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AIVC

Air Infiltration and Ventilation Centre

Use of Earth to Air Heat Exchangers for Cooling

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1 Introduction

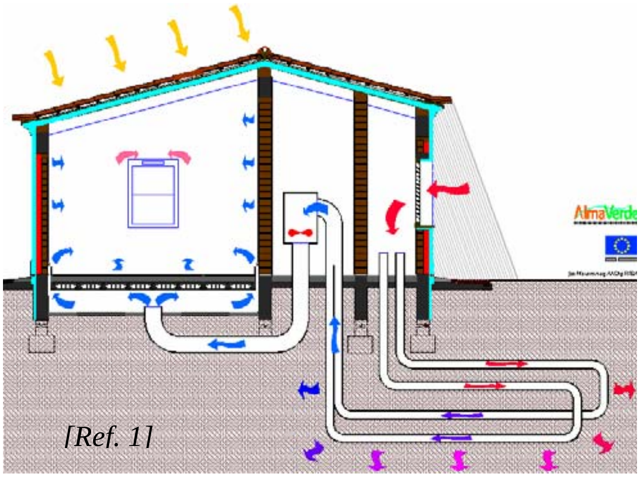
The present Ventilation Information Paper aims to present the basic knowledge on the use of earth to air heat exchangers. The increased need for air conditioning has made alternative passive and hybrid cooling techniques very attractive.

The technique is based on the use of the ground as a heat sink during the summer and winter period. In fact, the soil at a certain depth is at a much lower temperature than the ambient one, during summer and much higher during winter. Thus, the excess heat from a building may be dissipated to the ground through horizontally positioned buried pipes, reducing thus the indoor temperature in summer. In winter the pipes are used for preheating of the ventilation air, reducing thus the heating load of buildings.

The principles of operation as well as the way to apply earth to air heat exchangers are described. Performance data from various examples are presented as well. Finally, information on various methodologies to calculate the performance of the systems is given. Detailed information on earth to air heat exchangers can be found in Santamouris and Assimakopoulos (1996).

2 The Increased Needs for Cooling

Air conditioning has become popular during recent years because of the increased living standards in the developed world and the use of non-climatically responsive architectural standards.



According to the International Institute of Refrigeration (IIR) (IIR, 2002), actually there are more than 240 million air conditioning units and 110 million heat pumps installed worldwide. The same study shows that the refrigeration and air conditioning sectors consume about 15% of all electricity consumed worldwide (IIR, 2002). The annual sales of air conditioning equipment approach a level of $60 billion/year (IIR, 2002). This is almost equivalent to 10% of the automobile industry sales on a worldwide basis.

The penetration of air conditioning is increasing continuously. According to the Japan Air Conditioning and Refrigeration News (JARN) and Japan Refrigeration and Air Conditioning Industry Association (JRAIA) in 1998 the total annual number of sales was close to 35 million units; by 2000 it had increased to 42 million units and to 45 million units by 2002, with a predicted level of 53 million units in 2006 (JARN and JRAIA, 2002).

The use of air conditioning is the cause of different problems. Apart from the serious increase of the absolute energy consumption of buildings, other important impacts include:

- The increase of the peak electricity load;
- Environmental problems associated with the ozone depletion and global warming;
- Indoor air quality problems.

High peak electricity loads oblige utilities to build additional power plants in order to satisfy the demand, but as these plants are used for short periods, the average cost of electricity increases considerably.

One of the major scientific and technical requirements of our days is to address successful solutions to reduce energy and environmental effects of air conditioning.

Passive cooling techniques when applied to buildings have been proven to be very effective and contribute greatly in decreasing the cooling load of buildings, provide excellent thermal comfort and indoor air quality, together with low energy consumption.

3 The Use of the Ground as a Heat Sink

The ground temperature presents on average much lower temperatures than the ambient air during the summer period and higher during the winter period. The exact value of the ground temperature is a function of the depth, z, the thermal characteristics of the soil and in particular of its thermal diffusivity, (a), and of the variation of the surface temperature,

The ground temperature at any depth can be predicted using the equation given below.

Ground cooling is based on the dissipation of the excess heat from a building to the ground. During the summer period, the ground presents a much lower temperature than the ambient air. The dissipation of the excess heat may be achieved by the use of earth to air heat exchangers. More information on the potential of the heat dissipation to the ground can be found in (Mihalakakou et al, 1994).

An earth to air heat exchanger is a horizontal pipe buried at a certain depth. Air is circulated inside the pipe (in most cases by mechanical means) and because of the lower ground temperature its temperature is reduced, (figure 1).The cool air is then sucked inside the building to decrease indoor temperature.

$$T_{z,t} = T_m - A_s \exp\left(-z\left(\frac{\pi\,\alpha}{365}\right)^{0.5}\right) \cos\left(\frac{2\,\pi}{365}\left(t - t_0 - \frac{z}{2}\left(\frac{365\alpha}{\pi}\right)^{0.5}\right)\right)$$

Where :

T_m is the average annual temperature of the soil surface (K)
A_s is the amplitude of the surface temperature variation (K)
z is the depth (m)
α is the thermal diffusivity of the ground (m²/h)
t is the time elapsed from the beginning of the calendar year (days)
t_0 is a phase constant (hours since the beginning of the year of the lowest average ground surface temperature).

More information on the ground temperature can be found in Mihalakakou et al, (1992, 1997).

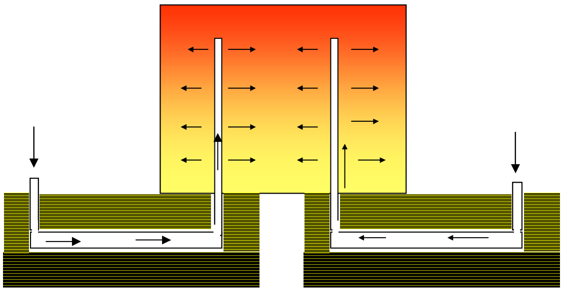


Figure 1: Principle of earth to air heat exchangers

There are two main configurations for the earth to air heat exchangers. The system may be an open or a closed loop circuit. In an open loop circuit the ambient air is circulated inside the pipes and then is transferred into the building (Figure 1) while in closed loop circuit configurations, both inlet and outlet are located inside the building (Figure 2). The specific performance of the earth to air heat exchangers and in particular the achieved air temperature decrease is a function of the inlet air temperature, of the ground temperature at the depth of the exchanger, of the thermal characteristics of the exchangers and of the soil, and finally of the air velocity and the pipe dimensions.

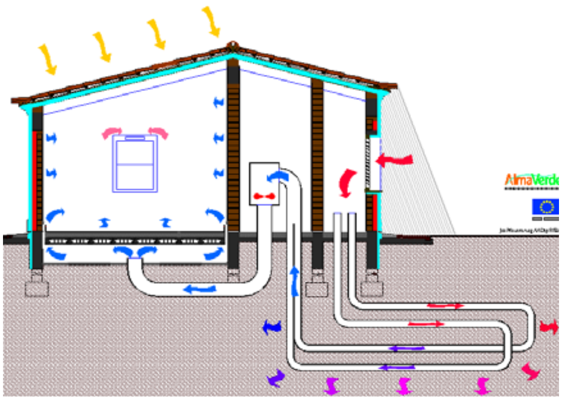


Figure 2: A close loop earth to air heat exchanger [Ref. 1]

Information on the cooling potential of earth to air heat exchangers can be found in (Mihalakakou et al, 1994b). Also information on the impact of ground cover on the efficiency of earth to air heat exchangers can be found in (Mihalakakou et al, 1994c, 1996)

4 Description of Earth to Air Heat Exchangers

An earth to air heat exchanger is a plastic, concrete, ceramic or metallic pipe buried at a certain depth in the ground (Figures 3-4). Given the very high thermal inertia of the ground, the conductivity of the pipe is of minor importance. In order to improve the thermal contact between the pipe and the ground, 5 cm of sand are typically placed below and above the pipe (Figure 5).

Figure 3: Placement of a pipe into the ground [Ref. 1]

Figure 4: Placement of a pipe into the ground

Figure 5: Placement of a pipe into the ground using sand to improve thermal contact between the pipe and the soil

Every exchanger has an inlet and an outlet part where air enters and exit. The pipes may be connected between them in order to have a common inlet and a common exit (Figure 6) or may be independent. The air is circulated through the pipes using either a common or individual fans. The selection of the fan has to be done in order to achieve the best appropriate air speed inside the tubes.

Although earth to air heat exchangers are in principle rather simple low-cost systems, condensation problems may appear, that may be the source of important indoor air quality problems. This may be resolved, for example, by having the pipes installed with a small tilt of e.g. 1% slope for drainage. A small hole at the lower part of the exchanger may help to avoid collection of water inside the tube. Design of a drainage system is also possible. Filtering of the air might be useful or necessary. In some cases the air is circulated inside the building through an air handling unit and thus air is filtered.

The main parameters to be defined before the installation of an earth to air heat exchanger system are:

- The depth the exchanger has to be placed;
- The length and the diameter of the pipes;
- The air speed inside the pipes;
- The control system to be applied.

Optimisation of the design requires a complete thermal simulation of the system. In the following some methodologies to design earth to air heat exchangers are presented.

Based on the existing experience some preliminary guidelines may be offered. These guidelines may be applied at any climate. In particular it has to be considered, that:

- The length of the exchanger should be at least longer than 20 m;
- The diameter of the exchanger should range between 0.2 to 0.3 m;
- The depth of the exchanger should range between 2 m to 3 m;
- The air velocity through the buried pipe should range between 6 and 10 m/s. Lower air speeds may be used as well, but the heat exchange coefficient inside the pipes will be lower, and thus the efficiency of the system will be reduced;
- The pipes have to be separated between them at about 2m distance to allow heat dissipation;
- In some of the cases, periodic cleaning of the tubes is important. This may be achieved by installing the tubes with a drop in height from start to end of 1:60 to allow jet washing.

Earth to air heat exchangers may be used to supply cool air directly to the building, or may be connected to an existing air conditioning system. In the later case, the exchangers may be used.

As it concerns the control of the system, a very simple strategy has to be applied. In a first step it has to be assured that the temperature at the exit of the pipes is at least 3-4 C lower than the indoor temperature (summer). Second it has to assured that the energy spent for the circulation of the air is much lower than the cooling power offered by the system. To achieve the above, the inlet and exit temperatures of the air as well as the indoor temperatures have to be measured. A very simple controller can be used to satisfy the above conditions.

Figure 6: Buried pipes with a common inlet and exit [Ref. 1]

5 Examples and Performance Data

Performance data from applications of earth to air heat exchangers to buildings are available from many projects. Information about the projects is given below. In most of the projects it is evident that the exit temperature from the tubes is quite low and can highly contribute to satisfy the cooling needs of buildings.

5.1 University building

Figure 7 shows the minimum and maximum ambient temperature as well as the exit temperature from an earth to air heat exchanger at the University of Ioannina, Greece, (Stournas Triantis et al, 1986). The length of the pipes was almost 30 m and the pipes were buried at about 3 m depth. Monitoring has taken place during the summer period and figure 7 shows data for 31 consecutive days in July. As shown, the achieved maximum temperature drop at the exit of the pipes was close to 10 C compared to the maximum ambient temperature.

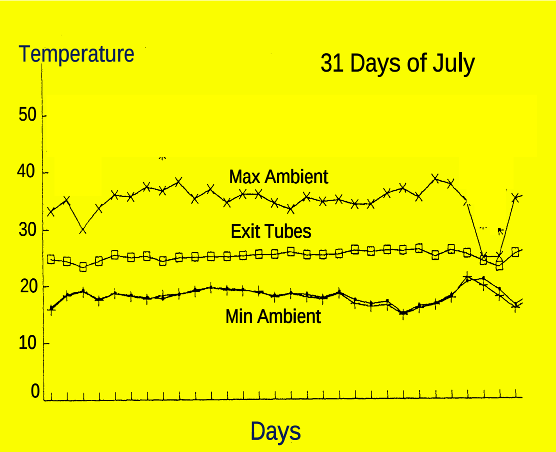


Figure 7: Performance of earth to air heat exchangers at the University of Ioannina

5.2 Paper warehouse

The Aggelidis building is a paper warehouse placed on a site of 10.900 m², 21km out of the center of Athens and on the Athens–Thessaloniki highway. It has three levels: the basement where the parking and central mechanical equipment are placed, the ground floor for the main storage room and lifting platforms, and the first floor for special products storeroom, platform and offices (see Figures 8, 9).

The building employs energy saving techniques such as the earth to air heat exchangers, shadow and windshield cladding and VRV (Variable Refrigerant Volume) type heat pumps, combined with simple ceiling fans for air conditioning in the office. The earth to air heat exchanger consists of two tubes of 0.315 m diameter buried at 2 m depth around the building. The length of each one is 50 m. They are designed to provide 4500 m³/h of air (air velocity equal to 8 m/s). The building is being monitored since November 2004 to assess the effectiveness of the energy saving techniques.

Figure 8: Outdoor view of the Aggelidis paper warehouse building

Figure 9: Point where the air from the earth tube is introduced in the building

The daily mean maximum inlet and outlet temperatures from one of the earth to air heat exchangers are given in Figure 10. As shown the mean temperature drop at the exit of the temperature is close to 5 C. The use of the earth to air heat exchangers has permitted to keep indoor temperature inside the comfort levels without the use of air conditioning. Figure 11 shows the distribution of indoor temperature in the warehouse during the summer period.

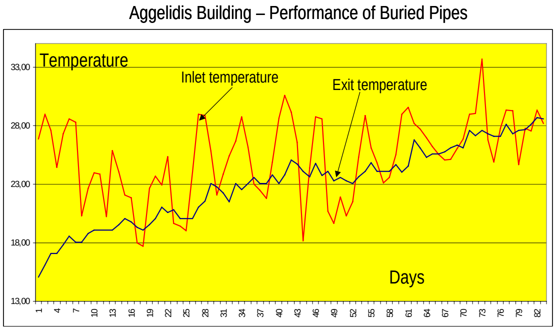


Figure 10: Inlet and outlet temperatures in one of the heat exchangers during the summer period

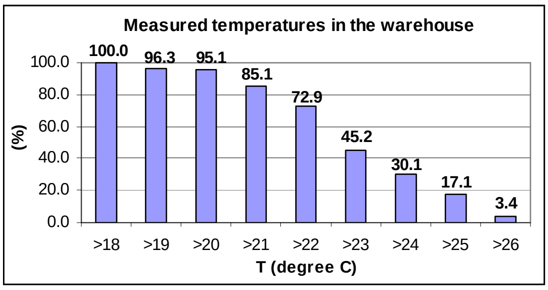


Figure 11: Distribution of indoor temperatures in the warehouse during the summer period

5.3 COOLHOUSE project

The COOLHOUSE project of the European Commission aimed to test the viability of alternatives to air conditioning using passive and low energy construction, cooling and ventilating techniques in Mediterranean and coastal climates and to demonstrate that such strategies can be practical and provide comfortable internal conditions for the occupants" (Burton, 2004).

The project involved three demonstration sites in Portugal, France and Italy.

5.3.1 Large new residential community in Portugal

The Alma Verde project in Portugal involves:

- 35.3 hectare new residential community;
- Numerous public and private amenities located in the unspoiled western Algarve 8km west of Lagos, Portugal, some 25km east of the tip of Europe
- 6 detached houses used to demonstrate the COOLHOUSE principles

The main energy components were

- External wall insulation;
- Solar shading;
- Internal thermal mass, including adobe internal walls;
- Ground cooling using standard PVCu drainage pipework.

The main characteristics of the earth to air heat exchangers used (Figure 2) are:

- Pipe diameter 160mm;
- Two ground tubes of 25m length each;
- Fan assistance;
- Separation between pipes of 2m to allow heat dissipation;
- 90º bends formed from two 45º pipe sections to reduce the air resistance;
- Periodic cleaning by installing the tubes with a fall from start to end of 1: 60 to allow jet washing.

Monitoring of the project has shown that the ground cooling system was very effective at removing the peaks and troughs of the external air temperature. The maximum +DT (i.e. heat removed from the incoming air) was 11°C, while the maximum -DT (i.e. heat added to cold external air) was 8°C. The temperature of the air from the ground pipes varied from 26 °C in August to 15 °C in winter.

Calculations show a 95% reduction in energy and CO_2 emissions, compared with the corresponding emissions in case conventional air conditioning was used. In parallel, additional ventilation pre-heat gains are also available in winter mode. A significant benefit of ground cooling is the reduction in internal relative humidity (RH). It may be about 25% to 30% of RH recorded something particularly important in Portugal.

5.3.2 Nursing home in France

L'Aubier de Cybele in Southern France, is an 80 beds care home for elderly people. It is considered as a first "green" nursing home in the south of France that uses bioclimatic and passive cooling design. It involves a number of energy efficiency and bioclimatic measures, like: insulation, solar shading, daylighting, thermal mass, natural ventilation, planting, solar water heating, passive solar gain and ground cooling.

The ground cooling system serves the dining room area of 380 m², and it consists of a grid of 11 pipes each of 200 mm diameter buried 2 m below ground (Figure 6).

The project is monitored in the frame of the Coolhouse project and it is found that while the initial cooling power was14 kW at 2 m³/s air flow-rate and 9.5 kW at 1m³/s air flow-rate, in July and August, the cooling power values have been reduced to about 5 kW after one to three days of uninterrupted use.

5.3.3 Aler Pavia

The Aler Pavia project (Italy) is in an area of existing social housing and is related to the refurbishment of 220 dwellings. It involves a new community centre, the "CircoLab", a multi-functional facility with corporate, conference, recreational, cultural and community functions. It is designed as a "concrete box", cut by two internal glazed patios and completely greened by creepers.

The project uses a ground cooling system, involving PVC pipes, with a diameter of 400 mm, 40 m long, buried 4 m below ground level (Figure 3). The outdoor air is taken from a shaded area at the opposite side of the courtyard. An air to air heat air heat exchanger is placed between the ground pipe and the ventilation system.

Monitoring has shown that ground cooling is very effective at removing the peaks and troughs of the external air temperature. The average temperature difference of the air entering the building below external air temperature was 2.9°C

6 Calculation Methods

Calculation of the thermal performance of earth to air heat exchanger is a complex problem. Calculation tools can be classified in simplified and detailed ones. Simplified tools are mainly designed to calculate the exit air temperature from the pipes. Detailed tools are simulation methodologies that solve simultaneously the heat transfer equations for the air, the tube and the ground.

A full presentation as well a comparison of most of the simplified methods is given by (Tzaferis et al, 1992). A simple validated parametric model to calculate the outlet temperature from buried pipes is proposed by (Mihalakakou et al, 1995b).

Various detailed simulation models to calculate the heat transfer phenomena associated with earth to air heat exchangers have been developed. A validated model coupled to the TRNSYS program is described in (Mihalakakou et al, 1994d).

The coupled heat transfer phenomena between buildings and earth to air heat exchangers are of high importance. Information on the ground temperature below buildings can be found in (Mihalakakou et al, 1995). In parallel, a method to estimate the specific performance of buildings coupled with earth to air heat exchangers is given in Santamouris et al, (1995, 1997).

7 References

1. Burton S.: Final Report of the Coolhouse Project. European Commission, Directorate General for Energy and Transport, 2003.
2. Japan Air Conditioning and Refrigeration News (JARN), Japan Refrigeration and Air Conditioning Industry Association (JRAIA). 2002. Air Conditioning Market. Tokyo, Japan
3. International Institute of Refrigeration. 2002. Industry as a partner for sustainable development – refrigeration,. Report Published by, Paris, France
4. Mihalakakou, M. Santamouris and D. Asimakopoulos :Modelling the earth temperature using multiyear measurements. J. Energy and Buildings, 19, 1-9, 1992.
5. Mihalakakou, M. Santamouris and D. Asimakopoulos : On the Use of Ground for Heat Dissipation J. of Energy, 19, 1, p.p. 17-25, 1994.
6. Mihalakakou, M. Santamouris and D. Asimakopoulos :On the Cooling Potential of Earth to air heat Exchangers, J. Energy Conversion and Management, 35, 5,395-402, 1994b.
7. G. Mihalakakou, M. Santamouris and D. Asimakopoulos and N. Papanikolaou : The impact of the ground cover on the efficiency of Earth to air heat Exchangers. J. Applied Energy , 48, p.p. 19-32, 1994c.
8. Mihalakakou, M. Santamouris and D.N. Asimakopoulos : Modelling the thermal performance of the earth to air heat exchangers.Solar Energy, 53,3, 1994d
9. .Mihalakakou, M. Santamouris, D. Asimakopoulos and A. Argiriou : On the ground temperature below buildings. Solar Energy, 55, 5, 355-362, 1995
10. Mihalakakou, M. Santamouris , D. Asimakopoulos and I. Tselepidaki : Parametric Prediction of the Buried Pipes Cooling Potential for Passive Cooling Applications. Solar Energy, 55, 3, p.p. 163-173, 1995b
11. Mihalakakou, J.O. Lewis and M. Santamouris :The Influence of Different Ground Covers on the Heating Potential of Earth to Air Heat Exchangers. Journal of Renewable Energies, 7,1, p.p. 33-46, 1996
12. Mihalakakou, M. Santamouris J.O.Lewis and D.N. Asimakopoulos : On the application of the energy balance equation to predict the ground temperature profiles. Solar Energy, 60,3/4,p.p, 181-190, 1997
13. Santamouris, G. Mihalakakou, A. Argiriou and D.N. Asimakopoulos : On the Performance of Buildings coupled with earth to air heat exchangers. Solar Energy, 54, 6, 375-380, 1995
14. Santamouris M, and D.N. Assimakopoulos, (Eds) : Passive Cooling of Buildings. James and James Science Publishers, London, 1996.
15. Santamouris G. Mihalakakou and D.N. Asimakopoulos : On the coupling of thermostatically controlled buildings with ground and night ventilation passive dissipation techniques. Solar Energy, 60,3/4, .p.p. 191-197, 1997
16. Stournas-Triantis, M. Santamouris και T. Metsis : Passive Solar Restoration of the new School of Philosophy building in the University of Ioannina, Greece. Proc. Conference "International Climatic Architecture Congress", Belgium, 1986.
17. Tzaferis, D. Liparakis , M. Santamouris and A. Argiriou : Analysis of the accuracy and sensitivity of eight models to predict the performance of earth to air heat exchangers. J. Energy and Buildings, 18, 35-43, 1992

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The Air Infiltration and Ventilation Centre provides technical support in air infiltration and ventilation research and application. The aim is to promote the understanding of the complex behaviour of the air flow in buildings and to advance the effective application of associated energy saving measures in the design of new buildings and the improvement of the existing building stock.