



Deliverable D1.3

Modelling energy demand and plant typology study for different levels of renovation in different types of buildings, climates and grounds

WP1

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1 Summary

The deliverable D1.3 “Archetype definition for analysing retrofit solutions in urban areas in Europe” is a public document delivered in the context of WP1, Task 1.3 named “Modelling energy demand and plant typologies for different renovation levels in different types of buildings, climates and undergrounds”.

Ground Source Heat Pumps (GSHP) are gaining interest for many applications and a very difficult issue is to look at their affordability in urban environments with limited spaces. In order to set up different cases with different levels of retrofit and try to generalize results, the project focuses the activity on archetypes, i.e. buildings which may represent the usual type of building which may be found more frequently in urban environments around Europe. The analysis of the archetypes has been based on literature review and analysing the existing databases of buildings in Europe. The work allowed to determine a reference building for single family house and a building representing an apartment block for multi-users. The multi-user building (apartment block) has been considered both as office building, while the terraced house just as residential. The buildings have been additionally subdivided into existing buildings, i.e. built up from 1960 to 1990 and historic buildings, i.e. buildings earlier than 1960. For these two types of buildings both current and post-retrofit envelopes have been contemplated

Three climatic locations different climates have been considered: Athens (defined: warm climate), Strasbourg (mild climate) and Helsinki (cold climate). The climatic conditions do not only affect the energy demand of the building and the peak power needed for heating and cooling, but also determine different ways of buildings’ construction and define different levels of insulation.

Finally, three kinds of ground conductivity have been analysed, based on the suggested values defined in Task 1.2. These values have been considered for the GSHP sizing for each building type. The GSHP solutions as well as the hybrid air/water solutions have been compared with traditional boilers and chillers.

This deliverable permit to define the different archetypes, their dimensions and way they are constructed. Based on the simulations the energy needs of the buildings as well as the peak power for heating and cooling have been determined. Once defined the energy demands and peak loads GSHP have been sized depending on available space as a function of ground conductivity and location (i.e. undisturbed ground temperature). This allows to create a matrix for the different levels of retrofit solutions which will be associated to related costs for a cost-benefit analysis to check the most achievable solutions in Tasks 1.4 and 1.5.

2 Introduction

The H2020 project GEO4CIVHIC (Most Easy, Efficient and Low-Cost Geothermal Systems for Retrofitting Civil and Historical Buildings) aims at destroying the barriers and increasing the market of Ground Source Heat Pumps in the retrofit of buildings in urban environments.

The Energy Performance of Building Directive (EPBD) states that buildings represent 40% of the final energy consumption in Europe [1-3]. Among them, 70% are residential buildings and 30% are commercial buildings. Most of the buildings which need to be renovated are in urban areas, where the space availability for installing the borehole field for a GSHP installation is an important issue. In fact, the standard space occupied by common borehole field have to be limited according to urban situation. In many cases the space availability will depend not only in already existing free space as gardens, parking lots, etc., but also considering the refurbishment level (higher levels will reduce the energy need, therefore the probes length and the space needed). The barriers and available space have been already handled in Task 1.1 where the discussion on the available space has been started.

Task 1.3 builds up a database of building energy profiles whose typology is selected based on the archetypes chosen in the project 4RinEU (led by EURAC) and on existing databases (TABULA INSPiRe, EFFESUS, Cheap-GSHPs). As shown in Chapter 3 and 4, single-user, multi-user and historic residential and non-residential buildings have been studied. Simulations have been carried out considering both the envelope without any insulation, and with good insulation. Building energy demand has been obtained for each archetype, considering three different climates (Chapter 5 and 6): Athens, Strasburg and Helsinki, corresponding to South, Centre and North Europe.

Using the energy profiles obtained by the simulations, shallow geothermal systems have been sized (Chapter 8), considering three different underground characteristics (defined in task 1.2). An analysis of the usual layout of urban environments has been set up, in order to answer to questions on limitations for installing GSHP systems in the urban area. Based on the layout of the city, different hypotheses of space availability have been decided, thus leading to different options either with GSHPs or hybrid solutions.

The overall results will be then used to develop a database of almost 108 cases, furtherly implemented considering three different heating and cooling terminal units to use the correct COP for the heat pumps: high temperature (radiators), medium temperature (fan coils) and low temperature (radiant systems).

3 Archetypes definition

The definition of archetypes inside urban environments must represent in a proper way the most common typology of buildings in the urban areas in all countries of Europe, that is important to better define the barriers and the problems related to the built environment.

Archetypes are generally defined as theoretical buildings obtained by statistical analysis of building characteristics grouped based on similarities. Building archetypes can be defined as models that allow the evaluation of the energy demand of a wide building stock, which allow the development of innovative strategies and technologies to increase the energy efficiency, therefore to reduce the energy consumption. Since archetypes have been chosen to be representative of the European building stock, in the GEO4CIVHIC project, the first step consisted in checking existing literature on the building sector seeing the average consumptions of buildings. The energy demand of existing buildings around Europe ranges from 150 kWh/(m² year) to 300 kWh/(m² year) based on recent studies [4]. Hence there is a big potential in Europe, estimated in about 25,000,000,000 m² of floor area.

The definition of reference buildings is important to know the most diffuse construction typologies, in order to get information on the possible solutions that can be proposed together with GSHP. Cheap-GSHPs [5] has been considered for the climatic data classification and for the types of buildings examined. The buildings present in Cheap-GSHPs are representative of European buildings, but different models have to be considered when dealing with urban dense areas. At the end, basically two sets of databases have been used as prevalent for the state of art of European buildings in urban environment: a COST action and two related European projects.

The first project is the COST action TU0901 “Integrating and Harmonizing Sound Insulation Aspects in Sustainable Urban Housing Constructions” [6], in which were involved around 90 experts from 29 European countries with the scope of establishing a common framework in building acoustics throughout Europe.

A reference database was defined to analyse the European housing stock regarding sound insulation, different types of sound transmission and the proportion of occupants which may experience sound transmission, collecting the most common type of housing and construction methods of each country. Using a combination of Eurostat statistics (2013) and information gathered during COST Action TU0901, the proportion of population which inhabit detached housing, attached (row/terraced, semi-detached) housing or apartment (flatted) housing was described (Figure 1). For these building types, information on building techniques were also been collected, both from sound insulation and from energy saving point of view.

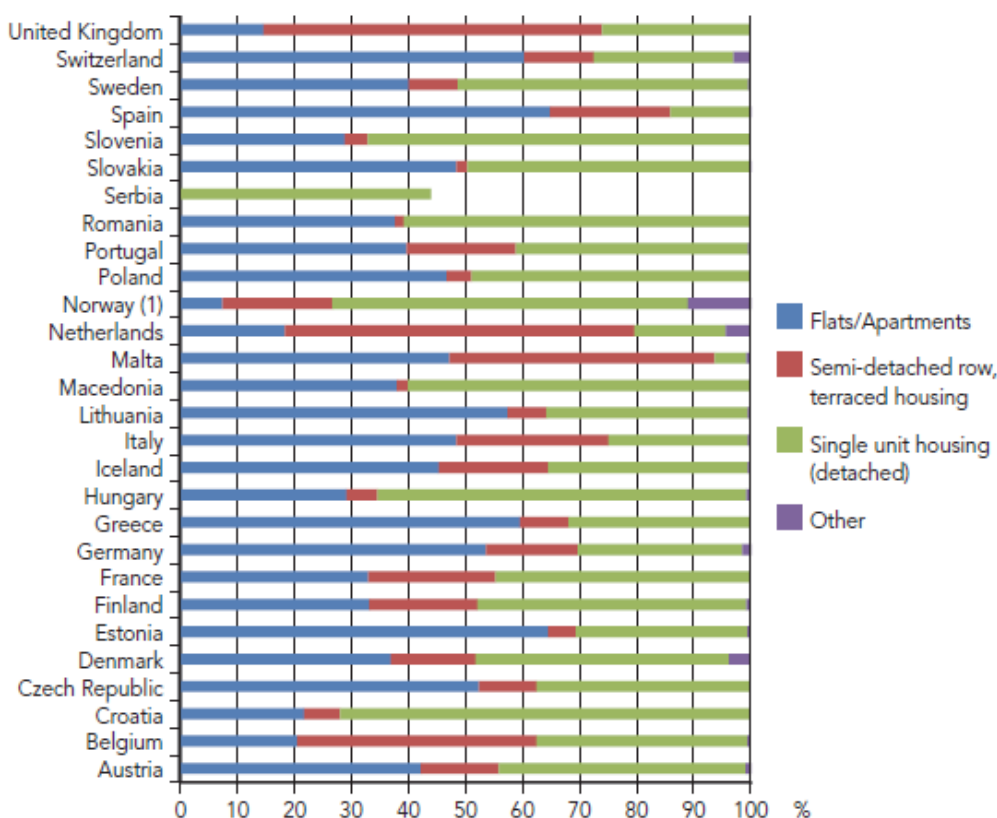


Figure 1 Building typologies sharing in the different countries from COST action TU0901

The second project that collects existing building types across 21 European countries is the EU project TABULA (Typology Approach for Building Stock Energy Assessment) [7] developed some guidelines to describe a methodology to choose proper reference buildings leading to the creation of a European database to share a general idea of national building stocks. EPISCOPE provides a database of energy performance assessment before and after renovation, accounting actions both on the envelope and on the plant, implementing several combinations of residential buildings and HVAC systems including NZEB buildings. The project TABULA - EPISCOPE is based on different national criteria according to the building and plant features and to the weather conditions. In particular, buildings envelope characteristics are listed as a function of the age class, i.e. the year the building has been built up.

Since the aim of the project is to look at the retrofit of buildings (both shallow and deep retrofit) in the urban environment, the present work will refer to “existing buildings” regarding the ones which are neither historical nor buildings of heritage significance built after 1960s, and “historical” the ones built before 1960s, that usually (but not always) allow only partial retrofit.

Comparable results are possible because the considered areas have been decided based on the same boundary conditions, even if they could vary depending on the country.

The main characteristics of the analysis focused on climatic zone, period of construction and building typology in order to divide the building stock into different categories. More parameters are needed to calculate the reference building energy profiles, such as geometry, envelope, heating and cooling systems, end-use and so on. Once these information had been collected, the extrapolation of the archetypes has been based on the most frequent type of construction, defining the geometric characteristics as average between all the buildings associated within that archetype.

Since the aim of the Geo4Civhic project is to increase the installation and application of GSHPs in the built environment in retrofitting buildings inside historical city centres, the different types of buildings, their age as well as the possible HVAC solutions have to be considered.

Even if there is no unique definition, a first subdivision must be done between historic and non-historic buildings. The standard FprEN 16883 [8] is the first which underlines the difference between a historic building and building protected by cultural heritage, considering that an historic building does not necessarily have to be statutorily designated as cultural heritage, but it is a specific form of objects, as defined in EN 15898 [9]. The term “object” is used in the standard for cultural heritage, both immovable and movable. In specific professional contexts, other terms are used: e.g. “artefact”, “cultural property”, “item”, “ensemble”, “site”, “building”, “fabric”. Therefore, a building with more than 50-70 years life is usually considered as historic even though it is not particularly or significantly important from the architectural point of view.

To standardize the entire population of data, Table 1 shows the subdivision groups based on the period of construction:

Table 1 Grouping division of the building population [7]

	Start	End
1	...	1918
2	1919	1944
3	1945	1960
4	1961	1980
5	1981	1990
6	1991	2000
7	2001	2010
8	2011	...

Buildings which have been built up later than 1990 have not been considered, since the main target of the project is the installation of ground source heat exchangers in difficult and confined urban setting such as historical city centres; therefore, it is unlikely the presence of such recent buildings or retrofit actions. Moreover, data available for typical buildings of the ‘90ies are present in the project Cheap-GSHPs. In order to match the project guidelines, two more classifications have been defined:

- Historical buildings, which includes which have been built before 1960;
- Existing buildings, which groups constructions between 1960 and 1990.

Since no free databases regarding non-residential buildings are available in literature, the hypothesis is to consider a structure similar to apartment block, varying internal loads and time schedule, which will be adapted according to the final end use (offices, rather than companies, etc.).

A discussion with EURAC managing the H2020 4RinEU project has been carried out in order to coordinate the archetypes selection and analysis in the two projects. The archetypes of 4RinEU are based on TABULA-EPISCOPE as well, but they differ from the ones selected in GEO4CIVHIC. The two databases are compatible, coherent (same input for internal loads etc.) and complementary.

4 Geometry of the archetypes

The main objective of task 1.3 has been the definition and the assessment of proper buildings archetypes according to European building stock in an urban context in order to apply geothermal energy in city centres. Looking at the urban environment, the analysis has shown that the main representative types of buildings are linear buildings. Figure shows how buildings can be subdivided in two main archetypes:

- Terraced House (TH), which contain more land-to-sky buildings with one or two floors (Fig. 2a).
- Apartment Blocks (AB) represented by typical construction of the popular neighbourhood (Fig. 2b)

Even if four different building typologies are present in the Tabula web tool (apartment block, single family house, multi-family house and terraced house), Single Family houses and Multi-Family houses have been excluded from the present work since the main area of interest of the Geo4Civhic project is the urban city centre, where usually these typologies of building are not present.

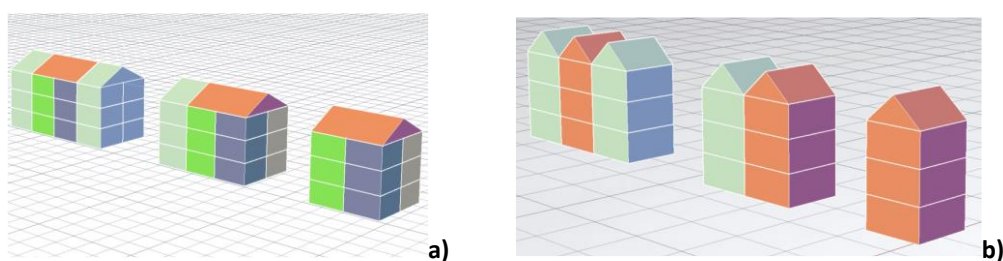
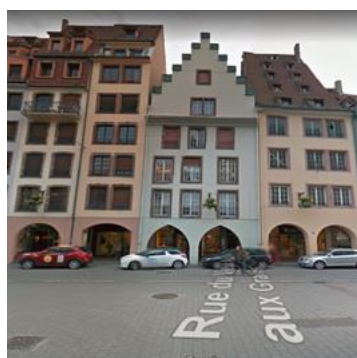


Figure 2 Example of possible solutions for apartment blocks (a) and terraced house (b)



a) Athens



(b) Strasbourg



(c) Helsinki

Figure 3 Building typologies characteristics of the historical city centres

In order to obtain a generalized profile based on the building typologies, each building must have standard shape and orientation. The apartment block has been defined as a sum of single housing unit with common stairwells (Figure 4).

According to statistical data coming from TABULA database, a 5-floor building has been selected to be considered as reference building for the apartment block solution.

Standard height for the ceiling in existing buildings has been set equal to 2.5 m, while in historical buildings an average height of about 3.15 m has been considered (25% higher than the height of existing buildings). The glazed/net floor surface ratio has been found to be typically in the range 12-24%, hence 19% as average value has been considered in existing buildings. In historical buildings an increased glazed surface has been considered according to the corresponding ceiling height, i.e. 22% as ratio between the glazed area and the net floor area.

Figure 4 shows the geometry and the layout of the residential plan, representing the multifamily archetype. The office building has been considered with the same configuration with 4 offices of the same size of the apartments.



Figure 4 Lay-out of the general floor for the multi-user apartment block

Existing and historical single-family buildings have been considered as linear terraced houses. According to statistical data coming from TABULA database, a 3-floor building has been considered.

The standard height for ceiling and the glazed/net floor surface ratio has been considered the same as the apartment blocks. In Figure 5 the geometry and the layout of the terraced house are reported. In this case the building has been considered only residential.



Figure 5 Layout of the single-family terraced house

5 Climatic conditions

Archetypes must be grouped based on the climate to define the proper boundary conditions in terms of the different parameters affecting energy in buildings. An analysis has been already carried out in Cheap-GSHPs [10] where the climatic conditions have been defined based on the Köppen-Geiger scale and the Degree-Days (DD) defined for the heating season (DDH) and in the cooling season (DDC).

Among the different ways to define the weather conditions, the Köppen-Geiger scale and the Degree-Days (DD) have been used as parameters [11] to group the archetypes of the 20 countries. The European map of the Köppen-Geiger climate classification is shown in Figure 6, highlighting the difficulties related to the presence of different of more than one climate in the same country.

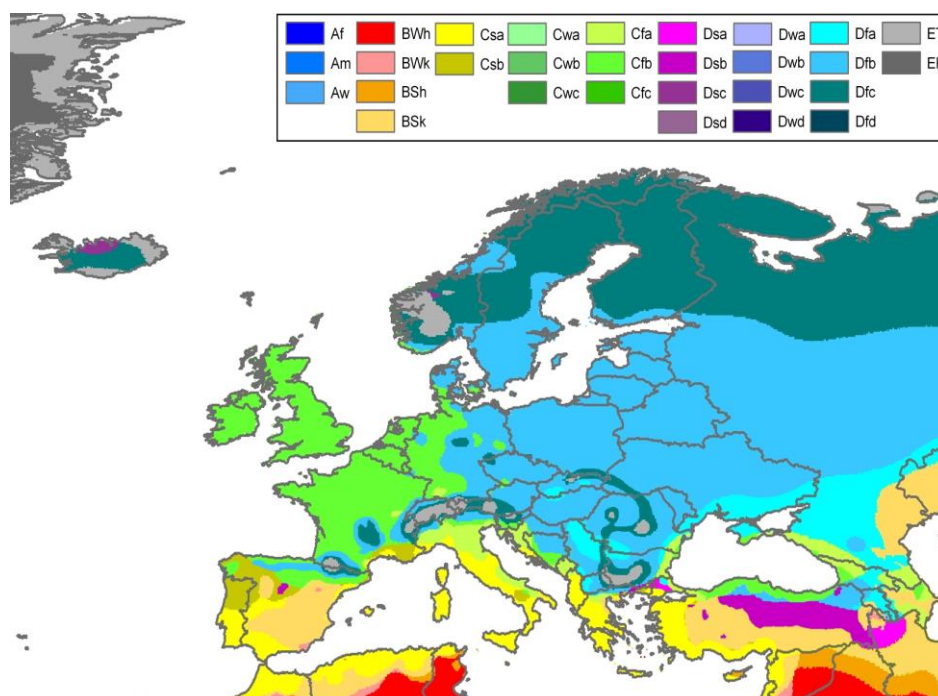


Figure 6 European map of Köppen-Geiger climate classification [11]

To limit the climatic analysis in the previous work [10], based on the values of the HDD and CDD, the following 4 macro-groups have been defined:

- Dry warm climates, including hot desert climate (BWh) and cold desert climate (BSk)
- Mild warm climates, including hot-summer Mediterranean climate (Csa), warm-summer Mediterranean climate (Csb), humid subtropical climate (Cfa)
- Mild cold climates, including temperate oceanic climate (Cfb) and subpolar oceanic climate (Cfc)
- Cold climates, including Warm-summer humid continental climate (Dfb) and subarctic climate (Dfc)

On the other hand, looking at the heat pump technology, the heat pumps efficiency values in the market are defined based on standardised profiles of energy defined in the standard EN 14825.

Based on this standard the European climatic conditions are summarised into 3 main groups, identified by a reference city (Figure 7):

- Athens as representative of the warm climate, DDH = 995 and DDC = 1046;
- Strasbourg for a mild climate, DDH = 2746 and DDC = 115;
- Helsinki as a cold climate, DDH = 4597 and DDC = 23.

where DDH and DDC have been calculated according to [10].



Average annual temperature:

- Athens, 17.9 °C
- Strasbourg, 10.3 °C
- Helsinki, 5.2 °C

Figure 7 Representative locations considered for the analysis

Compared with the defined climatic classes in [10] the 3 locations mean a reduction of reference weather conditions, i.e. to delete the mild warm climates class. In fact, looking at the Figure 8 Athens is well centred in the warm climates, Strasbourg is centred in the mild cold climate and Helsinki is well centred in the cold climate class.

About the mild warm climates, in principle Csa can be assumed as warm climate, while Csb and Cfa can be assumed as mild cold climates.

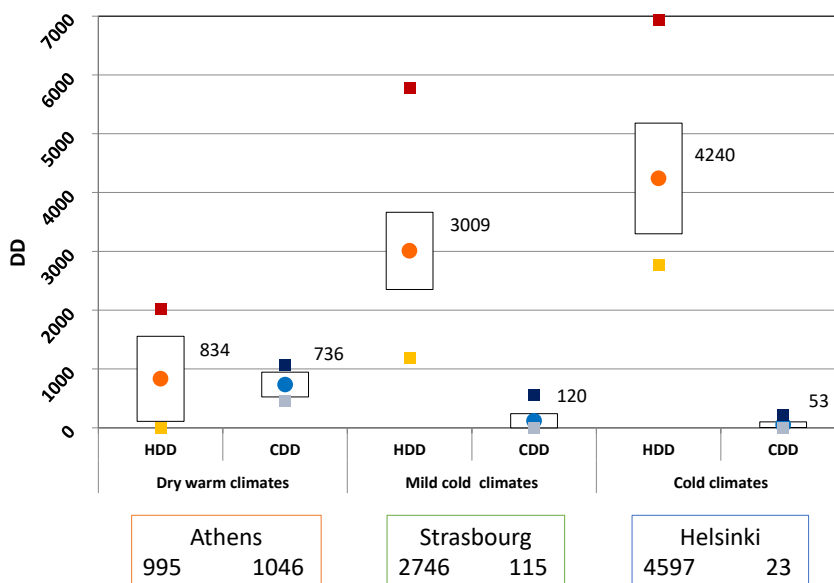


Figure 8 – Comparison between the locations defined by the EN 14825 [12] and the average values of the 3 climatic regions defined in [10].

6 Dynamic simulations

The further step regards the 3D model of the buildings, including all the properties collected in the previous steps, internal loads, heating and cooling systems operation, orientation, etc. Dynamic simulations to calculate the energy demand of the buildings have been carried out with the software TRNSYS.

6.1 Sensible and latent loads

First, thermal zones have been defined using a common assumption, so that results can be compared. The higher the number of the thermal zones, the more accurate are the simulations due to the higher level of the input data that can be implemented. The terrace house typology has been simulated with the hypothesis that each floor represents a thermal zone, dividing it in sleeping (SZ) and living zones (LZ).

The subdivision for the apartment block was simplified with respect to the terraced house because of the simulation velocity, which decreases significantly defining a thermal zone for each housing unit, one for the thermal room, one for the zone below the roof and one for the stairwells.

Tables 2 and 3 sum up the archetypes' characteristics regarding both the structure and the envelope, defining areas, volumes and thermal properties of the opaque structures and windows. These data have been considered according to the climate and similar building techniques, verifying that the colder the climate the lower the transmittance needed.

Table 2 Characteristics of the archetypes

Building type		Gross Volume [m ³]	$A_{\text{glazed}}/A_{\text{floor}}$ [-]	Net Floor Area per user [m ²]
Apartment Block	Existing	5825	0.19	82
	Historical	7125	0.23	82
Terraced House	Existing	500	0.17	138
	Historical	610	0.21	138

*average value between 94 m² (2 bedrooms) and 70 m² (1 bedroom)

Table 3 Thermal characteristics of the archetypes

Building type	Age	Climate	U_{Roof} [W/m ² K]	U_{Walls} [W/m ² K]	U_{Floor} [W/m ² K]	U_{Windows} [W/m ² K]
Terraced house	existing	warm	1.65	0.89	1.36	3.55
		mild	0.70	1.05	1.01	2.85
		cold	0.29	0.35	0.41	2.35
	historical	warm	2.30	1.75	1.29	4.97
		mild	1.19	1.75	1.38	3.69
		cold	0.54	1.11	0.79	2.72
Apartment block	existing	warm	0.79	0.79	1.15	3.90
		mild	0.82	1.01	0.68	2.93
		cold	0.13	0.22	0.16	1.43
	historical	warm	1.76	1.35	1.07	5.19
		mild	1.80	1.81	0.95	3.41
		cold	0.32	0.59	0.66	2.50

The schedules implemented for the internal gains have been developed according to the end use of the buildings, differentiating residential buildings and non-residential. Each used room has sensible and latent heat sources mainly due to people, but also to lighting and equipment.

The internal sensible load for a terrace house due to the presence of people is 70 W/person, considering an average occupancy of 60 m²/person. Defined the number of people, the total sensible load is shared between the living area and the sleeping area, based on the occupancy schedule. In order to obtain separately the contribution of the equipment, the sensible load due to people already calculated can be subtracted from the total sensible load due to people and equipment provided in the standard EN 13790 [13], according to a determined schedule (Figure 9).

Days	Hours	Residential buildings	
		Living room plus kitchen $(\phi_{int, Oc} + \phi_{int, A}) \cdot A_f$ W/m ²	Other conditioned areas (e.g. bedrooms) $(\phi_{int, Oc} + \phi_{int, A}) \cdot A_f$ W/m ²
Monday to Friday	07.00 to 17.00	8,0	1,0
	17.00 to 23.00	20,0	1,0
	23.00 to 07.00	2,0	6,0
	Average	9,0	2,67
Saturday and Sunday	07.00 to 17.00	8,0	2,0
	17.00 to 23.00	20,0	4,0
	23.00 to 07.00	2,0	6,0
	Average	9,0	3,83
Average		9,0	3,0

Figure 9 EN 13790 – total thermal load due to people and equipment for residential buildings [13]

People sensible load is implemented in the simulations as 60% of radiative load and 40% of convective load, while the equipment is 50% in both categories.

Example of schedule loads for each building typology are shown in Tables, divided in different categories based on working days and weekend days.

Table 4 Schedule example for specific and total sensible heat loads based on the building typology: a) terraced house, b) apartment block, c) office s

TERRACED HOUSE MON-FRI									
		Total		People		Equipment		People	
		LZ	SZ	LZ	SZ	LZ	SZ	LZ	SZ
Time		W/m ²	W/m ²	W/m ²	W/m ²	W	W	W	W
7:00	9:00	8.0	1.0	1.5	0.0	96	94	280	0
9:00	17:00	8.0	1.0	1.5	0.0	96	94	280	0
17:00	19:00	20.0	1.0	1.5	0.0	660	94	280	0
19:00	21:00	20.0	1.0	1.5	0.0	660	94	280	0
21:00	23:00	20.0	1.0	1.5	0.0	660	94	280	0
23:00	7:00	2.0	6.0	0.0	0.7	94	284	0	280

a)

TERRACED HOUSE SAT-SUN									
		Total		People		Equipment		People	
		LZ	SZ	LZ	SZ	LZ	SZ	LZ	SZ
Time		W/m^2	W/m^2	W/m^2	W/m^2	W	W	W	W
7:00	9:00	8.0	2.0	1.5	0.0	96	188	280	0
9:00	17:00	8.0	2.0	1.5	0.0	96	188	280	0
17:00	19:00	20.0	4.0	1.5	0.0	660	376	280	0
19:00	21:00	20.0	4.0	1.5	0.0	660	376	280	0
21:00	23:00	20.0	4.0	1.5	0.0	660	376	280	0
23:00	7:00	2.0	6.0	0.0	0.7	94	284	0	280

TERRACED HOUSE LOADS									
		MON-FRI				SAT-SUN			
		Living Zone		Sleeping Zone		Living Zone		Sleeping Zone	
		People	Equip	People	Equip	People	Equip	People	Equip
Time		W	W	W	W	W	W	W	W
7:00	9:00	280	96	0	94	280	96	0	188
9:00	17:00	280	96	0	94	280	96	0	188
17:00	19:00	280	660	0	94	280	660	0	376
19:00	21:00	280	660	0	94	280	660	0	376
21:00	23:00	280	660	0	94	280	660	0	376
23:00	7:00	0	94	280	284	0	94	280	284

APARTMENT BLOCK – MON-FRI									
		Total		People		Equipment		People	
		LZ	SZ	LZ	SZ	LZ	SZ	LZ	SZ
Time		W/m^2	W/m^2	W/m^2	W/m^2	W	W	W	W
7:00	9:00	8.0	1.0	1.8	0.0	32	51	280	0
9:00	17:00	8.0	1.0	1.8	0.0	32	51	280	0
17:00	19:00	20.0	1.0	1.8	0.0	500	51	280	0
19:00	21:00	20.0	1.0	1.8	0.0	500	51	280	0
21:00	23:00	20.0	1.0	1.8	0.0	500	51	280	0
23:00	7:00	2.0	6.0	0.0	1.4	78	26	0	280

b)

APARTMENT BLOCK – SAT-SUN									
		Total		People		Equipment		People	
		LZ	SZ	LZ	SZ	LZ	SZ	LZ	SZ
Time		W/m^2	W/m^2	W/m^2	W/m^2	W	W	W	W
7:00	9:00	8.0	2.0	1.8	0.0	32	102	280	0
9:00	17:00	8.0	2.0	1.8	0.0	32	102	280	0
17:00	19:00	20.0	4.0	1.8	0.0	500	204	280	0
19:00	21:00	20.0	4.0	1.8	0.0	500	204	280	0
21:00	23:00	20.0	4.0	1.8	0.0	500	204	280	0
23:00	7:00	2.0	6.0	0.0	1.4	78	26	0	280

APARTMENT BLOCK LOADS					
		MON-FRI		SAT-SUN	
		People	Equipment	People	Equipment
Time		W	W	W	W
7:00	9:00	280	83	280	134
9:00	17:00	280	83	280	134
17:00	19:00	280	551	280	704
19:00	21:00	280	551	280	704
21:00	23:00	280	551	280	704
23:00	7:00	280	104	280	104

SPECIFIC SENSIBLE LOADS - OFFICES				
Time		Total	People	Equipment
		W/m^2	W/m^2	W/m^2
7:00	9:00	1.6	0.0	1.6
9:00	17:00	15.2	4.0	11.2
17:00	19:00	1.6	0.0	1.6
19:00	21:00	1.6	0.0	1.6
21:00	23:00	1.6	0.0	1.6
23:00	7:00	1.6	0.0	1.6

c)

Latent loads have been defined according to standard ASHRAE 160 [14], where hourly vapour production is expressed as a function of the occupancy of the people and the type of the activity (Table 5a and 5b).

Table 5 Schedule example for latent loads based on the building typology: a) terraced house and apartment block, b) offices

LATENT LOADS 2-4 PEOPLE									
Time	Hours	Activity				People	Altro	Total	
			2p	4p				2p	4p
			<i>kg/h</i>	<i>kg/h</i>	<i>kg/h · px</i>	<i>kg/h</i>		<i>kg/h</i>	<i>kg/h</i>
7:00	9:00	2.00	Colazione	0.60	1.00	0.05	0.10	0.51	0.75
9:00	17:00	8.00	Pranzo	0.15	0.30	0.09	0.10	0.30	0.45
17:00	19:00	2.00		0.00	0.00	0.09	0.10	0.29	0.41
19:00	21:00	2.00	Cena	0.33	0.65	0.09	0.10	0.45	0.74
21:00	23:00	2.00	Lavast.	0.16	0.31	0.09	0.10	0.36	0.57
23:00	7:00	8.00	Asc. vest	0.75	1.50	0.05	0.10	0.30	0.44

a)

LATENT LOADS OFFICES MON-FRI				
Time		People	TOTAL	
			Uff. 70m ²	Uff. 90m ²
		<i>kg/h · pers</i>	<i>kg/h</i>	<i>kg/h</i>
7:00	9:00	0.00	0.00	0.00
9:00	17:00	0.09	0.32	0.41
17:00	19:00	0.00	0.00	0.00
19:00	21:00	0.00	0.00	0.00
21:00	23:00	0.00	0.00	0.00
23:00	7:00	0.00	0.00	0.00

b)

Regarding HVAC systems, input schedules define whether the systems is activated or not, considering a conventional heating season from October to April. Air node set point temperature is 20°C and without controls for the humidity. On the contrary, for the cooling season, temperature is set at 26°C, with fixed relative humidity at 50%. In the office building the system is working from 7am to 5 pm, whereas in residential building the scheduling starts at 7 a.m. ending at 9 p.m. (10 a.m. to 12 p.m. in summer).

6.2 Infiltration

Infiltration is managed using a constant value equal to 0.4 [vol/h] when non retrofitted buildings are simulated, while retrofitted buildings have a constant infiltration rate of 0.1 [vol/h] even though mechanical ventilation is present, due to unwanted infiltration due to the nature of the buildings.

6.3 Demand Controlled Ventilation

Demand controlled ventilation (DCV) has been implemented since it generates air with a better air quality, reducing energy use due to the presence of a heat-recovery units. Air flows have been calculated using the reference standard EN 16798 [15], based on the room's area and people

occupancy. Calculations have been done separately for retrofitted and non-retrofitted buildings, both with respect to the surface and of the occupancy, choosing at the end the strictest one. Table 6 shows the values of fresh air flow rates for historical and existing buildings, i.e. terraced house typology.

Table 6 Fresh air flow rates for apartment block

FRESH AIR FLOW RATE APARTMENT BLOCK				
AREA	PEOPLE		MAXIMUM	
147m ²	4	147-4	Existing	Historical
<i>l/s</i>	<i>l/s</i>	<i>l/s</i>	<i>vol/h</i>	<i>vol/h</i>
61.7	28.0	61.7	0.48	0.60

The calculation method is different for office buildings (Table 7), where the flow rate calculated based on the surface and on the temperature must be summed. A flow rate of 4 l/(s Pers) has been set based on standard EN 16798 [15].

Table7 Fresh air flow rates for office buildings

FRESH AIR FLOW RATES OFFICE BUILDINGS					
OFF.	PEOPLE	AREA	TOT	AIR CHANGE RATES	
<i>m²</i>	<i>l/s</i>	<i>l/s</i>	<i>l/s</i>	<i>vol/h</i>	<i>vol/h</i>
70	16.0	28.0	44.0	0.72	0.91
90	20.0	38.0	72.0	0.70	0.88

The flow rates defined in the last tables refer to the flow rates of fresh air which have to be supplied in the rooms. Hence for the apartment blocks 2 cases (residential and not) for four types of building envelopes have been considered, i.e. 8 cases. For the terraced house only, residential building has been considered with four types of building envelopes, i.e. 4 cases. The overall 12 cases have been examined for the 3 locations, thus leading to 36 cases. Steady state calculation method based on EN12831 [16] has been applied to determine the peak power for heating, as well as dynamic simulations have been implemented using the software TRNSYS [17], defined such as shown in Figure 10. Results obtained will be further discussed in paragraph 7.2.1.

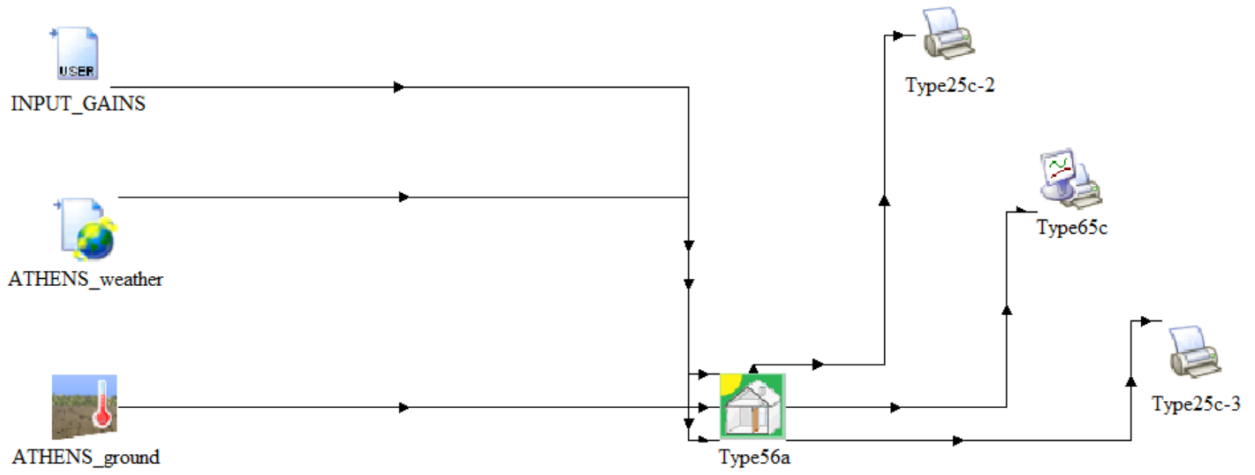


Figure 10 Input implemented in Simulation Studio interface

7 Sizing of the geothermal probes

7.1 Method

The total required borehole lengths for heating and cooling and then the extension of the borehole field of double U-tube ground heat exchangers have been calculated by means of the ASHRAE method. This procedure has been also included in the standard CTI-UNI 11466:2012 [18] with some modifications. The complete method has been implemented in a spreadsheet in Microsoft Excel. A simplified conceptual framework of this procedure is given in Figure 11, where the inputs are framed in red and the outputs in green.

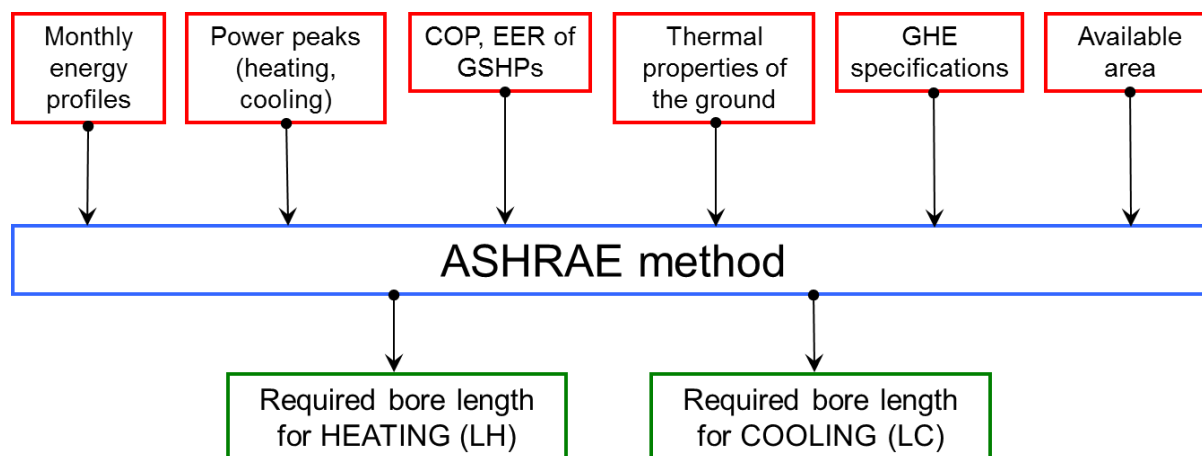


Figure 11 Simplified conceptual framework of the applied procedure.

7.1.1 The ASHRAE method

The design equations presented by Kavanaugh and Rafferty [19] and also reported in ASHRAE Handbook (2015) take the following form respectively for heating (1) and cooling (2):

$$LH = \frac{q_a \cdot R_{ga} + (q_{lh} - \bar{W}_h) \cdot (R_b + PLF_m \cdot R_{gm} + R_{gd} \cdot F_{sc})}{t_g - \left(\frac{t_{wi} + t_{wo}}{2} \right)_h - t_p} \quad (1)$$

$$LC = \frac{q_a \cdot R_{ga} + (q_{lc} - \bar{W}_c) \cdot (R_b + PLF_m \cdot R_{gm} + R_{gd} \cdot F_{sc})}{t_g - \left(\frac{t_{wi} + t_{wo}}{2} \right)_c - t_p} \quad (2)$$

where

F_{sc} = short-circuit heat loss factor

LC = required borehole length for cooling, m

LH = required borehole length for heating, m

PLF_m = part-load factor during design month

q_a = net annual average heat transfer to ground, W

q_{lc} = building design cooling load, W

q_{lh} = building design heating load, W

R_{ga} = effective thermal resistance of ground (annual pulse), (m·K)/W

R_{gd} = effective thermal resistance of ground (peak daily pulse), (m·K)/W

R_{gm} = effective thermal resistance of ground (monthly pulse), (m·K)/W

R_b = thermal resistance of borehole, (m·K)/W

tg = undisturbed ground temperature, °C

tp = penalty temperature for interference of adjacent boreholes, °C

twi = inlet fluid temperature at the borehole, °C

two = outlet fluid temperature at the borehole, °C

Wc = heat pump power input at design cooling load, W

Wh = heat pump power input at design heating load, W

The selected borehole length is the larger of the two lengths LC and LH found from Equations 1 and 2.

The calculation of the equivalent resistance of the ground derives from the solution proposed by Carslaw and Jaeger [20], in which the dimensionless Fourier number (Fo) is defined. This number relates the time τ in which the heat exchange takes place with the diameter of the perforation (db) and the thermal diffusivity of the soil (α), as follows:

$$F_0 = 4\alpha\tau/d_b^2 \quad (3)$$

It is assumed that the building load profile can be represented by three different pulses of heat corresponding to three different periods (τ_1, τ_2, τ_f), to account respectively for long-term heat imbalances (a 10 year pulse of qa), average monthly heat rates during the design month, and maximum heat rates for a short term period during a design day (a 6 hours pulse). Therefore, three Fourier numbers ($F_{0_1}, F_{0_2}, F_{0_f}$) are determined. An intermediate step in computing the ground's thermal resistance using the infinite cylindrical source model [21] is to identify the G-factors (G_1, G_2, G_f), which are determined from Figure 12 for each Fourier value.

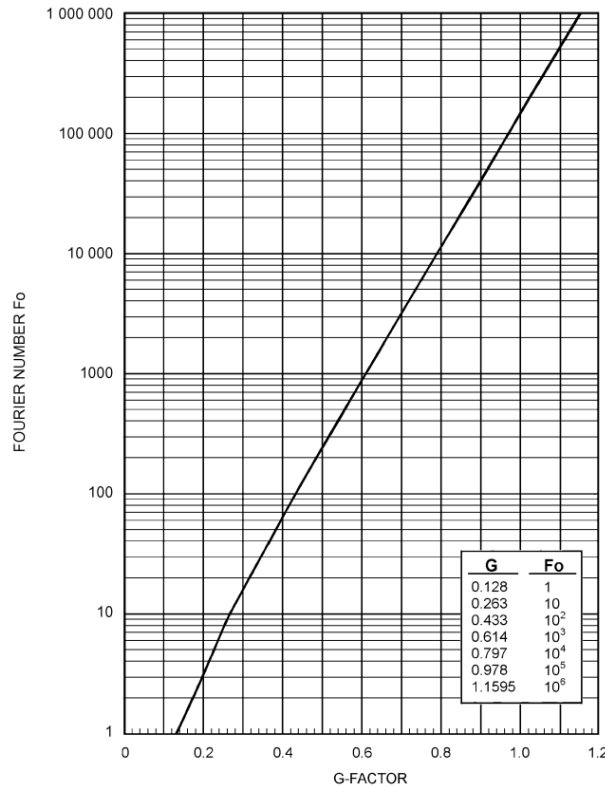


Figure 12 Parameter G as a function of the Fourier number

As result, the ground thermal resistances per unit length are calculated thanks to the following equations:

$$R_{ga} = \frac{G_f - G_1}{\lambda_g} \quad (4)$$

$$R_{gm} = \frac{G_1 - G_2}{\lambda_g} \quad (5)$$

$$R_{gd} = \frac{G_2}{\lambda_g} \quad (6)$$

where λ_g is the ground thermal conductivity. The borehole thermal resistance, R_b (i.e. the thermal resistance per unit of length between the heat-carrier fluid inside the pipe of the ground heat exchanger and the borehole wall), can be calculated using the steady state approach, as a consequence the thermal capacitance of the borehole (i.e., of both heat-carrier fluid and grouting material) is smaller than that of the surrounding soil. This assumption can be acceptable in a design approach when the thermal behaviour in long-term is investigated. When the short-term thermal performance is analysed the thermal capacitance of the borehole highly affects the results.

The F_{sc} factor in the Equations (1) and (2) takes into account the short-circuiting heat losses between the upward and downward flowing legs of a conventional U-bend loop. Normally U-loops are coupled in parallel to the supply and return headers in order to limit the pressure drops. Occasionally, when bore depths are shallow, two or three loops can be piped in series. In these cases, short-circuit heat loss is reduced, so the values for F_{sc} are smaller than for a single bore piped in series. Table 7 provides the values to be used for the dimensioning. The effect of this parameter on the results is surely limited, consequently an average value has been considered.

Table 7 Evaluation of the short-circuiting heat losses between the upward and downward flowing legs of a conventional U-bend loop (F_{sc}).

Bores per Loop	F_{sc}	
	36 mL/(s·kW)	54 mL/(s·kW)
1	1.06	1.04
2	1.03	1.02
3	1.02	1.01

When the borehole field consists of several ground heat exchangers the effect of the mutual thermal interference and the spacing between the boreholes has to be considered. This effect is outlined by the penalty temperature, i.e. the change of the ground temperature in long-term. In particular, in ASHRAE method the time of ten years is considered. The penalty temperature depends on the unbalance of the building load profile, on the spacing and layout of the borehole field. The allowed values of t_p are under 1 °C in order to avoid an excessive thermal interference between adjacent bores.

The choice of the temperature t_{wi} of the heat transfer fluid entering the heat pump is a critical step in the design process. Choosing a value close to ground temperature (t_g) results in a good energy efficiency of the system, but also in a higher total length of probes, with a significant increase of the installation costs. Choosing a value of t_{wi} far from t_g leads to a saving on the total length of the probes, but losses in system efficiency. In accordance with the compromise solution deriving from the North American experience, in cooling season (summer) the temperature value t_{wi} was set 14.5 K higher than t_g and in heating season (winter) it was set 9.5 lower than t_g .

There are different ways to assess the terms $(q_{lh} - W_h)$ and $(q_{lc} - W_c)$. In this case the performance coefficients of summer (COP_c) and winter season (COP_h) were considered, so:

$$(q_{lh} - W_h) = q_{lh} \cdot \frac{COP_h - 1}{COP_h} \quad (7)$$

$$(q_{lc} - W_c) = q_{lc} \cdot \frac{COP_c - 1}{COP_c} \quad (8)$$

7.1.2 Implementation of the ASHRAE method in the Excel spreadsheet

In the considered spreadsheet the ASHRAE method has been applied two times in a row to assess the total required borehole length.

When it is first applied the required bore lengths for heating (LH) and cooling (LC) are calculated disregarding the penalty temperature (tp). The longest one between LC and LH is divided in the GHEs, which are considered of equal length and have to be between 40 m and 120 m long. The spacing between the borehole heat exchangers is set to 7 m and if they are in greater numbers than 3 they are arranged in a regular grid in order to decrease the ground area. Then, it is possible to calculate the penalty temperature (tp) that is considered at the second iteration.

When the ASHRAE method is applied for the second iteration LH and LC are evaluated more accurately considering the penalty temperature tp. So once again the longest between the required bore lengths for heating and cooling is divided in the ground heat exchangers, which are arranged in the same way as previously assumed.

This procedure is summed up in the flowchart of Figure 13:

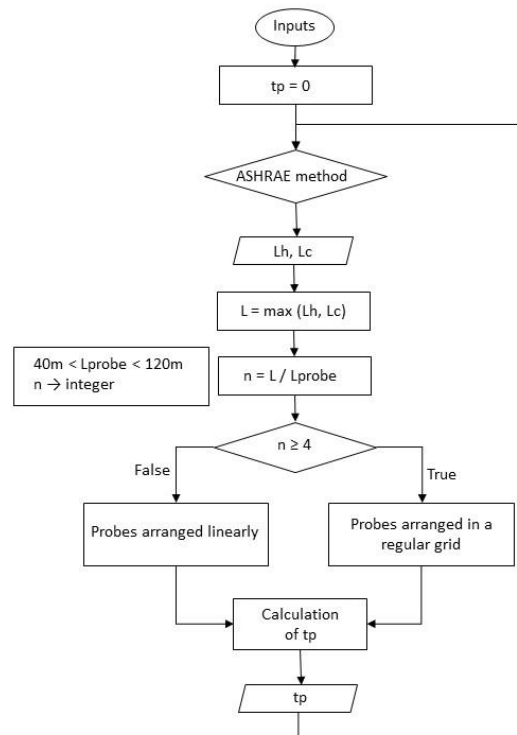


Figure 13 Flowchart of the ASHARE method as implemented in the Excel spreadsheet.

7.2 Inputs

7.2.1 Energy inputs and power peaks in heating and cooling

Overall 36 dynamic simulations have been carried out to determine the heating and cooling energy demands as well as the peak load for heating and cooling. Results are shown for the three climates Athens (Figure 14), Strasbourg (Figure 15), and Helsinki (Figure 16).

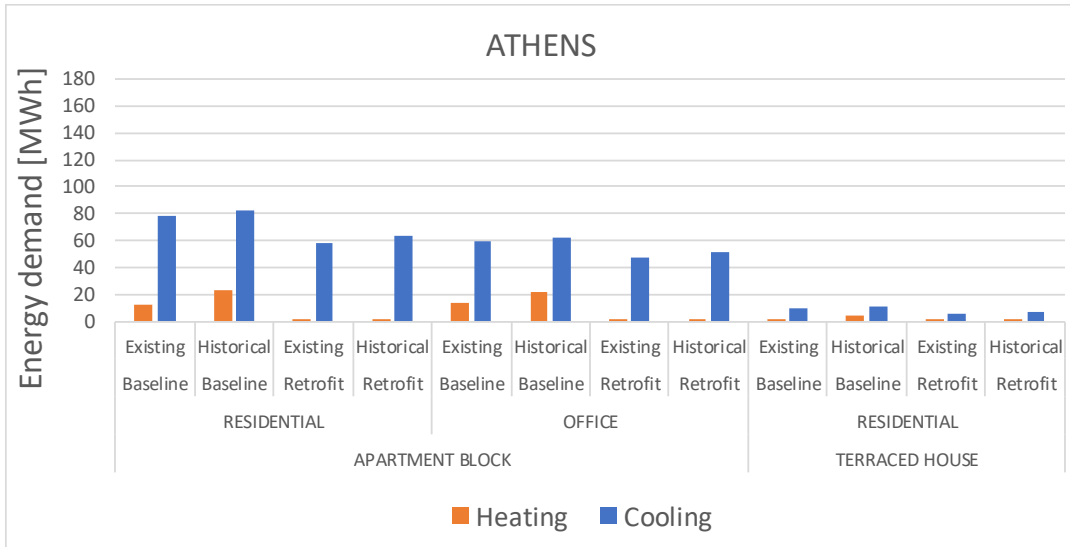


Figure 14 Energy demand for heating and cooling for Athens

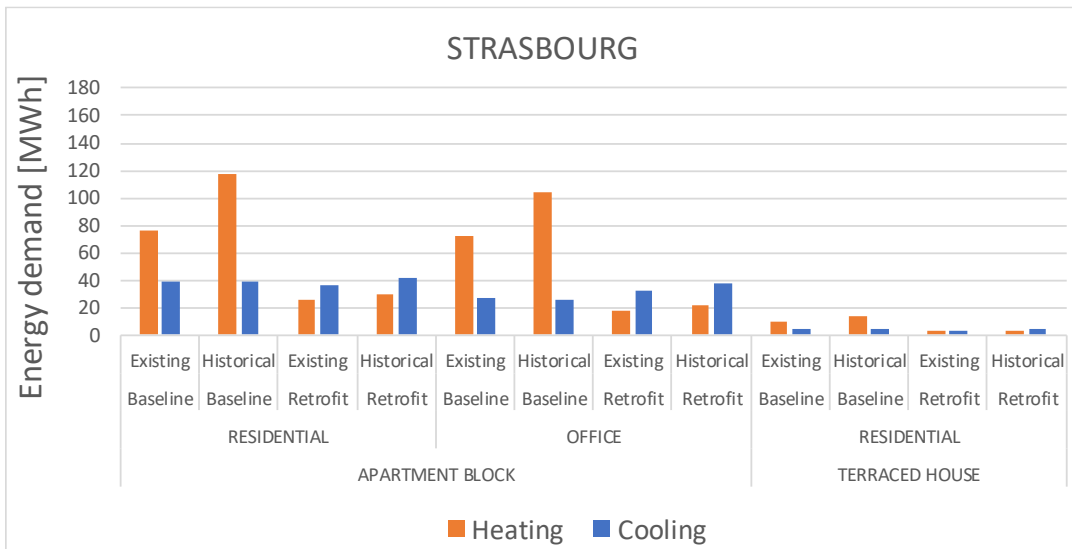


Figure 15 Energy demand for heating and cooling for Strasbourg

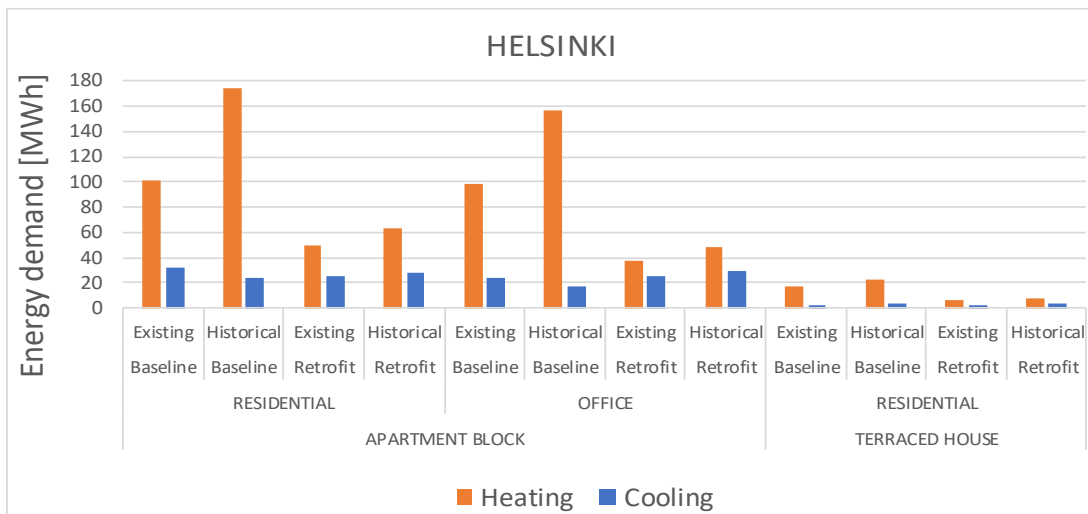


Figure 16 Energy demand for heating and cooling for Helsinki.

The data base of energy demands and peak loads have been used for sizing the GSHP in the different archetypes.

As can be expected, energy demand of the office buildings is lower than the energy demand of the residential buildings, due to the higher number of hours the heating/cooling system is operating.

In the baseline cases (i.e. in case the transmittance of the buildings are the ones reported in Table 2), in mild and cold climates the heating energy demand in buildings is dominant. On the contrary, when the buildings are retrofitted in Strasbourg the energy demand for heating and cooling are similar. This is important because in sizing the ground heat exchangers the most critical condition could be the summer, since in the cooling period the energy which has to be injected into the ground has to take into account the energy of the compressor of the heat pump, while in heating conditions the energy which has to be extracted by the ground is the energy of the building minus the energy of the compressor. Energy reduction is significant when looking at retrofitted buildings in Athens, which may lead to sizing issues for ground source heat pump.

7.2.2 COP and EER

In tables 8-10 design values of COP and EER are reported considering the heat pump connected to different heating and cooling systems (radiators, fan-coils, radiant floor) and three climatic locations (Athens, Strasbourg, Helsinki).

These values were determined referring to the datasheets of real heat pumps by Hi Ref-Galletti Belgium.

The seasonal values of COP and EER have been chosen according to design criteria of the system.

Table 8 Design and seasonal values of the heat pump connected to the different heating and cooling systems, considering Athens climate.

	ATHENS			
	HEATING			COOLING
	RADIATOR	FAN-COIL	RADIANT	FAN-COIL / RADIANT
Inlet - Outlet temperature [°C]	75 - 65	45 - 40	35 - 30	7 - 12
DESIGN COP/EER	2.4	3.6	4.8	4
SEASONAL COP/EER	2.5	4.1	5.3	4.4

Table 9 Design and seasonal values of the heat pump connected to the different heating and cooling systems, considering Strasbourg climate.

	STRASBOURG			
	HEATING			COOLING
	RADIATOR	FAN-COIL	RADIANT	FAN-COIL / RADIANT
Inlet - Outlet temperature [°C]	75 - 65	45 - 40	35 - 30	7 - 12
DESIGN COP/EER	2.4	3	3.8	5
SEASONAL COP/EER	2.5	3.3	4.3	5.5

Table 10 Design and seasonal values of the heat pump connected to the different heating and cooling systems, considering Helsinki climate.

	HELSINKI			
	HEATING			COOLING
	RADIATOR	FAN-COIL	RADIANT	FAN-COIL / RADIANT
Inlet - Outlet temperature [°C]	75 - 65	45 - 40	35 - 30	7 - 12
DESIGN COP/EER	2.4	2.7	3.4	5.9
SEASONAL COP/EER	2.5	3.0	3.8	6.5

7.2.3 Ground thermal properties and BHEs specifications

The simulations were performed considering the three values of thermal conductivity and volume thermal capacity specified in Table 11 which correspond to the mostly common types of ground.

Table 11 Thermal properties of the three considered types of ground.

Thermal conductivity [W/(m K)]	1.5	2.2	3
Thermal capacity [MJ/m ³ K]	2	2.5	2.6

The considered borehole heat exchanger is a double U-tube characterised by the following specifications (Table 12). The two U-loops are coupled in parallel as all the borehole heat exchangers.

Table 12 Specifications of the considered double U heat exchanger.

Pipe	Internal diameter	26 mm
	External diameter	32 mm
	Thermal Conductivity	0.35 W/(m K)
Grouting material	Borehole diameter	120 mm
	Thermal conductivity	1.5 W/(m K)

7.2.4 Available area

An analysis of the usual layout of urban environments has been carried out in order to answer to the question of limitations for installing GSHP systems in the urban area. Depending on the layout of the city, there might be buildings with small internal courtyards or even with gardens. However, the main problem is generally the restricted available area for BHE installation.

For these analyses it has been decided that the apartment block will host necessary GHEs arranged in a regular grid in the courtyard at a distance of 2 m from the neighbourhoods and under the hypotheses that 6-7 m spacing is the optimum distance between boreholes. As shown in Figure 17a, up to 15 probes can be installed in the courtyard, considering an available area of 392 m². With the assumption of a maximum possible probe depth (L_{probe}) equal to 120 m, the maximum length allowed for LH and LC is 1800 m.

The terraced house will host the GHEs arranged linearly in the courtyard at a distance of 3.3 m from the neighbourhoods and of 7 m between them. Under the considered assumptions a maximum of 2 BHEs can be installed (Figure 17b), so the length limitation for LH and LC is 240 m.

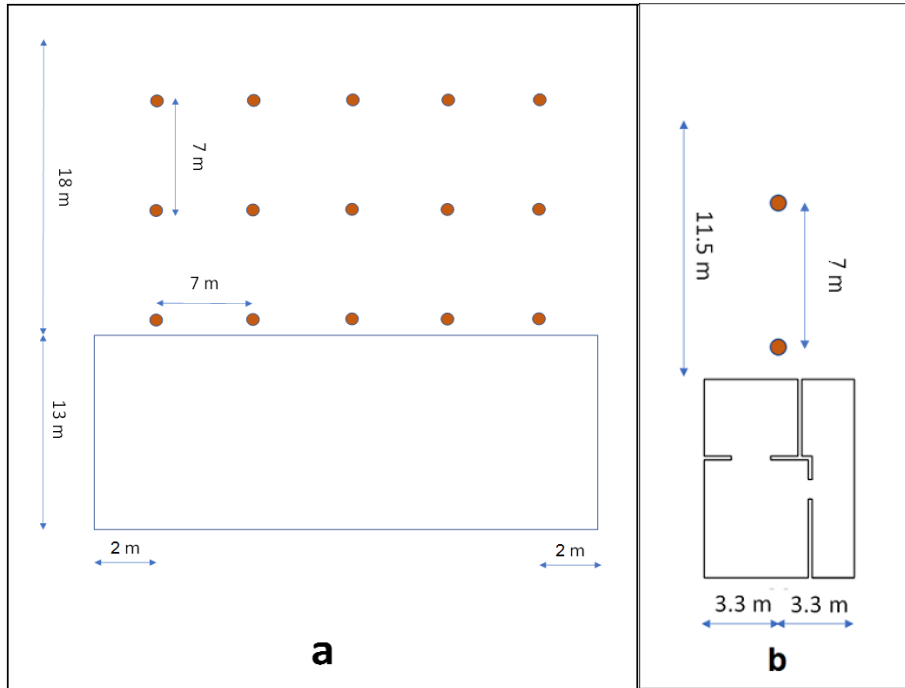


Figure 17 Example of possible layouts of the GHEs field using the courtyard, considering respectively the apartment block (a) and the terraced house (b).

8 Results and discussion

The final results of the ASHRAE method, implemented in the Excel spreadsheet, correspond to the required borehole lengths for heating (LH) and cooling (LC), which are compared to the maximum length allowed (1800 m for the apartment block, 240 m for the terraced house). In the following diagrams the comparison between the results is performed considering the different heating systems in the existing and historical buildings. Then the diagrams of current and post-retrofit envelopes have been placed side by side to cross-check the results. This analysis has been carried out for the same type of ground and climate zone.

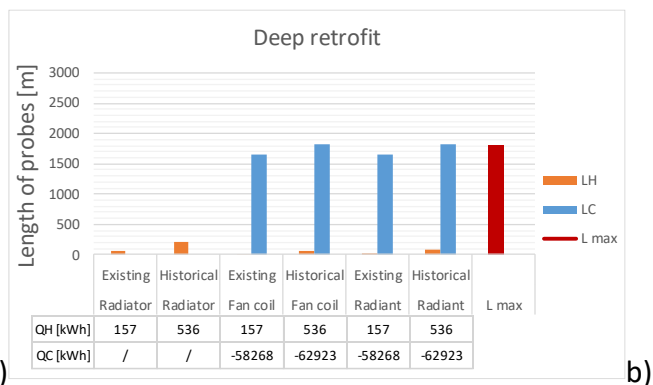
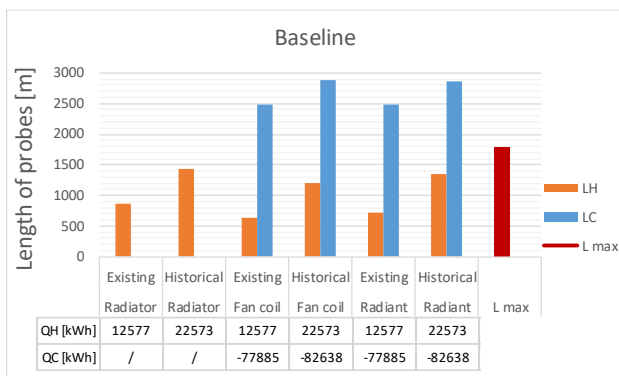
In the results the baseline represents buildings without insulation whereas deep retrofit refers to insulated buildings.

8.1 Ground thermal conductivity 1.5 W/(m K)

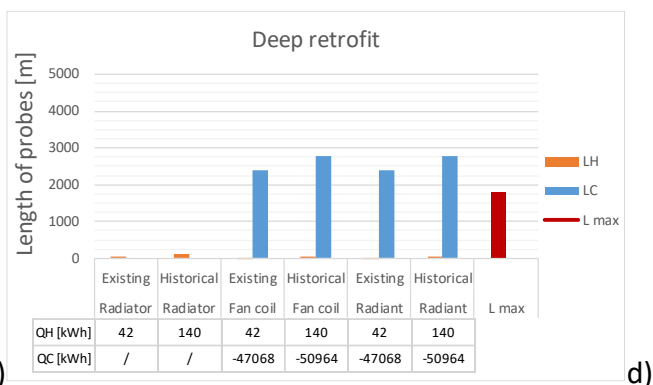
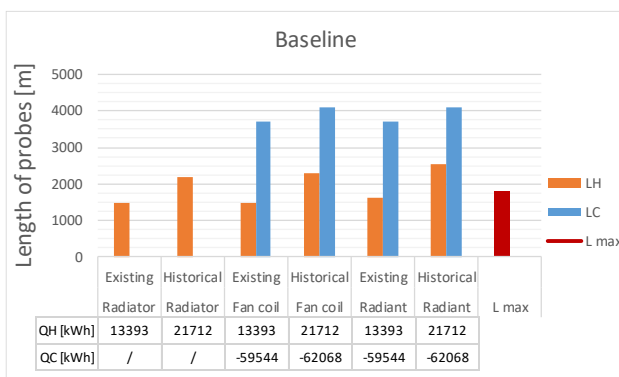
The first value of ground thermal conductivity which has been considered is the lowest, equal to 1.5 W/(m K).

8.1.1 Athens

Apartment block, residential



Apartment block, office building



Terraced house

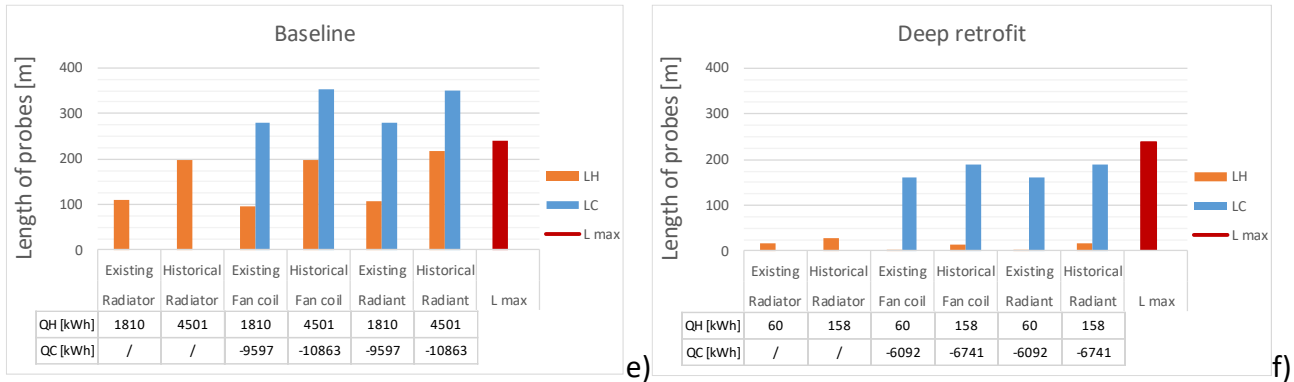


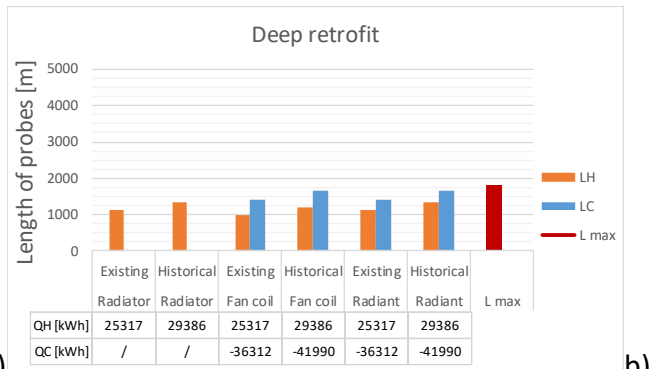
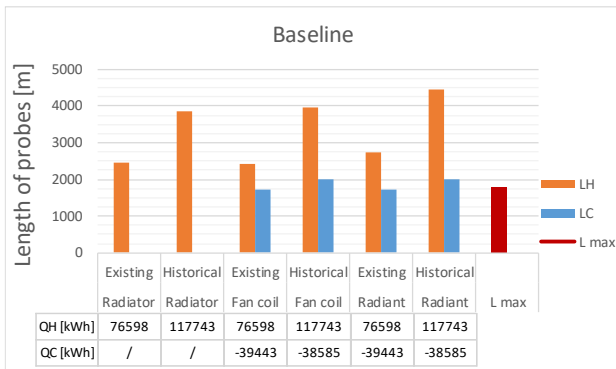
Figure 18 Comparison between the maximum length available and the required borehole length to satisfy the energy demand for the three building typologies both in the baseline and deep retrofit conditions for Athens

In this climatic location, considering both the baseline case (without the insulation of the building’s envelope) and the deep retrofit one (Figure 18 a, c, e.), the thermal load required by the building is unbalanced. The energy exchanged with the ground in summer and so the required borehole length for cooling (LC) is much greater than that one required for heating (LH). Despite the unbalanced thermal load, the ground source heat pump can be used avoiding problems concerning the ground thermal drift, because the penalty temperature, calculated with the ASHRAE method, is lower than 1 °C in all cases. As shown in the previous diagrams, if the retrofit of the envelope is performed (Figure 18 b d f) the required borehole length for heating is greatly reduced, while that one for cooling is slightly decreased, indicating an increase of the unbalance between heating and cooling thermal load. In this case the recommended bore length is LC (the larger of the two lengths found from Equations (2) and (3)), if it is shorter than Lmax (otherwise Lmax has to be the design length), even if an oversized ground coil results during heating mode. On the other hand, if the retrofit of the envelope isn’t carried out the suggested solution is to install the smaller heating length LH (or Lmax if LH > Lmax) along with an air to water heat pump to compensate for the undersized coil. However, the air to water heat pump is necessary when the selected required borehole length (LH or LC) is longer than Lmax.

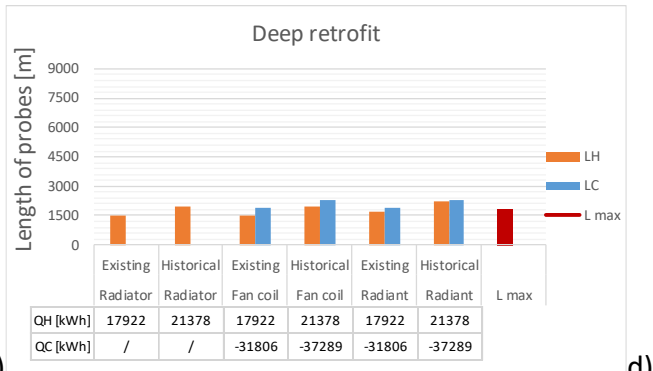
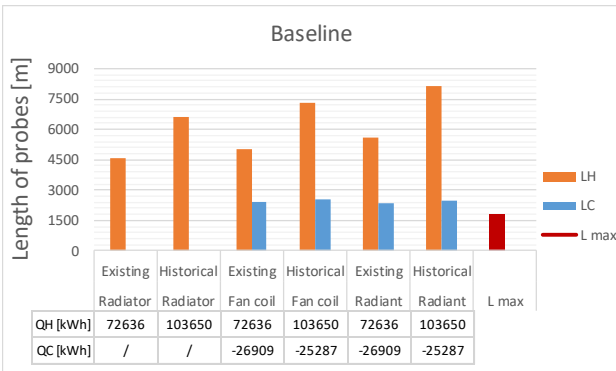
8.1.2 Strasbourg

In Strasbourg if the baseline cases are assumed (Figure 19 a c e) the thermal load is unbalanced with a higher energy demand in heating mode, while considering the deep retrofit cases (Figure 19 b d f) the heating and cooling energy requirement are balanced thanks to a reduction of the thermal load during the heating season. Therefore, this last solution is the recommended one, assuming as required bore the larger of the two lengths LC and LH, which is LC in all the deep retrofit cases. As in the previous analysis (in Athens climate) if LC is longer than Lmax, Lmax is the design length.

Apartment block, residential



Apartment block, office building



Terraced house

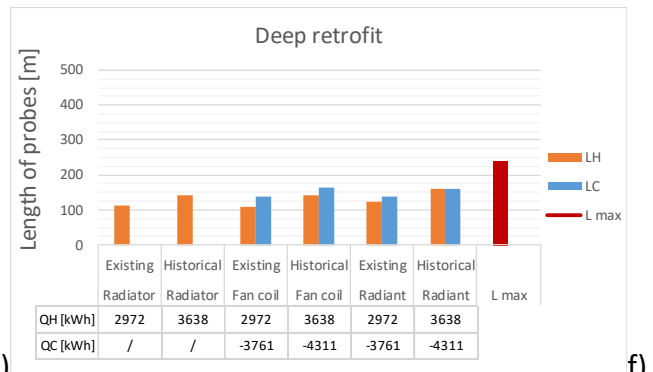
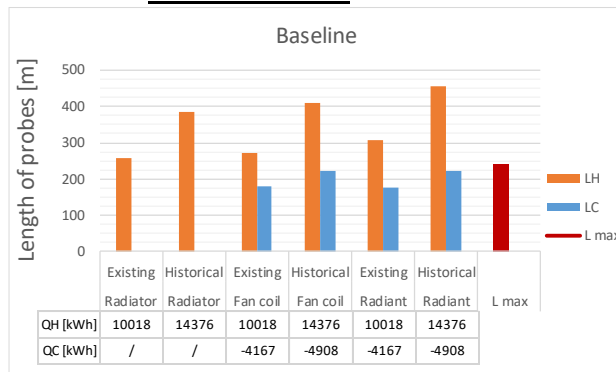
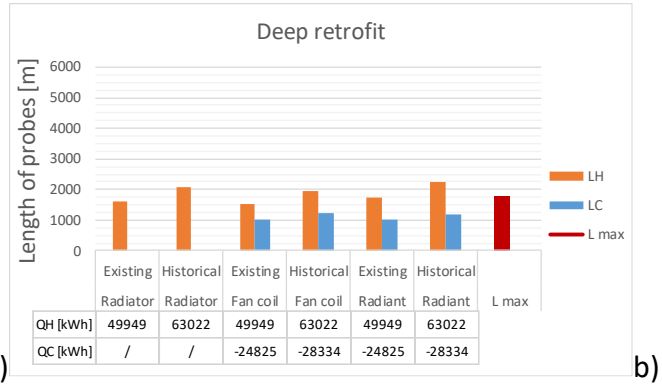
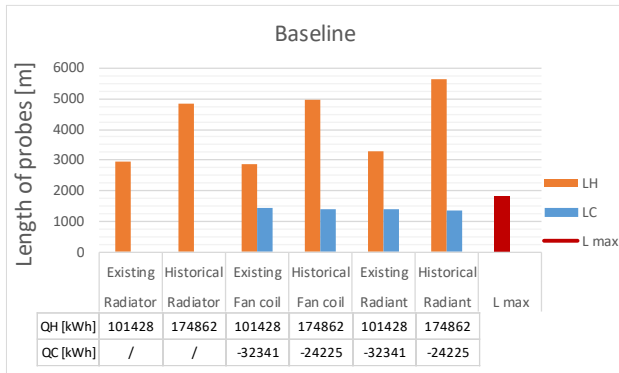


Figure 19 Comparison between the maximum length available and the required borehole length to satisfy the energy demand for the three building typologies both in the baseline and deep retrofit conditions for Strasbourg

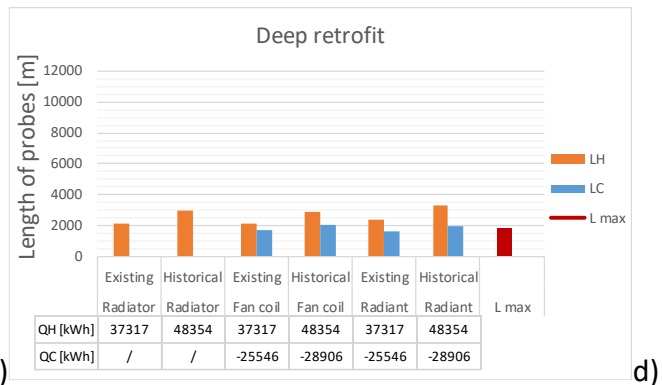
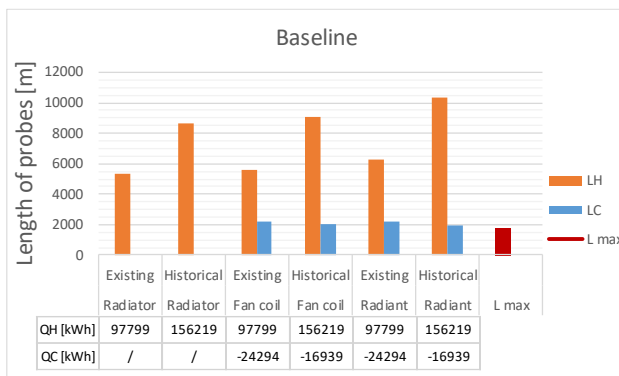
8.1.3 Helsinki

Considering Helsinki as location, the unbalance situation of the thermal load, observed for the baseline cases (Figure 20 a c e), is slightly more pronounced than that one noted for Strasbourg. The insulation of the building's envelope and the choice of the larger bore length (LH in this case) are the suggested solution, always paying attention to Lmax.

Apartment block, residential



Apartment block, office building



Terraced house

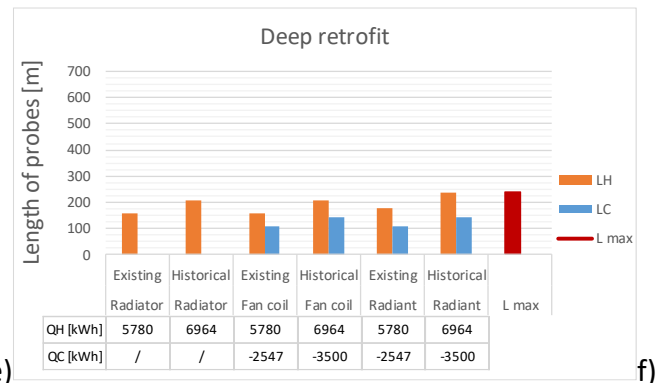
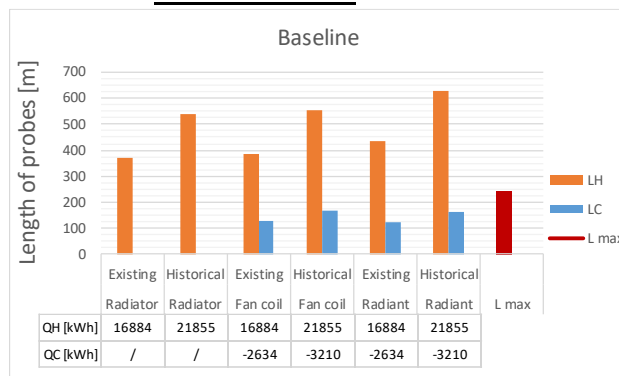


Figure 20 Comparison between the maximum length available and the required borehole length to satisfy the energy demand for the three building typologies both in the baseline and deep retrofit conditions for Helsinki

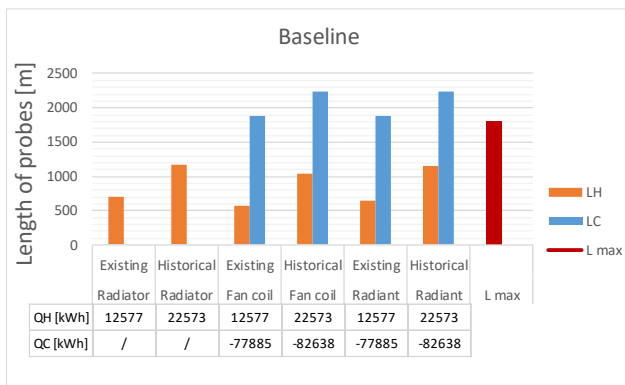
8.2 Ground thermal conductivity 2.2 W/(m K)

Assuming a type of ground more performing (thermal conductivity equal to 2.2 W/(m K)) the required borehole lengths are reduced in all cases, so it is more likely that LH and LC are shorter than the maximum length allowed (Lmax).

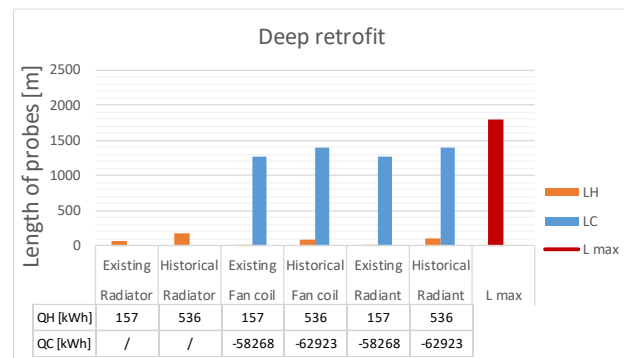
The results of the different locations are provided as follows and the considerations presented for the ground thermal conductivity equal to 1.5 W/(m K) are relevant also when the value is 2.2 or 3 W/(m K).

8.2.1 Athens

Apartment block, residential

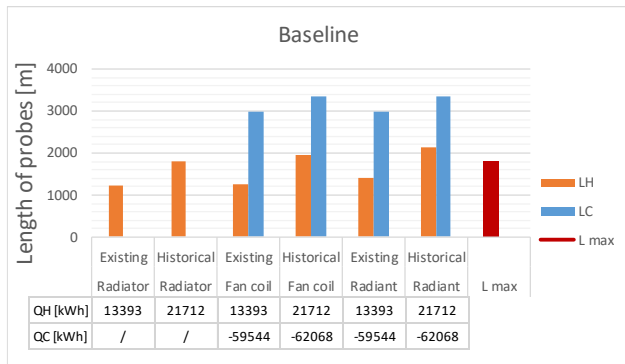


a)

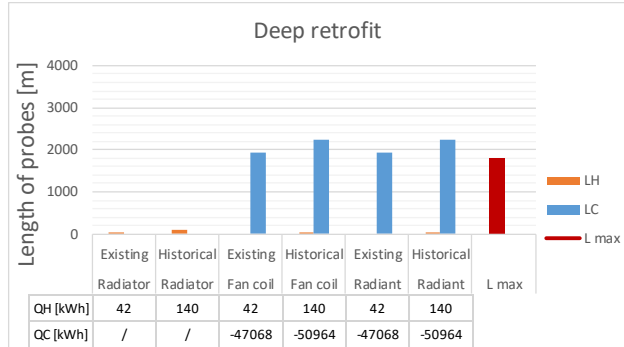


b)

Apartment block, office building

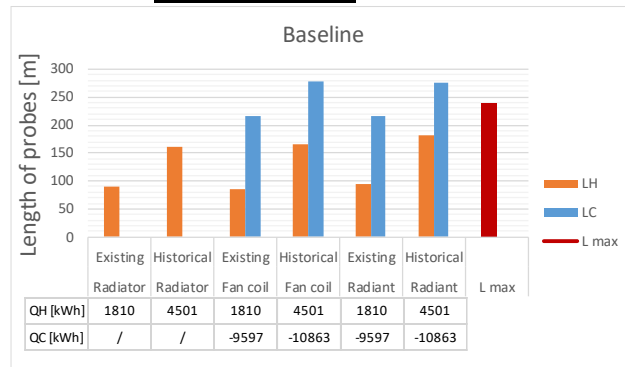


c)

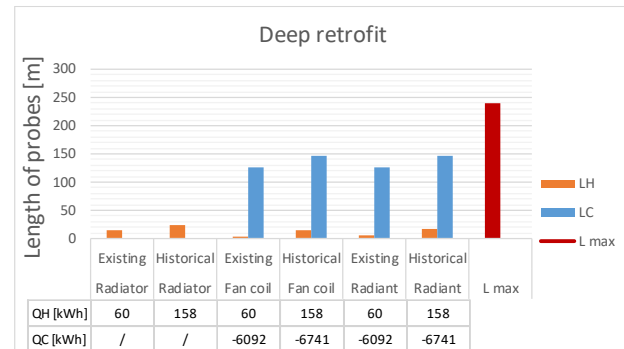


d)

Terraced house



e)

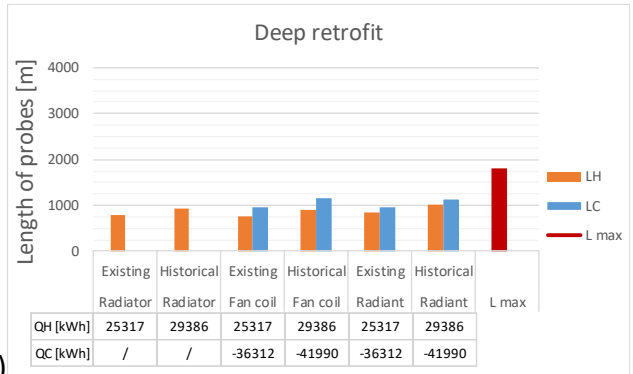
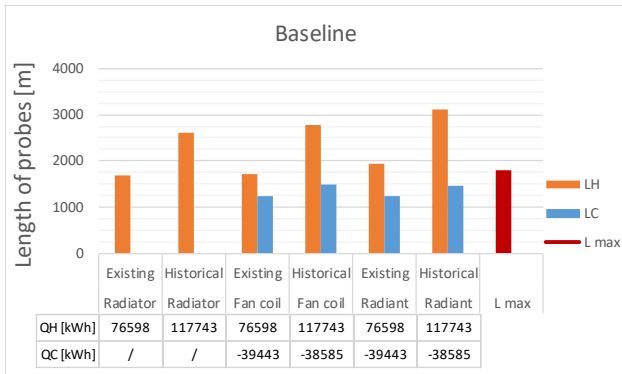


f)

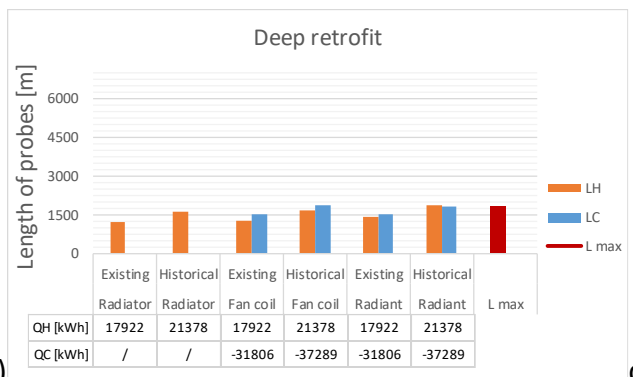
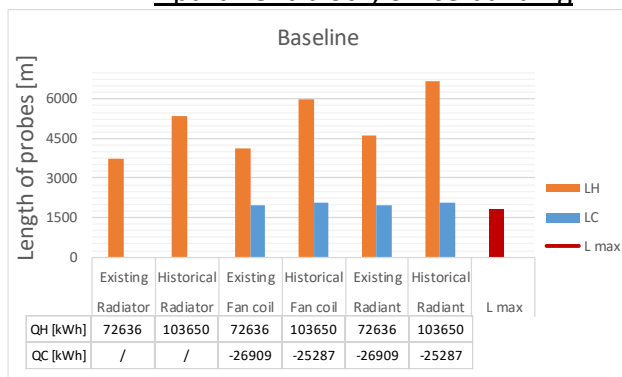
Figure 21 Comparison between the maximum length available and the required borehole length to satisfy the energy demand for the three building typologies both in the baseline and deep retrofit conditions for Athens

8.2.2 Strasbourg

Apartment block, residential



Apartment block, office building



Terraced house

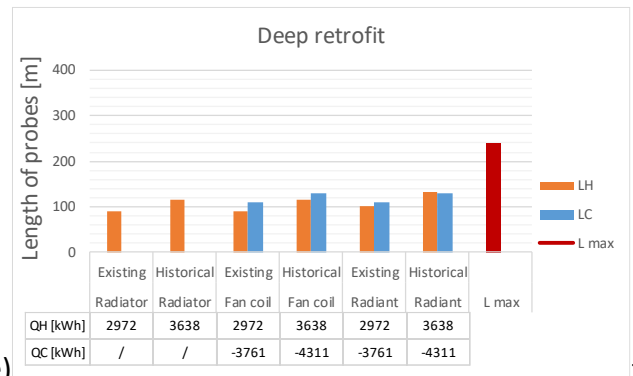
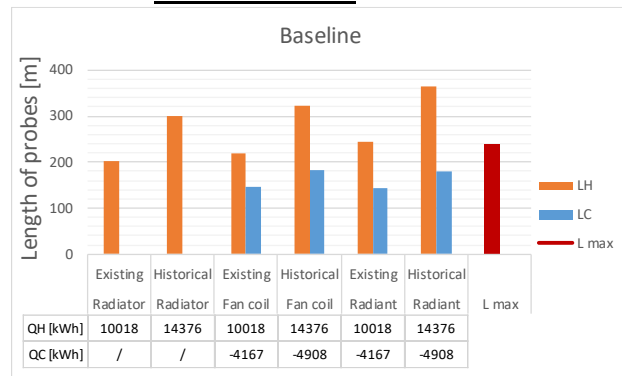
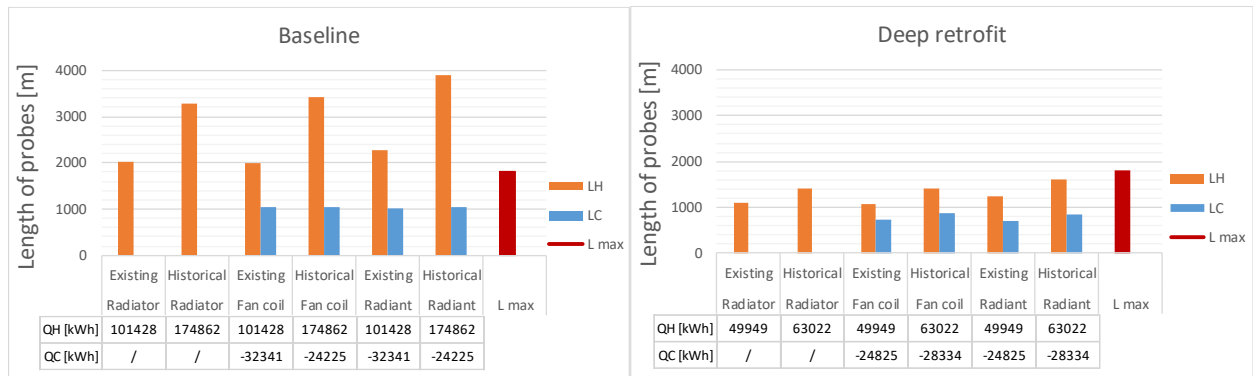


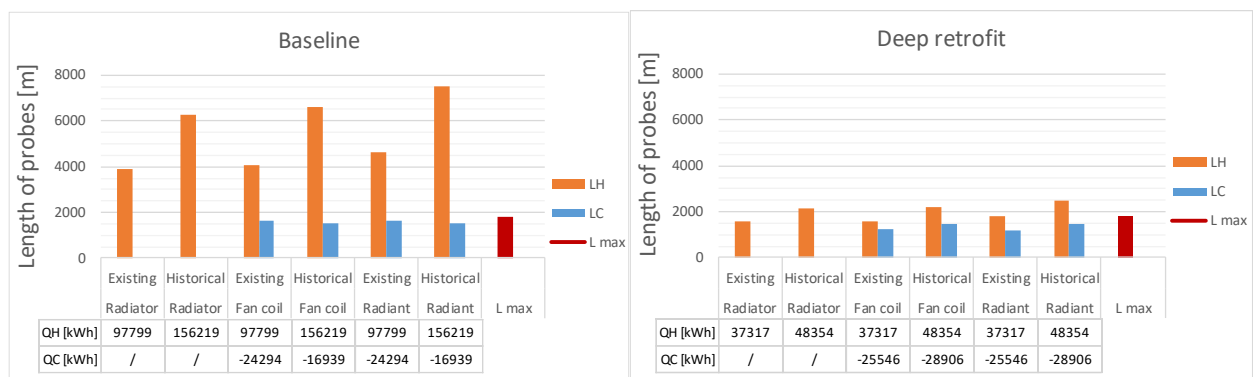
Figure 22 Comparison between the maximum length available and the required borehole length to satisfy the energy demand for the three building typologies both in the baseline and deep retrofit conditions for Strasbourg

8.2.3 Helsinki

Apartment block, residential



Apartment block, office building



Terraced house

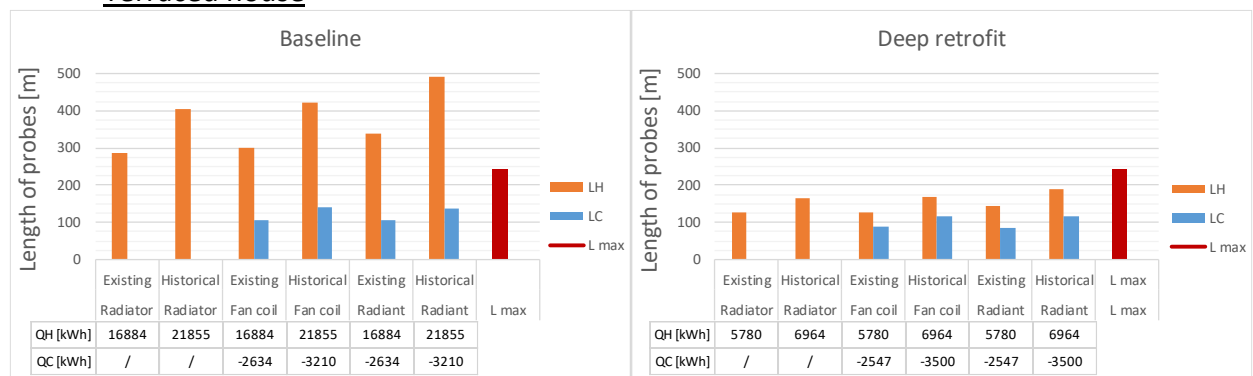
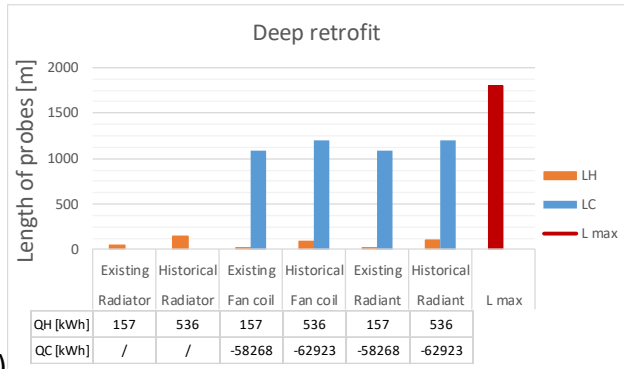
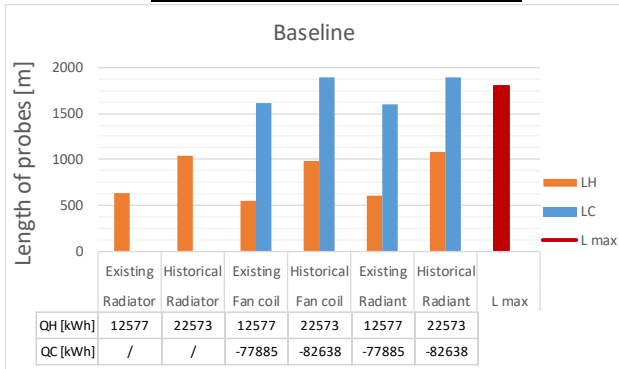


Figure 23 Comparison between the maximum length available and the required borehole length to satisfy the energy demand for the three building typologies both in the baseline and deep retrofit conditions for Helsinki

8.3 Ground thermal conductivity 3 W/(m K)

8.3.1 Athens

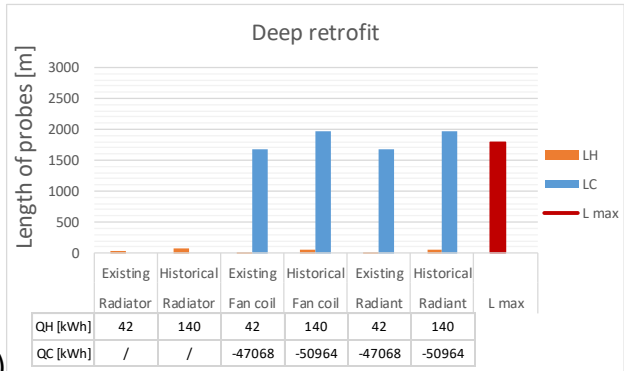
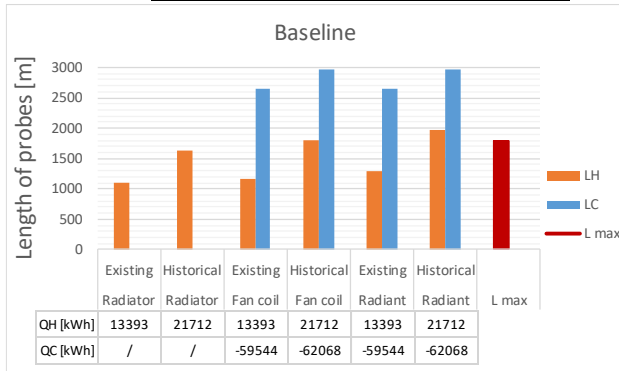
Apartment block, residential



a)

b)

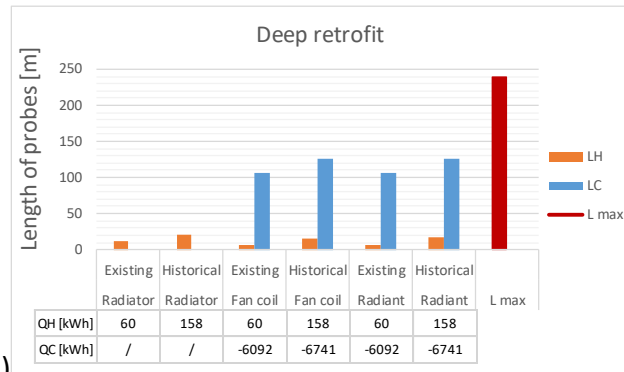
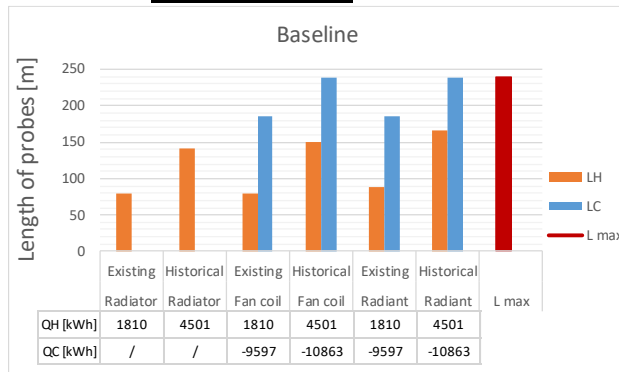
Apartment block, office building



c)

d)

Terraced house



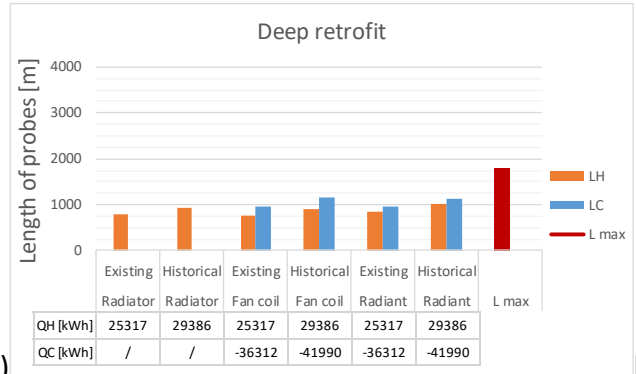
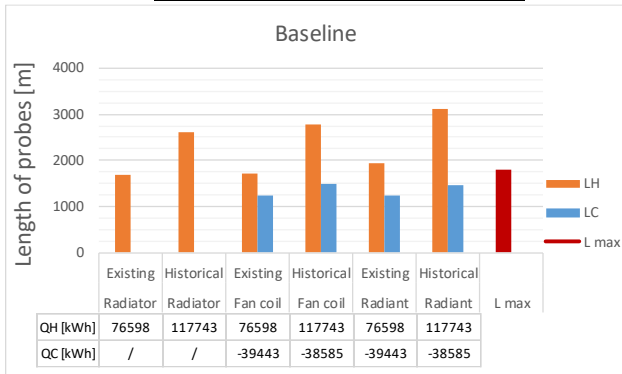
e)

f)

Figure 24 Comparison between the maximum length available and the required borehole length to satisfy the energy demand for the three building typologies both in the baseline and deep retrofit conditions for Athens

8.3.2 Strasbourg

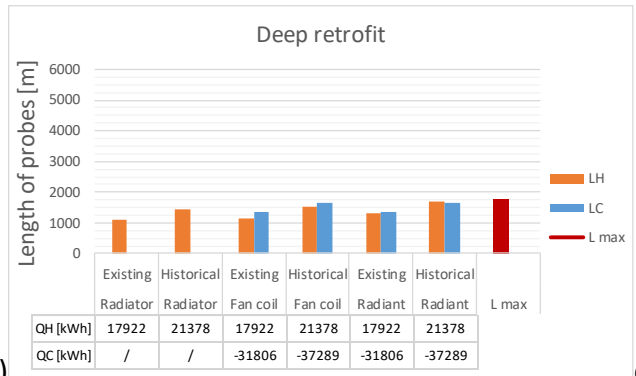
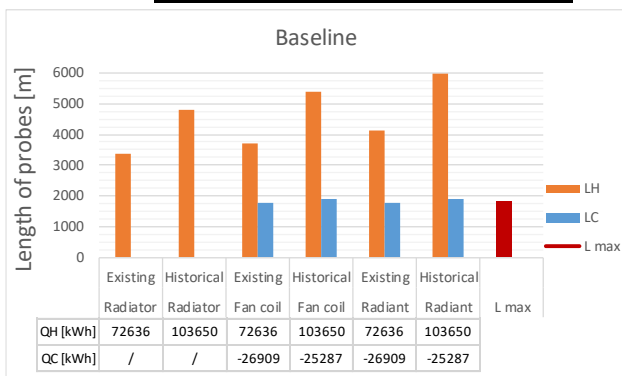
Apartment block, residential



a)

b)

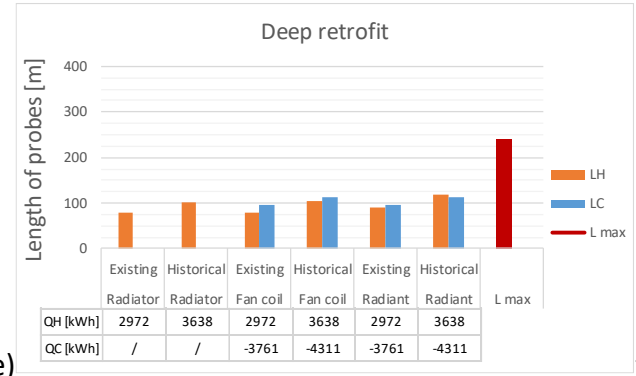
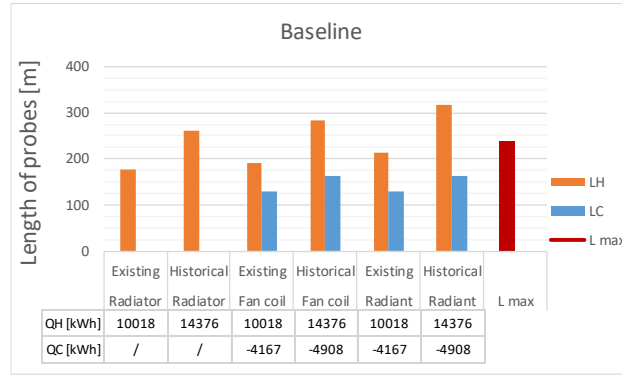
Apartment block, office building



c)

d)

Terraced house



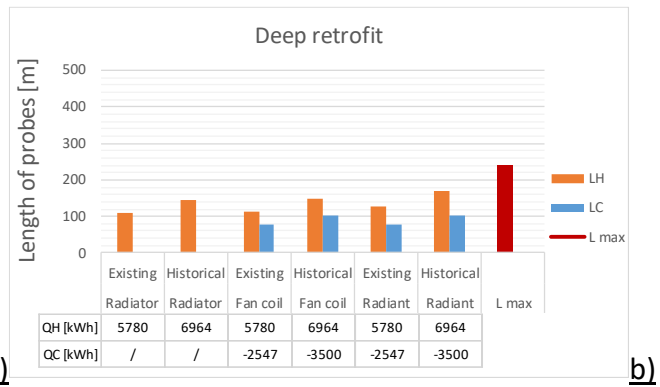
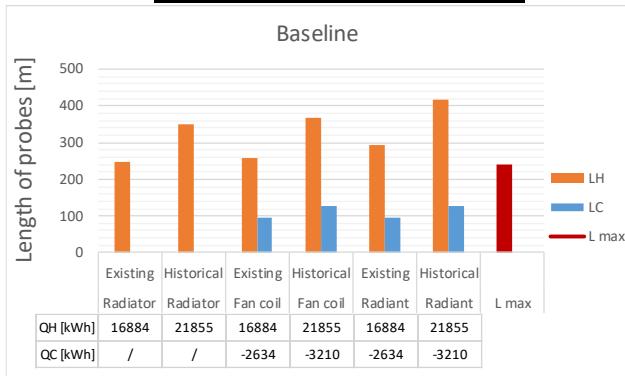
e)

f)

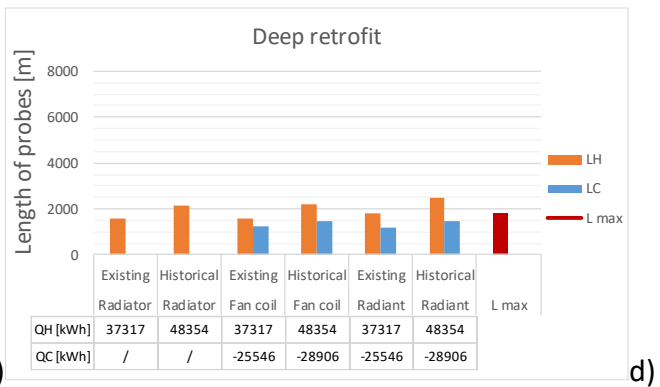
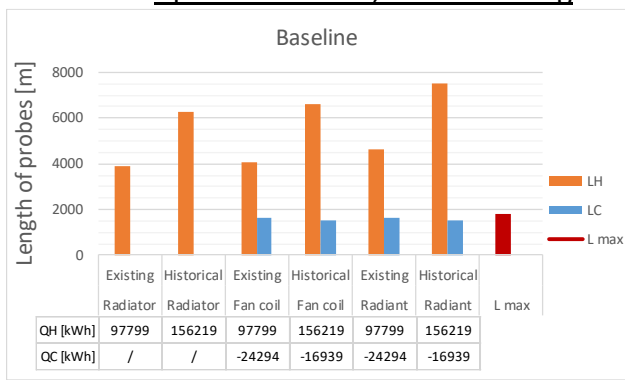
Figure 25 Comparison between the maximum length available and the required borehole length to satisfy the energy demand for the three building typologies both in the baseline and deep retrofit conditions for Strasbourg

8.3.3 Helsinki

Apartment block, residential



Apartment block, office building



Terraced house

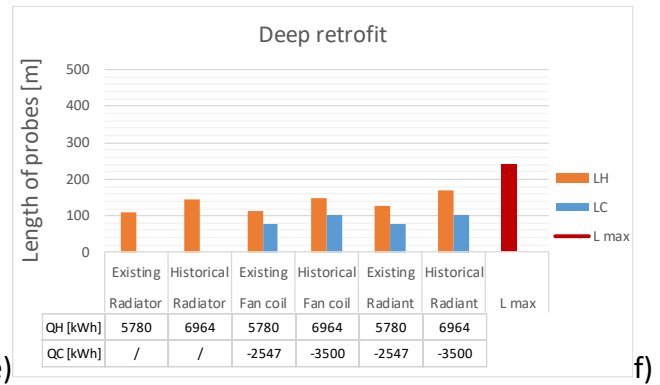
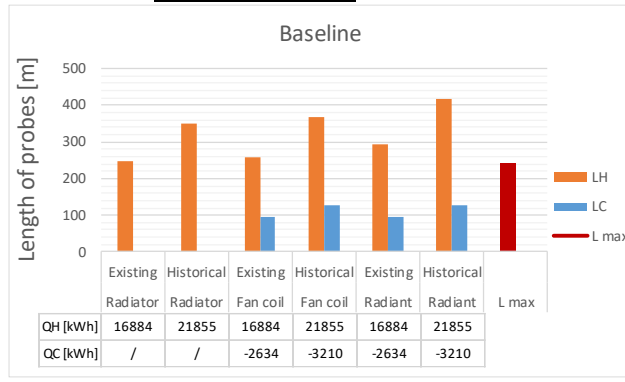


Figure 26 Comparison between the maximum length available and the required borehole length to satisfy the energy demand for the three building typologies both in the baseline and deep retrofit conditions for Helsinki

8.4 Optimal probes' length

Summing up the results presented in the last paragraph, Figure 27 shows the possible scenarios, comparing the maximum length available (L_{max}) with the probes' length needed to satisfy the building energy demand for cooling (L_c) and heating (L_h). There are three options: in option A there is space for the probes, in option B there is space for satisfying the energy need of heating or cooling ($L_{max} < L_h$ or $L_{max} < L_c$) and in option C there is no space for satisfying neither the heating demand nor the cooling demand of the building ($L_h > L_{max}$ and $L_c > L_{max}$).

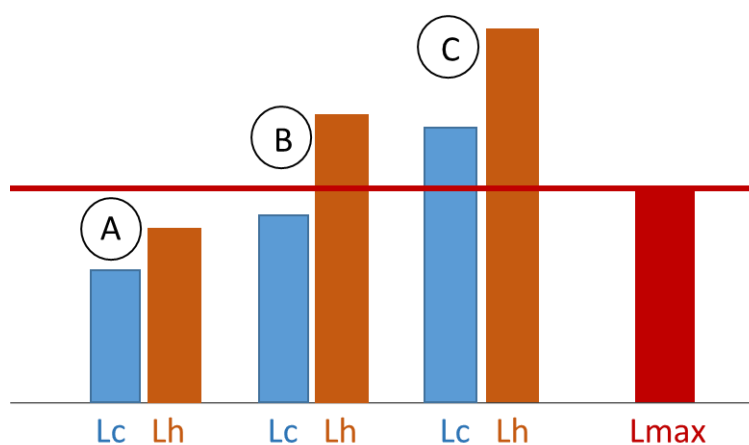


Figure 27 Possible scenarios of the case studies

When there is enough space for the probes ($L_{max} > L_c$ and L_h) there might be three possible cases (see table 13):

- Case 1 (option A): the length of the probes is almost the same for heating and cooling, the maximum of the two can be chosen (full demand of the building with a water to water reversible heat pump). A deviation of 10% has been adopted.
- Cases 2 and 3 (option A): if one of the two borehole lengths is greater than 10% then the other (cases 2 and 3) the choice can be done considering either the longest length of the probes (sub-cases 2a and 3a with full GSHP) or the shortest length of the probes (sub-cases 2b and 3b) with a hybrid system with two sources water and air (GSHP+AWHP).
- Cases 4 and 5 (option B): if one of the borehole lengths is shorter than the maximum installable probes length and the other is longer a hybrid system is the unique solution and the installed length of the boreholes is the shortest one (GSHP+ASHP)
- Case 6 (Option C): if both lengths are greater than the maximum installable length the length of the probe is the maximum allowable installation length with a hybrid solution (GSHP+ASHP).

The choice to fix the same length in heating and cooling means that the heat exchanged in the ground is balanced between heating period (heat extracted from the ground) and cooling period (heat released into the ground), thus avoiding ground temperature drifting. Working in the air for the rest of the period permits to optimize the energy sources available..

Among the different cases, when deep retrofit is carried out, probes' length is significantly reduced in wintertime (L_h), whereas the length necessary for cooling (L_c) remains almost constant. For this reason, case B is more frequent when considering warm climates, because heating energy demand can be neglected but the cooling energy demand is significantly high.

Table 13 Optimal length of the probes

A) LH, LC < Lmax	
1. LH ≈ LC (10% deviation accepted)	L = max (LH, LC)
2. LH > LC	2a) L = LH 2b) L = LC + AWHP
3. LC > LH	3a) L = LC 3b) L = LH + AWHP
B) LH or LC > Lmax	
4. LH > Lmax	L = LC + AWHP
5. LC > Lmax	L = LH + AWHP
C) LH, LC > Lmax	
6. L = Lmax + AWHP	

The cases shown in Table 13 have been used to calculate final and primary energy for the different possible solutions. From the case with only substitution of the generator, shallow retrofit and deep retrofit, looking at possible combinations (if possible) of just GSHP or hybrid solutions (GSHP+ASHP).

Further analysis on the energy savings will be done in Task 1.4, considering the optimal strategy both from the technical and from the cost analysis point of view, fixing a baseline case, i.e. original building with regular boiler and air conditioning system.

9 Conclusions

The work done in the Task 1.3 within the GEO4CIVHIC project aims at showing the potential of energy reduction of the European building stock in urban areas due to the retrofit by means of shallow geothermal systems. For this purpose, it is necessary to define archetypes which may represent the most frequent cases inside urban areas. These archetypes have been examined in terms of geometry, thermal properties of the envelope, end use, type of HVAC installed. Based on the different possible strategies and options, both shallow and deep retrofit have been examined. The decrease of the energy needs refer mostly to the annual energy balance, since high insulation levels reduce heat losses and maximizes the contribution of the internal gains. On the contrary, highly insulated buildings have higher cooling energy demand, due to a decrease of the heat transfer of the envelope.

The methodology used to define the archetypes has been shown, identifying two types of linear buildings as representative of the urban context. The first one is a multi-user building, named apartment block. It consists of 5 storeys with 4 units per floor and it has been examined both as residential and office building. The second typology is a single-user building, named terraced house, which has been considered only for residential end use.

A further subdivision has been made considering the construction period, defining as “historic” buildings built before 1960 and “existing” buildings built after 1960. For these two types of buildings both current and post-retrofit envelopes have been considered. As for the definition of geometrical parameters and thermal properties of the envelope the database TABULA-EPISCOPE has been used. For the retrofitted solution a survey on the most typical required values for the envelope under refurbishment in the different countries has been considered.

As for the climates, three climatic locations have been considered: Athens (warm climate), Strasbourg (average climate) and Helsinki (cold climate).

Figure 28 shows the overall 36 dynamic simulations carried out to determine the heating and cooling energy demand as well as the peak power for heating and cooling. For cooling energy demand both sensible and latent loads have been calculated.



Figure 28 Overall dynamic simulations

The database of monthly energy demand obtained from the simulations has been used to size geothermal heat exchangers using the ASHRAE method. Different ground properties have been used to consider multiple solutions, such as ground thermal conductivity of 1.5 W/(m K), 2.2 W/(m K) and 3 W/(m K).

The probes' length obtained have been compared with the maximum length available for the installation, obtaining different cases. In general, when the probes' length needed to satisfy the heating or cooling energy demand is bigger than the maximum length that can be used, hybrid solutions will be adopted installing an air-to-water heat pump to supply the remaining energy demand. Extreme results have been obtained for warm climates, where the heating energy demand becomes negligible and free cooling systems rather than traditional cooling systems are needed even in wintertime. In this case the penalty temperature was acceptable even if the energy demand was unbalanced.

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Abbreviations

AWHP	Air to Water Heat Pump
GEO4CIVHIC	Most Easy, Efficient and Low Cost Geothermal Systems for Retrofitting Civil and Historical Buildings
BHE	Borehole Heat Exchanger
BTES	Borehole Thermal Energy Storage
DHW	Domestic Hot Water
GHE	Ground Heat Exchanger (general term, includes BHE)
GSHP	Ground Source Heat Pump
IP	Intellectual Property
NZEB	Near-Zero-Emission Building
PBT	Pay-back Time
RES	Renewable Energy Sources
SFH	Single Family House
SGE	Shallow Geothermal Energy
ZEB	Zero-Emission Building