Numerical Evaluation of Earth to Air Heat Exchangers and Heat Recovery Ventilation Systems

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ABSTRACT

Balanced ventilation systems with heat recovery and earth to air heat exchangers are interesting techniques, which can reduce heating and cooling demand of buildings, and improve internal thermal comfort. A numerical study is carried out to evaluate the impact of these two systems on the energy consumption and thermal comfort of a single family house. The impact on the CO_2 emission is also given.

KEYWORDS

Earth to air heat exchanger, mechanical ventilation, heat recovery, CO_2 emission.

INTRODUCTION

Heat recovery ventilation systems and earth to air exchangers are promising technologies widely used in low energy buildings. Balanced ventilation combines extract and supply systems as separately ducted networks. It uses two fans for air supply and extraction. Typically, air is supplied to occupied zones and extracted from polluted zones. The heat recovery unit is usually a flat plate heat exchanger which recovers heat from extracted air to the supply air, and thus reduces the heat losses due to air renewing. Earth to air heat exchanger, sometimes called ground tube or ground coupled air heat exchanger, consist of tube putted into the ground, thought which air is drawn. Because of high thermal inertia of the soil, the temperature fluctuations at the ground surface exposed to the exterior climate are damped deeper in the ground. Further, a time lag occurs between the temperature fluctuations in the ground and at the surface. Therefore, at a sufficient depth, the ground temperature is lower than the outside air temperature in summer and higher in winter. When fresh ventilation air is drawn through the earth to air heat exchanger, the air is cooled in summer and heated in winter. In combination with other passive systems and good thermal design of the building, the earth to air heat exchanger can be used to avoid air conditioning units in buildings.
The aim of this work is to evaluate the energy consumption reduction and the improvements in summer thermal comfort obtained by the integration of a heat recovery balanced ventilation system and an earth to air heat exchanger to a small family house. Four cases are studied:

1. The dwelling with a mechanical extract ventilation system (EV),
2. The dwelling with a heat recovery balanced ventilation system (BV),

3. The dwelling with a mechanical extract ventilation system coupled with an earth to air heat exchanger (EV + EAHEX)
4. The dwelling with a heat recovery balanced ventilation system coupled with an earth to air heat exchanger (BV + EAHEX).

BUILDING DESCRIPTION

The studied building is a single family house called Mozart, taken from a typology on French buildings carried out by the CSTB (1995). Mozart has a floor area of 101 m², a volume of 253m^3 and an average ventilation air change rate of 0.57h^{-1}. The infiltration air change rate is 0.637h^{-1} under 4Pa of pressure difference. The envelope average U value is 0.4 W/m²/K. These characteristics were chosen according to the French thermal regulation. The house contains also a 0.5m of horizontal sunshades all over the windows.

CLIMATE CONDIDITIONS

The simulations were carried out for three French cities (cold, moderate and hot climates): Nancy, La Rochelle and Nice. The source of the weather data is the French thermal regulation. The following table gives some key data of the three cities weather.

TABLE 2

Climate conditions characteristics

	Nancy	La Rochelle	Nice
Minimum temperature [°C]	-11.9	-4.9	1.9
Maximum temperature [°C]	32.9	30.6	28.8
19 °C based heating degree-hours [°C.h]	86360	60610	44240
26 °C based cooling degree-hours [°C.h]	251.2	164.8	203
Global horizontal solar radiation [kWh/m²]	1066	1293	1397

HVAC SYSTEMS CHARACTERISTICS

Mechanical ventilation systems

The mechanical extract ventilation consist of a single fan which removes air from the kitchen and the bath room, creating thus an internal negative pressure which promotes an equal mass of fresh air into the other zones through air inlets and infiltration openings. In the balanced ventilation system, the air is extracted from the kitchen and the bath room and supplied to the other zones. The thermal efficiency of the flat plate heat exchanger is chosen to be 75% according to the Passivhaus calculation method guidelines PHPP (2004). This efficiency is assumed constant during the heating season which is the period corresponding to an external temperature below 15°C. For negative outside air temperatures, an electrical resistance is activated for freezing protection.

Earth to air heat exchanger

The length and number of the buried pipes depends not only on cooling and heating demand of the building, but also on the available space around the house. For a minimum available space, buried pipes could be putted all around the house perimeter. For Mozart, we have chosen one buried pipe with a 40m length which corresponds to the perimeter of the house. The diameter of the tube is 160mm. The depth of the buried tube is 1.8m, which is the maximum depth we can dig to without a necessary special treatment for the ground in France. The soil is supposed to be argil with a conductivity of 1.5 W/m²/K, a density of 1500 kg/m^3 and a capacity of 2085 J/Kg/K. The incoming outside air bypasses the buried pipe whenever the outside temperature is between 5°C and 20°C.

MODELS USED FOR SIMULATIONS

Simulations were carried out using SIMBAD Toolbox, developed by the CSTB in MATLAB/Simulink environment (SIMBAD 2005). The building thermal behavior is simulated using the multizone building model of SIMBAD developed by EL Khoury et al (2005). This model was compared to the Type56 of TRNSYS (2005) and shows very good agreement. The heat recovery unit model is based on the NTU-ε method of Brandemuhel et al (1993). The earth to air heat exchanger model is based on Al-Ajmi et al (2002). It consists of a one dimensional steady state model, modeled as two coupled heat transfer processes, namely, convection heat transfer between air flowing in the pipe and the pipe inner surface, and conduction heat transfer between the pipe outer surface and the soil environment. The model was validated against three other studies: Mihalakakou et al (1995), Dhaliwal et al (1984), and Shingari (1995). The validation process shows that the proposed model does agree with all of the three models with respect to the input parameters.

SIMULATIONS RESULTS AND DISCUSSIONS

The simulations were carried out for a whole year with a time step of 5mn.

Systems evaluation for the cold season

Figure 4 shows the heating demand and the auxiliary consumption (fans, electrical resistance) of the Mozart house, for the four cases previously mentioned.
Heating demands are computed for a temperature set point of 19°C.

The simulation results led to the following findings:

- Using balanced ventilation with a heat recovery unit of a 75% of efficiency, instead of mechanical extract ventilation, decreases considerably the heat demand of the Mozart house, for the three climates. The auxiliary consumption increases, but still less important than the reduction in heat demand (see Table 2).

TABLE 2
Extract ventilation *Vs* Balanced ventilation

	Nancy	La Rochelle	Nice
Heat demand reduction [kWh/a]	2772	1777	1108
Auxiliary consumption increasing [kWh/a]	394	291	286

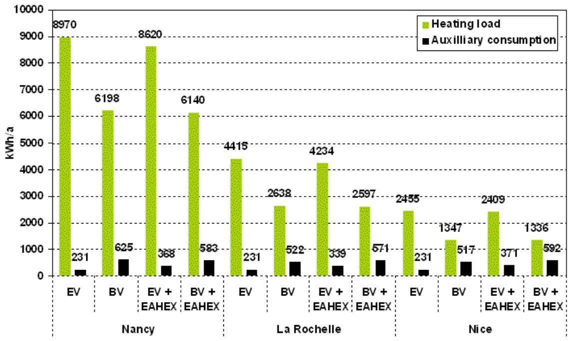

Figure 4: Heating demand and auxiliary consumption

- Using earth to air heat exchanger with the mechanical extract ventilation decreases slightly the heat demand of the Mozart house, for the three climates. Though, the increasing in the auxiliary consumptions is in the same order of the heat demand reduction, and is more important from the heat gain in Nice (see Table 3).

TABLE 3
Extract ventilation *Vs* Extract ventilation + Earth heat exchanger

	Nancy	La Rochelle	Nice
Heat demand reduction [kWh/a]	350	181	46
Auxiliary consumption increasing [kWh/a]	137	108	140

- The additional heat gain of the earth heat exchanger when it's coupled with the balanced ventilation is rather marginal. Besides, it increases the auxiliary consumption for La Rochelle and Nice (see Table 4). Though, even for negative outside temperatures, the air temperature at the outlet of the earth heat exchanger is always positive. Hence, it protects the heat recovery unit from freezing.

TABLE 4
Balanced ventilation *Vs* Balanced ventilation + Earth heat exchanger

	Nancy	La Rochelle	Nice
Heat demand reduction [kWh/a]	58	41	11
Auxiliary consumption increasing [kWh/a]	-42	50	75

Systems evaluation for the hot season

The impact of the earth to air heat exchanger on the summer thermal comfort in the Mozart house is evaluated. The operative temperature is chosen as a thermal comfort indicator. It's given by the following equation:

$$T_{op} = \frac{(h_{conv} \times T_{air}) + (h_{rm} \times T_{rm})}{h_{conv} + h_{rm}}$$

h_{conv} and h_{rm} are respectively the convective and radiation heating transfer coefficient in W/m²/K. T_{air} and T_{rm} are respectively the air and radiant mean temperature in °C.
The optimal operative temperature in summer time, which depends on the metabolism and clothing resistance, is calculated following ISO 7730 (2005). A threshold temperature of 26°C is found.
Figure 5 shows the degree-hours of operative temperature which exceeds the threshold of 26°C computed for the following cases:

- Mozart with a mechanical extract ventilation system (EV)
- Mozart with a mechanical extract ventilation system, coupled with an earth to air heat exchanger. The air flow through the buried pipe during the summer is 225m^3/h (EV + EAHEX , NF)
- Mozart with a mechanical extract ventilation system, coupled with an earth to air heat exchanger. This time, the air flow rate through the buried pipe is 450m^3/h (EV + EAHEX , HF)

The air flow rate of 450m^3/h corresponds to the maximum allowed air velocity in the ventilation ducts, which is 6m/s according to DTU68.1 (1995).

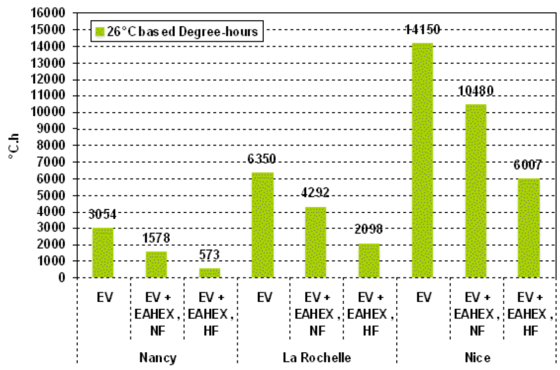

Figure 5: 26°C based degree-hours of the operative temperature

The results show that earth to air heat exchanger has a big potential for improving thermal summer comfort inside the Mozart house. The number of degree-hours of operative temperature which exceeds 26°C is noticeably decreased for the three climates. However, because of the limitation of the air flow and temperature difference between the supplied and internal air, earth to air heat exchanger was not enough to assure a good thermal comfort during all the hot season. Hence, other efforts should be taken, like improving building thermal inertia, using sun blinds and smart orientation of the building.

CO_2 emission calculation

Figure 6 shows the CO_2 emissions computed according to ADEME (2005). Two types of heat production unit are considered: condensing natural gas boiler with an efficiency of 109%, and air to water heat pump with a COP of 3.
Balanced ventilation system with heat recovery shows a big impact on the CO_2 emissions. The reduction is less important for the heat pump case than the gas boiler case. The influence of the earth to air heat exchanger on CO_2 emission reduction is relatively small.

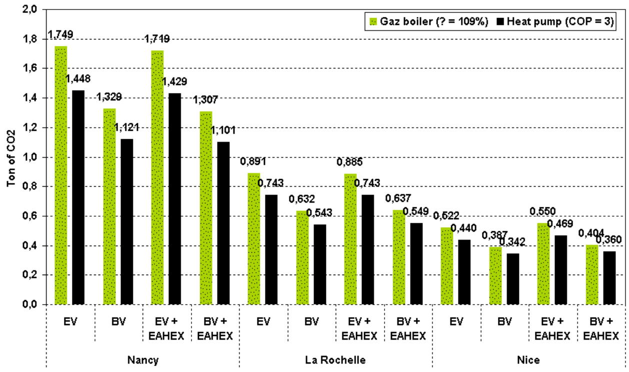

Figure 6: CO_2 emissions

CONCLUSION

Mechanical ventilation systems are an important element in the design of a low energy house. Balanced ventilation system with heat recovery and earth to air heat exchangers were evaluated with respect to three types of the French climate.
The results of the simulations led us to following conclusions:

- Balanced ventilation system reduces significantly the heat demand of buildings and thus the CO_2 emission related to it.
- The contribution of the earth to air heat exchanger to the heat gain and CO_2 emissions reduction is rather marginal. The only advantage during the cold season is the protection of the heat recovery unit from freezing.
- Earth to air heat exchanger presents a big potential for improving thermal summer comfort. One buried pipe with 40m of length gave a good reduction in indoor comfort. However, to assure a good thermal comfort during all the summer period, it should be combined with other solutions.

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