Renewable Energy 62 (2014) 563–570

Contents lists available at ScienceDirect

Renewable Energy

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

A 3-field earth-heat-exchange system for a school building in Imola, Italy: Monitoring results

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ARTICLE INFO

Article history:
Received 26 July 2012
Accepted 16 August 2013
Available online 11 September 2013

Keywords:
Earth-to-air horizontal heat exchangers
Ground cooling
Monitoring results
School building

ABSTRACT

The present study reports the results of a 12-month-long monitoring campaign of an earth-to-air horizontal heat exchanger (EAHX) system in a school complex in Imola, Italy. With more than 2 km of buried pipes, it represents one of the biggest Italian applications of this technology. Considerable differences between inlet and outlet air temperature have been noticed both in winter and in summer. Air temperature and relative humidity have been represented over a psychrometric chart while the energy performance of the system was analysed based on data of sensible heat exchange.

The monitored results have been compared with three other cases presented in literature in order to verify the parameter values of different EAHX in various climates and design conditions.

1. Introduction

The expansion of air conditioning demand has significantly increased global electrical consumption and peak power demand in summer, requiring new power plants for electrical energy production [1&2] as well as increasing the cost of peak electricity. In addition, global attention to the reduction of climate-change-inducing greenhouse gas emissions is stimulating the spread of passive cooling. As a matter of fact, among the various energy sources, electricity is characterised by the highest GHG emission factor in Countries – such as Italy – with a prevalent oil-dependent energy mix. Moreover, the oil reserve peak is approaching and costs for energy supply are expected to increase considerably [3].

Hence, earth to air heat exchangers (EAHXs) seem to be particularly suitable for the Italian energy-related, as well as geoclimatic, context. The object of this paper is the presentation and discussion of a monitoring campaign carried out in the largest EAHX field ever installed in Italy within a School building compound. The objectives of the monitoring programme are the following:

- check possible discrepancies between the foreseen and actual performance in order to improve future design approaches;
- develop a set of reference data that could be useful in future for parametrical studies supporting simplified system design tools;
- evaluation of the performance in terms of COP, considering the net cooling and heating energy obtained in relation to electricity consumption for ventilation.

2. Horizontal earth-to-air heat exchangers

EAHX systems are not everyday technologies and only in the last few years have several monitored cases been presented in literature [4–7]. Nevertheless, EAHX systems are particularly interesting because of their low maintenance and operational costs [5].

Examples of EAHX system design methodologies may be found in Refs. [8,9]. Analyses on thermal soil capacity and thermal saturation due to continuous use have been described in Ref. [8] although a monitoring of two EAHX systems at the same boundary conditions would be necessary in order to obtain reliable results regarding long-term soil thermal discharging. In addition, there is a lack of data on the thermal behaviour of EAHX systems in different seasons and climates, although long-term monitoring results have been presented in Refs. [5,6]. Only a few analyses have been made about specific and relative air humidity in spite of the fact that water vapour is an important variable for comfort analysis. A thorough work on this topic is presented in Ref. [10].

3. Imola's school building case study

The monitored EAHX system is located in Imola (BO), Italy in the High School Building "L. Orsini" (completed in 2008), which is characterised by a total floor area of 4800 m^2. Several sustainable

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0960-1481/$ – see front matter
http://dx.doi.org/10.1016/j.renene.2013.08.020

energy-saving technologies were designed and installed, in addition to the EAHX system. In particular vertical Solarwall® air-collectors were coupled with the EAHX in winter.

3.1. Description of Imola's EAHX system

Imola's EAHX system is composed of three fields each with a different number of 70 m long horizontally buried pipes (12 – 12 – 8; pipe diameter = 0.25 m) for a total length of 2240 m (Fig. 1).

All the fields supply air to a dedicated AHU connected to other 3 AHUs placed in the basement.

Each EAHX field comprises the following components: an air inlet chamber; a collector duct for distributing air into tubes; twelve or eight comb-like parallel pipes (distance from building respectively 6, 30 and 6 m) connected to a collector duct; a condensation drain chamber; a terminal connection duct; an air mixing chamber. The ducts and pipes are made of rigid polyethylene with a special treatment in order to prevent mould growth. The air inlet, condensation drain and mixing chambers are made of reinforced concrete with a special surface treatment based on a nontoxic finishing for water containers. Inlet openings are provided with a 100 mm grid device to avoid rain and rat infiltration and an anti-dust filter (class G4) is installed before the distributing collector duct. In every chamber a sump is present to collect infiltration or condensation water, while in the condensation chambers, catch basins bring collected water directly to the drainage system.

Ducts and pipes are positioned on a sand layer with a 6.5‰ constant slope. The connections between pipes and collector ducts are blended in order to reduce friction losses. Every tube presents expansion joints. The average depth of the tubes is 2.61 m while the distance among the pipes in the same field is 1.10 m.

3.2. Performance of the EAHX system

In the design phase, the annual energy performance of the EAHX system was evaluated using the software GAEA (Graphische Auslegung von Erdwärme Austauschern), which represents a simple, effective approach to dimensioning and evaluating the energy contribution of an EAHX system [11&12] during the preliminary design stage. Software such as TRNSYS and ENERGY+ could be used in the development design stages where more accurate and detailed data are possible. As GAEA input is limited to a maximum number of ten parallel tubes, separate analyses have been elaborated for each field. Moreover, for the 1st and the 2nd field the simulation results based on ten tubes were converted to the actual number of tubes (twelve) using a proportional approach. The soil properties used in the simulation are: type of soil – sand; density – 1780 kg/m^3; heat capacity – 1.39 kJ/(kg K); thermal conductivity – 0.93 W/(m K); ground water level – 6 m [8].

The system could treat 40 500 m^3/h, which is the demand for a full occupancy of the school building to comply with the ventilation requirement defined by national law (minimum ACH of 2.5 Vol/h [13]).

In Table 1, the design performance parameters of the EAHX system are shown with a comparison to results from monitoring when applicable, while Table 2 reports several characteristics of each field.

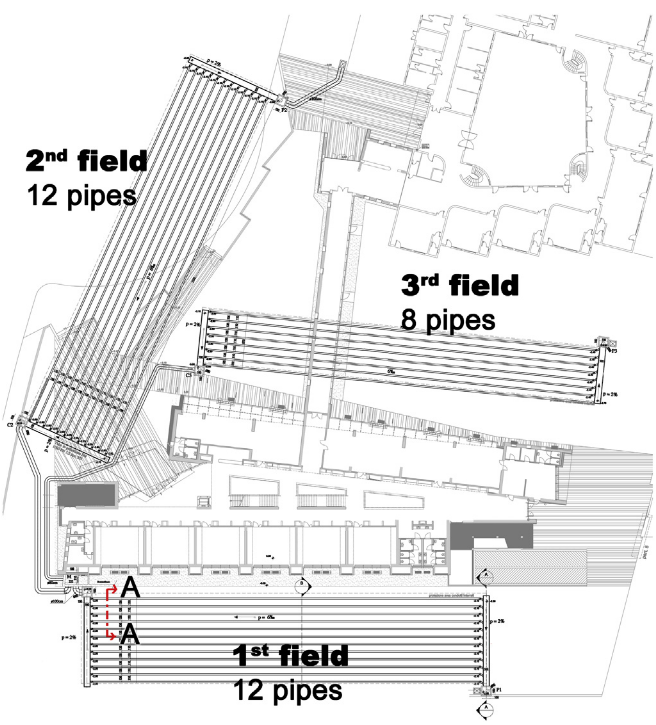

Fig. 1. General plan of the EAHX system.

4. Monitoring: methodology and results

4.1. Characteristics of the monitoring system

The monitoring system is composed of 49 sensors that allow for measuring air and soil temperature, air relative humidity and air

Table 1
EAHX system – comparison between measured and design values.

	Design – GAEA (1 year)	Measured (May 2010–April 2011)
1st field		
Averaged air flow rate	15 200 m^3/h	4948 m^3/h
Averaged air velocity (ON)	5 m/s	2.4 m/s
Annual gain (heating)	55 042 kWh	78 318 kWh
Annual gain (cooling)	8826 kWh	26 268 kWh
Averaged air velocity (ON cooling)		2.6 m/s
Add. electrical absorption (calc.)		1330 kWh (cooling)
COP (cooling)		19.7
Average specific cooling power		8.6 W/m
2nd field		
Averaged air flow rate	15 200 m^3/h	1265 m^3/h
Averaged air velocity (ON)	5 m/s	0.6 m/s
Annual gain (heating)	54 432 kWh	10 994 kWh
Annual gain (cooling)	8965 kWh	12 677 kWh
Averaged air velocity (ON cooling)		1.2 m/s
Add. electrical absorption (calc.)		220 kWh (cooling)
COP (cooling)		57.6
Average specific cooling power		4.2 W/m
3rd field		
Averaged air flow rate	10 100 m^3/h	3784 m^3/h
Averaged air velocity (ON)	5 m/s	1.8 m/s
Annual gain (heating)	35 442 kWh	34 427 kWh
Annual gain (cooling)	6556 kWh	28 646 KWh
Averaged air velocity (ON cooling)		3.3 m/s
Add. electrical absorption (calc.)		1216 kWh (cooling)
COP (cooling)		24
Average specific cooling power		14.2 W/m