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Risk Assessment Matrix

WP7

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Publishable summary

The Risk Assessment Matrix is a public document delivered in the context of WP7 and Task 7.2.

The main objective of this task was to build a risk assessment methodology to be used by both industry stakeholders and policy makers when considering the deployment of helicoidal & coaxial GSHEs that have been developed as part of the CHEAP-GSHPs project.

The matrix provides a support tool for assessing the specific aspects relating to the design, installation and operation of the collector in different environmental conditions as well as in the context of the different building types presented in the project and how the different characteristics of these as well as their energy demands can be addressed using the collector, drilling and heat pump technologies developed by the project.

The matrix also present the needs for considering the technologies developed in the project in the context of the building types, the potential for integration with other technologies and the heating and cooling delivery systems considered as part of these installations.

The risk assessment matrix will be included as one of the key support tools to the main recommendations to be provided in WP7 as part of deliverable D7.8. The structure of the risk assessment matrix and the outcomes of the decision recommendations made will be incorporated as part of the development of the DSS in WP5.

Abbreviations

Cheap-GSHPs **Ch**eap and **E**fficient **Ap**plication of reliable **G**round **S**ource **H**eat Exchangers and **P**ump**s**

CO_2 Carbon Dioxide

DSS Decision Support System

DTH Down the Hole Hammer

EIA Environmental Impact Assessment

GSHE Ground Source Heat Exchangers

GSHP Ground Source Heat Pump

TRT Thermal Response Test

WP Work Package

Introduction

The development of new ground heat exchangers and drilling methodologies as part of the CHEAP-GSHPs project has been considered in the context of common EIA risk assessment methodologies [1]. These methodologies are designed to assess the likely impacts, which a proposed development may have on soils, geological and hydrogeological environments, for the inclusion in an EIS.

The methodology behind this process has been applied in the context of the CHEAP-GSHPs technologies when considering the entire project development process. This includes the design and sizing of the ground loops and ground heat exchanger boreholes, the construction operations including the drilling methodologies to be used and the integration of ground source heat pump technologies in the context of different building types.

The risk assessment matrix considers all aspects of the site assessment and ground conditions, collector construction and heat pump integration where the environmental and safety conditions associated with collector construction are considered.

The work completed as part of work packages 1, 2 and 3 has been comprehensively reviewed as part of the matrix structure development and completion of the recommendations with respect to the selection of the new drilling methodologies and the deployment of collectors in the different ground conditions and buildings. The development of new heat pump technology, and in particular the selection process described as part of D4.1, has been the main source of information for considering the integration of GSHP technologies in buildings. The recent results of the real case study field operation in WP6, where the drilling techniques and collector deployment are being tested, have provided key inputs to the completion of the matrix.

The risk assessment methodology applied provides a number of outline recommendations for industry stakeholders and decision makers with respect to the CHEAP-GSHPs technologies selection process in the context of different ground conditions and building types. The recommendations proposed are formulated in such a way as to have the potential for being integrated with local regulatory conditions and allow for these to be adapted in different project jurisdictions.
The risk assessment structure will form the basis for the completion of outline EIA in the real case study sites and will facilitate the development of the DSS as part of the CHEAP-GSHPs project.

The risk assessment matrix will form an integral part of the main regulatory recommendations in D7.8 as part of the conclusion of the WP7.

1 Risk Assessment Matrix for CHEAP-GSHPs Technologies in Different Environments

The completion of ground source heat exchangers is considered as part of the risk assessment matrix in the context of the characteristics of the underground conditions most suited to the use of the helicoidal and coaxial heat exchangers developed by the CHEAP-GSHPs project.

The classification of the ground conditions and the drillability of the ground have been described in deliverable 1.1 where the ground conditions of the virtual and real case study sites were assessed. This thematic issues will be mapped at different scales and detail in the running task 1.5.

A comprehensive analysis of the local legislative and regulatory conditions across the case study sites has been presented as part of deliverables 7.1 and 7.2. The analysis shows the presence of varying regulatory conditions with respect to the drilling and completion of ground source heat exchangers in the context of the subsurface geology and the presence of drinking water and/or pressurized aquifers.

The ground heat exchanger technologies developed by the CHEAP-GSHPs project, as well as the drilling methodologies associated with the installation of these, are applicable to shallow subsurface conditions in the case of the helicoidal collectors and deeper installation depths in the context of the coaxial heat exchangers. One of the key factors highlighted in the regulatory analysis has been the interaction of the drilling process and the installation of ground heat exchangers with respect to the presence of aquifers.

The risk assessment matrix has therefore considered the potential for installation of these collectors in the context of three subsurface environments (table 1). A passive environment where collectors are likely to be installed above the water table is considered in category A. The presence of aquifer layers that may be present where collectors are planned to be installed are considered in category B. Category C considers vulnerable environments where either groundwater protection zones are applicable, where special of areas of conservation may be present and how specific applicable regulatory recommendation must be considered.

Table 1 – Summary of Environment Classifications

Type	Class	Description	Example
ENVIRONEMENT	A	**Passive**	Confined conditions, above water table
	B	**Dynamic**	Active Geological and Hydrogeological Environment – below the water table
	C	**Sensitive**	Groundwater Protection Zone, Areas mapped as high Vulnerability, Natura 2000 sites, Special Areas of Conservation

Table 2 – Risk Assessment Matrix for Different subsurface environments with considerations for the design, drilling and installation and operation of GSHE

SEC Class	Subsurface					GSHP Construction & Operation			
	Ground Characterisation	Collector Design & Space				Drilling & Earthworks			Extraction & Discharge of Heat
A	A site assessment identifying the exact underground conditions at a site should be undertaken based on the CHEAP-GHSPs underground classification (FAU-PARMAT Classification D1.4).	The helicoidal and coaxial collector are suited in ground conditions above the water table. Consideration of the specific thermal properties of the ground conditions to maximise collector efficiency and facilitate the design process.	Collector above the water table favour the use of auguring (conventional or enhanced EasyDrill system) or the use of the direct piling technology.	The direct piling technology provides the least amount of ground disturbance with limited use materials and drilling equipment.	Estimate potential Thermal properties of the ground to model the likely collector size and configuration using the CHEAP-GSHP DSS or specialist software. The design of the collector must match the heating or cooling load identified and facilitate an adequate selection process.	Determine drillability of the formation and estimated likely rate of penetrations. Where thick overburden or unconsolidated material is expected the drilling and completion may consider a single drilling method which favours the use of auguring or piling. Considerations to the presence of layers that are less easy to penetrate (gravels, tills) must be considered at the early stages of the drilling methodology selection and mitigating measures to overcome these problems should be identified. Where unconsolidated sediments are present over hard bedrock, several techniques to complete a collector may be required with the use of piling or auguring in the shallow surface section and the rotary tricone and DTH drilling methods in the hard rock formation.	Based on the characteristics of the ground conditions, consider appropriate drilling techniques: Wide diameter Easy Drill System for the installation of Helix collector. Best suited for unconsolidated formations and shallow collectors. Roto-Vibro drilling for the installation of coaxial heat exchangers best suited for unconsolidated materials or where minimal drilling spoil impact is required.	The use of helicoidal collector requires preservation of the spiral spacing (pitch) in order to ensure adequate performance. The use of helix pipe spacers must be considered. Backfilling of the borehole were the helix is installed should be completed from the bottom of the borehole using and injection pump. The use of water at the site for the drilling operations should be considered. This can be achieved through a water recirculation system and sump or through a separate water supply of adequate flow rate. The drilling operations need to consider areas where water may be lost in the underground and have adequate water supply available to mitigate this.	Assess thermal ground conditions been assessed to ensure adequate delivery of heating and cooling where the proposed collector is above the water table. Instantaneous or peak demand to the collector is a critical design parameter that affects long term operation.
B		Where groundwater may be present in the ground conditions at a given site, the impact of these of the expected heat extraction rates and the performance of the system should be considered at early design stages.	Where groundwater is present in the underground, the collector completion should include the use of grouting material in accordance with EN 17628:2015 should be used for both helix and coaxial collectors.	Where groundwater is expected during the completion of the collector, a suitable management system for water run off from the drilling operations must be put in place. This can include water recirculation.				Consider the hydrogeological conditions and height of the water table. Make provisions for adequate drilling methodology - All the CHEAP GSHPs drilling technologies may be suitable with lower potential for impact on groundwater	Assessment to determine site specific hydrogeological conditions, GW flow gradient as these are important in the event of proximity to other geothermal collectors upgradient of your site.
C	Assess restrictions imposed on the completion of geothermal systems in sensitive areas - proceed with a detailed risk assessment. Where systems are permitted in areas of environmental protection an adequate collector drilling methodology and collector completion strategy must be considered.			Collectors installed in the areas with existing aquifers or environmentally sensitive areas should be completed in accordance with local regulations on the construction and completion of ground source heat exchanger systems.	Where coaxial HE are planned consider electrical currents in the ground and need for cathodic/anodic protection. Local standards and protocols on anodic and cathodic protection.			Develop a detailed drilling programmes that minimises adverse impact to sensitive environment. This needs to consider the use of foam or polymer drilling with the use of biodegradable drilling materials possible.	Collector operation in environmentally sensitive areas should consider minimising any high peaks in temperature at the operational stage. Heat extraction and injection to the ground should be considered in the context of any local regulations that may be applicable. Where restrictions on the heat extraction and injection are applicable, a detailed operational model of the collector may be required to demonstrate minimal environmental impact.

2 Risk Assessment Matrix for CHEAP-GSHPs Technologies in Different Buildings

The methodology for considering risks of integrating GSHP technologies in different buildings has been considered in the context of the building types described in deliverable 1.4 (figure 1) [2]. Table 3 below presents the building classifications considered in the risk assessment matrix.

	RB 1	RB 2	RB 3	RB 4
External view				
S/V ratio	0.86	0.40	0.35	0.43
Net area (m^2)	210	126	1330	681
% glazed area	14%	12%	25%	14%
No. storeys	2	4	6	6
No. dwellings	1	1	20	10
Urban structure	stand alone	contiguous	stand alone	stand alone

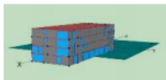
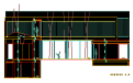
	NRB 1	NRB 2	NRB 3	NRB 4	NRB5
External view					
S/V ratio	0.5	0.5	0.33	0.37	0.26
Net volume (m^3)	5700	5700	3951	3366	5713
% glazed area	85%	50%	49%	45%	35%
No. storeys	5	5	4	2	2
No. people	100	100	454	201	50
Building Use	Administrative Building	Administrative building	Administrative building	Day care centre	Office building

Figure 1 – Summary of Building Typologies presented in deliverable 1.4.

Seven different building types are included in this classification. Residential buildings in category ‘D’ are considered in the case of individual family homes or in the case of communal buildings including multiple single houses or higher rise developments including flats and apartments. The energy demand assumptions of these were considered in line with those defined in deliverable 1.4.

Two different types of residential buildings have been considered in the completion of the matrix presented in this document. Three types of commercial buildings have been considered. These include office buildings, municipal and public buildings and health care facilities. The level of building insulation is considered to be relatively good or better following the completion of retrofitting or renovation. Buildings in category E are considered in most cases as having lower heating and higher cooling loads given the higher internal gains resulting due to higher occupancy levels and presence of IT equipment.

A separate category not considered in D 1.4 has been included in the risk assessment matrix to cover historical buildings and protected structures. The nature of these buildings is such that specific considerations are required. The location of historical buildings often in dense urban and historical city centre settings, presents challenges with respect to the design and installation aspects of ground heat exchangers. The integration of heat pump technologies and the use of heating and cooling delivery systems and terminals in these buildings also pose specific challenges not commonly met in the retrofitting of more modern buildings.

Tables 4 and 5 present the summary of the risk assessment matrix recommendations in the context of the design, construction, operation and integration of ground source heat exchangers and pumps in the different buildings considered.

Table 3 – Summary of Building Infrastructure Classifications

Type	Class	Description			Example
BUILDING INFRASTRUCTURE	D	Residential	D1	Single Family Home	Based on building envelope status and window types - Task 1.4
			D2	Flat or Apartment Building	
	E	Commercial	E1	Office Building	Envelope Type and Windows - low heating load due to internal loads - High cooling loads
			E2	Municipal/Public Building	
			E3	Health Care Facility	
	F	Historical / Protected Structure			National Heritage Site, Listed Buildings, Historical Buildings

Table 4 – Risk Assessment Matrix for Different building types with considerations for the design, drilling and installation and operation of GSHE

<table>
<tr><th colspan="2" rowspan="2">SEC Class</th><th colspan="5">Subsurface</th><th colspan="4">GSHP Construction & Operation</th></tr>
<tr><th>Ground Characterisation</th><th colspan="4">Collector Design & Space</th><th colspan="3">Drilling & Earthworks</th><th>Extraction & Discharge of Heat</th></tr>
<tr><td rowspan="2">D</td><td>D1</td><td>Single borehole collectors for smaller domestic applications, determine the proximity of other collector in neighbouring sites to ensure that adequate collector distances can be maintained</td><td rowspan="7">Site assessment to consider ensure sufficient space for the heat demand identified and chosen collector type - space may dictate the amount of collector that can be installed at a given location.</td><td>The helicoidal collector provides considerable space saving potential against any planned horizontal collector that may be considered in the case of residential systems with limited increase in cost.</td><td rowspan="7">In areas of confined space consider site safety and availability of safe ingress and egress at the drilling and construction stages. Portable equipment on tracks using auxiliary power packs and air supplies should be favoured over any other conventional drilling methods.</td><td></td><td rowspan="5">Assess the potential using piling based roto-vibro technology where foundations and piling is considered at early building installation</td><td rowspan="5">A site specific method statement describing the proposed drilling technologies to be used should be completed. This will address the selection of one or several technologies based on the ground conditions present as well as identify site construction and installation risks that can be mitigated at the drilling stage.</td><td rowspan="5">Sites with confined space for the deployment of either small scale residential ground source collectors or more complex collector should favour the use of CHEAP-GSHPs drilling technology that offers considerable smaller footprint for drilling and installation equipment. The potential for access to restricted sites is further increased with the use power and auxiliary modular systems</td><td>Consideration as to the operational load of smaller collector should be considered with respect o to nearby systems. Where local planning information and ground data is available this should b consulted to ensure adequate spacing to existing collectors can be achieved. Local regulations for residential systems siting should be considered.</td></tr>
<tr><td>D2</td><td rowspan="6">Ensure site specific data including the completion of test hole and a TRT test is planned where a multiple borehole collector is considered</td><td rowspan="4">Communal ground source collectors for multiple dwellings or non-residential facilities should be integrated into planned development and at refurbishment stage as a means of maximising system efficiency and installation costs.</td><td rowspan="4">Consider the location and size of other multi borehole collectors addressing larger loads in the proximity of the site to any other geothermal installation. The collector spacing and completion of boreholes should maximise heat transfers based on the collector type selected and the available geological conditions.</td><td rowspan="5">Model heating and cooling loads to the collector with respect to long term operation to demonstrate impact on the ground where large multiple borehole collectors are planned.</td></tr>
<tr><td rowspan="3">E</td><td>E1</td></tr>
<tr><td>E2</td></tr>
<tr><td>E3</td></tr>
<tr><td colspan="2" rowspan="2">F</td><td rowspan="2">Historical building sites may be limited in space and therefore the use of the coaxial heat exchanger may be favoured to achieve any potentially larger loads that the buildings may require.</td><td></td><td rowspan="2">A drilling programme in areas of historical buildings must consider the requirements for collector construction and completion that include the use of drilling fluids and water at the site, the management of drilling waste that may be necessary.</td><td>The use of the EasyDrill methodology for installation of helix collectors in appropriate ground conditions removes the need for drilling with water and mud based circulation systems, facilitating the drilling operations and the potential environmental impact at the site.</td><td>Historical building or protected structure may have noise and operational hour restrictions. The HYDRA drilling equipment provides lower noise level drilling solutions suitable to addressing restrictions.</td></tr>
<tr><td>Assess building foundations and ground conditions to avoid generating instability and potential for subsidence for the configuration chosen - where ground stability of subsidence is considered an issue, the installation of the coaxial collector using the roto-vibro method is most suited.</td><td>Identify any noise and vibration restrictions that might be applicable to the drilling operations- these may relate to the geomechanical properties of the ground conditions of the building or neighbouring structures</td><td>Preferential considerations to drilling methods generating lower vibrations including short borehole auguring and vibrating head technologies as these have the potential to cause limited disturbance in the underground instead of conventional DTH or air based technologies should be considered as an increased safety feature offered by the CHEAP-GSHPs drilling technologies in close proximity to sensitive basement and foundations.</td><td>Building foundations and local ground conditions need to be considered with respect to the long term operation of the system and proposed collector loads to ensure stability issues are correctly addressed.</td></tr>
</table>

Table 5 – Risk Assessment Matrix for Different building types with considerations relating to building characteristics and integration aspects of GSHP System

<table>
<tr><th colspan="2" rowspan="2">SEC Class</th><th colspan="4">Building</th></tr>
<tr><th>Building Characteristics</th><th colspan="3">HP Integration</th></tr>
<tr><td rowspan="2">D</td><td>D1</td><td rowspan="5">The use of heat pump technology in retrofit scenarios should consider the building fabric and the potential for integration of HP technology with other renewables. Where the ground source heat pump system is replacing an existing heating or cooling technology, the benefits of the installation based on the installation running costs and overall savings achieved with the ground source systems should be included.</td><td rowspan="4">Characterise the expected HP load based on other proposed/used technologies, ensuring that the use of hybrid systems is maximised and that the HP is integrated with other technologies</td><td rowspan="6">Where new build residential or non-residential projects consider the use of ground source heat pump technology, the heating and cooling delivery system selected must take into consideration the GSHP system and be completed in line with the local building regulations and specifications for new buildings.</td><td rowspan="6">GSHP integration as part of retrofits of buildings must consider the proposed heating and cooling delivery system. The installation should follow guidelines and regulations on the requirements for retrofitting buildings and consider the optimisation of heat delivery at lower temperatures where possible. Where lower indoor design temperatures are not achievable, the use of higher temperature heat pumps developed as part of the CHEAP-GSHPs project should be considered. These can make use of 2 separate cycles (low and high temepraturе) and improve the efficiency of the heat pump.</td></tr>
<tr><td>D2</td></tr>
<tr><td rowspan="3">E</td><td>E1</td></tr>
<tr><td>E2</td></tr>
<tr><td>E3</td><td rowspan="3">Detail the operating heating a cooling daily of monthly profiles for a historical buildings - the use of high temperature heat pump may be better suited to higher temperature requirements. The use of the Galletti transcritical CO2 heat pump can provide savings in both cooling and heating operation against existing or competitive technologies.</td></tr>
<tr><td colspan="2" rowspan="2">F</td><td>Overall level of insulation will typically be poorer compered to new build systems as a result of the listed/historical building status requiring the preservation of existing building finish. GSHP integration design should focus on the potential for integrating the Galletti high temperature heat pump suited for higher temperatures</td></tr>
<tr><td>Listed an historical building aspects including windows and other measures designed at improving building efficiency (reduction of thermal bridges, air tightness) are not likely to be able to be changed. System design must consider how these can affect the overall operational profile of a GSHP system</td><td colspan="2">Assess building characteristics and existing heating & cooling system infrastructure. Many of the existing infrastructure may not be changed in the case of historical buildings. Visual impact of potential of heating and cooling delivery technologies needs to be considered and a final design plan proposed to the authorities responsible for heritage. The use of the a high temperature heat pump will help facilitate the seamless integration of heat pump technology to historical building systems.</td></tr>
</table>

3 Conclusions

The new collector and drilling technologies developed as part of the CHEAP-GSHPs project have been assessed based on risk assessment methodologies common to EIAs. The application of the technologies was considered as part of the entire project development process and compared to the use of standard collector and drilling technologies.

A risk assessment matrix that considers different ground conditions where the CHEAP-GSHPs ground heat exchangers may be installed, as well as different building categories where GSHP systems may be integrated. The matrix considers all aspects of design, construction and operation of a GSHP system where the new technologies are being deployed.

A series of recommendations have been made to facilitate the decision making and technology selection processes when GSHP are being considered. These recommendations demonstrate the applicability of the different CHEAP-GSHPs technologies compared to conventional ground heat exchanger and how different collector and drilling technologies may be more suited for different ground conditions. Key considerations with regard to the selection of the drilling methods and completion of the collectors are made.

Recommendations on the inclusion of the innovative heat pump technologies developed by the project in different building categories including residential, commercial and historical buildings have been considered in the context of the installation and operation of the system.

The risk assessment matrix recommendations provides a decision support tool to industry stakeholders and decision makers and highlights the benefits of the use of the CHEAP-GSHPs technologies. This decision support process will be integrated into the DSS developed in the project and the matrix will be updated to form a key part of the regulatory recommendations to be provided at the end of WP7.

References

[1] Institute of Geologists of Ireland. Guidelines for the Preparation of Soils, Geology and Hydrogeology Chapters of Environmental Impact Statements. Dublin, May 2015.

[2] Badens et al.. Definition of Standardized Energy Profiles for Heating and Cooling of Buildings. CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 6. Aalborg: Aalborg University, Department of Civil Engineering.