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ABSTRACT

A number of exhaust air recovery units concerning energy conservation has been investigated in an apartment blocks retrofit project in the north of Sweden. The major aim has been to determine combinations of savings to be recommended in reaching the adopted goal stated by the government. The goal is to retrench the abroad oil dependence with 30 % in a ten year period started in 1978.

Exhaust air heat pumps for hot water preparation, and exhaust air-to-air heat exchangers provide a large potential for energy conservation in excisting apartment houses. Calculations show that exhaust ventilation constitutes about 40 % of the heating demand in the studied apartment houses. After normal installation procedures an effort to optimize the performances has been made on the basis of extensive measurements.

Concerning the heat pumps we have found that correct size is not achieved only by applying general rules in the strategy of projecting. Optimized function is reached first when actual conditions like hot water consumption, and exhaust air temperature and flow in the apartment house are considered.

Investigations of the air-to-air heat exchanger show that possible energy conservation potential is not reached because of freezing. We have found that only about 50 % of the possible amount of conservation is acheved. None of todays air-to-air heat exchangers are provided with any satisfying system in order to avoid freezing. It is rather common that electrical resistance heaters have been put in to critical areas in the exchanger. This take of action is not a good solution as it will decrease the overall efficiency. Our opinion is that some basic investigations concerning freezing problems must be done if this recovery unit should be included as a constituent in future exhaust ventilation systems in cold climates.

The general results however show that the achieved degree of saving in the installed systems is substantial, and in many cases it can have important beneficial effects on economy.

EXHAUST AIR HEAT RECOVERY

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INTRODUCTION

We will present some results gained from an apartment block retrofit project in Umeå, which is a town in the north of Sweden. The aim of the project has been to investigate if, and in what extent, new techniques can be adopted to existing buildings. The apartment houses contain a total of 476 apartments, built in 2, 3 and 4 floors, divided into two blocks. The blocks were built in 1970-71 during a period of intensive building in Sweden, and are from this point of view typical for other blocks. The houses are built with end walls and structural inner walls made of concrete. Insulation concists of mineral wool and the facing of the houses is of brick. The area is supplied with district heating via a secondary exchanger unit in each block of houses.

In this paper we will concentrate on some different ways of recovering the energy of exhaust air. The recovery units concist of heat pumps and air-to-air heat exchangers. The houses are ventilated by mechanical in- and outlet fans which are controlled by a timer for forced and normal flow. From energy balance studies we have concluded that ventilation stands for about 40 % of the heating energy consumption. The average consumption is about 220 kWh/m^2-Year for a normal year in Umeå. This means an average outdoor temperature of 0 °C. From this we state that efficient recovery of heat in exhaust air can provide energy savings of about 30 % or more if successfully adopted.

MEASUREMENTS

Two different strategies of measurements have been used separately. In the beginning of the project (in spring 1982) measurements were entirely made by hand. The work concerned readings of energy consumption and temperature levels in thirteen experimental houses.

The other method were based on a digital computer data acquisition and documentation aided technique. The computer communicated, via modem connected to telephone lines, with the data acquisition system, which were placed a distance of 3 miles from the host. Computer aided mesurements were applied to the more complex recovery units, two heat pumps and one air-to-air heat exchanger.

The advantage with the latter method is that measurements can be taken practically instantaneously and independently of current time of day. Average values can be made according to the actual caracter of the measured parameter. It is also very easy to locate sensors which are out of order.

METHOD OF ANALYSIS

The experimental houses are all identical from the construction point of view. Thanks to the measurement layout strategy, possibilities have been given to compare effects upon savings in two different ways. One way is to compare energy consumption in the same house before and after installation of a recovery unit. This we call before-and-after comparison. The other way is to compare consumptions in a measured house to an other identical house in which no savings has been done. This we call comparison-to-reference house. Both methods have their advantages and short comings which will be discussed below.

Before-And-After Comparison

Readings of both average energy consumption in a house as well as in- and outdoor temperature make it possible to determine the consumption signature of the house. By consumption signature we mean a plot of power consumption versus temperature difference, in-outdoor. The average values of power should be based on energy consumption during a period of days to make a good result. The parameters is then fitted linearly. The same plot after installation of a recovery unit normaly leds to changes in the signature. Conclusions can be made about the saving character due to the type of signature changes.

A constant saving which is independent of outdoor temperature results in a parallel displacement of the regression line. While an outdoor temperature dependent recovery unit like insulation or three glass of window pans results in changes of the derivative of the regression line.

Some shortcomings are that the spread in the plotted results will normally become quite large. This is due to the fact that the method does not account for solar radiation, which can be considerable during certain periods in the heating season. Changes in the heating regulation curve gives immediately large disturbances because the house cooperates with its own heat buffer, until a new stationary condition has been reached. Because of stationary condition is demanded the method needs a lot of time to guarantee reliable results.

Comparison-To-Reference House

An advantage with this method is that general tendencies can be traced and taken into account so that the effect upon the installed recovery unit can be isolated. In the project all the houses in the same block are connected to the same secondary exchanger unit for district heating. Because of this fact the method is not sensitive to neither outdoor temperature, solar heating or changes in the regulation curve.

Plotting the energy consumption in the prepared house versus the energy consumption in the reference house one can easily make conclusions about the effect upon a certain recovery unit. The method also makes it possible to , in time, continuously analyse the results until one finds a final qualitative analysis meaningsful.

EXPERIMENTALS, AIR-TO-AIR HEAT EXCHANGER.

The air-to-air heat exchanger has been installed in a 12 apartment house with a total area of 878 m^2. The exchanger unit is of conventional doubble cross-flow type with aluminum plates separating the two air streems. The air-to-air heat exchanger is placed on top of the roof.

As figure 1 shows, air channels, which are insulated, are connected from the excisting exhausts into the exchanger. Post heating of inlet air is made by the excisting air heating unit.

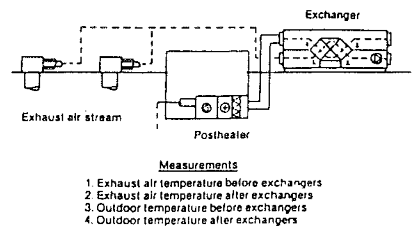

Figure 1. Illustration of air-to-air heat exchanger system.

The exchanger system is provided with a thermostat which according to the outdoor temperature regulates a damper in a by-pass manner. By-pass is supposed to be used during the summer to aviod unnecessary inlet air heating.

Results

Freezing has been the major problem in spoiling the possibility to save energy during cold periods. In our work we have used the dry temperature efficiency, ν, as a dimension indicating the function. The temperature efficiency is defined by

$$\nu = \frac{(T_i - T_o)}{(T_e - T_o)}$$

where

T_i - Inlet air temperature after exchanger
T_e - Outlet exhaust air temperature before exchanger
T_o - Outdoor temperature

Figure 2 shows how ν changes with outdoor temperature. In normal conditions ν is 75 % which is in agrement with product papers. One can clearly observe a drastic decrease in ν as the temperature lowers -6 °C.

This means that freezing starts, and frost continue to grow until several air channels in the exhaust section of the exchanger unit is plugged with ice.

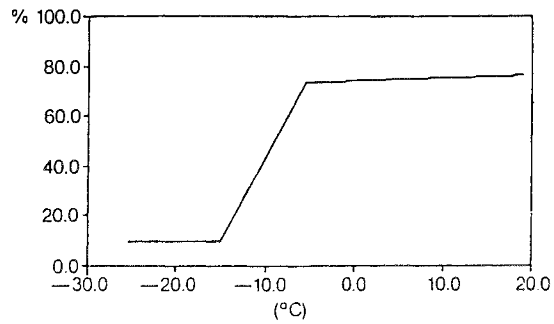

Figure 2. Temperature efficiency as a function of outdoor temperature.

The freezing lowers the grade of exhaust air ventilation which means that the balance between exhaust and inlet air ventilation is changed into an unacceptable condition.

Insulated exhaust air channels on top of roof is not to be recomended. Measurements shows that the exhaust air temperature is dependent on outdoor temperature. To gain optimum saving results the exhaust air temperature must be held constant in the inlets to the exchanger.

The measured saving with the air-to-air heat exchanger is indicated as a shaded area in figure 3. The saving reach a yearly recovery of 21.7 MWh or 12 % of the total energy consumption including hot water preparation.

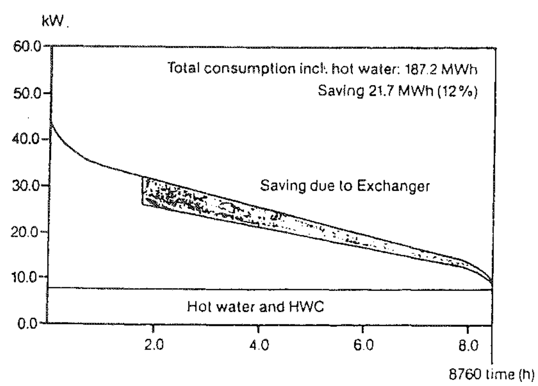

Figure 3. Power duration diagram indicating measured saving.

EXPERIMENTALS, HEAT PUMP IN A 12 APARTMENT HOUSE

The first heat pump to be described was installed in a 12 apartment house with a total area of 878 m^2. From considerations of space the heat pump was placed on roof, and connected to a hot water accumulator according to figure 4. The heat pump on roof is connected to exchanger VVX1 and VVX2 through pipes in the staircase-well. The brine solution in the primary circuit is water. To avoid freezing a smaller part outside is heated by an electrical cable.

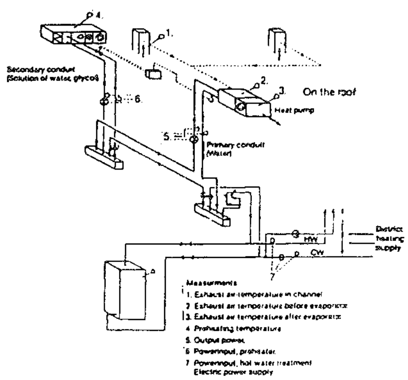

Figure 4. Illustration of exhaust air heat pump system.

Hot water is heated by exchanger VVX1 and stored in an accumulator tank containing 700 litres. Thermostatic valves regulates the flow in order to maintain a temperature of 50 °C in the hot water leaving the exchanger.

Exchanger VVX2 supplies heat to a pre-heater warming inlet ventilation air. The temperature can be raised from outdoor temperature to a maximum of 16 °C. The air preheater circuit is activated when the need for hot water is reduced. It is put into the system in order to extend the operating time of the heat pump.

A temperature sensor in the return of the primary circuit can switch the heat pump on or off. The connection to the previous system is kept intact and can be activated if the heat pump suddenly failes to work.

The produced energy is divided into three parts;

1. Energy for hot water.
2. Radiators connected to the hot water circuit.
3. Air pre-heating.

Results

Shortly after the heat pump was set to work we noticed that the output power was substantially lower than the value given by the contractor. At this time the installation was inspected according to normal procedures which does not include function testing. Without our extensive measurements the installation would had been approved and delivered to the care of the property holder.

We will here give a breaf description of the types of errors which took about a year to define and to take action. Based on the general experiance of this type of installation we do believe the situation to be quite typical.

The exhaust air temperature was much lower than the average indoor temperature. This was found to be due to a fire damper which always was slightly open due to an error in the damper motor.

The measurements indicated a dayly hot water consumption of 400 L/apt. which is about twice that expected. This was found to be caused by a leaking valve, at the point where the old and new installations met.

When the valve was finally sealed, we noticed that the extra supply trough the excisting district heating system was large, even though the operating time of the heat pump was low. The reason was an unfavourable placing of the temperature sensor which indicates the average temperature of the accumulator tank.

The main problem was concerned with the air pre-heater. Since it is directly connected to the exchanger, the heat pump experience a rather sudden demand of power as soon as the pre-heater is activated. This resulted in an on/off regulation with subsequent oscillation in the temperature of the primary circuit. The number of on/off-events for the compressor, caused during the nights when the hot water demand was low, was unacceptable high ,and was considered to increase the possibilities of damaging the compressor. Changing to slower sensors, with built in hysteresis effects reduced the on/off-events substantially.

Technical Notes. According to the contractor the heat pump is expected to output 20 kW at the following conditions;

Air flow - 3.800 m^3/h
Air temp. (before exch.) - 20 °C
Air temp. (after exch.) - 8 °C
Brine flow - 1.9-2.5 m^3/h

Figure 5 gives a summary of the power output at different exhaust air temperatures. The average power guaranteed by the contractor is only reached at the very highest temperatures. This corresponds to a coefficiant of performance, COP, of 2.0-2.2 compared to 2.9-3.2 as was given by the product paper.

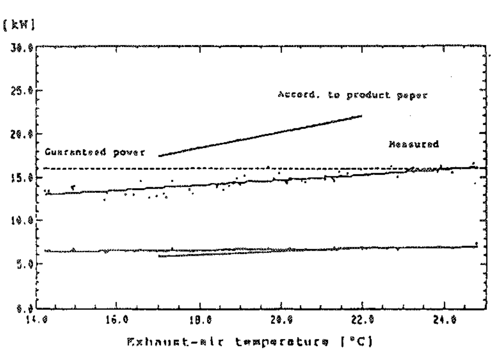

Figure 5. Output power as a function of exhaust air temperature.

The basic misjudgement is the fact that the air flow in the actual house is only 2-2.500 m^3/h which is only 60 % of that demanded for obtaining 20 kW. The energy recovery based on measurements corresponds to a yearly saving of 52.2 MWh (25 %) or 59.8 kWh/m^2.

EXPERIMENTALS, HEAT PUMP IN A 39 APARTMENT HOUSE

The heat pump was installed in a 39 apartment house with a total area of 2781 m^2. According to figure 6 the heat pump is placed in the cellar and connected to air exchangers in the exhaust air streem on top of roof. A brine solution of water an glycol is circulated in this circuit.

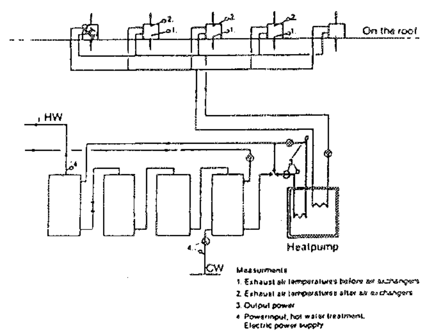

Figure 6. Illustration of exhaust air heat pump system.

The heat pump prepares hot water, which is stored in four accumulator tanks, each of 650 litres, and heat to radiators connected to the hot water circulation system.

A temperature sensor in the return of the condensing circuit switches the heat pump on or off. The connection to the previous system is kept intact, and can be activated if the heat pump suddenly failes to work.

Results

One of the basic ideas was that the installations should not affect the total amount of ventilation. The installation however introduced a pressure drop in the exhaust air channel, and hence reduced the total ventilation. After complaints from the tenants the fans were replaced to larger ones.

The output power was lower than expected. It was found to be caused by a low exhaust air temperature. After inspection we found that outdoor air was entering the exhaust air system through a channel in the rubbish-chute. This was prevented by mounting an extra damper which should be closed during the winter.

The circulation between the accumulators for hot water preparation did not work out as planned. Only the water in one of the four tanks were raised to a temperature of 52 °C. This resulted in unnecessary activation of the previous district heating system and the degree of cover by the heat pump was very low. The step of action which solved the problem was adjustment of the water flow, in both the hot water circulation and the condensing circuits.

Technical Notes. According to the product paper the heat pump is expected to output 25 kW at an exhaust air temperature of 20-22 °C and an minimum air flow of 3240 m^3/h. Figure 7 gives a summary of output and input power according to measurements and product paper as a function of exhaust air flow.

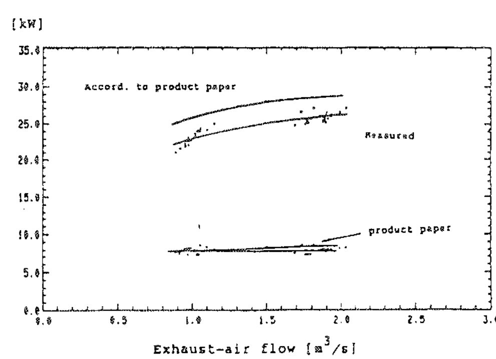

Figure 7. Output and input power as a function of air flow.

The COP should vary between 3.1 and 3.4, measurements showed a variation of 2.8 to 3.2 which means that the average COP during the heating season is 3.0. Based on this facts one can conclude that the heat pump states a good example of a well working recovery system. It is though worth mentioning that the function of today has been achieved first after amounts of extensive measurements. The energy recovery based on measurements corresponds to a yearly saving of 136 MWh (26 %) or 49 kWh/m^2.

DISCUSSION

The results gained from these illustrations shows that in normal cases a number of problems arises when new energy saving components are to be introduced into existing apartment houses. Using normal procedures of today no one takes the full responsibility for the connection between the new installation and the excisting system. We belive that in future a function test must be performed before the installation is approved and delivered to the care of the property holder.

The function test is however in many cases quite complicated and requires a computer based data aquisition system in order to collect and analyse the data. Even so, it is not quite straight forward. The obtained results has to be weighted according to some type of model in which parameters like COP, dayly duration operating time and power output are weighted to some effectivity factor, C. This factor can be used to give an objective dimension of the actual status of the installation.

Such a model based on COP, and the dayly duration operating time could be defined by a sum of ratios as

$$C = a_1 \cdot (COP_a / COP_{max}) + a_2 \cdot (t_a / t_{max})$$

Where

COP_{max} - 3.0
COP_a - Measured COP
t_{max} - 24 hours
t_a - Measured dayly duration operating time

The weighting coefficients a_1, a_2 are set equal to 0.5 but can in principle be varied independantly as long as their sum is unity.

C can now range from 0 to 1 if we assume that COP_a/COP_{max} and t_a/t_{max} is less than unity. For the two heat pumps analyzed we find C values ranging from 0.7-0.8. The second and better suited heat pump having the higher value. This simple model gives an indication of the status but one has to complicate the model further to increase the sensitivity. We do belive that this is a possible way of obtaining an objective dimension of the successfullness of an installation.

A more detailed model should of course take economical terms into account. We have for instance found that with the existing financing possibilities in Sweden of today none of the heat pumps would have been accepted on economical terms having the initial performance. After optimization the second one will turn out to be a good investment for the property holder. The first heat pump described, which is to large in size will never become economical, which indicates that there is of course a limit in the degree of saving that is possible to obtain by optimization of existing installations. In spite of this we conclude that the obtainable saving can be substantial, and does well motivate research money in this field.

ACKNOWLEDGEMENT

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