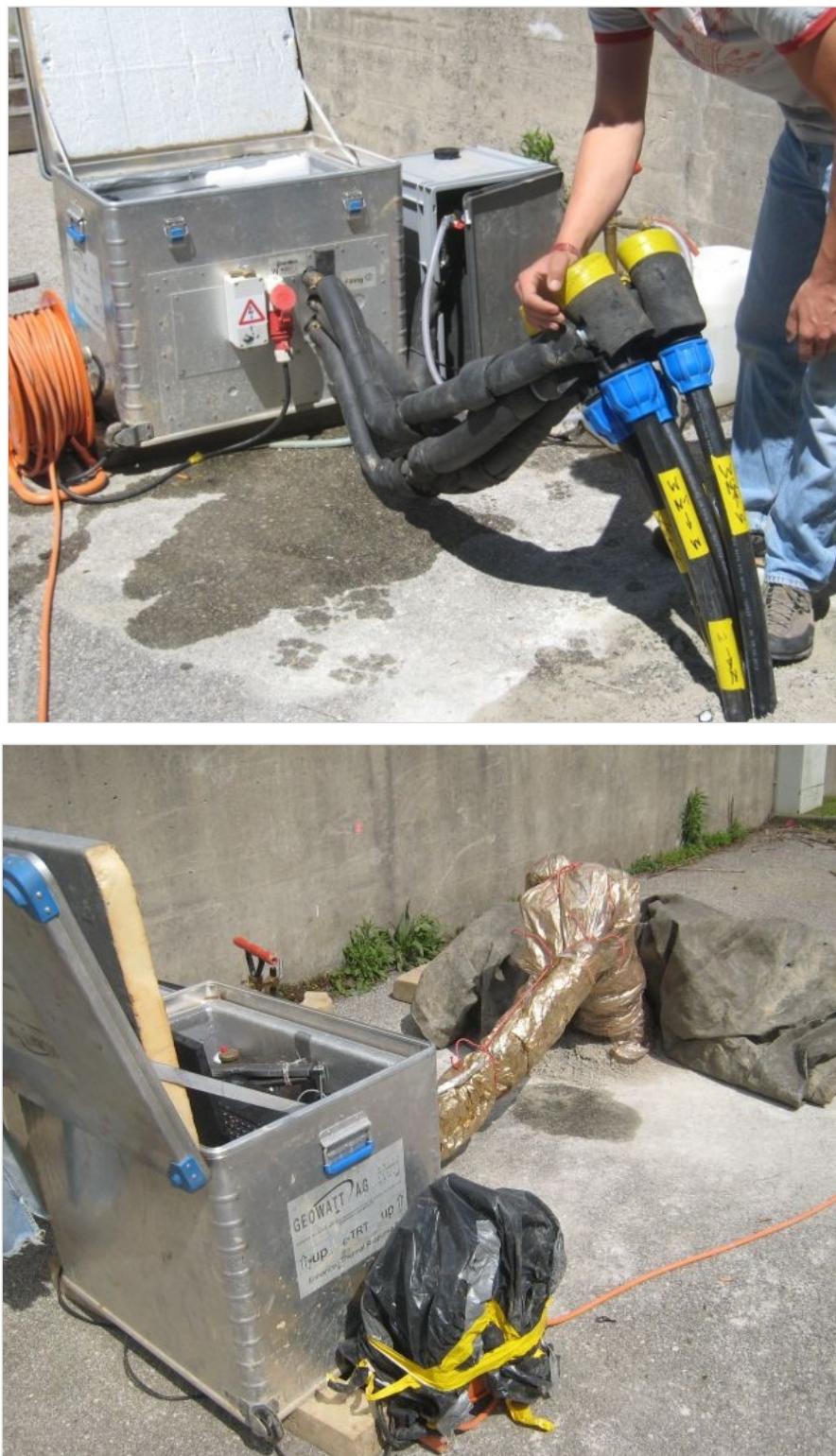


Figura 3-1: Installazione dell'apparecchio di misurazione TRT: gli allacciamenti tra l'apparecchio e la sonda sono stati isolati e coperti.

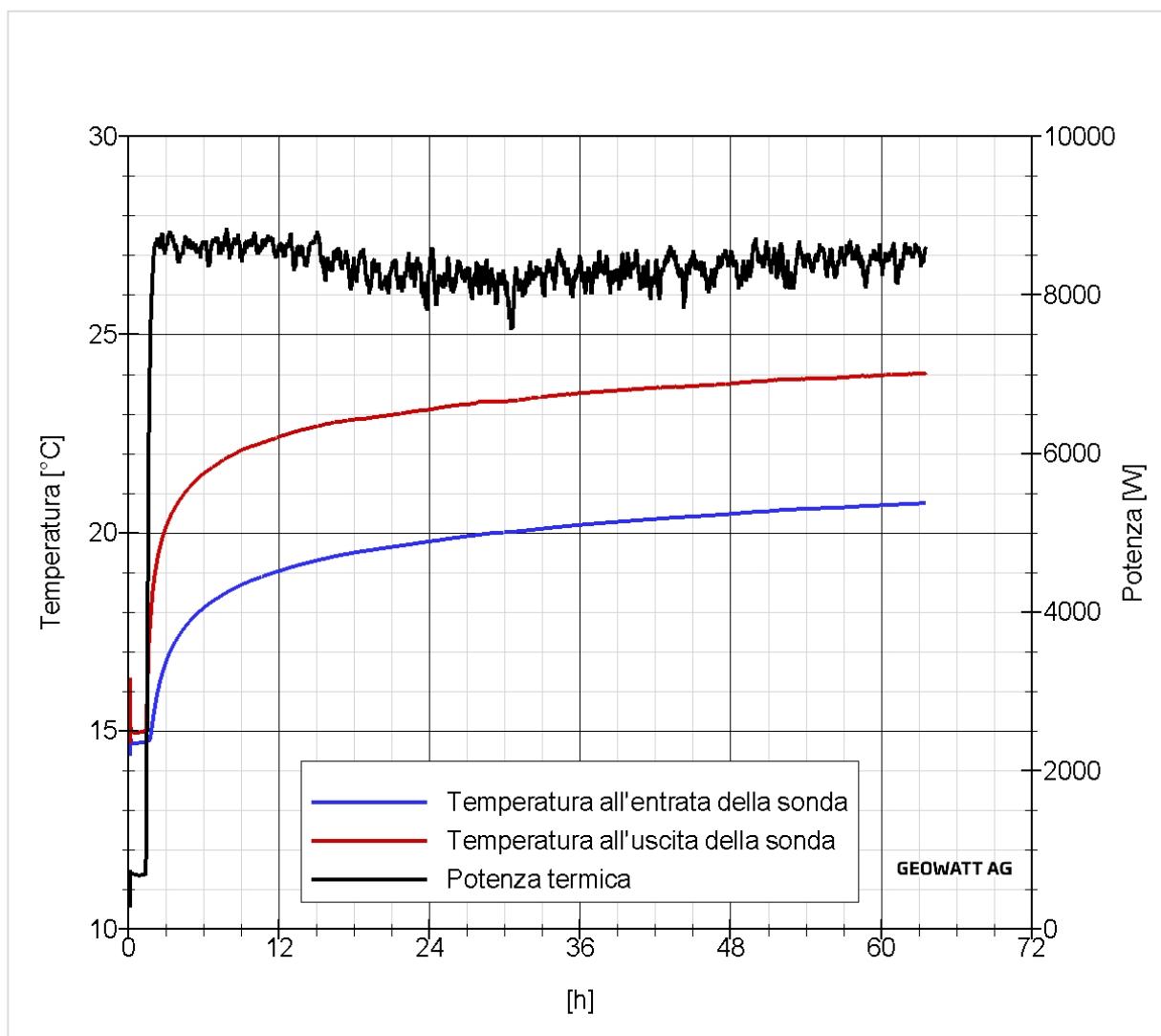


Figura 3-2: Evoluzione dei parametri dell'apparecchio TRT durante i misuramenti.

Tabella 3-1: Parametri impiegati per lo svolgimento del TRT.

Lunghezza sonda geotermica	Tipo di tubo a U	Raggio medio della perforazione $r_B$
200 m	Duplex, 40 x 3.7 mm	0.0675 m
Potenza media	Differenza di temperatura	Rata di circolazione
8'420 W	3.3 K	2'178 l/h

### 3.2 Risultati

I profili termici simulati con il modello FE sono stati accordati ai profili termici misurati nella sonda mediante l'aggiustamento di orizzonti con conducibilità termiche differenti. Da questo risulta il profilo della conducibilità termica di Tabella 3-2.

Tabella 3-2: Profilo misurato della conducibilità termica al sito Lugano-Besso.

Strato	Profondità [m]	Conducibilità termica [ $\text{W m}^{-1} \text{K}^{-1}$ ]
1	0 – 20	2.7 <sup>1</sup>
2	20 – 40	3.5
3	40 – 60	3.2
4	60 – 80	3.1
5	80 – 100	2.6
6	100 – 120	3.4
7	120 – 140	3.9
8	140 – 160	3.9
9	160 – 180	3.4
10	180 - 200	3.8 <sup>1</sup>

Per sonde lunghe 200 m possono essere adottati i risultati della Tabella 3-3. Per progettazioni di altre lunghezze il valore apposito è da calcolare secondo Tabella 3-2.

Tabella 3-3: Parametri geotermici per il dimensionamento di un accumulatore geotermico per sonde lunghe 200 m al sito Via Guglielmo Canevascini, Lugano-Besso.

Conducibilità termica media su 200 m	3.35 $\text{W m}^{-1} \text{K}^{-1}$
Resistenza termica media del foro (con materiale di riempimento standard, acqua come fluido di sonda e portata di 2178 l/h)	0.056 $\text{K m W}^{-1}$

<sup>1</sup> A causa di effetti numerici, lo strato più alto e quello più basso possono essere risolti solo in parte ( $\pm 0.25 \text{ W m}^{-1} \text{K}^{-1}$ ).

### 3.3 Verifica dei risultati

La verifica mostra come i parametri geotermici hanno potuto essere determinati molto bene con il modello di simulazione (cfr. Figura 3-3 a sinistra, Figura 3-4). Le imprecisioni del modello più grandi occorrono nello strato più alto e in quello più basso della lunghezza della sonda. Questo però non pesa in modo significante sulla determinazione dei parametri del suolo per il dimensionamento delle sonde.

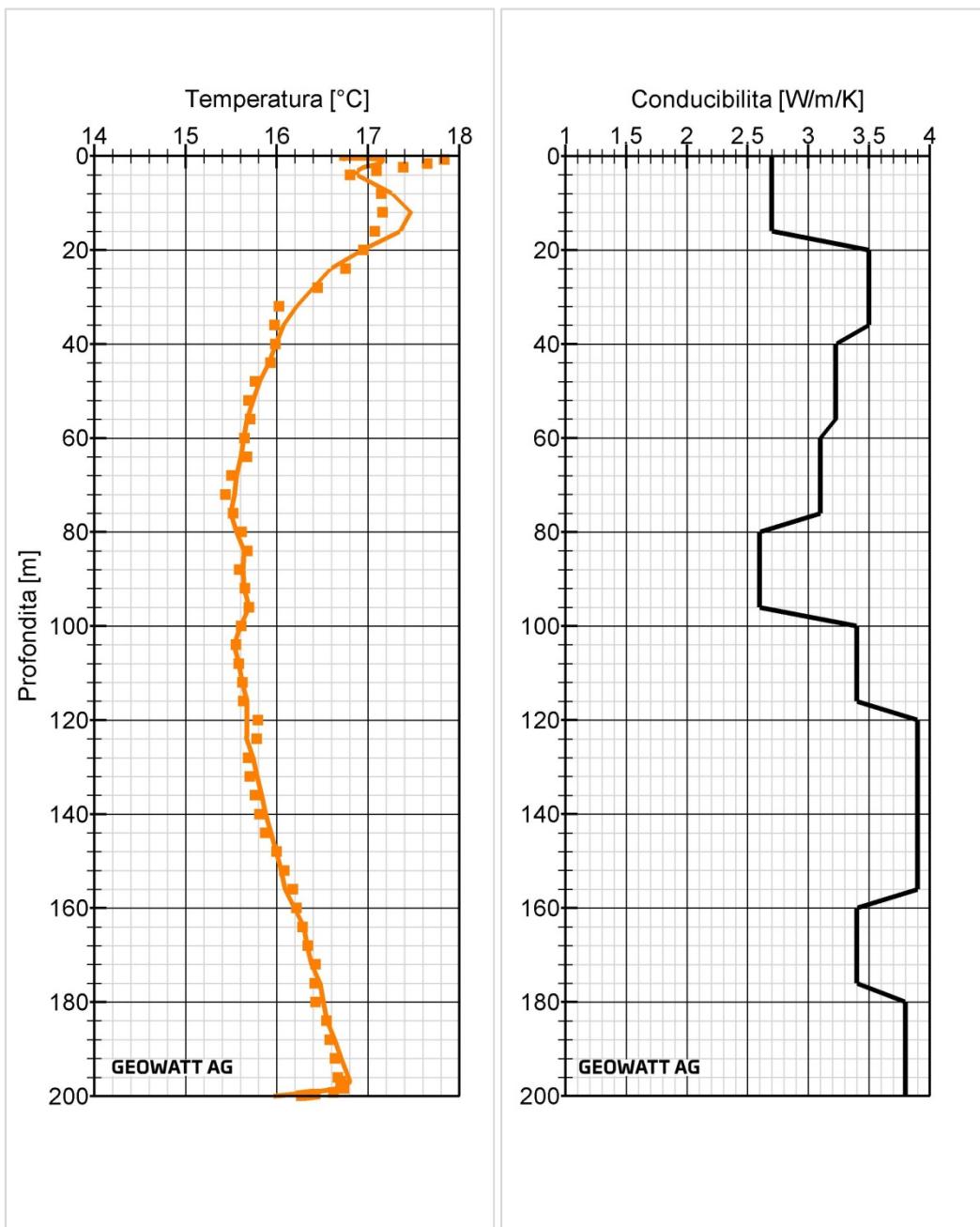


Figura 3-3: A sinistra: confronto tra misurazioni e simulazione, a destra: profilo della conducibilità termica.

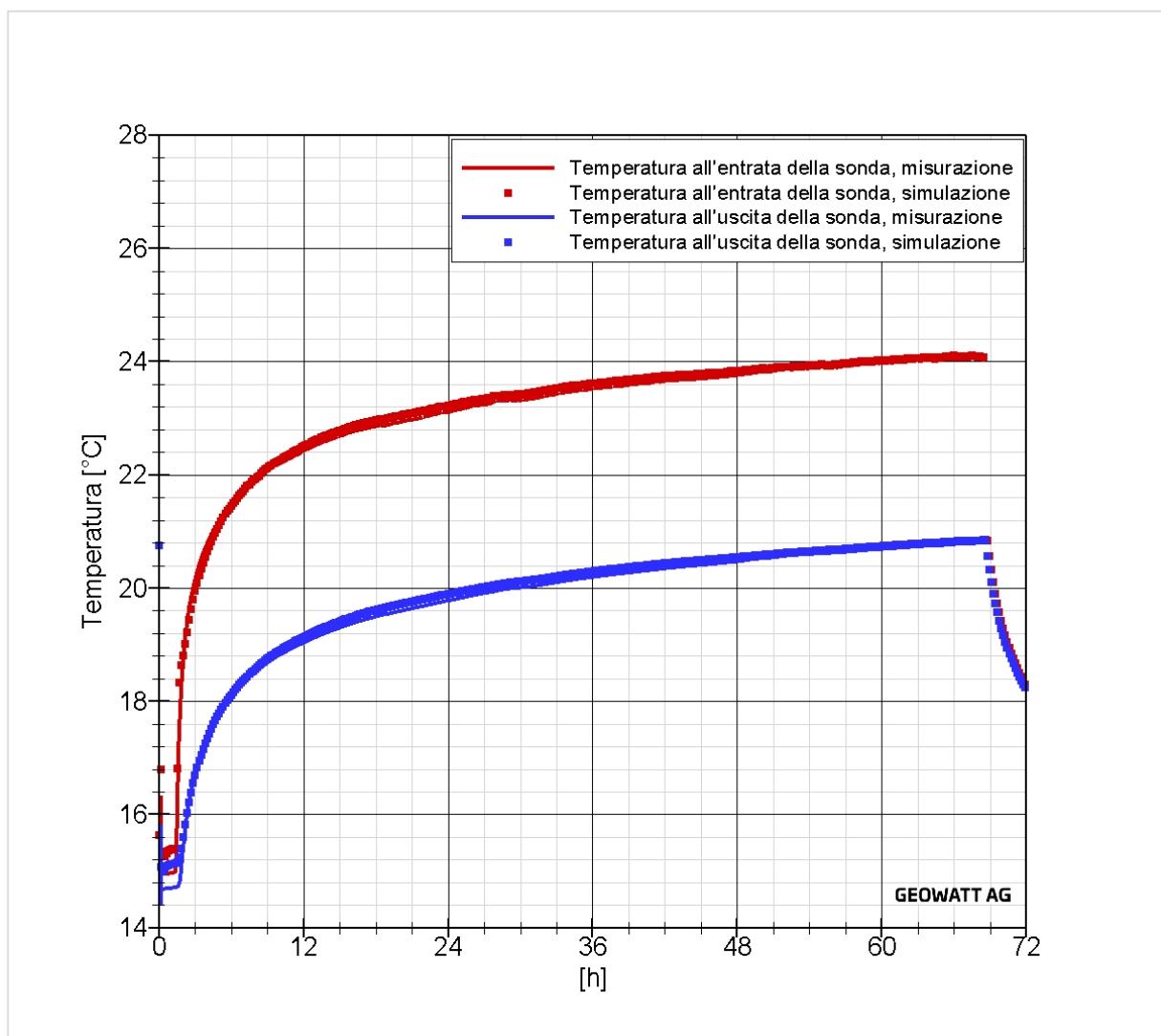


Figura 3-4: Confronto tra misurazione e simulazione della temperatura all'entrata e all'uscita della sonda geotermica.

#### 4. Consigli per il piazzamento di un impianto di sonde geotermiche

Impianti di sonde geotermiche con fino a 4 sonde possono essere pianificati e sviluppati senza problemi seguendo le indicazioni di progettazione della norma SIA 384/6 (appendice D). Queste indicazioni di progettazione si basano su un uso standard a scopo di riscaldamento di un piccolo impianto fino a 4 sonde.

Per il piazzamento di impianti di sonde geotermiche più grandi, che solitamente devono anche coprire un significante o addirittura principale uso a scopo di raffreddamento, le indicazioni di progettazione della norma SIA 384/6 non fanno più fronte. In questi casi, una simulazione totale del concetto di utilizzo effettivo per riscaldamento e raffreddamento dell'impianto è cruciale. Particolarmente, devono essere considerate le seguenti misure:

- Spazio a disposizione per le perforazioni
- Profili di carico annuale del fabbisogno energetico per il riscaldamento, l'acqua calda e il raffreddamento
- Temperatura di mandata per i singoli attingenti di energia
- Specificazioni e caratteristiche delle pompe geotermiche
- Separazione dei sistemi tramite scambiatore termico
- Sincronismo di componenti dell'impianto
- Idraulica del circuito di sonde geotermiche
- Eventuale integrazione di pannelli solari
- Eventuale integrazione di scambiatore di calore o freddo aria-suolo
- Concetto dell'impianto/Comandi elettrici
- Obiettivi per l'ottimizzazione

## Appendice 1: Sonda di temperatura senza cavo NIMO-T

NIMO-T è una sonda speciale per misurazioni della temperatura e della pressione in sonde geotermiche.

Comuni sonde di temperatura e pressione, le quali vengono inserite nella perforazione con un cavo dati annesso, sono problematiche da usare in tubi di sonde geotermiche lunghi. Questo per via della torsione della sonda geotermica attorno al suo asse verticale, che aumenta la frizione del cavo dati fino al punto da rendere impossibile il ricovero della sonda da una certa profondità. Inoltre, lo spostamento d'acqua provocato dal cavo risulta in una dislocazione della colonna d'acqua nella sonda geotermica e quindi in un errore di misurazione relativo. Per questi motivi, NIMO-T è stato costruito in modo da poter effettuare la misurazione in modo autarchico, senza collegamento via cavo con la superficie. NIMO-T è leggermente più pesante dell'acqua e scende con una velocità regolare di ca. 0.1 m s<sup>-1</sup> verso la base della sonda. Durante la discesa, la pressione e la temperatura vengono misurate in intervalli definiti di 2, 4 o 6 secondi. I dati delle misurazioni vengono salvati internamente. Dopo aver raggiunto la parte più profonda della sonda, NIMO-T viene riportato alla superficie per il ricovero dei dati pompando acqua nella seconda estremità della sonda.

Grazie ai corti intervalli di misurazione, NIMO-T fornisce un profilo termico praticamente continuo. Questo è importante per il dimensionamento di campi di sonde geotermiche, specialmente se è anche previsto un raffreddamento diretto ("free cooling"). In più, con questo metodo, è anche possibile individuare correnti di acque di falda.



## Appendice 2: Apparecchio di misurazione TRT a regolazione di potenza della Geowatt SA

L'apparecchio di misurazione TRT, sviluppato dalla Geowatt SA per uso proprio, ha misure di 0.83 m x 0.64 m x 0.61 m e pesa 63 kg. L'apparecchio è molto compatto e può così anche essere installato in cantieri difficilmente accessibili. La potenza può essere regolata continuamente da 0 a 10 kW. La potenza termica e la circolazione possono essere regolate indipendentemente l'una dall'altra. La precisione della misurazione della potenza elettrica e termica è di 1, rispettivamente 1.5%.

La registrazione dei dati esegue in modo interamente automatico. Il TRT è equipaggiato con un modem di telefonia mobile. Il pannello di controllo del TRT e i controlli di tutti i parametri sono accessibili in qualsiasi momento, come può anche essere effettuato il salvataggio dei dati, mediante log-in nel computer del TRT via la rete di telefonia mobile da un computer esterno della Geowatt SA.

