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Introduction

Vast amounts of energy are required every year in order for the needs for heating, cooling and lighting in buildings in the cities and rural areas around the world to be covered. In order for these energy demands to be met, as the case has been during the last decades, the energy has been provided mostly through the use of fossil fuels.

The use of fossil fuels has several consequences. First of all, not all places around the world enjoy the benefit of having their own sources of them, thus it is necessary to have them imported, which makes these areas and countries less resilient and more dependent on other ones. Moreover, fossil fuels can be expensive, as well as damaging to the environment, since using them means burning them and thus having a certain volume of pollutants released.

Another valuable resource that is practically required in every building around the world is clean (or clean enough) water. When thinking about it the first thing that comes to mind is drinking water, and by all means, this is necessary. However, what is usually less thought of is the water that is required in buildings for secondary uses, which can often be required in considerable quantities, as well. The secondary uses of water include uses such as the flashing of toilets and the watering of the plants inside and around a building. For these specific purposes the quality of water, although it still needs to meet certain criteria, does not need to be as high as this of drinking water.

In order to have the demands for water met, the common practice in many countries around the world (especially for areas which are densely populated, as the big cities are) is to have water extracted from one place, like a river, a lake or an underground aquifer, have the water transported to the area where is needed, have it treated and cleaned to drinking water quality and, finally, have it offered in the network. This procedure requires the use of energy, resources and infrastructure and can have a very substantial total cost. Moreover, it often leads to the depletion of natural resources, such as lakes and underground aquifers, which, in turn, can have negative consequences on the environment, as well as the water security of certain populations.

Due to the aforementioned reasons and as the disadvantages of the common practices became increasingly obvious, new ways to meet the demand for energy and water started being increasingly appealing and important. One way to cover these needs that became, and is still becoming, more popular has been the use of renewable resources in a sustainable way. This has led to an increased interest and use of many renewable energy sources, such as solar energy, wind energy and geothermal energy.

Geothermal energy is the energy that comes from the earth. This form of energy can be found in several countries around the world and one of them is Greece. Geothermal energy is often used in order for the energy needs of a building for heating, and even cooling in some cases, to be met.

On the other hand, the search for new water sources has not been so diverse, as in the case of new energy sources. Around the world, the advances that have been made in this area have to do with the improvement in our abilities to construct and maintain water dams, the improvements in our abilities to obtain water from underground aquifers of even greater depths and improvements in the technology that allows us to extract pure water from saline water.

However, there is a water source that has not been used to a great extent so far, although it can at times provide water of adequate quality and exactly where it is needed. This is the water that can be found in the underground aquifers, and especially the more shallow ones, which are located right beneath cities.

Our team, when designing the project, took into consideration exactly these previously mentioned renewable resources, the water in shallow underground aquifers and the geothermal energy.

The types of systems to make use of geothermal energy in buildings

The use of the geothermal energy in buildings, in order for their demands for heating to be covered, can happen via one of two main types of systems. A closed-loop system or an open-loop system. Both systems make use of the fact that the temperature of the ground at a certain depth below the surface is higher than that of the air or that of its surface, and in certain cases significantly so. Consequently, what the systems do is make use of this energy that is stored inside the ground.

The closed-loop systems work in this way (in short). A pipe network is constructed inside the ground and at an appropriate depth. The pipes are connected to one or more heat pumps inside the building and also to one or more water pumps. The pipes, the heat pumps and the water pumps form a closed loop and the water is forced to stay in it. If the pipes are placed horizontally in the ground the system is called horizontal, while, if they are placed vertically, the system is called a vertical one.

The water in the pipes collects energy that is stored in the ground, so its temperature rises. Then it is transported to the heat pumps, where heat is extracted from it and afterwards it is transported back in the pipes to reabsorb heat. The heat pumps are also connected to the heating system of the building and they use the amount of heat that was extracted from the water in order to heat it.

It is worth noticing here that the part of the system inside the ground, meaning the pipe network and the water pumps, is called a "geo-heat exchanger".

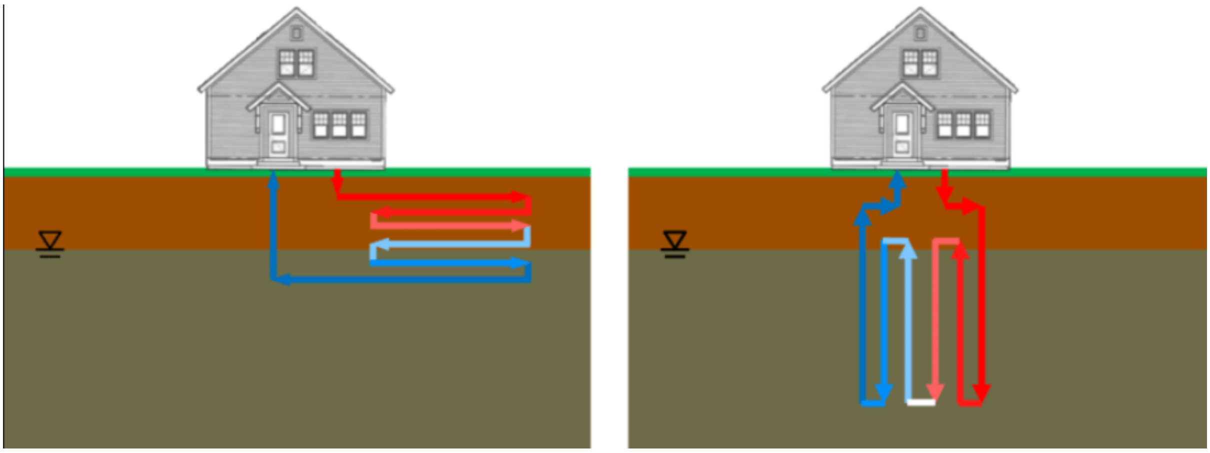

Figure 1. General design of a closed-loop system, a horizontal one (left) and a vertical one (right)

(Source: Cory A. Kramer, An experimental investigation on performance of a model geothermal pile in sand, Master's Thesis, August 2013)

The open-loop systems work in this way (in short). One or more wells are created around a building and water pumps are placed in them, in order to use the water of an underground aquifer located there. The ground at the area of the aquifer is of high enough temperature and consequently the water that is pumped has this same temperature. The water is transferred through pipes in the building and brought to one or more heat pumps in it.

In a similar fashion as in the closed-loop systems, heat is extracted from the water by the heat pumps and used to cover the energy demands inside the building. Unlike the closed-loop systems though, the water is not recycled and has to be discarded. This can happen either by it being re-injected in the ground, or by it simply being discarded in the sewer network.

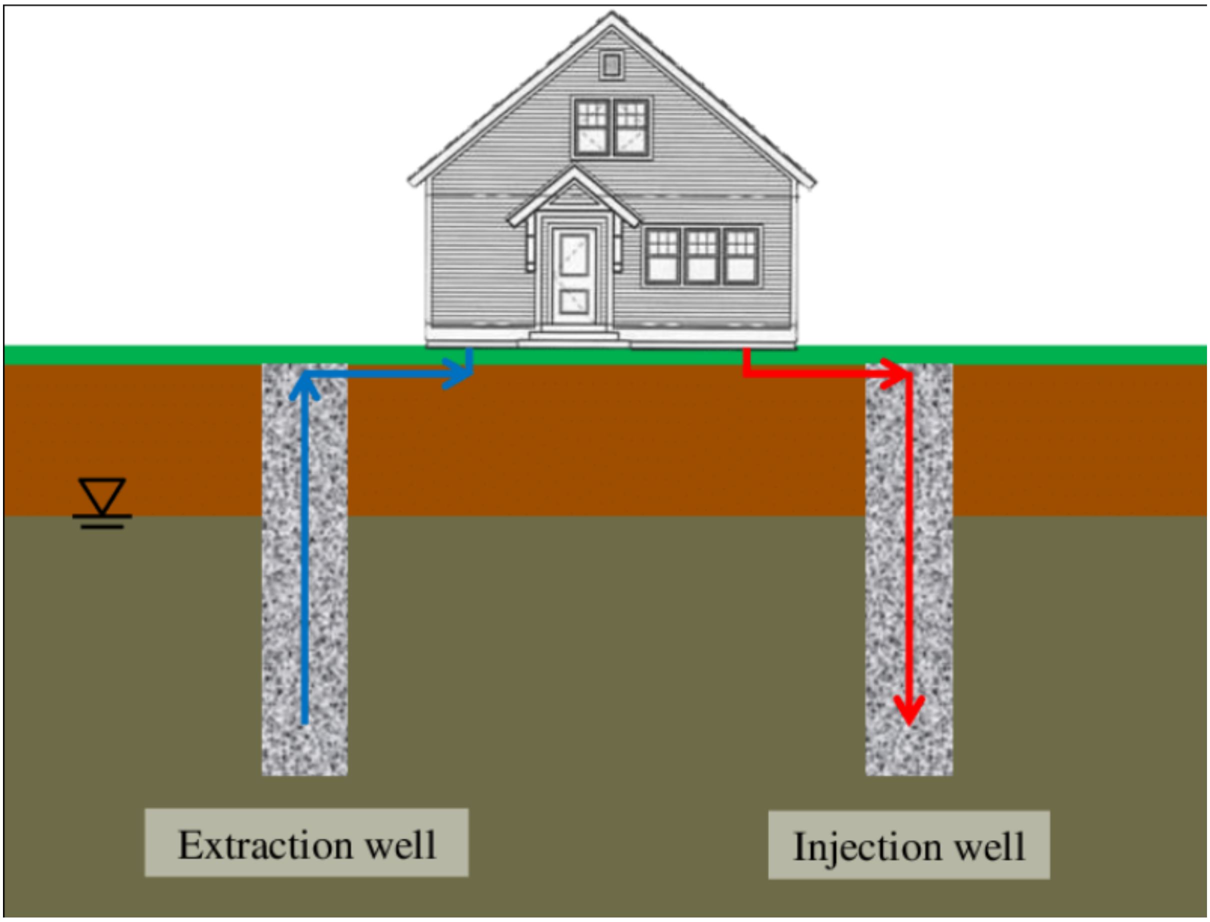

Figure 2. General design of an open-loop geothermal system in which the used water gets re-injected in the ground

(Source: Cory A. Kramer, An experimental investigation on performance of a model geothermal pile in sand, Master's Thesis, August 2013)

The water that gets pumped from the ground can have different quantities of several minerals and solids dissolved into it. This can be oftentimes well tolerated by the pipes and the water pumps, however not equally well from the heat pumps. In them it can cause erosion and damage and shorten their lifespan. Taking into consideration how important the heat pumps are for the system in order for it to work, and the fact that they are probably going to be the most expensive pieces of equipment in it as well, more often than not one extra piece is needed in the open-loop systems. This piece is the heat exchanger. The heat exchanger is a much more durable and resistant to erosion piece of equipment that works as a barrier between the water that gets pumped from the ground and the heat pumps. When placed in a system, the pumped water comes in contact only with it and the heat transfer to the heat pumps happens through it. In this way the system works more safely and is likely to have a longer life span. It is worth noticing though, that, when a heat exchanger is placed, there is an extra piece through which heat has to be transferred and this fact leads to certain additional energy losses from the system.

Finally, there is another part that can be found in any geothermal system (closed-loop or open-loop). It is not as vital as other parts previously mentioned, like the heat pumps, the pipes and the water pumps, and its use is not required every time. However, it can be sometimes needed. This part is the expansion tank. The purpose of it is to provide additional capacity to the system, in order for the pressure in it to be prevented from dropping too low under the worst-case conditions.

Additionally, it is worth mentioning that in order for any geothermal system to be used properly in a building the heating units need to be slightly bigger than when a typical heating system is used. Consequently, if a new building is being designed and a geothermal system is going to be used in it, the heating units in it need to be designed accordingly, otherwise they will possibly not be of adequate size. This is the case typically when a geothermal system is constructed in a preexisting building, however was not the case in our project.

The location of the pilot installation

A geothermal system was constructed in the Aristotle University of Thessaloniki and specifically at the Department of Civil Engineering. The Aristotle University of Thessaloniki (shortly A.U.Th.) is the largest University in Greece, located in the second biggest city of the country. A wide variety of Schools can be found in it and one of them is the School of Engineering. All the Departments of the Faculty share the same main building complex, located at the crossing of Egnatia street and Tritis Septemvriou street. Some of the Departments make use of other buildings around the main one, as well.

One of the aforementioned Departments is this of Civil Engineering. It consists of four different Divisions, such as the Division of Hydraulics and Environmental Engineering and more. This Division is located at a separate building, next to the main one, and it can be referred to as the building of Hydraulics in the following pages. The geothermal system was constructed in this building.

The location of the Aristotle University of Thessaloniki, of the School of Engineering and the building of Hydraulics is shown in the figures that follow.

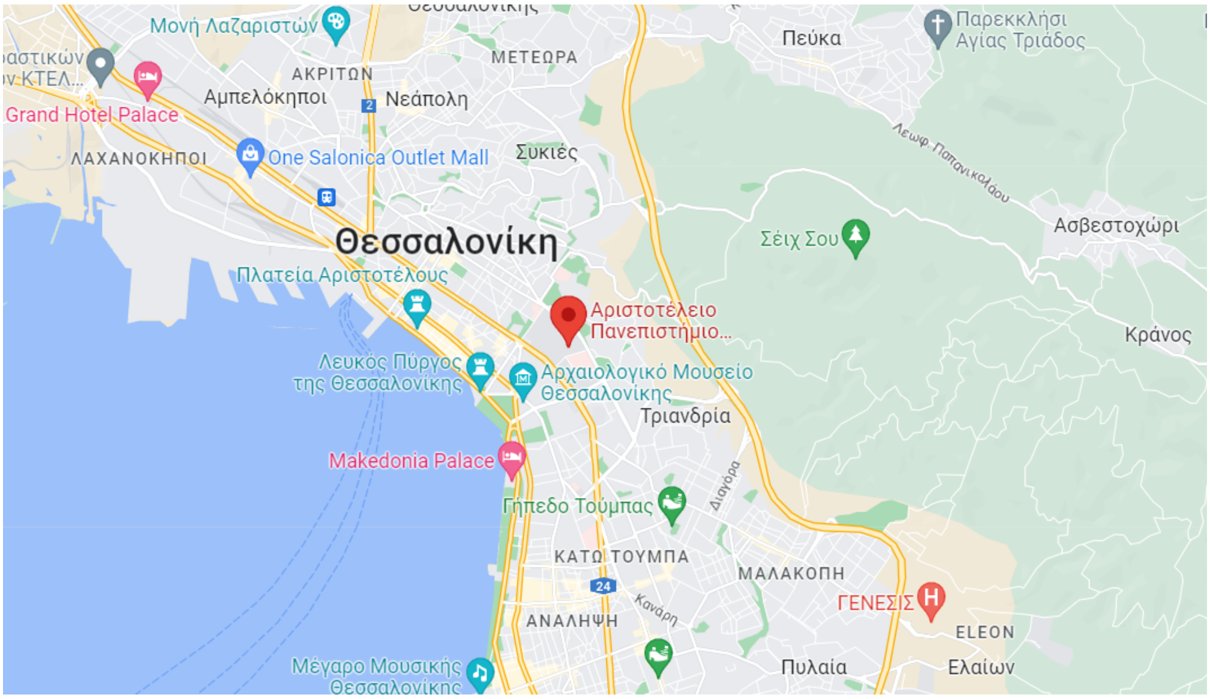

Figure 3. The map of Thessaloniki and the location of the Aristotle University of Thessaloniki marked with the red pointer

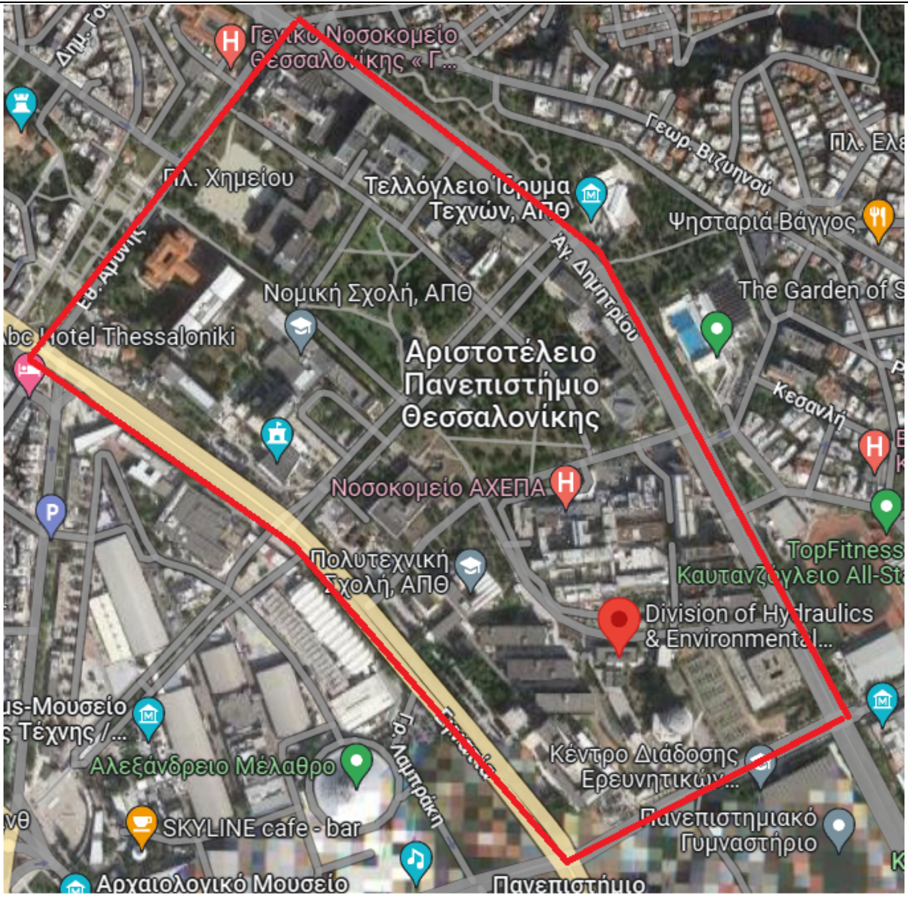

Figure 4. The location of the Aristotle University of Thessaloniki, marked with red lines and the building of Hydraulics, marked with the red pointer

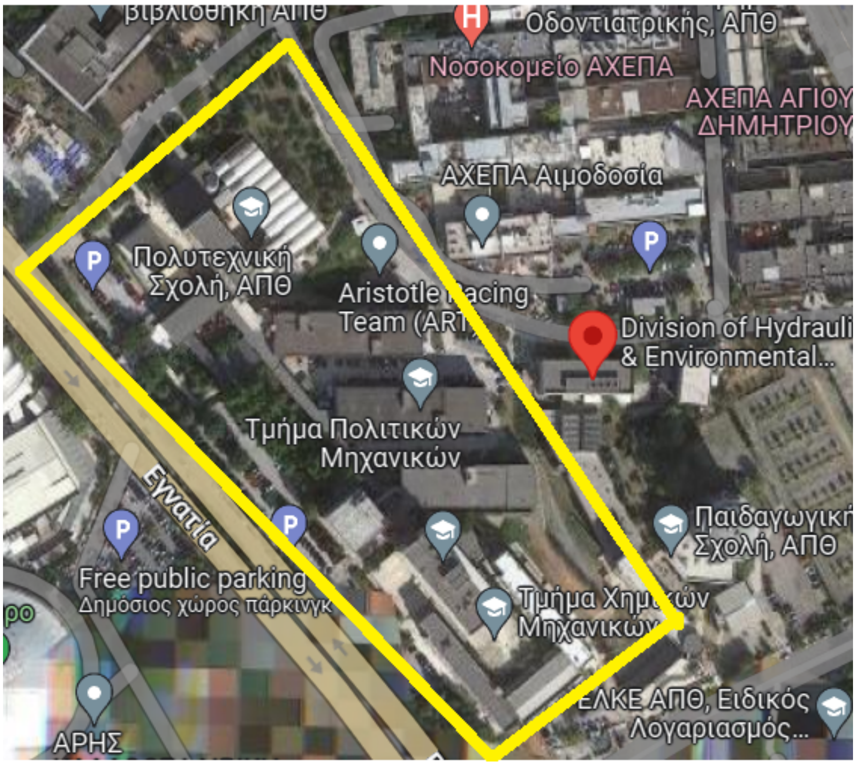

Figure 5. The main complex of building of the School of Engineering and the building of Hydraulics

The idea behind the pilot installation

The idea behind the pilot installation that was constructed in the Aristotle University of Thessaloniki was based on certain factors. To name a few, it was based on the scientific knowledge that the ground temperature, even in not great depth, would be high enough to make use of geothermal energy to heat a building. It was also based on the ongoing search for more sustainable and environmentally friendly solutions to cover energy and water demands in a building, as well as the estimation that below the University there is an aquifer, with a high probability of it being shallow.

A shallow aquifer could first of all provide water. This water would not be potable, however it could be of such quality that it could cover secondary uses, namely the water needed for the flashing of the toilets and for watering plants located around the building of Hydraulics. Inside the University, since most people buy bottled water to drink, the secondary uses are actually the ones that can lead to the greatest amounts of water used.

The water in this aquifer would be of adequate temperature for a geothermal system to function and, if the system would be an open-loop one, then the water would have to be re-injected in the ground. This practice though, would not only add an extra cost in the creation and function of the system, it would also be damaging, since some buildings in the University suffer from water inundation in their basements, and the re-injection of the used water would contribute in this problem.

Taking the above into consideration, the idea was formed to construct a system that could make use of renewable energy and water resources by:

a) making use of underground water located below the area where it is needed and that is currently not in use

b) heating a building with geothermal energy from this water

c) storing the water, after heat would have been extracted from it, in a tank inside the building so that it could be used later to provide the water needed for secondary uses in and around the building.

Such a system could serve as a prototype for other buildings inside and outside the city or the country. Additionally, the experience gained from its construction could be proven of value to other future installations of such systems.

Installation of equipment foreseen in the initial plan

The open-loop system, which was initially planned and constructed, is shown diagrammatically in Figure 6. Its main parts are:

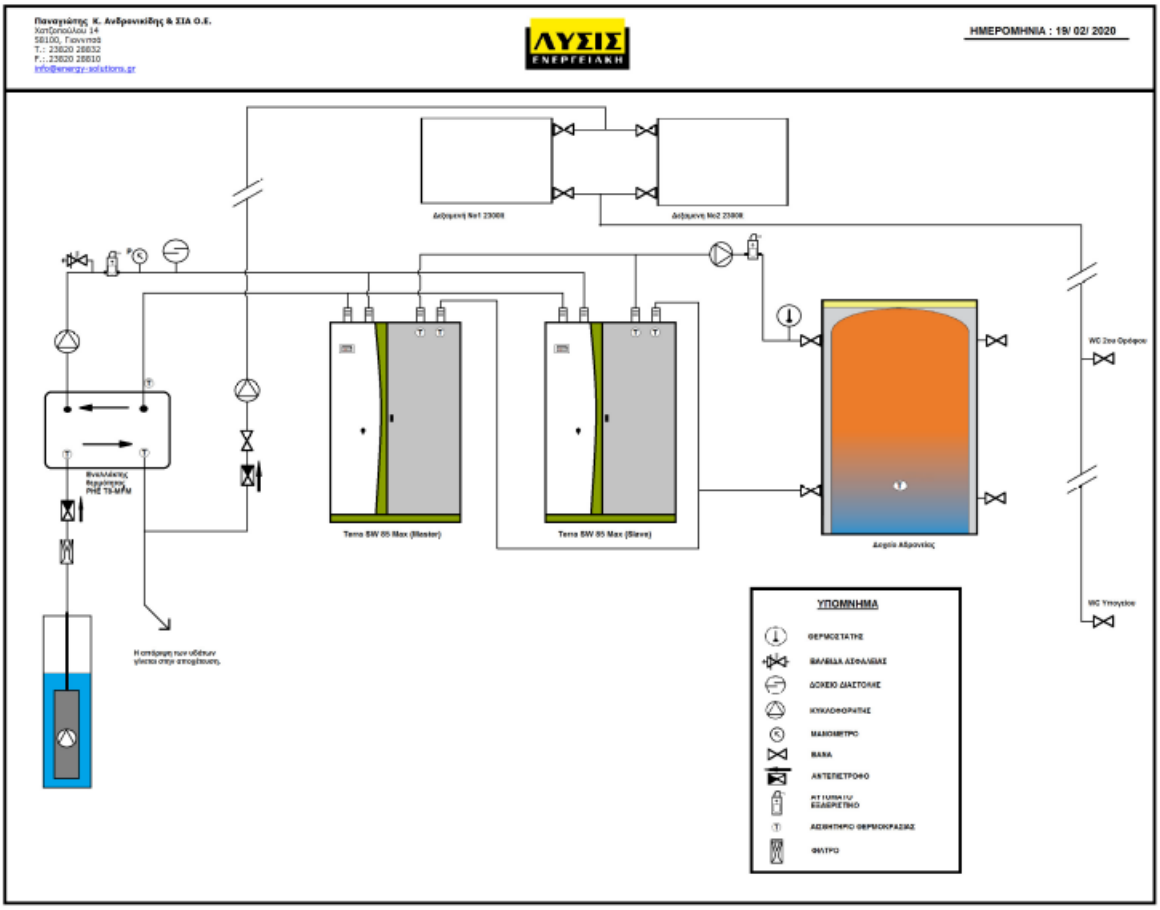

Figure 6. Plan of the initial installation

a. The pumping well (with a water pump and the required appurtenances). According to the initial plan, the water depth should be 18.0 m. Nevertheless, its depth reached 24.0 m, to increase the anticipated flow rate.

b. A plate heat exchanger

c. Two heat-pumps, with a capacity of 90 kw each

d. An insulated expansion tank with capacity equal to 1000 L

e. Two water tanks.

The items b to d were installed at the basement of the building of Hydraulics. The two water tanks were installed at the roof. The items b to e are shown in the photos of the following Figures.

The installation included a pipe network, which connected:

a) The well with the heat exchanger and the water tanks

b) The heat exchanger with the heat pumps and the expansion tank and through them with the pre-existing heating system of the building
c) The heat exchanger with the water tanks and the sewer system
d) The water tanks with the toilets of the building.

All the pipes are equipped with valves and other appurtenances. The potable water network is fully protected.

Moreover, the installation included a separate electricity table.

Figure 7. The heat exchanger (blue piece) and the heat pumps (grey)

Figure 8. The heat pumps

Figure 9. The inside of a heat pump

Figure 10. The pipe system behind the heat pumps

Figure 11. The expansion tank


Figure 12. The water tanks (a)


Figure 13. The water tanks (b)

Figure 14. The entrance of the building of Hydraulics where the system was created

Figure 15. The entrance of the building of Hydraulics with the sign of the project placed by it

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INTERREG V-A "GREECE - BULGARIA 2014 – 2020" COOPERATION PROGRAMME

PROJECT BENEFICIARY:	*ARISTOTLE UNIVERSITY OF THESSALONIKI*
PROJECT:	*Groundwater REsource managemENt for non-Potable water pUrposes, baseMent protection, and heating - Pilot application. GREENPUMP*
OBJECTIVE:	*HEATING OF THE HYDRAULIC BUILDING OF AUTH*
OPERATION:	*Expansion of works of the Geothermal project of the Hydraulic building of AUTh*
BUDGET:	*TOTAL BUDGET 73.128 € (ERDF: 62.159 € / National Funds: 10.969 €)*

Figure 16. The sign of the project placed by the entrance of the building of Hydraulics

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GREENPUMP

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Figure 17. The sign of the project that was placed by the entrance of the building of Hydraulics

Report of installation

During the construction of the pilot installation a number of different processes had to take place in order for it to be completed. Practical technical problems appeared and required a solution. Such problems may arise in installations taking place in urban environments, where traffic problems are not uncommon and the buildings where the installation is taking place can be older. The most important challenges were the following:

1. Due to the location of the building of Hydraulics, access to it proved to be very difficult for large and heavy vehicles, for the following reason: The building is located next to one of the main hospitals of Thessaloniki. It can be approached only by a one-way street, which carries heavy traffic because of the hospital, while its available width is curtailed by parked cars. The first day of the works, a heavy track was blocked for more than an hour, 200 meters away from the building. From then on, it was decided that heavy machinery would approach the building during weekends only. This situation caused some delay to the completion of the installation.

Figure 18. Transporting the heat pumps at the ground floor of the building of Hydraulics

2. The weight of each heat pump (TERRA SW Max GROUND SOURCE HEAT PUMP) is 600 kg and its dimensions 2019x1066x774 mm. Moreover, during transportation they should not form an angle larger than 15° from the upright position.

Carrying the heat pumps to the ground floor of the building was comparatively easy. The next step, though, namely putting them at their prescribed location in the basement, proved to be a formidable task, given the aforementioned restriction. The elevator of the old building was too small to be used. Finally, they were carried to the basement through a rear door, which had to be dismantled and reconstructed after the operation was completed.

Figure 19. How the heat pumps were able to be transferred inside the building

Figure 20. From the successful attempt to place the heat pumps inside the building

Figure 21. Bringing the heat pump inside the building

Figure 22. Transferring the heat pump inside the building (as seen from the inside)

3. The initial plan for a single larger water tank at the roof of the building had to be modified, and two smaller ones were placed instead. That was in order for the additional load that would be placed on the structure to be distributed more evenly. Their shape and their exact location (on beams) were dictated by similar thoughts.

Figure 23. The location of the two water tanks at the roof of the building of Hydraulics

4. Small-scale and local subsidence of soil under the load of the heavy drilling machinery occurred. This delayed the well construction, as better preparation and soil support was required.

5. Securing public safety during well construction, while also causing the smallest possible nuisance, required special consideration. The constructors had to completely close a certain pedestrian passage, since a number of people failed to adhere to safety rules.

6. The process of cleaning the well after the well completion presented some difficulties, because of it being located in an urban environment. Water with high mud content was disposed to a nearby flower bed, while the necessary care was taken for its spilling to the area around the bed to be avoided. Later on, cleaner water was disposed of at an inlet of the sewer network, without creating any problems to its function.

7. The hydraulic network, which carries water from the well to the tanks and from there to the toilets was tested after its completion. The pump functioned properly and no leak was detected.

8. The proper function of the electric system and the automatic startup and shutdown of the pump, based on water level inside the water tanks, was successfully tested, as well.

All in all, it can be concluded that the difference between theory and praxis can be substantial. Seemingly trivial details may pose considerable difficulties and may delay a construction. The installation of ground source heat pump systems to urban areas and to existing buildings, in particular old ones, presents specific challenges, which should be carefully considered. Thus, the planning of construction works should allow for adaptation to unexpected conditions.

Installation of equipment and technical works of the second phase

The well flow rate was not adequate for heating purposes, just a few minutes after the initiation of pumping. Possible solutions to this problem could either be the drilling of a deeper well or the transition to a closed-loop system. After examining both possible solutions, the transition to a closed-loop system appeared to be the best of the two and it was the one implemented.

When the closed-loop system was constructed the equipment needed on the inside of the building was in place already. What needed to be transformed was the part of the system on the outside of the building and in contact with the ground. In the following figures parts of the closed-loop system can be seen, as well as moments of the construction process.

Figure 24. Borehole drilling equipment in situ

Figure 25. Tube installation in the boreholes

Figure 26. Geo-heat exchanger boreholes

Figure 27. Geo-heat exchanger boreholes and the water well among them

Figure 28. Filling the boreholes with grout

Figure 29. The pipe network that connects the heads of the geo-heat exchanger boreholes

Figure 30. The central manhole of the geothermal heat exchanger

In this second phase, the construction process was probably not more simple. However it could be considered more efficient, since the experience gained from the first phase was helpful in order for mistakes and miscalculations to be avoided.

Moreover, no large-scale works had to take place inside the building. All the installations were on the outside of the building, where access and movement of people and equipment was easier and, additionally, the most (in a sense) fragile pieces of equipment, that required special attention during their transportation and installation, namely the heat pumps, were in place.

It is worth noting that a water pump was already in place and no extra water pump was needed to the system. The ability of the pump to provide the two tanks at the roof of the building with water was not affected and this is significant, since one of the main goals of the system is to be able to provide the building with water for secondary uses.

Testing the installation

In order for the ability of the closed-loop system to work to be tested two tests were performed, a thermal response test and a thermal response test of single U heat exchanger. In short, the goal of the tests was to see if indeed the water in the system would be heated adequately in the pipes of the closed-loop system. If the tests failed, that would mean that the system could not provide adequate heating for the building. If the test were successful, that would indicate that the system could function properly.

The Thermal Response Test

The thermal response test aims at measuring the thermal properties of the installed heat exchangers, not just those of the ground. The factors involved in those are: 1. The thermal properties of the ground, 2. The thermal properties of the filling material of the drills, and 3. The pipe type of the heat exchanger.

The thermal response test is valuable because it contributes to the correct design of the whole system. Moreover, in systems that are already in place, this test provides results that can be compared with the initial assumptions that were made when the system was being designed and it also examines the proper function of the heat exchangers.

In the thermal response test, the heat exchangers are provided with a steady amount of heat and for a specific amount of time (longer than 36 hours). By registering the temperature of the water entering and leaving the system conclusions can be reached about the thermal conductivity (λ) and the thermal resistance (rb) of the heat exchangers.

Bellow it is stated what the symbols used indicate:

λ: Thermal conductivity (W/m,K)

C: Heat capacity (J /m3,K)

α: Defusion (m2/s)

rb: Thermal resistance (K/(W/m)

ro: Radius of the drilling (m)

H: Depth of the drilling (m)

Q: Thermal power (W)

Tm: Average temperature of the water entering-leaving the system (oC)

Ts: Ground temperature (oC)

tb: Stabilization time (s)

γ: 0.5772

For tb > 5ro2/a, the main equation is:

$Tm=Q/4\pi\lambda H(ln(4at/ro2)-\gamma)+Qrb/H+Ts$

or

$Tm=Kln(t)+m$,

note that:

$K=Qln(t)/4\pi\lambda H$.

Consequently, the thermal conductivity is:

$\lambda=Q/4\pi KH$

and the thermal resistance is:

$rb=H(Tm-Ts)/Q-(ln(t)+ln(4a/ro2)-\gamma)/4\pi\lambda$.

The data that regard the drilling are the following:

ro=0,075 m

H=50 m

Q=3,5 Kw

Ts= 20 C

λ= 3 W/m,K (estimation)

α=0,0000012 m2/s

C=2500000(J/m3,K) (estimation)

tb=5ro2/a=23.437,50 sec=6h 31min

ln(23437,50)=10,06

Duration: 48 h.

The results of the test are shown in the following graphs.

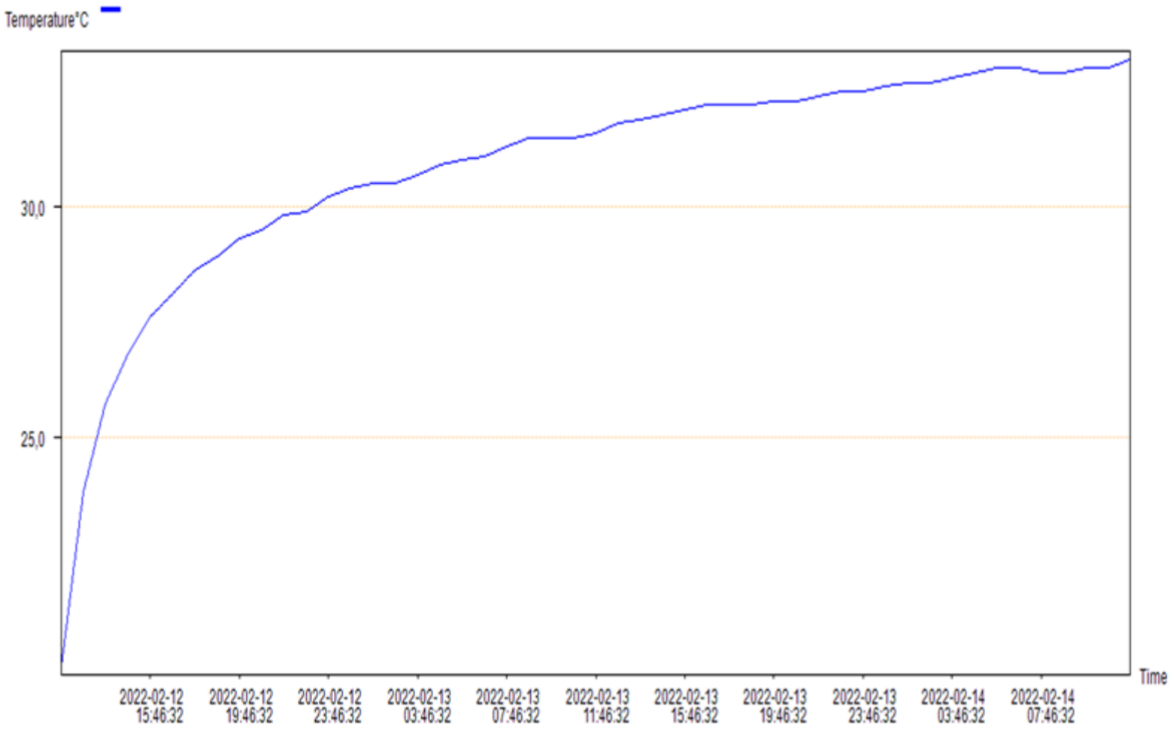


Figure 31. The initial temperature

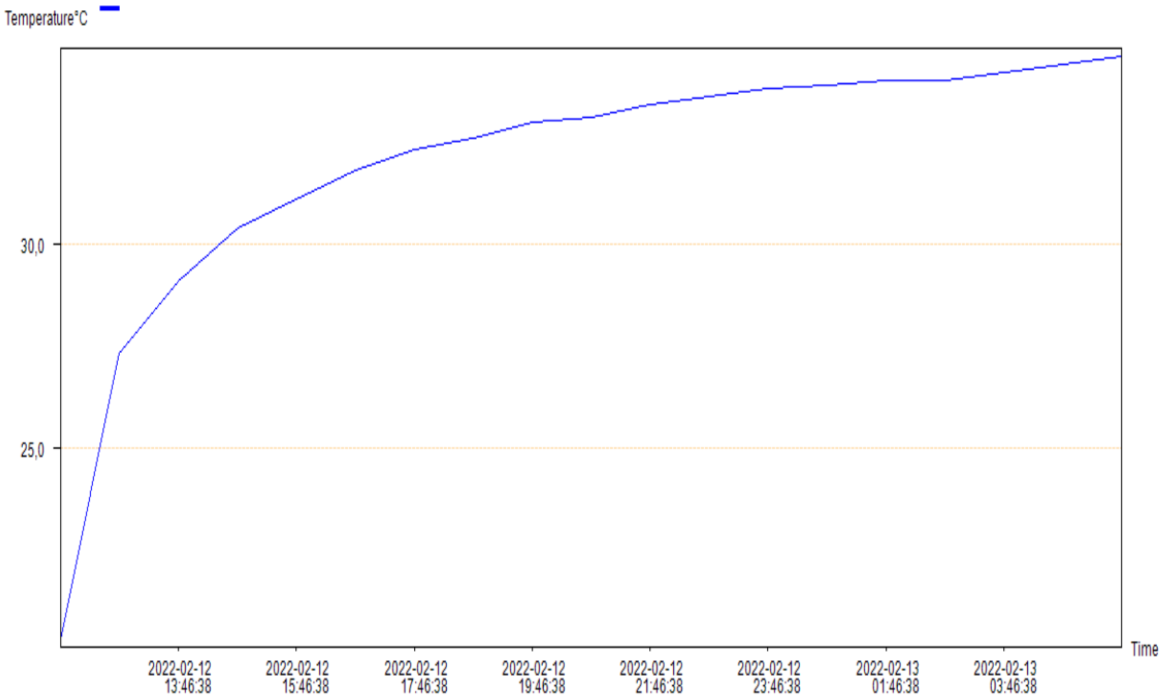
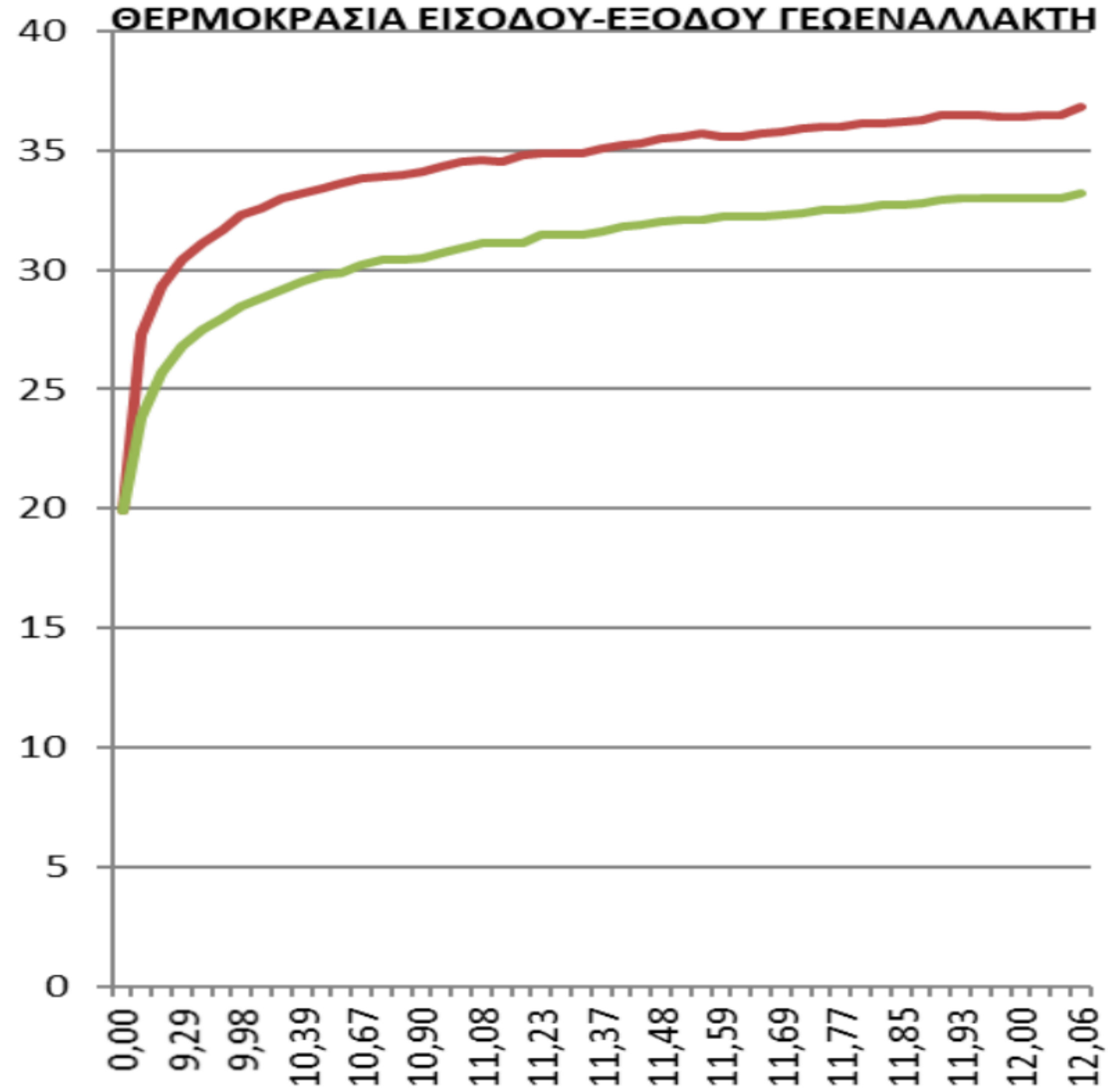


Figure 32. The temperature at the end



Figire 33. The temperatures at the heat exchanger at the beginning and at the end. The x axis shows the ln(t) in sec and the y axis the temperature in ^{o}C

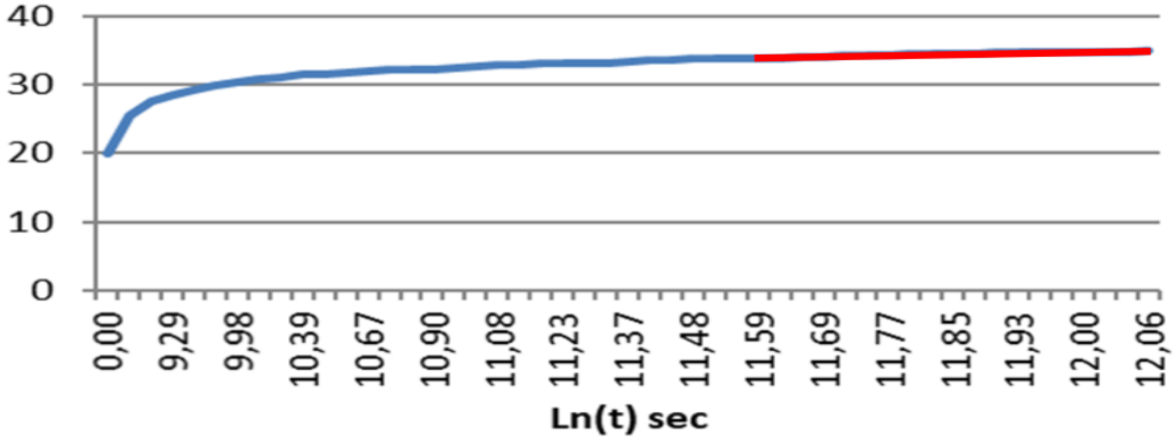


Figure 34. The average temperature of the heat exchangers. The y axis shows the temperature in °C

By using pieces of information previously presented it can be calculated that:

λ= 3,06 W /m,K.

And for Tm=34,8 and ln(t)=11,93 it is:

rb=0,04 K/(W/m).

Thermal response test of single U heat exchanger

The thermal response test of single U heat exchanger aims at measuring the thermal properties of the installed heat exchangers, not just those of the ground.

Following are the graphical representations of the results acquired:

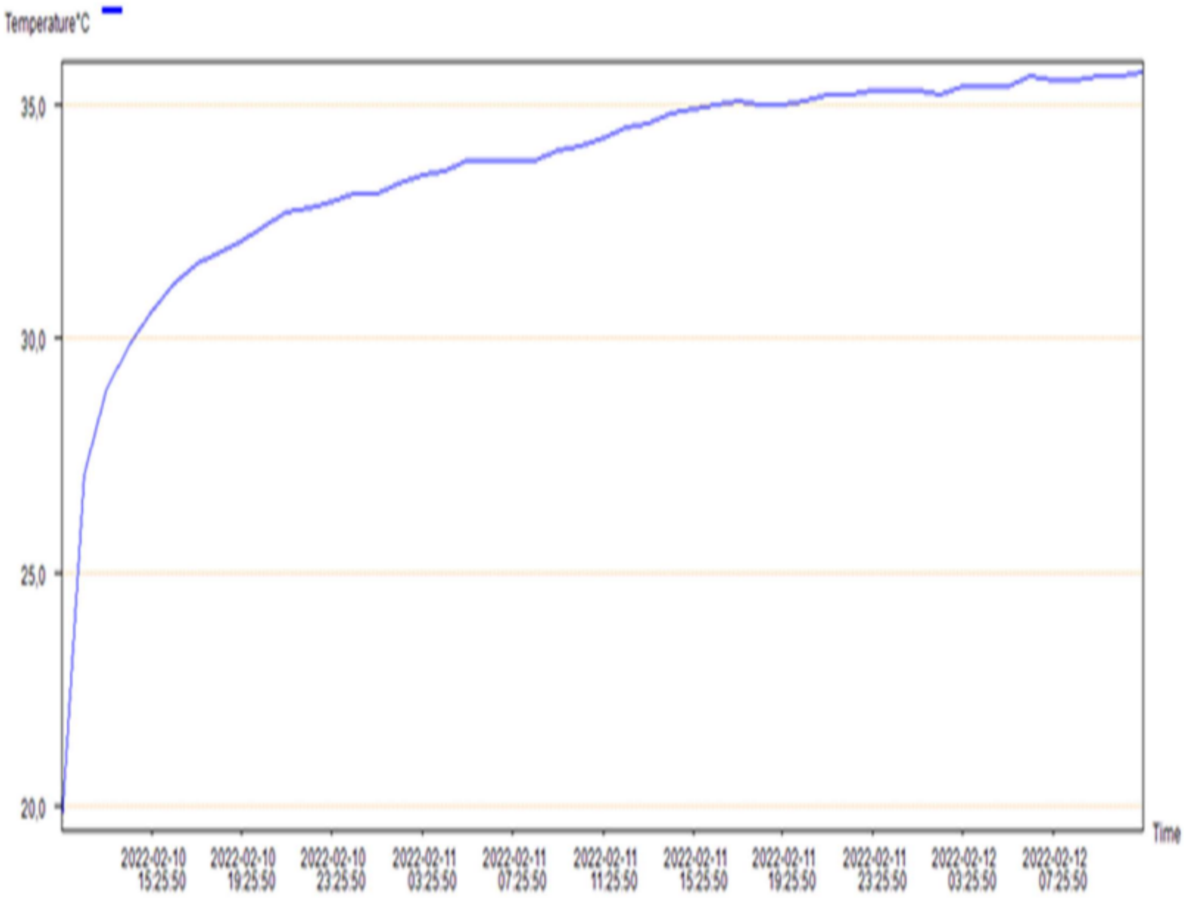


Figure 35. The initial temperature at the heat exchanger

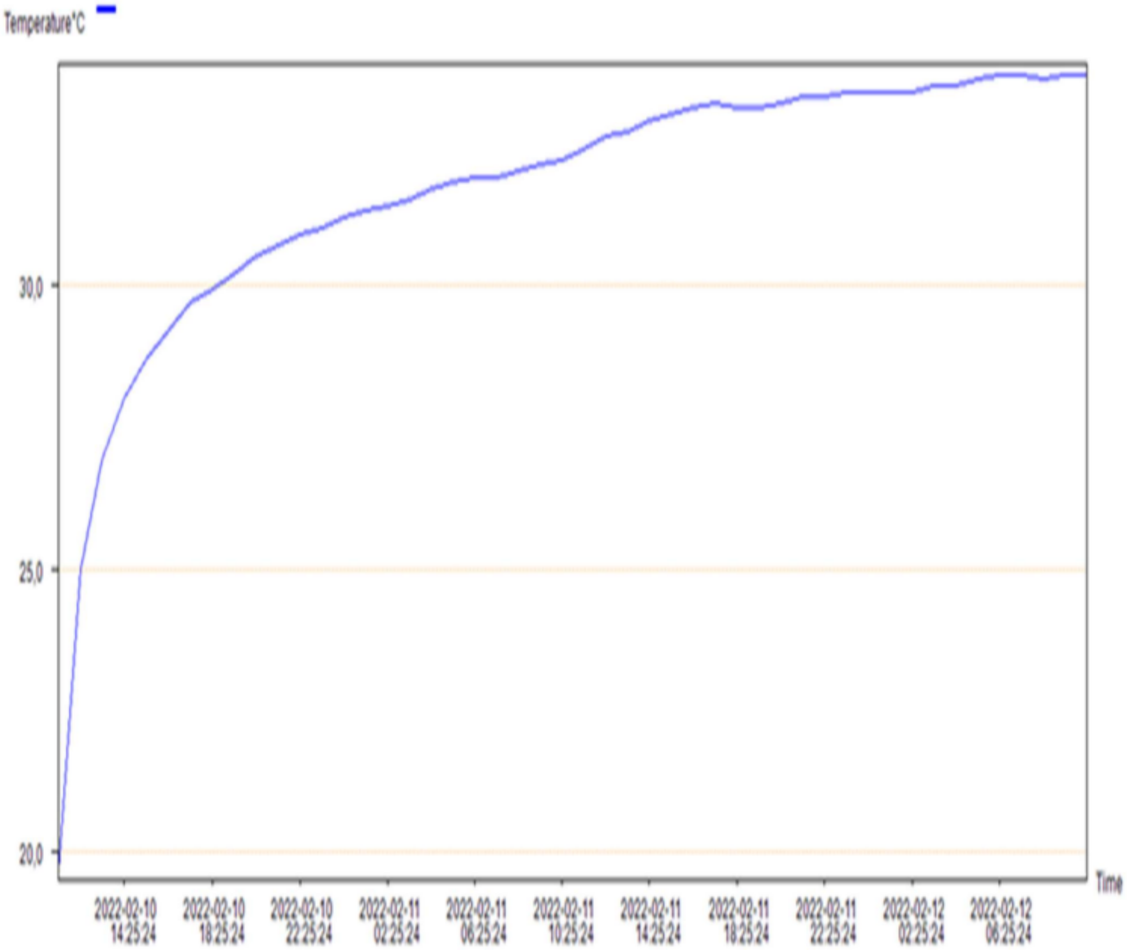


Figure 36. The temperature at the end

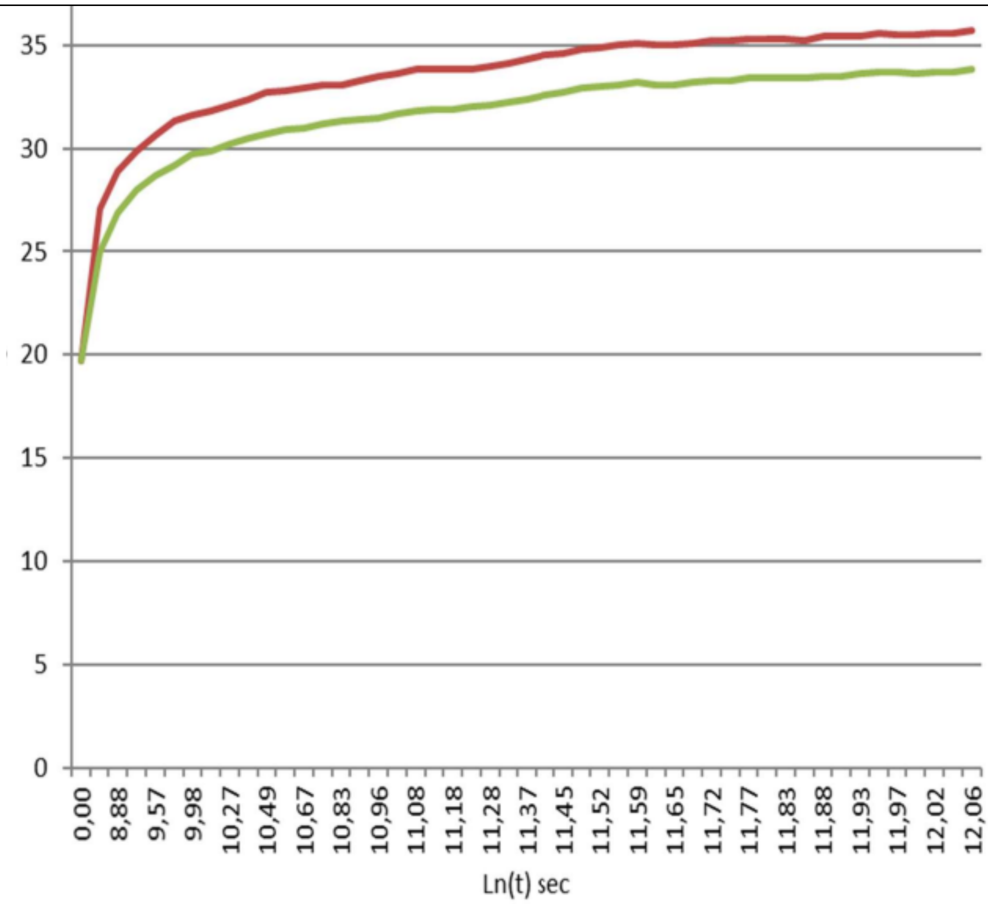


Figure 37. The temperatures at the heat exchanger at the beginning and at the end. The x axis shows the ln(t) in sec and the y axis the temperature in ^{o}C

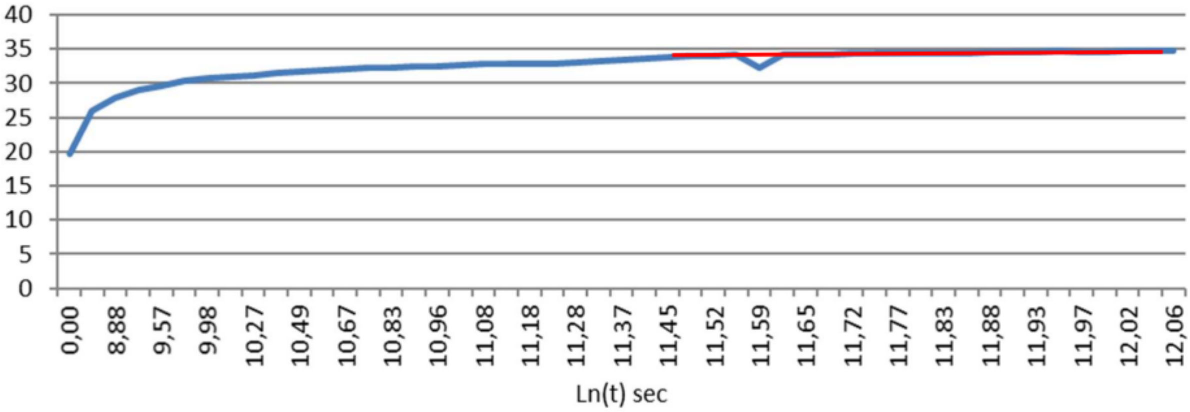


Figure 38. The average temperature of the heat exchangers. The y axis shows the temperature in ^{o}C

By using pieces of information previously presented we can calculate:

λ= 2,90 W /m,K.

And for Tm=34,5 and ln(t)=11,93 it is:

rb=0,18 K/(W/m).

The previous two tests indicated that the closed-loop system that was created could provide heating in the building where it was installed.