MARKET OPPORTUNITIES FOR ADVANCED VENTILATION TECHNOLOGY

22ND ANNUAL AIVC CONFERENCE
BATH, UNITED KINGDOM, 11-14 SEPTEMBER 2001

Earth-air heat exchangers in the Belgian climate: first practical experience

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SYNOPSIS

Following calculations of potential energy savings, several types of earth-air heat exchangers have been coupled to buildings in novel concepts for passive heating and cooling of ventilation air. For the first time this technology was used in the Belgian climate.
In a first case one short plastic tube is coupled to the HVAC system of an office building, to preheat/precool the fresh ventilation air. Measurements are presented on this system and it is shown that performance could have been improved by more concern during the design stage.
A second case involves four large concrete tubes coupled to the basement of an exhibition space. The low velocity hybrid ventilation system relies solely on control of pulsion and extraction grids and mechanical extraction in sanitary rooms. In winter, ventilation air is only preheated by the earth-air heat exchanger.
A last case study discusses the dimensioning and the construction of a prefabricated PE tube system for air intake.
Simulations and measurements show the importance of correct sizing and taking into account the conditions of the soil. Two calculation models are compared: one with CAPSOL, the other one developed at the Ghent University. It can be noticed that, for the Belgian climate, air can sufficiently be controlled by an earth-air heat exchanger and preheating equipment in ventilation systems can be avoided.

LIST OF SYMBOLS

$\dot{Q}$: the power transferred [W]
$\dot{m}_{air}$: the air mass flow rate in the tubes [kg/s]
$c_{p,air}$: the specific heat capacity of air [J/kgK]
T_{in} ,T_{out} : the temperatures of the air entering and leaving the segment [K]
d_o , d_i : the outside and inside diameter of the tube [m]
A : inside area of the section [m²]
α : the convection coefficient inside the tube [W/m²K]
λ_w : the conduction coefficient of the tube material [W/mK]

1 INTRODUCTION

For some years research effort has been focused on the application of earth-air heat exchangers in heating and ventilation systems for buildings. The ventilation air is drawn through a group of pipes buried into the soil. Due to the temperature difference between the air and the ground, the air is heated in winter and cooled in summer.
In the literature it is shown that this passive heating and cooling technology has great potential for reducing energy consumption in buildings [1], [2], [3], [4]. Several calculation methods were developed [2], [4] and some office buildings were constructed in Switzerland [5] and Germany [6]. The earth-air heat exchanger was now for the first time used in the Belgian climate. Two building projects have already been realised, the Zenit-house [7] and the Oxfam-office-building [8]. Two office buildings (Kamp C and SD-Worx) have left the design stage and are under construction.

The Zenit-house uses a tube of diameter 20 cm and length of 15 m, buried at a depth of 60 cm underground. The Zenit-house is a residential dwelling. This paper focuses on the use of earth-air heat exchangers in office buildings and on larger installations. The tube used in the Zenit-house will not be discussed.

The other three buildings are used as offices and have large ventilation systems. This paper discusses the concepts of the ventilation systems of the buildings and deals with the earth-air heat exchangers being part of the ventilation system. Not only thermal performance is discussed, but also the air quality and humidity are discussed. For the existing Oxfam-building measurements were done by Cenergie [8] and by the Ghent University [11] in two different time periods. For the buildings under construction both Cenergie and the Ghent University were involved in the design of the earth-air heat exchanger for these buildings. The problems encountered are addressed and the possible future problems, after delivery are studied.

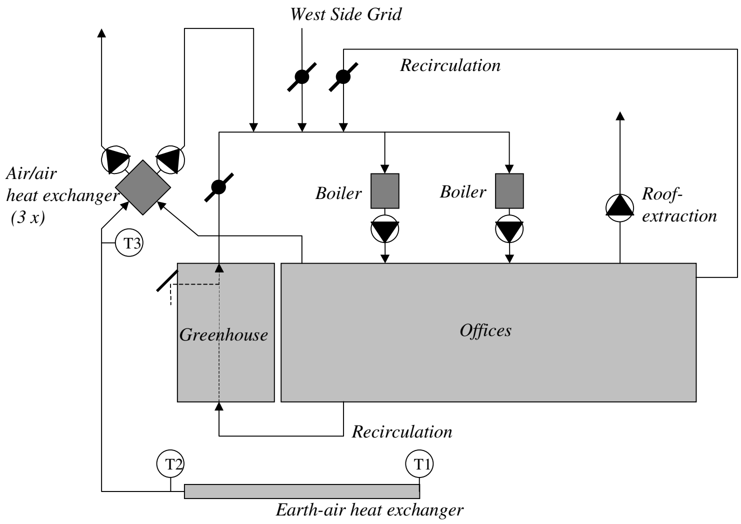

Figure 1 Ventilation system in the Oxfam building (source [8])

2 MEASUREMENTS ON THE OXFAM BUILDING

2.1 Building description

This building is situated in Ghent and was finished in 1999. It is used by OXFAM as offices and storage for their products. The building consists for about 28% of offices. The other part is a storage hall. The office part has 3 floors. The building is strongly insulated and 12% of the external surface is glass. On the south side the building has a greenhouse. In winter the recirculation air is heated in this greenhouse (Figure 1).

In the original design a short tube of 12 m at a depth of about 0.5 m preheats the fresh ventilation air (max. air flow rate 3 X 225 m³/h) during winter and cools the air during summer. The fresh air passes over three high efficiency air-to-air heat exchangers, which are heated with air extracted from the sanitary rooms. No special care was taken for the design of the earth-air heat exchanger.

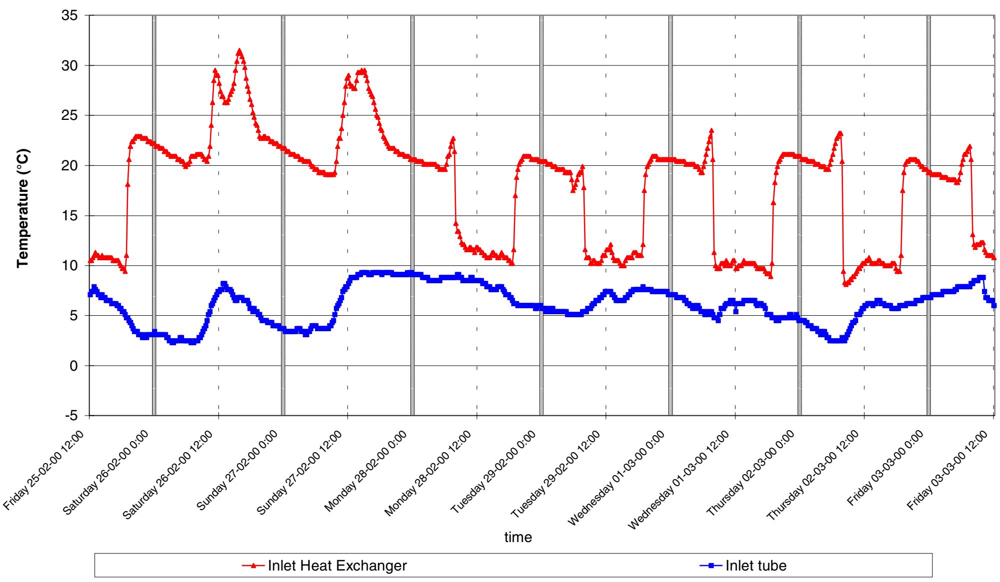

Figure 2 Performance of earth-air heat exchanger at OXFAM in winter [8]

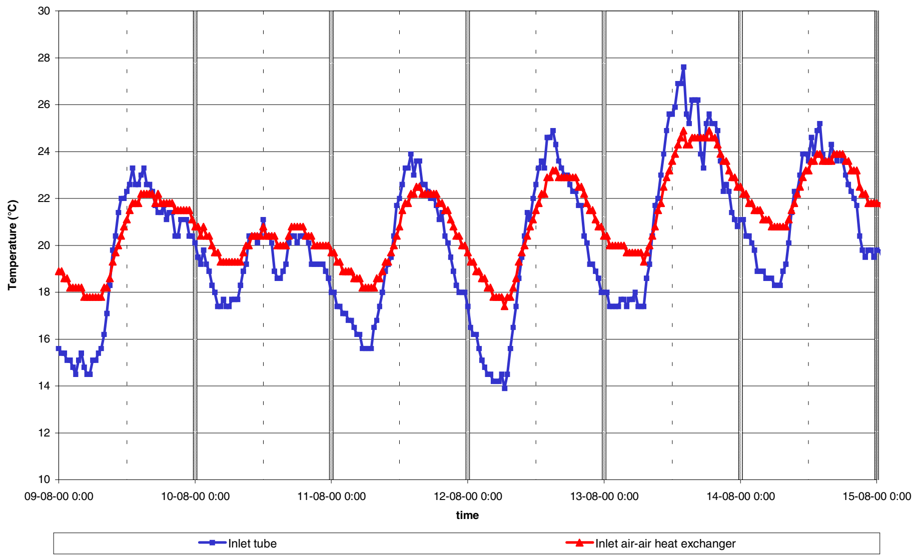

Figure 3 Performance of earth-air heat exchanger at OXFAM in summer [8]

2.2 Measurement data and evaluation

In February and August 2000 measurements were done by Cenergie [8] on the performance of the ventilation system of the building (Figures 2 and 3). Temperature sensors were inserted in the ducts just before the air-air heat exchanger (T3). The outside air temperature was measured (T1). Due to the long piping system between the earth-air heat exchanger and the air-air heat exchanger, the measured temperatures at inlet of the air-air heat exchanger are not exactly the temperatures at the outlet of the earth-air heat exchanger. The ducting however is well insulated, so the temperature difference can not be big. The measurements give a good indication of the performance of the ground tube.

At night and during the weekend the ventilation system is shut down, so there is no correlation between inlet and outlet temperatures. In winter, during day-time (8 am to 6 pm), the ground tube heats the air with about 1 °C to 3 °C. In summertime cooling with about 1 °C to 3 °C can be realised, during day-time conditions

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After these measurements were done, the owner decided to lengthen the tube by 7 meters. This new tube was measure by the Ghent University during the winter period in 2001 (February - March). In Figure 4 the measurements are shown. Now thermometers were inserted in front of the tube (T1) and just behind the earth-air heat exchanger (T2).

The first half of the measurement period during day time (operation) the air is heated with about 1 °C when the outside air temperature is rather high and is heated with about 5 °C when it is freezing outside.

In the second part of the measurements the outside air temperature has risen. The earth-air heat exchanger now cools the ventilation air. This is of course not the purpose of the tube, as the heating system in the building is still working. In general one can conclude that the thermal performance of the earth-air heat exchanger at the Oxfam building is rather poor.

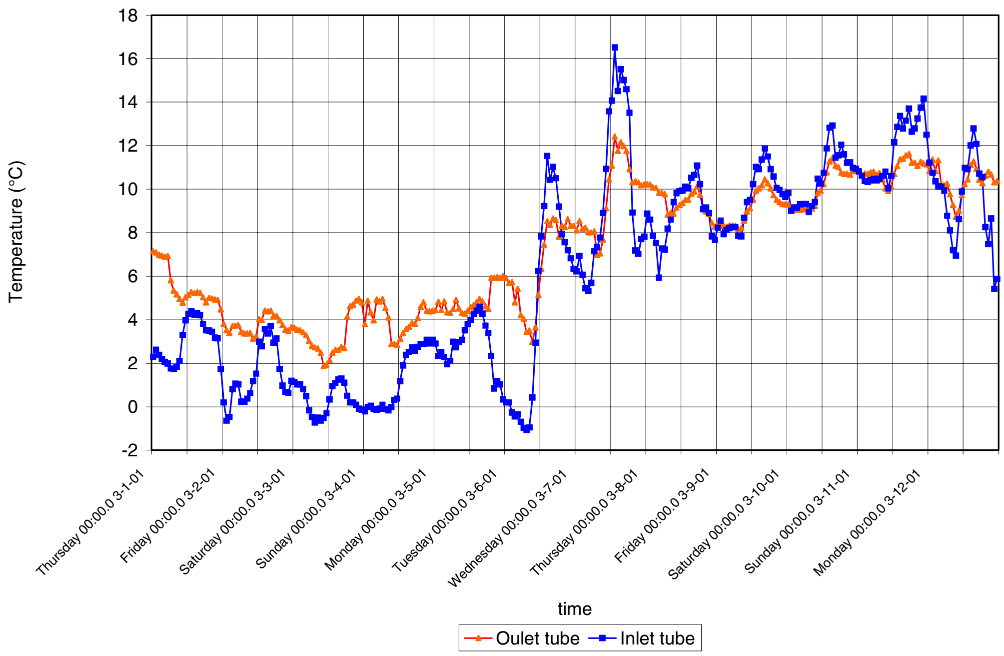

Figure 4 Measurements of the earth-air heat exchanger at Oxfam by the Ghent University

3 DESIGN ASPECTS OF NEW EARTH-AIR HEAT EXCHANGERS IN BELGIUM

3.1 Kamp C - Description

The provincial government of Antwerp, Belgium, wishes to establish a Centre for Sustainable Building at a former military domain 'Kamp C' in Westerlo as a first step towards further regional development. The building houses offices, an auditorium, a cafeteria, a library and an exhibition room. The building was divided into different ventilation and heating comfort zones. Since the exhibition space includes a large volume, it was decided to use less strict comfort criteria in this zone. High comfort standards were used for the cafeteria, offices, library (a former chapel) and education rooms. Furthermore an integrated energy saving concept is used for heating and ventilation, considering U-values of building walls, buffer spaces, night cooling, the use of a south oriented ventilated solar wall and roof integrated solar heating equipment.

An innovative demonstration was provided for the ventilation of the demonstration space, the offices and the education rooms. Air is inserted into a collector beneath the demonstration space by means of four concrete ground tubes (figure 5). The tubes have a diameter of 60 cm and are put 1 m to 2 m underground, which is above the ground water level. Three tubes can be closed to reduce airflow rate, considering night/day and seasonal control. Airflow rate is mainly provided by stack effect. The airflow is generally controlled on the extraction side. Controllable grids allow using the preheated air from the demonstration zone to provide a specified airflow rate for the education rooms. A similar approach is used for the ventilation of the former chapel. The preheated air from the demonstration zone is extracted in the sanitary facilities, which are provided with highly efficient mechanical extraction. The remaining air from the exhibition space is extracted via an elevator shaft by using the stack effect and controllable grids (figure 5). The building is now under construction and will be finished at the end of 2001.

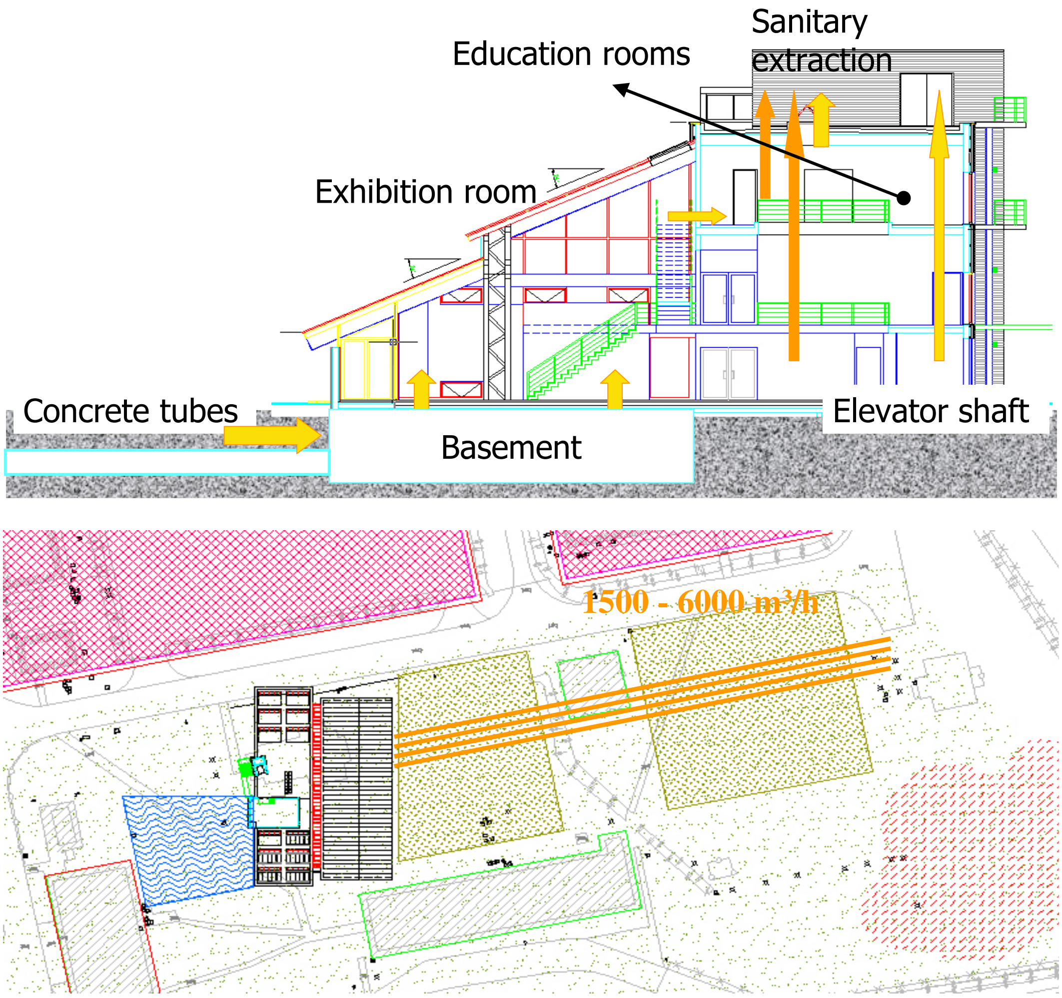

Figure 5 The ventilation system and the earth-air heat exchanger at Kamp C
(source : Cenergie and Studiegroep Omgeving)

3.2 SD-Worx - Description

The social section of the Flemish Economic Union, SD-Worx, is constructing a new office building situated near Kortrijk, Belgium. The building consists of two floors with offices and at the ground floor a car park and an entrance hall (figure 6). At the south side of the building a buffer zone is situated, which serves as a circulation zone and as a collector for passive solar energy. Six PE-tubes are inserted under the building through which the fresh air is mechanically drawn.

Ventilation of the buildings has three different operation modes. In summer during daytime the air is drawn through the ground-cooled tubes and fed through floor-panels into the office zone. Due to overpressure, the air flows through acoustical absorbing ventilation openings to the circulation zone, which is shaded from the sun by controllable louvers at the outside. The heated air is evacuated by natural draught through grids in the top of the building (figure 6). At night, extra grids are opened at the north side of the offices. Due to wind and stack-effect cold air from the outside is drawn through the offices and evacuated through the circulation

zone. A strong night cooling is realised. During winter the outside air is sucked through the earth-tubes, for preheating. Then it passes through a high efficiency air-to-air heat exchanger. The heated air is fed through floor panels to the offices. Due the southern orientation of the circulation zone, the sun heats the air in it. This air is then send to the air/air heat exchanger to heat the incoming air, making maximum use of the heat input from the sun.
The PE-tubes in this building are placed as one cluster at 3 m depth, which is beneath the groundwater level. The design airflow rate is 4800 m³/h, but it can be raised to 8000 m³/h to obtain extra cooling power.

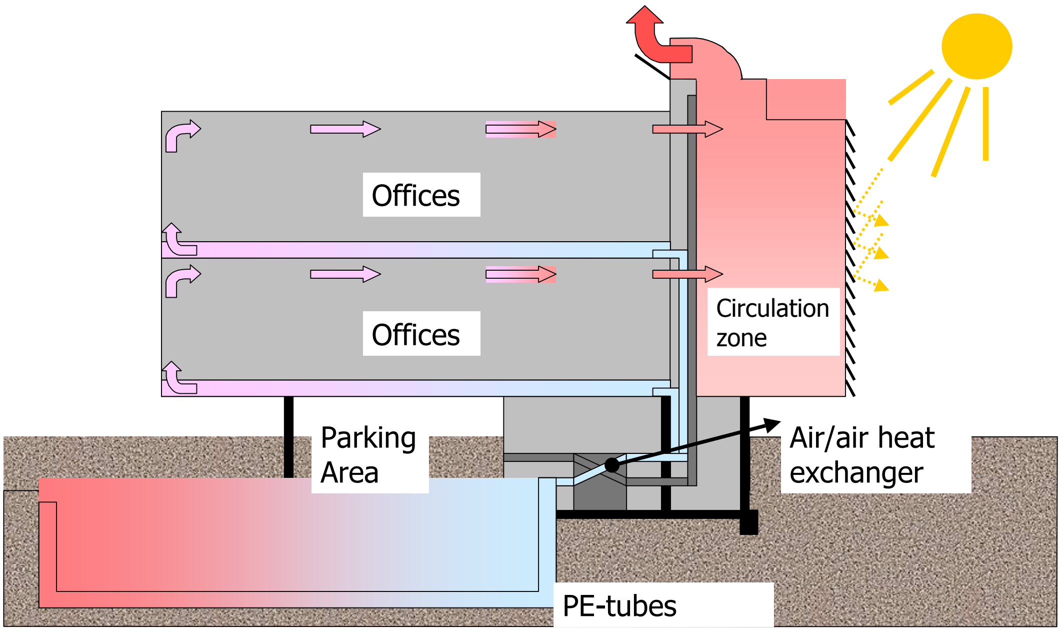

Figure 6 The ventilation system at SD-Worx (source : Cenergie)

4 THERMAL PERFORMANCE : MODELLING AND DESIGN CRITERIA

The thermal performance calculations were done with a multi-zonal dynamical model CAPSOL [9] and with a 1 dimensional model developed at the Ghent University [12]. The one-dimensional model assumes a constant wall temperature (T_w) at the outside of the tubes. The tube is divided in 100 segments. For each segment the convection problem is solved:

$$\dot{Q} = kA(T - T_w) \tag{1}$$

$$\dot{Q} = \dot{m}_{air} c_{p,air} (T_{out} - T_{in}) \tag{2}$$

$$k = \left[\frac{1}{\alpha} + \frac{d_o}{2\lambda_w} \ln\left(d_o / d_i \right) \right] \tag{3}$$

In figure 7 the temperature of the air leaving the earth-air heat exchangers is given as a function of the air inlet temperature of the heat exchanger. Both experimental results and calculations according to the Ghent model are shown. For the calculations the ground temperature was varied according to the depth of the tubes and the season.

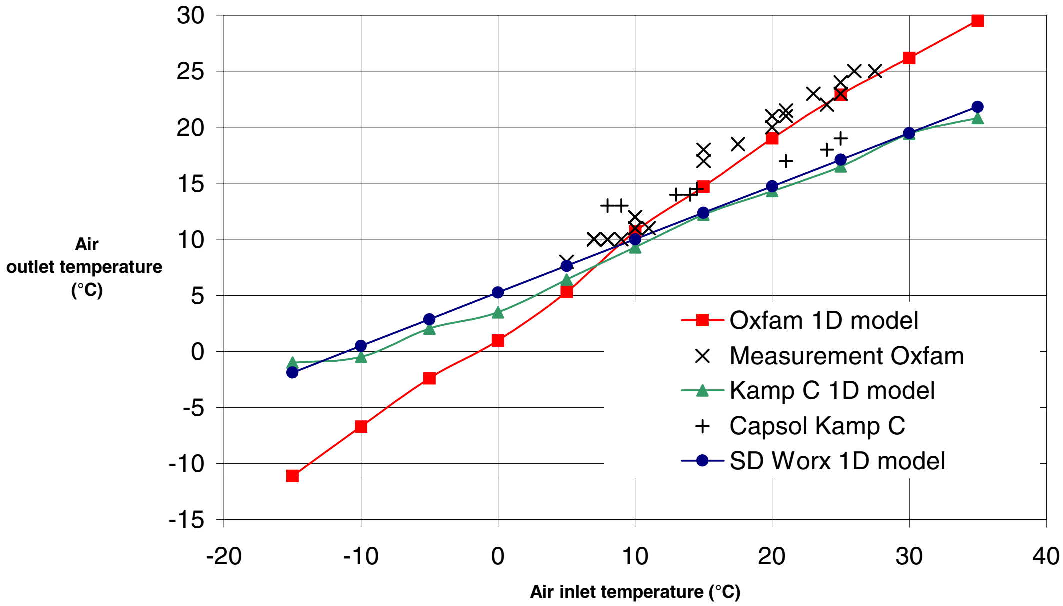

Figure 7 Thermal performance of the earth-air heat exchangers

For the Oxfam building a very good correlation is shown between the measurements and calculations. For Kamp C simulations of the ground tubes with CAPSOL are compared with the results of the program of the Ghent University. Both the calculations show the same trend. Compared to the 1D model, CAPSOL systematically predicts approximately a 2 °C smaller temperature change in the tubes.
For the SD-Worx case a linear variation of the outlet temperature with the inlet temperature is calculated according to the 1D model. This is caused by the fact that for all the calculations a constant ground temperature of 10 °C was assumed. As stated before, the tubes will be placed at a depth of 3 m, which is below ground water level. The influence of the seasons on the ground temperature thus becomes negligible.
Finally it can be noticed that the thermal performance of the small earth-air heat exchanger at Oxfam is much lower than the other two cases. This is the consequence of the poor attention that was paid to the design of it.

5 CONDENSATION AND POSSIBILITY OF THE GROWTH OF MOULDS

5.1 Condensation

The possibility of the forming of water by condensation inside the tubes is studied. Both temperature and humidity of the air have an important influence on the air quality in the building. Water in the tubes or corresponding structures can be a source for the growth of mould or mildew. This can cause a reduction in air quality, as spores can be responsible for respiratory problems or allergic reactions in humans. Mould and mildew grow on most surfaces if the relative humidity at the surface is above a critical value and the surface temperature is above 4 °C. The International Energy Agency Annex 14 (1990) established a surface humidity criterion for design purposes: the monthly average relative humidity at the surface should remain below 80 % [10].
For all three cases the inside wall temperature at of the end of the pipe was calculated with equations (1) and (3). Condensation will occur if the temperature of the inside tube walls is lower than the dew point temperature of the air. Dew point temperature of the air depends on

the air temperature and on the humidity of the air. In summer the air is cooled and the risk for condensation is greatest. To make a prediction of the condensation mass flow rate, it was assumed that, if condensation occurs, the air leaves the tubes saturated for the wall temperature at the exit of the tube. This gives the maximum possible condensation mass flow rate.
The Belgian climate is moderate. The winters have no extremely cold periods and are humid. Summers do not have high temperature peaks. The maximum average hourly value in summer for relative humidity is 60 % with an air temperature of 30 °C. These values will result in a prediction of the maximum condensation mass flow rate.
For all three cases this mass flow rate is calculated as a function of the relative humidity and the entering temperature of the air (ranging from 30 °C to 10 °C and *RH* 0% to 60 %).
If the monthly average humidity is above 80%, risk for moulds growing is imminent [10]. After calculating the wall temperature (T_w), this is translated in :

$$RH_{w,monthly\ average} = \frac{p_{water}}{p_{sat}(T_w)} > 0.8 : risk\ of\ moulds \quad (5)$$

For Kamp C the *RH* near the basement wall was calculated with the TRY of Ukkel, Belgium.

5.2 Results

For Oxfam no condensation will occur. During the measurements no problems with condensation were detected.
Condensation in the tubes of Kamp C results in maximum 59 l/h water production per tube (figure 8(a)), with an air flow rate of 1500 m³/h. If the air flow rate is reduced the condensation mass flow rate will be reduced accordingly. To be sure that this water is evacuated the tubes are tilted, being at 1 m depth near the building and at 2 m at the entrance. If the temperature is lower, there is a strong reduction of the condensation mass flow rate. Most of the time no problems with condensation are to be expected. Calculations with CAPSOL show that the basement wall temperature in summer does not surmount 14 °C. In figure 8(a) the possible condensation mass flow rate in the basement is shown with triangles. No special measures were taken to extract condensation water from the basement.

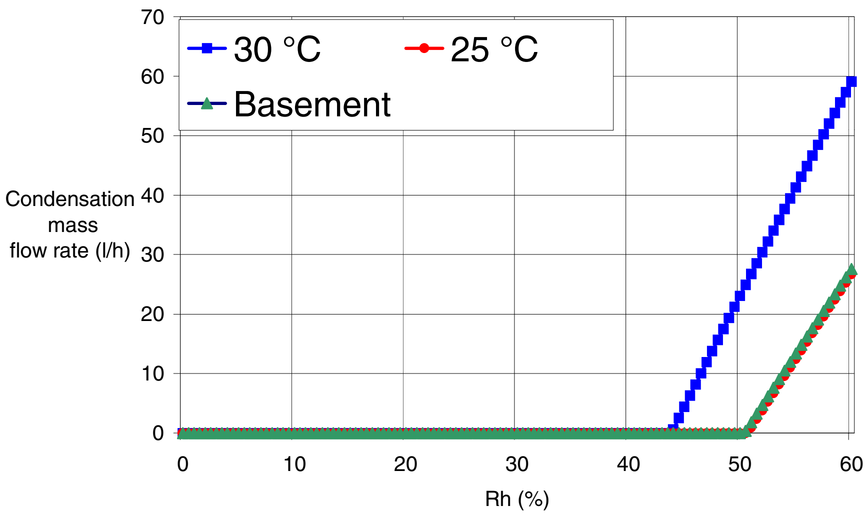

Figure 8 (a) Condensation mass flow rates in the tubes Kamp C

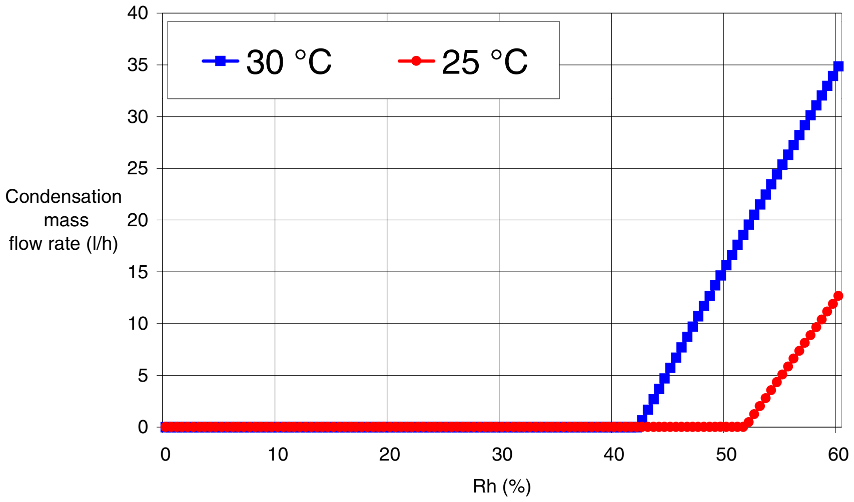

Figure 8 (b) Condensation mass flow rates in the tubes : SD Worx

In case of the plastic tubes the underground is not fit for growth of moulds. In Kamp C concrete tubes are used and the air is delivered to the basement, made with concrete walls. A risk of moulds growing can exist and is to be verified. The relative humidity in the months July and August of the air near the basement walls is shown in figure 9. The RH is high and the average value for July is 87.2 % and for August it is 80.2 %. So there might be a risk of moulds growing inside the basement. Although these calculations do not take into account the controls on the ground tube, the absorption of moisture in concrete and the drying effect of air at high velocity, it is recommendable that the basement will be carefully watched and logged. If measurements confirm the calculation results, the authorities will have to take special measures for the basement.

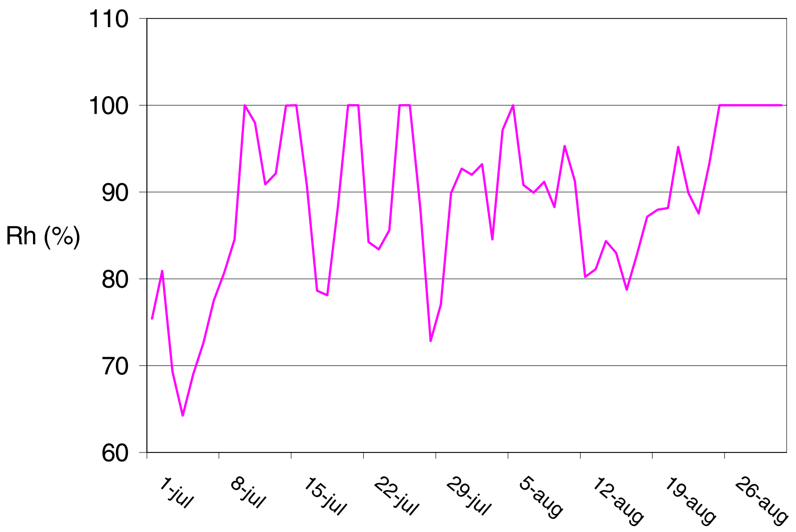

Figure 9 RH in the basement of Kamp C
(simplified model & max. air flow)

For SD-Worx the condensation mass flow rate for the worst case scenario is 35 l/h in each tube (Figure 8 (b)). To avoid water standing in the tubes, the tubes are tilted 1°. In a service pit at the lowest point of the tubes the water can be captured and pumped. The extraction pump was designed to take out the maximum calculated water flow rate. To ensure that no groundwater enters the tubes the choice was made to use PE-tubes instead of concrete tubes. These tubes are fully watertight. To avoid water entering through bends and connections, these will be prefabricated and the whole tube systems will be connected above ground, after which the complete system will then be put into the ground.

6 CONCLUSION

In the Oxfam building a very short earth-air heat exchanger is used, which is placed at a depth of 0.5m. Both measurement and calculations show that the performance is not good. Condensation is not detected in the tube and is not to be expected. This is obvious because of the shortness of the tube.
In the other two buildings a better performance can be expected. Measurements will have to proof the calculations.
Condensation inside the tubes will occur on hot and relatively humid days. This is anticipated by providing tilted tubes, so the water can be drained.
In the basement of the Kamp C building condensation can occur. For the moment, no special measures were taken. During the follow up special attention will be paid to the measurement of conditions and air quality in the basement. Problems with air quality could occur on hot and humid days.
The use of earth-air heat exchangers is a very energy efficient technique for heating/cooling and ventilation of office buildings in the Belgian climate. It was shown that for severe thermal comfort requirements the ground tubes can be used in combination with other energy efficient technologies. Careful design of the tubes is necessary otherwise this will result in poor performance.
The use of PE-tubes is necessary if the tubes are placed in the ground water to avoid water diffusion through the tube walls. Concrete tubes can be used if the tubes are placed above groundwater level, but careful concern should be taken about air quality.
Condensation in performing tubes will occur in summer. To avoid the risk of microbial proliferation and moulds growing, provisions should be made to evacuate the water out off the tubes. Other parts of the building, subject to low temperatures can be at risk for condensation of water.
In the future measurements will be done to check if there is water standing in the pipes or connecting structures. The influence of the construction and possible mould growth on air quality will be evaluated during measurements after delivering the buildings.

REFERENCES

1. *SANTAMOURIS, M., MIHALAKAKOU, G. and ASIMAKOPOULOS, D.N.*
   "On the coupling of thermostatically controlled buildings with ground and night ventilation passive dissipation techniques"
   Solar energy, Vol. 6, 1997, pp 191-197.

2. *BOIJ, M., TRIFUNOVIC, N., PAPADAKIS, G. and KYRITSIS, S.,*

"Numerical Simulation, technical and economic evaluation of Air-to-earth heat exchanger coupled to a building."
Energy, Vol. 22, 1997, pp 1151-1158.

3. *AGAS, G .and MATSAGGOS, T., "O the use of atmospheric heat sinks for heat dissipation", Energy and Buildings, 1991, pp 321-329.*

4. *SANTAMOURIS, M, MIHALAKAKOU, G. AGRIRIOU, A. and. ASIMAKOPOULOS, D.N "On the performance of buildings coupled with earth to air heat exchangers", Solar energy, Vol. 54, 1995, pp 375-380.*

5. *ZIMMERMANN., M "The Schwerzenbacherhof Office and Industrial Building Swerzenbach, Switzerland", Ground Cooling (Air), IEA Low Energy Cooling Demonstration, 1998, pp 15/1-15/8.*

6. *SCHULER, M, "Design for Daylighting and Energy in Ingolstadt", Advanced Building Newsletter 23/24, 18-23, Oktober 1999.*

7. *LIEVENS, W. "Zenit, het 'andere' huis van de toekomst", de Koevoet, 1999 (in Dutch).*

8. *CENERGIE Research report 069 in the framework of the research program 'Kantoor 2000' with project partners BBRI, Ghent University, Wenk St-Lucas, supported by the Flemish Regional Government (IWT) (in Dutch).*

9. *PHYSIBEL "Capsol versie 3.3 computerprogramma voor het berekenen van multizonaal dynamisch warmtetransport" Physibel Document M-CP-A-N05, Maldegem, Belgium, 1999 (in Dutch).*

10. *ASHRAE Fundamentals Handbook, 1997.*

11. *Van Wesenmael G. "Passieve koeling & verwarming door een aarde-lucht-warmtewisselaar" Master Dissertation, Promotor A. Janssens, supervisors, H. Breesh, M. De Paepe. Department of Architecture and Urbanism, Ghent University, 2001 (in Dutch).*

12. *De Paepe, M. EA-HTX , A design program for Earth-air heat exchangers, Internal Report, Ghent University, 2000.*