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Deliverable D6.4

Common MCDA Methodology & Risk Assessment of individual case study sites

WP6

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Contents

Publishable summary

Deliverable D6.4 is a public document delivered in the context of WP6, task 6.3, a risk assessment for the use and installation of the innovative systems developed as part of the GEO4CIVHIC project.

The deliverable comprises a number of parts that include a Multi Criteria Decision Analysis (MCDA) tool and a risk assessment matrix. This report provides an overview of the work carried out for the development of the MCDA tool aimed at non-technical stakeholders and the development of the risk assessment matrix. The tool provides an initial screening methodology to define the applicability of the project technologies to certain retrofit scenarios and relates these to the risk assessment carried out in the second part of the task.

Abbreviations

ASHP	**A**ir **S**ource **H**eat **P**ump
BER	**B**uilding **E**nergy **R**ating
BHE	**B**orehole **H**eat **E**xchanger
Cheap-GSHPs	**C**heap and **E**fficient **A**pplication of **r**eliable **G**round **S**ource **H**eat **E**xchangers and **P**umps
DHW	**D**omestic **H**ot **W**ater
DSS	**D**ecision **S**upport **S**ystem
EIA	**E**nvironmental **I**mpact **A**ssessment
EPBD	**E**nergy **P**erformance in **B**uildings **D**irective 2002/91/EC (EPBD, 2003) & subsequent amendments
GHE	**G**round **H**eat **E**xchanger
GEO4CIVHIC	**M**ost **E**asy, **E**fficient and **L**ow **C**ost **G**eothermal **S**ystems for **R**etrofitting **C**ivil and **H**istorical **B**uildings
GSHP	**G**round **S**ource **H**eat **P**ump
HP	**H**eat **P**ump
HTHP	**H**igh **T**emperature **H**eat **P**ump
MCDA	**M**ulti **C**riteria **D**ecision **A**nalysis
MPEPC	**M**aximum **P**ermitted **E**nergy **P**erformance **C**oefficient
MPCPC	**M**aximum **P**ermitted **C**arbon **P**erformance **C**oefficient
nZEB	**N**early **Z**ero **E**nergy **B**uilding
RE	**R**enewable **E**nergy
RER	**R**enewable **E**nergy **R**equirement

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Introduction

The implementation of the GEO4CIVHIC project technologies has been considered in this deliverable in the context of the potential for developing a generic risk assessment methodology for non-technical stakeholders seeking to understand the viability of the technologies developed by the project in the context of different retrofit scenarios. The methodology assesses the viability of the application of the project innovations along with other additional measures in the case of retrofitting measures applied to existing or historical buildings.

The implementation of this task was considered following the review of the work completed in the other project work packages, where the applicability of the GEO4CIVHIC technologies in the retrofit scenarios was assessed. Table 1 below summarises the input data to this task and shows the basis for the development of the MCDA methodology and the development of the risk recommendations matrix completed in the second part of the task.

Table 1 – Information considered in the development of the task

Task	Deliverable	Relevant Information
T1.1	D1.1	Identification of the barriers to the implementation of the project technologies in deep renovation
T1.2	D1.2	Drillability information for the project case study sites
T1.3	D1.3	Energy demand for different levels of renovation and building typologies
T2.1	D2.1	Vertical geothermal heat exchangers and drilling equipment - overview
T2.2	D2.2	Details of the compact rotation-vibration drill head for urban areas
T2.3	D2.3	Compact drilling machine for urban areas
T2.4	D2.4	Coaxial Heat exchanger performance
T3.1	D3.1	Review of heat pump technologies available on the market
T4.1	D4.1	Proposed solutions for the integration of the GEO4CIVHIC technologies to historical and existing buildings based on D1.1 barriers
T5.3	D5.3	Virtual case and real case preliminary design information
T6.1.1	D6.1	Regulatory aspects of building retrofit and GSHP system installation and operation
T6.1.2		EIA and Risk Assessment methodologies applied to the case study sites
T6.2	D6.3	Interference of BHEs and neighbouring systems and the implementation of regulations or best practices in the context of the case study locations

The task has focussed on the outcomes of the deliverables outlined in table 1, in order to develop and early assessment methodology for retrofit projects aimed at supporting decision making for non-technical stakeholders and demonstrating the applicability of the project technologies to such projects.

The objective of the task has been to consider the initial assessment of a number of key criteria highlighted as part of deliverable D1.3 and D4.1 of the project as critical in to building refurbishment where the GEO4CIVHIC technologies could potentially be implemented.

A common set of criteria developed as part of the project has been assessed to complete this task. The criteria specifically cover the following topics:

- Technical aspects relating to refurbishment of different building types;
- Technical aspects relating to the design and implementation of GSHP and hybrid heat pumps;
- The environmental aspects of both the construction and long term operation of the proposed technology solutions;
- The regulatory requirements that cover both retrofit and the GSHP aspects of a project.

The report provides a summary of the development of the MCDA tool as an initial screening assessment for the GE4CIVHIC technologies and the development of the risk assessment matrix and recommendation for the user. A presentation of the input criteria and the methodology used to complete the MCDA is presented. Based on the outcomes of the assessment the Risk Assessment Matrix and structure are also presented.

1 Multi Criteria Decision Assessment Tool

An MCDA tool has been developed as part of the deliverable to allow for initial screening and assessment of the suitability of the project technologies based on a number of retrofit scenarios. The tool has been developed as an Excel spreadsheet to allow non-technical stakeholders to obtain an overview of the suitability of the GEO4CIVHIC technologies developed for specific building retrofit scenarios. The outcomes of the tool are an indication for the user as to the type of system they might consider in advance of obtaining a detailed assessment and design specific to their project.

The sections below describe the development of the tool, the applied methodology to define the scenarios, the criteria considered and the outcome solutions.

1.1 MCDA Methodology

Extensive research was undertaken in the early parts of the task to identify the most suitable MCDA methodology applicable in the case of the tool provided. MCDA has been applied widely in various energy, sustainability and building refurbishment problems [5]. Most of the studies concern large scale energy systems electricity systems community level heating system [5] and renewable energy systems [8]. The criteria are mostly defined on a case specific basis, as there is no standardized methodology or criteria set for evaluating energy sector problems.

Under the concept of a Multiple-Criteria Decision Analysis (MCDA), the principal aim is not to discover a solution, but to construct or create something which is viewed as likely to help an actor taking part in a decision process either to shape, argue, and/or transform her/his preferences, or to make a decision in conformity with his/her goals.

In generic terms, common decision making processes follow a set of steps of a decision making process that are broadly summarised in Fig1. To achieve the goal and objectives, choosing the appropriate decision making method that fits the problem type is the first step. To select the best method, different types of problems must be compared and the pros and cons of each highlighted. In the second step, the requirements of a decision are defined based on expert’s judgments or technical constraints. In the third step, goals must be clarified and the most important part is that goals must be considered positively, in this case that a ground source heat pump and drilling solution can be applied to a retrofit project. The forth step is defining alternatives. Alternatives are the methods that change the preliminary condition into preferred condition [7].

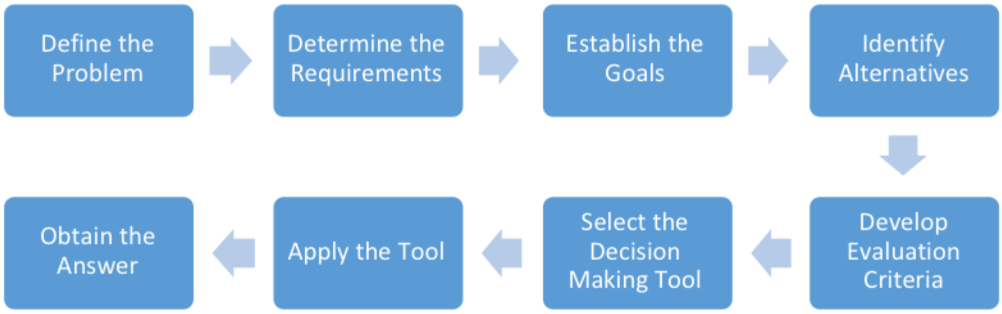

Figure 1 - Decision Making Process

The alternative that best suits the goals, can then be selected by evaluating the different alternatives against a set of criteria. These are presented and discussed in the following sections based on the work completed in other parts of the project. The objective of the criteria, is to help to differentiate among alternatives and select the most relevant solutions based on decision maker’s preferences or based on a technical assessment.

The objective of the methodology developed was therefore to compile a series of ‘problems’, which in this case were defined as different retrofit scenarios, consider these against a set of different ‘criteria’ and propose a set of ‘alternatives’ defined in this case as the combinations of the project solutions in a simple outranking matrix.

It is important at this point to consider the type of data used in the criteria and understand how a weighting scale can be applied to these. This process allow for a combination of both quantitative and qualitative data by applying a normalisation scale and facilitating the final scores and more accurate decisions.

A number of decision making methods for different types of problems were assessed as part of the task in order to define the most appropriate one to the problem and to the qualitative solution to be obtained. These decision making methods were deemed critical in defining the initial screening tool outcomes used by a non-technical user, prior to them obtaining a more detailed technical assessment.

The following methods were reviewed: Analytic Hierarchy Process (AHP), *Elimination et Choix Traduisant La Réalité* (ELECTRE) and PROMOTHEE [3]. The AHP method is based on pairwise comparison, whilst PROMETHEE and ELECTRE are outranking methods.

The decision criteria tool built as part of the task was developed as an Excel workbook and based on the PROMETHEE method. PROMOTHEE method has five main steps: in the first step, a preference function showing the preference of the decision maker for an action or criteria (in this case the criteria defined by the tool) with regards to other criteria is defined. The second step compares the suggested alternative with the preference function.

As a third step, the outcomes of these comparisons are presented in an evaluation matrix as the estimated value of every criterion for every alternative. The ranking is realised in the two final steps where a ranking of alternatives is provided based on the end user decision.

As the data for this particular assessment required the use of both quantitative and qualitative criteria (refer to section 1.1.2 below), a weighting structure was applied in order to facilitate normalising of the ranking. Figure 2 shows a basic representation of the workflow applied as part of this methodology.

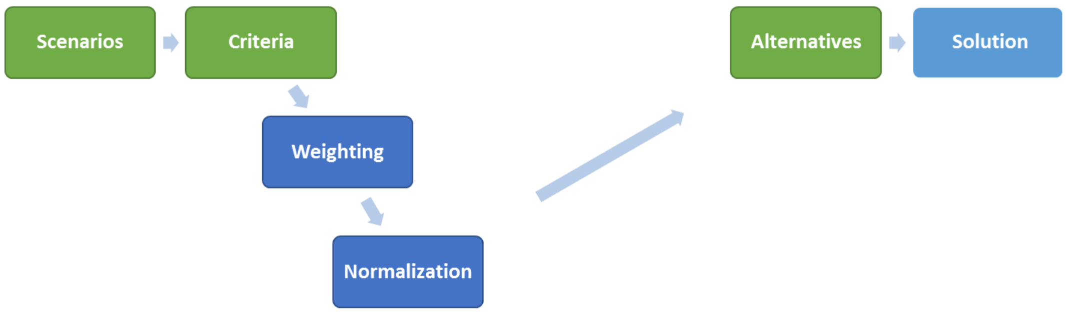

Figure 2 - GEO4CIVHIC MCDA project workflow

The following sections present the criteria, the scenarios and the outcome solutions of the MCDA.

1.1.1 The Retrofit Scenarios

Three retrofit scenarios are defined as part of this task in line with those presented in D1.3 and D4.1 of the project.

1.1.1.1 Scenario 1 – Historical Buildings

The Historical Buildings scenario considers those historical buildings where the possible level of retrofit corresponds to a minimal intervention on the fabric of the building. This category is the most appropriate in the case of listed buildings where cultural heritage aspects and preservation of building aspects (both internal and external) must be preserved. In the context of local building regulations and the transposition of the EPBD, this category coincides with those buildings that are usually exempt from these regulations with respect to their cultural status and where retrofit to the building fabric is deemed not to achieve a cost optimal performance level [4] as defined in the local regulations.

1.1.1.2 Scenario 2 – Medium to Low Retrofit

The medium to low retrofit scenario is considered in the case of those buildings where preservation of part of the building elements is applicable. In this case, only a partial retrofit intervention may be possible to allow for the building to achieve the highest energy efficiency and the reduced energy demand. An example of this could be the consideration that external aspects (opaque elements) of a building (irrespective of these being historical or not) are subject to preservation such as the external façades, roof or glazing, whilst other exterior structural elements and the internal parts of the building can be subject to deeper retrofit.

This scenario represents a middle case of intervention between the restrictions applicable to historical buildings in scenario 1 and the extensive intervention measures applied in deep retrofit settings. The buildings in the medium to low category are those where renovations are planned and that comply with the '*Existing Buildings'* category as defined in the EPBD [4] for non-domestic buildings where the cost optimal level of renovation performance requirements are less than 25% of the surface area of the building envelope as defined in the local building regulations and where specific performance of building elements (roofs, walls, floors, external doors & windows) are specified in the context of material alterations or changes of use.

This case also covers buildings where local transitional regulations from the final implementation of the EPBD may be applicable prior to the 30th of December 2020. Retrofit buildings in this category are expected to achieve the required BER rating specified in the local regulations for renovation works, comply the MPEPC and MPCPC and RER requirements imposed, without necessarily having the possibility to implement **all** the Building Fabric and Building Service (in the cases of non-domestic buildings) required in the regulations.

1.1.1.3 Scenario 3 - Deep Retrofit

The deep retrofit scenario considered in the tools is in line with the definition of the *Major Renovation* works as defined in the EPBD [4], where more than 25 % of the surface of the building envelope undergoes renovation. The energy performance of the building or the renovated part thereof is upgraded, in order to meet minimum energy performance requirements with a view to achieving a cost optimal level, in so far as this is technically, functionally and economically feasible [4]. This is applicable to both domestic and non-domestic buildings, where extensions, material alterations, material change of use or major renovations are being undertaken.

In this scenario the building undergoes extensive renovation with specific improvements focussed on the fabric of the building in line with the local building regulations to include:

- Cladding of the external surface elements with insulating materials;
- Drylining of internal surface element insulation;
- Replacement of windows; and
- Exposure of the basic structural components to allow for rebuilding and compliance of all necessary performance requirements.

The focus of the retrofit measures in this scenario is for the implemented design **to exceed the MPEPC and MPCPC resulting in a significant increase in energy efficiency and a reduction of energy consumption**. This intervention typically allows such buildings to have a more flexible (reduced) RER applied.

1.1.2 Criteria Selection

Seven criteria were selected based on the review of the deliverables completed in the earlier parts of the project. The seven criteria are presented in the sections below. The basis for criteria selection has been the data presented in the deliverables outlined in table 1 above.

1.1.2.1 Building Archetype

The building archetype criteria are aimed at allowing the user to define the type of building that best describes the renovation project being considered. The selection is based on the building archetypes defined in D1.3 of the project and are grouped into two categories:

- *Historical Buildings (HB)* – these are considered all buildings older than 1960 which are considered of cultural importance (protected/listed or not)
- *Existing buildings (EX)* – these are all buildings younger than 1960 where retrofit is undertaken

Two sub categories in each of the above with *Single Detached Residential* and *Office/Apartment Block* are also provided in line with the archetypes defined in D1.3.

This criterion has been normalised, using a weighting distribution in each of the three scenario based on a scale of 1 to 4, where 1 and 2 represent the historical building subclasses, and the existing building sub-classes are represented by 3 and 4.

1.1.2.2 Thermal Envelope

This category includes three classifications aimed at allowing the user to select the final thermal envelope specification that will be achieved following the building retrofit phase.

- *Low* – will apply to those buildings where minimal building fabric intervention is possible. This is potentially the case for all historical buildings with protected elements or of high cultural importance and where insulation measures (internal or external) can mostly not be implemented;
- *Medium* – this addresses those buildings where only partial retrofit of the building fabric is possible to comply with building regulations but not to achieve nZEB status;
- *High* – covers the best thermal envelope performance that can be achieved in line with the nZEB standards set out in the local building regulations.

This criterion has been normalised using a weighting distribution in each scenario above based on a scale of 1 to 3, that represents the low to high values respectively.

1.1.2.3 Installed Capacity - Load

The user is asked to select between ranges of installed capacities that best describe the energy demand and load expected after the project. These are to be met using a heat pump solution once the retrofit measures are complete. There are 7 subcategories in this criterion ranging from 0 to 50kW in the first category to >1000kW in the last. Each of the subcategories are weighted and normalised for each scenario based on a numerical scale applied to each subcategory.

1.1.2.4 Drillability – Ground Conditions

The subcategories selected for this criterion were based on the work undertaken in T1.2 of the project. A review of this work in the context of the other modelling and system design tools was also considered. The more complex assessments provided through the project DSS and the dedicated app, assumes that the user has some technical knowledge of GSHP systems and the installation of GHEs. However, during the development of this tool, it was noted that non-technical stakeholders using the MCDA method may not have such knowledge at an early assessment stage.

For this reason, this criterion was also considered in the context of the ability of project drilling technologies and their ability to successfully penetrate different subsurface conditions and a simplified classification comprising three main categories was used. This includes:

- *Hard Rock* – this classification assumes that the ground conditions to a depth of up to 100m (the depth at which GHEs might be installed) is dominated by solid, competent rock;
- *Unconsolidated* – this assumes that the ground conditions to a depth of up to 100m are dominated by loose unconsolidated sediments (gravels, sand, clay, etc.);
- *Unconsolidated & Hard Rock* –assumes that the ground conditions to a depth of up to 100m (the depth at which GHEs might be installed) below a site are mixed, with the presence of unconsolidated sediments close to the surface as well as solid, competent rock at greater depths.

This criterion has been normalised using a weighting distribution in each scenario above based on a scale of 1 to 3, that represents the *hard rock* to the *unconsolidated and hard rock* sub classes respectively.

1.1.2.5 Installed Capacity/Load to Outdoor Space

This criterion is calculated based on the user inputs to three parameters requested by the tool. These include:

- *Approximate Energy Demand Area*
- *Outdoor Space Available*
- *Projected Installed Capacity*

The ratio between the demand area and the outdoor space and separately that of the outdoor space and the projected installed capacity are considered. The aim of the indices is to assess the viability of implementing either of the two following solutions based on the user input:

a) a GSHP solution to meet the full energy demand (this can be conventional GSHP or a high temperature option).

b) the need to consider a dual source heat pump

The indices are calculated based on assuming the need for a minimum spacing of 8m between BHEs in the outdoor space. The calculated index is weighted in each scenario and normalised to facilitate scoring and selection of the final solution.

1.1.2.6 Land Use Setting

This criterion draws on the work of previous projects that have defining land zoning conditions where different GSHP installations may be applicable. Such zones were first presented in the REGEOCITIES project [2] and provide a basis for the setting of a planned retrofit or refurbishment project.

A summary of this classification was also reviewed as part of D1.1. Subsequent recommendation regarding the urban, city centre and historical centres in the context of the deployment, operational interactions of GHEs and neighbouring systems were presented in D6.3. The development of this criterion was therefore focussed on allowing the user to determine a land zones for the project that is being considered with the MCDA tool based on the sub categories provided. The subcategories are chosen to allow the assessment of the following:

- Logistical difficulties associated with the access, drilling and installation of GHEs in city centre locations;
- Difficulties that may be faced in the implementation of hybrid systems where both a geothermal and the ASHP component need to be installed
- The long-term operational effects of GHEs in close proximity and potential environmental impacts.

The subcategories for the Land use criterion used in the MCDA tool are:

- *Historical Centre*
- *Dense Urban*
- *Sparse Urban*
- *New Development*
- *Industrial Commercial Area*

Each of the subclasses are weighted and normalised using a scale of 1 to 5 to reflect the order listed above. The MCDA tool user is required to select from a drop down menu the category that best reflects the project location that they are considering in the assessment.

1.1.2.7 Regulatory Requirements

This is the final criterion of the MCDA tool to be selected by the user. The classes selected summarise the work undertaken as part of subtask 6.1.1 of the project and task 6.2, that comprehensively reviewed the permitting and regulatory requirements relating to both the retrofit and refurbishment of buildings, as well as those regulations and licensing aspects related to the implementation of the GSHP system.

Based on the review of the work undertaken and the target stakeholder groups that this tool is aimed at, the following 3 sub classes have been developed for the user to best describe the permitting requirements that might apply to the their project:

- *Simple GSHP application* – this may be applicable in the case where no major works are implemented to the building. This permit is considered to be applicable only for the GSHP element of the project, and is issued in a relatively short timeline.
- *Planning/Construction Specific Permits* – where more extensive refurbishment works are applicable and are subject to construction permits (this may or may not include the HP element of the project). This type of permit is considered more lengthy and complex to obtain with more extensive timelines.
- *Conservation permits, planning/construction permits & GSHP permit* – this permit category reflects the retrofit intervention in historical buildings where extensive consulta-

tion and multiple permits need to be secured. These are considered to require long timelines prior to approval.

Each of the subclasses are weighted and normalised using a scale of 1 to 3 to reflect the order listed above and the user is required to select from a drop down menu the category that best reflects the project location that they are considering in the assessment.

1.1.3 Scenario Weighting Matrix

Based on the criteria discussed above and considered as part of the MCDA methodology development, a weighting matrix for each criteria was applied. Table 2 below summarises the matrix applied as part of the MCDA tool.

Table 2 – MCDA Tool Criteria Weighting according to different scenarios

Scenario *% Weighting*	Building Archetype	Thermal Envelope	Installed Capacity Range	Drillability – Ground Conditions	Installed Capacity/ Outdoor Space ratio	Land Use Setting	Regulatory Requirements
SCENARIO 1 Historical Building	5	10	20	10	35	15	5
SCENARIO 2 Med- Low Retrofit	5	18	14	10	31	12	10
SCENARIO 3 Deep Retrofit	2	35	5	10	25	5	18

1.1.4 Proposed Solutions

The proposed solutions or alternatives obtained from the MCDA methodology to test a project proposed by the user are discussed below. These are split into two categories and provide a summary of the applicability of the drilling and heat pump solutions developed by the GEO4CIVHIC project.

Drilling Solution – this category presents the possibilities in terms of drilling technologies applicable to the case being tested. The solution compares the conventional drilling methods on the market with the technologies developed by the project. The applicability of the following three categories are assessed:

- *Conventional Drilling* – this includes the main drilling solutions (as reviewed in D1.2 of the project) that are used for GHE installations (Down the Hole Hammer, Tricone, Rotary etc). The category assumes that larger scale machinery to complete the drilling operations and implement the appropriate waste management methodologies are applicable.

- *Hydra-RED* – this category provides the user with the applicability of the Hydra-RED method developed in the project (as described in D2.1 and D2.3). The solution is true when unconsolidated ground conditions are selected by the user and assumes that stainless steel coaxial heat exchangers can be piled directly into the ground (with or without grout). The use of compact, modular drilling equipment with minimal footprint is considered.

- *Hydra-TKI* – this category provides the user with the applicability of the Hydra-TKI methods developed in the project (as described in D2.1 and D2.2). The solution is true when hard rock or a combination of unconsolidated ground and hard rock conditions are selected by the user and assumes that stainless steel coaxial heat exchangers can be with grout. The use of compact, modular drilling equipment with minimal footprint is considered.

Heat Pump (HP) Solution – this category applicability of the heat pump technologies both available on the market as well as the new heat pumps developed as part of the project. The applicability of the following three categories are assessed:

- *Conventional GSHP* – this includes heat pumps as described in D3.1 of the project that can deliver hot water and low temperature heating up to 55ºC (On-Off, Inverter, Multi-function and new generation plug-and-play GSHP solutions from the Galletti group). This solution in the MCDA tool is favoured in the cases where the thermal envelope of the building is significantly improved in the retrofit process.

- *Galletti Dual Source Heat Pump* – this category refers to the dual source heat pump developed as part of the project that integrates an ASHP and a GSHP in a single unit. The Dual Source unit alternates both systems when meeting the energy demand based on the outdoor air and ground conditions. This unit is particularly suited to retrofit scenarios where space restrictions are applicable.

- *Galletti High Temperature Heat Pump* – this category refers to the single source high temperature heat pump developed as part of the project that delivers hot water at 60ºC to 70ºC. This unit is particularly suited to historical buildings scenarios where limited or no intervention on the fabric of the building or the terminals is possible.

The results of the proposed solutions provide the user with a qualitative assessment of the technologies reviewed. The results provided are in no way a substitute for a specific site assessment or design for a retrofit project that need to be undertaken by specialist technical experts. The MCDA solutions provide the user with an indicative assessment of which technologies may be more suitable to help better understand the technical requirement for the next steps of a project.

The qualitative solutions are provided in three specific categories:

- *Preferred Solution* – this is deemed the preferred solution based on the inputs provided;

- *Second Solutions* - this solution may be possible subject to further assessment and investigation by a technical expert;

- *Not Suitable* - this solution is deemed not suitable based on the inputs provided.

1.2 MCDA Tool

The MCDA tool has been developed as an Excel workbook and has been made available to the end user as part of the public status of the deliverable.

The workbook allows the user to provide some basic information on the project they are considering based on a limited number of selections for the criteria discussed above.

1.2.1 Unser Interface

Figure 3 below presents an example of the MCDA tool interface and shows the locations of the inputs required by the user highlighted in the green cells.

In the ‘*Initial User Questions*’ section, the user is required to input three numeric values relating to the energy demand area of the building, which is being assessed for retrofitting, the outdoor space available around the building and finally the estimated installed capacity of the final system.

The user then need to specify the type of retrofit scenario that best describes the project they are considering and provide input to the seven criteria discussed in the earlier sections of the report. All these inputs are provided as a drop down list.

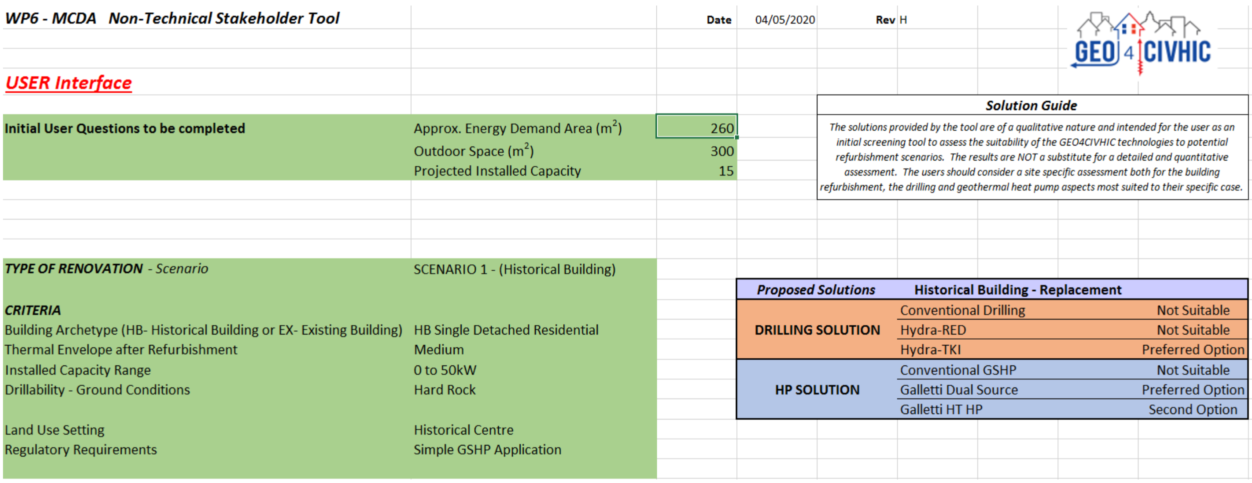

Figure 3 - Worked example of the GEO4CIVHIC MCDA tool and user interface

The alternatives (solutions) for both the drilling and heat pumps categories are provided in the final table based on the ranking discussed above.

1.2.2 DSS Integration

The MCDA tool has been developed in conjunction with the work being implemented in WP4 of the project relating to the DSS. The current MCDA tool is proposed to act as an initial assessment step of the DSS and focussed for non-technical users.

The current version of the MCDA is being integrated to the main DSS interface. However, work will continue on the integration process beyond the submission of the D6.3 deadline, to ensure that in particular the MCDA criteria used are in line with the DSS structure and background project information. This may imply that some criteria and their associated categories will need to be revised to facilitate this integration.

2 Risk Recommendations Matrix

The second part of task 6.3 has focussed on undertaking an outline risk assessment of the retrofit scenarios considered as part of the task in the context of the criteria described in the above MCDA tool. The objective of this risk matrix is to provide the non-technical stakeholder with a set of recommendations based on the assessment for the implementation of the project technologies.

The methodology is based on the risk assessment matrix developed as part of the Cheap-GSHPs project [6] and has taken into consideration the risk assessment work being done as part of T6.1.2 on the outline EIA for the GEO4CIVHIC real case study sites. The work of the outline EIA considers the construction and operational aspects of the project technologies at the real case study sites.

The matrix developed as part of this task, provides initial recommendations based on the risk assessment outcomes for case study sites of the project for the three retrofit scenarios that a non-technical stakeholder would be considering when using the MCDA tool. The recommendations focus on the potential requirements for the implementation of the project technologies.

The matrix is linked to the structure of the MCDA tool and allows the user of the tool to obtain recommendations that will facilitate the implementation of the required next steps of the project based on the outcomes of the risk assessment in the project case study sites and the project technologies at the project technologies deployed. The structure for each scenario, therefore, reflects that of the tool, where recommendations are made on the individual criteria (in some cases these are common to both residential and multi occupancy buildings such as office and apartment blocks), as well as for the individual solutions identified that may be most applicable to that scenario.

The completed matrix and associated recommendations are also being integrated into the DSS as an added output to the MCDA tool outcomes. The matrix is currently provided as an independent Excel spreadsheet for ease of reference.

The sections below present the individual recommendation tables for each scenario, however, the reader is invited to use the Excel version of this matrix for ease of reference

2.1 Scenario 1 – Historical Buildings

Based on the case study site risk assessment works carried out during GEO4CIVHIC on the implementation of the project technologies in historical buildings, table 3 presents a summary of the recommendations made for the key criteria and solutions that may be applicable.

2.2 Scenario 2 – Medium to Low Retrofit

Table 4 presents a summary of the recommendations made for the key criteria and solutions that may be applicable in the case of the implementation of retrofit measures in medium to low retrofit scenarios. It is important that these recommendations be considered in line with local building regulations, where guidelines on performance requirements of the final building as well as the building fabric elements to be retrofit are specified. The building regulations in the area specific to the proposed project should be consulted and a set of intervention measures based on the characteristics of the building, the implications of any restriction (of cultural heritage or other) be determined. These may include the integration of different RE technologies and partial building fabric element upgrades to achieve the necessary regulation standards.

2.3 Scenario 3 – Deep Retrofit

The deep retrofit case recommendations are focussed on the experiences from the implementation of the project technologies in a deep retrofit scenario. The retrofit measures to be considered by the user are defined in the local building regulations covering the Energy Performance of Buildings for the ‘*major renovations’* category. Table 5 summarises some of the recommendations focussed on the implementation of the project technologies.

Table 3 – Risk Recommendations Matrix for the integration of GEO4CIVHIC technologies to historical buildings

	Building Type	Load/Installed Capacity	Outdoor Space	Thermal Envelope After Refurbishment	Ground Conditions (Drillability)	Neighbouring Systems (Land Use)	Regulatory Requirements	Possible Solutions
Historical Building								**DRILLING SOLUTIONS**
SINGLE DETACHED RESIDENTIAL	The historical building category considered in this case comprises any building older than the 1960s of cultural/historical heritage. The building should be considered in the context of it's historical character but also in the case where it is a listed building. In both the residential and multi occupancy case (office or apartment), the building elements considered of cultural and historical value need to be carefully understood by the project developer and the designer in order to determine the level of retrofit intervention possible. Whilst it may be possible to integrate one of the GEO4CIVHIC project solutions, the viability of building fabric retrofit (insulation and glazing) as well as the replacement of heating & cooling terminals need to be considered. A successful design needs to consider all the above aspects in the definition of a detailed energy demand profile and allow for the selection of the most suited solution.	The load and energy demand profile for historical buildings is critical in understanding the possible ground source heat pump or hybrid combinations thatcould be implemented. A detailed energy demand profile should be completed based on the building fabric characteristics and the heat losses from the building structure. Larger loads (>15kW) may need to be met using hybrid solutions. The specific GEO4CIVHIC Heat pump solution for a historical residential building may require the delivery of high temperatures (>55oC) to existing terminals wth no possibility for upgrade to lower temperature terminals.	The availability of outdoor space for a residential historical building needs to be considered in the context of the planned load and energy demand for the building. It is likely that where a GSHP solutions is favoured an adequate amount of space to ensure the long term system performance will be required. The available space is important in the context of the spacing and the collector design as a function of the energy demand load and installed capacity of the system. The accessibility of plant equipment and machinery to allow the installation of GHEs is important and where a dual source system is required, additional space to allow for the combined GSHP and ASHP unit will be required. Whichever of the project technologies are selected, adequate plant room space to accomodate the Heat pump and ancillary equipment is required.	The thermal Envelope of the building after the completion of any refurbishment works is the main key factor determining the GSHP solutions applicable to a historical building. In the case of a residential setting, it is important that accurate heat loss calculations are performed to determine the peak energy demand running profile and the terminal delivery temperatures required. Where possible the design should consider the possibility of reducing the energy demand (in particular peak demand) by improving thermal elements of the building such as reduction of air tightness, improvements of glazing or added glazing, insulation of attic spaces or internal walls where this is possible.	The detailed assessment of the ground conditions expected at a particular site should be undertaken at the early design phase of the project. A technical specialist (geologist, geoscientist, geothermal expert, engineer) will have to complete an assessment of the ground conditions to determine the following key properties: 1) the type of underground conditions present below a site - these will need to focus firstly on the presence of either consolidated or unconsolidated sediments (in some cases both will apply) in order to determine the most suitable drilling method to be used. 2) the thermal properties of the underground sediments will have to be used to define the required total length of borehole heat exchanger needed in for the system. Finally 3) the hydrogeological characteristics (presence of aquifers, and groundwater flow conditions) will need to be determined. The above information will be necessary to determine the following key aspects of the project: a) the total length of ground heat exchanger needed for the demand of the building, b) the selection of the adequate drilling methodology to be implemented based on the land use setting and space available at the site as well as c) understanding the long term subsurface conditions resulting from the operational phase of the system. Where GHE are planned in urban areas, it will be critical that the presence of other underground infrastructure (including archeaological./historical remains) are checked through existing information or new survey methods.	The planning and design of a GSHP or a hybrid heat pump system require the proximity to other GSHP users to be known. BHEs requirement for residential systems are low (up to 2 or 3 probes), the location of neighbouring properties, other historical buildings and other heat pump users will impact both the construction and completion phases of the system as well as the operation and long term ground temperature profile. The urban setting of the system therefore needs to be considered. In historical and urban centre areas, there are greater challenges in the mobilisation of equipment favouring the more compact GEO4CIVHIC drilling solutions. The strict implementation of an environmental management plan including the handling of water and drilling fluids as well as rock cuttings will be critical & more challenging to implement. In the case of both residential and multi occupancy settings, the proximity of buildings with regard to the drilling related vibration and safe operation of equipment needs to be considered and low impact strategies such as those offered by the stainless steel heat exchangers using the Hydra RED method or the TKI methods need to be considered. The planned operational profile of the heat exchanger will need to consider the effect of long term ground temperature on the buildings structures and other nearby GSHP systems. A detailed design should be undertaken in all land use settings with extended focus on higher density areas. Whilst the impact of the drilling and installation works of the GSHP and hybrid technologies is likely to be low risk, a detailed monitoring plan for the operational phase of the building should be undertaken where multi borehole collectors are planned. This should focus on the vibration and proximity of other buildings and historical structures.	Ensure that all regulatory requirements and permissions are obtained. Permission for historical buildings may require not just permits for the GSHP element of the project and planning permissions (building permits), but may also require approval in the context of conservation and preservation of any building aspects. It is important to consult a specialist (architect and mechanical electrical designer) at the early stages of the project to understand the requirements. A consultation with any relevant authorities will also be required.	**Conventional Drilling**: Conventional Drilling Methods are very common and include DTH, Rotary and tricone methods. In most cases these either require high plant equipment footprint or more complex fluid and solids management systems and extended installation times. All of these tend to be less suited for dense urban environments and historical centres. Where percussive drillgin methods are considered (especially where using complressed air) adequate stand off disctances from buildings and structures may further restrict the operational footprint and GHE possibilities. **Hydra RED/ Hydra TKI**: The Hydra-RED & TKI methods is a comprehensive solution for using significantly smaller footprint drilling equipment combined with innovative stainless steel coaxial heat exchangers. The Hydra-RED method allows the heat exchanger to be inserted (piled) into the unconsolidated sediments. This significantly reduces the waste management requirements and the drilling and installation time for each probe. Where hard rock is present, the Hydra-TKI method provides the same benefits. The technology is ideally suited for restricted access and congested urban centres . It is important that a detailed subsurface assessment be completed prior to selecting this method.
								HEAT PUMP SOLUTION
OFFICE-APARTMENT BLOCK		To meet the energy demands of apartment and office blocks, it may be the case that where larger loads are required in more confined urban settings, the heating and cooling loads may have to be met using a hybrid system with ASHPs and a GSHP combined. Careful design of this type of system and in particular of the potential for upgrade of delivery terminals needs to be considered in conjunction with other energy demand reducing measures to the building fabric. It is important that in the early phases of the project, the availability of plant room space for the technical elements of the systems including the HP, the requirements for high temperature buffer vessels, pumps and main internal terminal pipework) be determined and an adequate solution that suits a communal distribution system should be identified. Where outdoor plant equipment is planned (ASHP hybrid) or where a ground source collector is to be installed, the entry of the outdoor pipework into the building to the technical room needs to be planned and accommodated. This should facilitate the design and	The development of a GSHP system in the context of the refurbishment of a multiple occupancy historical buildings such as an apartment block or office, is expected to require a more significant area to accommodate a ground heat exchanger than that of smaller residential systems. In this case, a detailed energy demand profile needs to be modelled with the known ground conditions over the operational life of the system. This will determine the BHE spacing and overall space and configuration requirements of the borehole field. The presenceo f neighbouring systems and users will also affect the size of the GHE that can be completed. Where insufficient area for implementing a GHE with a high temrepatrue heat pump solution is identified, the retrofit desing of the system shoudl focus on splitting the demand load using different technologies whilst maximising the potential for space heating and DHW with a HTHP as much as possible.	The refurbishment potential for apartment block and office buildings should attempt to maximise the implementation of energy efficiency measures within the boundaries of the needs for preservation and conservation of the historical aspects. The requirements under preservation orders of buildings aspects and elements need to be established by a specialist architect in the early stages of the project. Where little potential for refurbishment exists and the thermal envelope of the building cannot be meaningfully improved (through increased insulation, air tightness and glazing) the use of a high temperature heat pump may be the only technology for consideration. This will allow for a renewable alternative to fossil fuel fired high temperature heating systems that are common in historic buildings, with a ground source heat pump alternative. The feasibility of refurbishment measures and their impact on reduced energy demand after retrofit need to be established first in the early stage of the project and used to determine the likely energy demand profile to be used to specify the			The regulatory requirements outlined above in the context of historical buildings should be observed. Where multiple occupancy/ownership of historical buildings is applicable additional agreements/approvals may be required by different stakeholders for the works planned. It is important for the designer/project manager to check if any monitoring requirements are applicable and if this is the case, an adequate system for long term monitoring should be considered. The requriements for specific permits, or the presentation of any EIA studies for large GHE system shoudl be checked and the appropriate authorities consulted	**Conventional GSHP**: The use conventional heat pumps delivering up to 55°C in heating mode, is more limited in the case of historical building refurbishment. It can mostly be considered where a significant improvement in the thermal envelope of the building can be achieved and where adequate terminals can be installed. This type of heat pump is considered to less suitable in the case of historical buildings where reductions in energy demand and energy efficiency measures are considerably more challenging to implement. **Galletti Dual Source**: A dual source heat pump can include a GHSP and a water to water unit or a hybrid GSHP and ASHP system, to meet the energy demand loads of a historical system. In confined urban settings, this might be a preferred option as it may not be possible to satisfy the load entirely using a GSHP in sites where space restrictions apply. The design of the dual source system needs to make all the considerations outlined with respect to GSHSP as outlined in this matrix, but a comprehensive study by a technical expert should be undertaken to define the positioning and integration of the outdoor ASHP elements with the historical building aspect. A detailed structural assessment may be required is supporting frames need to provided. **Galletti HTHP**: The high temperature heat pump is a likely to be a preferred solution particularly with those buildings where little or no refurbishment interventions are possible. This will be the case for listed buildings and those where the internal elements (including the terminals) cannot be modified. The HTHP offers the possibility of delivering 70°C water to existing high temperature terminals and for DHW requirements. It is important to note that HTHPs typically have lower COPs to more conventional type systems. The project manager and installer need to give specific attention to the electrical requirements of the units and the available power source in the buildings which may need upgrading. The use of a HTHP may also need to be considered with other peaking technologies if temperature or energy demand loads cannot be met by a single system . A dedicated monitoring and BMS system which allows more accurate demand control through the HP is critical in this case.

Table 4 – Risk Recommendations Matrix for the integration of GEO4CIVHIC technologies in medium to low retrofit scenarios

Medium/Low Retrofit	Building Type	Load/Installed Capacity	Outdoor Space	Thermal Envelope After Refurbishment	Ground Conditions (Drillability)	Neighbouring Systems (Land Use)	Regulatory Requirements
EXISTING SINGLE DETACHED RESIDENTIAL	The medium to low retrofit category is focussed on those existing buildings (typically built after the 1960s) there may be partial historical elements requiring preservation. These buildings assume that some level of retrofit can be achieved unlike those in the historical building category where greater restriction may apply. In this category building that may have to be partially preserved (eg facades) or distinctive historical structural elements of the building but that allow a retrofit intervention to bring the existing building within the local buildings regulations delaing with the transpositing of the EPBD, without necessarily having the ability to achieve full nZEB status.	The loads assumed in the context of existing buildings where medium to low retrofit are likely to be similar to those considered for historical buildings. The energy demand profiles and in particular the peak demand for space heating and cooling are likely to be strongly dependent on the potential for implementing other energy efficiency measures that help in transitioning from high temperature system to lower ones. The designer needs to consider that in the case of residential buildings of this nature, the ability to meet the energy demand using a GSHP system will potentially require a considerable amount of space. Where high peak demands are applicable, the use of hybrid technologies and systems should be considered.	Out Outdoor space requirement for medium/low residential retrofits using GHSPs are likely to require the completion of several boreholes to meet the demand. The space available at the site needs to be considered in context of neighbouring systems and in unban settings, where restricted outdoor space is available, the possibility of using hybrid heat pumps will require the possibility of adequate substructures to be constructed to achieve this.	Medium to Low retrofit scenarios imply that only partial retrofit measures can be achieved to a building, thus limiting the final reduction in energy consumption that could be achievable if more in depth retrofit measures were possible. Where this is the case, the design generally seeks to maximise energy efficiency measures and reduce heat loss in the building fabric. In a residential setting it may be possible to consider insulation aof some of the elements (attic, floors and internal walls) and improved glazing in line with the preformance requirements set out in the local regulations.	The detailed assessment of the ground conditions expected at a particular site should be undertaken at the early design phase of the project. A technical specialist (geologist, geoscientist, geothermal expert, engineer) will have to complete an assessment of the ground conditions to determine the following key properties: 1) the type of underground conditions present below a site - these will need to focus firstly on the presence of either consolidated or unconsolidated sediments (in some cases both will apply) in order to determine the most suitable drilling method to be used. 2) the thermal properties of the underground sediments will have to be used to define the required total length of borehole heat exchanger needed in for the system. Finally 3) the hydrogeological characteristics (presence of aquifers, and groundwater flow conditions) will need to be determined. The above information will be necessary to determine the following key aspects of the project: a) the total length of ground heat exchanger needed for the demand of the building, b) the selection of the adequate drilling methodology to be implemented based on the land use setting and space available at the site as well as c) understanding the long term subsurface conditions resulting from the operational phase of the system. Where GHE are planned in urban areas, it will be critical that the presence of other underground infrastructure (including archeaological./historical remains) are checked through existing information or new survey methods.	The proximity of other ground source systems should be considered in the case of residential and multi occupancy medium to low retrofit projects. The configuration of the BHE and the long term operational ground temperatures of these can be influence by the proximity of other GSHP users. The proximity of systems is likely to be more important where systems are located in densely populated urban areas. The interaction and performance of the system needs to allow for sufficient spacing between GHE elememts. Where space (or adequate distances between probes) cannot be observed, alternatives such as dual source system may have to be considered. The drilling and completion works for BHEs should be considered in the early stages of the retrofit so as to facilitate access requirements to the site.	The undertaking of a retrofit project will require the owner/project manager to comply will all local regulatory requirements. These may include obtaining planning permission for the proposed changes to the building elements. In the case of low to medium retrofits, the design team should ensure that both the requirement of the local building regulations (in the implementation of the EPBD) are met, but also that any historical building elements (preservation orders on certain building elements) are considered at the early project stages. Where historical elements of a building need to considered in the context of refurbishment, it is critical that specialist advice (conservation architect) be considered to determine the compliance of any medium to low retrofit measures in advance of seeking final permission. In the case of larger scale systems for office or apartment buildings, the regualtiosn around the permitting, installation and monitoring of a GHSP system shoudl be know and adequate expertise sought to comply with any permit and regulatory requirements.
EXISTING OFFICE-APARTMENT BLOCK		The installed capacity of multi occupancy buildings exposed to medium or low retrofit levels, may be significantly higher than those with deep retrofit potential. The design of the system should consider the installed capacity requirements and consider where appropriate the use of hybrid systems and multiple technologies in order to satisfy the RE requriements set out in local building regulations. In particular the ability to upgrade terminals with lower temperature solutions shoudl be taken into consideration and whrere possible and partial loads satisfied using lower temepratrue technologies.	The availability of outdoor space for larger office or apartment blocks is critical at determining the viability and implementation of any GSHP options. Where restricted access to outdoor spaces for drilling operations is present, the GEO4CIVHIC drilling technologies may be the only solutions possible for the completion of a GSHP system. At the early design stage, the temperature and peak demand profiles of the of the multi occupancy buildings should be determined and any available outdoor space considered for installing BHEs. Where the outdoor space to indoor demand area requirement is too high, the use of outdoor areas should be maximised to use GHEs for cooling and space heating, with the use of a dual source system to provide the balance of the demand. The desinger will also have to give careful consideration to any space requriements for techncial plant room elements (these can be larger where several technologies are used) and to the potential for ugrading centralised heating and cooling mains distribution systems.	In larger medium to low retrofit projects, the thermal envelope of the building elements could be significantly improved through internal insulation measures of walls and floors and where possible windows. The thermal envelope achieved should favour the possibility of replacing primary high temperature heating systems and the asscociated distribution pipework with lower temperature heat pumps. This will also require the upgrading of terminals that could potentially reduce the level of demand required. Whilst any historical character of the building should be preserved, in larger buildings the possibility of achieving close to nZEB retrofit standards should be achieved. The use of energy efficient glazing, internal insulation and increased air tightness measures should be maximised as much as the building fabric allows in line with the local regulations that are applicable where not major renovation are being undertaken.			

Possible Solutions					
DRILLING SOLUTIONS					
Conventional Drilling	Conventional Drilling Methods are very common and include DTH, Rotary and tricone methods. In most cases these either require high plant equipment footprint or more complex fluid and solids management systems and extended installation times. All of these tend to be less suited for dense urban environments and historical centres. Where percussive drillgin methods are considered (especially where using complressed air) adequate stand off disctances from buildings and structures may further restrict the operational footprint and GHE possibilities.	**Hydra RED/ Hydra TKI**	The Hydra-RED & TKI methods is a comprehensive solution for using significantly smaller footprint drilling equipment combined with innovative stainless steel coaxial heat exchangers. The Hydra-RED method allows the heat exchanger to be inserted (piled) into the unconsolidated sediments. This significantly reduces the waste management requirements and the drilling and installation time for each probe. Where hard rock is present, the Hydra-TKI method provides the same benefits. The technology is ideally suited for restricted access and congested urban centres . It is important that a detailed subsurface assessment be completed prior to selecting this method.		
HEAT PUMP SOLUTION					
Conventional GSHP	The use conventional heat pumps delivering up to 55°C in heating mode will be limited in medium to low retrofit scenarios only where the thermal envelope of the building can be significantly improved and where heat loss can be minimised. The lower temperature HP will also require an upgrade to terminals in many of the building zones to deliver heating and cooling. The type of heat pump is considered to be potentially less suitable in the case of historical buildings where only partial retrofit measures (not to nZEB standard) can be implemented. Conversely it may be applicable where high thermal envelopes can be achieved in the retrofit and air tightness can be imporved.	**Galletti Dual Source**	A dual source heat pump can include a GHSP and a water to water unit or a hybrid GSHP and ASHP system, to meet the energy demand loads. In the case of the medium to low retrofit scenrio this may be ideally suited where medium to high thermal envelopes can be achieved or in confined urban settings, this might be a preferred option as it may not be possible to satisfy the load entirely using a GSHP. The design of the dual source system needs to make all the considerations outlined with respect to GSHSP as outlined in this matrix, but a comprehensive study by a technical expert should be undertaken to define the positioning and integration of the outdoor ASHP elements with the historical building aspect. A detailed structural assessment may be required is supporting frames need to provided.	**Galletti HTHP**	The high temperature heat pump is a likely to be a preferred solution particularly with those buildings where llow retrofit scenrios may apply and where limited building fabric improvement works are possible. The HT HP offer the possibility of delivering 70°C water to existing terminals and for hot water requirements. It is important o note that HTHPs typically have lower COPs to more conventional type systems. The project manager and installer need to give specific attention to the electrical requirements of the units and the available power source in the buildings which may need upgrading. The use of a HTHP in this scenrio is therefore favoured on ly in the limited cases where only a low thermal envelope can be achieved.

Table 5 – Risk Recommendations Matrix for the integration of GEO4CIVHIC technologies in deep retrofit scenarios

	Building Type	Load/Installed Capacity	Outdoor Space	Thermal Envelope After Refurbishment	Ground Conditions (Drillability)	Neighbouring Systems (Land Use)	Regulatory Requirements	Possible Solutions					
Deep Retrofit								DRILLING SOLUTIONS					
EXISTING SINGLE DETACHED RESIDENTIAL	The buildings considered under this category would comprises mostly buildings post 1960 where deep retrofit measures in line with those of the local building regulations for the major refurbishment of buildings are applied. The Deep retrofit case considers the application of significant retrofit and energy improvement measures to a building. In both the cases of the single residential and the apartment/office block buildings, the assumption is that the retrofit measures to be applied are in line with nZEB building standards and passive house standards. In these scenarios the designers an project managers will aim to retain only a minimal part of the original building structure and maximise energy efficency measures as part of the proposed retrofit works.	A single residential building that has undergone deep retrofit is likely to have very low energy demands with limited peak demand profiles. The latitude and climatic conditions of the residential building being considered will define the requirements for cooling and heating, The load will be mostly determined by the peak demand profile. Where the energy demand is to be met using a GHSP system, this may be likely to require a low number of BHEs (in some cases a single HE may be sufficient).	The outdoor space requirement for the installation of BHEs for deep retrofit projects can be significantly lower than in the case of that of historical buildings. The reduced energy demand typically requires 1 BHE to be installed. It is likely that with the implementation of deep retrofit measures, the presence of favourable ground conditions may be able to satisfy 100% of the of the heating and cooling load in residential applications.	The refurbishment aspects of a deep retrofit project are critical. The designer and project manager (or architect) will aim to achieve the nZEB standards as set out in local regulations. These strongly focus on the implementation of high end insulation material and maximising the building fabric and opaque element upgrades in order to minimise heat losses in the heating season. Heat gains in the cooling will be minimised through mechanical ventilation, shading and glazing. Thermal modelling of heat loads in the final design is critical to understanding the final energy demand of the residential building.	he detailed assessment of the ground conditions expected at a particular site should be undertaken at the early design phase of the project. A technical specialist (geologist, geoscientist, geothermal expert, engineer) will have to complete an assessment of the ground conditions to determine the following key properties: 1) the type of underground conditions present below a site - these will need to focus firstly on the presence of either consolidated or unconsolidated sediments (in some cases both will apply) in order to determine the most suitable drilling method to be used. 2) the thermal properties of the underground sediments will have to be used to define the required total length of borehole heat exchanger needed in for the system. Finally 3) the hydrogeological characteristics (presence of aquifers, and groundwater flow conditions) will need to be determined. The above information will be necessary to determine the following key aspects of the project: a) the total length of ground heat exchanger needed for the demand of the building, b) the selection of the adequate drilling methodology to be implemented based on the land use setting and space available at the site as well as c) understanding the long term subsurface conditions resulting from the operational phase of the system. Where GHE are planned in urban areas, it will be critical that the presence of other underground infrastructure (including archeological./historical remains) are checked through existing information or new survey methods.	The land use setting of a ground source heat pump system and collector (residential or larger multi occupancy building) will need to be considered. Whilst deep retrofit projects typically result in reduced energy demands and smaller installed GSHP capacities, the operational setting of the GHE in context of neghbouring system should be considered. In dense urban environments, challenges may present themselves in the deployment of ground collectors where other GHSP systems are present in close proximity, where other subsurface uses are taking place (underground infrastructure) and nearby building structures. Whilst it can be assumed that these challenges are most likely less applicable in the case of small scale collector like those for residential systems where deep retrofits have been undertaken, the development of larger collector for apartment blocks and office buildings may need to considered in much more detail. Where GSHP systems are planned outside of urban areas, the construction phase challenges for drilling plant equipment are likely to be reduced, as well as the potential for impact between neighbouring systems given the typically more dispersed nature of developments. The project manager and designer will need to take the construction and operational aspects of the projects during the planning phase and adapt these to local regulations and requirements.	Regulatory requirement for deep retrofit project will in most cases require a planning consent from the local authorities. It may be necessary for residential GSHP system to register the (or obtain a permit) for the installation of the GHE elements. The designer/project manager should focus on ensuring that all such permits are obtained and that local guidance on the drilling construction and completion of GHEs are followed as well as any requirements under the local building regulations concerning the retrofit elements.	**Conventional Drilling**	Conventional Drilling Methods are very common and include DTH, Rotary and tricone methods. In most cases these either require high plant equipment footprint or more complex fluid and solids management systems and extended installation times. All of these tend to be less suited for dense urban environments and historical centres.	**Hydra RED/ Hydra TKI**	The Hydra-RED & TKI methods is a comprehensive solution for using significantly smaller footprint drilling equipment combined with innovative stainless steel coaxial heat exchangers. The Hydra-RED method allows the heat exchanger to be inserted (piled) into the unconsolidated sediments. This significantly reduces the waste management requirements and the drilling and installation time for each probe. Where hard rock is present, the Hydra-TKI method provides the same benefits. The technology is ideally suited for restricted access and congested urban centres . It is important that a detailed subsurface assessment be completed prior to selecting this method.		
								HEAT PUMP SOLUTION					
EXISTING OFFICE-APARTMENT BLOCK		Existing buildings including apartment blocks and offices that undergo deep retrofit are likely to have low energy demands with limited peak demand profiles. The latitude and climatic conditions need to be considered to define the requirements for cooling and heating. It is important in the early design phases of the system to identify the space heating, hot water and cooling temeprature profiles required and if these may be required simultaneously to determine the most adequate technology selection. The loads will be mostly determined by the peak demand profile. The load capacity determination and technology selection should consider maximising the GSHP solution where cooling is required and maximising a potential for balanced collector loads.	Available outdoor space in larger multi occupancy buildings such as apartment blocks and offices is important in determining the heat pump solution best suited to the demand profile. The available outdoor space needs to be considered in the context of the land use setting of the proposed development (urban centre or other), the presence of other neighbouring systems and other users. Whilst deep retrofit projects are likely to have lower space requirements as a result of the increased energy efficiency measures included as part of the retrofit, the available space around (or below if possible) the building should be considered to allow for the development of GHEs especially where a cooling demand is present.	The implementation of deep retrofit measures in multi occupancy buildings including apartment blocks and offices needs to follow local regulation that transpose the implementation of the EPBD. In the case of commercial and public buildings, the completion of nZEB standard buildings is required as part of this design. The implementation of several energy efficiency measures, the used of specific buildings materials, insulation and glazing will be coupled with other technologies including shading, mechanical air ventilation to increase energy efficiency and reduce demand. A detailed thermal model of the refurbished building structure needs to be completed at early project design stage to understand the heating and cooling energy requirements. The demand obtained from the design shall determine the sizing of the heat pump solution for the project and the ground heat exchanger needed to satisfy this.			The deep retrofit of multi occupancy buildings such as offices and apartment block will require necessary permits in term of planning/construction permissions to be obtained. In some local jurisdictions, legislation and regulation relating to obtaining permits for large or multi borehole heat exchangers for GHSPs will also apply. It is critical that any initial design (spacing, layout, operational profile and BHE construction details) be approved for permission by any responsible authorities in line with local regulations. The project manager/designer needs to consider that any potential restriction (due to the presence of nearby systems or underground users) may limit the potential for meeting the energy demand from GHSPs. The final design of the proposed retrofit project to include detailed specification of retrofit materials and solutions as well as specification of the renewable technology options to be used needs to been lime with the regulations relating to the EPBD and submitted for approval at the planning	**Conventional GSHP**	The use of lower temperature (35°C) heat pump solutions will be the preferred option for deep retrofit buildings. This technology provides greater COP and seasonal performance (SPF).	**Galletti Dual Source**	The dual source heat pump provides a potential solution for the provision of renewable heating and cooling solution in challenging spaces where little or no access may be possible for GHEs. The use of this technology can facilitate in providing higher efficiency options whrer heating and cooling loads are present and whrere space restrictions are present..	**Galletti HTHP**	The use of a HTHP in a deep retrofit setting will very unlikely. The refurbishment measures implemented should have contributed at reducing the energy demand temperatures and promoting higher COP heat pump solutions.

Conclusion

The new GEO4CIVHIC technologies developed for the drilling and installation of ground heat exchangers as well as the new heat pump solutions have been considered based on a number of possible retrofit scenarios similar to those described in the project case study sites.

A review of the barriers and the potential solutions for the implementation of the project technologies carried out in the early parts of the project has been undertaken, in order to develop tools for non-technical stakeholders to demonstrate the integration potential of the project technologies.

An MCDA tool has been developed, allowing the user to complete initial qualitative screening assessments of the suitability of the project technologies, based on seven key criteria. These were identified throughout the project as critical to the implementation of the project technologies in the retrofit sector. The criteria define the type of buildings being considered and the possible retrofit measures that can be implemented, in order to increase energy efficiency and promote the use of ground source and dual source heat pumps.

The scenarios modelled are based on the implementation of the EPBD in local building regulations, where specific intervention measures in the context of the building fabric, use of renewable technologies are defined. The scenarios considered include historical buildings that are typically exempt from these regulatory requirements. Medium and deep retrofit intervention scenarios are also considered. The project technologies provide solutions for the implementation of ground heat exchangers and heat pumps solutions, in sites where space restrictions would otherwise not permit such interventions and the integration of HP technologies, such as historical and urban centre locations.

The MCDA tool allows a non-technical user to provide basic project characteristic and assess the viability of the GEO4CIVHIC technologies, by selecting from options for seven criteria that have been defined as critical to the design of refurbishment measures and selection of renewable heating and cooling technologies.

A risk assessment of the project technology implementation at the case study sites has been developed. The outcome of the assessment provides a set of initial recommendations and considerations for the non-technical end user on the best strategies for the integration of the project drilling and GHE technologies, as well as the heat pump innovations. The outcomes of the tool are provided as a qualitative result in advance of progressing a project to detailed technical design and implementation. A recommendations matrix based on the criteria and scenarios discussed as part of the MCDA tool has been developed.

The MCDA tool and the recommendations matrix are being integrated into the GEO4CIVHIC DSS in WP4 to facilitate its use for non-technical stakeholders. The outputs of the tool and recommendations matrix will be integrated into the training and dissemination activities planned as part of WP8.

The outputs of this deliverable have considered the cost aspects presented for the real and virtual case studies during the project. However, as the implementation of the technologies in the WP5 tasks has not yet taken place at the time of writing, an outline cost benefit in the context of actual costs incurred and necessary contingencies, will be completed in the later stages of the project. The recommendations matrix will be updated in the later part of WP6, when the final technology recommendations will be made (D6.7) and include cost contingency recommendations.

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