\# 5968

Ventilation for Energy Efficiency and Optimum Indoor Air Quality
13th AIVC Conference, Nice, France
15-18 September 1992

Paper 11

Energy Savings by Balanced Ventilation with Heat Recovery and Ground Heat Exchanger.

H. Trümper, K-J Albers, K. Hain

Universität Dortmund, Fakultät Bauwesen,
Lehrstuhl TGA Technische Gebäudeausrüstung,
August-Schmidt-Str.6, W-4600 Dortmund 50,
Germany.

Summary

This paper investigates quantitatively the energy conservation achieved by balanced ventilation with heat recovery and upstream ground heat exchanger. The investigations were conducted on an occupied single-family house equipped with such a balanced ventilation system. The heat recovery unit of this system consists of a plate-type heat exchanger with a downstream small air-to-air heat pump. In addition this house is equipped with a ground heat exchanger.

This balanced ventilation system with heat recovery and upstream ground heat exchanger not only covers the entire ventilation heat requirement for the house, but also a part of the transmission heat requirement.

Symbols and abbreviations

EWT	Ground heat exchanger
el. Hzg.	Electrical storage heating units
Gt	Degree days
WGT	Heat recovery unit
$\vartheta_{L,m,Erdrohranfang}$	mean air temperature at the beginning of the ground heat exchanger
$\vartheta_{L,m,Erdrohrende}$	mean air temperature at the end of the ground heat exchanger

Introduction

In low-energy houses, the transmission heat requirement of the building is reduced by the high heat insulation standard to such an extent that the ventilation heat requirement is becoming increasingly significant. An important step in the direction of ventilation heat loss reduction is the installation of a mechanical balanced ventilation system with heat recovery. The heat recovery unit can be a plate-type heat exchanger or a combination of plate-type heat exchanger and downstream small air-to-air heat pump.

An additional option for reducing the ventilation heat losses is to instal a ground heat exchanger. The outdoor air is drawn through a pipe buried in the ground and only passes into the dwelling via the heat recovery unit. In this way the supply air is preheated in winter and partial cooled in summer. In addition, in the summer the outdoor air is partial dehumidified if the temperature falls below the dew point in the ground heat exchanger. This should not be underestimated with regard to comfort, since in summer supply air which is cooler and drier than the outdoor air is experienced as pleasant.

If the ground heat exchanger is correctly designed, the supply air temperature at the end of the ground heat exchanger is, in winter, not lower than 0°C, even with extremely low outdoor air temperatures. This is very important in order to avoid problems regarding any possible icing up of the plate-type heat exchanger in the heat recovery unit. In the summer the cooling of the outdoor air is becoming increasingly important because of the problem of easily achievable overheating in modern, highly insulated low-energy houses.

System of balanced ventilation with heat recovery and upstream ground heat exchanger

The ground heat exchanger set up for a single-family house in southern Germany was designed with regard to practical considerations. Minimisation of installation costs was a prime factor. In order to avoid the need for an additional trench and the related extra costs, the ground heat exchanger was laid on the floor of the building trench around the house. This also determined the length of the heat exchanger, namely 42 meters. Because of the need to reliably take off the condensate produced in the summer, a corrugated tube was not used for the ground heat exchanger, but a smooth folded spiral-seam tube, and this was laid at an incline of 2 %. The inside diameter of the tube is 125 mm, the wall thickness 0.8 mm. The position of the ground heat exchanger with details of the laying depth and distance from the house is shown schematically in Figure 1.

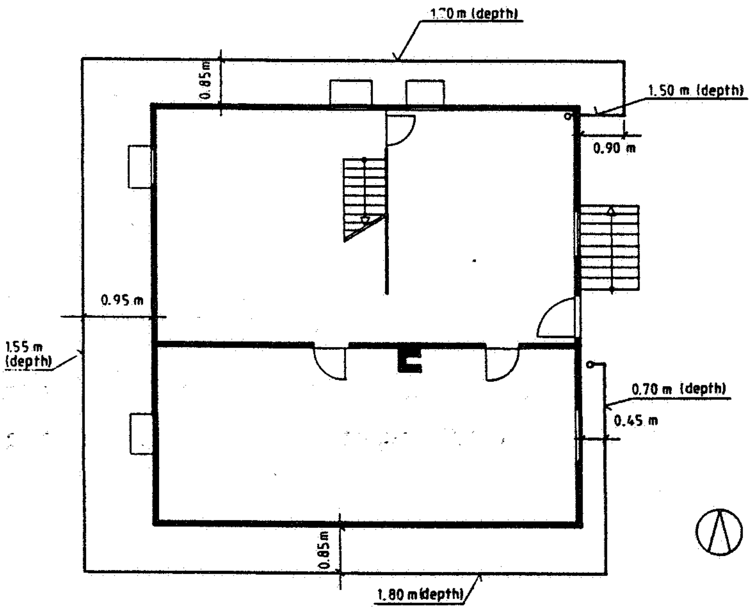

Fig. 1 Scheme of the ground heat exchanger

Figure 2 shows the scheme of the entire ventilation system. The outdoor air is conveyed through the ground heat exchanger using a tube fan with a measured power consumption of 50 W. The volumetric flow is 140 m^3/h. After it has flowed through the ground heat exchanger, the supply air passes through the heat recovery unit and then it passes through a

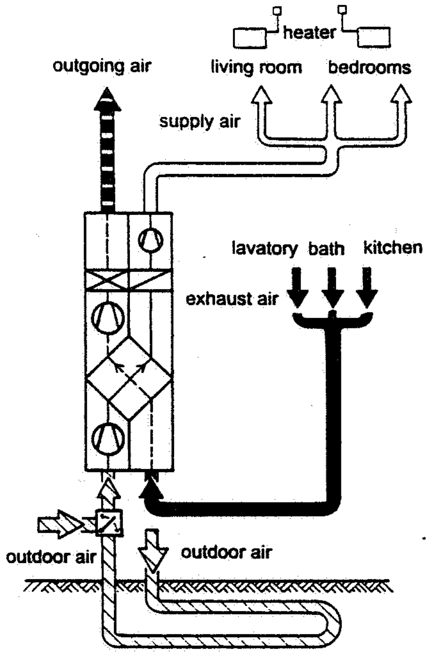

Fig. 2 Scheme of the ventilation system

small tube network into the residential rooms and into the children's and parents' bedrooms in the house. The exhaust air is removed from the bathroom, toilet and kitchen. The heat recovery unit consists of a plate-type heat exchanger and a downstream small air-to-air heat pump. The power consumption of the heat pump compressor is 500 W, that of the supply air fan 20 W and that of the exhaust air fan 16 W. In the summer the small heat pump is not in operation and the plate-type heat exchanger is replaced by a double-duct piece, since the supply air cooled in the ground heat exchanger is not to be subsequently reheated. Because the heat output of the ground heat exchanger in winter is lower at a certain temperature than the power consumption of the tube fan, and in summer it is not necessary to cool the outdoor air below a certain temperature, suction through the ground heat exchanger can be sealed off using a cap controlled by thermostats. At the same time a second opening is released through which the outdoor air is directly drawn in via the roof. The thermostat is installed under the eaves and adjusted in such a way that the outdoor air is drawn in, at temperatures below 4°C and above 20°C, through the ground heat exchanger, and otherwise directly via the roof. The fact that this ventilation system is not also a room heating system is symbolized in Figure 2 by the heaters needed in addition in winter for room heating. In this case these are electrical storage heating units.

To investigate the thermal technology of the ground heat exchanger, the temperature and relative humidity of the air drawn in upstream and downstream of the ground heat exchanger and furthermore the wall temperatures of the ground heat exchanger are measured at a distance of 2 meters. For the energy-related evaluation of the heat recovery unit, the temperatures and relative humidities of the supply air and exhaust air are measured upstream and downstream of the system. The measured quantities are registered every five minutes and stored for further evaluation after every hour as hourly mean values. In addition the operating times and power consumptions of the tube fan for the ground heat exchanger, of the compressor and of the supply air and exhaust air fan are registered.

Results for the ground heat exchanger

The ground heat exchanger plays a particularly important role. Thanks to the extremely high heat storage capacity of the ground, supply air is provided at almost constant temperature, regardless of that of the outdoor air. For this purpose, the length of the ground heat exchanger must be correctly established as a function of the outdoor air temperature fluctuations /1/. Figure 3 and 4 show the temperature curve for the air upstream and downstream of the ground heat exchanger for a longer period in the winter period 1990/91 and summer period 1991 under investigation here. These temperature curves

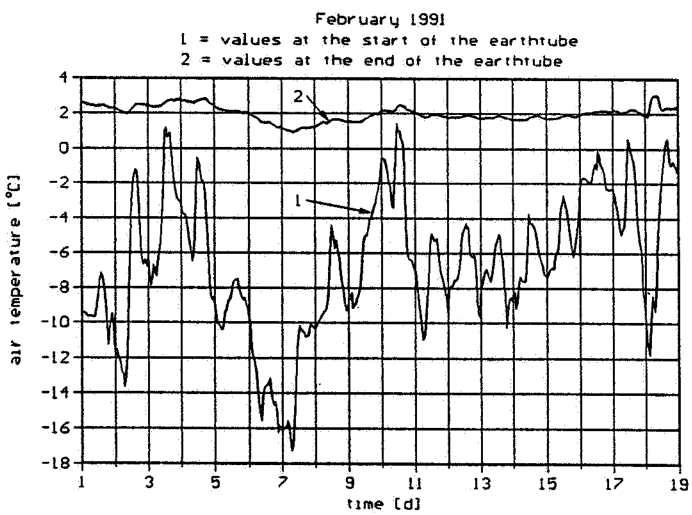

Fig. 3 Temperature curve upstream and downstream of the ground heat exchanger

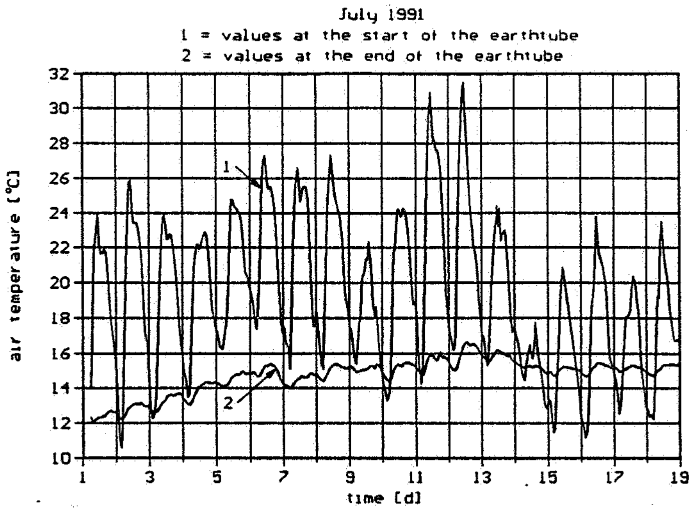

Fig. 4 Temperature curve upstream and downstream of the ground heat exchanger

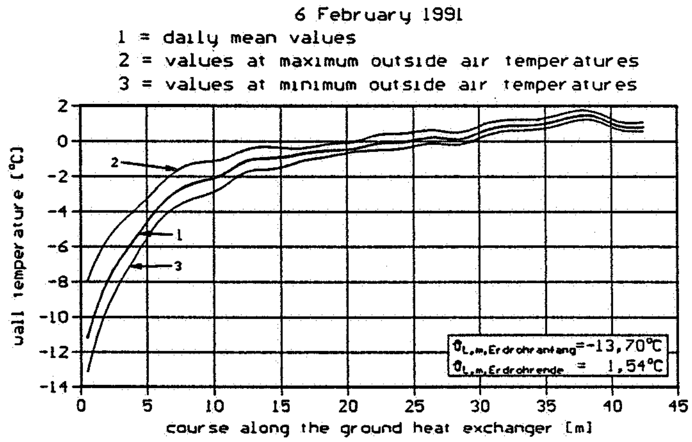

Fig. 5 Temperature curve along the wall of the ground heat exchanger

highlight the very great decaying capacity as against short-term, extreme outdoor air temperature fluctuations. The way in which such short-term temperature fluctuations are reduced along the ground heat exchanger can be seen if we look at the example of a winter day as shown in Figure 5. In addition to the daily mean values for the wall temperatures, the wall temperatures at maximum and minimum outdoor air temperatures are plotted. Furthermore, the daily mean values are given for the air temperatures upstream and downstream of the ground heat exchanger.

In winter the possible icing up of the plate-type heat exchanger as mentioned at the beginning is prevented by the supply air temperature, which is always above 0°C. Furthermore, the almost constant supply air temperature, which is higher than that of the outdoor air, increases the output of the heat pump. In summer, with extremely high outdoor air temperatures and humidities, the clearly cooler and drier supply air leads to greater comfort. The design principles of such ground heat exchangers were developed in /1/ and presented for the first time at the 12th AIVC Conference /2/.

Results for the entire balanced ventilation system

With the balanced ventilation system with heat recovery and upstream ground heat exchanger as shown here, not only the entire ventilation heat requirement of the house is covered, but also a part of the transmission heat requirement.

The single-family house investigated with a residential area of 150 m^2 had a heat turnover of 22,150 kWh in 1991, of which a total of 35 % was taken care of by the heat recovery unit (6,710 kWh) and by the ground heat exchanger (1,000 kWh). The remaining 65 % was covered by electrical storage heaters. The compressor and the fans of the heat recovery unit had a power consumption of 1,600 kWh, so that the performance number obtained for this system is 4.2. The tube fan of the ground heat exchanger had a power consumption of 140 kWh during the heating period. The performance number of the ground heat exchanger is thus 7.1. In the months from June to September the ground heat exchanger provided cooled and dried supply air. The perceptible cold gain in this period was 330 kWh and the entire (perceptible and latent) cold gain was 870 kWh. For this purpose 77 kWh electrical energy had to be provided to drive the tube fan, which produces a performance number in relation to the perceptible cold gain of 4.3 and in relation to the total 11.3.

Figure 6 shows the heat turnover in kWh provided by the individual systems and calculated from the degree day numbers (Gt) /3/ determined at the location of the house. Only slight deviations are evident between the heat turnover ac-

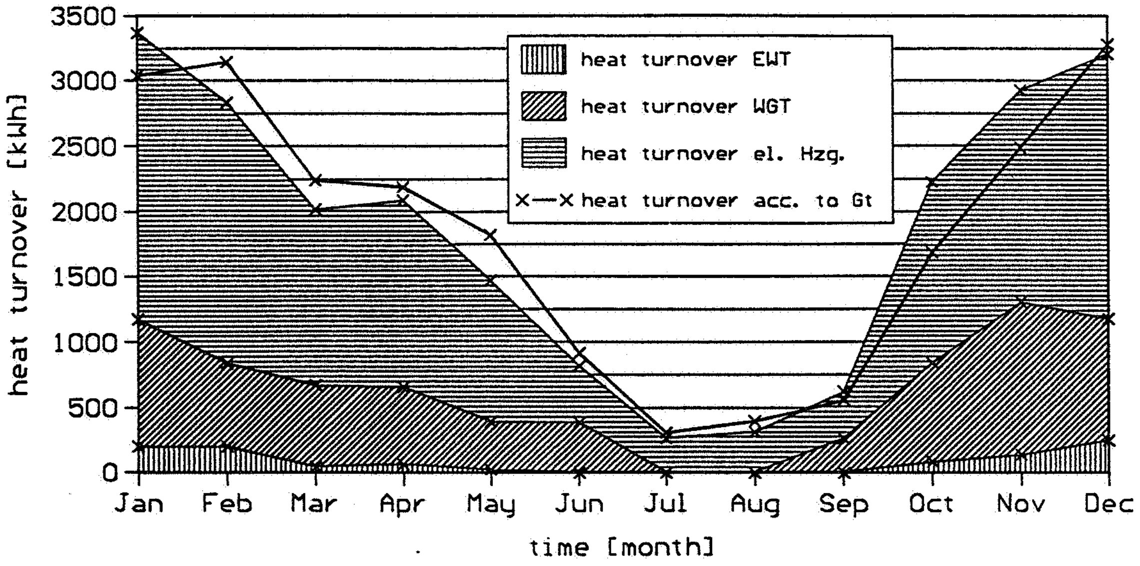

Fig. 6 Heat turnover of the house

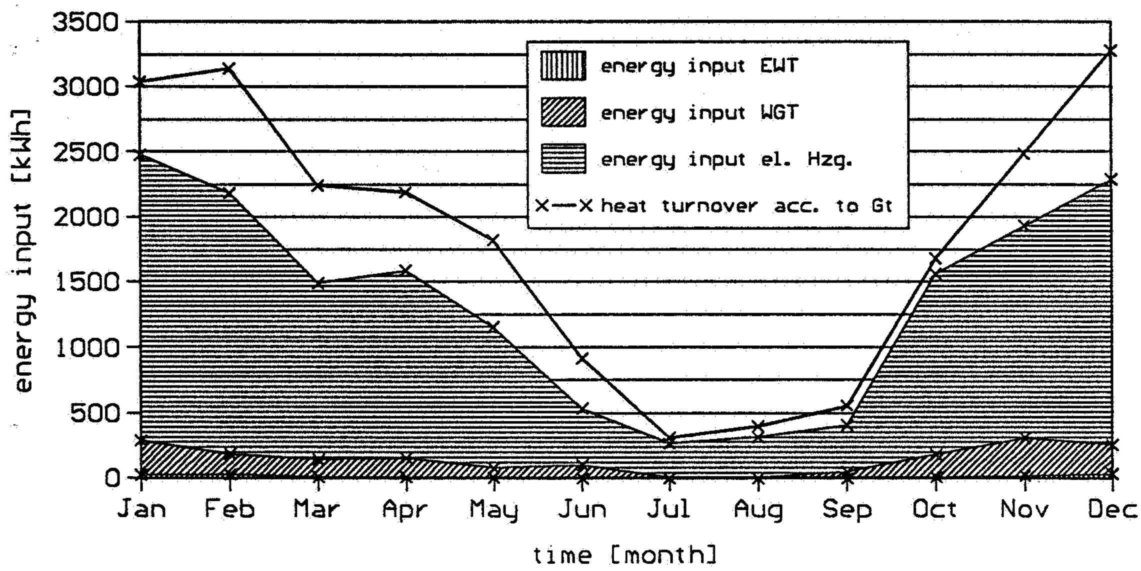

Fig. 7 Energy input to cover the heat turnover according to Figure 6

cording to degree day numbers and the actual heat turnover, and so the heat turnover according to degree day numbers can be used very well for the purpose of comparative calculations. Figure 7 plots the energy input over the year under investigations as needed to cover the heat turnover shown in Figure 6. This figure makes clear that balanced ventilation with heat recovery and upstream ground heat exchanger has a considerable energy conservation potential. To cover the heat turnover of 22,150 kWh needed to heat the house in 1991, an energy input of 16,190 kWh was needed. The energy input thus accounts for only 73 % of the heat turnover, which gives an energy saving of 27 %.

The heat turnover of 22,150 kWh/a seems at first glance to be very high for a modern single-family house with 150 m^2 residential area. However, this absolute figure is inadequate to evaluate the energy situation of the house. This is made clear by the fact that the location is not taken into account. If the same house were to stand not on its present site, but for example in Essen, it would display a 21 % lower heat turnover, which is caused only by the difference in climate. While at the present location of the house the degree day number for the year under investigation was determined as 4,560, and the normal outdoor temperature is -18°C /3/, in Essen one obtains a degree day number for the same period of 3,634. The normal outdoor temperature for Essen is -10°C /3/.

More informative is an energy-related evaluation of the house, if it is compared with a notional house of the same dimensions whose outer shell still corresponds to the u-values (values for the coefficients of heat transfer) from standards, regulations or generally known recommendations. In Germany, these are the Heat Control Ordinance /4/ or the recommendations for low-energy houses /5/. For this purpose the heat requirement of the house is newly determined with the respective u-values given for the outer shell and the heat turnover is calculated with the help of degree day numbers (Gt). The values thus obtained are shown in Table I.

	Design as is	Design as /5/	Design as /6/
Heat requirement in [W]	11,972	15,446	11,348
Heat turnover acc. to Gt in [kWh/a]	22,055	28,455	20,905

Table I: Heat requirement and turnover for the house in various designs

The comparison shows that the existing house has a 29 % lower heat turnover than a design which just complies with the Heat Control Ordinance. Compared with the design which just meets the recommendations for low-energy houses, however, its heat turnover is 5 % higher. In relation to the transmission heat requirement then the house under investigation does not yet meet the requirements of a low-energy house. This is also made clear by the relatively low proportion of the total heat requirements accounted for by the ventilation heat requirements, namely 31 %. With low-energy houses the proportion of ventilation heat requirement in relation to the total heat requirement is about 35-40 %. If we consider, however, that, as shown above, energy savings of 27 % are achieved by built-in balanced ventilation with heat recovery and upstream ground heat exchanger, this house can be called a low-energy house in spite of the 5 % higher transmission heat losses.

A further variable which influences the heat turnover of buildings but cannot be recorded is the user behavior. All calculations which are used to determine the anticipated heat turnover assume the normal inside temperature /6/. This is for living rooms and bedrooms 20°C. In /7/ it was established for multi-occupation houses that, during the heating period, the room temperatures are over 20°C. The investigations is also confirmed by this single-family house. Most of the rooms during the heating period had an average temperature of more than 21°C. The higher heat turnover caused by these elevated temperatures can be seen in Figure 6. Since the heat turnover according to degree days does not take into account own-heat or solar heat gains, it always has to be higher than the actual heat turnover. Figure 6, however, shows that the heat turnover according to degree days in the months January and September to November is lower than the actual heat turnover. This indicates an increased heat turnover due to user behavior.

Acknowledgments

The research product on which this publication is based was financed by funds from the Federal Ministry for Regional Planning, Construction and Urban Development, assistance code B I 5 - 80 01 89 - 108.

References

/1/ Albers, K.-J.
"Untersuchungen zur Auslegung von Erdwärmeaustauschern für die Konditionierung der Zuluft für Wohngebäude"
Forschungsbericht Nr. 32, Stuttgart, Deutscher Kälte- und Klimatechnischer Verein 1991

/2/ Trümper, H.; Albers, K.-J.
"Preheating and Cooling of the Incoming Air of Dwellings Using an Earth-Laid Pipe"
Proceedings of the 12th AIVC Conference, Air Movement and Ventilation Control Within Buildings, Ottawa, Canada 24 - 27 September 1991, Volume 2 pp 133-152

/3/ VDI 2067 Blatt 1
"Berechnung der Kosten für Wärmeversorgungsanlagen
Betriebstechnische und wirtschaftliche Grundlagen"
Düsseldorf, VDI-Gesellschaft für Technische Gebäudeausrüstung 1983

/4/ N.N.
"Wärmeschutz bei Gebäuden, Wärmeschutzverordnung vom
24. Februar 1982"
Bundesministerium für Wirtschaft, Bonn 1983

/5/ N.N.
"Wege zum Niedrigenergiehaus"
Bundesministerium für Raumordnung, Bauwesen und Städtebau,
Bonn 1990

/6/ DIN 4701, Teil 2
"Regeln für die Berechnung des Wärmebedarfs von Gebäuden
Tabellen, Bilder, Algorithmen"
Berlin, Beuth Verlag 1983

/7/ Trümper, H.; Hain, K.; Schmickler, F.-P.
"Demonstrationsvorhaben Duisburg, Phase II, Vergleichende Untersuchung verschiedener Lüftungssysteme in bewohnten Mehrfamilienhäusern"
Forschungsbericht T 86-239, Bonn, BMFT 1986