AIR TO AIR HEAT PUMPS RESULT FROM A FIELD STUDY IN SWEDEN

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Abstract: The situation on the Swedish market for air to air heat pumps is characterized by high and increasing energy prices, increasing sales volumes and relatively low initial costs (purchase and installation). Air to air heat pumps are sold worldwide mainly as air conditioners. Those heat pumps have maintained a growing interest especially in Sweden and Norway for retrofitting single family houses without hydronic heating systems. The most common type sold in Sweden is air to air system of split type with one indoor unit and one outdoor unit. The main aim for the end-user is to decrease the annual cost for heating the building. To maintain the public acceptance for the technology and to ensure a continuous positive development of the market, efficient and reliable systems are of great importance. Additionally, negative consequences such as noise issues need to be minimized. This paper describes the first results from an ongoing field study on air to air heat pumps in Sweden.

Key Words: ***air to air heat pumps, field study, efficiency, reliability, noise***

1 INTRODUCTION

Sweden has a long tradition of utilizing heat pumping technology for heating purposes and the acceptance and interest for the technology is high in relation to most other countries as illustrated in Figure 1, showing the sales figures for residential heat pumps in Sweden.

The total number of heat pumps sold up to the year of 2007 is about 670 116 units and the total number of air to air heat pumps is 197 543 [Forsén M., 2008]. The heat pump business in Sweden has had its share of ups and downs, though, due to various reasons but during the period 1995 – 2006 a steady increase of sales is clearly visible as shown in Figure 1. The stagnation in sales of primarily Ground Source Heat Pumps (GSHP) during 2007 is a result of the fact that the most important market, i.e. houses heated by oil- or electric-boilers, is beginning to decline due to most of houses being retrofitted with heat pumps [The Swedish

Heat Pump Association, 2008]. The same is true for the sales of air to air heat pumps, although those numbers are more unreliable since not all units sold are included in the statistics. Exhaust air heat pumps are not affected by this since the main market for that type of heat pump is new single family houses.

The market in Sweden is due to the high degree of utilization regarded as a mature market and one of the explanations for the high interest for air to air heat pumps is increasing energy prices and the fact that heat pumping technology is a well known technology in Sweden. The air to air heat pumps are products imported mainly from Asia. The main reason for the growing market is the low initial cost (cost of heat pump and installation) and the large stock of buildings without hydronic heating systems and often also without chimney. Most of these houses were built during the period 1960 to 1990, [SCB, 2007]. The other alternative for the house owner would be to install both a central heating system and a ground source heat pump, air to water heat pump, pellet boiler or connect the house to district heating, if available. The main part of those buildings is, however, located outside the area for the existing district heating networks.

A lack in objective knowledge and information about how well the systems operate, how they are installed, their efficiency etc. in real installations was present. Due to this SP was requested by the Swedish Energy Agency to perform a field study focusing on air to air heat pumps in the same way as earlier studies performed on first ground source heat pumps and later also on exhaust air heat pumps. The study was initiated in the year of 2007 and will end during the spring 2009.

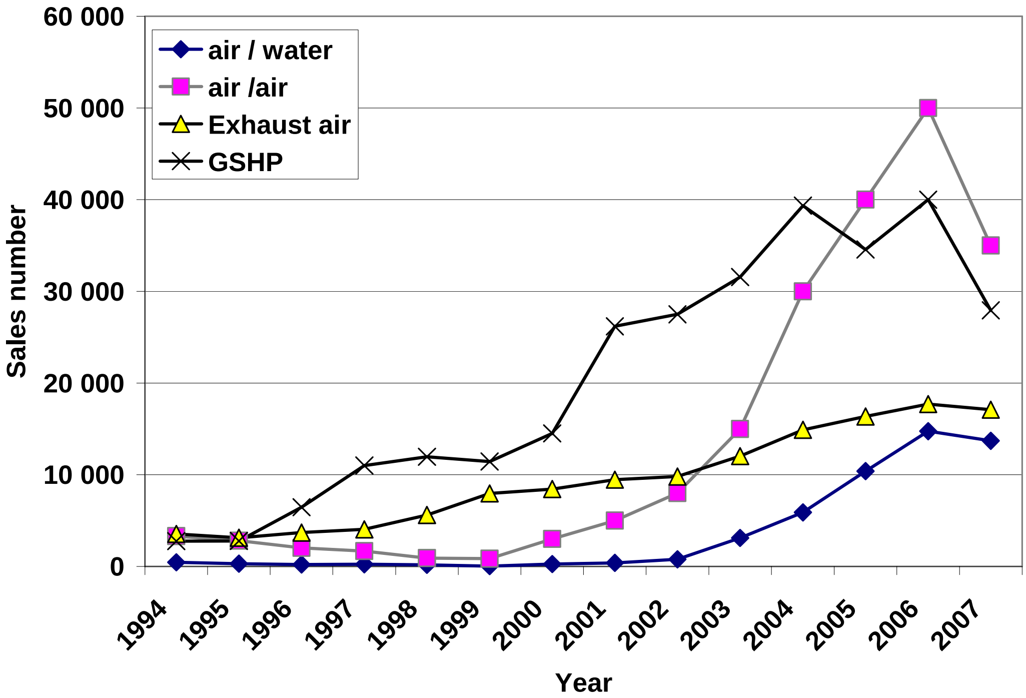

Figure 1: Sales statistics for Heat Pump systems in Sweden. (The Swedish Heat Pump Association, 2008).

2 AIM

The main objectives of this study were to evaluate the efficiency of the air to air heat pumps, reliability, noise level and to record the experiences of the end users. The study focused on single family houses, reflecting the current market in Sweden, and the vast majority were retrofits where the heat pump was installed as a complement to the existing heating system in the house.

3 METHODOLOGY

The field study includes following three steps:

1. Enquiry
2. Field study including inspection of the installation, interview with the end-user, measurement of noise and control of function of the air to air heat pump
3. Measurement of efficiency and thermal comfort. Efficiency is measured for calculation of seasonal performance factor and annual savings

Questionnaires were sent to 482 domestic end users from north to south of Sweden who had installed air to air heat pumps predominantly during the period 2000-2006. The questionnaires dealt with questions such as system design, experience from operation and the purchasing process.

From the questionnaire, 25 systems were inspected more in detail by means of interviews, ocular inspections and measurements. The main objectives were to record the experiences of the end-users, to identify problems in order to enable future improvements of air to air heat pumps and to gather information about present systems. The field study of 25 air to air heat pumps also included a test of the function of the system and measurements of noise. In addition the aim was also to compare the result from the interview with the end-users with the result from the first step in the study (the enquiry).

The third phase in the study includes measurements during 12 months on five selected air to air heat pumps of different designs, age and size. This part of the study is not finalized yet and will be reported later. The main objective of the measurements is to determine the seasonal performance factor and the annual savings achieved by installing an air to air heat pump.

3.1 Noise Measurements

The noise measurements indoors were conducted according to the Swedish standard SS 025263, both in the room where the indoor unit was mounted and also in a nearby bedroom when possible. For the outdoor unit the sound pressure levels were measured at a distance of 1 m from the centre in front of the unit and at 1.2 m height above ground. In cases where the outdoor unit was placed high above ground level the measurements were made in front of the centre. The measurements were made at close distance in order to have better signal to noise ratio to background noise and to have as little influence as possible of environmental conditions such as wind and ground attenuation.

In the first set of measurements the operating conditions of the heat pump were not changed, but set as the owner's preferences. This means that the operating conditions differ between the heat pumps included in the investigation not only depending on outdoor temperature and indoor temperature but also depending on selected fan speed etc. The measurements should therefore be seen as a survey of sound pressure levels that normally are found in practice. Indoor measurements were performed in the room where the heat pump was mounted and in a nearby bedroom, when possible. In total 18 different end users were included in the survey measurements, and in 8 of them bedroom measurements were also performed.

In the second set of measurements the running conditions were set by the operator in order to have as comparable and repeatable results as possible between various installations. The heat pump was set to operate at maximum capacity and highest fan speed in order to reproduce the operating conditions normally used in laboratory measurements, as far as possible. Additionally, this setting gives the highest sound pressure levels with largest margin to background noise. The indoor measurements were in this case made with doors and windows closed. In total 25 end users were included in the maximum power measurements.

4 SWEDISH NOISE REGULATION

In Sweden the building regulations refer to a sound classification system for setting noise requirements [SS 25267, 2004]. The Swedish sound classification system set requirements for the indoor as well as the outdoor sound environment of residential buildings. The indoor requirements are set for sound insulation, traffic noise, reverberation time and service equipment noise. The classification system divides the requirements into four classes; A to D, where class A corresponds to the highest acoustic requirements and class D to the lowest demands. Class C should correspond to the minimum requirements for new buildings and class D should only be used when class C can't be fulfilled for example during careful renovation of old houses. The noise from heat pumps has to fulfill the requirements for building service equipment noise, which are summarized in table 1.

Table 1: Requirements on building service equipment noise in residential buildings

SS 25267, edition 3, 2004	**L_{pAeq} (dB)**				**L_{pAFmax} (dB)**				**L_{pCeq} (dB)**			
	A	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
In spaces for sleep and recreation and daily living.	22	26	30	30	27	31	35	35	42	46	50	-
In other spaces.	31	35	35	35	36	40	40	40	-	-	-	-

L_{pAeq} is the equivalent A-weighted sound pressure, L_{pAFmax} is the A-weighted maximum level measured with time weighting fast (F) and L_{pCeq} is the C-weighted equivalent sound pressure level. A-weighting is used to take into account the sensitivity of the ear at different frequencies and underestimate the levels at low frequencies. The C-weighting is used in practice to take into account low frequency noise.

For outdoor noise the Swedish Environmental Protection Agency has guidelines for external industry noise [Swedish Environmental Agency, 1978], which is the most applicable noise criterion for heat pump outdoor units. The limiting case regards noise levels during night in residential areas and is L_{pA} = 40 dB at the border to the neighbor. This limit agrees well with previous suggested Swedish noise limits of external noise from heat pumps see [Bodlund, 1986]

5 PARTICIPANTS IN THE STUDY

The send-out (I am not sure what you mean by send-out – are you referring to a questionnaire which was sent out to users?)included systems spread across Sweden, from the far north to the most southern parts. The geographical location is important since the climatic- and geological prerequisites vary substantially across Sweden. The annual outdoor mean temperature, as an example, varies between 1-8 °C [Alexandersson, 2002] between different geographical areas which naturally may influence the operation, effectiveness of the air to air heat pump and the annual energy savings. Also other prerequisites that might have been influenced by the choice of the participants were carefully evaluated in order to gain an overview perspective of the viability of the technology reflecting the current situation. The installation can influence both the efficiency and the sound level from the air to air heat pump. The design of the house and the location of the indoor unit are important factors influencing the thermal comfort, the annual savings and the noise level. The size (capacity) of the heat pump in relation to the heating demand is another factor influencing the annual energy savings and seasonal performance factor.

About 254 end-users, corresponding to 53 % of the send-out, decided to participate in the enquiry.

6 RESULT

6.1 Enquiry and field study – Experience of the end-users

The study shows that the vast majority (93 %) of the participants are satisfied with their heat pump, with respect to whether their expectations and motives for the purchase were considered to have been fulfilled. This may be viewed in figure 2 bellow presenting the results to the question whether or not the participants on the whole would say that they are satisfied with their heat pump.

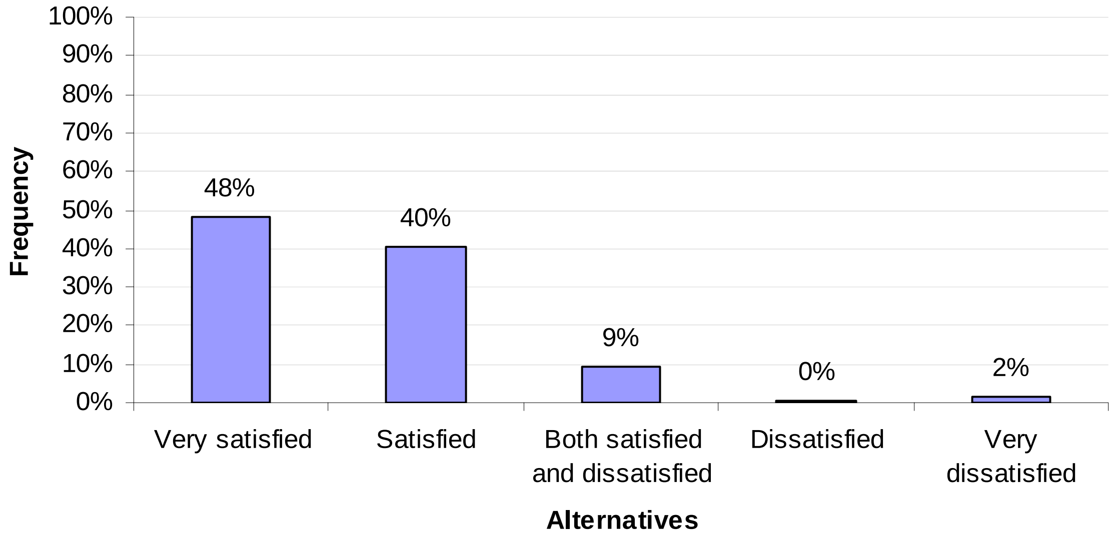

Figure 2: Results for the question whether or not the participants in the study was satisfied with their heat pumps.

Amongst the 7 % who were more or less dissatisfied the most frequently occurring motivations were that the energy savings was suspected to be less than anticipated by the buyer or than what was promised by the installer/retailer; disturbing noise from the heat pump; poor thermal comfort and/or that the final cost of the heat pump ended up to be higher than expected.

Due to the nature of air to air heat pumps, both regarding the technical construction and operation as well as the fact that the heat pumps usually are installed in, or near by, frequently occupied rooms, disturbing noise emissions can be expected to be a quite commonly occurring problem. Although the study showed that only about 40 % of the participants were not disturbed at all by the noise emissions from the indoor or outdoor unit only about 7 % claimed to be disturbed or very disturbed. During interviews however, when asked in this matter, a relatively high percentage said that they could hear the heat pump and that they had been disturbed initially but now had grown custom to the noise. In addition, some of the interviewed owners had chosen settings of the heat pump's control system, primarily the speed of the indoor unit fan, in order to reduce the nose emission.

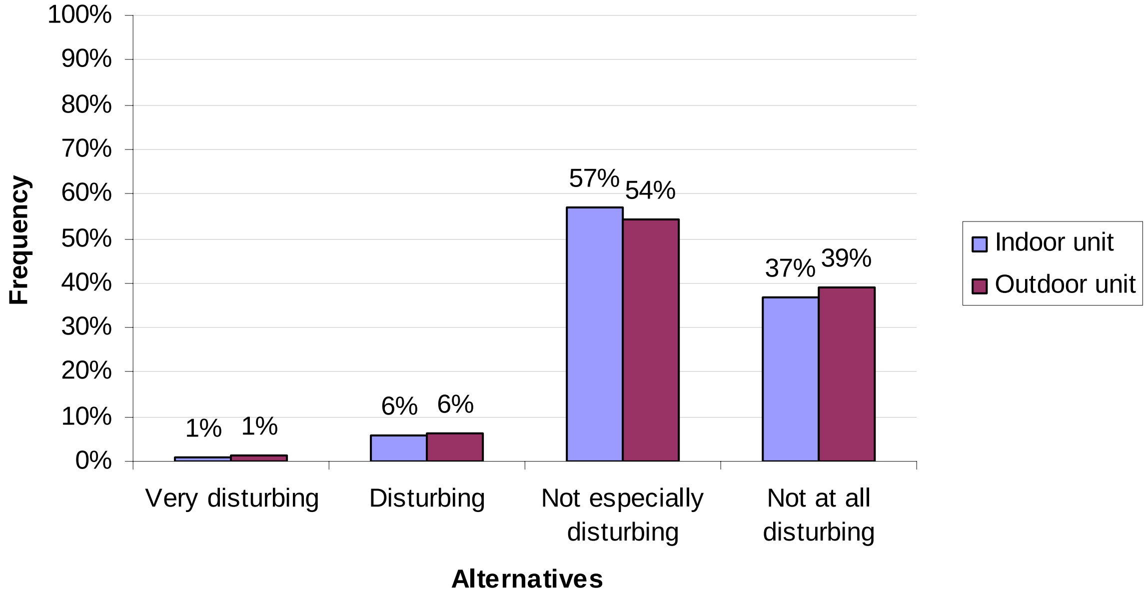

Figure 3: Results to the questions "how would You describe the noise emission emanating from the indoor unit of your heat pump" and "how would You describe the noise emission emanating from the outdoor unit of your heat pump" as related to the total number of answers to the questions.

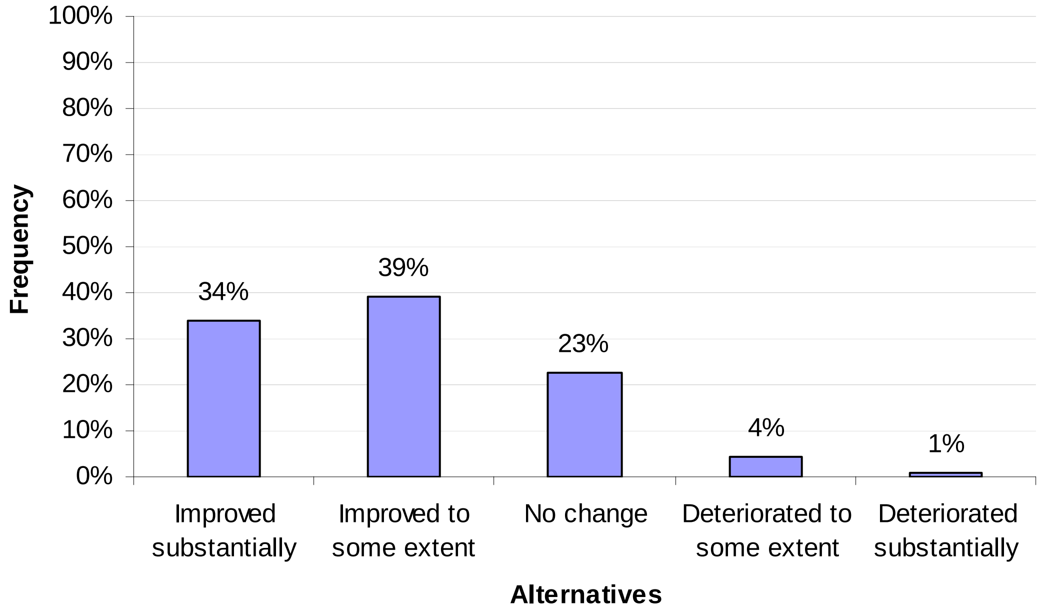

Figure 4: Results to the questions "how would You describe the influence of the thermal comfort since the heat pump was installed" as related to the total number of answers to the question.

Another factor that might be influenced by the installation of air to air heat pumps is the thermal comfort. This is primarily due to that the produced heat commonly is distributed from a point source rather than from a number of heat sources distributed around the house, as is the case with "normal", hydronic heating systems. In order to avoid temperature gradients between rooms a sufficient air circulation in the house is required and often also a correct positioning of the indoor unit. The design of the house is another important factor influencing how the heat is distributed in the building. A house with on open design is preferable. In addition, it is a risk that the control of an existing heating system might be rendered inefficient if the possibility to control the temperature in individual rooms is restricted. This is however, generally not a problem in Sweden since eight out of ten heating systems in combination with air to air heat pumps are individually controlled direct-electrical radiators or similar. The study also shows that the risk of getting a serious worsening of the thermal comfort is low. Only 5 % of the participants in the study have noticed a decline in comfort while more than 70 % claim that the thermal comfort has been improved since the heat pump was installed, as can be viewed in figure 4.

The effect on the indoor climate and the thermal comfort is, according to the enquiry, usually a more evenly distributed temperature in the house (47 %); a more unevenly distributed temperature in the house (38 %) and a higher indoor temperature (29 %). Another influence, revealed during interviews of 25 heat pump owners, seems to be that the indoor air is experienced as being "better/cleaner" or more "comfortable" since the heat pump was installed and the old heating system was used less.

According to figures of energy usage before and after the installation of the heat pump, as supplied by the participants in the enquiry, the relative energy savings spanned between 5 and 52 % with an average of 24 %. Only those who could be expected to have roughly the same energy demand today in relation to before the heat pump was installed, i.e. those who had not done any refurbishing to the house and appliances etc. were included in the calculations. Note however, that the supplied figures have not been corrected due to annual variations of the outdoor climate.

The study shows that malfunctions, leading to replacements of the heat pump, are a relatively frequently occurring problem in Sweden. More than 8 % of the participants in the study reported this. A common failure is breakdown of valves, fan motors and fan bearings in the outdoor unit. Drainage of condensate water from the outdoor unit and build-up of ice on the outdoor unit is also relatively common problems according to the study; about 11 % each of the participants. Of 25 inspected installations only two had a proper drainage of condensate.

6.2 Noise indoors

The survey measurement results at normal operating conditions are shown in figure 5 for the indoor unit. In the room where the heat pump was mounted the sound pressure level was higher than the minimum requirements according to sound class C in 5 out of the 18 measured cases. The average indoor A-weighted sound pressure level in the room where the heat pump was mounted was 35 dB, with a standard deviation of 3.0 dB. In the nearby bedrooms, the average was 28 dB with a standard deviation of 3.3 dB and the sound pressure levels in these measurements were larger than the minimum requirements according to sound class C in 2 of the 8 available measurements.

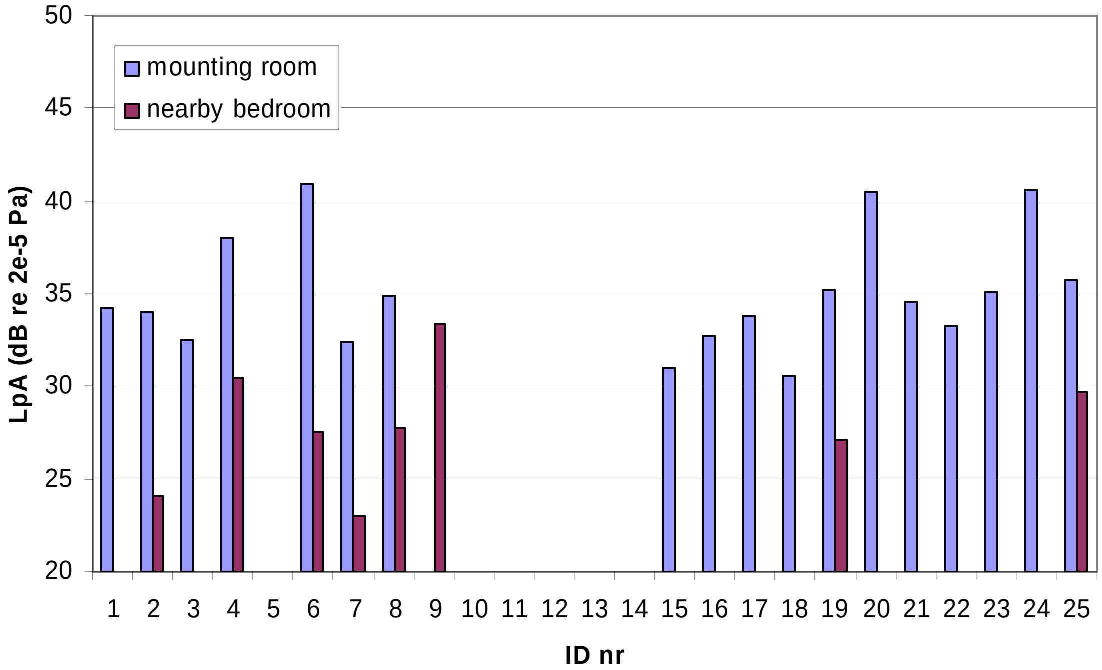

Figure 5: Measured A-weighted sound pressure levels in the mounting room and nearby bedroom under normal operating conditions

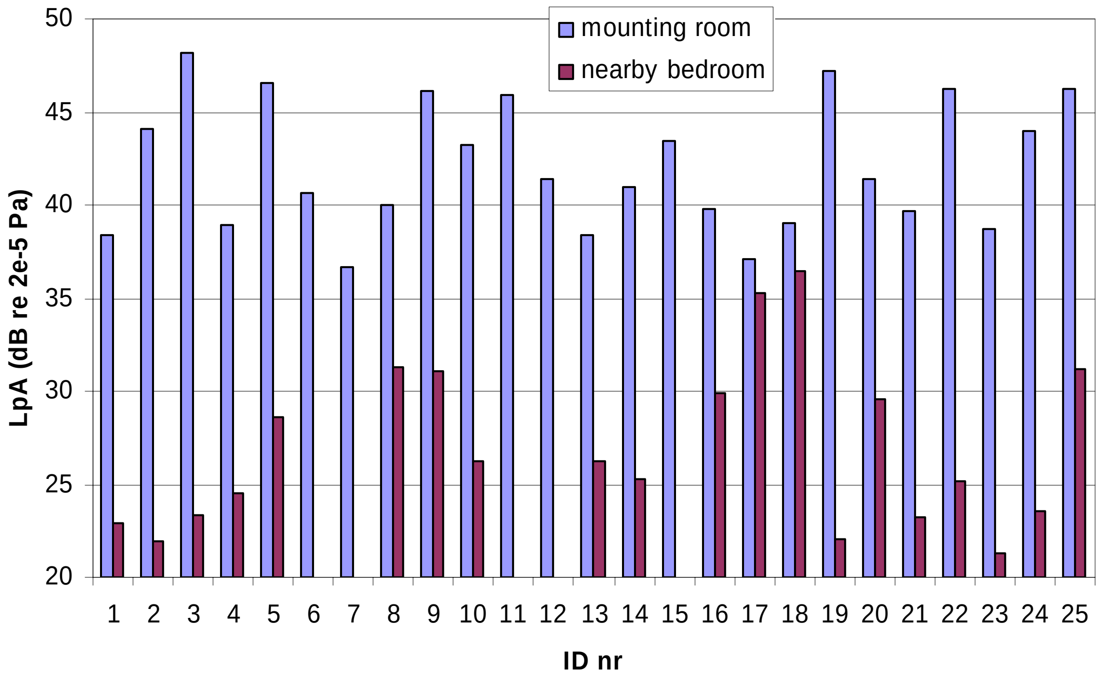

Figure 6: Measured A-weighted sound pressure levels in the mounting room and nearby bedroom under maximum capacity conditions

At maximum capacity the measured A-weighted sound pressure levels in the room where the heat pump was mounted were higher than the requirements according to sound class C in all

25 measured cases. The average level was 42 dB with a standard deviation of 3.4 dB. In the nearby bedrooms the sound pressure level was higher than the requirements in 5 out of 23 available cases. The measurements in the bedrooms were conducted with doors and windows to the bedroom closed. The average was 26 dB with standard deviation 5.2 dB. The results are shown in figure 6.

The difference between the average sound pressure levels at normal operating conditions and at maximum capacity was 7 dB in the room where the heat pump was mounted. In the nearby bedrooms the difference between the averages in these measurements was 2 dB with highest levels under normal operating conditions. The reason for the higher levels during normal conditions is that the measurements were made with doors open in that case, while the measurements under maximum capacity conditions were performed with doors closed. Note that the spreading in the results is large in the measurements.

6.3 Noise outdoors

In the survey measurements of the outdoor unit under normal operating conditions the average A-weighted sound pressure level was 52 dB and standard deviation 4.8 dB. The measurement results are given in figure 7.

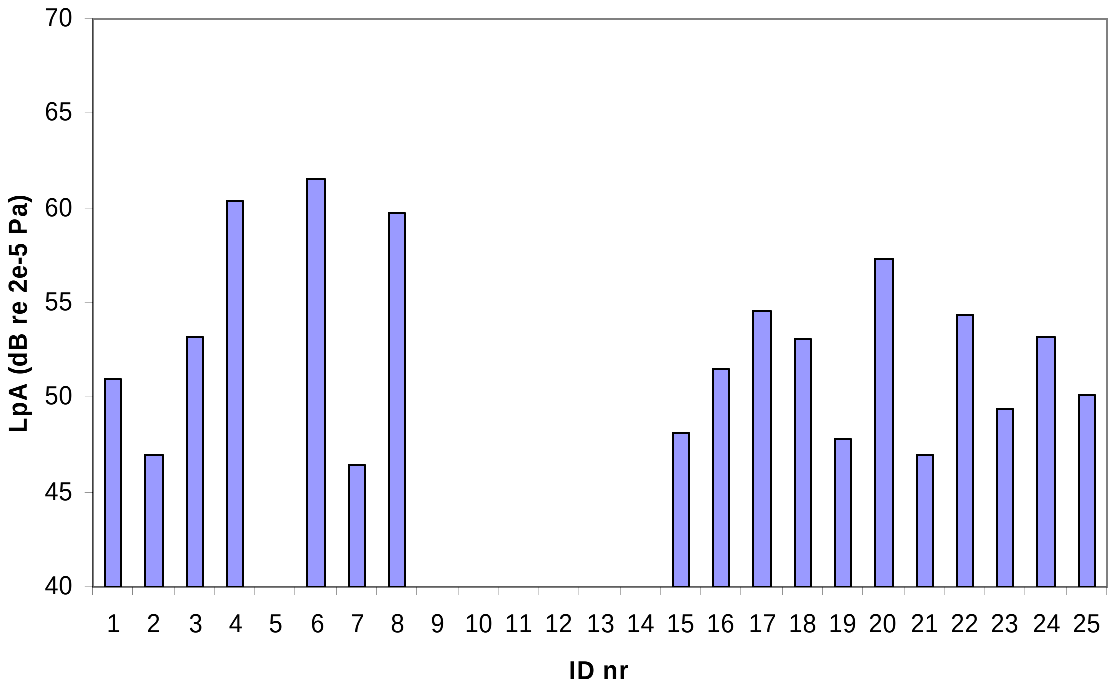

Figure 7: Measured A-weighted sound pressure levels 1 m from the outdoor unit under normal operating conditions

The measurement results for maximum capacity conditions are shown in figure 8. In that case the average A-weighted sound pressure level was 56 dB with standard deviation 3.2 dB. The difference in average sound pressure levels between normal and maximum running conditions was 4 dB for the outdoor unit.

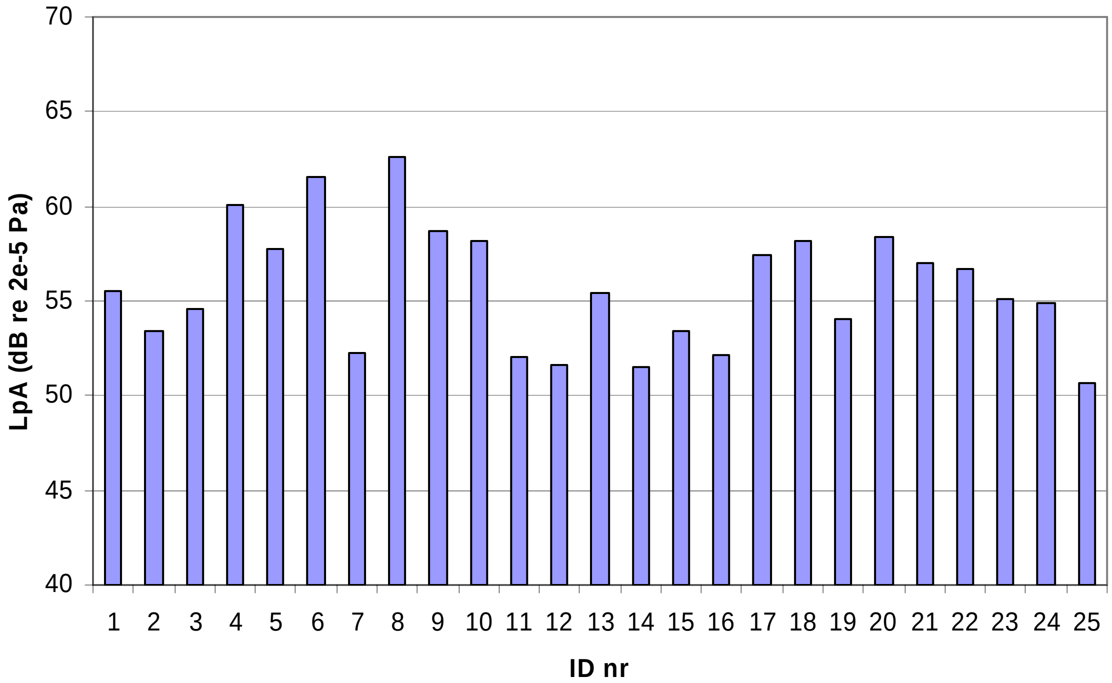

Figure 8: Measured A-weighted sound pressure levels 1 m from the outdoor unit under maximum capacity conditions.

6.4 Discussion of noise measurements

A thorough analysis of the causes of noise has not been done at this phase of the project, but the measurement results are presented in this paper. The results of the measurements show that the noise levels in many of the measured cases are higher than the minimum requirements according to sound class C. At the same time, the spreading in the measurements is large, and the service equipment noise requirements are fulfilled in most of the bedrooms. The spreading in the measured results is lower when the operating condition is set to maximum power both for the indoor unit as well as for the outdoor unit, which is in accordance with expectance. Under maximum capacity conditions the noise in the mounting room from the heat pumps was generally higher than the minimum noise requirements. However, the survey measurements show that the noise generated under normal operating conditions is considerable lower. The indoor noise might also depend on the positioning of the outdoor unit. In cases where it is placed close to a bedroom window the noise level indoors might be determined by the outdoor unit, especially if the windows are opened, which is rather common in Sweden during night. Additionally, outdoor unit noise close to the façade can be a problem at a nearby terrace or balcony. The noise from the outdoor unit should not disturb neighbors, which means that the positioning of the outdoor unit should be made with care. There are currently no specific noise limits for the outdoor unit noise. However, based on the noise requirements on industrial noise a value of 40 dB A-weighted sound pressure level at the border to the neighbor can be used. In [Bodlund, 1986] a model of sound propagation from heat pump outdoor units was presented. Based on that model the sound pressure levels as function of distance can be estimated. Calculated A-weighted sound pressure levels at 4.5 m distance from the outdoor units are presented in figure 9. The distance 4.5 m is used as this is normally the minimum distance between the façade and the border to the neighbor. The results show that 5 out of the 25 investigated heat pumps meet this requirement at maximum power, but 9 out of 18 investigated cases meet the requirements under normal running conditions. Based on this model the maximum A-weighted sound power level of the outdoor unit is 61 dB re 1pW to meet the requirements.

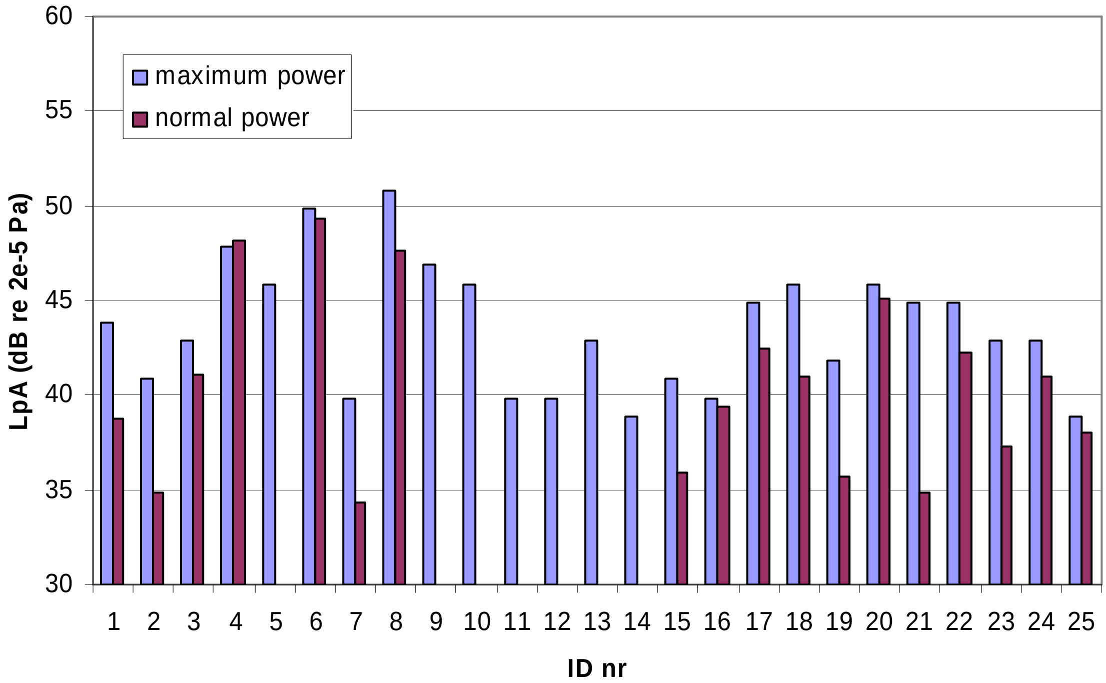

Figure 9: Estimated A-weighted sound pressure levels 4.5 m from the outdoor unit.

7 CONCLUSIONS

The study showed that a great majority of the end-users were satisfied with their heat pumps and with the service and work performed by the installers. A relatively low number of serious malfunctions (such as compressor failures) occur. However, also relatively small failures (such as damaged fan bearings) often leads to the entire heat pump being replaced. .

Nearly half of the end-users (48 %) in the study reported an improved thermal comfort in the house after installation of the air to air heat pump.

The noise measurements showed that 72 % (13 out of 18) of the measured cases fulfil the minimum requirements on indoor noise levels in the room where it was mounted under normal operating conditions. However, for maximum capacity 100 % of the measured cases have noise levels above the minimum requirements. In nearby bedrooms, 78 % of the measured cases (18 out of 23) meet the minimum requirements under maximum capacity.

For the outdoor unit it is estimated that 20 % (5 out of 25) of the investigated cases could meet the requirements under maximum capacity and 50 % (9 out of 18) of the measured cases meet the requirements under normal operating conditions. Note that these are estimated figures based on calculations. No measurements were conducted in this investigation to verify that the outdoor units fulfil the requirements.

In the future, the measurement results from this investigation will be used to compare with existing laboratory measurements to study the influence of the installation on the noise generation. Since laboratory measurements of noise emission are for sound power level, the declared values will be converted into estimated sound pressure levels in the specific rooms in the field measurements. Additionally, comparisons for the outdoor unit will be done.

Although noise from the indoor and/or outdoor unit to some small extent is disturbing for a majority of the participants only 7 % claims the noise to be disturbing or very disturbing. Often the participants grow custom to the noise after some time of operation.

A previously conducted evaluation [Karlsson et al., 2006] showed that air-to-air heat pumps have become more efficient at same time as prices have fallen, reducing the expected pay-back with about 30 %. At the same time, however, the spread in efficiency increased, i.e. the deviation between the worst and the best model is greater in 2005 compared to 1991 which indicates further need of improvement. The same study shows the importance of using the Seasonal Performance Factor when comparing products on the market since a heat pump with peak performance at a specific operating condition does not necessarily have the best performance on an annual basis. The results regarding energy savings and seasonal performance factor resulting from the final part of the presented study will be reported during the spring of 2009.

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