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A First European Collection of Thermal Response Tests

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ABSTRACT

The energy performance of a Ground Source Heat Pumps (GSHP) system depends on the thermal performance of the ground heat exchangers which, in turn, depends primarily on the local ground heat exchange capacity, which represents a sort of fixed factor in the designing of new GSHP systems, due to its immutability. For this reason, particular attention has to be paid to the correct evaluation of the local ground heat exchange capacity during the design phase. Recently, thanks to international collaboration raised within the Horizon 2020 EU funded projects Cheap-GSHPs (2015–2019) and GEO4CIVHIC (2018–2022), results from several thermal response tests (TRT) performed in several European countries have been collected in a first European TRT database. The TRT database includes more than 140 TRTs from different geological settings all around Europe, mostly located in Italy, Belgium and Greece. In this paper, the data contained in the European TRT collection are presented by means of a first level of elaboration. Firstly, the thermal conductivity values from the TRT procedure are compared with the ones evaluated from the lithological sequence. Secondly, some observations about the measured ground undisturbed temperatures and the borehole resistances are reported. These are only a first level of elaborations that can be deepened and widened, including increasing the dataset with new TRT data.

1. INTRODUCTION

Ground Source Heat Pumps (GSHP) are well-established systems for building conditioning, and the closed-loop ground borehole heat exchanger (BHE) is the most widely used configuration (Sarbu and Sebarchievici, 2014). The sizing process of a new Ground Source Heat Pump (GSHP) system aims at coupling the heating and cooling requirements of the building with the thermal exchange capacity of the local underground, by finally calculating the total borehole length required to supply the requested thermal loads. Hence, the assessment of the thermal behaviour of the local underground where the building has to be constructed is crucial for the correct sizing of new borefields, due to its immutability. An overestimation or an underestimation of the thermal exchange capacity of the ground could strongly affect the installation costs, the running costs of the whole GSHP system and the long-term efficiency and performances of the system. In the design phase, if the heat exchange capacity of the soil is underestimated, the probe's total length calculated will be uselessly high, leading to high initial costs; on the contrary, in case of underestimation, the probe's total length will be lower than that required to satisfy the buildings' energy demand, leading to a low energy efficiency of the whole system, or even inability to cover the cooling needs.

The thermal behaviour of the ground depends on the local stratigraphy and on the hydrogeological conditions. Each geological deposit contributes in relation to its granulometry, mineralogical composition, state of consolidation and water saturation. Furthermore, the presence of ground water and subsurface permeability may considerably enhance heat transfer due to subsurface flow patterns, which change the dominant heat transfer mechanism from conduction to convection. Currently, there are two main methods for assessing the thermal properties of the local underground where a new borefield has to be designed: (I) the thermal response test (TRT), directly performed on site by means of a specific testing procedure; and (II) the evaluation of the global thermal exchange capacity by associating the thermal properties tabulated in the GSHP guidelines for each lithology identified in the local stratigraphy.

During the TRT, water is continuously injected into the pipes of the tested borehole heat exchanger and the inlet and outlet temperatures are monitored. Thus, the heat exchange with the ground can be evaluated to estimate a global value of thermal conductivity to be assigned to the whole borehole. The experimental procedure has been precisely set by the ASHRAE association (ASHRAE, 2011). The experimental results can be analysed by means of several analytical models described in literature (Li and Lai, 2015; Zarrella et al., 2017). The estimated thermal conductivity takes into account the whole stratigraphy and the in-situ conditions of groundwater, undisturbed temperature and state of confinement of the ground. In addition, the TRT test involves a large volume of ground in the probe's surroundings, which depends on the geometry of the well and on the thermal behaviour of the well materials and of the ground itself (Ghelin and Spitler, 2001; Ghelin and Nordell, 2003).

On the other hand, performing a TRT test is quite expensive and, in most countries, it is strictly required by the authorization authorities only for larger GSHP systems. In case of smaller GSHP systems, designed to provide heating and cooling to residential single houses, the TRT test is often not performed. The owner often prefers to construct one additional BHE, rather than carrying out a TRT. In those cases, when the local stratigraphic succession is available, a global value of the thermal conductivity along the whole GSHE can be estimated by using the thermal properties indicated for each lithology in the most important guidelines (e.g., ASHRAE and VDI (ASHRAE, 2001; VDI, 2010)) as an averaged value of the thermal conductivity of each deposit weighted by the thickness of the deposit itself. This approach is fast and cheap but is affected by several uncertainties related to the attribution of the values due to the identification of the correct lithology class and, finally, the overall subjectivity of the choice. The tables reported in the guidelines contain only selected rocks and sediment classes (the VDI presents 34 lithological classes and the ASHRAE 13 classes); in addition, for each lithology the tables present a wide range of possible values. Furthermore, the values reported in the tables only consider the heat transfer by conduction and completely disregard heat transfer by convection, which could be significant where there is groundwater flow. Finally, the TRT procedure provides also the undisturbed ground temperature and the borehole thermal resistance, which are key parameters when designing a suitable GSHP system.

This paper presents a first European database collecting more than 140 thermal response tests. The database aims at collecting TRT data acquired in different regions and geological settings, produced by different companies. Most of the TRT tests have been acquired directly from the testing companies. At this stage, more than 70% of the TRTs were performed in Italy, 20% in Belgium, 5% in Greece and 5% in other countries. The database is structured in order to be extended by including new TRT datasets.

The database gathers the most important information about the BHE, such as location, probe type, length, and materials used for the pipes and the grout. In addition, the TRT testing conditions are reported in terms of duration, heat released, water injected discharge, fluid temperatures and test outputs (undisturbed ground temperature, probe's resistance, global thermal conductivity ($\boldsymbol{\lambda}_{\mathbf{TRT}}$)).

On the other hand, the local stratigraphy associated with each TRT location has been directly acquired, in the majority of the cases, from coring performed at the installation site in order to estimate the global thermal conductivity by attributing to each deposit the thermal properties recommended in the guideline tables ($\boldsymbol{\lambda}_{\mathbf{TABLE}}$). In case the coring data was not available, the stratigraphy was estimated from available lithology information in the vicinity of the site.

Several comparisons and observations can be driven from this data collection. First of all, the two values of global thermal conductivity (one directly acquired from the TRT interpretation and one estimated from the local lithological sequence) have been compared and discussed.

2. MATERIALS AND METHODS: THE TRT DATABASE

Figure 1 shows the locations of the TRTs present in the database. The database is organized in two main tables, one dedicated to the description of the TRT tests, and the other dedicated to the description of the tested probe. Each well is addressed with a proper alphanumeric code made up by numbers indicating the geographical position (latitude and longitude) and by a letter, used to distinguish different boreholes with the same location. The field is identified as primary key of the table, so it is impossible to have more than one borehole with the same name. Similarly, each TRT test is addressed with an acronym to identify the company performing the test or the information source, followed by five ordering numbers. This allows for immediate discrimination of the information source, the executor and the applied device. Each TRT test in the database is directly linked to the tested borehole and, vice-versa, each borehole is directly connected to one or more tests (Dutto, 2018).

Figure 1: Locations of the TRTs included in the database.

Table 1: Description of the fields included in the main tables of the database.

	Table field	description
WELL_TABLE		
General information	ID_HOLE	alphanumeric code
	Source	Information source (company or paper)
	Stratigraphy	Source of stratigraphic information
Position	Longitude	
	Latitude	
	Altitude	
	Coordinate system	Reference used
Administrative Information	Address	
	City	
	Region / State	
Technical Information	Tubes configuration	(coaxial, double U, single U)
	Well diameter	(mm)
	Well depth	(m)
	Grouting	
	Pipe material	
	Fluid	Heat carrier fluid
	Pipe internal diameter	(mm)
	Pipe external diameter	
	TRT	Codes of the executed TRT
TRT_TABLE		
Identification codes	ID_TEST	Acronym + 5 numbers
	ID_HOLE	Identification of the tested well
Test features	Starting date	
	End date	
	Duration	Total duration of the test (hrs)
	Power	Total power released (W)
	Well depth	(m)
Outputs	Tg°C_TRT	Undisturbed ground temperature estimated from TRT
	λ_TRT	(W/mK)
	Rb	Thermal resistance of the probe

All the information collected in the database fields is listed in Table 1. Within the database, the table describing each well is directly connected to the one reporting the stratigraphy of the well. For each identified layer, the depth, the thickness as well as the geological description are reported. A proper function has been developed to assign to each layer the thermal conductivity value indicated in the reference guidelines (both the ASHRAE then the VDI). This way, an averaged thermal conductivity value is estimated by weighting each thermal conductivity value on the deposit thickness. The function allows the use of the suggested value or the minimum/maximum ones.

3. RESULTS AND DISCUSSION

3.1 Thermal Conductivity Comparison

The database allows for the comparison of the calculated and the measured 'global' thermal conductivity values. Figure 2 shows scatter plots of the values, by directly comparing the thermal conductivity obtained from the TRTs with the ones calculated using the VDI (left plot in Figure 2) or the ASHRAE (right plot in Figure 2) values. In Figure 2, the blue straight lines identifies the diagonal, where the calculated and the TRT values are equivalent. The grey and orange dotted lines represent the ±15% error considered to affect the TRT procedure, mainly due to the accuracy of the measuring devices and the potential presence of heat losses (Witte, 2013).

If the point is in the upper part of the graphs shown in Figure 2, the global thermal conductivity evaluated from the stratigraphic sequence is overestimated compared to the ones effectively obtained by performing the TRT. Conversely, if the point is located in the lower part of the graph, the thermal conductivity acquired by the TRT test is higher than the calculated one, probably due to the presence of significant groundwater flow that contributes to the heat exchange by convection.

In the graphs of Figure 2, the data has been differentiated by country. Most of the population falls in the interval of the acceptable error of ±15%, whilst the scattering is more prominent in the lower part of the graphs, thus identifying locations where the groundwater flow contribution is not negligible.

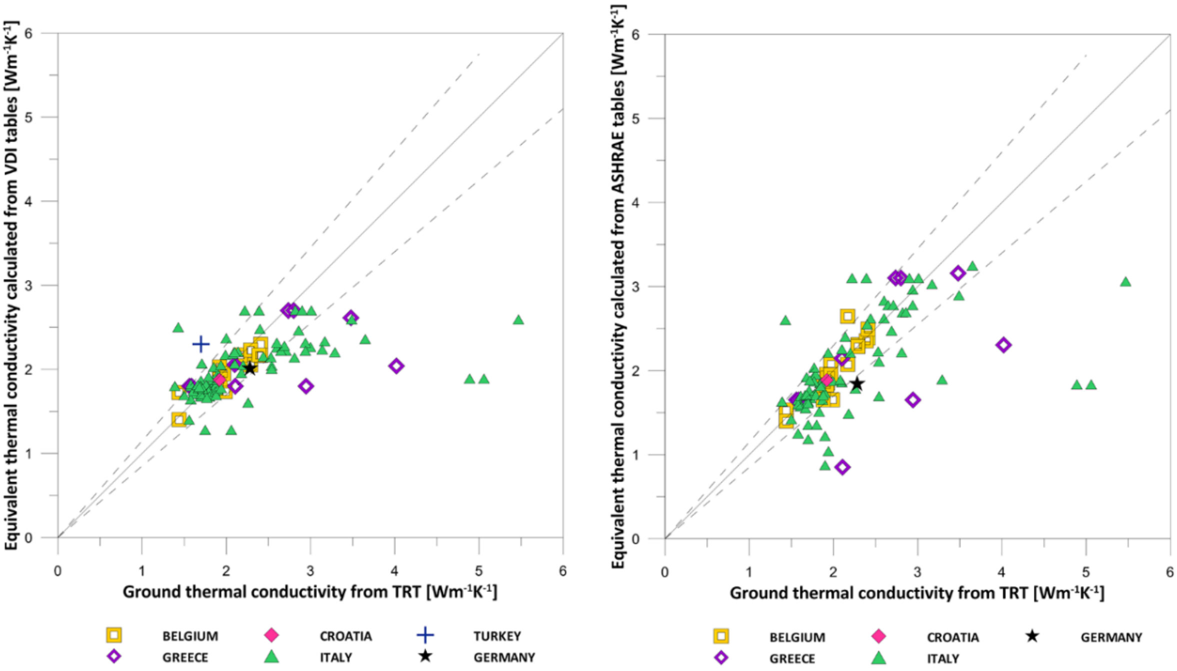

Figure 2: Global thermal conductivity of the ground calculated by using VDI (left) or ASHRAE (right) tables plotted against the thermal conductivity directly evaluated by the TRT measurements.

3.2 Ground Undisturbed Temperature

In order to correctly design the borehole field, the undisturbed ground temperature must be evaluated. In Figure 3, the undisturbed ground temperature measured by TRT is plotted against the borehole depth used for the evaluation.

Even in this case, the data have been gathered according to the country in which the thermal response test has been performed. In general, the undisturbed ground temperature shown by the TRTs depends on the climate in the different countries. For example, the Greek ones (violet points) show higher temperatures than the Belgian ones (orange points). Obviously, for shallower probes, the undisturbed temperature acquired from the TRT is more affected by the air temperature and by seasonal variations, as shown by the two points in the left part of the graph (violet square points, TRTs performed in Greece). In the higher part of the graph the TRT performed in thermal anomaly regions can be identified, with an undisturbed ground temperature around 40°C whilst the 178 m deep borehole shows an undisturbed ground temperature of 12.1 °C, as it is located in an area with lower geothermal gradient. Finally, in the lower part of the graph, the TRTs performed at high altitude, where ambient temperatures are lower, are grouped.

For medium to high BHE total length, the studied dataset does not display a dependence on the undisturbed ground temperature on the BHE total length.

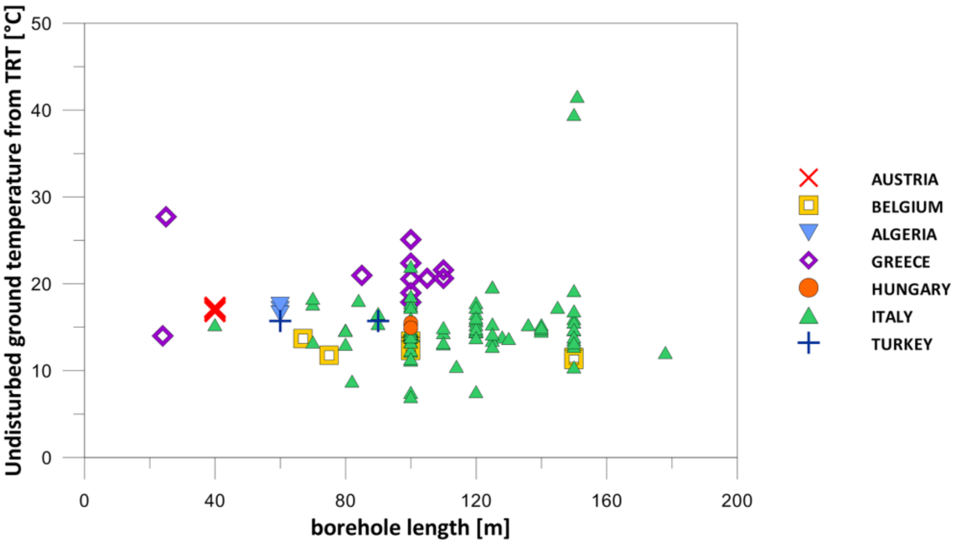

Figure 3: Undisturbed ground temperature measured by TRT plotted against borehole depths.

The standard TRT procedure based on the infinite line source model is usually used. As it is well known, this procedure models temperature in an infinite solid which is heated along an ideal thin infinite line. The heat rate is assumed to be released at a constant rate with heat flowing radially. Using the infinite line source model, the borehole temperature can be evaluated; consequently using the mean temperature of the heat-carrier fluid between the inlet and the outlet at the top of the borehole, the borehole thermal resistance can be calculated. In Figure 4, the borehole thermal resistance (Rb) evaluated by means of the TRT method is directly plotted against the TRT thermal conductivity. The data have been again distinguished by country.

The knowledge of the geological settings related to each TRT allows the identification of some clusters of homogeneous behaviors: the grouping in the lower left side of the graph (hence, low thermal conductivity and low borehole resistance) indicates tests performed in correspondence to a significant presence of clay deposits. In case of presence of sandy layers and gravels, the TRTs show a wider variability of thermal conductivity up to 5 W/(m K), thanks to the advection contribution to the heat exchange, even though the borehole resistance values are quite constrained in a small range, higher than the one derived in clayey undergrounds (varying between 0.1 and 0.22 m K/W). As for rocks, the points present in the bottom/center of the graph show a prevalence of limestone, while the ones where conglomerates dominate are concentrated in the bottom right part of the graph. Where magmatic rocks dominate, the borehole resistance is higher.

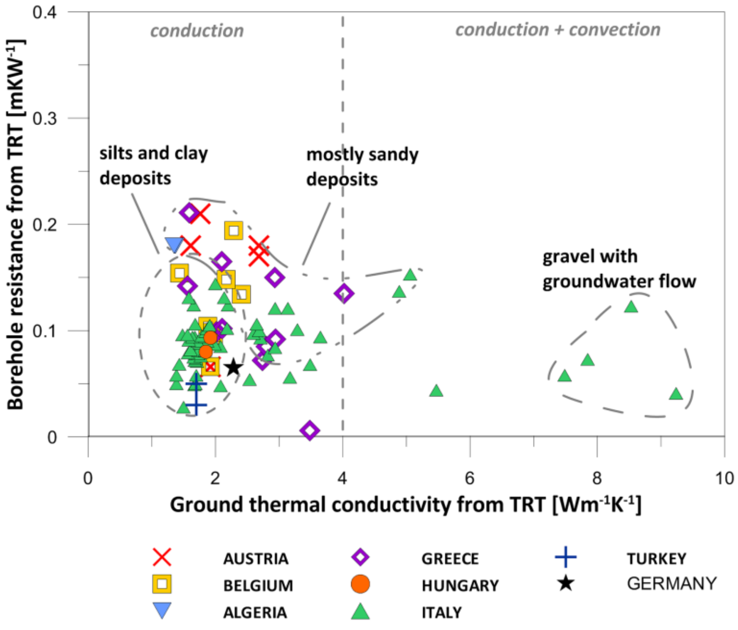

Figure 4: Borehole thermal resistance plotted against ground thermal conductivity. The one indicated is the dominant lithology in the stratigraphic sequence.

4. CONCLUSION

The evaluation of the thermal properties of the ground is the first step to design a ground source heat pump systems. The designer (engineer or geologist) needs to know the equivalent thermal conductivity of the ground and the undisturbed ground temperature. Usually these parameters can be obtained using the well-known thermal response test (TRT) procedure. However, this procedure is quite expensive and is only financially viable when the size of the borehole field is large enough. Another option is to evaluate the thermal properties using data from the literature taking into account the type of the stratigraphy. In this work, results from thermal response tests and from manuals are compared. The database presented here gathers the first collection of more than 140 European TRT datasets, completed with the information about the local stratigraphy. First of all, direct comparison between the global thermal conductivity values obtained by TRT and the values evaluated based on the thermal conductivity of each deposit indicated in the guidelines show that most of the population (around 70%) falls in the interval of the expected error of ±15 %, which is considered to usually affect the TRT results. The points outside this limit relate mainly to geological settings with significant groundwater flow.

Additional observations of the influence of the local geothermal gradient, the altitude and climate and, finally, of the main lithology characterizing the TRT site, can be inferred by combining different kinds of information contained in the TRT database. Obviously, more TRTs and increased data variability in terms of location and geological settings, will be more informative and will improve the database and the observations that can be obtained.

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REFERENCES

ASHRAE: *Geothermal Energy, in Heating, Ventilating and Air-Conditioning Applications.* SI Edition., vol. 34, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (2011).

Colucci, F., & Moia, F. Thermal Response Tests and effects of geological heterogeneity. *Rendiconti online della Società Geologica Italiana*, **32**, (2014), 7–14. doi: 10.3301/ROL.2014.142

Dutto, A. *Comparison between TRT field tool and laboratory analisys for ground thermal parameters evaluation*. Degree Thesis – University of Padova – Department of Geociences.

Gehlin, S. & Spitler. J. D. *Thermal Response Test - State of the Art*. Report IEA – ECES (2001)

Gehlin, S. & Nordell, B. *Determining Undisturbed Ground Temperature for Thermal Response Test*. ASHRAE 2003 Winter Meet. CD, Chicago, IL; United States (2003)

Li, M. & Lai, A.C. Review of analytical models for heat transfer by vertical ground heat exchangers (GHEs): A perspective of time and space scales. *Applied Energy* **151**, (2015), 178–191

Sarbu, L. & Sebarchievici, C. General Review of Ground-Source Heat Pump Systems for Heating and Cooling of Buildings. E*nergy and Buildings* **70**, (2014), 441–454

Zarrella A, Emmi G, Graci S, De Carli M, Cultrera M, Dalla Santa G, Galgaro A, Bertermann D, Muller J, Pockelé L, Mezzasalma G, Righini D, Psyk M, Bernardi A (2017). Thermal response testing results of different types of 2 borehole heat exchangers: an analysis and 3 comparison of interpretation methods. Energies 2017, 10, 801; doi: 10.3390/en10060801

VDI, VDI-Standard: *VDI 4640 Blatt 1. Thermal use of the underground* (2010)

Witte, H.J.L. Error analysis of thermal response tests. *Applied Energy*, 109, (2013), 302-311