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Deliverable D6.7
Transferrable guideline for the integration of GSHP systems to historical buildings
WP6

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Publishable summary

Deliverable D6.7 is a public document describing transferrable guidelines developed as part of the GEO4CIVHIC project for the integration of GSHP systems in historical buildings. The deliverable reviews the lessons learnt as part of the project implementation specifically relating to those aspects deemed critical to the successful integration of ground source heat pump for heating and cooling applications based on the work carried out in the virtual and real case study sites of the project.

The recommendations developed are based on the consideration of six key project development aspects applicable to historical buildings. These include the requirements for design and retrofit strategies adopted in the context of sensitive historical buildings as the initial starting point for the successful implementation of the technology. The design and retrofit measures deal with the conservation aspects of the building themselves and the importance of implementing a building fabric approach in the selection of a suitable GSHP technology. The practical aspects of geothermal collector selection and implementation as well as the selection of the most adequate heat pump technologies are discussed in the context of the dense urban setting locations of historical buildings.

Both the design and implementation aspects are also considered with respect to permitting and regulatory environments that are applicable to both geothermal systems and historical buildings. The guidelines developed are considered a transferrable guide for the application of GSHPs in historical buildings irrespective of jurisdiction and aimed at both technical and non-technical stakeholders to demonstrate the workflows to be considered in the design and implementation processes that where the integration of GSHPs at these sensitive and individually specific sites buildings is planned.

Abbreviations

ASHP	Air Source Heat Pump
BHE	**B**orehole **H**eat **E**xchanger
Cheap-GSHPs	Cheap and Efficient Application of reliable Ground Source Heat Exchangers and Pumps
COP	Coefficient of Performance
DHW	Domestic Hot Water
EPB	Energy Performance of Buildings
EPBD	Energy Performance of Buildings Directive
ETHICAL	Easy THermal InterferenCe evaluation tool
GEO4CIVHIC	Most Easy, Efficient and Low Cost Geothermal Systems for Retrofitting Civil and Historical Buildings
GHE	Ground Heat Exchanger
GPR	Ground Penetrating Radar
GSHP	Ground Source Heat Pump
GWP	Global Warming Potential
HB	Historical Buildings
HE	Heat Exchanger
HP	Heat Pump
HTHP	High Temperature heat Pump
SCR	Selective Catalytic Reduction
SPF	Seasonal Performance Factor
TI	Terra Infrastructures GmbH

1 Introduction

The integration of GSHP systems for heating and cooling in historical buildings has been the main focus of the GEO4CIVHIC project. The development of GSHP technologies for these applications has been a continuation of previously funded projects, notably Cheap-GSHPs (https://cheap-gshp.eu/) and Effesus (https://cordis.europa.eu/project/id/314678), which were tasked with reviewing the potential for the introduction of renewable heating and cooling technologies to these sensitive buildings.

GEO4CIVHIC has focussed on further addressing the needs of historical buildings (HBs), which by their nature are sensitive to upgrade or refurbishment works in particular when these are considered in the context of increasing energy efficiency and the decarbonisation of heating and cooling demands. The often listed and protected structures that these buildings comprise in the cultural and historical heritage, are such that minimal intervention measures are possible with respect to building fabric upgrades as these can have an adverse effect of the architectural aspects and visual impact of these buildings.

The majority of cultural heritage buildings in Europe are found in dense, historical urban settings, which make such interventions even more logistically challenging. The objective of the GEO4CIVHIC project has therefore been to address such challenges and the associated barriers to the implementation of renewable heating solutions, by providing low impact strategies focussed on preserving the historical nature of these buildings.

The project has focussed on progressing the technology developments of Cheap-GSHPs to deliver new ground heat exchangers and drilling methodologies adapted specifically for the deployment of ground source heat pump solutions in the challenging urban environments where historical buildings are located.

The outcome of the development of such innovations and their implementation in four case study sites in Europe, has allowed for a set of transferrable recommendations to be based on the lessons learnt, with respect to successfully integrating GSHPs in historical buildings. The following work packages have provided direct input to these guidelines on the following aspects:

- WP1:
    - barriers to the integration of GSHPs in historical buildings
    - level of renovation and opportunities in historical buildings in different climates and geologies
- WP2:
    - Innovative rigs and drilling methodologies to improve installations in confined urban environments
    - High efficiency heat exchangers and configurations to reduce geothermal collector installation requirements
- WP3:
    - New generation of hybrid and high temperature heat pumps to address HB energy demands
    - Integration of emitters and terminals to increase HB comfort levels with reduced visual impact
- WP4:
    - development of solutions to overcome barriers to integrating renewables in HB
    - decision support systems for assessing the viability of RE integration
- WP5:
    - Lessons learnt from practical installation of the project innovations in HBs
    - Evaluation of efficiency and viability of installations for historical buildings

- WP6:
  - Policy & Environmental Impact recommendations for the integration of GSHPs
  - Recommendations on applicable standards for the new technologies
- WP7:
  - Business plans for the implementation of GSHPs in HB retrofit scenarios
- WP8:
  - Training, education and dissemination measures on GSHPs for technical and non-technical stakeholders

This deliverable presents recommendations and guidance for the integration of GSHPs in historical buildings as a basis for providing technical solutions for the decarbonisation of heating and cooling. The recommendations have been developed for policy makers and responsible authorities as a set of transferrable concepts and strategies for integration to existing HBs irrespective of their location in Europe.

2 Methodology

The implementation of renewable technologies and in particular the integration of a GSHP to a historical building needs to be governed by a holistic system design approach. The holistic design process needs to seek to identify the best possible intervention measures that will lead to the decarbonisation of a heating and cooling system in a historical building.

The scale of such interventions and the measures applied to both retrofit and install a GSHP, are governed by the need of the system designer to take into consideration the following key technical aspects for implementation:

- Building character and historical listing grade;
- Location of the site (dense urban areas or other) including surface area distribution and space;
- Building fabric and construction elements;
- Energy demand profile for heating/cooling and requirement for secondary temperatures to be delivered;
- Subsurface characterisation to determine the possible geothermal solution;
- Geothermal collector design specification;
- Plant room system design (P&ID) and specification of terminal to be installed in the building;
- Management system and control strategy for operation.

Overall, the system design process outlined above would be typical of that implemented for any building where retrofit measures and a GSHP system is planned. However, due to the sensitive nature of historical heritage buildings, an approach that also focuses on key non-technical aspects also needs to be considered as this often can dictate the level of intervention possible. Some of these non-technical aspects include (but are not limited to):

- **Building preservation regulations for a specific site**: guidelines and standards around the potential for completion of retrofit measures in historical buildings are dictated by the historic character of the building. A national and UNESCO international register of structures typically defines the main architectural and cultural heritage features of such buildings. In the case were retrofit measures to the external part (or in some cases internal aspects if required) may require the advice of a conservation architect and permission from the local (or international) responsible for building conservation.

- **Archaeological and Historical artefacts:** cultural heritage sites are often located in areas of archaeological heritage. These areas often contain buried artefacts in open spaces and below buildings. The siting of geothermal collectors is often focussed on using open spaces where such artefacts may be present. Therefore, consultation with specialist archaeological consultants and appropriate permission may be required prior to completing a design.

- **Biodiversity and ecology:** the historical nature of many buildings is often accompanied by the presence of biodiversity elements that may include mature trees and other associated ecosystems. The consideration of these aspects with respect to the location of a geothermal collector solution and the necessary measures for safeguarding these need to be considered.

- **GSHP system regulatory permissions:** many European (and international) jurisdictions have varying degrees of regulation and permitting around the installation of shallow geothermal systems. These are focus on the sustainable deployment of geothermal solutions and the management of subsurface resources. This aspect is of particular importance in dense urban areas where geothermal systems can be in close proximity to other operating GSHPs. Consultation and advice by specialist consultants and local authorities as to any possible design limitations should be identified in the early parts of the project process.

- **Visual impact:** the application of renewable heating and cooling solutions in historical building settings should always seek to minimise long term visual impact to the existing building character and its surrounding. Whilst the installation of GSHPs have clear advantages given the below ground nature of the solution and the possibility of implementing landscaping measures to restore the original views, such measures require additional planning. This is evident with respect to the final completion of the geothermal collector aspects, however additional consideration needs to be given to the above ground elements (plant room location and site, location and type of terminals as well as integration of new pipework) where additional measures to conceal from view the internal technical elements of the system may be required.

- **Existing infrastructure and utilities**: congested urban centres that are often the location of historical buildings share space with many other subsurface users. These may be characterised by utilities (water, sewerage, gas, fibreoptic, telecoms) or by larger infrastructure such as underground rail, historical sewer, viaducts or underground river. The successful implementation of a GSHP with therefore require the designer to carefully document these in advance.

The methodology for the development of the transferrable recommendations developed as part of the project has sought to consider all of the above aspects and to integrate both the technical and non-technical considerations when implementing a GSHP solution in a historical building. Figure 1 below outlines the structure of the proposed guidelines and highlights the interaction required between both the technical and non-technical disciplines. The individual aspects of these guidelines are further discussed in subsequent sections of the deliverable.

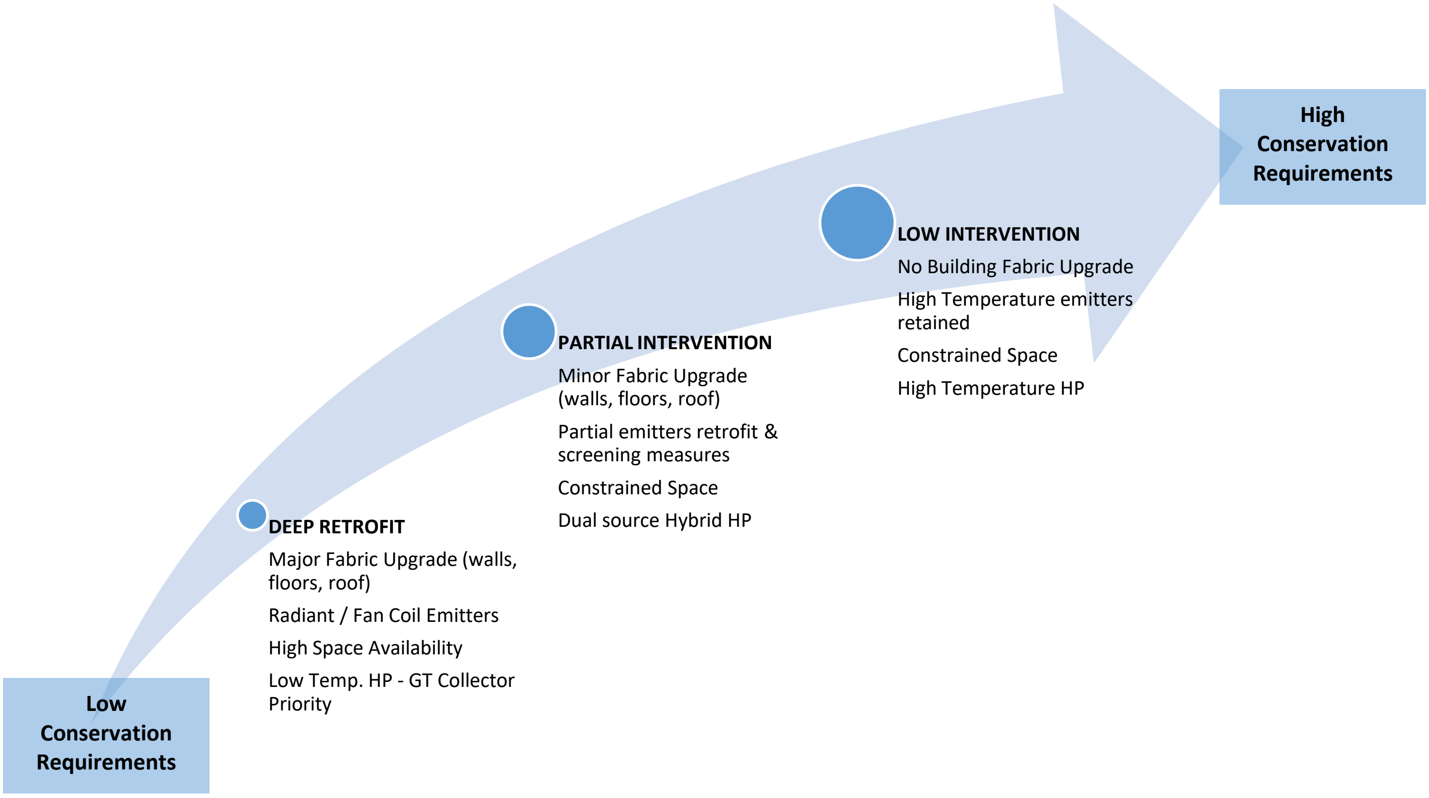


Figure 1 Considerations for retrofitting and integration of GSHPs in historical buildings

3 Design & Retrofit Strategies

The potential for integration of a GSHP to historical building is governed by the climatic condition of the building location and the fabric or composition of the main building elements. Both of these aspects ultimately define the energy demand profile and corresponding sizing of the geothermal solution that can be implemented. The potential for decarbonising the historical building stock can therefore be considered in the first instance based on the usual methodologies in the applied in the built environment. These prioritise the implementation of retrofit measures to reduce the energy demand profile and are then followed by the introduction of renewable technologies, smart and improved control systems and the integration (figure 2).

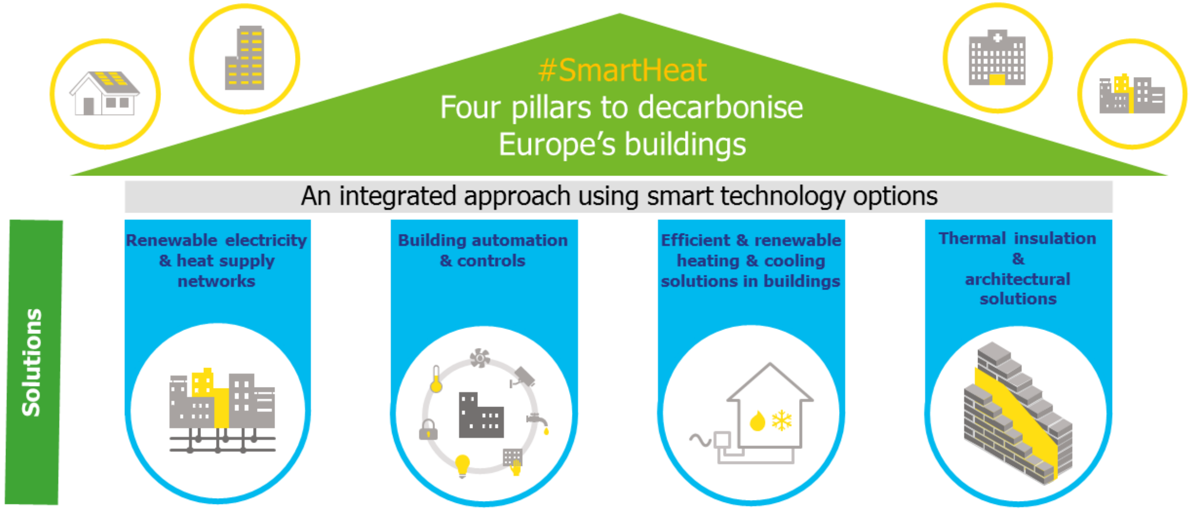


Figure 2 Solutions for decarbonising Europe's building stock (adapted from eubac.org)

The historic nature of cultural heritage buildings, due to their age, is such that these are not typically constructed using modern building methodologies and materials. The basic use of stone, wood and often historical glazing elements render the buildings more susceptible to the effects of climatic variations throughout the seasons. These are commonly overcome in modern buildings using higher performance building materials and insulation techniques that reduce this susceptibility. In many cases, the level of thermal insulation improvement to the building fabric in the historical building case is significantly reduced.

The selection of the most adequate solutions, therefore, needs to consider all building aspects and any (if at all possible) levels on retrofit that can be implemented to reduce their energy demand. The sizing and selection of renewable energy alternatives to delivering heating and cooling needs to be governed by a holistic system design approach.

This approach starts with the assessment and consideration of the building itself prior to selecting and sizing the renewable energy solution. The section below outlines the main recommendations in the case of historical building that should be implemented in refurbishment projects. Figure 3 demonstrates the general applicable workflow in the case of the design and technology selection process.

Figure 3 Generic workflow for system design and technology selection in historical buildings

3.1 Insulation and Building Fabric

The primary focus on improving building energy efficiency relates to the improvement of the main building fabric elements to reduce heat losses and gain in specific climatic conditions. The conservation aspects of historical buildings are governed by definition of the cultural and architectural elements in national and/or international cultural heritage inventories. The definition of possibilities for building intervention measures including improvement of insulation elements (walls, roofs and floors) to these buildings are set out in requirements by the cultural heritage authority in the preservation of the architectural aspects of the building and the surrounding spaces. These requirements often necessitate the implementation of low visual impact solutions both for the external and internal elements of the building. The external elements relating to the completion of a shallow geothermal collector are generally easy to achieve, once the space available for the installation is defined. The collector is installed below ground and landscaping measures to restore the area of installation to its previous status can be easily integrated. The elements that require additional planning may include the integration of the plant room and the introduction of heating and cooling terminals inside the building.

The composition of the structural (external and internal) elements of a historical building are critical in the definition of the energy demand profile and the design of a renewable heating and cooling solution. Historical buildings vary in age and usage from private residences to public building. For larger non-domestic buildings, it is more difficult to complete an initial energy demand based on standard building typologies such as those defined for the European buildings [1, 7]. A design approach therefore needs to consider the surface area but also (and more importantly) the volume of non-residential buildings to complete an accurate assessment given that non-standard ceiling heights are common in historical buildings [3].

The physical and thermal properties of the building envelope including the walls, roof(s), floors and windows will vary on the basis of the age and topology. In order to find a suitable solution, the energy demand profile therefore needs to consider the thermal properties of the opaque structures and determine the level of insulation that could be installed. An initial energy demand assessment can be developed based on the present-day level of insulation using categories commonly found in non-residential buildings in Europe based on the age of the structure. Three categories can be considered during the initial analysis: no insulation, low level of insulation and good level of insulation [2]. A detailed assessment through building specific U values testing and the completion of a hygrothermal risk assessment is therefore recommended to validate the design. The use of standard benchmarks [7] for energy demand profiles of European buildings are useful to undertake a high-level assessment, but is discouraged for the completion of the final design of a GSHP system for a specific historical building. This should be achieved on a case bycase basis with detailed values relevant to the building being considered.

Careful consideration also needs to be given to the glazing elements of the building and how these can impact the energy demand. In the case of historical buildings where only low level of retrofit may be possible, the glazing elements typically comprise single glazed windows with higher U-values than where the upgrades to double glazing or better can be considered and lower U-value windows can be integrated [2].

The sensible and latent load of the building need to be calculated as part of the assessment through the subdivision of the building into thermal zones. These define the internal sensible loads resulting from people, equipment and lighting based on the end use and hours of occupancy of the building in the zones identified [3]. This assessment needs to be performed in line with applicable standards [6] on the energy performance of buildings.

The effects on the heating and cooling energy demand of air infiltration and natural ventilation that vary considerably between non-retrofitted historical buildings and retrofitted also have to be considered as part of the demand model. The introduction of demand-controlled ventilation delivering improved building air quality and reducing energy requirements in accordance with applicable standards [8], is common with the introduction of HVAC measures and GSHPs. This too requires to be modelled as part of the energy demand assessment.

The completion of the energy demand assessment, therefore needs to consider the implementation of a dynamic simulation to determine the heating and cooling energy demand as well as the peak power for heating and cooling. The simulation needs to consider the climatic conditions specific to the location of the building and account for both sensible and latent loads where there is a cooling requirement [3].

Some of the possible necessary steps required for the assessment of the possible interventions to a historical building can be summarised as follows:

1 Engagement with conservation authorities;
    a. Historical and cartographic research of the site being considered where the building is located in the context of applicable local and international regulations around historical buildings;
    b. Architectural Record and Inventory of the main historical building elements. This focusses on the identification of the main aspects of the building and the preservation requirements of the individual structures leading to a *Statement of Significance* that outlines the main elements of the building to be preserved;
    c. Initial consultation with the authority responsible for cultural heritage (this will vary at different project locations) to outline an initial proposal of the main retrofit measures (if any are possible) and proposed GSHP system elements (geothermal collector, plant room & emitters)

2 Detailed survey of the building
    a. Building material assessment to complete an external and internal condition survey through the use of a conservation specialist;
    b. U-value testing and hygrothermal risk assessment to define the thermal properties of the building stratigraphy

3 Energy Demand profile definition
    a. Building specific heat loss/gain calculation (not benchmarks)
    b. Dynamic simulation based on the building elements to determine an hourly energy demand profile for the building and site-specific climatic conditions.

3.2 Secondary Temperatures and Emitters Integration

The secondary side temperature requirements of a historical building need to be considered as part of the design process. Along with the energy demand requirements, the heating and cooling temperatures to be delivered dictate the heat pump selection and system operational process which is further discussed in the next section.

In broad terms, heat delivery terminals in existing historical buildings can vary greatly. Some historical buildings such as those used as real case study sites as part of the GEO4CIVHIC project in Malta and in Ferrara (Italy) may have no heating and cooling systems present prior to the integration of a GSHP system.

The end of use of the buildings in this case is critical to understanding the secondary side temperatures. For example, historical buildings used for civic and public may simply be used as office or public spaces, whilst others, such as museums may act also as repositories for art and cultural artefacts. The latter use generally requires increased levels of temperature control to ensure the long-term preservation of the building's content with strict requirements on indoor temperatures and humidity levels being maintained. An example of this is the Nikola Tesla Museum in Zagreb, where a GSHP was installed as part of the Cheap-GSHPs project [14].

The operation of GSHP technologies in building retrofit scenarios generally consider the potential for implementation of lower temperature delivery solutions following the introduction of building fabric upgrade measures. These measures deliver reduced energy demand and overall, a decrease in the secondary temperatures to deliver the necessary comfort levels in heating. Where the delivery of cooling is applicable, the GSHP system provides higher efficiency solutions than other technology options to reduce the temperatures of buildings subject to heat gains, allowing passive or active cooling to be delivered through the same terminals with the added benefit of recharging ground collector temperatures.

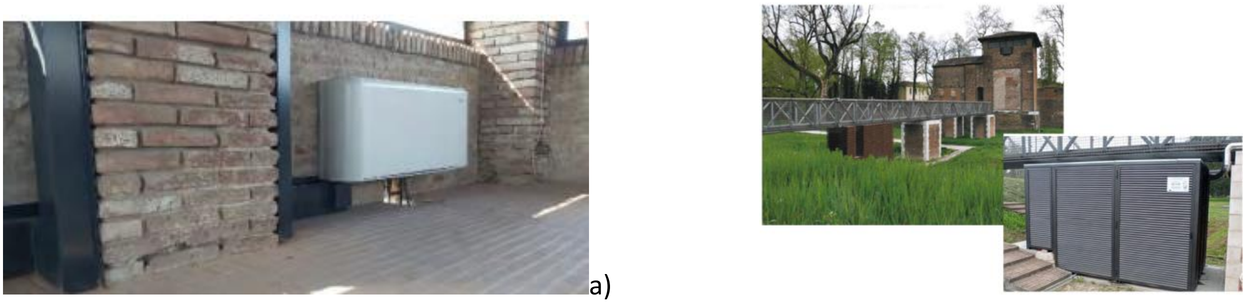
The retrofit scenario generally favours the use of radiant systems, fan coils or chilled beam emitters as part of the GSHP installation. These offer higher efficiencies and deliver lower temperatures. The use of existing high temperature terminals such as radiators are generally discouraged, where secondary side temperatures of up to c. 45°C are to be achieved to increase the efficiency of the GSHP at the operational stage. Where the use of radiators is retained, these often require upgrading to larger sizes than those installed with high temperature fossil fuel heating systems to maintain the GSHP efficiencies [1].

In the case of historical buildings, the use of low temperature emitters may be less achievable with the more common solution for heating being radiators. The selection of emitters that will operate with a GSHP system in a historical building setting, can be considered as driven by the level of acceptable intervention when retrofit measures are considered. The level of intervention is guided by the historical building listing and by the preservation requirements of the internal architectural and visual elements. In the case of the retrofit design of a GSHP system for a historical building, the designer is faced with the following considerations:

- Significant conservation requirements of the internal building elements forcing the retention of high temperature emitters and preventing the use of new low temperature terminals. This case then can imply the need for a high temperature GSHP if coupled with no or low retrofit levels. The heat pump selection then is impacted (c.f. section 4). Successful integration of a GSHP in a low retrofit scenario was demonstrated in by the project in Ireland where a new high temperature GSHP was coupled with existing radiators (figure 4);

Figure 4 Ireland case study site showing a) external plant room and b) integration of the GSHP solution to existing high temperature radiators

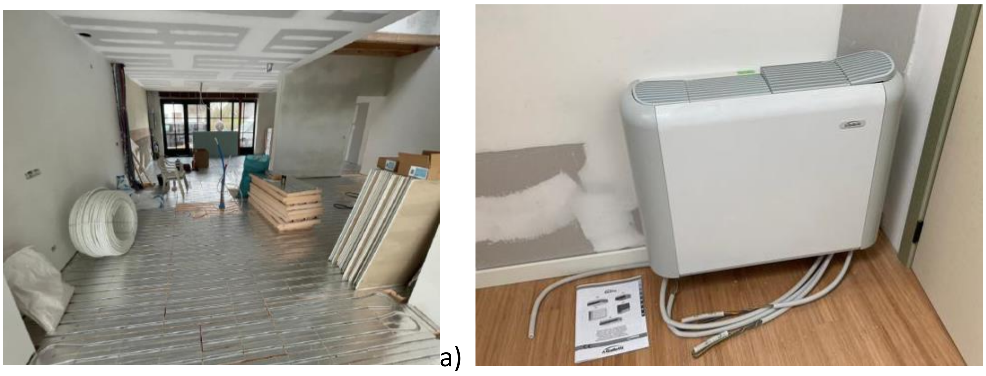
- Conservation of the internal building elements but a possible retrofit (or partial) to low temperature emitters. This solution required careful planning and consideration of the visual impacts of the solutions proposed. These impacts may have to mitigated with the use of screening or concealing elements in keeping with the building interior. An example of this type of solution has been very successfully implemented as part of the GEO4CIVHIC project in the Malta and Ferrara cases (figure 5);



a)
b)

Figure 5 a) concealed pipework and emitters at the Ferrara case study site. b) concealed plant room at the UNESCO site at Angel’s Gate (Ferrara)

- Low or no requirement of internal building element conservation and possible retrofit to high specification including the introduction of fan coils and radiant systems. An example of this implementation has been successfully achieved by GEO4CIVHIC at the Belgian case study site (figure 6).



a) b)

Figure 6 a) low temperature radiant underfloor system and b) higher temperature fan coil units installed at the Belgian case study site

The considerations around the use of emitters in a historical building and the upgrade of these con be summarised as follows:

- Scoping of potential to change historical building emitters;
- Requirements for heating and cooling temperature set points in the building;
- Cooling and dehumidification requirements to preserve conditions.

3.3 Geothermal Collector Design

The design of the geothermal field is directly connected to the energy demand requirements of building that are defined in the initial steps of the design process. The collector specification needs to seek to achieve a sustainable operation of the GHEs over a long operational life which is generally considered as >50 years in compliance with applicable standards (c.f. section 7).

A specialist and experienced GSHP collector designer therefore need to be engaged to determine the most optimal collector solution. Aside from the building specific energy demand profile that determines the heating, cooling and sanitary hot water requirements, the designer needs to give specific consideration to the site characteristics including the details subsurface profile of the ground. The site-specific subsurface profiling seeks to determine the thermal properties of the subsurface layers present at the location of the installation and the determination of the hydrogeological conditions that may affect operational properties of the collector. The definition of these properties needs to be undertaken based on the availability of nearby geological and hydrogeological data from previous boreholes as part of the development of an initial geothermal collector design, but ultimately need to be verified through the completion of a test borehole and thermal or geothermal response tests in line with applicable best practice guidelines [12]. An example of these is given in section 6 [10, 11] but specific guidance in the jurisdiction based on local regulations should be consulted.

Consultation with the local authorities responsible for licensing and permitting shallow geothermal systems along with the applicable regulations (c.f. section 6) will ultimately determine the collector design specification and selection of the heat exchanger type. The profiling of the ground conditions will also ultimately determine the selection of the most appropriate drilling methodologies.

The implementation of a geothermal collector for historical buildings is often guided by the location and the space available for the system. In the context of densely populated urban centre areas, consideration with respect to space and the need for additional surveying to be considered (c.f. section 5.1). Where there is obvious space restriction for the geothermal array and insufficient areas for installing a geothermal collector that would meet the full heating and cooling demand of the building, the GSHP design will be required to consider alternative strategies to deliver a high efficiency solution. These may include the use of hybrid ASHP and GSHP system solutions (c.f. section 4) where minimal impact to the aesthetic and cultural impact can be achieved of the building. In the case of high temperature heat pump applications, these integration strategies may also include other high temperature energy source such as those implemented at the real case study site in Ireland in the GEO4CIVHIC project.

The main considerations for the development of a geothermal collector design for a historical building can therefore be summarised as follows:

- Size of the geothermal field based on energy required considered against availability for geothermal field space;
- Detailed assessment of the subsurface conditions at the site where the system is planned to develop a final GHE and geothermal collector design;
- Undertaking of additional testing and surveying (TRT) to determine the site specific thermal properties;
- Subsurface Conditions & Drilling Method selection based on the geological conditions;
- Space restrictions requiring the need for hybrid solution implementation.

3.4 Ground Heat Exchanger Selection

The integration of geothermal collector solutions in historical building settings are often in confined areas with restricted space and in urban settings. As described in sections 3.1 and 3.3 above, these buildings are often characterised by higher energy demand requirements and potentially lower level of retrofitting measures. This affects the geothermal collector sizing and requires a designer to be able to maximise the potential for energy exchange with ground in a confined space.

The potential for using groundwater resources through an open loop (water to water) geothermal collector can sometimes be constrained by groundwater protection regulations of shallow aquifers (c.f. section 6). The preferred selection is often to use a closed loop geothermal collector with grouting to minimise the impact of the geothermal system during the operational lifecycle of the GSHP. Given the space constraints and the higher energy demands observed in historical buildings, the selection of GHE technology for the geothermal collector is critical and needs to ensure the highest performance in heat extraction and rejection modes.

The most common heat exchangers on the market are based on the use of a sealed, polyethylene or PEX pipework that are installed in the completed boreholes. The plastic based collectors offer a lower cost solution to installing GHEs for a GSHP, however their thermal properties are not optimal to energy exchange with thermal conductivities of c. 0.4W/mK [15]. In order to maximise the energy exchange potential, the designer needs to consider the thermal properties of the subsurface which can vary between 1.2 to 2.2 W/mK for unconsolidated, saturated sediments and reach value of >3.5 W/mK in some hard bedrock conditions [16].

The reduced space (and potential depth) due to the local site specific conditions therefore requires that the energy exchange potential from the ground is maximised and the use of higher thermal conductivity materials to those of the common plastic pipe collectors is selected. The use of coaxial heat exchangers developed initially as part of the Cheap-GSHP project and then progressed during the course of GEO4CIVHIC, are based on the use of stainless steel outer pipework and enhanced plastic materials. In both cases, the outer pipe of the collector offers significantly higher thermal conductivity properties (up to 16 W/mK for stainless steel and 1.2 W/mK for enhanced plastic probes developed as part of the GEO-COND project. The improved performance of the collector pipe material coupled with the careful design of the GHE borehole and selected grouting materials, offer significant improvements in borehole thermal resistance values compared to common market competitor products [15].

The use of coaxial heat exchangers also offer improvement in hydraulic properties, allowing pressure drops to be minimised at the design stage due to their wider diameters compared to conventional single-U and double-U plastic probes. The improved hydraulic properties allow for a reduction in pumping requirements on the primary side of the heat pump during operation and hence reduce the electrical load of the system.

In areas where shallow subsurface aquifers are present that are not subject to groundwater protection measures, the use of shallower collector such as coaxial well points in a tight array [17] can be considered. In areas where there are no space restrictions for the installation of high efficiency horizontal collector technologies such as energy mats [18] can also be considered. However, these require more extensive groundworks for their installation and are more sensitive to air surface temperature variations between the seasons.

The design of a geothermal collector for a historical building application therefore needs to focus carefully on the geothermal probe selection to achieve the highest efficiencies in confined spaces. The key recommendations therefore are focussed on the following aspects:

- Selection of high efficiency stainless steel or enhanced plastic heat exchanger probes to maximise energy exchange potential with the ground;
- Use of coaxial probe configuration as these can offer better hydraulic properties and reduced pumping powers in building with high energy loads.

4 Heat Pump Selection

The heat pump selection process for integration in historical buildings is defined by the design aspects discussed in sections 2 and 3. The main controlling factor in the heat pump selection that needs to be considered is the energy demand profile of the building and if the demand is balanced (comprising both heating and cooling), or if single mode operation (heating or cooling) is dominant throughout the year. The balanced nature of the load is driven by climatic setting of the building and the level of retrofit or intervention that can be undertaken.

The use of a geothermal collector solution in dense, urban historical city centre locations presents a number of challenges when considered in the context of building conservation requirements of a particular structure. The first controlling aspect is the availability of space for installing a geothermal collector. This is further discussed in section 5 of the report; however, it is important to consider that where unbalanced energy demand is identified in a building (mostly heating or mostly cooling), the sizing and design of the geothermal collector is directly affected and generally results in more numerous GHEs at deeper depth being required. Therefore, to meet such an energy demand with a GSHP only solution, the site at the location of the historical building needs to be able to accommodate a larger collector.

The second consideration (as discussed in section 3) is the level of retrofit that can be applied. Where deeper building fabric interventions are possible, these typically result in a reduction of energy demand and a reduction of the secondary side temperatures required to achieve the comfort levels. At the other end of the scale, where historical builds cannot be upgraded and the existing secondary side terminals have to be retained, the heat pump solution needs to be able to deliver higher temperatures (>65-70ºC). There are also a number of scenarios at historical building locations where partial implementation of retrofit elements are possible, where conservation of only some of the building elements are possible. Therefore, the heat pump solution may be required to cater for both reduced secondary side temperatures in building areas that can retrofitted, whilst others area where no or low intervention has occurred will require delivery of higher temperatures [13]. There are very few integrated heat pumps on the market that can address such challenges faced in the historical buildings, where two secondary side temperatures are available and less where high temperatures can be delivered with smaller installed capacity units, that would be used in building setting. The latter are more common in large, industrial scale applications.

The GEO4CIVHIC project has focussed on developing innovative types of heat pumps that can provide a technical solution that can cater for most historical building retrofit scenarios irrespective of building fabric and conservation requirements. The innovations include:

- A dual source (air and water) heat pump to deliver mid-range temperatures and cooling;
- A single source (water to water) heat pump to deliver high secondary side temperatures to existing high temperature emitters (radiators);
- A single source (water to water) heat pump that can deliver two levels of temperatures to a mix of low and high temperature emitters.

The three heat pump innovations developed as part of the GEO4CIVHIC project are focussed on future proofing of the technology solutions with the selection of low GWP refrigerants. In addition to the low GWP for the systems selected, the project technologies have specifically focussed on the needs of the historical buildings and prioritise the use of non-flammable refrigerants that reduce the fire hazard in buildings and offer improved safety features compared to other heat pump solutions on the market [13].

4.1 Plant Room Requirements & Pipework Integration

One of the main challenges of retrofitting historical buildings with GSHPs is the space requirement for the main mechanical elements of the plant room equipment and the upgrade to the building pipework. There are several additional plant room element requirements in the design and installation of a GSHP such as space heating buffers, a domestic hot water cylinder and circulation pumps. The sizing of the additional elements is dependent on the energy demand and the building size. In the case of smaller buildings GSHPs (c. up to 18kW) can be installed with integrated DHW cylinders. These allow for smaller footprint of the plant equipment required to be more easily accommodated. For larger systems however, this is generally not possible and two separate cylinders are required. Where a cooling demand is present and the GSHP is not planned to operate in free cooling mode, an additional cooling heat exchanger and cold-water buffer are required.

The plant room design also needs to consider the need to domestic hot water treatment for legionella, which can be achieved through weekly increased temperature cycles, when water is fed directly from the heat pump to the DHW vessel, or through an instantaneous supply of hot water using an indirect heat exchanger and circulation pump circuit.

The plant room elements therefore comprise a key consideration for the designer during a final heat pump specification, when a system is to be integrated in a historical building. The plant room equipment can therefore be accommodated in the two ways. These are presented by the solutions delivered at the GEO4CIVHIC case study sites where the main requirements and potential mitigation strategies are demonstrated.

Two examples of successful integration of a heat pump solution in a historical building have been implemented in the GEO4CIVHIC project in two specific buildings where minimal interventions were possible. The plant rooms and the Ferrara and Malta had to be designed and implemented to ensure that no visual impact to the historical buildings and their surroundings were achieved. Figure 5 shows the example of the Ferrara case study, where the heat pump and all the pipework elements of the systems have been carefully concealed from view, to preserve the building’s architectural elements and character. The heat pump plant room and associated equipment were installed in a specially designed and constructed space, that was integrated to an existing metal gangway and pedestrian access structure linking a walking path to the norther part of the historical building (figure 5).

Alternative possible solutions to above ground plant rooms, which include purpose build underground plant rooms, can be executed as part of larger building intervention measures in the refurbishment of historical buildings, where the nearby ground conditions are deemed to be suitable and free from any cultural or archaeological heritage artefacts.

The integration of a GSHP system (irrespective of the delivered temperature) is likely to require the upgrade of the secondary side pipework in the building. The use of old pipework, which is often poorly insulated in the cases of historical structures, is not recommended, even in the case of when high temperature heat pumps are applied, as this would result in excessive heat loss, increased operating hours and costs, as well as significantly reduced efficiency from the GSHP. In the case where significant conservation elements to the internal section of a historical building are applicable, measures to conceal pipework must be implemented, especially where free standing emitters such as fan coil units are installed. Figure 5 shown an example of these measures implemented as part of the Ferrara case study site, where the main flow and return pipework has been concealed as part of the access structures (stairs and walkways) of the building and covered using appropriate panelling to reduce the visual impact.

In the case of external pipework connecting either the geothermal collector or split air source heat pump units in a hybrid system, the pipework should always be pre-insulated and installed below ground level, so as to minimise the visual impact to the external character of the building.

The design and integration aspects of a heat pump solution in historical buildings, with respect to the plant room and pipework elements to be considered at the design stage, can therefore be summarised as follows:

- Space requirement for GSHP Equipment & Buffers – internal space availability and alternative external installation in dedicated structure
- Low Visual Impact to maintain building character & aspect
- Power requirements/availability

4.2 Dual Source, Hybrid Systems

The use of dual source heat pumps (air and ground/water) offers an alternative solution to other market technologies, to integrate a high efficiency heating and cooling solution for historical buildings. The space saving arrangements (figure 5) demonstrates the possibility for integration in concealed configuration that effectively achieves the integration of the two heat pump technologies in one single unit.

The use dual source hybrid heat pumps is therefore recommended in historical building settings with mild to warm climates, where space constraints in the area surrounding the building determine the potential for deployment of the GSHP solutions and where partial retrofit measures to the building fabric are possible. The benefits of this arrangement are such that the hybrid heat pump solution can provide:

- Reduced space requirements in a confined setting – this is achieved through the reduced size of the heat pump, the ability to complete an outdoor installation that minimises the impact on space inside the building and finally, the apportioning of the energy demand to the air source part of the unit provides a reduced geothermal collector size facilitating installations in space constrained sites;
- An adaptable solution for different climatic conditions that maximises operational efficiency;
- A reduced CAPEX for the overall installation of the dual source solution can therefore be achieved as part of the retrofit of historical buildings, given the expected reduction in drilling and GHE requirements envisaged from the GSHP portion of the system only addressing a portion of the energy demand;
- The use of low GWP and less flammable working fluids in the heat pump providing additional fire safety in historical buildings;
- Opportunity to couple the HP with renewable electricity technologies, if the building conservation requirements allow this.

During the selection of a dual source hybrid system in historical buildings, the designer will have to consider the following key aspects:

- The available space for the geothermal collector and verify that this is adequate to meet the energy demand, when less favourable air temperatures occur, which can reduce the efficiency of the air source part of the cycle;
- Consider the proximity of other neighbouring buildings from both a visual impact and also from the point of view of noise when the air source portion of the system is in operation.

4.3 High Temperature Heat Pumps

The innovations developed as part of the project provide solutions for integrating a geothermal heat pump in historical building settings with low retrofit potential, that cannot be the subject of major retrofit measures due to higher restrictions on the cultural and architectural aspects of the building. These solutions provide the opportunity to use existing high temperature emitters (radiators) with the GSHP upgrade.

To maximise efficiency of the GSHP, the HP solution implemented requires the use of a dual cycle heat pump (two refrigerant cycles) in cascade mode, to deliver the higher temperatures required on the secondary side [13]. The dual cycle nature of the units requires some additional plant room space due to the slightly larger nature on the unit. Such a space requirement is therefore critical in the design of the system and the integration of the system elements. There is a possible opportunity for installation of the heat pump in an external plant room space, if integration in the internal part of the building is not possible. For historical buildings in cold climates, any outdoor plant room will require adequate insulation to ensure that heat loss is minimised.

The integration of the heat pump with the secondary side emitters will certainly require upgrade to existing pipework in a historical building. This is particularly the case, where older existing pipework connected to high temperature fossil fuel fired boilers is often in poor condition or lacking insulation. The retrofit of a high temperature HP needs to maximise efficiency and comfort level in a historical building and this requires minimising heat loss between the space heating buffer and the terminals. As part of the retrofit measures, the designer would therefore need to consider the possibility of either upgrading existing pipework with pre-insulated solutions or, if the existing pipework is in good condition, installing high density insulation to achieve heat loss reductions between the HP and the terminals.

The use of high temperature heat pumps is therefore recommended in historical building where low or no retrofit measures are possible and where these are located in mild or cold climates. The benefits of the HTHP integration can be summarised as follows:

- Plug and play solution to retrofit a HP solution with existing high temperature terminals;
- Minimal building intervention requirements to the building fabric;
- Increased system efficiency (COP/SPF of 2.3 to 2.5) compared with fossil fuel solution installed;
- Potential integration of the HTHP with other high temperature heating solutions (gas/oil or biomass) to deliver partial demand for peak heating or as back up;
- Opportunity to couple the HP with renewable electricity technologies if the building conservation requirements allow this.

The main requirements for a HTHP integration to a historic building that need to be considered as part of the design and heat pump selection phase of the system are:

- Space requirements at a historical building location – the HTHP solution is based on the implementation of a GSHP solution only and therefore requires an adequate area for the installation of the geothermal collector that is dictated by the energy demand. Where a large enough area is not available, the HTHP will only meet a partial demand of the building and alternative high temperature peaking technologies will need to be integrated to the system through the space heating buffer;
- The condition of the existing pipework and high temperature terminals in the building will need to be surveyed prior to the final system design and pipework insulation (or replacement with pre-insulated pipe) may be required to minimise heat loss between the HP and the emitters as well as reducing the operational hours of the system;

- Additional plant room space will be required for the installation of the solutions. A HTHP system will have a significantly larger space footprint to that of a fossil fuel boiler. Adequate space (possibly through an external plant room) will need to be considered at the design stage.

5 GSHPs in Urban Settings

5.1 Installation of the Geothermal Field

The development of a GSHP or hybrid air source and geothermal solution for historical buildings and the sites, where these are located, needs to consider the space requirements for the system installation. Sections 3 and 4 above present the challenges and recommendations with respect of the sizing of the geothermal collector and the space requirements for the plant rooms to accommodate the GSHP system.

This section focusses on the challenges and recommendations associated with completing the installation elements and more specifically, identifies improved methodologies for completing the geothermal collector in urban environments.

The typical urban setting of historical buildings provides logistical difficulties, associated with the access and operation of drilling equipment for the completion of the geothermal collector. Site space is frequently tight and at a premium on larger building refurbishment projects. The selection of the drilling methodology to be implemented must also match the subsurface conditions that are identified at the site and will vary depending on location variations.

One additional challenge in urban environments is the frequent restrictions of operating hours to respect daytime and night time noise levels to neighbouring properties. Some of the drilling methodologies, that can be used in the case of GHE installation, also can be a source of concern with respect to the development of vibration during drilling and its potential effects to historical buildings and neighbouring structures.

GEO4CIVHIC has developed innovation aimed at overcoming such challenges to facilitate the installation of GSHP systems at historical building sites. The innovations include the use of compact drilling rigs, drilling methodologies that allow for increased drilling speed and installation of the geothermal collectors. Figure 7 shows the compact drilling rig developed for urban and historic centres.

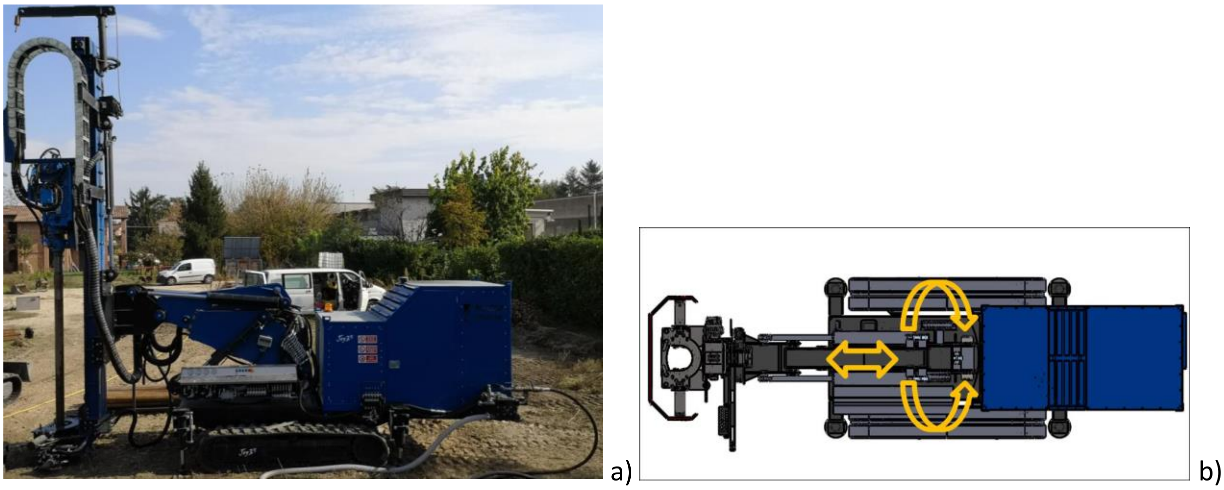


Figure 7 a) Compact Hydra Joy3P fitted with the TI VD80 vibro-drill head; b) mast position rotation from a single undercarriage position.

Drilling rigs:

The drilling and completion of a geothermal collector in historical buildings and urban centres requires the use of small scale drilling rigs with the ability to drill and complete heat exchangers to >100m depth. The Hydra Joy 3 drilling rig developed in GEO4CIVHIC is identified as a critical enabling solution for installing geothermal collectors in these settings. The Joy 3 has a very compact footprint (2m width and 6m length) and is equipped with a rubber tracked system suitable for accessing confined spaces. The drill mast and rigging are equipped with a fully rotating drive allowing up to 3 No. borehole positions to be completed with the undercarriage in one single stationary position. The inclination of the mast can also be changed to achieve completion of radial or inclined boreholes from one individual position. The drilling rig is also equipped with a detachable power pack that further facilitates the implementation of borehole drilling works in confined spaces. The two features described are critical in maximising the use of confined spaces for geothermal collector and differentiate this rig from other rigs available on the market. The drilling package includes the integration of high efficiency and extremely low emission STEP 5 engine with SCR and an automatic drill rod handling system, which greatly improves site safety with reduced gas emissions and allows to streamline the drilling operations through the use of remote control operation [22]. These measures are ideal for the installation in sensitive and confined sites.

Drilling methods:

The development of the new Hydra Joy 3 drilling combined with the new TI rotation-vibration drilling head developed in GEO4CIVHIC, can be used in cities and buildings (like historical buildings and cellars), in courtyards and gardens (like historical buildings with an inner square or existing complexes with green areas inside). The new drilling head is specifically designed for geothermal drilling applications with very compact dimensions suitable for operation with the small and portable Joy3 drilling rig. The head operates at a frequency of >100 Hz which provides negligeable vibration impact and rapid drilling speeds in both soft and medium hard rock conditions measured and validated during the project. The improved drilling speed and the newly developed disconnecting full face drill bit (lost drill bit = LDB) at the end of the drilling operation allows for to simultaneously drill and install the geothermal coaxial stainless steel heat exchanger providing significant time saving from other market technologies. [21]

Guidelines with respect to the installation and completion of GHEs in city centre locations and historical buildings can therefore be summarised as follows:

- Access for drilling equipment should guide the selection of small compact drilling rigs that can access confined spaces and successfully complete the collector. The use of larger truck mounted machines in confined sites should be discouraged, as they will offer limited manoeuvrability and opportunity to access drilling positions for GHEs where space constraints are present;

- The drilling methodology selected should limit exposure to buildings and nearby structures to vibrations. The use of rotary, water flush methodology to achieve this either with conventional drilling methods or coupled with a vibro-drilling method should be considered preferable. The vibro-drill method is demonstrated to have low impact or surrounding structures, due to the use of high frequency vibration above applicable standards.

- The vibro-drill methodology has been demonstrated to have improved drilling times in soft unconsolidated sediments and comparable performance in medium to hard rocks. The vibro-drill method developed as part of the project, also allows the drilling and collector installation process to streamlined. Such methodology results in shorter drilling operation phases during the system installation with reduced noise impact on local neighbouring properties.

- Where space restrictions occur, the availability of space to position the collector elements at the correct spacing to ensure long term sustainable operation of the system is crucial. When selecting a compact drilling solution, this space can be maximised and the potential subsurface area for the collector improved.

5.2 Presence of Neighbouring Systems

The dense urban setting of historical buildings can be influenced by the proximity of other geothermal systems installed in neighbouring properties. This is particularly the case in more mature markets, where GSHPs are more common in urban city centres. The operational profile of neighbouring GSHPs is governed by the energy demand requirements. When planning the development of a GSHP system with a collector that could be potentially be located in close proximity to other systems, this needs to be carefully considered at the design stage. Shallow geothermal systems that are dominated by a heating demand, have a tendency to reduce ground temperatures over the operational life. Such reduced ground temperatures can therefore affect the performance of a new system being planned in a historical building. The opposite is true of cooling dominated systems, where over their operational life, the geothermal collector has a tendency to increase ground temperatures over time [23].

Distance between systems is often (but not in every jurisdiction) dictated by regulatory guidelines (c.f. section 6), which dictate the distance between neighbouring land owners and properties that need to respected. The planning phase of a GSHP installation in historical buildings in urban settings therefore needs to consider a number of key parameters, that will ultimately affect the geothermal collector design, the effective long term delivery of energy from a geothermal option (complete or partial energy demand) subject to the space available at the proposed project location. The design phase of the project should be implemented by an experienced designer, who would seek to access information on geothermal utilisation in proximity of the proposed new system, to complete prior to finalising the No. of GHEs required and the necessary spacing. The following considerations are applicable in the context of neighbouring systems:

- Distance between nearby GSHP collector: this may be set in regulatory guidance at the project location, or may need to be determined by a competent expert to determine any long term temperature impact in the subsurface, that may affect the operations of the geothermal field. The separation of planned new system may require the designer to apply and standoff distance between the site boundary, where this is set in regulation and this may impact the physical usable space at a site to install a geothermal collector. The operational profile of neighbouring collectors could have an influence on the ground temperatures of a newly planned system. In this case, the system would have to be placed in an area of available space, that minimises this impact and provides long term sustainable ground temperatures to be achieved.

- Operational system data: to achieve a sustainable design and guarantee long term operation of the GSHP, requires that any existing operational system data is obtained through local authorities and regulators with records of existing systems. These may include the installed capacity of neighbouring systems, their energy demand profiles or monitoring data. Where large scale installations in historical building settings are planned, modelling of a geothermal collector using detailed sub surface information and neighbouring system data is recommended prior to selecting the final configuration. The ETHICAL tool [24] developed as part of the GEO4CIVHIC project can facilitate this decision making.

As part of the geothermal system design process for historical buildings, the following mitigation measures could be considered subject to the verification of the site specific conditions to overcome the influence of nearby systems and improve the long term efficiency of the planned heat pump solution:

- Increased Depth of GHEs: where a potential influence of neighbouring systems is expected, the design of the geothermal collector could consider reducing the number and increasing the depth of individual GHE elements to achieve improved ground temperatures. This effectively can act as a buffer to operating geothermal collectors in the vicinity of the new system.

- Reduced GSHP Load: where a suitable configuration cannot be achieved to meet the energy demand of the building, the load to the geothermal collector may have to be reduced and a GSHP solution used to offset only part of the energy demand of the historical building.

- Use of hybrid ASHP/GSHP solutions: in space constrained sites, it may be difficult to achieve the necessary standoff distances to guarantee the sustainable operation of the geothermal collector, when this is too close to other existing systems. In this case, the potential for deployment of a hybrid ASHP and GSHP solution, as demonstrated in Malta and Ferrara case study sites, may be the more adequate strategy. This option allows a HP solution to be optimised by providing and strategy that will allow the ground array and the ASHP to operate optimally and result in a reduced impact on both the ground and nearby operating systems.

5.3 Underground Infrastructure & Landscaping

The completion of a geothermal collector at a historical building location is disruptive in the context of the cultural setting of most historical buildings. The grounds around HBs are frequently characterised by the presence of gardens, mature trees and/or other cultural heritage elements such as graveyards, burial sites or buried industrial heritage infrastructure. The planning phase of geothermal collector, therefore, needs to give careful consideration of these aspects and implement adequate mitigation measures to integrate the elements of the collector in a respectful way. The integration process needs to give consideration to required measures for the re-instatement and restoration of the grounds, on which a collector is located, to minimise the visual impacts of a GSHP solution at a cultural heritage site.

Detailed surveys of the surroundings of a historical building, where a geothermal collector is planned, are therefore required prior to finalising the design. A survey to include assessment of the presence of the following aspects would be required:

- Buried Archaeological, cultural or industrial heritage artefacts
- Presence of utilities, services, infrastructure and ordinances constraints
- Presence of protected tree species and associated root systems

To assess the presence of any of the above elements, the system planning phase should seek the advice of conservation archaeologist and the consultation of existing cultural archives. The location of modern buried services (water, gas, electric, fibre optic cables etc.) should be checked by consulting local utilities companies, that can provide detailed maps of infrastructure. The presence of historical services (medieval sewer, aqueducts and water supplies) should also be considered as part of the initial planning phase. Aside from a careful desktop assessment of available information to map any above constraints to the installation of a geothermal collector, the use of surveying methods such as (but not limited to) GPR to map exact locations of buried structures should be implemented (figure 8).

Figure 8 GPR surveying at the Greystones case study site in Ireland to map the location of services and structures.

The presence of mature vegetation at historical building sites is not uncommon. Secular trees, that sometimes have preservation orders, can impede the installation of GHE and surface pipework in certain areas of the site. The drilling and completion of the GHEs in a closed loop geothermal borehole array potentially has a lower impact on such trees and their root structures. However, the footprint of the surface pipework connecting the GHEs to a central manifold can affect these at the optimal depth of burial. It is important therefore to put forward a design, that considers the root network of existing trees to minimise impact during the construction phase of the root network, but also to ensure that these are shielded from temperature variation in the soil, that may occur during the heating and cooling period. It is therefore recommended, that a surface pipework design ensures that shared trenches are away from significant tree root systems and that where necessary, protection measures are adopted as part of the installation. These measures may include the use of root barriers buried on the walls of the trenches or the use of pre-insulated pipework.

The design and implementation phases of a geothermal collector should therefore consider:

- The need for detailed surveying through the detailed desktop assessment of relevant information (archaeological artefacts and utilities) and the use of surveying techniques (GPR) to identify sub-surface structures prior to the completion of the design;

- Existing Landscape constraints to geothermal field connections. These may require consultation with a tree specialists, arborists and local authorities prior to finalising the need for surface connections.

6 Permits & Licensing

The implementation of renewable heating and cooling solutions, such as heat pumps in historical buildings, are governed in many jurisdictions by the application of licensing and regulatory systems, that affect the different components of the system. On the one hand, regulations around building retrofit measures and specifically regulations or guidelines with respect to the retrofit and refurbishment of buildings as well as requirements for conservation measures are applicable to the buildings themselves and in many cases to the grounds surrounding these. In addition to this, the permitting and licensing around the installation of the shallow geothermal systems are defined in local law and regulations and dictate the potential for deployment in GSHP solution in urban centres and at building locations. A comprehensive review of the permitting and regulatory conditions applicable in the case of GSHP installations and the refurbishment of historical buildings was completed as part of the project [25].

This document summarises the main permitting and licensing recommendations for projects seeking to implement retrofit measures and the integration of shallow geothermal systems in historical building settings. Specific permitting and licensing aspects conditions are not covered in this deliverable.

Historical Buildings:

The energy efficiency and implementation of measures associated with reducing the carbon footprint of the built environment are governed broadly by the implementation of the EPBD (Recast- Article 4) [26], which seeks to set out measures for doubling the annual renovation rate of buildings by 2023, and the Renewable Energy Directive (Recast) [27]. Members States in the EU have developed national policy objectives and regulations, that are applicable to the retrofit and refurbishment measures in buildings. Historical and protected buildings are typically exempt from these regulations; however, the project technologies could significantly reduce building operational costs without altering building structure or character and promoting preservation of cultural heritage. This could potentially position the GEO4CIVHIC technologies to deliver on low impact retrofit solutions for heating and cooling, which could benefit from reduced permitting requirements. The regulatory aspects relating to building refurbishment of historical buildings are connected to applicable standards and are further discussed in section 7 of this deliverable. Applicable regulations to the refurbishment of buildings in Europe in the context of historical buildings can be summarised as follows:

- The transposition of the EPBD into local regulations governs the building codes with respect to the construction and implementation of retrofitting measures in buildings. The EPBD makes reference to the Renewable Energy Requirements (RER) for the total energy demand of buildings mandating the introduction of renewable heating and cooling technologies such as heat pumps.

- The implementation of the requirements under the EPBD to the refurbishment of buildings extend to retrofit of residential and public sector buildings, whilst requirements are not imposed on historical buildings, which are considered as mostly exempt.

- Requirements with regard to the refurbishment of historical buildings are mostly in line with existing planning, construction laws and regulations, as well as standards (c. f. 7); expert advice and consultation with local authorities responsible for the preservation of cultural heritage are required. This is especially true when buildings are listed as protected. In many European jurisdictions, guidelines are present, that cover the main aspects of refurbishment of historical buildings but none that specifically deal with the implementation of renewable energy sources aside from international standards (c.f. 7).

Shallow geothermal systems:

The regulatory requirements for the installation of shallow geothermal systems in different European jurisdictions vary across the EU. The requirements tend to be more extensive in mature markets, with fewer measures applicable where GSHP technology is less well established. The main aspects relating to the regulatory frameworks around shallow geothermal systems are focussed on groundwater and aquifer protection. The regulations typically dictate the types of geothermal systems that are permitted based on the subsurface conditions, the drilling methodologies that are applicable, the types of probes that can be installed and any restriction on the operational profile of GHEs.

The regulations tend to be more comprehensive in groundwater protection zones and in urban environments, where a higher density of GSHP and other subsurface users may be competing for resources. The installation of larger scale GHEs system and GSHPs may also be more restrictive in these areas due to the possible impacts associated with the drilling and installation phase and the resulting ground temperatures from a newly proposed system [25].

The design of new GSHP systems in urban areas for historical buildings, therefore needs to take consideration at the earliest possible stage of local regulations around the design, construction and operation of a geothermal array. The expected energy demand (c.f. 3), the proposed heat pump selection (c.f. 4) and potential restrictions that may result from the site itself (space, cultural heritage character, conservation measures) should therefore be defined in the context of local applicable regulation for the sub surface elements of a geothermal solutions, to ensure that achievable system design can be developed.

A system designer is therefore recommended to consider the following items with respect to the regulatory environment that may be applicable for geothermal collectors in advance of the technology selection being completed:

- Licensing and permitting for GHEs and GSHP systems in line with local applicable regulations. These could range from a simple authorisation or notification to more complex permitting procedures in the case of larger systems. The permitting process may highlight restrictions relating to the design of the system, the methodologies adopted, where these concern aquifers, and the need for potential measures (i.e. casing and grouting), to prevent the cross contamination of groundwater resources. The latter may also restrict ground temperatures that GHEs can have during the operation of the system. Other restrictions in urban areas are also in place with basic rules with regard to proximity of GHEs to other systems and neighbouring boundaries.

- Consultation of any available databases or registers at regional or municipal level, where details of existing systems may be recorded. The information included in the databases can help finalise the locations possible for the ground heat exchanger and determine the ultimate size of the GSHP.

- Use information of existing systems (from monitoring data if available), to assess the potential influence of operating GHEs in close proximity with the proposed systems and the long term ground temperatures, that need to be achieved to maintain system efficiency throughout the operational life of the system.

7 Standards

European and international standards govern the application of retrofit measures, the installation of shallow geothermal systems and interventions in historical buildings. Other aspects of the project innovations developed as part of the GEO4CIVHIC project, which deal with heat pumps and drilling methodologies are described as part of a detailed review of technical European and national standards [26]. This document reviews the aspects of technical standards, that require consideration for the design and implementation of GSHP systems in historical buildings. A more detailed description of these standards is available in deliverable 6.6 [26].

7.1 Historical Building standards:

The definition of historical and cultural heritage elements is provided in standard EN15898:2020 [27], which sets out in general terms the definitions with respect to cultural heritage elements including buildings. Standard EN16883:2017 sets out guidelines for improving the energy performance of historic buildings providing guidelines for sustainably and the improvement of energy performance of historic buildings, e.g. historically, architecturally or culturally valuable buildings, while respecting their heritage significance [4]. Both standards demonstrate that both movable and immovable objects (defined under different terms) should be treated as 'objects' of historical significance, when their age exceeds 50 to 70 years [26], and the guidelines, set out in both standards, are not limited to buildings with statutory heritage designation, but rather as being applicable to historic buildings of all types and ages.

The adoption of these standards in national and local jurisdictions, where a historical refurbishment project is being developed, are therefore critical to understanding the opportunities for intervention measures on the building itself but also to the surrounding areas. The designer and project manager are therefore guided to understanding any of the regulatory aspects applicable in line with these standards prior to defining refurbishment measures and designing a geothermal solution for a historical building.

As part of these recommendations, the initial project development steps need to also consider the applicability of other related standards to specific historical building uses, that may be applicable in the context of retrofit projects. Some of these standards (but are not limited to) those shown in table 2 below.

Table 1 - EN Standards applicable to historical buildings and retrofit measures

Standard	Title
EN 15759-1:2011	Conservation of cultural property - Indoor climate - Part 1: Guidelines for heating churches, chapels and other places of worship
EN 16096:2012	Conservation of cultural property - Condition survey and report of built cultural heritage
EN 16085: 2012	Conservation of Cultural property - Methodology for sampling from materials of cultural property - General rules Released
EN 16141:2012	Conservation of cultural heritage - Guidelines for management of environmental conditions - Open storage facilities: definitions and characteristics of collection centres dedicated to the preservation and management of cultural heritage
EN 16142:2012	Conservation of cultural heritage - Procedures and instruments for measuring humidity in the air and moisture exchanges between air and cultural property

7.2 Refurbishment and Retrofit standards

The measures associated with the refurbishment and retrofitting of buildings to improve their energy efficiency is governed in the European Union by the implementation of the EPBD in Member States. Other international guidelines on the implementation of these measures are adopted in other jurisdictions. The

EPBD is currently under review with the objective of generally increasing the level of intervention to improve energy measures in buildings by 2030. The EPBD is based on five overarching standards explicitly mentioned in the EPBD:2018. These provide a modular approach to energy performance assessment, the implementation of indicators and the implementation of technical building systems to achieve the required standards. The five overarching standards are listed in table 3.

Table 2 - Overarching Standards referencing the energy performance of buildings as set out in the EPBD modules

Standard	Title: Energy Performance in Buildings	Topic
ISO 52000-1	Overarching EPB assessment — Part 1: General framework and procedures	Systematic, comprehensive and modular structure for assessing the energy performance of new and existing buildings (EPB) using a holistic way approach.
ISO 52003-1	Indicators, requirements, ratings and certificates – Part 1: General aspects and application to the overall energy performance	Describes the relation between the EPB indicators and the EPB requirements and EPB ratings, and it discusses the importance of project-specific, tailored values as requirement or reference for certain EPB indicators.
ISO 52010-1	External climatic conditions — Part 1: Conversion of climatic data for energy calculations	Procedures to assess the climatic data needed as common input or boundary condition for many elements in the energy calculations.
ISO 52016-1	Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads — Part 1: Calculation procedures	Calculation of internal temperatures and energy needs for heating and cooling in buildings
ISO 52018-1	Indicators for partial EPB requirements related to thermal energy balance and fabric features — Part 1: Overview of options	Overview of options of indicators enabling (optional) specific EPB requirements (post-processing) at building level.

The transposition of the EPBD in national and local building codes in Member States, defines the regulatory requirements for retrofit measures in building construction regulations. Whilst, historical buildings are mostly excluded as a category from the EPBD for the implementation of such measures, the definition of historical buildings (c.f. 7.1) can vary with buildings of different ages, level of conservation and construction. The design of refurbishment measures and introduction of GSHPs may therefore need to consider such buildings, where the level of cultural heritage significance is limited or reduced and where there might be scope for integrating both conservation measures on the elements of highest architectural significance, but also where intervention measures completed may need to comply with modern building codes and methods. Examples of this scenario are given in the GEO4CIVHIC project case study sites, where intervention measures to external elements of buildings need to respect cultural heritage and significance, however internal measures including the installation of insulation and improved energy delivery terminals can be implemented. The design phase of retrofit measures in historical buildings therefore needs to be mindful of the potential need for integrating conservation measures and the need to achieving model energy efficiency standards during retrofit through adequate intervention measures. Such measures can only be assessed on a case-by-case basis in consultation with applicable local regulations and standards.

8 Conclusion

The integration of GSHP systems to decarbonise heating and cooling in historical buildings offers clear advantages over other renewable technologies. The frequent location of these buildings in dense urban areas and historical centres, as well as the cultural heritage significance of these sites bring additional challenges to the design and implementation of a GSHP project that requires careful planning.

The GEO4CIVHIC project innovations have developed solutions to overcome most of the technical challenges to delivering GSHPs in historical buildings. These solutions are presented in the individual chapters of this document and demonstrate how these can be implemented to reduce logistical challenges, achieve levels of retrofitting to reduce energy demand, that are respectful to the historic nature of these particular buildings, whilst implementing lower environmental impact solutions both in the construction and installation and long term operation of the renewable heating and cooling solutions.

The guidelines developed in this document, have focussed on key aspects of project design and implementation, based on the need to implement a holistic approach to a historical building refurbishment project. The guidelines are aimed at both non-technical and technical stakeholders and can be used as a reference to develop the necessary workflow as part of the initial evaluation process. These provide the reader an outline methodology, to conduct an initial screening of potential solutions for the retrofit measures for integration of GSHPs in historical buildings. The screening process is aimed at considering critical elements of a project, that include the building fabric and its level on conservation to determine the scale of interventions, that might be possible, and the most adequate HP solutions (geothermal, hybrid or high temperature) that may be installed. The screening process recommends that a holistic site characterisation is undertaken in the early parts of the project, to identify cultural heritage limitation and help define the energy demand of the historic building and the practical aspects of delivering a geothermal system in historical building settings, where other space and access constraints may be present [17].

The workflow behind the guidelines proposed in this document has been integrated into a number of decision support tools that comprise a DSS to complete an outline screening design [20] and an application to support decision makers when sizing and designing and geothermal system [28]. Both of these tools provide stakeholders of both non-technical and technical backgrounds to define potential solutions based on site specific characteristics.

The guidelines provided in this document are designed to support the initial system evaluation, the risk assessment and the use of the DSS to allow potential project managers seeking retrofit solutions in historical building setting, to identify possible shallow geothermal options. The aspects and considerations covered by the guidelines are summarised below. However, these guidelines are not a substitute for a site and building specific assessment. A potential project developer needs to carefully engage with special technical discipline experts in:

- Conservation architecture;
- Building fabric elements and energy demand assessment;
- Specialist mechanical and electrical contractor with experience in the installation of GSHP systems and user side terminals;
- A heat pump provider that can deliver the adequate heat pump solution for the project;
- Geothermal system designers for the geothermal collector elements;
- Specialist drilling contractor with adequate drilling equipment to install the geothermal collector solutions;
- A building contractor that will deliver any potential retrofit and restoration measures;

- Landscaping specialist that will design and implement any re-instatement works as part of the site restoration when the works are complete;
- Project manager with experience of working in historical buildings.

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