

Work Package 2: Communication & Dissemination

Deliverable 2.7.4 (former 2.3.4): Overall public open report on the projects results (partners contribution)

Beneficiary: IHU (former TEICM)

INTERREG V-A COOPERATION PROGRAMME:

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About this document:

The present Deliverable summarizes the contribution of IHU (former TEICM) in the implementation activities of IHU (former TEICM) in the framework of the GREEN PUMP project. The following are briefly presented in the sections of the deliverable:

- Site and building selection for the IHU (former TEICM) studies.
- In-situ measurements.
- Study of the secondary water system.
- Study of the geothermal heating system.

A detailed presentation of the aforementioned subjects is given in the separate IHU (former TEICM) Deliverables of the project.

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1. Scope of Deliverable 2.7.4 (former 2.3.4) – IHU (former TEICM) contribution

The scope of the present Deliverable 2.7.4 (former 2.3.4) is to summarize the implementation activities of IHU (former TEICM) in the framework of the GREEN PUMP project. The following are briefly presented in the sections of the deliverable:

- Site and building selection for the IHU (former TEICM) studies.
- In-situ measurements.
- Study of the secondary water system.
- Study of the geothermal heating system.
- IHU contribution to the reports concerning the simplification of permits and identification of environmental and social benefits.

A detailed presentation of the aforementioned subjects is given in the separate IHU (former TEICM) Deliverables of the project.

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The IHU (former TEICM) scientific team would also like to acknowledge the contribution of Athina Zacharoudi, Elias Pantazis, Vasileios Grounas and Andreas Dellios in several parts of the implementation activities.

2. Site and building selection for the IHU (former TEICM) studies

2.1 Hydrogeology of Serres basin

In the present day, the hydrographic network of the low section (lowland) of the Serres basin is almost entirely artificial. The predominant element of this is the river Strymonas, which on its natural course, in the past and before the construction of the land reclamation

works, coming from Bulgaria in the area of the basin, deposited sludges forming the great alluvial ripple of Strymon River.

The design and construction of major land reclamation projects, mainly in the low part of the basin, resulted in both the destruction of old abandoned dormitories and the integration of some of them into the irrigation network. In the natural environment of the basin, there were permanent lakes or lakes, which have played an important role in shaping the field of deposits that constituted the local basic level of the rivers Strymonas, Belitsa, Aggitis.

The tectonic draft of river Strimonas has been created between the geotectonic zones of Rodopi in the east and the Serbo-Macedonian mass in the west. The boundary of the two zones is the river Strymonas, while the tectonic contact line is not visible on the surface (over two restricted positions) due to its cover from the deposition of the Neogen and Quaternary sediments that have paid the tectonic draft. The basin of Serres consists of two basic systems:

- The system of the rocks of the background (The background of the basin of Serres is the transformed rocks of the Rhodopean zone to the east and the Sermakedonian to the west).
- The system of post-polar sedimentary deposits (Neogen, Quaternary).

Groundwater body included in this basin and associated with surface water is:

- GR1100010 Serres System.

This underground system, which extends to the development of neogen and quaternary deposits, is estimated to receive an average annual volume of about 350 million m³ of water.

In general, we can make the following assessments for the hydrogeology of the rocks of the Serres basin:

- In the E/NE department, the presence of marbles creates the conditions for the development of a significant potential for karstic aquifer, which contributes both to note numerous of sources.
- In the W/SW division, the dominance of shale-gnosis-ambivalence, creates the conditions for surface drainage and drainage of surface water in Strymon basin.

The absence of significant sources characterizes the above development. The tectonic fragmentation of all background rocks has created the conditions for the development of

secondary porosity and the creation of local underground aquifers. These zones are either discharged surface by springs or feed the aquifers of the sedimentary deposits of the basin via lateral transfusions.

Characteristic of quaternary deposits is the complex structure of their materials depending on their location and distance from the outlets of the torrents and rivers in the lowland zone. The periphery of the basin is dominated by the coarser materials deposited by the rivers in the creation of the alluvial ridges. Most torrents end up, without continuity, in the zone of complex alluvial ridges, where their runoff infiltration takes place. Because of these intense and important infiltrations, surface water primarily feeds underground aquifers. In addition, significant underground aquifers are also supplied via lateral transfusions from the underground aquifers grown in the karstic basins mainly. The major human hydrological interventions in the plain of Serres, caused the inactivation of the role of many alluvial ridges in the main supply of the underground aquifers. The rapid abstraction of surface water on the perimeter of the plain through the drainage ditches does not allow, as in the past, to filter the same quantities of water for the supply of groundwater. Fine materials were deposited in the central section of Serres plain, on either side of the broad metameric zone of the river Strymon. There, due to repeated flooding and the presence of the lake of Achinos, a zone with a thick central layer system with low porosity and permeability was created. Within this system are discontinuous horizontal horizons or sand lenses, which favor the development of underground under pressure or partially under water pressure. The largest thickness of this system is located in the area where the lake of Achinos was located before being dried up. The exploitation of the underground aquifers of the lowland area, developed in quaternary and neogenous deposits, is carried out through a large number of irrigation and irrigation water wells.

In conclusion, we can make the following assessments of the hydrogeological conditions of the basin deposition system of Serres.

In the Quaternary deposits and especially in the chondrocytes of the alluvial ridges of the plains of the lowland area, the main aquifers in the area develop. These deposits in the northern part of the basin of considerable thickness

In general, the aquifer of the basin of Serres, according to the management plans of the Ministry of Environment and Waters, is: *The underground water system of Serres*. It is an alluvial aquifer located in the drainage basin of the River Strymon. It has an area of 2253.46 km², a maximum length of 100 km, a maximum width of 35 km and a thickness ranging from 10 to 120 m. Surface water is associated with the River Strymon, River Agitis and Lake Kerkini.

2.2 Underground water conditions at the selected area (former TEICM campus in Serres)

The city of Serres is located almost at equal distance from Thessaloniki, Kavala and Petrich (Greece-Bulgaria borders) as presented in Figure 1. The selected site of TEICM campus is located at the southern part of the city of Serres, next to the city Ring Road (Figure 2). The selection of the site is convenient since it fulfils the selection criteria presented in the first section of Deliverable 4.3.1 and, at the same time, is the base of one of the GREEN PUMP project beneficiaries (IHU-former TEICM).

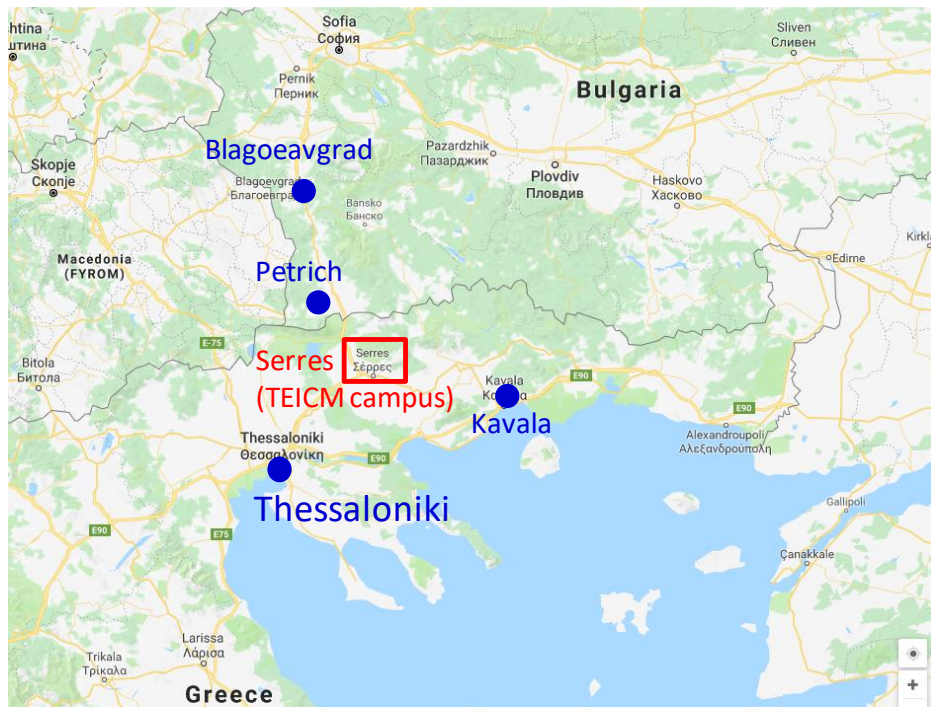


Figure 1. Location on map of the selected study area in Serres (TEICM contribution). Cities of the other project beneficiaries are highlighted as well.

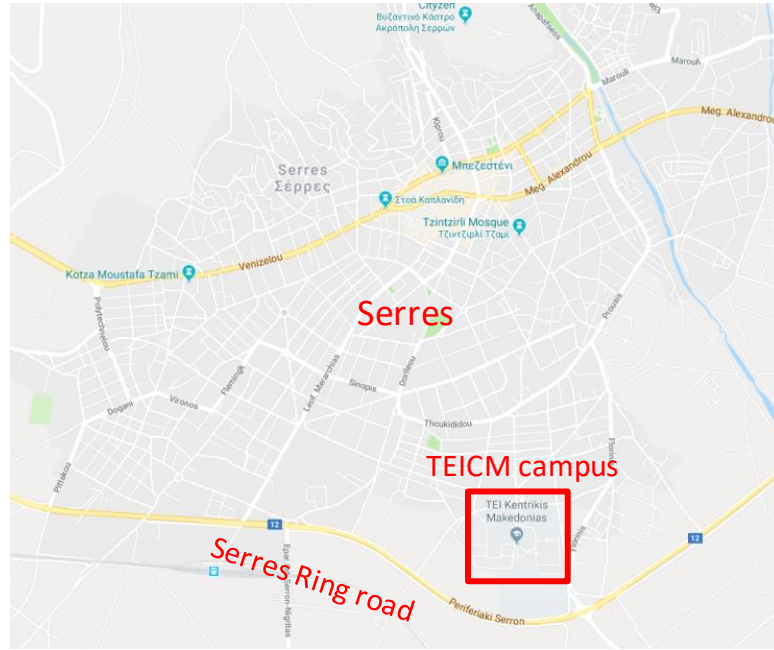


Figure 2. Location on map of former TEICM campus, at the southern part of Serres city near the Ring Road.

One of the basic criteria for the site selection is the shallow depth of the aquifer. Existing measurements near TEICM site (Egnatia Odos SA in Table 1), verify that the water table depth is located at shallow depth in the broader area of the northern part of the city of Serres and especially near the TEICM premises (from N17 to N22 in Figure 3).

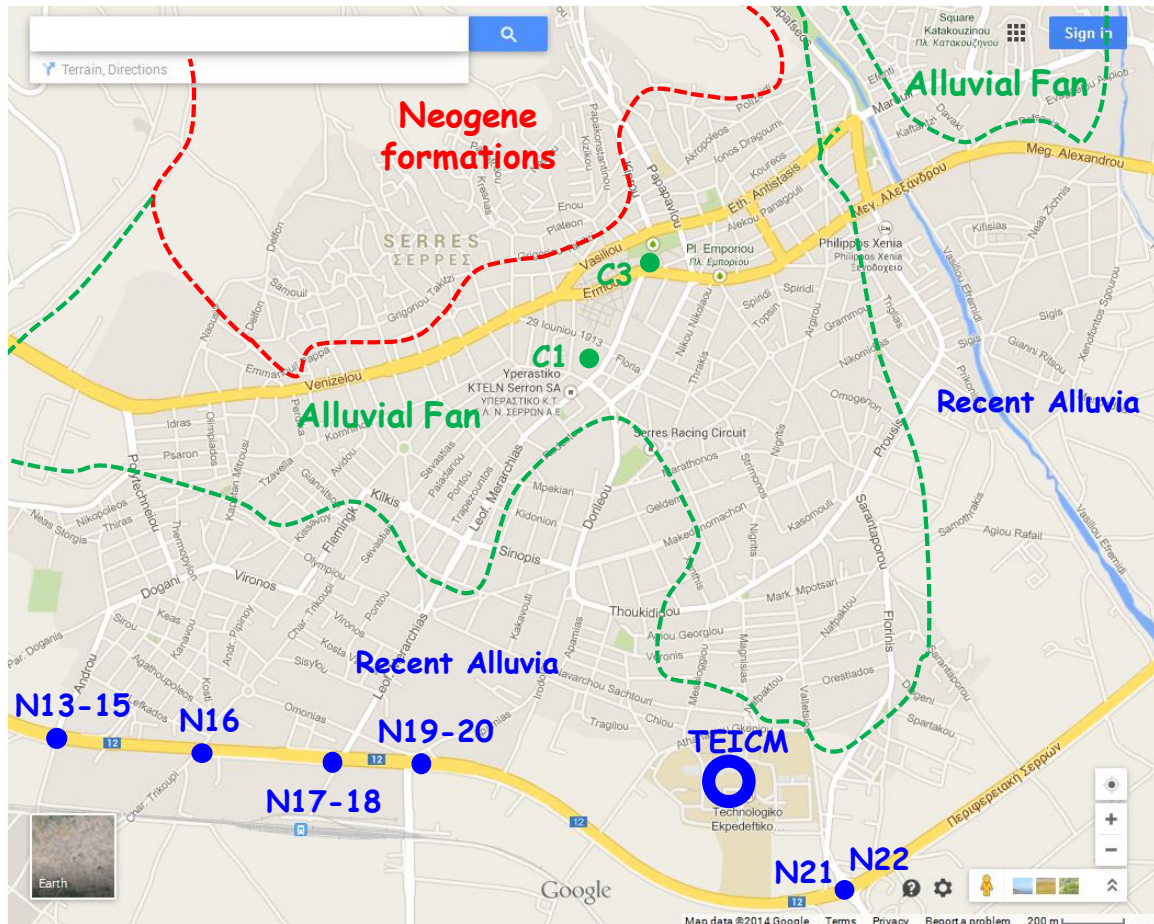


Figure 3. Position of existing geotechnical data (modified after Kirtas et al, 2016).

Table 1. Water table level from measurements in Egnatia Odos SA boreholes (combine with Figure 3) (data retrieved from GEOT.ER. 2013)

Borehole number	Borehole depth (m)	Water level monitoring (m)	
		Min	Max
N17	39.95	1.50	2.50
N18	40.05	1.50	2.50
N19	40.25	0.70	3.91
N20	45.35	1.55	5.80
N21	40.25	2.13	3.67
N22	45.25	0.62	5.10

2.3 Flooding events in the buildings of TEICM campus

Flooding incidents are quite often at the basements of several buildings in TEICM campus. Indeed, photos of the discolored basement floor indicate the previous presence of stagnant water as can be easily observed in Figure 4. Moreover, in several parts of the basements, a thick layer of dirt/soil is visible near objects that were not moved after the last flooding events.

Even during the last few months, after the GREEN PUMP project has started, flooding of basements with teaching rooms, laboratory facilities and storage of expensive equipment has taken place (Figure 5). It is quite obvious that these situations may disrupt the educational procedure and endanger expensive property of the institution.



Figure 4. Discolored floor slab indicates the previous presence of stagnant water (left), whereas thick layer of dirt/soil is visible near objects that were not moved after flooding events (right).



Figure 5. Flooding of teaching rooms or laboratories may disrupt educational procedure and endanger expensive equipment.

2.4 Existing pumps in TEICM campus

The common approach to prevent flooding events from shallow water table is to use water pumps permanently installed below the basement level and operating, if required, at 24 hour basis. A built-in mechanism detects abnormal depth of the underground water and triggers the pump to remove excessive water quantities (details and operation status measurements are presented in Deliverable 4.3.2).

The extent of the underground water problems in the campus of TEICM required a large number of installed water pumps, more than 40, at the basements of the various buildings and other installations (Figure 6). It should be mentioned that in some installations of Figure 6 it was not possible to visualize the location of all existing pumps, e.g. in the Ceremony Hall (no. 12) a total number of 12 pumps have been installed, scattered at suitable positions in the large basement of the building.

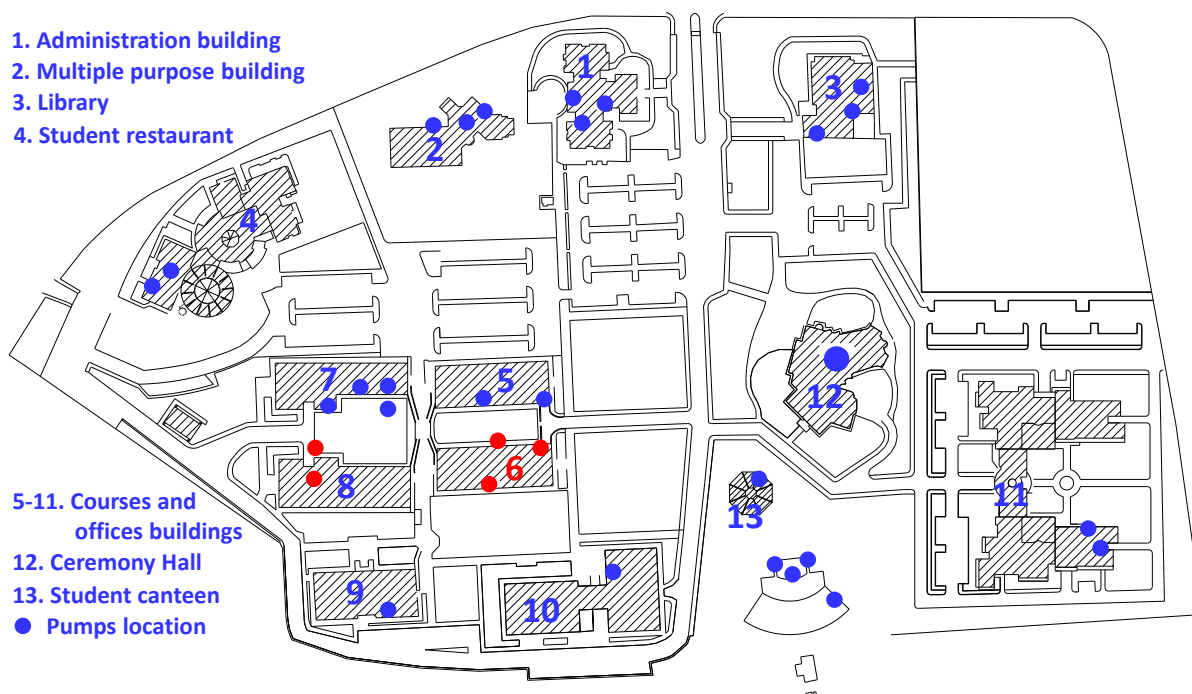


Figure 6. Location of existing water pumps in TEICM campus. The monitored pumps in the framework of GREEN PUMP project are highlighted in red color and are located at the basements of Building B (no. 6) and Building C (no. 8).

In most cases the pumps are installed in properly constructed manhole size wells, near power supply to facilitate the pump operation (Figure 7). A protective cover is placed on the top of the installation construction to prevent accidents as well as garbage or small animals entering the well and disrupting the pump operation. The underground water level is only a few centimeters below the basement level.



Figure 7. Water pumps are located inside manhole size wells, near power supply, at basement level (Building B - number 6 of Figure 6).

2.5 Selection of specific building for the studies

The main criterion for selecting a specific building in TEICM campus for the studies was to present a continuous operation from a large number of students, which would be representative of other University buildings and demanding in terms of heat and water requirements. Buildings such as the Ceremony Hall do not comply with those conditions since they only present an occasional use on specific events. On the other hand, buildings that host teaching rooms and laboratories are ideal since a large number of students and teaching staff is present for many hours during the day.

Based on the above, the Building B is selected for the studies of the present project (Figure 8 and Figure 9). As presented in detail in Deliverable 4.7.3 (former 4.3.3), this building has 3 stories and a basement and contains in total 21 classrooms, 4 of which amphitheatrical, serving each day several hundreds of students. Additional teaching rooms, nowadays used mainly as storage and student recreation areas, are also present in the basement of the building. Approximate dimensions of the building in plan are 55m length and 20m width.

With respect to the given selection criteria, Building B has faced several problems in the past due to the shallow water table. Three water pumps installed at the basement level (red dots of Building number 6 in Figure 1) reduce significantly any flooding risk, unless random malfunction of one of pumps leads to surface appearance of ground water locally. The position of each pump in the plan view of the basement is given in Figure 10.

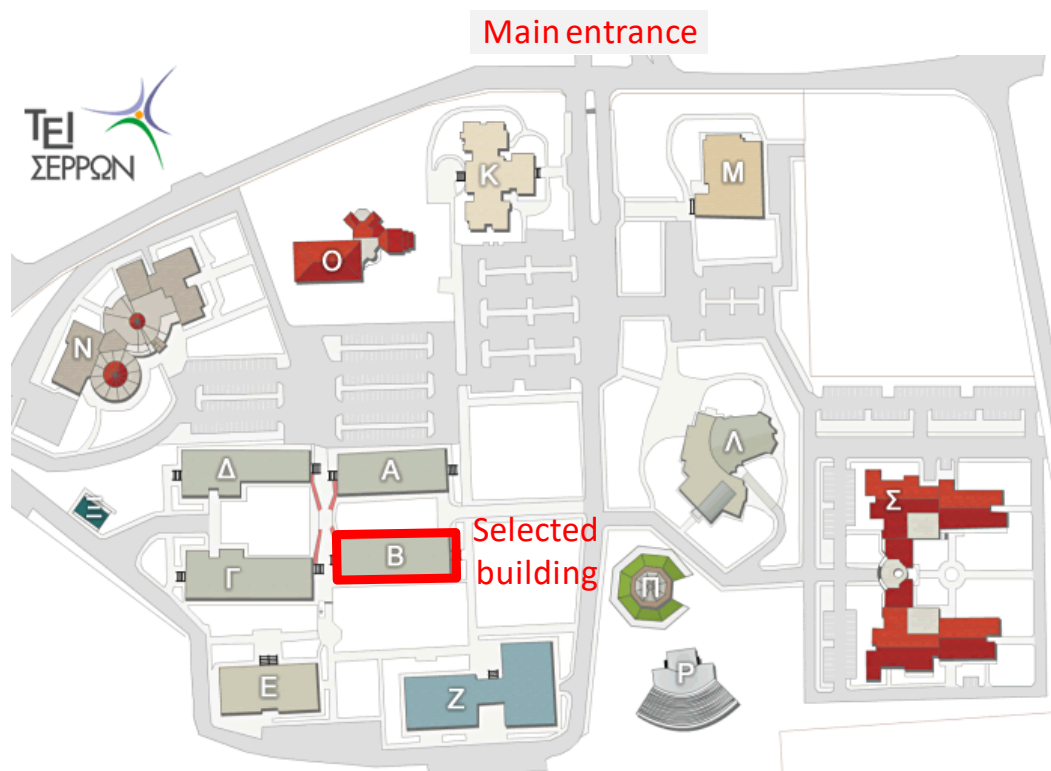


Figure 8. Building B is selected for the studies in GREEN PUMP project.



Figure 9. Front and north side view of selected Building B for the studies.

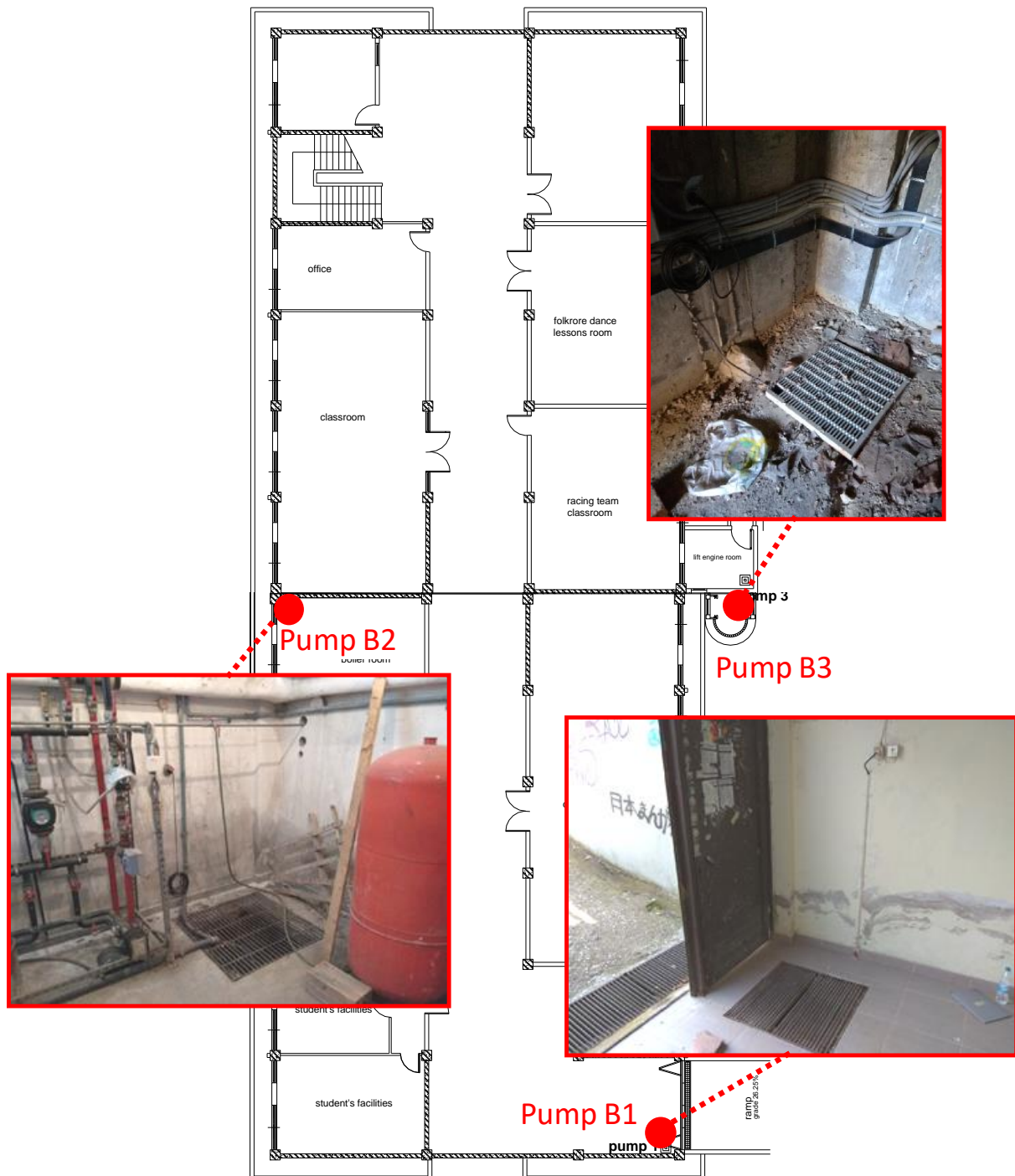


Figure 10. Position of existing water pumps at the basement level of Building B (Pump B1 near the ramp entrance, Pump B2 inside the boiler room and Pump B3 under the elevator).

The toilets of the building are concentrated to the two edges of each floor (except the basement) at the corners of the building (top left and bottom right corners of the plan view). Heating of Building B is currently based on a central heating system with an oil boiler and an oil storage tank placed at the basement of the building. Piping from the oil boiler to the radiators in each classroom is visible and installed in a way that does not allow separate heating of selected building areas. The last 3rd floor of the building was built in a different construction period, several years after the first two stories, using different materials. Thus, the heating system of the 3rd floor does not contain radiators but it uses a central air distribution system for heating of the classrooms and fan coils for the offices. Yet, this system is also based on the oil boiler.

The selected Building B is identical to Building A of the TEICM campus (number 5 in Figure 6 or Building A in Figure 8). This can be easily observed from the aerial view of Figure 11 and is verified by the technical services of the Institution. Therefore, not only the building is representative of the characteristics of similar buildings in other Institutions, but any study concerning it is actually directly applicable to another building of the same campus.

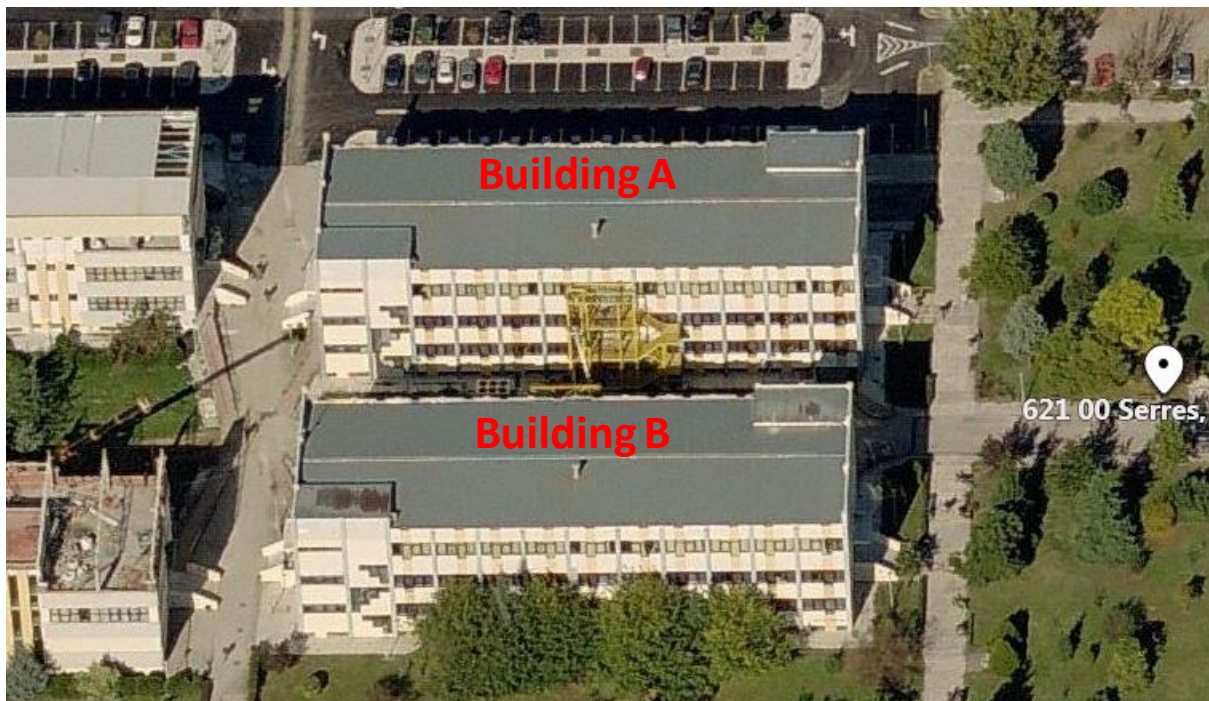


Figure 11. Aerial view of Building B and identical Building A (from South) (www.bing.com/maps).

3. On site measurements

3.1 Measurement of water quantities from existing pumps

In order to measure the pumped water quantities from the existing pumps in the selected Buildings B and C, it was decided to use an indirect approach by measuring the power consumption of the pumps and taking into consideration the pump water flow properties. To this end, two (2) measurement approaches are attempted, using:

- Analogue power consumption measurement devices (Figure 12)
The main advantages of those devices is the easy installation (the device is installed between the socket and the power plug of the pump) and the continuous recording since there is no danger to loose recorded data due to malfunctions, short-circuit etc.
- Digital power consumption measurement devices with Wi-Fi data transfer (Figure 13)
The main advantage of those devices is the constant data transfer online and the ability to check the functioning status and recorded measurements remotely. The devices employed in this project measure the power consumption inductively using a proper sensor/transmitter that sends the recorded data wirelessly to a hub connected to the campus network.



Figure 12. Analogue power consumption measurement device



Figure 13. Digital power consumption measurement device with Wi-Fi data transfer (left side: hub connected through LAN to campus network, right side: recording sensor/transmitter)

An indicative installation of the analogue and digital Wi-Fi devices measuring the power consumption of an existing pump is presented in Figure 14. Indicative photos of the analogue devices taken near the end of the project are depicted in Figure 15.



Figure 14. Installation of analogue and Wi-Fi digital power consumption measurement device (Pump C1). The isolated current phase of the cable to achieve power consumption measurement inductively is clearly depicted.



Figure 15. Power consumption measurements of existing water pumps in a) Building C (Pump C1 on the top-left and Pump C2 on the top-right) and (b) Building B (Pump B3 on the bottom-left and Pump B1 on the bottom-right), (photos taken on 11/02/2022).

It should be mentioned that the digital devices (inductive power consumption measurements), apart from the real time data transfer through WiFi offer several more useful features on a dedicated online platform created by the product manufacturer (freeware for product owners):

- Real time recording observation of both instant usage value and time-history of power consumption (Figure 16). Detail of the recorded usage time-history is depicted in Figure 17 (note: the max recorded energy consumption equal to 1kW is larger than the device's nominal value of 0.75kW).
- History usage data in diagram format for each monitoring device (Figure 18).
- Cost calculation due to the pump energy consumption based on pricing details of the local provider (user required information). Of course the cost for the occasional pumps' function is not expected to be significant.
- Approximation of carbon emission (CO₂ in kg) due to the consumed energy of the pump, based on the country's carbon emission factor that is set by the user.
- Reports of power consumption data in convenient format (csv) that allows for further data processing. The report may even contain data per hour or per minute.



Figure 16. Indicative image of real time power usage recording of Pump C2 (instant power usage value in kW on the top left of the figure and consumption time history at the depicted diagram).

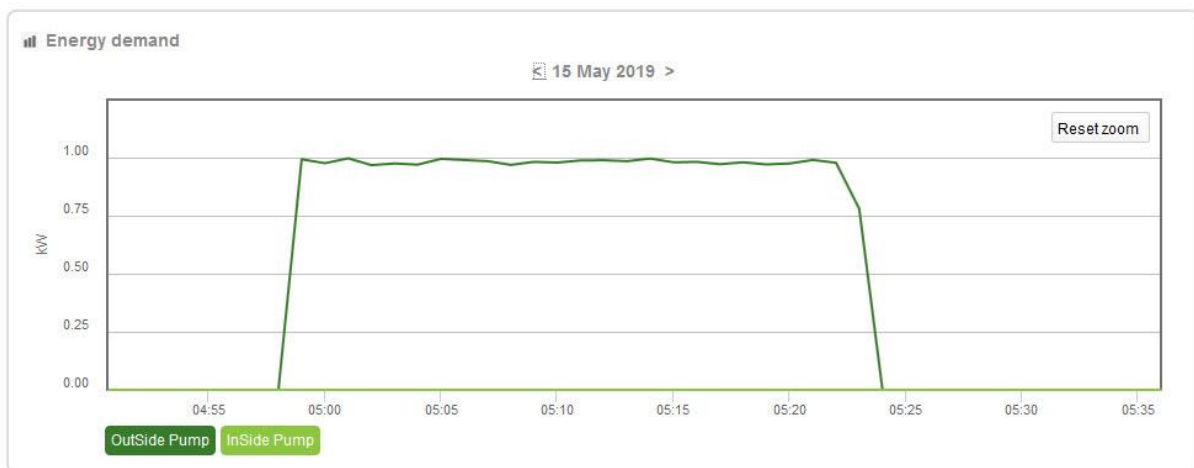


Figure 17. Detail of the recorded usage time history (Pump C2).

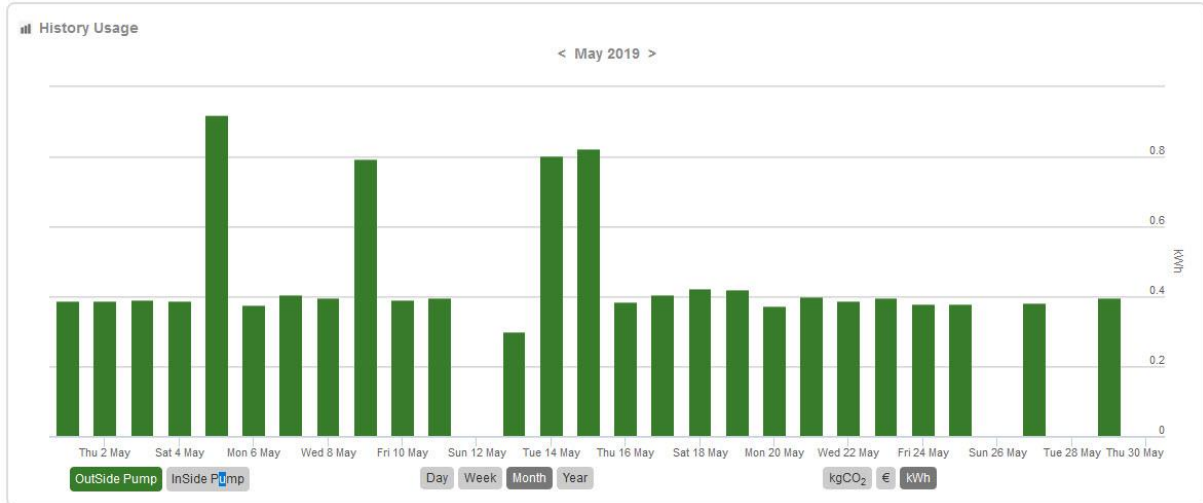


Figure 18. Diagram of history power usage (in kWh) of Pump C2 (May 2019).

The cumulative monthly power usage diagram for Pumps C1 and C2 is depicted in Figure 19 and Figure 20 respectively. Taking notice that the scale of the Y-axis is different between the diagrams, it is quite clear that Pump C2 is functioning very often whereas Pump C1 only scarcely during the entire monitoring period of approximately 3 years.



Figure 19. Diagram of monthly power usage (in kWh) of Pump C1 (Years 2019 to 2021).



Figure 20. Diagram of monthly power usage (in kWh) of Pump C2 (Years 2019 to 2021).

The cumulative consumption data of water pumps (B1-B3 of Building B and C1-C2 of Building C) are presented in Table 2 (in kWh) from the initiation of the monitoring till the end of the project. The validation of the digital/WiFi monitoring approach using the respective analogue measurements has been presented in Deliverable 4.7.2 (former 4.3.2) and also for the extended time period till the end of the project in Deliverable 5.7.1 (former 5.3.1).

Table 2. Power consumption measurements of existing water pumps

Pump ID	Date	Power Consumption (analogue) (kWh)	Power Consumption (digital/inductive) (kWh)
Pump B1	01/02/2019	Installation (0.00 kWh)	-
	17/05/2019	2.3 kWh	-
	23/07/2019	2.8 kWh	-
	21/08/2019	2.8 kWh	-
	24/10/2019	3.1 kWh	-
	31/01/2020	4.1 kWh	-
	26/02/2020	4.5 kWh	-
	22/05/2020	9.0 kWh	-
	22/07/2020	9.8 kWh	-
	07/06/2021	13.4 kWh	-
	12/10/2021	13.8 kWh	-
	07/12/2021	14.1 kWh	-
	11/02/2022	16.3 kWh	-
Pump B2	01/02/2019	Installation (0.00 kWh)	-
	17/05/2019	0.00 kWh	-
	23/05/2019	Device removed	-

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Pump B3	01/02/2019	-	-
	23/05/2019	Installation (0.00 kWh)	-
	23/07/2019	0.00 kWh	-
	21/08/2019	0.00 kWh	-
	31/01/2020	0.00 kWh	-
	26/02/2020	0.00 kWh	-
	22/05/2020	0.00 kWh	-
	22/07/2020	0.00 kWh	-
	07/06/2021	0.00 kWh	-
	12/10/2021	0.00 kWh	-
	07/12/2021	0.00 kWh	-
	11/02/2022	0.00 kWh	-
Pump C1	01/02/2019	Installation (0.00 kWh)	-
	25/02/2019	3.4 kWh	-
	08/04/2019	4.0 kWh	-
	15/04/2019	4.0 kWh	Installation (0.00 kWh)
	17/05/2019	4.1 kWh	0.021 kWh
	23/07/2019	4.1 kWh	0.028 kWh
	21/08/2019	4.1 kWh	0.028 kWh
	24/10/2019	4.4 kWh	0.029 kWh
	13/01/2020	4.4 kWh	0.029 kWh
	31/01/2020	4.4 kWh	0.029 kWh
	26/02/2020	4.4 kWh	0.029 kWh
	22/05/2020	4.5 kWh	0.029 kWh
	22/07/2020	4.5 kWh	0.030 kWh
	07/06/2021	4.5 kWh	0.34 kWh
	12/10/2021	12.8 kWh	7.47 kWh
	07/12/2021	24.7 kWh	18.49 kWh

	11/02/2022	46.8 kWh	38.77 kWh
Pump C2	01/02/2019	Installation (0.00 kWh)	-
	21/02/2019	11.7 kWh	-
	25/02/2019	14.2 kWh	-
	08/04/2019	32.9 kWh	-
	15/04/2019	39.4 kWh	Installation (0.00 kWh)
	17/05/2019	55.5 kWh	17.17 kWh
	23/07/2019	65.6 kWh	28.67 kWh
	21/08/2019	65.6 kWh	28.67 kWh
	24/10/2019	67.9 kWh	31.37 kWh
	13/01/2020	110.1 kWh	76.58 kWh
	31/01/2020	118.4 kWh	85.91 kWh
	26/02/2020	131.1 kWh	100.45 kWh
	22/05/2020	290.3 kWh	277.64 kWh
	22/07/2020	313.7 kWh	303.94 kWh
	07/06/2021	459.4 kWh	467.41 kWh
	12/10/2021	465.9 kWh	474.57 kWh
	07/12/2021	480.0 kWh	494.79 kWh
	11/02/2022	585.5 kWh	572.02 kWh

The calculation of the pumped water quantities in pump C2, which seems to manage almost all the excess underground water in the area, yield an amount of approximately 285m³ per month during the winter (rainy) period. It is quite clear that it is not realistic to associate the calculated pumped water volume with the water deriving from the underground water table alone. Even if half the above value is assumed, taking into consideration other sources of energy loss (increased head requirement to dispose the pumped water etc), the estimated volume is still quite large. Probably, due to the positioning of the pump at the lower end of a ramp and the local site topography, there are additional sources of water in the specific pump such as:

- Surface rainwater during rainy days

- Water coming from the irrigation of the surrounding garden (the pump is located 2-3m lower than the soil surface next to the building)
- Possible formation of water well in the location of the specific pump (according to neighborhood testimonies in the past)

Nevertheless, the pumped water quantities could be used for a secondary water network, regardless their initial origin.

3.2 Measurements in a borehole well

Implementation of a geothermal heating system for a building of large dimensions requires detailed information on the water supply quantities and the underground water reserve in the area of interest. More specifically, an open-loop geothermal heating system requires large quantities of constant water flow to exploit the underground water temperature in order to provide heating to the building. Flow testing of the well provides important data for the design of the heat pump system since the groundwater flowrate chosen is based on pumping power.

To this end, it was deemed necessary to perform a test pumping on a borehole well that will be constructed for the needs of the GREEN PUMP project. The results of the test pumping will determine the suitability and adequacy of the pumped water for the purposes of the project.

The location of the borehole well in the former TEICM campus is presented in Figure 21. The well is located in a distance approximately equal to 130m from the Building of interest (Building B). Since the measurement data will be only used for studies in the framework of the project, it was not considered necessary to select a position closer to the aforementioned Building that would disrupt the educational and other activities of the University and/or change the surrounding landscape.

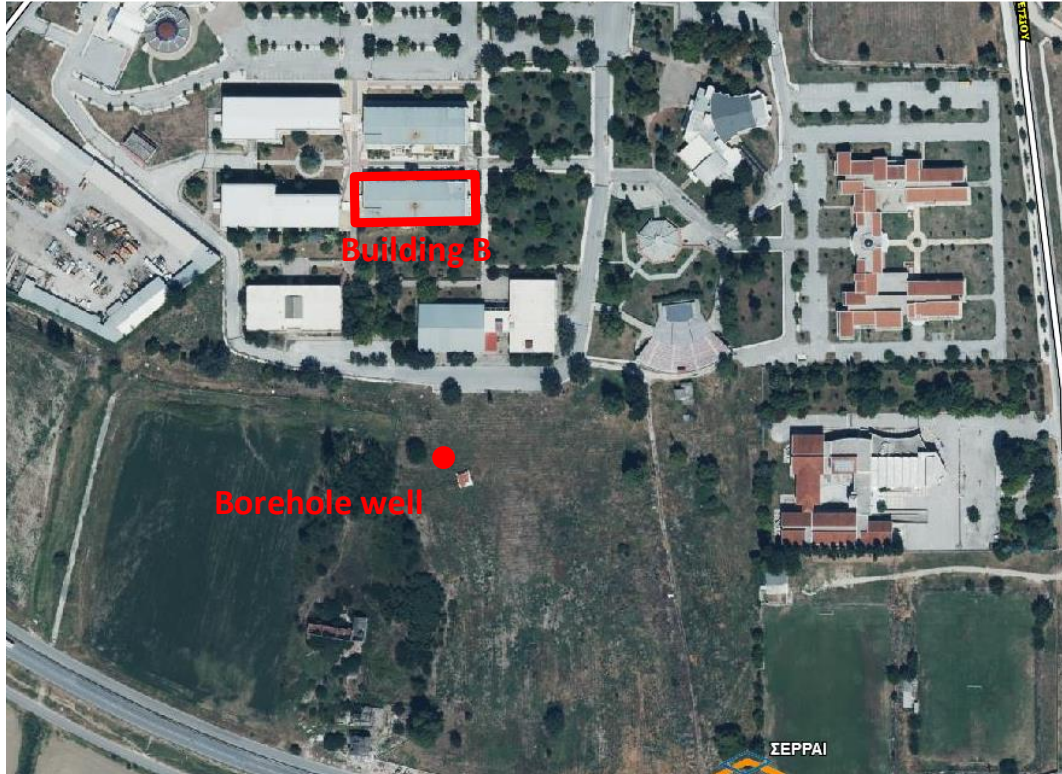


Figure 21. Location of the borehole well which was constructed for the needs of the project, along with the location of Building B (source: <http://gis.ktimanet.gr>)

According to the specifications of the borehole well, a drill depth of 30m is prescribed to make sure that the water flow will be adequate for the purposes of the study. The technical specifications of the well follow those of common water drilling activities.

Before well drilling initiations, some preparatory works are required to facilitate the drilling activities. More specifically, an excavation of 2x3m dimensions and 2m depth took place next to the drilling position. The drilling rig is afterwards installed at the location of the well, right next to the excavation. In the case of the GREEN PUMP project, a movable drilling rig is employed (Figure 22). The required water for the drilling activities is provided from an outside source through the excavation inside the well. In this case, the excavation serves as a temporary water tank. At the same time, drilling material such as mud, drilling fluids and slurry, bentonite etc, are also deposited inside the same excavation that assumes a two-fold role, as presented in Figure 23.



Figure 22. Installation of the drilling rig next to the excavation



Figure 23. Drilling procedure (the two-fold use of the excavation to provide water and accept the drilling materials can be observed)

Following the construction of the well and the installation of the piping and gravel pack, the development of the well takes place using air surge (air-lift technique), in order to wash sediments and fine soil particles as well as any remaining drilling fluids from the water inside the pipes. The procedure continuous up to the point that the water exiting the well does not contain any fine soil particles.

After the development of the well, the achieved pumped water quantities are determined through flow testing. To this end, a pump of known specifications is used to pump water from the well, whereas, at the same time, constant measurement of the aquifer depth takes place to determine the sensitivity of the underground water table level to pumping (Figure 24). The pumped water should be disposed in a way that does not interfere with the underground water table level, preferably in a separate sewage system, as presented in Figure 25 for the examined case.



Figure 24. Water pumping during flow testing and simultaneous aquifer depth measurement



Figure 25. Disposal of pumped water during flow testing

In order to secure the well and facilitate the installation of the automated aquifer depth measurement device, a concrete base of 1.5x1.5m dimensions and approximately 20-30cm depth is constructed surrounding the underground piping. A 6m height galvanized steel pipe is then anchored at the base, to facilitate the installation of the aquifer depth measurement equipment and suspension of the required cables (Figure 26). The measurement device consists of a data logger (place on the steel pole) and a submersible sensor as presented in Figure 27.



Figure 26. A 6m steel pipe is anchored to the concrete base. The water level monitoring device is installed on this steel pole and transmits measurements via Wi-Fi.



Figure 27. Data logger (left) installed next to the borehole well and submersible sensor (right)

Measurement data are transmitted via Wi-Fi and can be retrieved either using a dedicated pc software (Opton4) or from the CAPTUM/SYMMETRON online platform. More details on the data retrieval and processing are presented in Deliverables 4.7.2 (former 4.3.2) and 5.7.1 (former 5.3.1). In order to facilitate Wi-Fi transmission, the network of the Institution had to be expanded using an access point as explained in the aforementioned deliverables.

Measurement results of the underground water table level for the entire monitoring period are presented in Figure 28. The fluctuation of the water table depth during an extended period of time is evident. More specifically, both during 2020 and 2021, it is observed that the aquifer depth is lowering starting from May-June till October. Then, when rainfall increases during autumn, the water table depth is decreasing reaching its minimum value during spring. As clearly depicted in this Figure, the depth of the water table fluctuates between 2.5m to 3.5m from the soil surface.

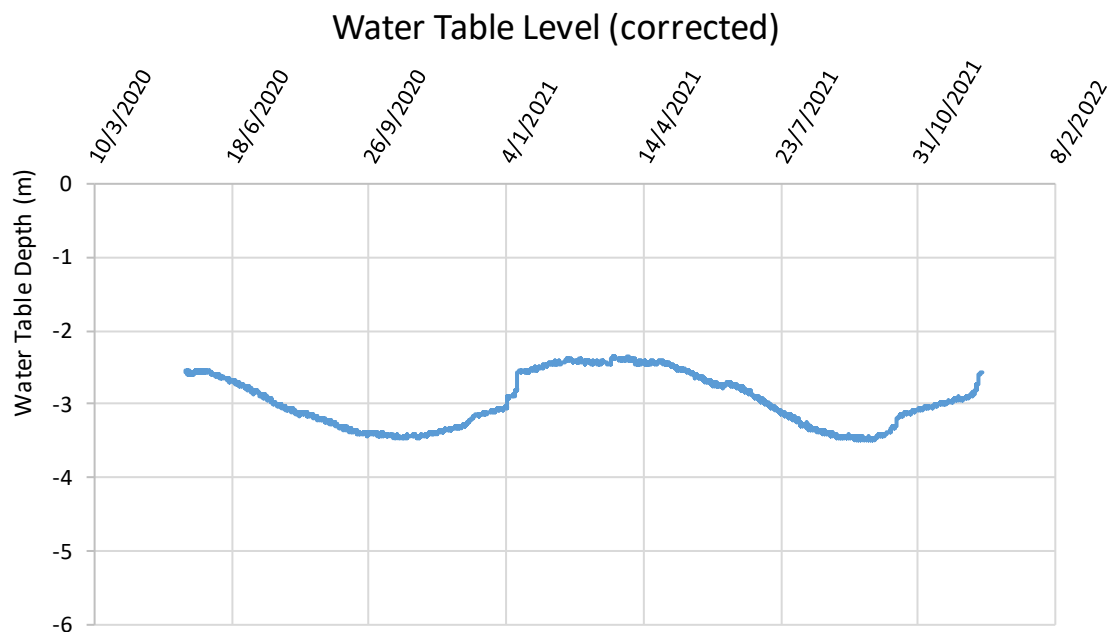


Figure 28. Monitoring of water table depth (corrected) during an extended time period

3.3 Correlation of existing pump function and water table level measurements vs rainfall data

Rainfall data in Serres area have been used to check if there is a distinct correlation with the monitoring taking place in the framework of the GREEN PUMP project. More specifically, the diagram of Figure 29 presents the correlation of the C2 pump function (pump placed outside Building C), measured in kWh, versus rainfall data for Serres area in the same time period. It is evident that there is a clear link between the rainy periods and increase of C2 pump operation hours. On the other hand, when rainfall is reduced mainly during summer months, the function hours of C2 pump are also reduced.

Moreover, the water table depth has been also compared with rainfall data in Figure 30. As observed from the diagram, increased heights of rainfall (mm) result in elevation of the water table depth. On the other hand, when rainfall is reduced, the aquifer level drops. More details can be found in Deliverable 5.7.1 (former 5.3.1).

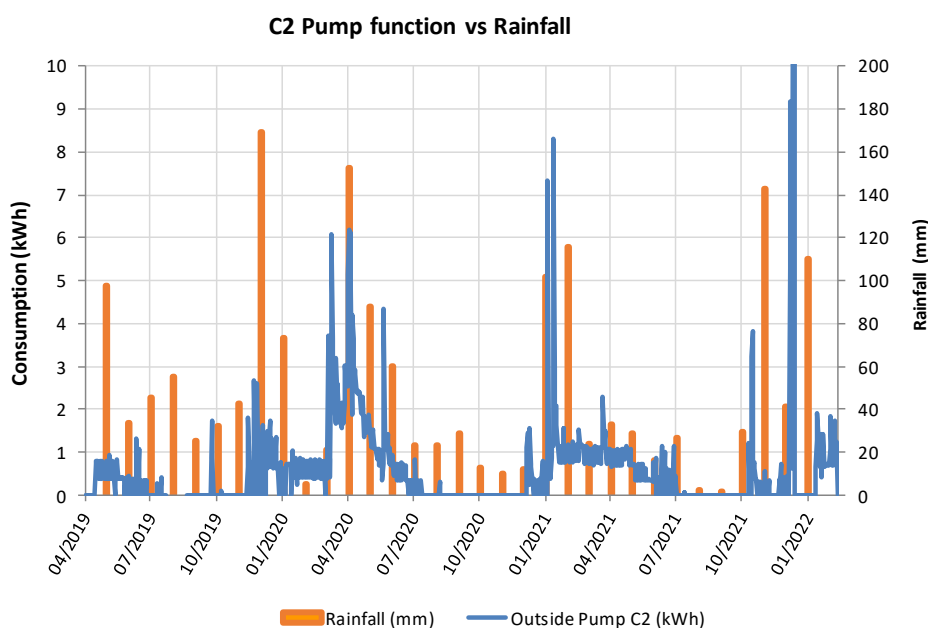


Figure 29. Correlation of C2 pump function with Rainfall data for Serres area

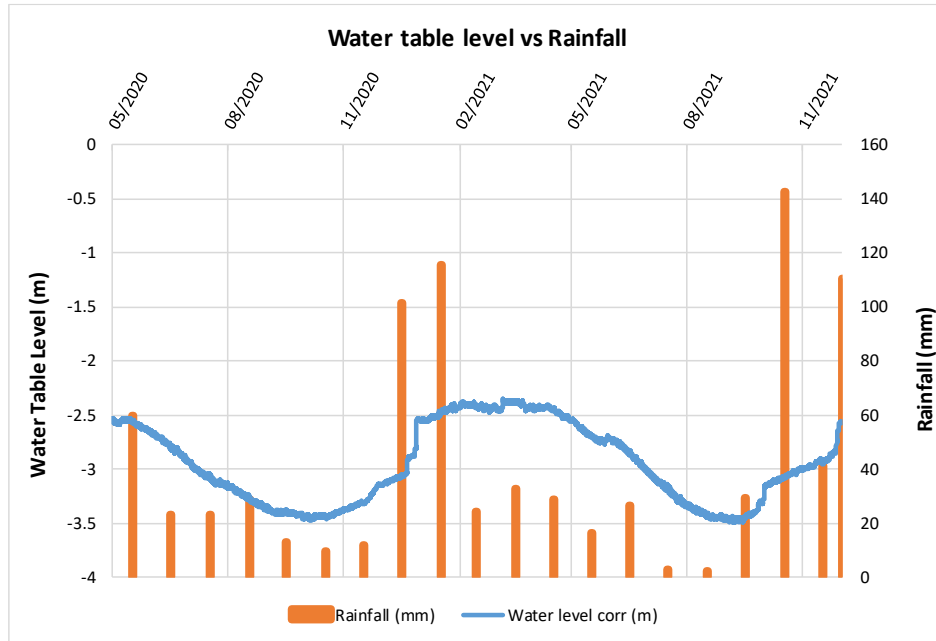


Figure 30. Correlation of Water table level with Rainfall data for Serres area

3.4 Chemical analysis of the pumped water

In order to determine the suitability of the pumped water, both from the well and from the already existing pumps, a chemical analysis was deemed necessary, to ensure the absence of particular harmful contents. To this end, water samples were collected (Figure 31) and a detailed chemical analysis of the water took place in a specialized laboratory.



Figure 31. Water samples for chemical analyses

Indicatively, results of the microbiological and chemical analysis of the water from the borehole well are presented in the following Table 3 and Table 4 respectively. It should be mentioned that the allowed limits refer to potable water. In the microbiological analysis, E.coli and Enterococcuse sp. have not been detected. Moreover, the large Manganese (Mn) value detected during the chemical analysis of the borehole well is not easy to explain taking into consideration the simultaneous absence of other related minerals, and should be monitored accordingly in future.

Detailed presentation of chemical analysis results is included in the respective Deliverables 4.7.2 (former 4.3.2) and 5.7.1 (former 5.3.1). Simplified detection of main water properties (pH, EC, TDS) using a portable measurement device can be also found in the aforementioned deliverables.

Table 3. Microbiological analysis of water sample from borehole well (sampling on 09/03/2020)

Parameter	Methodology	Result	Units
OMX @22°C	ISO 6222: 1999	>300	cfu/ml
OMX @37°C	ISO 6222: 1999	>300	cfu/ml
Total coliforms	ISO 9308-1:2014	15	cfu/100ml
E. coli	ISO 9308-1:2014	0	cfu/100ml
<i>Enterococcus sp.</i>	ISO 7899-2:2000	0	cfu/100ml
<i>Cl. perfringens</i>	ISO 14189:2013	2	cfu/100ml
<i>P. aeruginosa</i>	ISO 16266:2006	1.5*10 ²	cfu/100ml

Table 4. Chemical analysis of water sample from borehole well (sampling on 09/03/2020)

Parameter	Units	Result	Reference limit	Uncertainty	Maximum allowed limit	Methodology
Calcium (Ca)	mg/L	139	0.5		-	O.B.01.040 ICPMS 3125 A,B Mod. St.Met.
Magnesium (Mg)	mg/L	17.8	0.5		-	O.B.01.040 ICPMS 3125 A,B Mod. St.Met.
Potassium (K)	mg/L	3.3	0.5	8.40%	12	O.B.01.040 ICPMS 3125 A,B Mod. St.Met.
Sodium (Na)	mg/L	39.5	0.5	3.80%	200	O.B.01.040 ICPMS 3125 A,B Mod. St.Met.
Copper (Cu)	mg/L	N.D.	0.01	10.00%	2	O.B.01.040 ICPMS 3125 A,B Mod. St.Met.

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Iron (Fe)	µg/L	N.D.	10	13.70%	200	O.B.01.040 ICPMS 3125 A,B Mod. St.Met.
Zinc (Zn)	µg/L	N.D.	50			O.B.01.040 ICPMS 3125 A,B Mod. St.Met.
Manganese (Mn)	µg/L	1542	10	9.70%	50	O.B.01.040 ICPMS 3125 A,B Mod. St.Met.
Nitrates (NO ₃)	mg/L	13.7	2	9.00%	50	O.B. 01.018 4500 NO3-B Mod St.Met.*
Nitrites (NO ₂)	mg/L	0.19	0.03	3.30%	0.5	O.B. 01.011 4500NO2-B Mod St.Met.
Phosphates (P)	mg/L P2O5	N.D.	1.14	8.50%	5	O.B.01.040 ICPMS 3125 A,B Mod. St.Met.
Ammonium	mg/L	0.69	0.06	4.40%	0.5	O.B.01.009 4500 NH3-F Mod St.Met.
Sulfate (SO ₄)	mg/L	107	20	6.80%	250	O.B. 01.008 4500 SO4-E Mod. St.Met
Boron (B)	mg/L	0.06	0.05	14.90%	1	O.B.01.040 ICPMS 3125 A,B Mod. St.Met.
Chlorides (Cl)	mg/L	30.1	10	2.80%	250	Internal method based on HACH Application DOC 316.52.93091 based on ISO 9297:2000.
pH	units pH 22 oC	7.7	1		≥6.5 και ≤9.5	O.B.01.005 4500-H,B St.Met.
Conductivity	µS/cm σε 20 oC	846	10-11670	2.90%	2500	O.B.01.006 2510 B St.Met.
Total Dissolved Solids (TDS)	mg/L	541	10			2540 St.Met.*
Total hardness	german deg (d)	23.4	0.18		-	O.B. 01.013 2340-B St.Met.
Alkalinity P	mgCaCO ₃ /L	0				O.B.01.019 Volumetric 2320-B mod. St.Met.*
Total alkalinity	mgCaCO ₃ /L	352	20			Internal based on: Application DOC 316.52.93091 based on ISO 9297:2000*
Carbon trioxide (CO ₃)	mg/L	0				O.B.01.019 volumetric*
Hydrogencarbonate (HCO ₃)	mg/L	429	25			O.B.01.019 volumetric*
Carbon hardness	German deg (d)	20.4				O.B.01.019 calculated*
Non-carbonate hardness	German deg (d)	3				O.B.01.019 calculated*
Fluoride (F)	mg/L	0.26	0.2	11.50%	1.5	O.B.01.030 4500 F-D SPADNS Method Mod.

						St.Met.
Odor		Acceptable				O.B.01.033 Mod. based on 2160C St.Met.
Taste		Not acceptable				O.B.01.033 Mod. based on 2160C St.Met.
Total Organic Carbon (TOC)	mgC/L	N.D.	3			O.B.01.038 HACH LCK 385
Oxidizability	mgO2/L	N.D.	1.5	3.60%	5	O.B.01.037 mod. based on EN ISO 8467
COD	mg/l	N.D.	33	3.9%	-	APHA 5220D, modified closed refluxed method
BOD	mg/l	N.D.	6	15%	-	Manometric method based on APHA 5210D

4. Study of the secondary water system (pumped water for secondary uses) and cost estimation

The water conservation system is based on the usage of water quantity supplied by the existing water pumps installed at the building basement for flooding prevention. This water is intended for secondary uses such as toilet flushing. In case the pumped quantities are not adequate, the secondary water distribution system will be complemented by water supply from the wells which will be part of the geothermal heating system of the building. As a safety measure, a connection to the existing water network will also be predicted.

Alternate options for the secondary water distribution system has been considered as described in detail in Deliverable 4.7.3 (former 4.3.3). It was finally decided to use a separate from the existing water distribution network (new piping), that will be connected with a water tank placed at the basement level of Building B. A schematic layout of the proposed system is presented in Figure 32 whereas a plan view at the basement level is depicted in sFigure 33

As analytically derived in Deliverable 4.7.4 (former 4.3.4), the total (market) cost of the secondary water distribution system is estimated close to 9100€. Approximately 3800€ refer to equipment and parts whereas 5300€ to the construction labor cost.

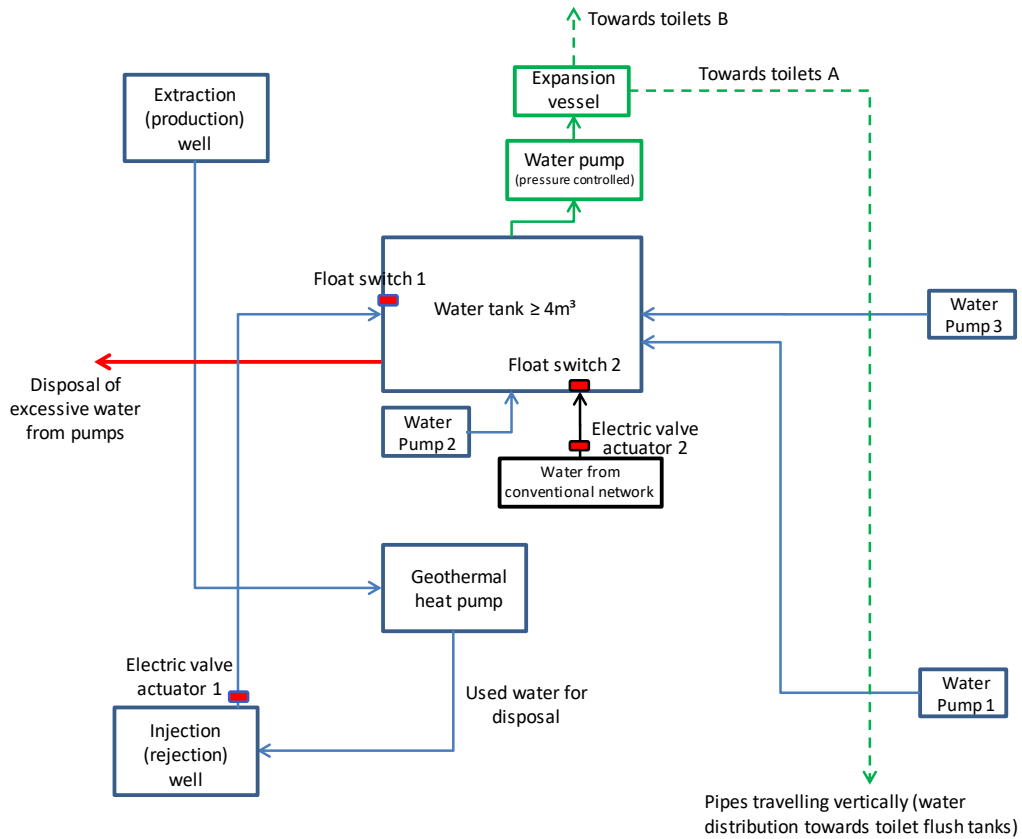


Figure 32. Schematic layout of the secondary water system

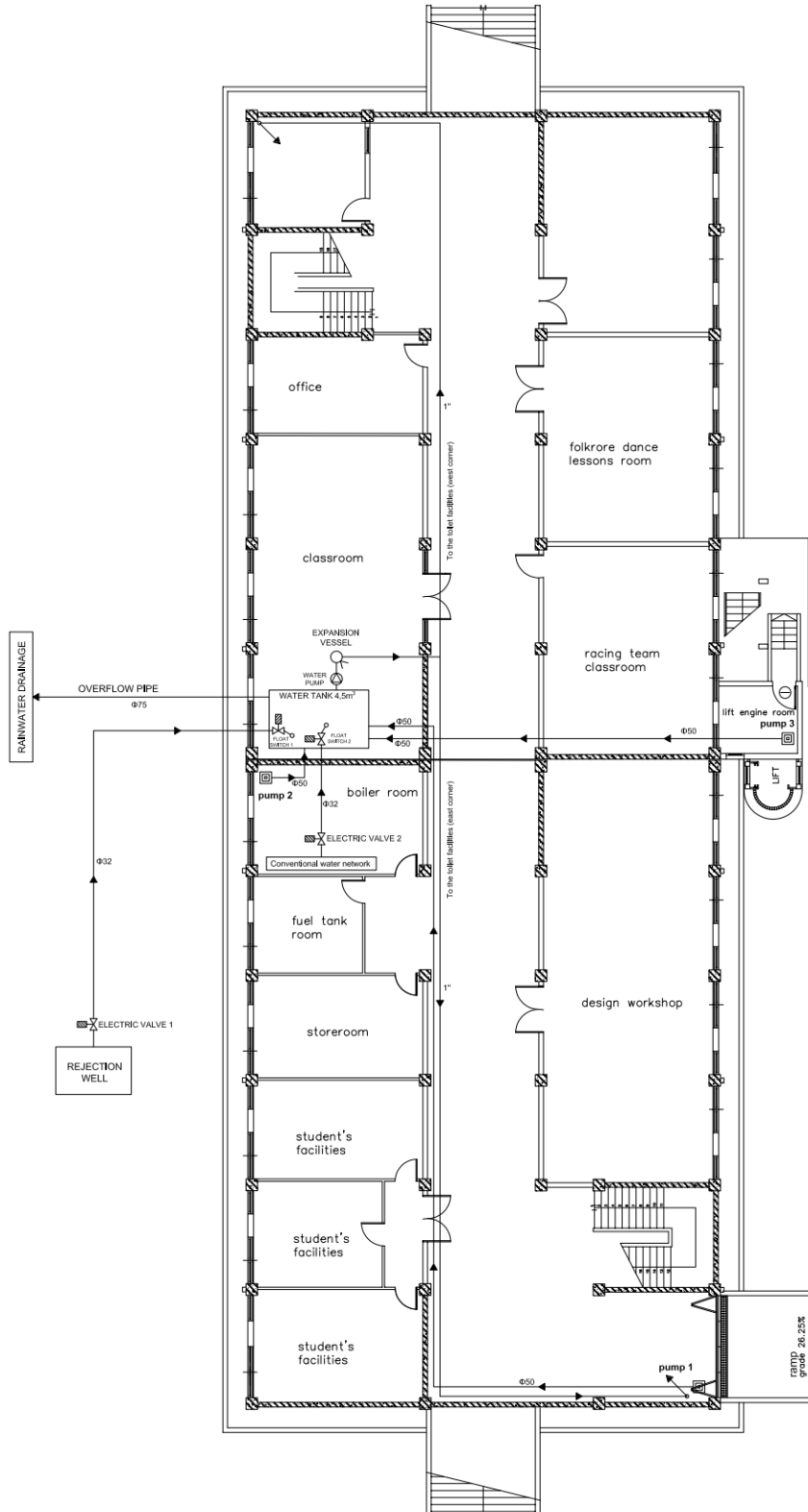


Figure 33. Layout of the secondary water system (basement plan view)

5. Study of the geothermal heating system and cost estimation

As mentioned earlier, the heating of the entire building is based on an oil boiler at the basement of the building. The heating system consists of common radiators interconnected in pairs and linked to the oil boiler, to transfer the hot water from the basement to the first and second floor of the building. The heating of the third floor of the building is also based on the basement boiler, using though a combination of central air distribution system for the classrooms and fan coils for the offices.

Due to the shallow aquifer in the campus area, as revealed from the respective water table depth measurements in the framework of the project, an open loop system has been selected for the studies. In this system, a borehole well is used to pump natural water from the underground water table into the heat exchanger inside the heat pump. The water is returned to the ground using a separate injection well at a distance from the originating well (Figure 34). Additional reasons for the open loop system selection is to use pumped water for the secondary water distribution network inside the building, as well as to reduce the danger of flooding events in the basements of the surrounding buildings.

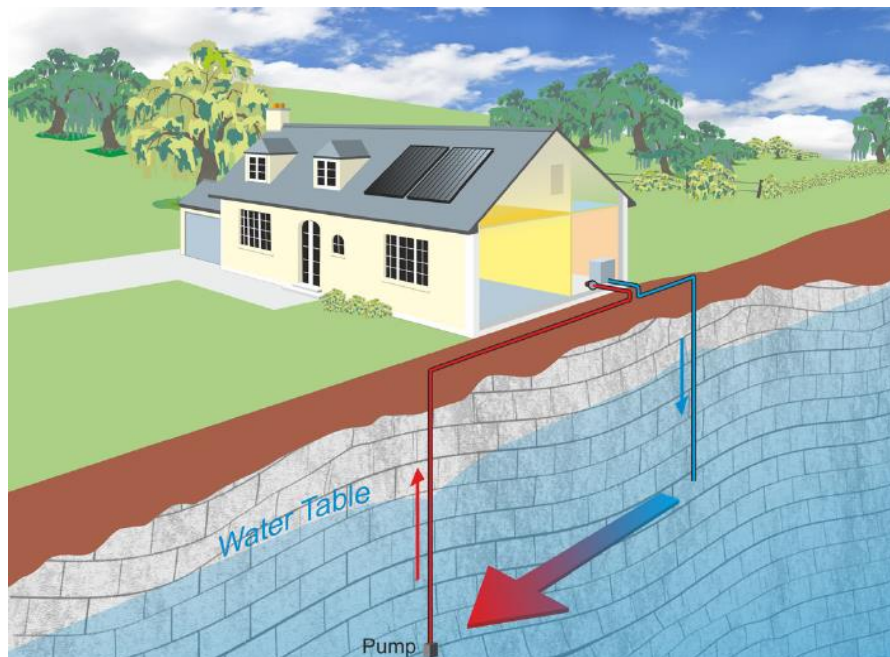


Figure 34. Illustration of an open loop geothermal system (<https://www.gsi.ie>)

The required activities to install the geothermal heating system comprise of the following:

- Drilling of the water extraction (production) well
- Drilling of two (2) injection (or rejection) wells
- Installation of the heat exchanger (placed between the boreholes and the heat pump)
- Installation of the heat pump and the closed network for heat transfer between the heat exchanger and the heat pump
- Installation of the buffer tank (contains a volume of heated water to limit cycling of the heat pump)

The location of the extraction (production) and injection wells of the open loop geothermal heating system is depicted in Figure 35. This is an indicative layout since the exact location of the wells depends on local conditions revealed from preliminary in situ investigation, before the final study and before the drilling stage.

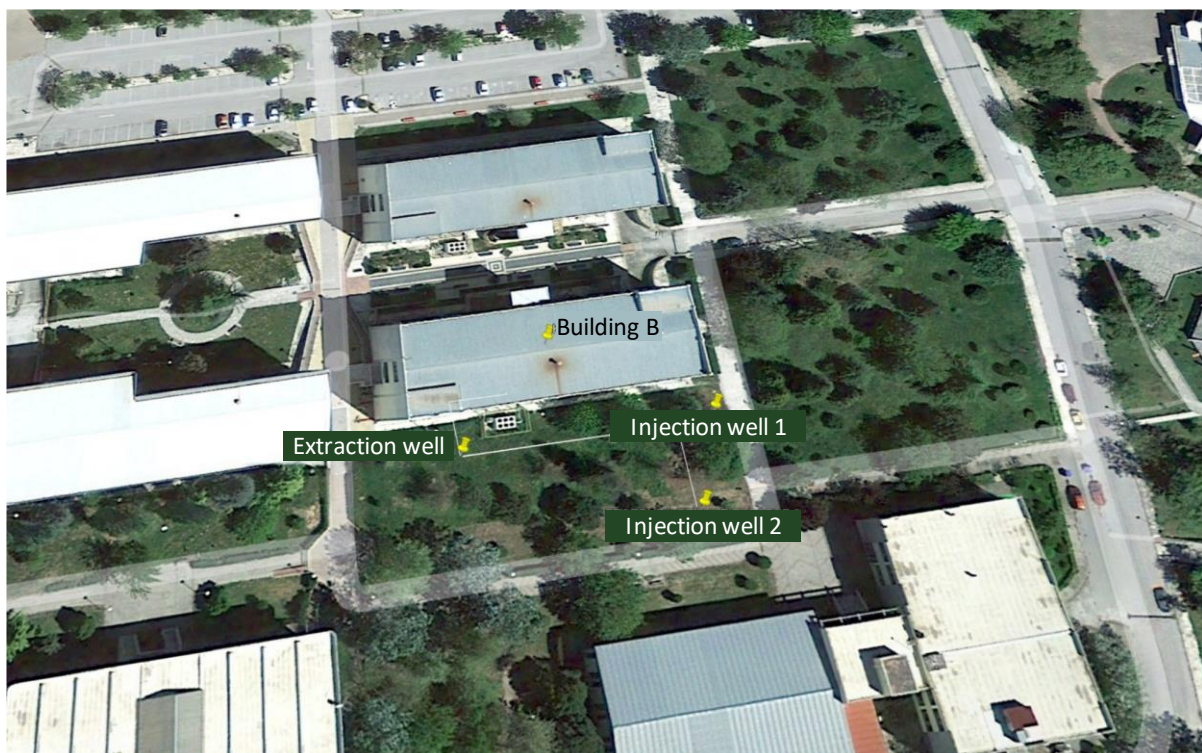


Figure 35. Indicative layout of the extraction and injection wells (Building B)

The -required for the study- hydraulic properties of the underground water table in the area have been determined with a test pumping that took place right after the drilling of the borehole well that monitors the aquifer depth. Moreover, specialized measurements of the heat transfer characteristics of the building were performed by simultaneously monitoring the air temperature inside and outside the building as well as the surface temperature of the examined building walls (Figure 36).



Figure 36. Measurement of heat transfer properties of an outside wall – 3rd floor of Building B

Details on the employed methodology, calculation basis and respective assumptions of the study can be found in Deliverable 4.7.3 (former 4.3.3). After calculation the total heat losses of the building (Table 5), the specifications of the heat exchanger and the geothermal heat pump were determined based on specialized software. Indicative optimization calculations regarding the heat exchanger are depicted in Figure 37 and Figure 38.

Table 5. Total heat losses of Building B

Level	Heat losses (Watt)
Basement	77447
1 st floor (Ground Floor)	68039
2 nd Floor	90206
3 rd Floor	117456
Total Building Losses	353148

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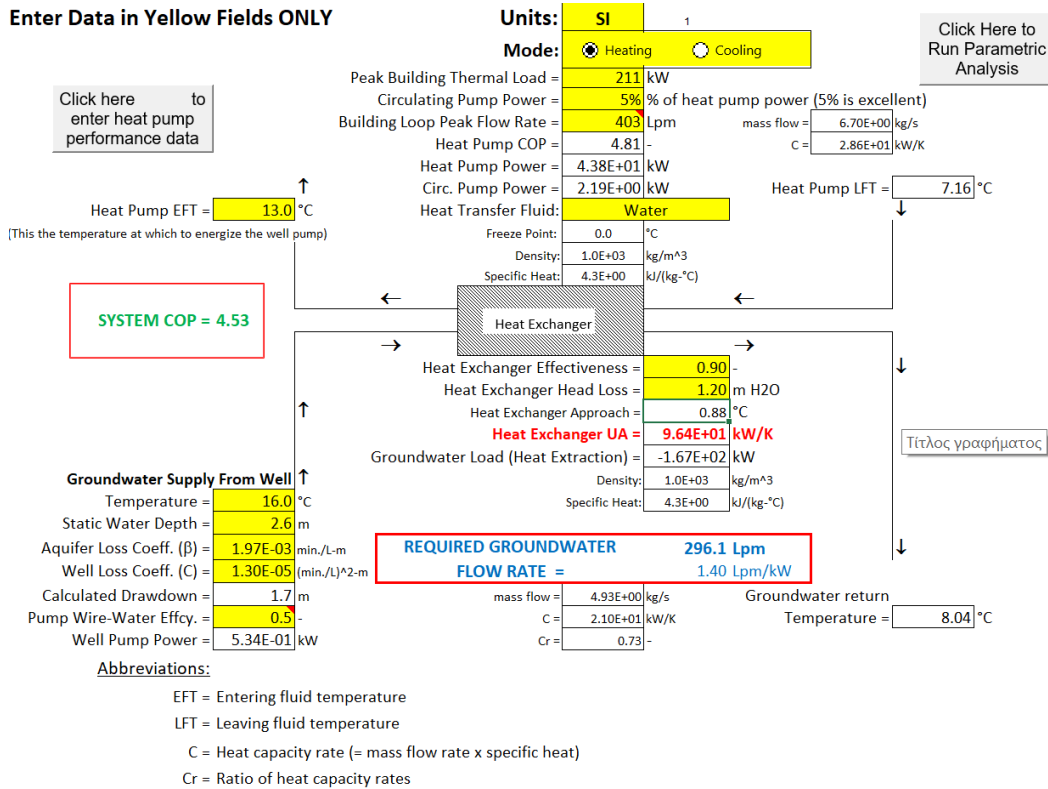


Figure 37. Calculation parameters of heat exchanger (figure 1 of 2)

Parametric Analysis

Heat Pump EFT °C	System COP	Groundwater Flow Rate Lpm	Heat Exch. UA kW/K
1			
2			
3			
4			
5			
6	3.95	1.61E+02	3.53E+01
7	4.03	1.73E+02	3.89E+01
8	4.12	1.86E+02	4.32E+01
9	4.20	2.02E+02	4.86E+01
10	4.29	2.19E+02	5.55E+01
11	4.37	2.40E+02	6.46E+01
12	4.45	2.66E+02	7.73E+01
13	4.53	2.96E+02	9.64E+01
14	4.60	3.34E+02	1.29E+02
15	4.67	3.83E+02	2.02E+02

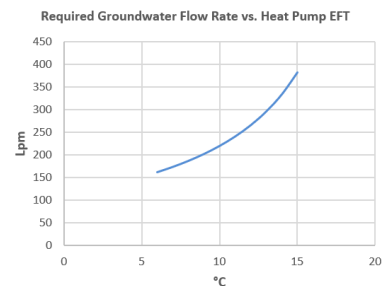
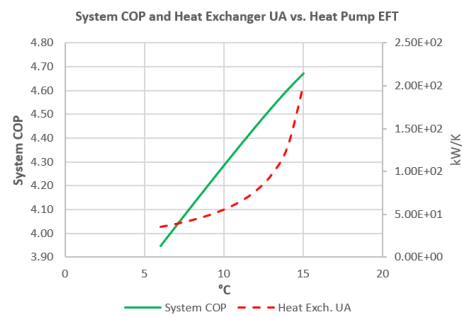


Figure 38. Calculation parameters of heat exchanger (figure 2 of 2)

The final required characteristics of the system are summarized below:

- Stainless steel heat exchanger 170kW (inlet-outlet water temperature: 16/8 °C - 13/7 °C)
- Heat pump 210kW capacity, inlet-outlet water temperature: primary 13/7 °C and secondary 45/40 °C (indicative type AERMEC WRK0700°HL)
- Water flow rate of submersible pump $Q=17.8 \text{ m}^3/\text{h}$ (296.1 lt/min), $H=10\text{m}$
- Supply from the heat exchanger to the heat pump $Q=24.20\text{m}^3/\text{h}$, $H=2.1\text{m}$
- Heat pump primary supply (from heat pump to Buffer) $Q=37.00\text{m}^3/\text{h}$, $H=3.0\text{m}$
- Heat pump secondary supply (from Buffer to the heating distribution manifold) $Q=37.00\text{m}^3/\text{h}$, $H=8.0\text{m}$

The schematic (operating) diagram of the geothermal heating system is presented in Figure 39.

The total cost of the geothermal heating system comprises of equipment purchase, installations and labor. Depending on the consideration regarding the current state of the building, i.e. if the building shell is thermally insulated, if the radiator units inside the building are fan coils or conventional type radiators, additional costs may arise depending on the desired investment plan. The cost of the geothermal heating system alone, without replacement of the distribution system inside the building, was estimated at 168000€. Such cost requires almost 16 years to yield full payback of the initial investment. Of course, if the building was already insulated the required equipment could have been much cheaper (heat exchanger and geothermal heat pump), thus the investment cost would be much lower and the expected payback period would be also reduced. More details regarding the cost of several scenarios (insulation requirement, replacement of the internal distribution network) are examined in Deliverable 4.7.4 (former 4.3.4).

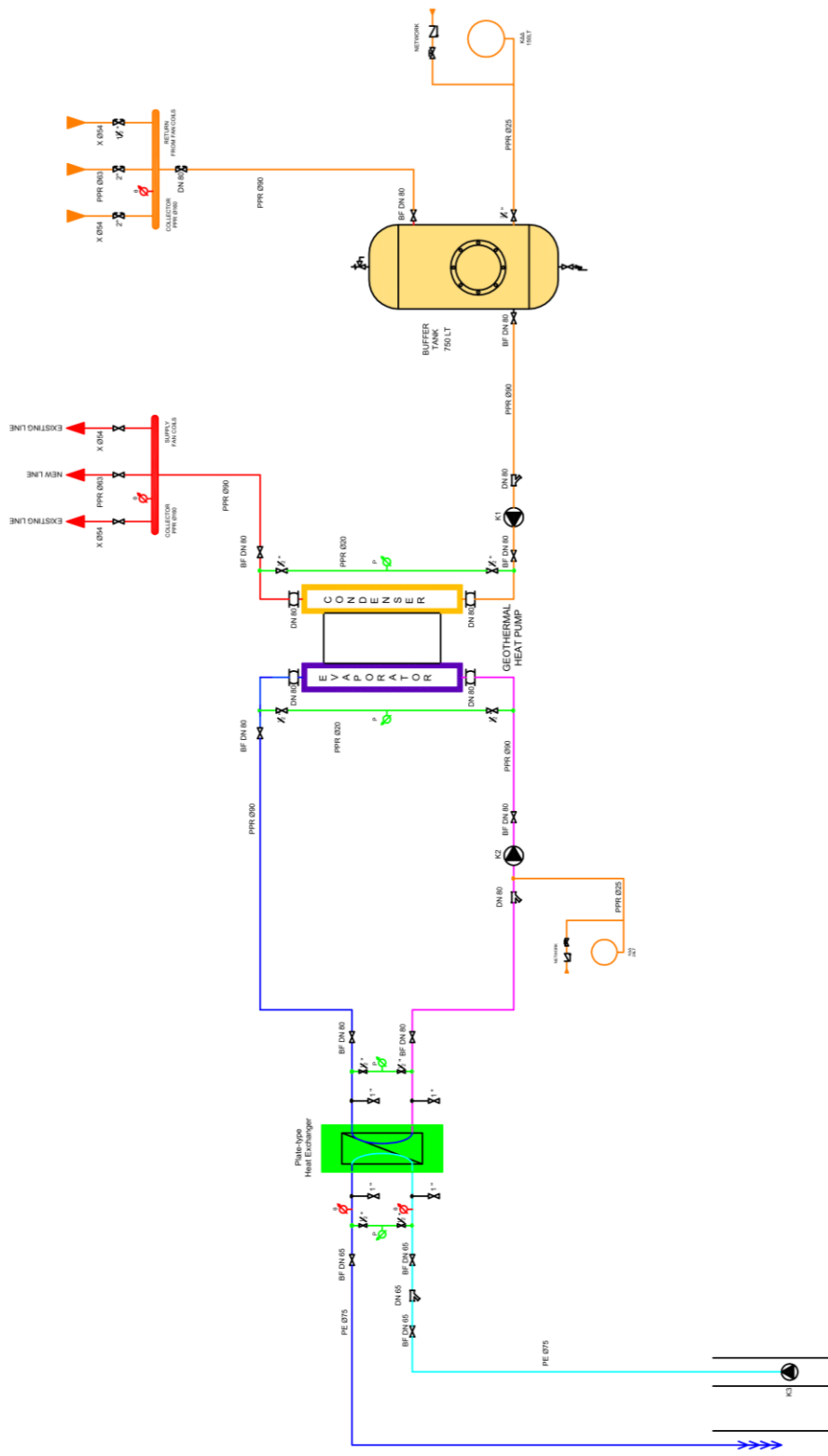


Figure 39. Schematic (operating) diagram of the geothermal heating system

6. Simplification of permits and elimination of bureaucratic barriers

IHU (former PB3) contribution in the policy report document regarding the simplification of permits and elimination of bureaucratic barriers with respect to the aforementioned studies and constructions is limited to the extent of IHU involvement in project, i.e. the monitoring of the existing pumps and the construction of the groundwater monitoring well that was drilled in the framework of the project in IHU-former TEICM premises (Serres). Detailed reference to such bureaucratic procedures is presented in Deliverable 4.7.5 (former 4.3.5).

Taking into consideration that IHU-former TEICM involvement in the project concerned only drilling of a borehole well for research and monitoring purposes, the standing legislation did not present any obstacles or time consuming requirements. On the contrary, the only requirement according to legislation provisions was to inform the responsible Water Directorate of the Decentralized Administration of Macedonia-Thrace region and make sure that the well is properly sealed after the research activities have been concluded.

On the other hand, the implementation of the studies that were part of the GREEN PUMP project would require permits and/or face bureaucratic and legislative barriers at several stages. More specifically, the different activities that require proper permits would concern the following:

- Permit to use the pumped water for a heating system based on shallow geothermal energy
- Permit to use the pumped water for usual secondary purposes (e.g. irrigation)
- Permit to use the pumped water for secondary in-house purposes (e.g. toilet flushing)
- Compliance with legislation regarding water quality (chemical and microbiological analysis results)

Some proposed modifications and/or additions to the legislation could be proposed aiming less legislation barriers against using pumped water quantities in a separate, secondary, in-house water network, as the one described in the framework of this project.

7. Environmental and social benefits

As part of IHU (former TEICM) involvement in the GREEN PUMP project, a report was prepared on the environmental and social benefits emanating from the broad application of studies similar to the ones described herein.

Based on the detailed references of Deliverable 5.7.2 (former 5.3.2), the environmental benefits could be summarized as follows:

- Reduce the oil consumption by satisfying heating requirements with shallow geothermal energy, having a direct positive effect to global oil reserves.
- Replace oil as a raw material for heating with renewable energy sources such as shallow geothermal energy.
- Reduce CO₂ emissions linked to oil usage for heating purposes.
- Reduce chemical treatment of the water by replacing water source for secondary uses.
- Reduce chemical residues in the soil by using untreated water for some applications such as irrigation.

The social benefits could be summarized as follows:

- Teach the public of the multiple advantages of renewable energy sources.
- Educate citizens to select environmental friendly approaches to satisfy their everyday needs.
- Raising public awareness with respect to the excessive usage of potable water to needs that do not require water treated with chemicals such as irrigation and toilet flushing.
- Improve life standards of unprivileged social groups.
- Facilitate energy access in rural areas
- Prevent social discrimination related to side-effects of using fossil fuels

Of course, application of the specific studies included in TEICM participation in the GREEN PUMP project would also have similar direct positive effects, yet in smaller scale compared to a broader application of the GREEN PUMP project findings.

8. Acknowledgements

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The contents of the report are sole responsibility of IHU (former TEICM) and can in no way be taken to reflect the views of the European Union, the participating countries the Managing Authority and the Joint Secretariat.