ENERGY EFFICIENT DOMESTIC VENTILATION SYSTEMS FOR ACHIEVING ACCEPTABLE INDOOR AIR QUALITY

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EFFICIENCY OF AIR-TO-AIR HEAT EXCHANGERS IN OCCUPIED HOUSES

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Synopsis

The purpose of the project has been to determine the saving in energy obtained in the practical operation of an FTX-system -that is, a fan-controlled supply and exhaust ventilation system with heat recovery - compared to an F-system, which is solely a fan-controlled exhaust system.

The investigation, carried out in a terrace-house district in Skellefteå, showed the following savings for the FTX-systems in comparison with the F-systems:

in 1-storey houses (81 m^2, airtightness approx. 1):
appr. 1000 kWh/year

in 2-storey houses (99.5 m^2, airtightness approx. 3):
appr. 1250 kWh/year.

This saving is only about 40% of the theoretical saving at the same air exchange in the different experimental groups.

This low saving was discovered to be due to the differences in air exchanges in houses during the warming-up period. The cause of this is partly the airtightness of the houses, which influenced infiltration, and partly the draught problem met in the houses with the F-system. Because of the draught problem the windowframe ventilators were closed and thus a lower air exchange ventilation was obtained.

Special attention must therefore be given to these draught problems if F ventilation is planned in new construction.

A fairer comparison of the saving in energy is to make the comparison at the same air exchanges (0.5 exchanges per hour), but with the corrections for infiltration that occur during operation.

In this case the saving in energy becomes:

for a 1-storey house: appr. 1900 kWh/year,

for a 2-storey house: appr. 2700 - 2800 kWh/year.

EFFICIENCY OF AIR-TO-AIR HEAT EXCHANGERS IN OCCUPIED HOUSES

In new construction the requirement for airtightness of the house as laid down in Swedish Building Standards 1980 applies. This requirement usually means that fan-controlled supply and exhaust air must be installed. In this way is created a possibility of controlling the airflow that ventilates the building. Buildings put up earlier often have a relatively large involuntary ventilation because of air-leaks. In such cases the total flow of ventilation air is difficult to control.

With balanced ventilation it is possible to install equipment for the recovery of heat from the exhaust air to the supply air. Both the energy thus saved as well as the total energy requirement to maintain a certain climate in the building can be calculated. The involuntary ventilation, which in the more airtight building is relatively small, and the associated energy requirement can however only be calculated approximately. Knowledge about the extent to which degree calculations on energy saving are relevant when the plant has been in operation under actual working conditions over a longer period is however almost completely lacking. Nor has the actual energy consumption in buildings utilizing heat recovery been compared to any great extent which the actual energy consumption in buildings without heat recovery. In order to increase knowledge within these areas it seemed useful to compare energy consumption in a number of similar buildings where some are fitted out with fan controlled supply and exhaust ventilation without heat recovery and some with fan controlled supply and exhaust ventilation plus heat recovery.

Occurrence of FTX-systems

Balanced ventilation - fan controlled supply and exhaust ventilation - plus heat recovery (known in Sweden as the FTX-system) is nowadays just as common as fan controlled exhaust ventilation (known in Sweden as the F-system) in newly produced one-family houses. An investigation carried out by the Swedish Association of Heating and Ventilation Engineers shows that approximately 20 000 FTX-systems and some 19 000 F-systems have been installed in Swedish one-family houses during 1980. Of the approximately 35 000 one-family houses completed in 1980 almost 50% have an FTX-system and just as many an F-system, including an F-system with an exhaust ventilation heat pump.

Requirements by authorities

For FTX-systems in one-family houses it is necessary, among other things, that the heat exchanger packet is easy to get at so that it can be cleaned by the user. The filter in the kitchen range ventilation hood shall be able to separate fat to such a degree that the least possible quantity is deposited in the duct system and the heat exchanger. The filter shall be cleaned at regular intervals.

In the Swedish Building Standards for 1980 the regulations state that the ventilation shall be so constructed that cooking odours and air pollutants are not spread from the kitchen and rooms for personal hygiene. These requirements mean that the kitchen range ventilation hood may not be connected to a regenerative (cyclic) heat exchanger, for this also recycles water-soluble substances in the exhaust ventilation to the supply ventilation. In certain types of regenerative heat exchangers part of the exhaust ventilation is recycled because the direction of the flow through the heat exchanger packet is altered.

The project packet

The Swedish Council for Building Research (BFR) has initiated a large project concerning heat recovery from ventilation air using heat exchangers, partly for one-family houses and partly for blocks of flats. Implementation of the project has been carried out in two stages:

Stage 1: Companies were invited to submit their technical solutions.

Stage 2: The implementation of a selection of the solutions submitted in Stage 1.

It was suggested by BFR that for one-family houses the project should comprise about 30 like buildings and for the blocks of flats four similar buildings within one and the same district.

In Stage 1 BFR received six applications for participation in the one-family house project and six for the project involving blocks of flats. Because of the difficulties met in discovering suitable housing areas there was a large falling off for Stage 2. Altogether the following projects were obtained:

One-family houses:

o at block Anderstorp 20, Skellefteå, with heat recovery unit type Bahco Minimaster ACC. Comprises 30 houses. The project was completed in 1981.

o at block Malstenen, Bomhus, Gävle, with heat recovery unit type:

a) Husqvarna Reginair FTX in 15 houses,

b) Elektrostandard's exhaust ventilation heat pumps type Aquarex in 15 houses.

The total number of houses is 44. Measurements commence in the autumn of 1982.

Blocks of flats

- o at Elinsborgsbacken, Tensta, with Luftkonditionering AB Heat-pipe system. The houses concerned are gallery-access houses erected at the beginning of the 1970s. Each house contains 25 flats, there being five flats on each of five floors.
  Measurements will be completed in the spring of 1982.

- o at Stenbacksvägen, Söderhamn, with plate heat exchangers from Air Frölich. The houses were built in 1970 and each contains 30 flats divided between three floors.
  Measurements will be completed in the spring of 1982.

The present paper deals only with the Skellefteå project.

Planning of the experiment

There are a number of factors of varying importance that may influence the results of such a study as this. It is important to be as clear as possible about which factors are involved and whether it is possible to give consideration to them or whether consideration can be given. It is already known from earlier investigations that the consumption of energy can vary greatly between houses of the same type. This variation depends to a certain extent on differences in the houses' construction and position and also on the behavioural differences of the occupiers.

If the variations in energy consumption between houses are large in relation to the expected effects of the action taken it may in practice be difficult to decide whether it has had any effect at all. This problem can be resolved by measuring all those factors that influence consumption. One disadvantage of such a procedure however is that the measurement program becomes extremely comprehensive and complicated. A simpler method is to use statistical theory and by means of suitable planning of the project arrange to transfer the variation concerned to a random one subjected to statistical control. The measurements can then be concentrated on the factors that are most important, and the unexplained variations can remain unexplained. Here the effect of a certain step taken means the average effect. The second and simpler method has been utilized in the Skellefteå project.

We have proceed from 15 + 15 houses, that is to say 15 houses without heat recovery and 15 houses with it, as there is then a 55% probability of obtaining a statistically confirmed difference between the experimental and control groups if the saving is 3 000 kWh and the spread is 4 000 kWh. Greater probability may be achieved by increasing the number of houses. Alternatively the ratio between the expected saving and the spread in the material can be increased, which was done in the present project as factors were measured that were of importance for the unexplained variation.

Anderstorp 20, Skellefteå

Anderstorp 20 is a terrace-house district - National Association of Tenants' Savings and Building Societies (HSB) - where initially 31 houses were selected for inclusion in the investigation. All of these houses had type Bahco Minimaster ACC heat recovery units installed. In 16 of the houses the air supply fan was shut off and the inflow duct was plugged. Thus the ventilation system in them has functioned as a fan-controlled exhaust ventialtion system (an F-system). The remaining 15 houses remained unaltered and so functioned as a conventional balanced ventilation system plus heat recovery (FTX-system). One house in the second group was omitted as the tenants refused to take part in the investigation. Two types of houses were included in the investigation; one-storey houses of 81 m^2 (Figure 1), and two-storey houses of 99.5 m^2 (Figure 2).

Measurement program

The following variables have been measured for all houses involved using weekly readings of the instruments:

- Inside temperature (average weekly value)
- Total consumption of electricity
- Consumption of electricity for heating
- Consumption of electricity for hot-water heating.

Additionally in FTX-houses the following weekly measurements were carried out:

- The temperature of supply air after the post-heater of the heat recovery unit (average weekly value)
- Length of time the post-heater was in operation.

The outside temperature was measured at a central spot in the district. In addition to these measurements the airtightness of the houses was checked by the so-called pressure method as well as in some cases with the assistance of a thermal camera. The total air exchange of the houses in normal operation was checked using tracer-gas measurements during various different external conditions. Fan-controlled supply and exhaust ventilation was measured by means of measuring devices built into the ventilation system.

Instrument readings have mainly been done by the tenants themselves as well as by HSB's caretakers in the district. Sometimes the personnel of the National Swedish Institute for Building Research (SIB) have carried out supplementary readings. Every week forms with reply paid envelopes were sent from the Institute. After completing the forms with the various meter readings the tenants and caretakers returned the forms. Measurements were carried out from September 1980 to August 1981.

Results

The airtightness of the houses is of great importance for the saving in energy that may be anticipated. Therefore careful measurements of this were carried out in all 30 houses. The results of these measurements are shown in Table 1. The variation in any particular group is small, but between both groups of one-storey and two-storey houses the difference is comparatively large.

House type/ Vent. system	Tightness in airchanges per hour when p = 50 Pa
1-storey/F	3.1 ± 0.4
1-storey/FTX	3.25 ± 0.25
2-storey/F	0.94 ± 0.18
2-storey/FTX	0.97 ± 0.19

Table 1. Airtightness of the houses included in the investigation.

In both F as well as FTX ventilation an undesired air leakage is found that depends on the weather, so-called involuntary ventilation. The involuntary ventilation must be small if the advantages of heat recovery are to be made available. The tighter the house the greater the saving of energy, and the better the advantages of the FTX-system are utilized.

It is generally thought that F-ventilation produces a low pressure in the house that to a certain degree is able to resist the pressure differences caused by the weather. With the FTX-system this counterbalancing low pressure is not present, which causes this system to be more dependent upon the weather.

In order to obtain some idea of the low pressure in the F houses the pressure was measured in the more airtight group (2-storey houses). When the windowframe ventilators were open the low pressure was approximately 2 Pa; when closed the figure was approximately 6 Pa. This small difference in pressure of 2 Pa with open ventilators has in practice very little stabilizing effect. It therefore seems reasonable to state that if the F-system is to have a more stabilizing effect than the FTX-system then the air supply ventilators should be closed. However, this should not be the normal setting of the devices in an F-system.

In houses with F ventilation there were general complaints about draught. But in the FTX houses there were only occasional complaints about draught, which could be dealt with by turning up the thermostat in the air supply duct. Because of the draught problem in the F houses the residents closed their windowframe ventilators and thus obtained a somewhat lower air exchange in their homes whilst concurrently the low pressure producing a higher stabilization was obtained so that the air leakage was less dependent on the weather.

The size of the reduction in the air exchange was measured. It was discovered that the exchange dropped by 0.06 air exchanges per hour in the 1-storey houses and 0.12 per hour in the 2-storey houses. The reason why the decrease is greater in the latter is that these houses are more airtight.

It should be noted that before the measurements were started the airflows in all houses were adjusted to values corresponding to 0.5 exchanges per hour, which is the value laid down by the building standards. During the measurement period deviations from this value were obtained, because of the problems described above.

The energy savings measured are for:

1-storey houses 0.155 kWh/degree and day

2-storey houses 0.17 kWh/degree and day.

These figures have been obtained by calculating the total energy consumption used for heating, that is to say the total of:

- o energy for heating via radiators,
- o energy for the post-heating of the air supply (FTX-system),
- o 50% of the household's electricity consumption and
- o energy consumed by the air supply fan (FTX-system).

These measured values signify that in Skellefteå with 155 500 degree-hours we get the following savings of energy with the FTX-system:

a 1-storey house $0.155 \times 155\,500 \frac{1}{24}$ 1000 kWh/year

a 2-storey house $0.17 \times 155\,500 \frac{1}{24}$ 1100 kWh/year

As the energy consumption of the air-supply fan during the periods when the outside temperature exceeds +11°C cannot be utilized the values above are decreased by 87 kWh. If a small error in the adjustment of the airflows is also taken into account the following corrected values are obtained:

a 1-storey house approximately 1000 kWh/year,

a 2-storey house approximately 1250 kWh/year.

These differences thus constitute the savings obtained in actual operation with the FTX-systems in comparison with the F-system in these two types of houses. The savings will be compared with those obtained from a theoretical calculation. According to the manufacturer of the heat-recovery units the temperature efficiency in dry heat exchangers at the airflows concerned is 64%. The investigation has resulted in an average value during the year of 69%. The higher figure may be explained by the formation of condensation in the heat exchangers during a large part of the year.

When it is known how the airflows in the system fluctuate with external temperatures, then the proportion of maximally recovered energy η_e (η_e = efficiency of energy) can then be calculated. This proportion, η_e, is defined as:

$$\eta e = \frac{\text{energy obtained}}{\text{available energy}}$$

On the basis of these the degree of energy efficiency has been calculated to 51% on average during the heating-up period. In doing so consideration has also been given to the defrosting period of the unit.

Recovered energy when η_e = 51% and the number of degree-days 155 000 becomes at the actual airflows (0.028 and 0.033 m^3/s respectively):

per 1-storey-house:

0.51 x 155 500 x 0.028 x 1.2 x 1 = 2665 kWh/year

per 2-storey house:

0.51 x 155 500 x 0.033 x 1.2 x 1 = 3140 kWh/year.

Taking into consideration, as earlier, that the energy consumption of the air-supply fan cannot be utilized during the periods when the outside temperature exceeds +11°C the above values are decreased by 87 kWh. This gives the following theoretical savings:

per 1-storey house: 2578 kWh/year,

per 2-storey house: 3053 kWh/year.

In the one-storey houses it has been determined that there was a heat loss in the air-supply ducts of approximately 180 kWh during the heating-up period.

The differences in saving that can be attributed to the fact that the air exchange was different between the two groups of houses can now be calculated:

a 1-storey house: 2578 - 180 - 1100 ≈ 1400 kWh/year

a 2-storey house: 3053 - 1250 ≈ 1800 kWh/year.

If the whole difference in energy consumption is explained by lower air exchange in the F houses this lower air exchange becomes Δn_1 and Δn_2 respectively as follows:

$$\text{per 1-storey house } \Delta n_1 = \frac{1400 \times 3600}{81 \times 2.4 \times 1.2 \times 1 \times 155500} = 0.14 \ h^{-1}$$

$$\text{per 2-storey house } \Delta n_2 = \frac{1800 \times 3600}{99.5 \times 2.4 \times 1.2 \times 1 \times 155500} = 0.14 \ h^{-1}$$

The conclusions that can now be drawn with regard to the average air exchanges during the year in the different groups of houses and from the measurements made is that the air exchanges had the values shown in Table 2:

Type of house/ Vent. system	Average air exchange Exchanges/hour
1-storey/F	0.40 - 0.45
1-storey/FTX	0.55 - 0.60
2-storey/F	0.35 - 0.40
2-storey/FTX	0.50 - 0.55

Table 2. Average air exchanges in the different groups of houses.

Assessment of profitability of the heat recovery units

The installation of a heat recovery unit is of course undertaken in order to save energy. A profitability calculation can be carried out that takes into consideration the efficiency of the recovery system, the capital, operational and maintenance costs as well as the temperature conditions of the district concerned.

In assessment of profitability it seems reasonable to carry out the comparison at an air exchange of 0.5 air exchanges per hour for both groups, that is to say for both the F- and FTX-systems, but with the corrections for infiltration that occur during operation.

On the basis of the houses in Skellefteå the saving with the same air exchange should be for a:

1-storey house (81 m^2) approximately 2400 kWh,

2-storey house (99.5 m^2) approximately 3050 kWh.

Presuming that the correction for increased infiltration in the one-storey houses with the FTX-system is approximately 0.05 exchanges per hour greater than in the F houses and half of this value in the more airtight two-storey houses, the following savings are obtained with the FTX-system compared to the F-system:

for a 1-storey house approximately 1900 kWh,

for a 2-storey house approximately 2800 kWh.

With an energy cost of 0.20 Skr/kWh the savings are:

for a 1-storey house: 380 Skr

for a 2-storey house: 550 Skr.

The additional cost for an FTX-system as an alternative to an F-system can be estimated at about 8 000 Skr for a smaller one-family house. So the saving in this case corresponds only to an annual interest of 5 and 7% respectively. Therefore if only the financial result is considered the installation cannot be regarded as profitable.

However, the great difference between the F- and FTX-systems has proved to be the climate in the houses. The draught problem found in the F houses has been eliminated in the FTX houses. It is not easy to evaluate this in terms of cash but it is undeniably a factor clearly advantageous to the FTX-system. In view of this it can perhaps still be said that if the airtightness factor is better than 3, then heat recovery shows a profit.

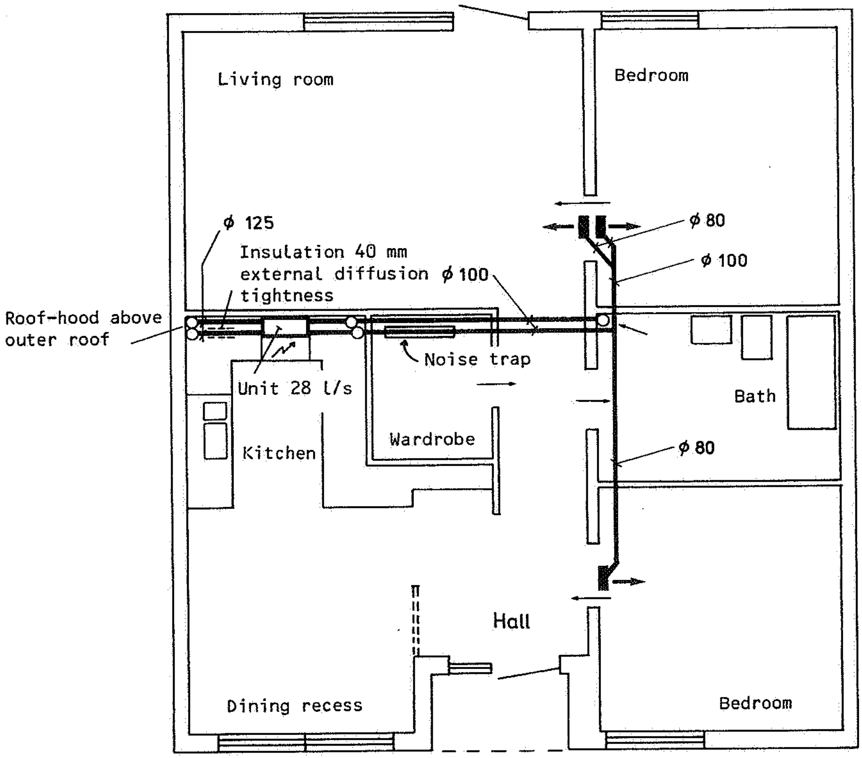

Figure 1. One-storey house

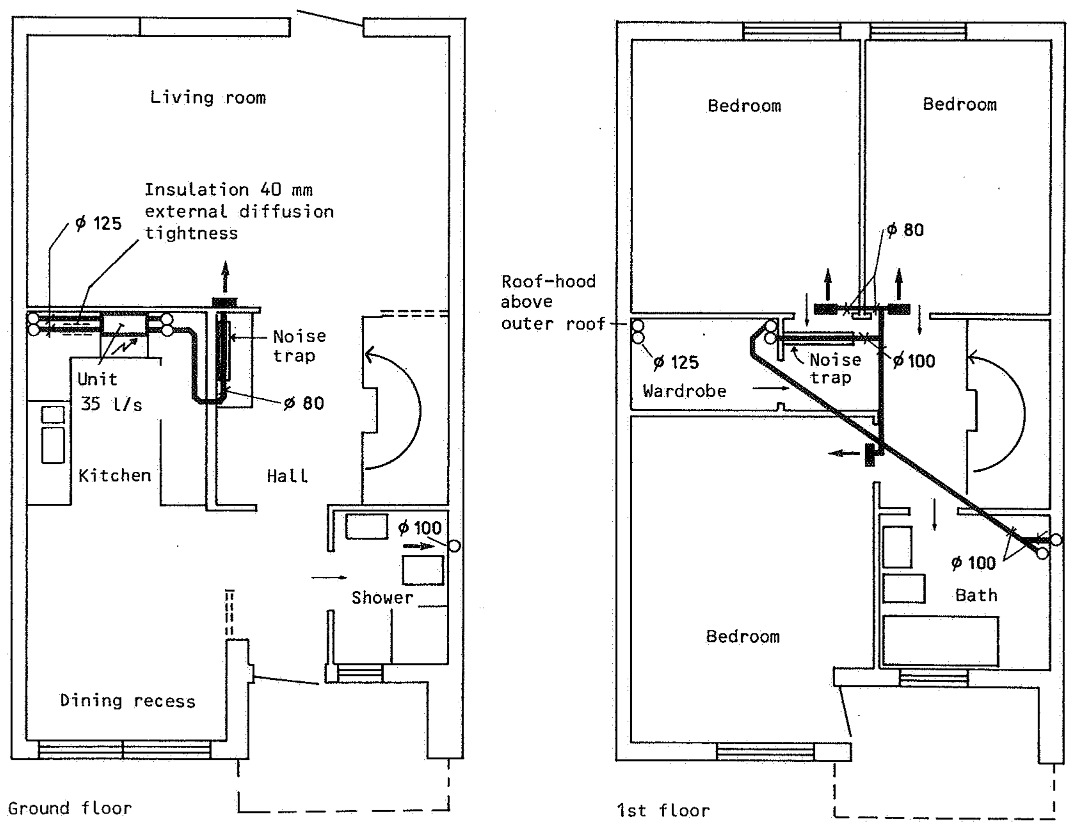

Figure 2. Two-storey house