



Dyna

ISSN: 0012-7353

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Dyna, vol. 82, núm. 190, abril, 2015, pp. 221-226

Universidad Nacional de Colombia

Medellín, Colombia

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Inspection of radiant heating floor applying non-destructive testing techniques: GPR and IRT

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Received: June 15th, de 2014. Received in revised form: October 7th, 2014. Accepted: November 25th, 2014

Abstract

The inspection of radiant heating floors requires the use of non-destructive techniques, trying to minimize inspection impact, time and cost, and maximize the information acquired so that the best possible diagnosis is given. With this goal, we propose the application of infrared thermography (IRT) and ground penetrating radar (GPR) for the inspection of radiant heating floors with different floor coatings, in order to evaluate the capabilities and information acquirable with each technique. Specifically, two common floor coatings have been inspected: ceramic tiles and parquet flooring. Results show that each technique provides different information: condition of the pipelines (IRT), geometry and configuration (GPR), concluding that the optimal inspection is constituted by the combination of the two techniques.

Keywords: NDT; infrared thermography; ground penetrating radar; radiant heating floor.

Inspección de suelos radiantes mediante técnicas no destructivas: GPR y IRT

Resumen

La inspección de suelos radiantes requiere el uso de técnicas no destructivas, tratando de minimizar el impacto de la inspección, así como el tiempo y el coste, además de maximizar la información adquirida de cara al mejor diagnóstico posible. Con este objetivo, la aplicación de termografía infrarroja (IRT) y georradar (GPR) se propone para la inspección de suelos radiantes con cobertura de diferentes materiales, para evaluar las capacidades y la información adquirible con cada técnica. Los resultados muestran que cada técnica proporciona diferentes tipos de información: estado de las tuberías (IRT), geometría y configuración (GPR); concluyendo que la inspección óptima está formada por la combinación de ambas técnicas.

Palabras clave: NDT, termografía infrarroja, georradar, suelo radiante.

1. Introduction

The inspection of radiant heating floors is a key aspect given the influence of their installation in the building. On the one hand, the radiant heating floor determines the temperature of both the room and the floor, with the subsequent determination of the thermal comfort and well-being of the users [1]. On the other hand, radiant technologies are low-temperature heating technologies, which are believed to reduce energy consumption in the building sector, and consequently the determination of the expenses destined to heating the building is also possible [2].

Since this paper deals with the inspection of installations in-use, all actions must be based on the use of non-

destructive techniques in order to minimize the impact on the users and the building. Currently, the most widely used technique for the inspection of radiant heating floors is infrared thermography (IRT). In fact, infrared devices can be used in general, from non-contact thermometers [3] to cameras [1], to analyze the heat transfer phenomena and their influential parameters. If we focus on the inspection itself, infrared cameras have been used to detect both small-scale defects on electric radiant heaters [4] and large-scale ones in water pipelines [5]. The application of this technique allows the reduction of maintenance tasks thanks to the recognition of the exact failure spot, its classification and severity evaluation. The main limitation of the technique is the measurement of highly reflective materials

(i.e., with an emissivity value of under 0.8; that is, a reflectivity value of over 0.2), where the temperature measured is the reflected temperature from the surrounding objects and not the temperature of the inspected object itself.

Ground penetrating radar (GPR) is a geophysical technique that allows the detection of buried objects thanks to their different dielectric response due to their shape and especially to their material. It has been widely used for the detection of rebar in concrete [6,7], but there are, to date, few published studies about its specific performance in the detection of heating pipelines in buildings, with some notable exceptions [8,9].

This article presents a methodology for the evaluation and characterization of thermal floors in as-built buildings by means of both IRT and GPR techniques. Section 2 explains the processes of data acquisition and data processing followed for each technique. Section 3 presents the results obtained from the proposed methodologies applied to two different test areas. Finally, Section 4 includes the conclusions reached after the analysis of the application of the different non-destructive methods to radiant heating floors, and the parameters measurable with each technique.

2. Materials and Methods

This section includes a description of the areas used for testing the techniques, and the procedure followed with each of them.

2.1. Test areas

Given the high diversity of building configurations that can nowadays be equipped with radiant floor heating, two rooms of different use and floor coating have been chosen for testing (Fig. 1). The first test scene is a busy space such as a joint kitchen and living room, with low-reflectivity ceramic tiles as floor coating; while the second scene is a room used as a bedroom, with parquet flooring in brick pattern. These areas were chosen mainly due to their uses, which imply the presence of users for long periods and usually in relaxation or rest situations. Thus, the importance of thermal comfort in these rooms is greater than in rooms destined for other uses.

What is more, both floor configurations of ceramic tiling and parquet flooring are common in residential buildings, so the analysis of the performance of the GPR and IRT techniques in them covers the majority of possibilities.

Regarding the radiant heating installation, the kitchen-living room was equipped with 3 pipelines, 1 of which was damaged, whereas the bedroom was covered by 2 pipelines, both working.

2.2. Infrared thermography

Infrared thermography is the technique which receives the infrared radiation emitted by the bodies as a function of their temperature; thermograms appear as images of this radiation [10]. Several parameters affect the thermographic

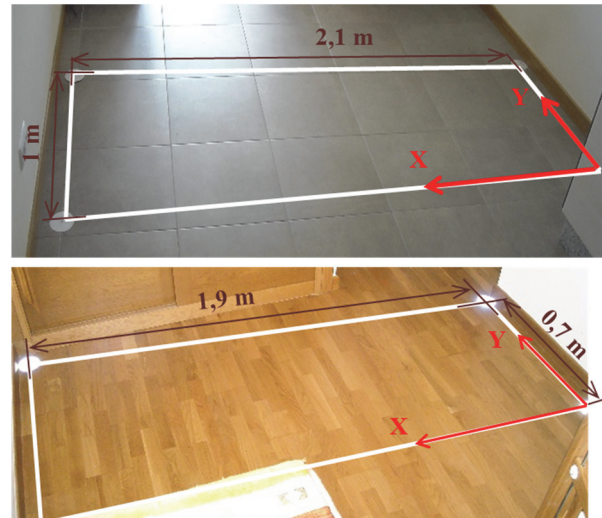


Figure 1. Test areas, with tiling coating (upper) and parquet flooring (lower). The rectangular 3D grids prospected with GPR, as well as the origin for the data-acquisition and the axis (X-Y) assumed for collecting data are also shown.

Source: compiled by authors.

measurement, such as emissivity of the material (or its opposite parameter, reflectivity), presence of reflections, and environmental conditions (ambient temperature and relative humidity) [11]. Regarding the latter, the application of IRT requires the existence of a temperature difference between an object and its surrounding environment in order to distinguish the object from the background; as a consequence, the thermographic inspection of a radiant heating floor must be performed with the installation working. In this case, the installation was turned on 5 hours before the inspection in order to reach a 5-10°C temperature difference between the pipelines and the background, sufficient time in advance so that the installation reaches steady state. This last issue is important in order to ensure that thermal anomalies are due to defects in the installation, and not to inhomogeneities in the starting process.

Lights were turned off during the inspection in order to avoid reflections. Finally, given that the purpose of the study is the analysis of the capabilities of the technique for the inspection of radiant heating floors and not the quantification of the temperature values of the floor, its emissivity value is not calculated.

The thermographic inspection was performed using a NEC TH9260 camera with a 640*480UFP sensor, 0.06°C resolution and $\pm 2^\circ\text{C}$ accuracy. Given that the camera's field of view was 21.7° (Horizontal) x 16.4° (Vertical), a single image could not cover the dimensions of the room. Therefore, several thermographic images had to be taken for each test area (Fig. 2). Since the spatial distribution of the temperatures measured within the images is required for correct interpretation of the installation; for example, to detect the presence of defects or malfunctions, images are mosaicked in order to work with only one image per installation. Within this image, the defects detected can be spatially located, and therefore repair actions can be performed in the right place directly.

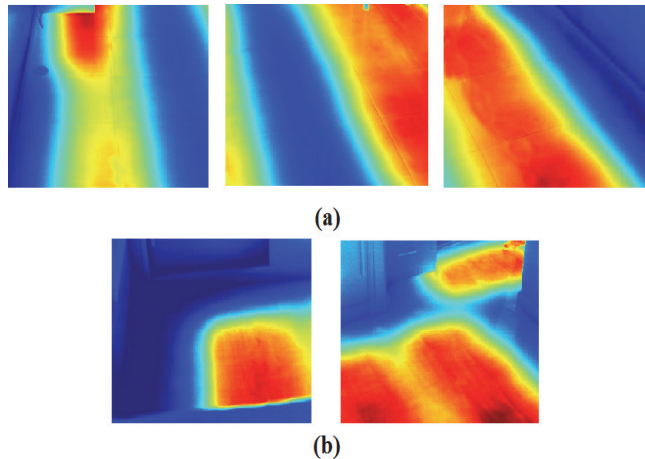


Figure 2. (a) Thermographic images acquired for the inspection of the 3 pipelines under the tiling floor. (b) Images of the thermographic measurement of the radiant heating floor installation in the bedroom (parquet flooring).

Source: compiled by authors.

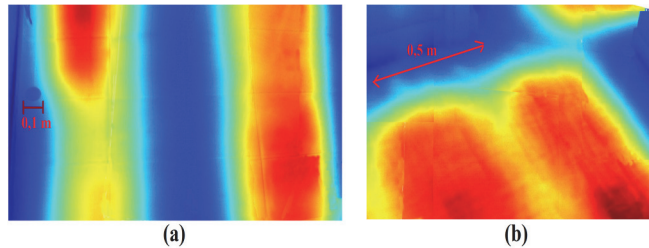


Figure 3. Thermographic mosaics of the radiant floor under tiles (a) and parquet floor (b).

Source: compiled by authors.

The next step was the generation of a thermographic mosaic for each case so that the installation could be completely inspected with one single image. The registration of each thermographic image in its position in space was performed using a self-proprietary algorithm developed in Matlab®. First, the distortion (both radial and tangential) introduced in the images by the lens was corrected. This step was possible thanks to the geometric calibration of the camera prior the inspection, following the procedure explained in [12]. Once images were corrected, the software extracted characteristic points from each image using SIFT [13], and obtained their correspondence between images through the computation of the correlation value, as in [14]. Fig. 3 shows the final mosaics.

2.3. Ground Penetrating Radar

With the GPR method, when surveying with a bistatic antenna, a transmitting dipole emits an electromagnetic pulse into the ground that is partly reflected when it encounters media with different dielectric properties and partly transmitted into deeper layers. Next, a receiving dipole records the reflected signal. Using the common-offset-mode (CO), the antenna is moved over the surface in a specific direction while a constant distance is maintained between the transmitting and receiving dipoles. This allows

us to obtain an image of the shallow subsurface under the displacement line. These two-dimensional images, called radargrams, are XZ graphic representations of the reflections detected. The X-axis represents antenna displacement along the survey line and the Z-axis represents the two-way travel time of the pulse emitted (in terms of nanoseconds). Additional information on the basic principles of GPR can be found in [15,16].

If the time required by the signal to travel from the transmitting dipole to the reflector and return to the receiving dipole is measured and the velocity of this radar-wave in the subsurface medium is known, then the position, or depth, of the reflector (d) can be determined from:

$$d = v \frac{twt}{2} \quad (1)$$

where;

d is the distance travelled by the wave, v is the radar-wave velocity of propagation in medium, and twt is the travel-time distance to and from the reflection.

In this work, the MALÅ ProEx system was used, with a central frequency of 2.3 GHz. In this case, the most influencing parameter that determines the effectiveness of the method is the vertical resolution. This spatial resolution, which mainly depends on the central frequency of the antenna and the radar-wave velocity, allows for the differentiation of two adjacent signals in depth like different events. Heating installations are placed in the near subsurface, usually not deeper than 10-20 cm, to ensure proper heat transfer and, therefore, lower vertical resolutions are required to avoid the influence of near-field antenna coupling induction effects to facilitate detection. If the depth of the target is less than the vertical resolution, the reflection from the object is combined with the direct coupling signal and is not identified. The 2.3-GHz frequency was selected since it provides signal penetration to a depth of approximately 40 cm (under optimal conditions) and vertical resolution about 1-2 cm [17].

The GPR survey was carried out using the CO mode with the antenna polarization perpendicular to the direction of data collection (X-direction in Fig. 1), and the survey parameters selected were 2 cm spatial sampling with a 12 ns total time window and 512 samples per trace. Based on Equation 1, this time window was set to guarantee the signal penetration needed to detect the target, while to avoid possible energy decay or signal attenuation by the presence of some kind of conductive material in coatings like soil cement. The conversion of travel-time distance into depth was made using Equation 1, and the radar-wave velocity was assumed from the published literature [16] by considering a concrete floor below coating.

An encoder-based wheel was attached to the back of the antenna serving as a distance measurement instrument (DMI) to measure the profile lengths, as well as to control the 2 cm spatial sampling, or “trace-distance” interval, along each GPR profile.

Three-dimensional (3D) GPR methodologies were performed in order to obtain an optimal visualization and improve the interpretation of the acquired data. This methodology consisted in the acquisition of equidistant

Table 1.

Sequence processing and parameters selected to filter the 2.3-GHz data obtained.

1	Time-zero correction
2	Dewow filtering (time window: 0.5 ns)
3	Subtracting average (average traces: 500)
4	Gain function (linear: 6 & exponential: 6)

Source: compiled by authors.

parallel 2D-lines in the Y-direction (Fig. 1), at regular intervals of 5 cm.

ReflexW v.6.1 software [18] was used to process all the profiles collected, applying the following processing sequence: time-zero correction, temporal (*dewow*) and spatial (*background removal*) filtering, as well as gain application (*gain function* with linear and exponential components). The objective of the sequence was to correct the down-shifting of the signal due to the air-ground interface, as well as to remove both low and high-frequency noises in the vertical and horizontal directions (temporal and spatial filters, respectively), and to amplify the received signal. Table 1 shows the parameters selected for filtering.

Once processed, the 2D data were exported to the 3D-data interpretation module of the same software for its interpolating in a 3D cube. Fig. 4 shows the time-slices obtained at 2 ns depth (in time) from the 3D cubes generated for the kitchen-living room floor (a) and bedroom floor (b).

3. Results and discussions

Regarding infrared thermography, the resulting mosaics show the high capacity of the technique for the inspection of radiant heating floors installed under low-reflectivity coatings (i.e., with an emissivity value of over 0.8; that is, a reflectivity value of under 0.2) such as parquet and matte ceramic tiling. As we can see in Fig. 3, the thermal print of each pipe can be perfectly distinguished, allowing the evaluation of their performance. In the case of the radiant floor of the kitchen-living room (Fig. 3(a)), a non-working pipe can be detected in the middle of the installation, where the floor is at the lowest temperature (represented in blue). The conclusion of its malfunction is extracted from the knowledge of its existence thanks to the GPR inspection; otherwise, the thermographic inspection alone would lead to the conclusion of the non-existence of a pipe in the area. What is more, the pipe on the left does not work properly, which can be directly detected in the thermographic mosaic by the much lower temperature in its first half compared to its second half. In the case of the bedroom, the two pipes present an adequate performance, being at similar temperatures: straight pipelines present higher temperatures in the middle, where the pipe is closer to the surface of the floor, and lower temperatures at the sides, where the influence of the hot fluid in the pipe diminishes. The lowest temperature areas correspond to the middle axis between adjacent pipes.

With respect to ground penetrating radar, the results obtained demonstrate the capabilities of the technique to detect

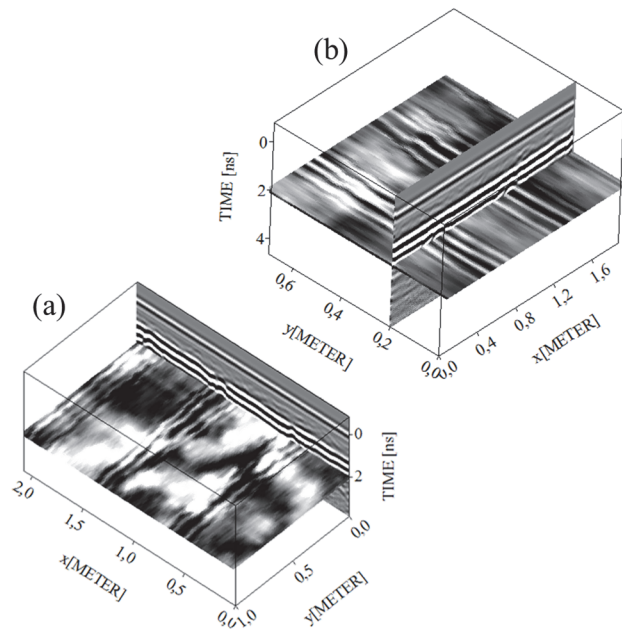


Figure 4. GPR time-slices obtained at 2ns (approx. 10 cm depth) from the 3D cubes generated at both test areas: (a) kitchen-living room floor and (b) bedroom floor.

Source: compiled by authors.

and map heating pipelines. Their identification was possible because of the large dielectric contrast between the installation and the surrounding backfill. Fig. 4(a) presents the 3D data generated, showing the existence of 3 pipelines, even the non-working one centered at 1.5 meters in the X-axis, in the kitchen-living room test area. The results obtained for the bedroom test area (Fig. 4(b)) illustrate the presence of two heating pipes. In addition, the 3D images provide the geometry and distribution of these pipes in the floor. What is more, assuming an estimated velocity of 10 cm/ns for the radar-wave propagation throughout medium, the depth of such pipes was determined at approximately 10 cm.

4. Conclusions

This paper proposes the use of two non-destructive techniques: ground penetrating radar and infrared thermography for the inspection of radiant heating floor with different floor coatings. The capabilities of each of them for this task are analyzed in Table 2.

After the analysis of the results, we can see that infrared thermography can be mainly applied to the inspection of the performance of each pipeline, detecting also those that do not work and those that present faults that lead to thermal anomalies, such as overloading, obstructions, water leaks, among others. The first is possible in the case the configuration of the installation is known, so the inspector knows the number of pipelines installed, and consequently the number of thermal prints appearing if they are all working properly. The only requirement of the thermographic technique is that the installation must be on at the time of the thermographic inspection. The ground penetrating radar can detect the presence of any pipeline, whether they are working or not, so it is the adequate

technique for the surveying of unknown installations, giving information about the number of pipelines, distribution, and depth under the floor. This conclusion is illustrated in Fig. 5, where the radargram shows the existence of 3 pipelines (Fig. 5a) whereas the thermographic mosaic only shows the thermal patterns of 2 pipelines (Fig. 5b). The spatial correspondence between radargram and thermographic mosaic leads to the conclusion that the central pipeline is not working. What is more, the different thermal print between the pipelines on the left and those on the right shows the malfunction of the pipeline on the left, given its colder temperature distribution.

Consequently, the combination of both techniques is optimal for the inspection of radiant heating floors in buildings where the installation is unknown because of the age of the building, the loss of the design plans or because the current owner does not know, as well as to monitor quality control.

Future studies will deal with the different parameters of influence in both the GPR and IRT measurements (floor coating, depth of the installation, heating temperature) towards

a parameterization of the inspection and the direct quantification of the energy efficiency of the installation.

Acknowledgments

The authors would like to thank the Consellería de Economía e Industria (Xunta de Galicia), Ministerio de Economía y Competitividad and CDTI (Gobierno de España) for the financial support given through human resources grants (FPU AP2009-1144, FPU AP2010-2969) and projects (IPT2012-1092-120000, ENE2013-48015-C3-1-R, and ITC-20133033). Additionally, this study is a contribution to the EU funded COST Action TU-1208 “Civil Engineering Applications of Ground Penetrating Radar”.

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Table 2.

Capabilities of each technique for the inspection of radiant heating floors.

CAPABILITY	GPR	INFRARED THERMOGRAPHY
PIPELINE DETECTION	Either turned on or off	Only turned on
GEOMETRIC CHARACTERIZATION	Buried depth Position/Distribution	Only after certain processing operations (image rectification)

Source: compiled by authors.

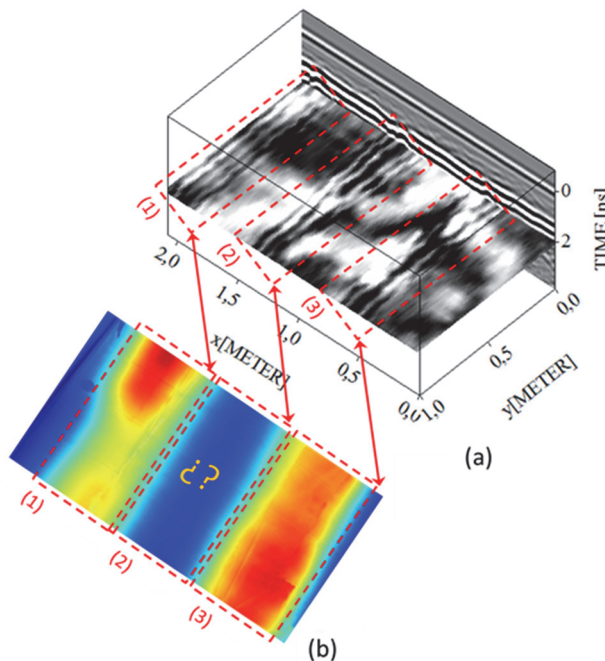


Figure 5. (a) 3D GPR data obtained for the radiant floor with a central frequency of 2.3 GHz and (b) thermographic mosaics. The comparison of both data has revealed the existence of a non-working heating pipeline.

Source: compiled by authors.

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