THE EXHAUST AIR HEAT PUMP – A RATIONAL WAY OF HEATING LOW-ENERGY HOUSES

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ABSTRACT

The low-energy house-building sector is constantly searching for compact solutions for heating, ventilation, hot water production, heat recovery and controls. The exhaust air heat pump (EAHP) is particularly suitable for this application. As energy for ventilation takes an increasing part of the total energy demand for new houses, it has became common to connect space heating and domestic hot water systems to the ventilation function.

Since the beginning of the 1970s, exhaust air heat pumps have been steadily developed and taken a larger share of the market in new single-family houses in Scandinavia, especially in Sweden. From having originally supplied heat only for domestic hot water production, these units now provide heat for domestic hot water, space heating and ventilation.

Key Words: ***heat pumps, exhaust air ventilation, low-energy buildings***

1 INTRODUCTION

The 1973 oil crisis drove home awareness of the coming situation with insufficient energy for transportation, heating, lighting and industry. One sector in which it has seemed easier to find replacement forms of energy is that of the heating of buildings.

Before the oil crisis, there was very little consideration of energy efficiency for heating purposes. Sweden's response to the oil crisis was to reduce the use of oil by replacing it with electricity. As it was very cheap, direct electric heating dominated the market for new single-family houses. In existing buildings, owners started to use electric boilers or multi-fuel boilers that could switch between oil and wood, backed up by electric immersion heaters.

Most houses of this period had natural draught ventilation systems, powered by the chimney effect of rising warm air through an exhaust duct.

As energy prices continued to rise, interest grew in reducing heating bills. In houses with natural ventilation, occupants tried to reduce the heating cost by weather-stripping around windows and doors, and also by closing ventilation air inlets and outlets. The Building Regulations were revised, increasing the airtightness of buildings to reduce uncontrolled ventilation.

Fig. 1. Representation of sick building syndrome.

Unfortunately, more airtight buildings and occupants' efforts to reduce ventilation led to the sick buildings syndrome (Fig. 1), causing damage to buildings and ill-health to occupants. The best solution to this problem has been shown to be mechanical ventilation. However, mechanical ventilation meant that indoor air at 20-22 C was discharged directly to the exterior, with an obvious waste of heating energy and therefore also of money. Air/air heat exchangers were introduced, but had some disadvan-

tages. They required, for example, a balanced ventilation system, with both exhaust air and supply air being ducted. The energy returned to the supply air was not sufficient to cover the total heat demand, and so the ventilation system merely supplemented the heating system.

The exhaust air heat pump was therefore developed, to provide a simple exhaust air ventilation system. It could recover heat from the exhaust air and use it for different heating purposes.

2 THE DEVELOPMENT PHASES OF THE EXHAUST AIR HEAT PUMPS

2.1 The domestic hot water exhaust air heat pump

The first exhaust air heat pumps were units designed to maintain sufficient ventilation and to recover some of the energy in the exhaust air for heating domestic hot water. The major market for such heat pumps started in Denmark, with Metro in Helsinge, Denmark starting production of heat pumps for domestic hot water production at the beginning of the 1970s, i.e. even before the oil crisis.

These units had a fairly small compressor, as the average 24-hour heat demand for domestic hot water, in a normal family, is about 500 W. A water tank volume of 280 litres provided sufficient hot water most of the time (Fig. 2).

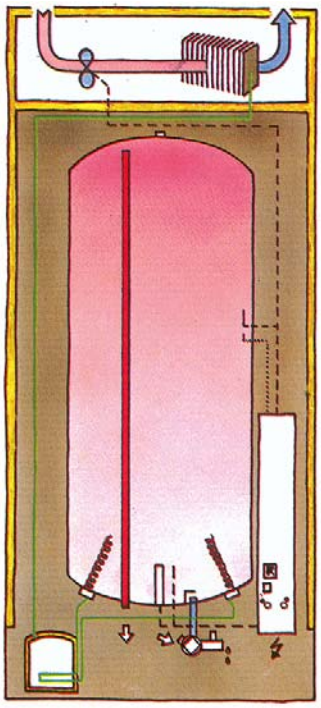

Fig. 2. Exhaust air heat pump for domestic hot water only.

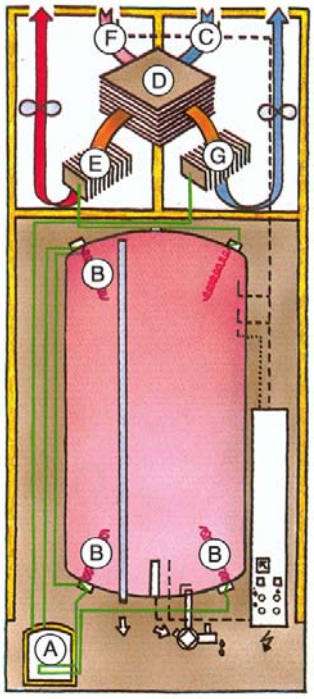

Fig. 3. Exhaust air heat pump and air to air heat exchanger for domestic hot water and partial heating.

2.2 Exhaust air heat pumps for partial heating

It was soon realised that more energy could be recovered from ventilation exhaust air than was needed for the domestic hot water production alone. More powerful heat pumps were developed (Figure 3), more energy was recovered from the exhaust air and recycled to the house for heating purposes. From 1.5 to 2.3 kW could be used for heating.

However, due to the situation with predominantly direct electric heating in new buildings, most buildings had no means of internal distribution of water-borne heating. Different ways to distribute this extra heating were developed.

- Heat pump and integrated air-to-air heat exchanger.
- Heating the supply air in a balanced ventilation system.
- Using an underfloor piping system for partial heating.
- A few radiators in specific rooms.

Some heating systems circulated the domestic hot water through the space heaters, while others delivered the extra energy from the heat pump to a separate system.

2.2.1 Balanced ventilation with integrated air-to-air heat exchanger

Some manufacturers produced units with the supply air heating system built into them, either as a heat pump with an air-to-air heat exchanger or a heat pump only. The combination of air-to-air heat exchanger and heat pump for ventilation only has been on the market for many years. Its disadvantage is that it takes care only of the ventilation.

Units that combine a heat pump and air-to-air heat exchanger with domestic hot water heating have the advantage that the hot water can be heated in an efficient way. This gave a very compact unit, including all facilities such as ventilation, heat recovery, supply air heating and hot water, all in a package occupying only 0,36 m^2 of floor area.

Such systems normally have more than one controller. There will be a room thermostat, placed centrally in the house for the heat pump, and thermostats on each electric radiator. It is very important to set all thermostats so that the heat pump has the maximum running time. The electric radiators should operate only below the balance point of the heat pump.

2.2.2 Balanced ventilation with heat pump only

The less complex exhaust air heat pump for supply air heating was developed for the Swedish market. The decision not to include the air-to-air heat exchanger was based on the fact that electricity was quite cheap and was used for the additional heating. This meant a bigger compressor and more heat pump power for the domestic hot water

Other manufacturers chose to have a separate unit for the heating of the supply air. This gave some flexibility. It was not necessary to have all the ductwork to one point, and the same heat pump unit could also be used for other heating equipment.

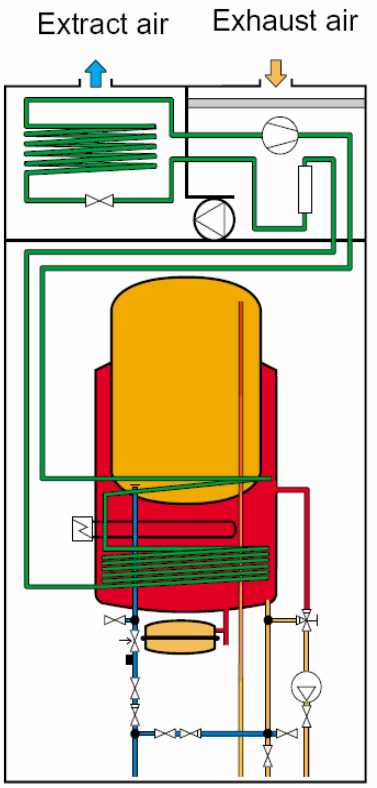

Fig. 4. Double-jacketed exhaust air heat pump for domestic hot water and partial heating.

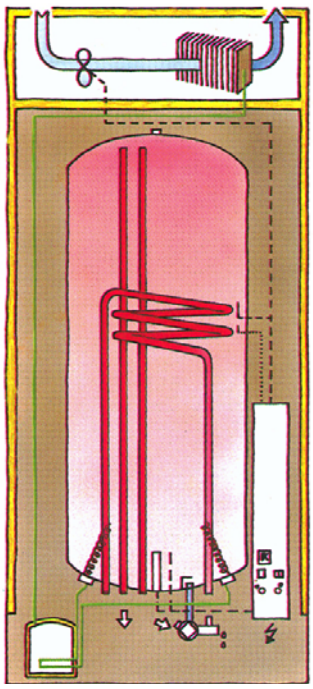

Fig. 5. Exhaust air heat pump for domestic hot water and partial heating. Condenser directly in the tank.

2.2.3 Underfloor heating

Many houses were equipped with an underfloor heating circuit laid along the inside of the outer walls, in the kitchen in front of the working places, in the hallway at the entrance and in the bathroom. This provided good comfort and allowed the electric heater between the bottom of the outer wall and the foundation to be omitted.

There are three schools of design for the pressure vessel for domestic hot water. The water may be indirectly heated, either by a coil in the tank, or the tank is double-jacketed (Fig. 4). Alternatively, the hot water can be heated directly by the heat pump condenser in the tank. A double wall condenser is obligatory for some markets, to minimise the risk of getting refrigerant or refrigerant oil into the domestic hot water. (Fig. 5)

The water for the partial space heating is automatically available from units with indi-

rect heating of the domestic hot water. With the condenser in the domestic hot water tank, a coil must be included for indirect heating of the heating water (Fig. 5, see also under Sect. 3.2.4, “The heat distribution medium.”)

2.2.3 Radiators in specific areas

Houses with only a ventilation exhaust air system and unsuitable for underfloor piping, had a couple of radiators installed. One was usually in the bathroom, and the other in the hall or any other open space in the house. The bathroom normally has a heat demand even when the rest of the house does not need heating. This arrangement gave good comfort at low running cost, allowing the electric heaters to be turned off for much of the time.

2.2.4 The heat distribution medium

Domestic hot water, or a separate water circuit, has been used as the heat distribution medium. The advantages of using the domestic hot water for heating purposes are:

- The heat pump needs to heat only one medium
- There is no need for an expansion vessel, a pressure gauge, another safety valve or valves for filling the system
- System design is simple and cost-efficient.

The disadvantages of domestic hot water as the heat distribution medium are:

- The system is pressurised to full mains pressure. Leaks can therefore be serious.
- A special circulation pump for fresh water is needed
- Steel radiators cannot be used

Modern systems of this type do not use the mains water directly as the heat distribution medium. There are several reasons, of which some are:

- Avoiding the risk of having the house filled with water if there is a leak
- It is easier to find components designed for normal closed-circuit heating water

2.3 The exhaust air heat pump for full heating

The above systems all need a complementary system for heating the house to a comfortable temperature under all outside conditions. The earlier direct electric heating radiators were a cheap solution, easy to install and control.

However, due to the inflexibility of direct electric heating, the Building Regulations and other regulations now discourage the use of direct electric heating.

Nevertheless, when a new house is built, the heating equipment must use as little space as possible. In the 1980s, the complete exhaust air heat pump package was developed. This meant that, in one unit, it contained:

- Exhaust air ventilation or balanced ventilation
- An exhaust air heat pump for heat recovery to a water system
- Domestic hot water
- Controls
- An add-on heater

- Expansion vessel
- Safety valves
- Circulating pump
- Installed on 0,36 m^2 floor area

When being installed, only the heating system, cold water, hot water, ventilation ducts and electric supply needed to be connected. All other components for the complete system were included in the unit.

2.3.1 'Mono-energy' heating

As most exhaust air heat pump installations cannot normally meet 100 % of the total heating energy demand, some kind of supplementary heater is necessary. The most effective is to use the type of energy to which the exhaust air heat pump is already connected – electricity. The small additional amount of heat will come from an immersion heater somewhere in the water circuit. As only one type of energy input is used, the installation can be said to be of single-source type in terms of drive energy input. (Figure 6 shows an exhaust air heat pump for total heating with integral heating of supply air.)

If the heating system is of the air heating type, which is not very common nowadays, the supplementary heater can be an electric heater in the supply air system.

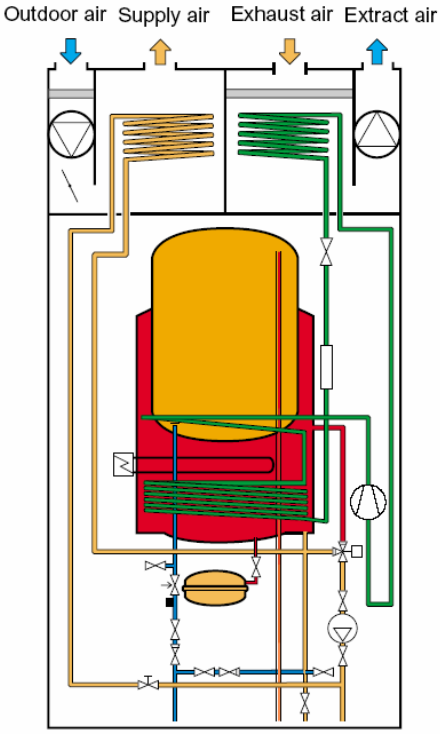

Fig. 6. Exhaust air heat pump for total heating, supply air included.

2.3.2 Bivalent heating

If the supplementary energy comes from gas, oil or district heating, the system is referred to as being a bivalent heating system. As exhaust air heat pumps are installed in low-energy houses, there is normally no need for any other additional heat source apart from electricity.

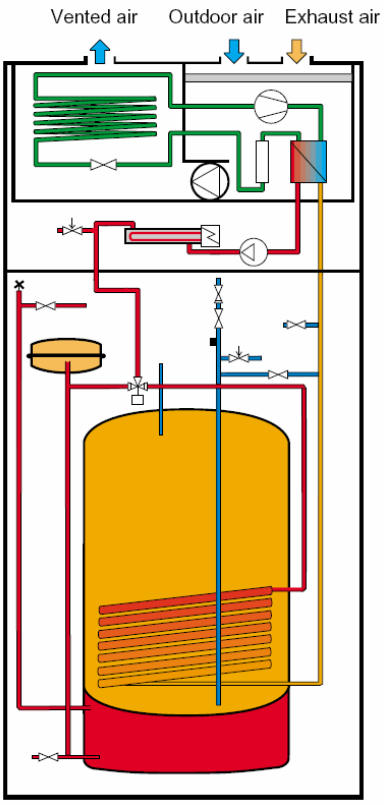

Fig. 7. Combined exhaust air and outside air heat pump for total heating.

For political reasons, gas or district heating can be prescribed as additional energy. These installations are much more expensive. They need an extra meter for the gas or the district heating supply. The equipment is much more complex and expensive than an immersion heater. In the case of gas, there is a yearly cost for the inspection of the gas system. Although expensive, there are examples of these on the market.

2.4 Extended heat source

As the heat source for the exhaust air heat pump is limited, due to the amount of ventilation, the amount of top-up heating required will be higher than is the case for, for example, a ground source heat pump.

Different measures can be taken in order to increase the heat source for the exhaust air heat pump. The most common is to use the outside air. Another way is to use the ground, with the help of a horizontal or vertical collector, to increase the heat source and also to obtain a higher heat pump output.

The simpler way is to use outside air. This means advantages for the builder. The unit requires only an extra connection to the outside in order to draw in outside air, which is mixed with the exhaust air. The heat pump output can be almost doubled for most of the heating season. When the outdoor temperature is low, the heat pump normally uses only exhaust air as the heat source (Fig. 7).

The combination exhaust air and ground source means a higher output, maybe monovalent, but with a much more complex installation.

3 EXHAUST AIR HEAT PUMP MARKET

Exhaust air heat pumps have been available in the Scandinavian countries since the early 1970s. With reasonable electricity prices in Sweden, Norway and Finland, the exhaust air heat pump has become the most popular heating device in new single-family dwellings.

For many years, Sweden has been by far the largest market for heat pumps in Europe. Last year, 2004, more than 60.000 exhaust air, outside air or ground source heat pumps were sold and installed. About 15.000 were exhaust air heat pumps, of which 60-70 % were installed in new single-family dwellings. The rest went to the retrofit market or as replacement of exhaust air heat pumps installed at the beginning of the 1980s. A moderate estimate is that more than 80 % of all new single-family houses have exhaust air heat pumps, with most of them providing full heating with an electric immersion heater for top-up heating.

Exhaust air heat pumps have also become increasingly important on the central European market. Germany especially has opportunities for this type of technology due to the development of low-energy houses.

4 FURTHER DEVELOPMENT OF THE SCANDINAVIAN TYPE OF EXHAUST AIR HEAT PUMPS

The Swedish exhaust air heat pump market has achieved a very high degree of penetration with standardized exhaust air heat pumps. (Figure 8 shows numbers of exhaust air heat pumps and new single-family homes sold in Sweden over a six-year period.) Cost-efficient heat pumps from a couple of manufacturers have made it almost impossible for others to get a toe-hold in the market.

Higher electricity prices on the Continent have encouraged the development of more expensive and more complex products. The combination of exhaust air heat recovery with a heat exchanger and a heat pump for domestic hot water and heating has been tested (Bühring, 2004).

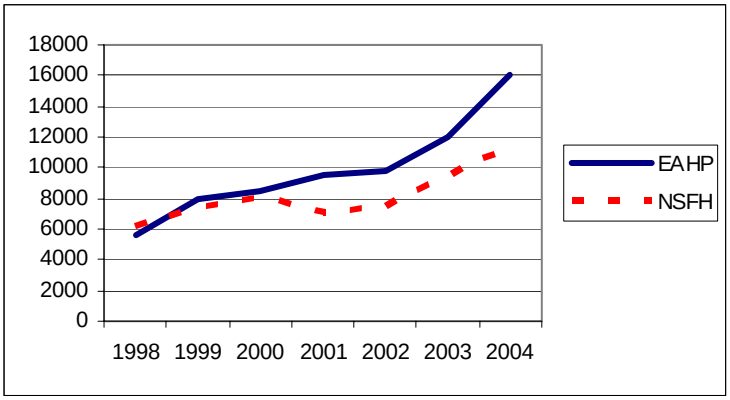

Fig. 8. Numbers of exhaust air heat pumps sold (EAHP) and new single family houses (NSFH) in Sweden 1998 to 2004.

Combination of a heat pump with solar panels, and reversibility of the heat pump to provide cooling, has been increasingly important for central European countries.

As the exhaust air heat pump can meet all essential requirements for domestic hot water, space heating and heat recovery in a package of 0.6 x 0.6 x 2.1 m, the single-family dwelling market will be the major target for this type of equipment. Figure 9 shows five different types of typical exhaust air heat pumps.

Fig. 9. Typical exhaust air heat pump range of five different types. DHW only, partial heating, full heating exhaust only, full heating supply and exhaust, full heating with exhaust air and outside air as heat source.

REFERENCES

Bühring A. , Heat pumps in high-performance retrofit buildings, IEA meeting in Hannover, 25.5.04