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Horizontal earth-to-air heat exchanger in Imola, Italy. A 30-month-long monitoring campaign.

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Abstract

The present paper reports the results of a 30-month-long monitoring campaign of a EAHX (earth-to-air heat exchanger) system installed in a school building in Imola (ITA). The horizontal EAHX is divided into three fields for a total of 32 buried pipes. The system pre-treats the inlet air of three dedicated AHUs. The analysis follows a consolidate methodology used in a previous shorter monitoring of the first Imola's field that was already published. In this study, a comparison between different years of monitoring is introduced, together with the soil temperature trends of the first field.

Keywords: EAHX; ground cooling; passive cooling; monitoring results

1. Introduction

Air conditioning is a rising voice in several National energy balances. This trend has characterised at least the past three decades [1-4], increasing global electrical consumptions and, especially, the peak power demand during hot summer days. This increase is causing a rising cost of electricity, particularly, the electricity peak, a need of new power plants, a higher risk of blackouts, and growing CO_2-eq emissions. The emission factor of electricity is, in fact, very high compared to other sources in oil-dependent countries like Italy [5]. This general trend has to be reversed, according to the EPBD 2010/31/EU Directive on Nearly-Zero Energy Building (NZEB), and this can be realized with the contribution of passive and hybrid cooling systems [6]. Amid these systems, Earth-to-air heat exchangers (EAHX) are particularly suitable for reducing the electricity demand in climatic and energy context such as the Italian one. The

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EAHX systems are effective and low cost technologies, although only few monitoring studies are described in literature [7-11].

This paper reports and discusses the results of a monitoring campaign of a three-field EAHX installed in the premises of a School building in Imola (BO). A first analysis on monitoring results was already published [7]: it describes results related to the first Imola's field during a 12-month period as well as a comparison between monitored and designed performance data. The present contribution applies the same methodology for data analysis, but with different objectives:

- comparing the system performance during two different years for evaluating possible trends;
- developing a more complete set of reference data for future studies and model validations by using a 30-month-long monitoring campaign;
- reporting soil temperature trends during a two years long period.

2. Monitoring campaign

The EAHX system is installed in the premises of the school building "L. Orsini" localised in Imola (BO), Italy. This building was designed and completed between 2003 and 2008. The building has a floor area of 4800 m^2 distributed on four floors, including basement entirely dedicated to locate the technical systems. It is composed of two E-W oriented parts connected by a glazed atrium. In addition to the three EAHX fields, several energy-saving technologies were installed: a 20kWp PV system; 70 m^2 of vacuum solar thermal panels for DHW as well as integration for space heating and cooling; a 268-m^2 vertical south-oriented Solarwall® system coupled with the EAHX in winter. Moreover, the building reached class A based on *CasaClima* national standards.

The EAHX system is organized in three fields comprising pipes and collecting ducts made of rigid polyethylene, buried at an average depth of 2.6 m. The total of 32 tubes - 70 m long and with a diameter of 0.25 m – is differently distributed: 12, tubes in two fields, 8 in the other (Fig. 1). . Each field is composed of: an inlet chamber; two parallel collector ducts connecting the pipes, one for distributing inlet air and the other for collecting outlet air; a condensation chamber; and a mixing chamber. The EAHX system supplies four dedicated AHUs located in the basement.

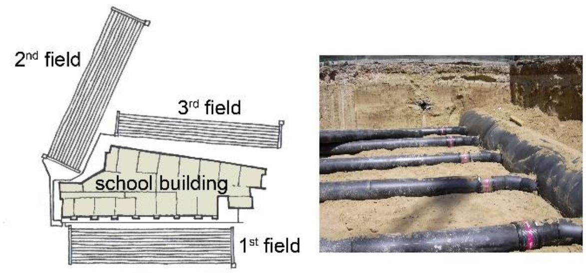

Fig. 1. The Imola's EAHX system.

2.1. - Monitoring data and methodology

The following parameters were monitored: in each field, inlet (ϑ_{in}) and outlet (ϑ_{out}) air temperatures, RH values, and outlet air velocities (ν_{air}); only in the first field, soil temperature (ϑ_{ground}). Additional temperature sensors were located along two pipes of the first field. Data recording from each type of sensors was scheduled at different intervals and elaborated as hourly and daily mean values. The collected datasets were analysed using a methodology described in Ref. [7] and compatible with the standard method proposed by Pfafferott in Ref. [8]. The methodology is synthesised as follows. After an assessment of general temperature trends, the system effectiveness (ε) was calculated by using Scott, Parson and Koehler's expression [2]. Furthermore, a psychrometric analysis, based on calculation of the vapour content of inlet and outlet airflows, was carried out. Moreover, the monitored data were used for calculating the sensible energy balance (Q_{sens}) of the EAHX system and the coefficient of performance (COP) of each fields.

3. Results and discussion

Inlet, outlet and soil temperatures of the 1st Field for a 31-month-long period are shown in Fig. 2. Differences in flow rate are due to a change in daily schedule of EAHX and to differences in percentage of usage of this system compared to solarwall® in winter and direct external air in summer.

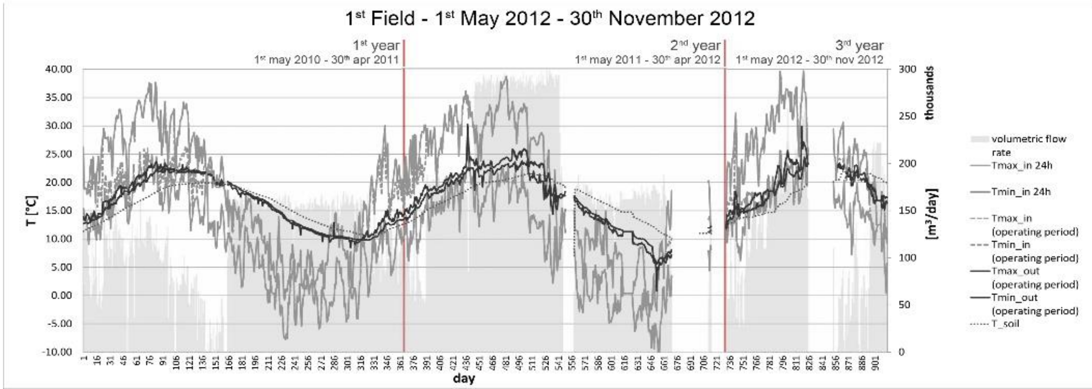

Fig. 2. Monitored hourly-average values for a 31-month-long period of: ambient temperature; duct inlet and outlet air and soil temperature; volume airflow (missing data are due to computer disconnections).

As the graph of Figure 2 shows, the high efficiency of the EAHX system in pre-cooling in summer and pre-heating in winter inlet air is apparent. Outlet air temperature values are very close to ground temperature showing a high system effectiveness.

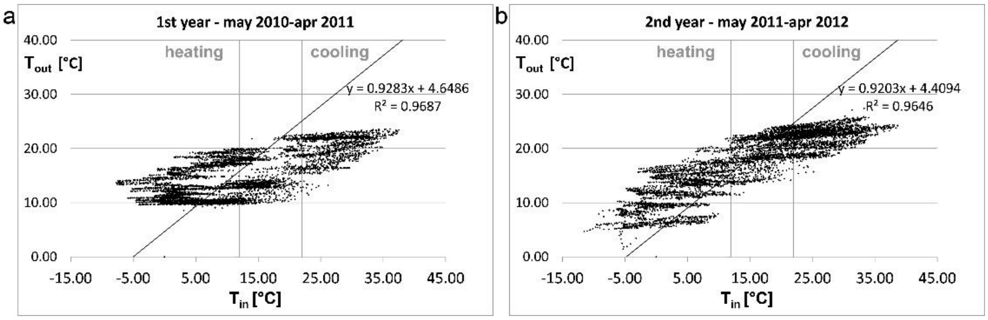

Fig. 3. Ambient and EAHX outlet air temperature values at Imola: (a) 1st year-period from May 2010 to April 2011; (b) 2nd year-period from May 2011 to April 2012.

Fig. 3 reports the characteristic regression lines, calculated as shown in Ref. [8], for two year-periods of monitoring: a) from May 2010 to Apr 2011; b) from May 2011 to Apr 2012. These lines are useful to characterise the system and compare its performance to other monitored cases [4]. Imola's EAHX system operated during the entire recorded period without a fixed time schedule control, hence several values are referred to thermally neutral conditions, i.e., between 12 and 22 °C of inlet air temperature. A wider variation range of outlet air temperature increase was recorded in the second period compared to the first one. This is partially due to a wider variation range of the inlet air temperature (lower temperature values in winter and higher in summer) as apparent in a psychrometric diagram (Fig. 5). This behaviour suggests that EAHX system's characteristics do not have a great long-term influence neither on performance nor on the ground temperature trend as confirmed by the similar inclination of the regression lines of Fig. 3.

EAHX effectiveness, calculated using eq. 1, is an important parameter for comparing system performances in the two periods. The effectiveness of each field (ε) was calculated for the two year-periods and for each month. Fig. 4 shows ε annual values for Imola's first field.

$$\varepsilon = \frac{(\vartheta_{in} - \vartheta_{out})}{(\vartheta_{in} - \vartheta_{soil})} \quad [-] \tag{1}$$

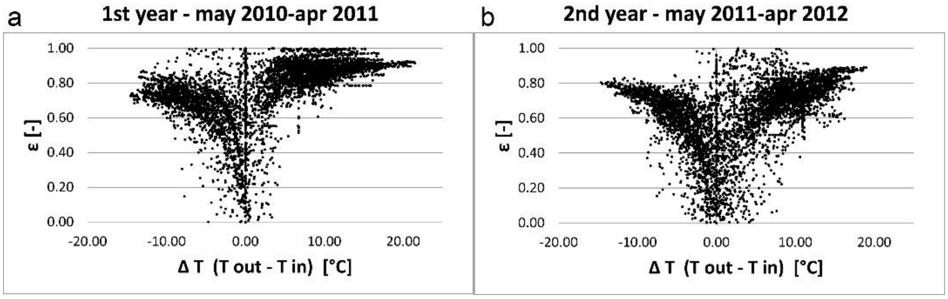

Fig. 4. EAHX system effectiveness of Imola's 1st field: (a) 1st year-period; (b) 2nd year-period.

As shown in Figure 4, the EAHX system effectiveness is very high, particularly in winter, and is slightly different in the two year-periods, reaching pick values in the range 0.8÷0.9 in the first period and 0.7÷0.8 in the second. However, this difference might be affected by the number of hours with system off, which is higher in the second year-period (3223 hs compared to 2822) also due to lack of recorded data in March, April and November. Furthermore, the smaller number of ΔT (T_{out}-T_{in}) values near zero are principally due to the cases when the temperature difference between T_{in} and T_{soil} is very small.

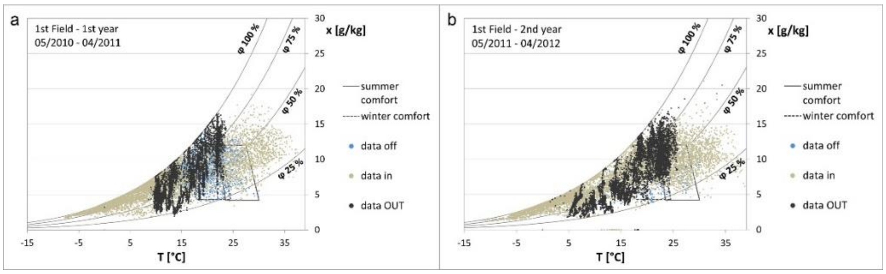

Fig. 5. Psychrometric diagram of the EAHX system: (a) 1st year-period; (b) 2nd year-period.

The two diagrams of Figure 5 represent hourly-averaged values of inlet and outlet air temperature and humidity – both relative (RH) and absolute (X) – shown in a psychometric chart. The vapour quality (X) is calculated according to Ref. [7,12-13]. Summer and winter comfort zones do not consider building influence but only local climate parameters. In summer, outlet air temperature reaches values always within the lowest part of the comfort zone although high RH values require a de-humidification treatment. In winter, the EAHX system increases air temperature without reaching comfort values but reducing the required energy to do it.

Monitored data were used as well for calculating: a) the sensible heat exchange of the system; b) the COP of each EAHX fields. The energy balance is calculated applying the eq. 2, introduced in Standard ASHRAE, 1985 et seq.

$$Q_{sens} = A_{pipe} v_{air} \rho_{air} c_{air} (\vartheta_{out} - \vartheta_{in}) \quad [\mathrm{W}] \tag{2}$$

where:

A_{pipe} = section area of the terminal connection duct [m^2],

ρ_{air} = air density [kg/m^3]

c_{air} = specific heat of air [1000 J/(kg K)].

The value of sensible heat exchange was used for calculating the system COP using eq. 3. The electrical consumption of fans (E_{el}) was calculated theoretically by estimating the system pressure drop by using coefficients from literature and a constant fan efficiency (0.8). The energy balance for the year-periods described above plus a third period of 7 months, was calculated separately for cooling and heating, and then summed up for each period ($Q_{heating}$ + $Q_{cooling}$) for calculating the annual COP . Table 1 shows the different results. The high difference in the COP values between the three periods are influenced by local climate variations, as well as by the increase of air velocity as underlined by changes in the average pressure loss.

$$COP = Q_{sens} / E_{el} \tag{3}$$

Table 1. Comparison between data of different years.

Variable		1st year	2nd year	3rd year (7 months)
av. ε	[-]	0.76	0.63	0.55
COP annual	[-]	38	21	-
COP cooling	[-]	20	14	21
COP heating	[-]	55	26	-
mean air flow	[m3/h]	4948	7339	5830
av. air velocity	[m/s]	2.4	3.1	2.7
pressure loss at av. air velocity	[Pa]	257 (calculated)	508 (calculated)	328 (calculated)
Q heating	[kWh]	78318	87520	17551
Q cooling	[kWh]	26268	32247	30497

As shown in Fig. 6, the monitored soil temperature data are compared to values calculated by using the following simplified algorithm presented by Hadvig [6 & 14]:

$$\vartheta_{ground,z} = \vartheta_{sf,mean} + A_s\, e^{-z\sqrt{\frac{\pi}{\alpha \cdot t_0}}} \cos\left[\frac{2\pi}{t_0}(t - t_{max}) - z\sqrt{\frac{\pi}{\alpha \cdot t_0}}\right] \tag{4}$$

where:

z = depth of the point where soil temperature is calculated
$\vartheta_{sf,mean}$ = annual average temperature of the soil surface
A_s = semi-amplitude of the annual variation of soil surface temperature
t_0 = duration of an year in seconds
α = ground diffusivity [m^2/s]
t = instant of calculation in seconds (1= January1st)
t_{max} = phase shift constant

Soil and air temperature of the 31-month period are reported as daily averages in figure 6(a). Calculated and measured undisturbed soil temperature (assumed as the sensor TT5, located 2 m far from the tube) conveniently fit, while soil temperature values recorded by the near-pipe TT3 sensor (30 cm far from the tube) show that buried pipes influence the closest layer of soil both in term of absolute values and time fluctuations. Because of these results, EAHX systems do not influence yearly-averaged undisturbed ground temperature fluctuations on the long-term. However, a wider database would be needed to draw a conclusion on this matter.

Finally, the air temperature profiles along a single tube for the hottest and coolest month, July and January, in the considered periods (three for July, two for January) were analysed (Fig. 6b). As Fig. 6b shows, the profiles of each month are similar in the different periods and resulting air temperature variations along the pipe due to thermal exchange occurs mainly in the first third of the tube (more than 70% as an average estimate). For this reason, it is possible to assert that Imola's EAHX has over-dimensioned pipes, as already reported in [7].

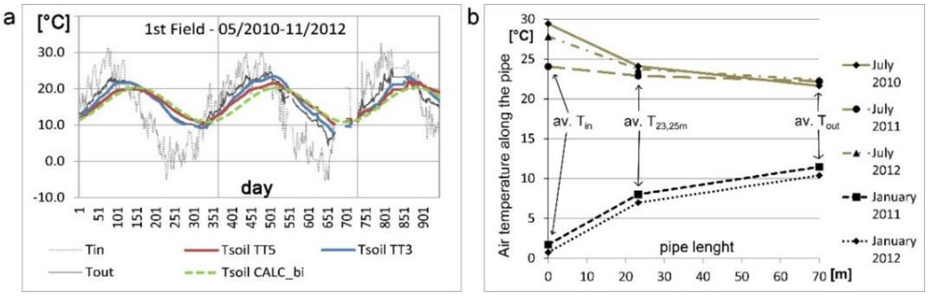

Fig. 6. (a) Monitored and calculated soil temperatures for a 31-month period. (b) Temperature profile along the 3rd pipe of the considered field, for different months and years.

Conclusions

This paper reports an analysis of data from a 31-month-long monitoring campaign on an EAHX system installed in a school building in Imola, Italy. Data were evaluated based on year-periods in order to compare the different time-dependent thermal performances and to study the possible long-term influence on the EAHX system on soil temperature. Results show a high performance and COP both in winter and summer, even if a reduction of effectiveness occurred in the second year-period although a lack of data may have influenced it. In any case, these data have to be validated in future by using experimental electrical consumption measures considering the high possible discrepancies between theoretical and measured results. Furthermore, soil temperature is influenced in the proximity of tubes in terms both of phase shift and temperature variation range (max and min) but no significant long-term impact was recorded for the more distant sensor. This suggests that EAHX systems are effective in mild Mediterranean and temperate climate zones and their performance are long-lasting reducing the fossil consumption of buildings.

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