

Exhaust air heat pumps – results from a field study in Sweden

Johan M. Berg, Svein H. Ruud, Ulla Lindberg, Mattias Stenlund, Monica Axell

SP Swedish Technical Research Institute
Division of Energy Technology
P. O. Box 857
SE-501 15 Borås
SWEDEN

ABSTRACT

Exhaust air heat pumps use exhaust air from the house in order to provide heat and domestic hot water. The Swedish market for this type of heat pumps has, due to energy recovery legislation, been the dominating installation in new built single family houses during the last two decades.

The main objectives of this study included evaluating the efficiency of exhaust air heat pump systems and recording experiences of the end users. A further objective was to compare the energy consumption and system efficiency of the studied heat pumps to that of similar installations that apply Best Available Technology (BAT), using computer simulations.

Questionnaires were sent to 516 home owners who had installed exhaust air heat pumps during the period 1985-2003. The main focus was on single family houses where the home-owners had received the heat pump with the purchase of the house; this reflects the Swedish market for exhaust air heat pumps. From the questionnaire, 25 systems were inspected more in detail by means of interviews and ocular inspections. The study was concluded with measurements during 12 months, in three selected systems of different designs, age and size. The measurements incorporated data necessary to evaluate the seasonal performance factor.

Although the home owners in general were satisfied with their heat pumps, the study highlights various problems encountered: noise, inferior efficiency, too low exhaust air flow. At a higher level, it is clear that it would be desirable to introduce incentives for installers to perform routine follow-ups with home-owners. The simulations showed that by applying BAT the energy consumption would decrease and the system efficiency would increase. They also show that recent legislation for new construction can be satisfied by the new generation of exhaust air heat pumps for low energy building shells, or for standard building shells in the more favorable climates within a given region. Finally, the study underpins the fact that reliable, impartial test data of the heat pumps on the market are necessary in order for market-driven product improvement of exhaust air heat pumps to occur.

1. INTRODUCTION

In Sweden, there has been a large interest for exhaust air heat pumps for a number of years. One main reason for this is that, in the wake of the oil crisis of the 1970s, legislation was passed in the 1980s, requiring construction companies to use energy recovery in all new-produced single-family dwellings. One straight-forward and effective way to achieve this was found to be to install exhaust air heat pumps. Since the start of the new millennium this has been reflected in the sales statistics of exhaust air HP's in Sweden, see Fig. 1 (SVEP 2010). The recent decline in sales are due to the economic recession, leading to an overall decline in the building sector (EHPA 2010).

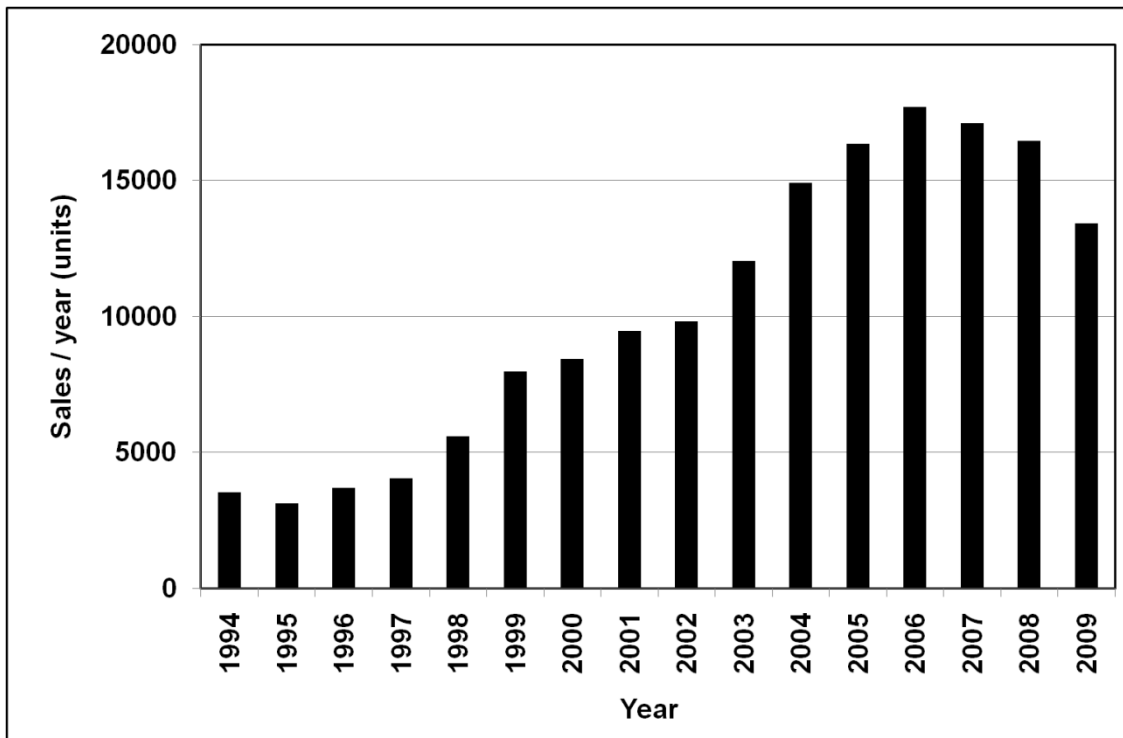


Figure 1. Sales statistics for exhaust air heat pumps in Sweden

An exhaust air heat pump uses the exhaust air from the house to provide the house with heat and domestic hot water. There are various complete systems for such type of heat pumps in order to provide an efficient ventilation, domestic hot water and a comfortable indoor environment.

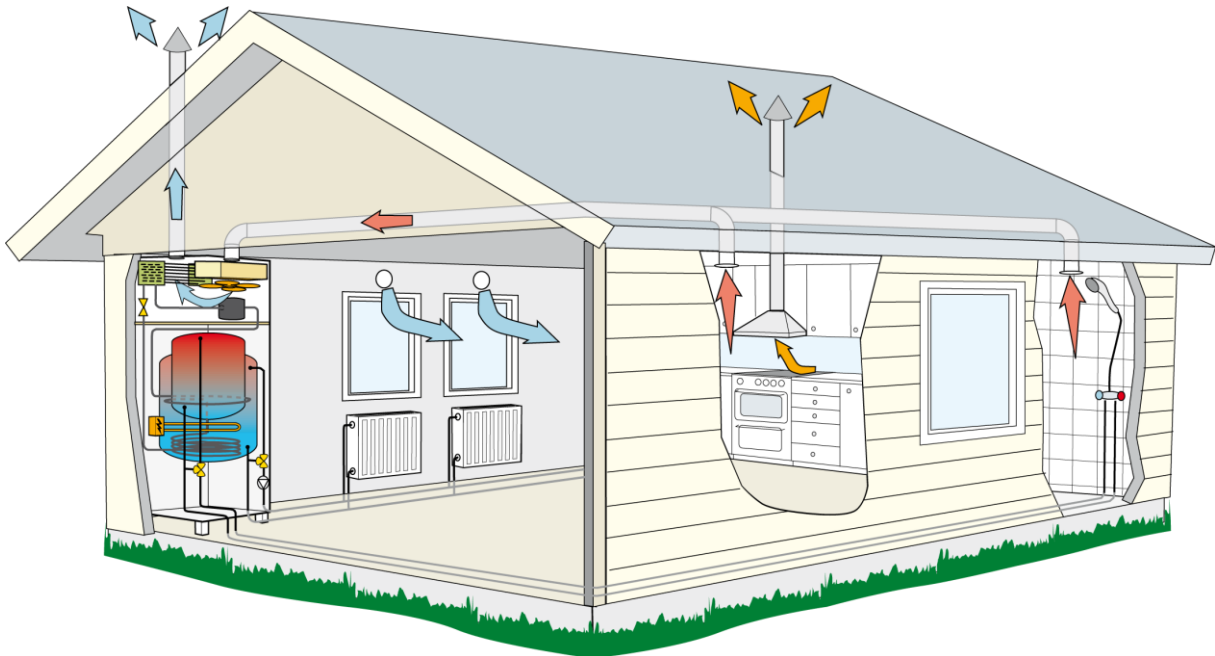


Figure 2. Schematic of a house equipped with an exhaust air heat pump

However, there has been a lack in objective knowledge and information regarding the efficiency, and experience of end users, of exhaust air HP-systems in real applications on a long term basis. Due to this SP performed a field study with focus on residential exhaust air HP systems. The study was initiated in the year 2004 and lasted for one year.

In the present article we want to present some results and conclusions from this study. Although the data are a few years old, they are still valid, since the houses and individual heat pumps still remain, to a large extent. Also, we want to indicate what the performance (Seasonal Performance Factor, SPF) of the heat pumps could be if these heat pumps would be used in low-energy buildings, or if modern technology exhaust air HP's would have been installed in low-energy buildings, especially in relation to recent Swedish legislation.

2. METHODS

This study is based on a questionnaire, a field study, and a set of field measurements, as well as on a computer simulation. The questionnaire survey, the field study, and the field measurements were all made during 2004 and 2005.

2.1. Questionnaire

The questionnaire, consisting of 37 questions, was sent out to 516 home owners who had purchased a new house with exhaust air HP, or installed an exhaust air HP during the years 1985-2003. The send-out was addressed to owners of randomly selected systems spread across Sweden, but with a dominance (about 2/3) of central and southern Sweden. 302 end-users, corresponding to 65 % of the sendout, decided to participate in the enquiry. For most of the questions, a given respondent could select more than one alternative; thus the percentages for a given question could add to more than 100 %.

2.2. Field study

25 owners were selected for the field study visit. They were selected from the questionnaire respondents based on their answers to the questionnaire. The requirements were that they were positive to be visited, and the full group of owners in the field study should display a representative variety regarding properties, such as heat pump brand and system type, year of installation, heating system, and degree of satisfaction/encountered problems.

The HP owners in the field study were interviewed regarding their HP experience, knowledge, information, maintenance, properties of the house and the heat pump and heating systems, etc. Also, their systems were inspected regarding factors such as the pressure level in the expansion vessel, placement of the outdoor sensor, etc. Further, the available documentation was inspected. Finally, the exhaust air flow was measured prior to and after filter exchange.

2.3. Field/seasonal measurements

Based on the result of the field study, three home owners (designated A-C) were selected, for exhaust air HP field/seasonal measurements. The measurements were initiated in October/November 2004 and ended in October/November 2005. The selection was based on similar criteria as was the field study.

The measured quantities were primarily (see Fig. 3)

- delivered thermal energy to the radiators of the space heating system ($Q_{1,rad}$)
- thermal energy delivered to the hot water system ($Q_{1,dhw}$)
- total supplied electric energy to the full system (heating + DHW) (W_{hs})
- supplied electric energy to the supplementary heating system (W_{sh})
- indoor and outdoor temperature
- temperature and relative humidity of air entering the heat pump
- compressor runtime.

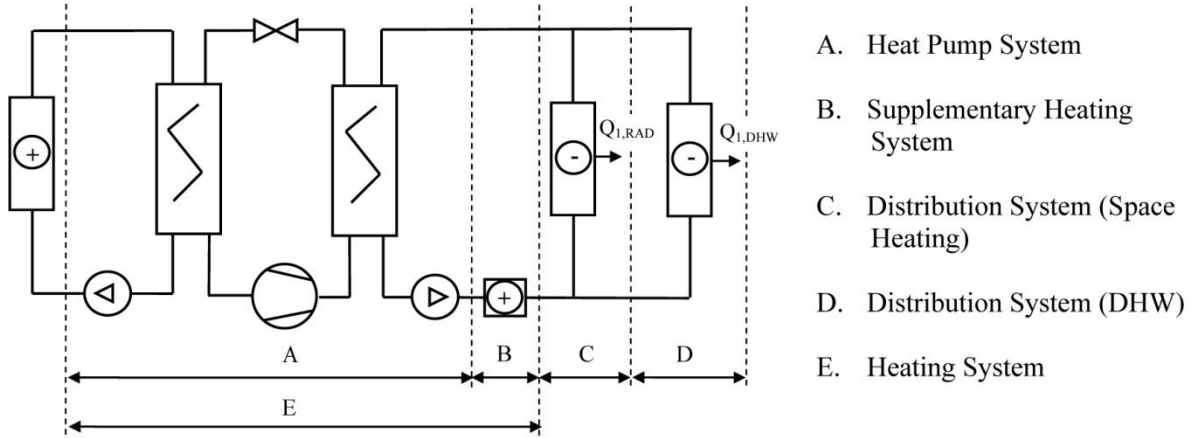


Figure 3. Definitions of terms used in the equations (see also “Nomenclature”)

The measuring equipment was monitored by the system owners on a weekly basis and reported every month. The collected data were used to determine the seasonal efficiency of the systems. For this, the Seasonal Performance Factor (SPF), defined as in equation (1) (below) was calculated. This is an indicator of the performance of the entire system, including the supplementary heating unit.

However, the main bulk of the Swedish exhaust air HP's are not designed to cover the entire heat power demand of the building, why a supplementary heater is necessary. The amount of supplementary heating will affect the SPF considerably. In order to visualize the effect from supplementary heating the Energy Coverage Factor (ECF), defined as in equation (2), was calculated.

$$SPF_{hs} = \frac{Q_{1,rad} + Q_{1,dhw}}{W_{hs}} = \frac{Q_{1,hps} + Q_{1,sh}}{W_{hps} + W_{sh}} = \frac{Q_{1,hps} + W_{sh} \eta_{sh}}{W_{hps} + W_{sh}} \quad (1)$$

$$ECF = \frac{Q_{1,rad} + Q_{1,dhw} - Q_{1,sh}}{Q_{1,rad} + Q_{1,dhw}} \quad (2)$$

2.4. Simulations

The energy simulation calculations were made with an energy calculation method originally developed for a Swedish association of producers of timber framed single family houses (TMF, Swedish Federation of Wood and Furniture Industry). It is used to make a preliminary energy declaration of specific energy use in new built single family houses according to the new Swedish building code of 2009. Due to the implementation of the European Energy Performance of Building Directive (EPBD), the Swedish National board of Housing and planning has, in the new regulations, set maximum values on specific energy use for space heating and domestic hot water in new buildings. The calculation method is based on the European standard EN ISO 13790:2004, but with national parameters for usage (Levin et al. 2007). In the present paper the calculation method has been slightly modified to suit the purpose of the study.

3. RESULTS

3.1. Questionnaire

The questionnaire dealt with questions such as system design, experience from operation and the purchasing process. About 70 % of the respondents had their system installed during year 2000 or later.

According to the study, a typical exhaust air heat pump heats water for the radiator system, or for a radiator system and floor heating. In 90 % of the cases, hot water is also produced.

As indicated above, the vast majority of the participants had obtained their heat pump as a mandatory or option when buying their new house, see figure 4. Thus, a large majority, 78 %, of the end users were not present during the installation.

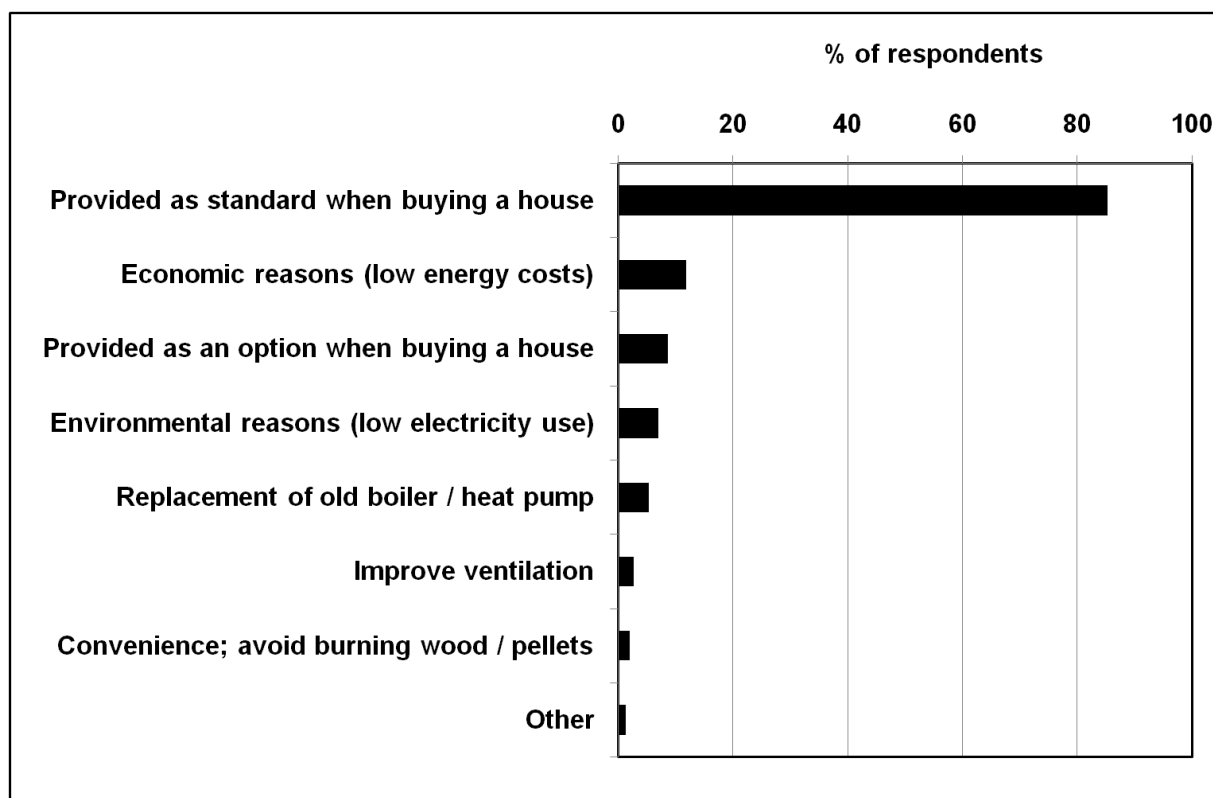


Figure 4. Reasons for purchasing an exhaust air heat pump

Since the respondents were all customers of new houses, this result, as well as other in this study, might be judged as being biased, i.e., not valid for the full exhaust air HP market. However, according to available statistics, the number of subsidies for retrofit exhaust air HP installations is very low compared to exhaust air HP's installed in new houses. Thus, we believe that the results are actually representative for the full exhaust air HP market.

As a result of this, the end users have low knowledge regarding the installation process. For instance, 77 % did not know whether the installer was a member of the Swedish heat pump association (SVEP) or not.

Instructions from the heat pump installers, regarding issues such as periodic maintenance and troubleshooting in case of power failure, were given in written form and orally to 16 % of the respondents, only orally to 4 %, only written to about 80 %, and neither oral nor written instructions to less than 1 % of the respondents, see figure 5 (full bars).

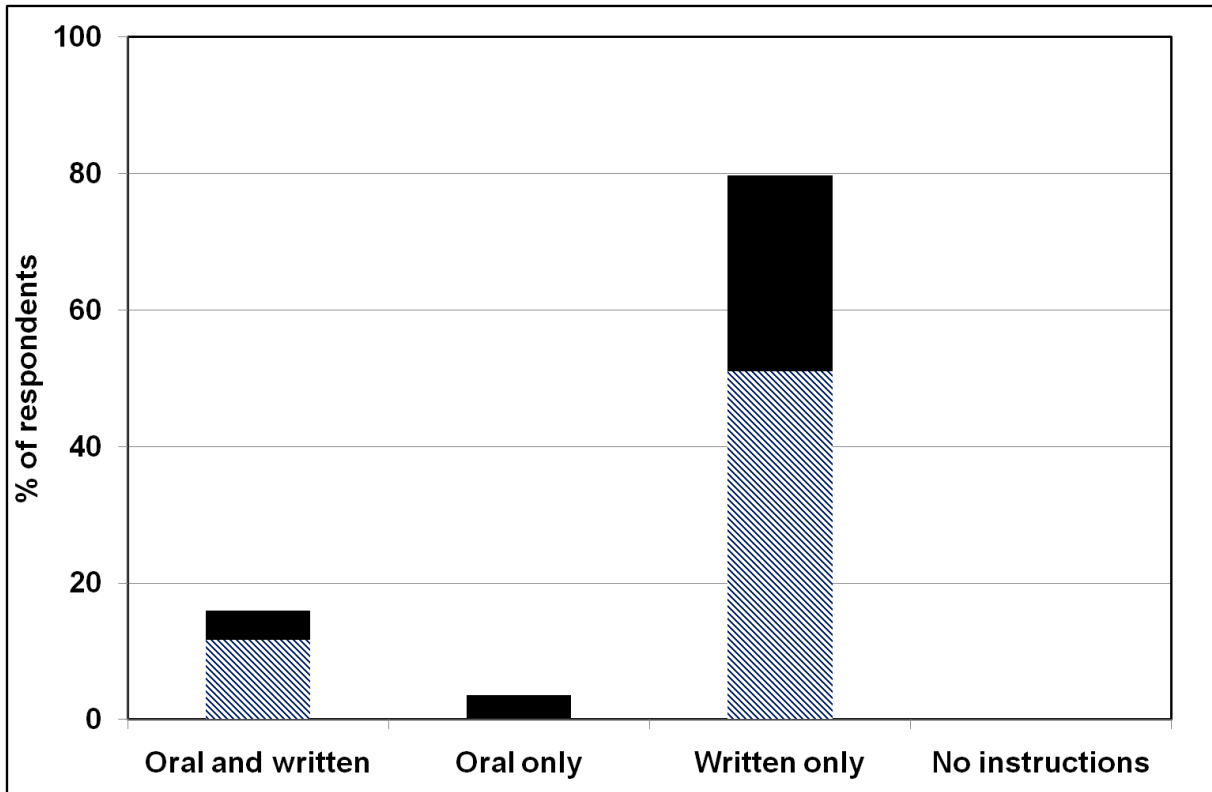


Figure 5. Form of provided instructions to owners

The number of owners that were satisfied with the instructions given were 73 %, 9 %, and 64 %, respectively of the classes described in the last sentence (hatched area in each column in figure 5). Thus, instructions should at least be given in written form, and preferably also in oral form.

A majority of the users, 74 %, are largely satisfied with their system, and 83 % would recommend it to a friend considering installing an exhaust air HP.

The reasons for dissatisfaction that are mentioned by the respondents are running problems, mainly due to breakdown of the compressor, but also noise, suspected inefficiency, and inadequate thermal comfort. The most frequently reported problem was noise, 26 % of respondent reporting noise from the heat pump itself and 5 % from the radiators/heating system. Those that are satisfied motivate this by stating that the heat pump operation has been without problems, that the maintenance is easy, and that the heat pump is energy efficient.

Regarding compressor breakdowns, this is analysed by year of installation in figure 6.

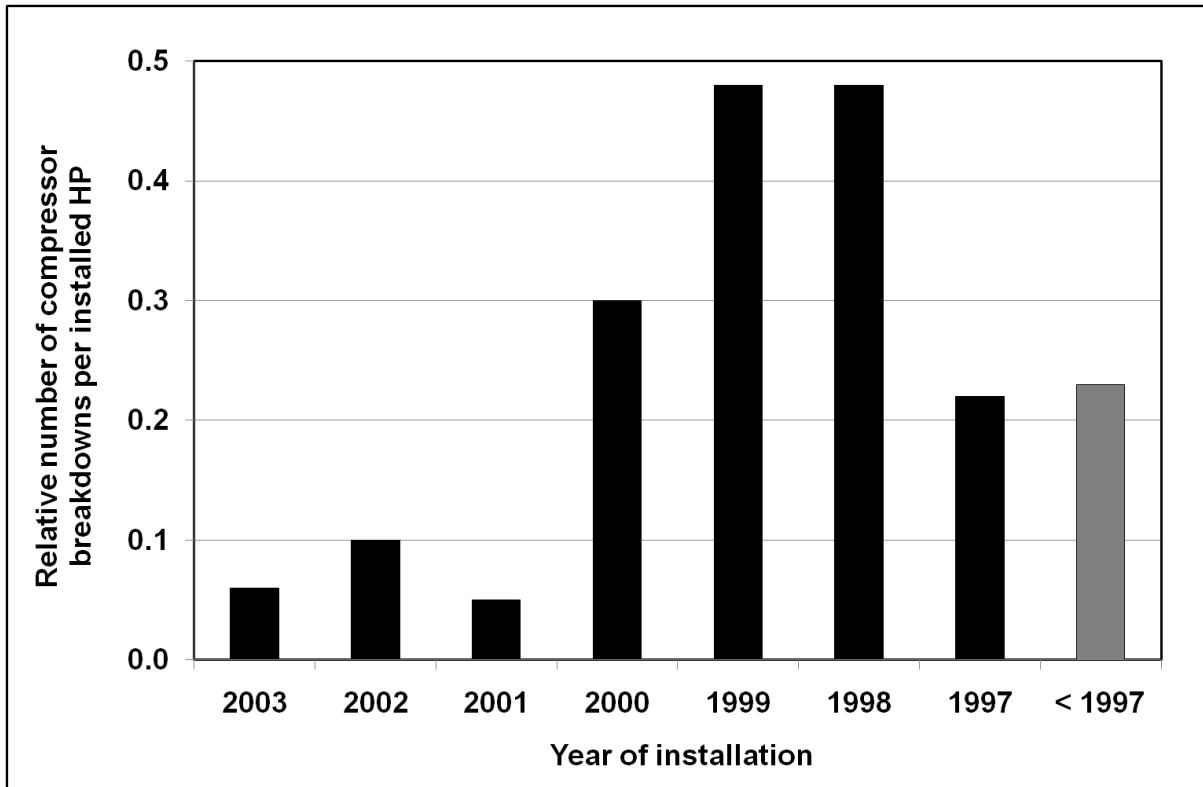


Fig. 6. Rel. number of compressor breakdowns per installed exhaust air HP, by year of inst.

There are two clear tendencies. First, with increasing age, heat pumps run a larger risk of breakdown. Second, there is a maximum for heat pumps installed around 1998-2000. This is due to the change of refrigerant to propane, which in some cases caused some lubrication problems, mainly for the compressors. This problem was subsequently solved, according to the manufacturers.

The respondents reported that the periodical maintenance that they have done has mainly been restricted to cleaning filters and exhaust air terminal devices. Maintenance that requires more knowledge and/or time is often neglected. This includes exercising safety valves and checking/exchanging the sacrificial anode.

3.2. Field study

Measurements of exhaust flow before and after cleaning of filters showed that the average flow improvement after cleaning was 7 %, with values from three heat pumps in excess of 10 %. However, the median was a more moderate 4 %.

It was noted that about half of the heat pumps, of the 25 that were subject to measurements, had an exhaust flow that was lower than the projected flow. This was the case for all of the three houses studied in the field measurements.

In the field study, as well as in the questionnaire/survey, there were clear indications that a large majority of the respondents were not aware of the importance of the magnitude of the exhaust air flow for the heat pump performance.

3.3. Field/seasonal measurements

The seasonal performance factor (SPF, equation (1)), and the energy coverage factor (ECF, equation (2)) for houses A, B and C are shown in table 1.

Table 1. Seasonal Performance Factor (SPF_{hs}) and Energy Coverage Factor of houses A-C

House	A	B	C
Seasonal Performance Factor, SPF_{hs}	1.4	1.7	1.5
Energy Coverage Factor, ECF [%]	53	73	72

The SPF values were all within the range 1.4 – 1.7. However, in the electric energy consumption used for calculating this ratio, both the exhaust fan and heating system circulation pump is included. Since the fan and pump are necessary and would be running even if a different heating system would be used, it could be argued that only the electric energy used to overcome internal pressure losses should be included in the SPF calculations. If this is taken into account, the SPF values will improve by approximately 5 % (fan) and 2 % (pump), resulting in a total of approximately 7 % higher values (not shown in any table or figure).

The Energy Coverage factor (ECF) was 53-73 % (table 1). This low value is largely a result of the relatively low capacity of the heat pumps, which results in a significant use of the supplementary heating unit.

3.4. Simulations

For house B, simulations were performed as described in 2.4, in order to make a comparison with a virtual house, using Best Available Technology (BAT). BAT was assumed to be used for the building shell (passive house), heat pumps (inverter-controlled), and household appliances (low power demand). As shown in figure 7, the SPF increases (uncorrected data) with about 0.5 units when BAT is applied.

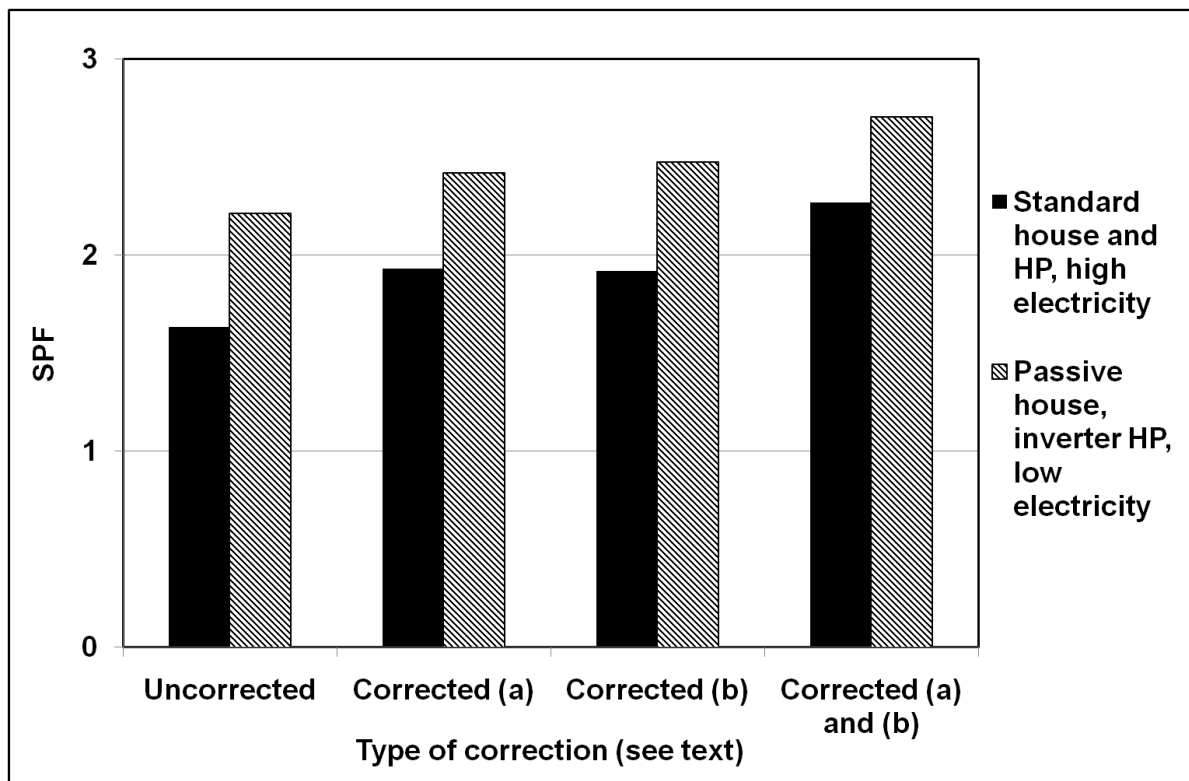


Figure 7. Influence of specified corrections and BAT on SPF values

The SPF values increase if the heat loss from the hot-water boiler is included as produced energy in the calculations (correction (a)). If instead another correction is applied, where only the electricity used for the heat pump compressor and the direct electric heating is included (correction (b)), approximately the same SPF increase is obtained. Further, if the SPF is calculated using both correction (a) and (b), the differences to the uncorrected data are approximately 0.65 and 0.50, for the standard and the BAT conditions, respectively.

Comparing the Energy Coverage factor (ECF) for the standard and the BAT conditions, it is clear that the BAT conditions are much more favourable, giving an ECF value of 1.00 (fig. 8); i.e., using BAT, the heat pump itself can deliver all the heat required, without the need of the direct electric heating.

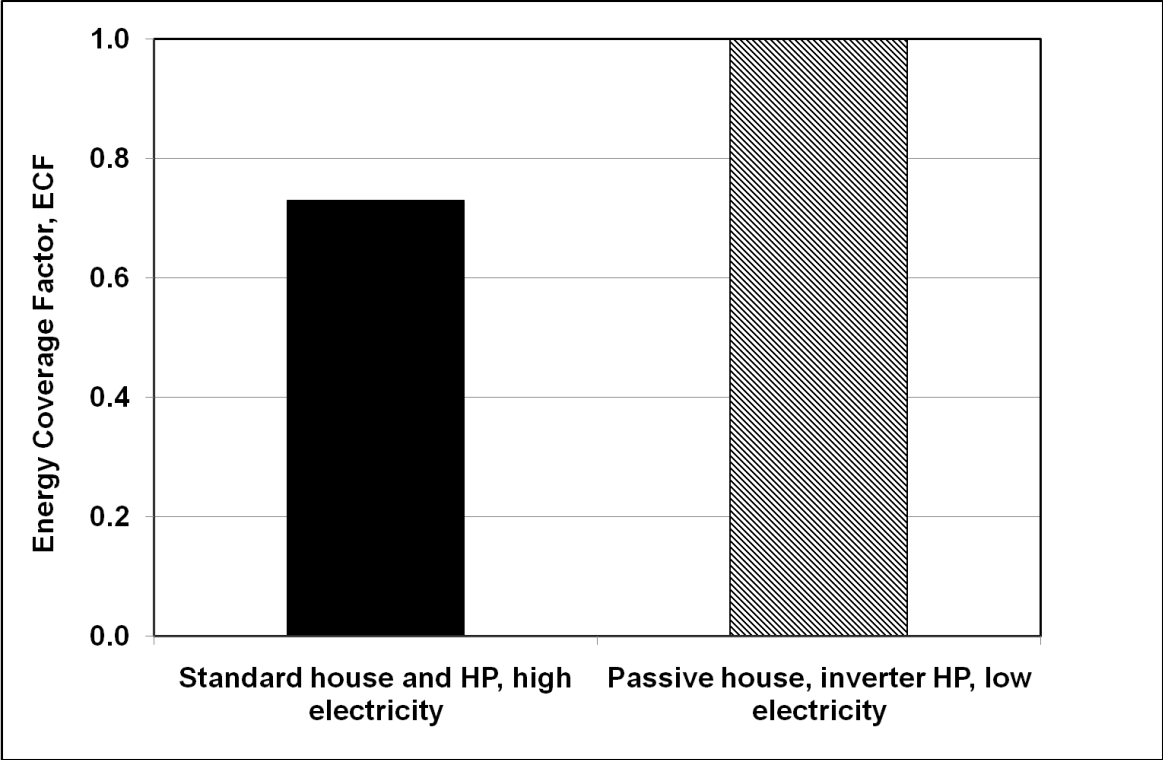


Figure 8. Energy Coverage Factor (ECF) for standard and BAT conditions

Finally, the total electric energy consumption is nearly 40 % lower for the BAT conditions than with the standard conditions, figure 9.

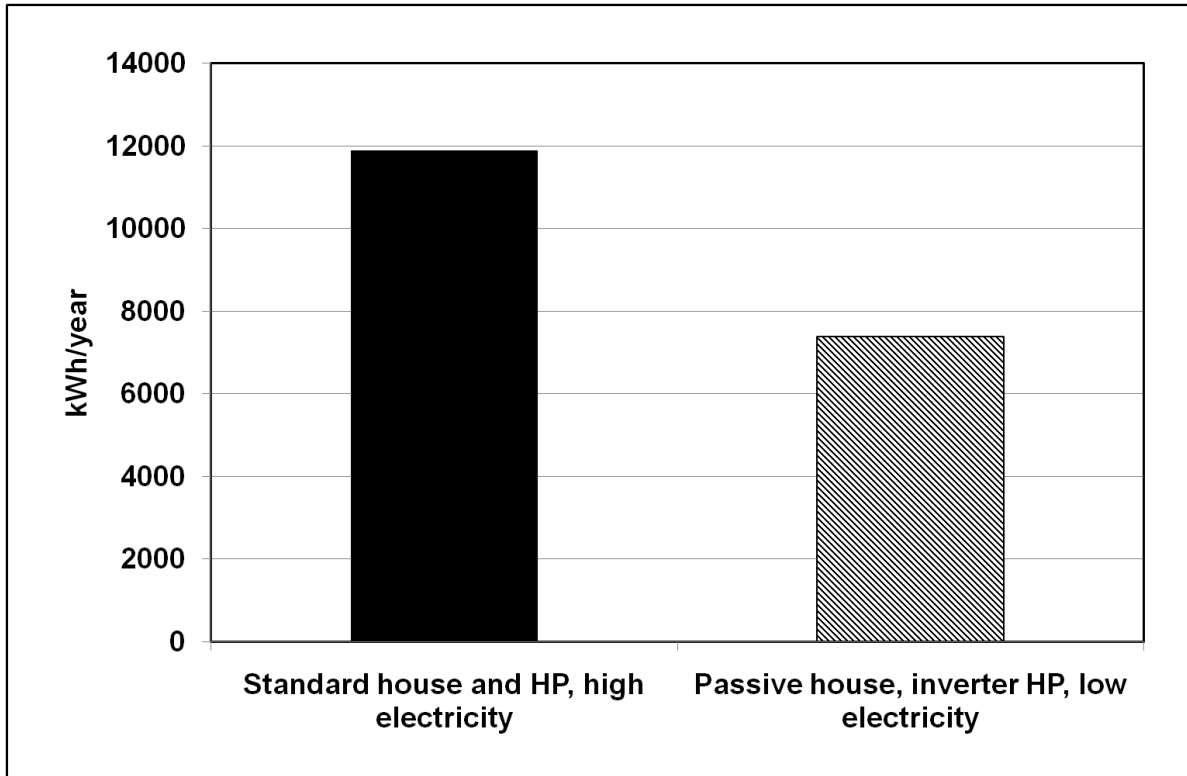


Figure 9. Total electric energy consumption for standard and BAT conditions

4. DISCUSSION

According to this study, the most common problem encountered by the house owners was noise. However, noise may be due to a number of factors. For instance, noise from radiators could be the result of insufficient deaeration, from vibrations originally emanating from the heat pump, or from the release of thermal tension as a result of hot water entering a cool system. However, most of the noise problems originate from the heat pump itself, and are probably due to unsuitable location of the heat pump, for instance adjacent to a bedroom.

The SPF values reported for the full heating systems are relatively low. A major reason for this is the low capacity of the heat pumps, in relation to the heating demand, forcing the supplementary heating system to run a considerable part of the time. We want to point out that with the modern types of exhaust air heat pumps, more energy is extracted from the exhaust air than with the heat pumps studied here; thus the SPF values will be higher for the modern types. Further, it could be argued that part of the energy consumption of the fans and circulation pump should not be included in the SPF calculation, and energy could be saved by using more efficient fans and pumps, as well as by not running the circulation pump when there is no heating demand, i.e., during the summer. In the study, it was also noted that there are large standby power losses from the hot-water boiler; this should be remedied by improved isolation. However, it should be noted that exhaust air heat pumps normally do not perform as well as, for instance, ground-source heat pumps (Nowacki 2007).

One important factor in order to obtain good performance of an exhaust air heat pump is that the exhaust air flow is large enough. In this study, about half of the heat pumps where this was measured had too low flow values. This may be due to incorrect or omitted final adjustment, alternatively to the gradual blocking of filters and ducts, with time. This problem is accentuated by the fact that most owners do not perform regular maintenance; the need for this should be emphasised by the installers.

The exhaust air flow has a large influence on the performance of an exhaust air heat pump, because too low values will lead to poor heat transfer. Also, inferior ventilation may result in adverse thermal environment and air quality, for both houses and people. However, there needs to be a balance, since excessive ventilation is a waste of energy, both due to the energy used by the fans and to the energy lost in the exhaust air.

Using the simulation program, it is possible to make “what if” comparisons of energy use. Here we have highlighted the improvements that will result from applying Best Available Technology (BAT) regarding heat pumps (inverter-controlled compressor), passive house technology, and low-energy household appliances. It comes as no surprise that the use of BAT results in higher SPF and ECF values, and a lower total energy consumption. In this context, it should be noted that although this study was performed a few years ago, the individual houses and heat pumps still remain, to a large extent.

For some time, there have been requirements regarding heat recovery of exhaust air, in all newly produced single-family dwellings in Sweden. More recently, maximum energy requirements for houses have come into force (Boverket 2008, Boverket 2009). Thus, for houses in the region of the study, a maximum energy consumption for heating, DHW and ventilation of 55 kWh/(m²*year) is allowed if the house is heated by electric power (including heat pumps); for houses not heated by electric power (instead heated by biofuels or district heating), the maximum allowed energy consumption is 110 kWh/(m²*year). Calculations with the simulation program show that the requirement for electrically heated houses cannot be satisfied with the old type of exhaust air HP's (such as those of the house-owners in this study). However, it is indeed satisfied by the new generation of exhaust air heat pumps, for a low energy building shell, or for a normal building shell in the warmer parts of the region.

Since manufacturers of exhaust air HP's are likely to want to expand the market beyond that of low energy houses and/or favorable climates, this new legislation can be expected to exert pressure on the manufacturers that will lead to product improvement. Also, there will be a pressure from customers in

the retrofit sector of the heat pump market, and legislation is underway also for this sector. However, in order for the construction company or house-owner to be able to make an informed decision regarding what heating system to purchase, they will need reliable impartial data. Data both from laboratory tests and from field studies are necessary to have access to, one of them cannot replace the other. Those data can only be produced by well-equipped, experienced organisations, such as applied research institutes.

5. CONCLUSIONS

It is clear that a systematic study of the type described here, carried out in three distinct steps, may provide significant and interesting information, at different levels, and aimed at different actors. In general, the home owners are satisfied with their systems. However, in this study various problems are highlighted, and which actor(s) that should address the problem is suggested. Examples stated are noise problems (house owner or contractor should choose a suitable location of the heat pump), low SPF values (manufacturers should choose efficient components, and use good isolation, especially of the hot water boiler), and low exhaust air flow (installers should indicate need of maintenance, such as periodic filter change, to owners). Also, it is generally clear that it would be desirable to introduce incentives to have installers perform routine follow-ups with home-owners.

A useful tool is the simulation computer program. Using this, it was possible to quantify the improvements in SPF, Energy Coverage Factor, and general energy consumption attained by using BAT (inverter-controlled heat pumps, passive house technology, and low-energy household appliances) instead of existing technology.

For a number of years, Swedish legislation has, in reality, forced construction companies to install heat recovery of exhaust air in all newly produced single-family dwellings in Sweden. Recent legislation for new construction can be satisfied by the new generation of exhaust air heat pumps for low energy building shells, or for standard building shells in the more favorable climates within a given region. Provided that the market-driven interest of home-owners can be reflected in the choice of retrofit heat-recovery system, this, together with the new legislation, may create opportunities for product improvement of exhaust air heat pumps. However, this will only take place if there are reliable, impartial test data available of the heat pumps on the market.

6. NOMENCLATURE

<i>BAT</i>	Best Available Technology	
<i>DHW</i>	Domestic Hot Water	
<i>ECF</i>	Energy Coverage Factor	(-)
<i>SPF_{hs}</i>	Seasonal Performance Factor	(-)
<i>Q_{1,dhw}</i>	Domestic hot water energy supply	(MWh/year)
<i>Q_{1,hps}</i>	Thermal energy supplied to the space heating distribution system by the heat pump system	(MWh/year)
<i>Q_{1,hs}</i>	Thermal energy supplied by the heating system to the space heating distribution system.	(MWh/year)
<i>Q_{1,rad}</i>	Thermal energy supplied to the radiator system	(MWh/year)
<i>Q_{1,sh}</i>	Thermal energy supplied by the supplementary heater	(MWh/year)

W_{hps}	Electrical energy input to the heat pump system	(MWh/year)
W_{hs}	Electrical energy input to the heating system	(MWh/year)
W_{sh}	Electrical energy input to the supplementary heating system	(MWh/year)

ACKNOWLEDGEMENTS

The support for this project from the Swedish Energy Agency (*Energimyndigheten*), Diary No. 530-03-8265, is gratefully acknowledged.

REFERENCES

Boverket (2008), Boverkets författningssamling, BBR 16, BFS 2008:20 (*Boverket*; in Swedish), www.boverket.se

Boverket (2009), Regelsamling för byggande, BBR 2008. Supplement februari 2009, 9 Energihushållning (*Boverket*; in Swedish), www.boverket.se

EHPA (2010), *Outlook 2009 – European Heat Pump Statistics*, can be downloaded from <http://www.ehpa.org/>

Levin, P., Blomsterberg, Å., Wahlström, Å., Gräslund, J. (2007), *Indata för energiberäkningar i kontor och småhus*, report to the National Board of Housing, Building and Planning (*Boverket*; in Swedish), www.boverket.se

Nowacki, J.-E. (2007), *Heat pumps in energy statistics – Suggestions*, report to the Swedish Energy Agency (*Energimyndigheten*), www.energimyndigheten.se

Stenlund, M. (2004), *Enkät- och fältundersökning av frånluftsvärmepumpar*, report to the Swedish Energy Agency (*Energimyndigheten*; in Swedish), P3 04392-1, www.energimyndigheten.se

Stenlund, M. (2005), *Fältmätning på fem frånluftsvärmepumpar*, report to the Swedish Energy Agency (*Energimyndigheten*; in Swedish), P3 04392-2, www.energimyndigheten.se

SVEP (2010), Martin Forsén, personal communication, www.svep.se