Applied Thermal Engineering 82 (2015) 39–47

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research paper

How to correct the ambient temperature influence on the thermal response test results

Roque Borinaga-Treviño [a, *], Jose Norambuena-Contreras [b], Daniel Castro-Fresno [c]

[a] Department of Materials Engineering, University of Salamanca, E.P.S. Zamora, Spain
[b] Department of Civil and Environmental Engineering, University of Bío-Bío, Concepción, Chile
[c] GITECO Research Group, Universidad de Cantabria, Santander, Spain

HIGHLIGHTS

- A TRT evaluation method is proposed to reduce its ambient temperature influence.
- The method reduced the time dependent ground thermal conductivity variation.
- Enhanced insulation reduced the ambient influence on the mean fluid temperature.
- The ambient to mean fluid temperature influence occurred with about a 3 h delay.

ARTICLE INFO

Article history:
Received 24 October 2014
Accepted 20 February 2015
Available online 3 March 2015

Keywords:
Energy efficiency
Temperature influence
Thermal conductivity
Thermal response test

ABSTRACT

Due to global warming and to the increasing energy demand, it is necessary to improve energy efficiency on buildings. In this context, Ground-Coupled Heat Pumps (GCHP) have proved to be the most efficient heating and cooling system. The main parameters to define a ground heat exchanger are obtained via an in situ test called Thermal Response Test (TRT). However, ambient air influence on this test is remarkable due to the exposition of the testing machine, and even the ground undisturbed temperature varies with the ambient temperature oscillations. Therefore, despite the fact that the influence of ambient conditions on the TRT results is an important topic in order to define a ground heat exchanger, there is yet a limited literature on new theoretical methods to correct the ambient temperature influence on the predicted ground thermal conductivity measured via TRT. This paper presents a new methodology to analyse and mitigate the influence of the ambient conditions on the TRT results, with the main advantage that it is not necessary to know its physical origin previously. The method is focused on reducing the mean fluid temperature oscillations caused by the ambient temperature, by analysing the influence of the chosen time interval to fit the data to the infinite line source theory formulae that finally predicts the ground thermal conductivity. With these purpose, results of two different TRTs were analysed, each of them with a different equipment and ambient exposition. Results using the proposed method showed that thermal conductivity oscillations were reduced in both tests. For the first test, the uncertainty associated to the chosen time interval for the estimation was diminished by 33%, reducing significantly its predicted value and thus avoiding the future installation possible under-designing. However, because of the equipment insulation improvements and the smoother ambient temperature variations, the method obtained similar results for the predicted thermal conductivity and for its uncertainty for the second test.

1. Introduction

Over 40% of the world's energy consumption takes place in heating, cooling and lighting of buildings [1], which indicates the importance of making efficiency improvements on buildings to reduce its environmental impact. For that purpose, buildings not only must be well insulated to reduce involuntary energy loss-gain, but renewable energy sources should be used to reduce the use of fossil fuels. In that scope, Ground-Coupled Heat Pump Systems (GCHP) have proved to be a reliable, efficient system for heating and cooling buildings [2]. As heat pumps work by using electricity, greenhouse gas emissions could be reduced to zero if the electricity

* Corresponding author. Tel.: +34 980 54 50 00.
E-mail address: roque.borinaga@usal.es (R. Borinaga-Treviño).

http://dx.doi.org/10.1016/j.applthermaleng.2015.02.050
1359-4311/

is obtained by other renewable energies, such as solar, marine, or wind energies, even with deep geothermal energy. During the design of a GCHP system, is vital to evaluate on field the thermal behavior of at least one of the boreholes already finished, which is usually determined via Thermal Response Test (TRT). The procedure consists in injecting a constant heat flow, measuring the temperature increment with time in order to study the thermal response of the ground [3].

In this context, Rainieri et al. [4] summarized the different existing TRT procedures and the alternative data analysis methods to predict ground and borehole thermal performance up to the year 2011. These methods could be classified in two main groups: analytic and numerical methods. Analytic methods predict the ground and borehole thermal performance by fitting the registered fluid temperature to the equations proposed by different authors [4]. Most of them are based on two main parameters: one defining the borehole contribution to the heat exchanger performance (borehole thermal resistance or similar) and ground thermal conductivity (λ_s). Numerical methods describe the borehole and ground configuration with a higher geometric definition and with more material properties governing the time dependent heat diffusion problem. Apart from the properties reported by the analytic method, latest numerical methods estimate the ground and grout heat capacity or quantify the ground heterogeneity influence on the heat exchanger performance: groundwater presence [5], variation of the ground temperature and thermal properties with depth [6], etc [4]. Recent papers related to new TRT interpretation methods have also been released after the review written by Rainieri et al. [4] taking into account different phenomena on the estimated GCHP system performance [7–12]. Robert and Gosselin [13] have even proposed a method based on cost minimization to design a complete GCHP system, where the necessity of a TRT depends on the designed bore-field size. However, these methods do not take into account the ambient temperature, which is an easily and economically measurable variable that needs to be considered when designing a geothermal heat exchanger. In this way, different authors studied the ambient temperature influence on the TRT results obtained. Although Austin et al. [14] and Witte et al. [15] already detected this influence on the recirculated mean fluid temperature, Bandos et al. [16,17] were the first to analyse its origin. As a result, Bandos et al. [16] determined that ambient temperature induced an oscillation of approximately 0.1 °C on the mean undisturbed ground temperature in a daily period for typical Spanish temperature oscillations. Additionally, Bandos et al. [17] also proposed a method to reduce the effect of the pipe-to-ambient convection heat transfer occurred in the exposed section. Nevertheless, there exist other environmental heat transfer phenomena that were not taken into account, such as solar radiation, heat transfer occurred between the equipment and the ambient, etc. Thus, despite the fact that ambient influence on the TRT conditions results is an important topic in order to define a ground heat exchanger, there is still a limited literature referent to new methods to correct the ambient temperature influence on the predicted ground thermal conductivity measured via TRT. For all these reasons, in this paper a new methodology is proposed to analyse and partially eliminate the influence of the ambient conditions on the TRT results, without being necessary to know its physical origin.

2. Experimental procedure

2.1. TRT equipment and testing process

Two TRTs were performed in Spain at different places. Each test was carried out by using different equipment: one test was performed in Boecillo-Valladolid (TRT_A) by using equipment A, while the second was performed in Tres Cantos-Madrid (TRT_B) by using equipment B. Table 1 summarizes the characteristics of the equipment used and the test settings for each performed test. Apart from the borehole depth, borehole configurations and materials used were also completely different for both tests.

Regarding to test duration, the testing procedure was similar on both TRTs developed. Tests were carried out at least 14 days after the construction of the GHE to avoid any influence of the cement paste hydration process on the obtained TRT results. Equipment A was the same already explained in a previous release [18]. Equipment B was an enhanced version of the equipment A. With a similar flowmeter, equipment B had two pt100 thermal sensors to measure the fluid outflow and inflow temperatures, reducing the error attributed to them when the instantaneous heat injected is calculated. The hydraulic pump was also improved by using one more powerful to ensure that recirculated fluid was on turbulent regime on the TRT_B. Finally, as shown in Fig. 1, thermal insulation of the new equipment was also improved by using a wooden box to cover the equipment as an additional protection before covering everything with a geotextile to protect it against radiation.

2.2. Formulation used for the analysis of the data

The new method developed in this paper was based on the time dependent ground thermal conductivity variation. Therefore, as the analytical theory used on the comparison is the same, factors such as borehole geometry or length affected in the same degree for all time periods. Thus, the improvement achieved by the method proposed was independent to the chosen analytical theory. In this case, a simplification of Infinite Line Source method (ILS) of Mogensen [19] has been used for the analysis. This method has been successfully used recently to analyse the influence of different borehole configurations: different grouting materials [18–20], pipe configurations [21,22] or borehole diameters [23], among others. However, as for the methodology proposed by Bandos et al. [17], the one explained in this paper was valid for any other analytical model (Finite Line Source (FLS), cylinder source theory (CLS), etc.) that estimate the governing parameters by

Table 1
TRT parameters used and equipment specifications.

Thermal response test		Test A	Test B
Specifications of the equipment used			
Mass flowmetter	Sensor model	Kobold DRG-1925-G5-L342 (A & B)	
	Datalogger	Testo 175-S2	Testo 175-S2
	Accuracy (%)	3	3
Inlet-outlet temperatures	Sensor model	k-type Thermocouple	Pt100
	Datalogger	Testo 177-T4	Testo 176-T2
	Accuracy (°C)	±0.3	±0.2
Test parameters			
Borehole depth (m)		97	140
Borehole diameter (m)		0.12	0.17
Pipe system	Type	Double U	Simple U
	Model	PE100/SDR11	PEX/SDR11
	Outside diameter (mm)	32	40
	Shank spacing (mm)	57	80
Undisturbed ground temperatura (°C)		16.2	17.2
Average water flow (l/min)		28.1	16.1
Time averaged injected heating power (W)		5639	6418
Test duration (h)		61	72