

THE PROBLEM OF GEOTHERMAL POWER INSTALLATION ON BUILDINGS: STRUCTURAL BUILDING MONITORING AND ASSESSMENT DURING DRILLING ACTIVITIES

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1. Abstract

The current European Union (EU) policy aims to increase the use of “green” energies, and within this strategy the exploitation of the geothermal energy is a well promising approach. The European Horizon2020 project GEOFIT (Deployment of novel GEOthermal systems, technologies and tools for energy efficient building retroFITting) aims among the others to deploy and to integrate advanced methods of worksite inspection, ground research, and building structural monitoring, drilling and worksite characterization into advanced geothermal based retrofitting methods.

When dealing with “plants of power production”, one needs to develop a Life Cycle Analysis and to apply a Life Cycle Assessment (LCA) for evaluating any environmental aspects and potential influences throughout the whole life cycle of a product or process or service. The paper first provides a preliminary discussion on this aspect. Then it focuses attention on a pilot site made available within the GEOFIT Consortium. The results from a structural monitoring campaign in this pilot site before and during the drilling operations associated to the implementation of the geothermal power system are presented discussed.

2. Introduction

The authors are currently engaged in the European Horizon2020 project GEOFIT (Deployment of novel GEOthermal systems, technologies and tools for energy efficient building retroFITting). It aims, among others goals, to deploy and to integrate advanced methods of worksite inspection, ground research, and building structural monitoring, drilling and worksite characterization into advanced geothermal based retrofitting methods [1]. One of the pillars of the ongoing investigation is the exploitation of Life Cycle Analysis and Life Cycle Assessment (LCA), according to the definitions in ISO 14040 [2], toward the rationalization of the design. It is a technique for evaluating environmental aspects and potential impacts throughout the life cycle of a product or process or service through:

- the compilation and inventory of the significant inputs and outputs of the system;
- the assessment of the potential impacts associated with these inputs and outputs;
- the interpretation of the results of the inventory and evaluation phases, in relation to the objectives of the study.

When focusing on plants of power production, LCA is often adopted for comparing solutions exploiting different sources. A deep study was produced by the US Department of Energy in 2010 [3]. More recently an updated review was published in 2017 in [4]. All these studies report on large-size plants (see Figure 1). Section 3 discusses these aspects for small size applications. The further sections illustrate the expertise caught in monitoring the implementation stages.

3. Life Cycle Assessment outcome for small size geothermal plants

Any geothermal plant shows interfaces with the external world at the source and at the output levels. Under

the assumption that no disturbance is left at any time at the source level, a regular performance of the plant does not offer impacts at the output level. By contrast, any stop obliges the user to move to the power offered by the power company of reference. The associated global costs become losses originated by each stop of the geothermal plant and they strongly depend on the time of unavailability.

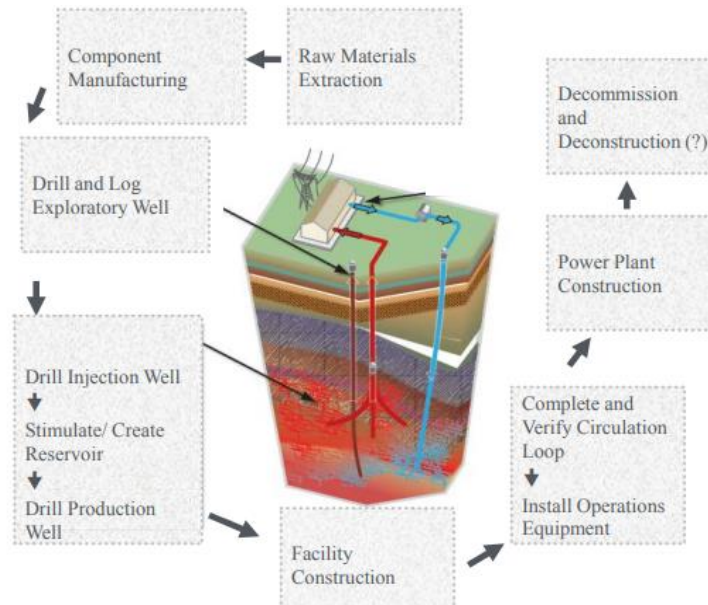


Figure 1 – The plant sketch considered by the US Department of Energy.

In the specific case of GEOFIT, the attention is focused on rural buildings or small size town buildings being “geothermal retrofitted”. Thus, one of the expected goals covers the optimization of the plant design. This is the specific target pursued in this section.

When approaching LCA analysis and studies, the possibility to deal with redundancy system is fundamental to compute the reliability of the resulting system. As a first step one needs to idealize whether the system is classifiable as [5-7] :

- *Series systems* that also are non-repairable: the system works if and only if all components work (*non-redundant system*);
- *Parallel systems* that also are non-repairable: the system works even if some components are not working (*redundant system*).

Once the plant is idealized as the series/parallel assemblage of components, the target is to compute the reliability of the resulting system, characterized by a number of redundancies to be optimized. These redundancies are better adopted for those components whose replacement requires more time. The actual economic options, however, can only be caught when data on the costs encountered after a system failure are made explicit.

As well outlined in the GEOFIT research activity progresses, three classes of component characterize a geothermal plant: the pipe, the pump and the conversion device (i.e. single redundancy). In the following table the reliability versus time for systems with single redundancy as obtained by CARDINAL [8] are presented. The selected redundancy degree influence the extent of the drilling the implementation of the power system requires.

Redundancy	1 year	5 years	10 years	20 years
borehole	1 - 0.1045	1 - 0.4237	1 - 0.6700	1 - 0.8933
geothermal pump	1 - 0.0526	1 - 0.2894	1 - 0.5505	1 - 0.8449
radiant panel	1 - 0.0837	1 - 0.3650	1 - 0.6134	1 - 0.8668
Double:bor.&pump	1 - 0.0409	1 - 0.2474	1 - 0.4990	1 - 0.8114

Table 1 – Reliability vs. time for systems with single and double redundancy as obtained by CARDINAL

4. Pilot case: The “Pins del Vallès School in Sant Cugat”

The case under study covers “Els Pins del Vallès” School, which is located in Sant Cugat, about 25km North-West of the town of Barcelona (Spain) (see Figure 2). The building under study consists of three reinforced concrete elements:

1. School main building;
2. Administrative building (see Figure 3);
3. Pavilion building.

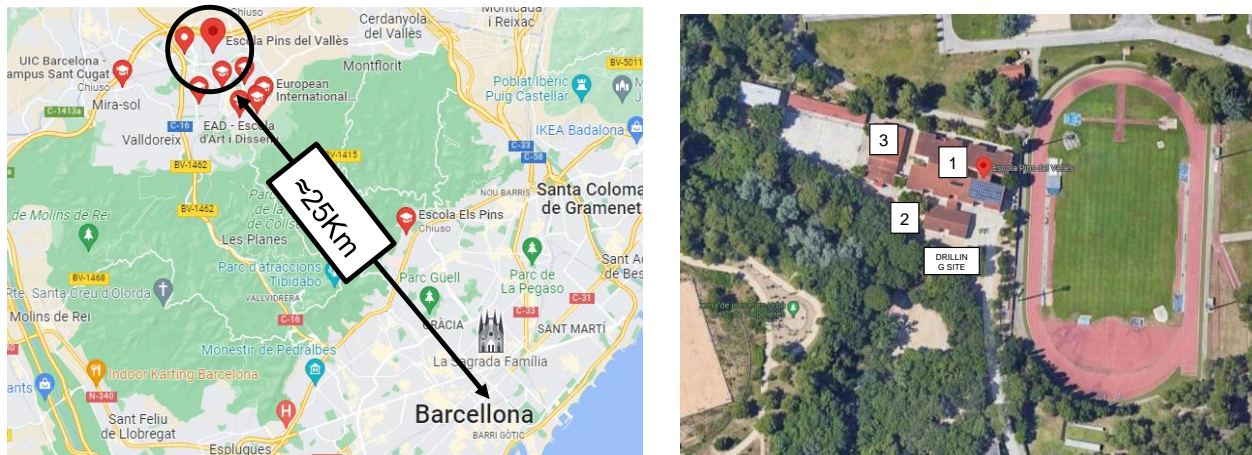


Figure 2: Pilot site location.

The building investigated in this paper is the administrative building (building #2 in Figure 2), i.e., the closest to the selected drilling site. From a structural point of view, its scheme consists of reinforced concrete (RC) columns, beams and walls. Geometrically speaking the building has a rectangular-shaped plan: about 23.70 by 12.75 m. It has only one floor above the ground and a double-pitch roof. The inter-floor height varies in the range from 2.50 to 3.50 m (see Figure 3).

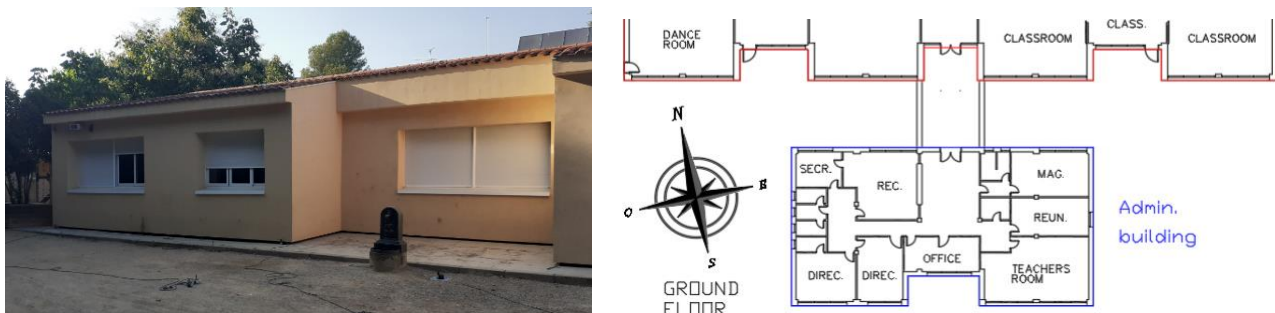


Figure 3: Administrative building: frontal view (left); plant (right).

Due to some technical issues related to the implementation of the geothermal technology, and in particular due to the vibration caused during drilling activities, standard application refers only to buildings in isolated locations, i.e., far from urban nuclei. Nevertheless, the installation itself requires to drill close to the building. The source of vibrations caused by this activity may result dangerous for the target building. Thus, a careful Structural Monitoring (SM) on site, during excavation activities, has to be planned to prevent from any sort of structural damage [9].

5. The experimental campaign

A dedicate monitoring campaign based on the acquisition of acceleration data of sensitive points along the administrative building under environmental loads and under drilling activities has been designed and

implemented. This campaign had a double purpose:

1. To identify the dynamic behaviour of the building in the original state (pre-drilling) and during the drilling activities;
2. To customize and to validate a “building monitoring strategy when implementing geothermal power system” in an existing building.

The tests carried out on site has been organized as follows:

- A. a preliminary visual investigation of the building to determine the current state of the structure in its operational state and the detection of possible anomalies and/or damage.
- B. *environmental loads survey campaign* carried out by the acquisition of accelerometric signals to assess the building dynamic behaviour in the pre-drilling phase;
- C. *drilling phase survey campaign* to cover the collection of accelerometric data during the installation of the geothermal energy system (i.e. drilling activities).

The monitoring system designed for the above purpose is made by a set of tri-axial *EPISENSOR Model FBA ES-T* accelerometers [10] coupled with a Wireless Data Acquisition, collection and transmission System (WDAS) designed in [11-12] and tested during several test applications [13-14]. The main advantages of using these sensors are: very-low self-noise, resulting in 155 dB dynamic range; user-selectable full g-scale range: from $\pm 0.25g$ to $\pm 4g$; user-selectable full output range: from $\pm 2.5V$ to $\pm 20V$, differential; wide frequency response: from DC to 200 Hz (Figure 4).

When using wireless sensor units for the data transmission and collection there is the risk of data losses during transfer. The workstations adopted in the test come with the option of storing not only the received data but also the history of the transmission. This allows the operator to detect if data lost occurred as well as if some workstations received more points than others did. Therefore, in selecting the test among the several replicates carried out at the same sensor locations, the criterion of having the same number of recorded points was adopted. In other words, the elaborations cover reliable data only.

All recorded data have been gathered in terms of “Volts” and then converted into acceleration “ m/s^2 ” simply multiplying “Volts” by the factor “1/2.5” according to the technical specification of the accelerometers (SEE Figure 5).



Figure 4: Device equipment. Left: EPISENSOR Model FBA ES-T accelerometers; Right: Wireless Data Acquisition, collection and transmission System (WDAS)

During the fourth day (*drilling activities phase*), in order to identify the drilling-machine working frequencies for further and easier data elaboration and discussion, a data acquisition test focused on the drilling machine, was carried out by installing an *Episensor FBA* accelerometer directly on the machine (Figure 6).

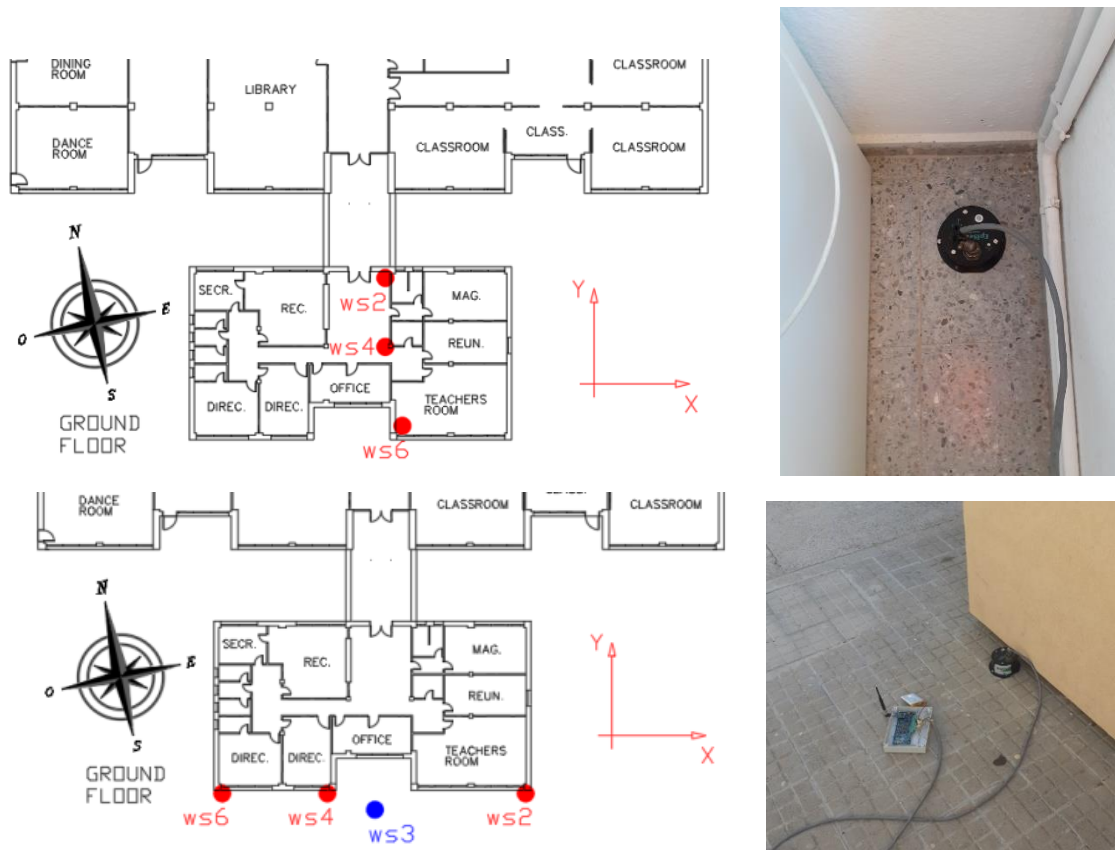


Figure 5: Devices configurations



Fig. 6 Drilling machine (left); The accelerometer on the drilling machine (right)

6. Some results

In this section the signal data elaborations (accelerations) gathered during the monitoring campaigns is presented. The data analysis used the tools offered by the *MatLab environment* (www.mathworks.com) and plotted in terms of *periodograms*. One estimates such periodogram in two alternative ways:

1. either by plotting the square of the absolute value of the signal's *Fast Fourier Transform (FFT)* multiplied by the time step (0.01s for all the recorded signals) and divided by the numbers of recorded points. The covered frequency range is from 0 to 50Hz, for a time step of 0.01s, and the frequency step results from the division of the higher frequency value, 50, divided by one half of the number of available recording times.
2. or by estimating the power spectral density of the signal for a given frequency step.

Option “1” was used to analyse the dynamic behaviour of the drilling machine as shown in Figure 7, mainly due to the wish of exploiting the entire reliable parts of the recorded signals.

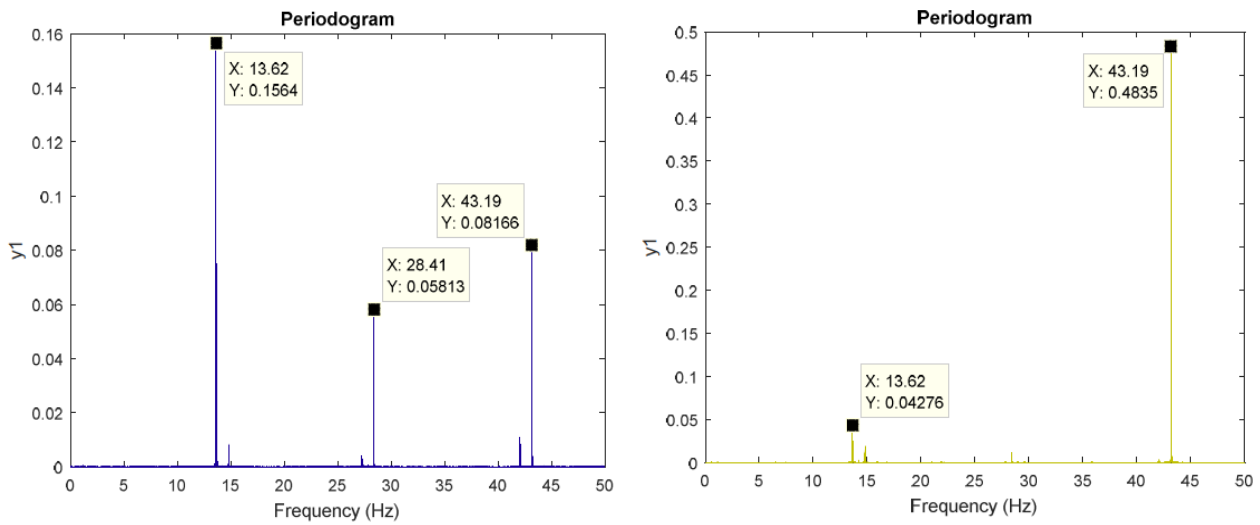


Figure 7. Dynamic characterization of the drilling machine. Periodograms for the signals recorded along the directions X (left) and gravity (Z) (right).

Option “2” was selected to analyse the administrative building response pre- and during-drilling activities (see sections 5). A discretization of the range 0-50 Hz in 512 points has been adopted. This scheme works on windows of the signal of 1024 points and keep the mean over the available windows. To preserve the same degree of accuracy not the entire signals are compared but segments of the same length, multiple of 1024 points, i.e., 2 to power 10. In particular, segments of length 32,768 (2 to power 15) were retained. For any selected set of data, the mean is first removed. Then a band-pass filter covering the window 0.8 – 50 Hz filters the signal. The plots give the periodograms achieved by a Power Spectral Density (PSD) estimate on windows of 2^{10} (=1,024) points.

The data plotted in Figure 8 and Figure 9 come from the elaboration of the data recorded at WS3 along directions Z and X respectively. The left column covers the “pre-drilling” tests; the right column those during the drilling activities. The work station unit WS3 is located on a manhole nearby the building (see Figure 5). The signals collected in that location represents the incoming ground vibration for the building.

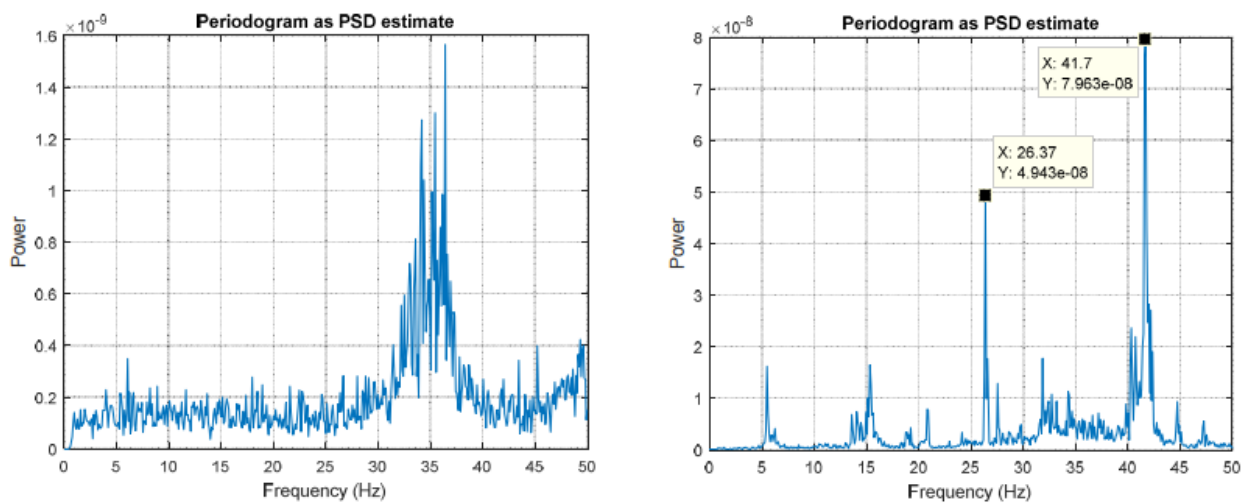


Figure 8. WS3: PSDs of the signals collected along gravity direction (Z): left “pre-drilling”; right “during the drilling”

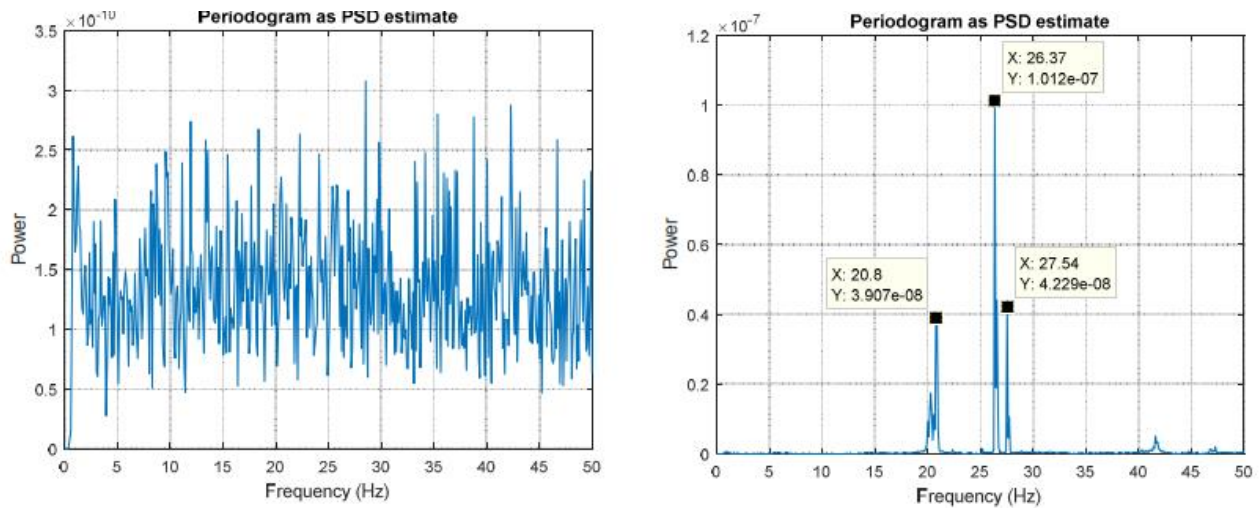


Figure 9. WS3: PSDs of the signals collected along horizontal direction (X): left “pre-drilling”; right “during the drilling”

As shown in Figure 7 the drilling machine itself generates three main frequencies, around 13 Hz, 28 Hz and 43 Hz. Moreover, the workstation on the manhole labelled as WS3 (Figure 5) shows that there is an external input when the drilling machine is active, input that was absent in the previous days when drilling activities was not carried out (Figure 7 and Figure 8).

7. Conclusions

In this paper the data gathered in a RC single-story building located in San Cugat (Barcelona-Spain), a pilot case within GEOFIT Project, have been collected, elaborated, presented, discussed and implemented within a LCA (Life Cycle Assessment) process to validate a “building monitoring strategy when implementing geothermal power system” in an existing building.

The basic steps of LCA, as introduced in Section 3, showed out the main role of the “system redundancy”. The estimates in Table 1 outline the role of redundancy on the system reliability. Nevertheless, one cannot ignore the role of reparability and availability in the decision process.

Regarding the “building monitoring strategy” scope of the “pilot case” experience, one could extract the following items in view of guidelines for an automatic implementation of a geothermal power system in an existing building:

- define the dynamic behaviour of the “drilling machine” (by direct data acquisition);
- test the propagation of the vibration from the drilling location to the existing building;
- replicate the test at different depth of excavation, to understand the different response at the basement;
- produce the building signature to identify the frequencies sensible to nearby vibrations.

The experience carried out shown as the whole data acquisition process could easily be implemented in a consultation assistant and would be easily implemented in the field by technicians in thermo-technique, also without any background in vibration mechanics.

Acknowledgments The activity reported in this paper has received funding from the European Union Horizon 2020 research and innovation program under grant agreement No 792210 (GEOFIT).

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