NOISE LEVEL IN RELATION TO ENERGY PERFORMANCE OF AIR-TO-AIR HEAT PUMPS

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Abstract: With increased use of air source heat pumps, a possible barrier for further market growth and customer acceptance is their noise level. The disturbance is both an issue for the owner of the heat pump and the neighbors since both the indoor and the outdoor units radiate sound. The purpose of this study is to create an understanding of the noise generation of air-to-air heat pumps and relate this to their energy performance. This knowledge is then to be used in continued work when describing the total disturbance of a heat pump.

Two heat pumps, both of inverter type and with different noise performance were selected for measurements. Energy performance, in the form of Coefficient of Performance (COP), was evaluated at different operating conditions. Measurements of the sound power level were performed on both the outdoor and the indoor units. Results show that the sound level from the indoor units is independent of the outdoor conditions. The noise from the outdoor units varies with different climates and the variation is particularly large at part load conditions.

Key Words: heat pump, air-to-air, noise level, energy performance

1 INTRODUCTION

The introductory section presents the motivation for this study in a short background passage. This is followed by a section describing the aim and scope.

1.1 Background

New directives that aim for a reduced energy use, an increased share of renewables in the energy mix and a reduced dependency on fossil based energy have been, and will be, put in place on the European market. One of these directives is the Renewable Energy Source Directive which will define the heat pump technology as renewable at certain conditions. The use of heat pumps will most probably continue of increase, and a possible barrier for further market growth and acceptance is their noise level.

Today, noise from heat pumps is declared by the sound power level measured at a single operating condition. But the variation in sound level of an inverter-type heat pump is high enough to conclude that a single measurement based on steady state operation is not representative of real operation, (Bessac 2004). This is true also for energy performance

which should be evaluated with an Seasonal Performance Factor (SPF) rather than a COP-value at one operation point (Karlsson et al. 2006). A new methodology for rating the seasonal noise performance of heat pumps should be developed. But to do so, one must understand how the noise is related to the energy performance, since it is the energy performance that decides in which state the heat pump is operating.

1.2 Aim and scope

The purpose of this study is to build up a knowledge base that can be used when developing a seasonal performance indicator for the noise level of an air source heat pump. We wanted to investigate the noise generation of air-to-air heat pumps and to relate this to their energy performance. Two heat pumps with different noise performance were selected to compare the sound power levels at different operating conditions. Measurements were performed on both outdoor and indoor units to correlate the noise performance to entities such as outdoor temperature and part load operation.

2 METHODOLOGY

This section shortly describes the methodology of this study. The measurements standards, the measurement procedure as well as an estimation of the measurement uncertainties are presented.

2.1 Set-up

Two air-to-air heat pumps with similar heating capacity (approximately 6 kW at nominal condition) were used in the measurements. One of them has a relatively good noise performance according to previous testing and manufacturer information. The other one was chosen thanks to its significantly worse noise performance.

The energy performance was evaluated according to standard En 14511 - Calorimeter method. The indoor and outdoor units were installed in separate climate chambers where the temperature and relative humidity were kept within the prescribed permissible deviations.

The sound power levels were determined according to standard EN 12102:2008. The sound pressure level was measured in four microphone positions which were evenly spread out in the climate chamber. The sound pressure level was averaged from measurements of 30 seconds and later recalculated to sound power level (A-weighted). During this 30 second period the climate chambers were shut down to achieve as low background levels as possible. This caused minor temperature drifts, but the drifts were within the allowed deviations.

2.2 Operation conditions

Measurements were performed at varying temperatures and part loads. The operation conditions were chosen from EN 14511 (Full load - Standard and application rating conditions) and PrEN 14825 (Part load), plus a few additional conditions around 0°C. Table 1 presents the different test conditions. The part load ratio is defined as the percentage of the heat pump's maximum delivered capacity at that specific temperature. The noise measurements of the indoor units were performed with the highest fan speed as required by the standard.

Table 1. Test conditions.

	Full load								Part load							
Outdoor dry bulb temperature (°C)	-15	-7	-2[1]	0[1]	2	4[1]	7	12[1]	-7	-7	2	2	7	7	7	12
Outdoor wet bulb temperature (°C)	-	-8	-3	-1	1	3	6	11	-8	-8	1	1	6	6	6	11
Part load ratio (%)	100								88	61	54	37	70	35	24	18
Indoor temperature (°C)	20															

1) Not standard conditions

2.3 Uncertainties

Energy

The uncertainty of the measured thermal capacity of the heat pump is estimated to ±4%. The determining contribution to this value is the uncertainty of the temperature difference in the cooling coil in the indoor climate chamber. A larger temperature difference or more exact temperature sensors would therefore reduce the total uncertainty. COP is defined as the ratio between the delivered heat and the electricity power to the heat pump. The uncertainty level of the electricity power meter (±1%) is negligible in comparison, resulting in a total COP uncertainty of approximately ± 4%.

Noise

According to standard EN ISO 3740 the estimated upper values of the standard deviation of A-weighted values are 1.5 dB. Since all measurements in this investigation were made with the same set-up and the same instrumentation, the relative uncertainty from one measurement to another are probably much smaller than 1.5 dB. Due to relatively high background levels, the difference between the measured value and the background level did not exceed 6 dB (which is the minimum level according to EN ISO 3740) for the lowest frequency bands. But since the lowest frequency bands only affect the A-weighted value marginally, the influence is considered negligible.

3 RESULTS

The first part of the third section describes the energy performance of the heat pumps. We can see how the COP varies with temperature and load ratio. The second part presents the sound power levels at different operating conditions.

3.1 Energy performance

The energy performance of the heat pumps expressed in COP and thermal capacity are presented below. Figure 1 shows the COP values at full load at different operation temperatures. Heat pump B has generally lower values but is more even throughout the temperature range. Possible reasons for this may be under-dimensioned heat exchangers, too low fan speeds and/or the specific control of the overheat in the evaporator. Figure 2 presents the delivered power at the different operation temperatures. One can see that the heat pumps have similar capacity characteristics with a flattened curve at temperatures around 0°C where the frosting conditions have a larger effect on the performance.

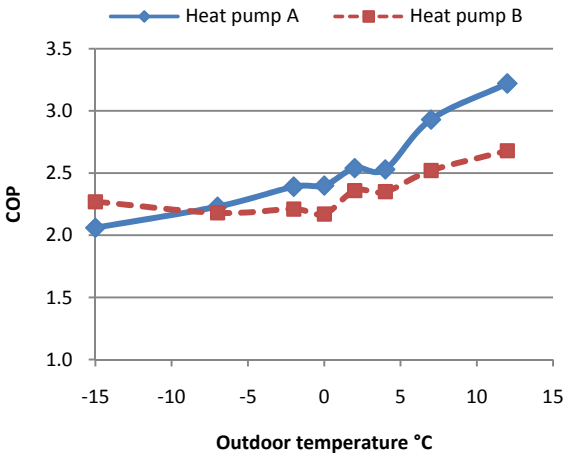


Figure 1. COP at different temperatures.

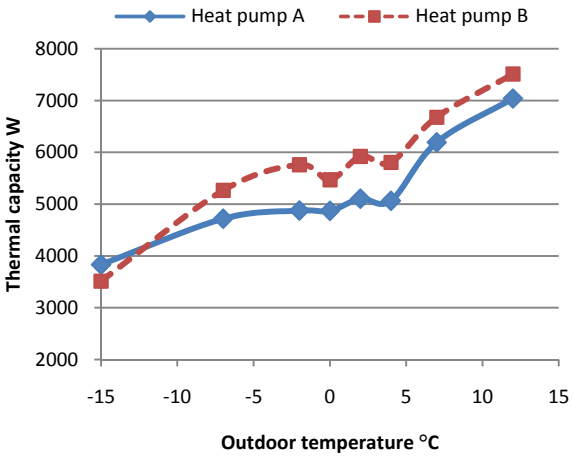


Figure 2. Thermal capacity at different temperatures.

At part loads the performance of the heat pumps increases quite considerable, COP is nearly doubled for the lowest part loads. Figure 3 shows that the part load dependence (curve shape, inclination) for the two heat pumps is rather similar except for the lowest part loads, <40%, where the COP of heat pump B is reduced. Here heat pump B must cycle on/off to reach the desired capacity and the cycling may be the reason for the reduced COP (Karlsson 2007). The performance reduction could probably be avoided with a compressor with a wider capacity range.

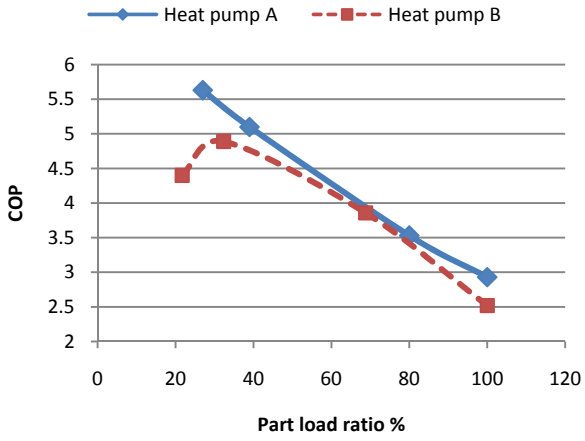


Figure 3. COP at part load.

3.2 Sound power level of the heat pump units

In the measurements in this study the heat pumps were operated with constant indoor fan speed (maximum level = A-1300 rpm, B – 1230 rpm) for all temperatures. The results give a clear picture that the noise level is independent of the operation conditions of the outdoor unit. Figure 4 presents the A-weighted sound power level of the indoor units when the outdoor temperature is varied and we see that the noise level is constant throughout the temperature range. Another thing worth noticing is the significant difference (~6 dB) between the two different heat pumps, even though the fan speed is similar. However, the air flow and speed of heat pump A is much larger at this fan speed, which may be one reason for the difference in sound power level.

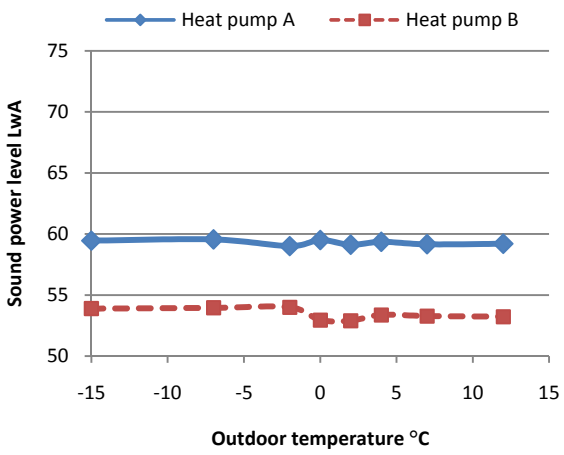


Figure 4. Indoor unit sound power level, at full capacity.

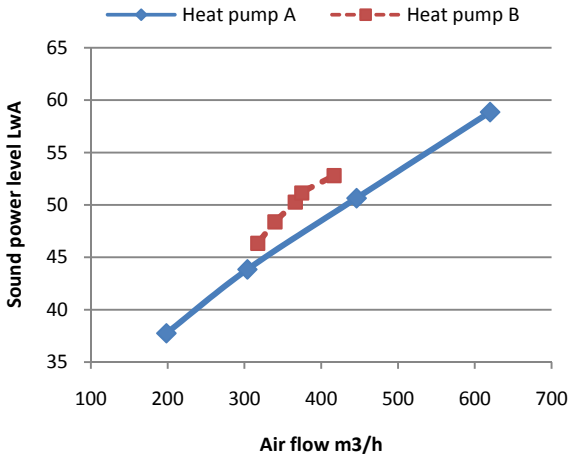


Figure 5. Sound power level of indoor unit vs air flow. Note that the scale is different from the other figures.

Contrary to temperature, air flow has significant effect on noise. Johansson et al., 2011 show that the fan speed of the indoor unit has a major influence of the noise level from the indoor unit. Figure 5 shows that heat pump A is less noisy for a certain air flow, and the range of available air flows is much greater than for heat pump B. The inclinations of the curves are rather similar though, meaning that the noise will increase at the same pace for an increase in airflow.

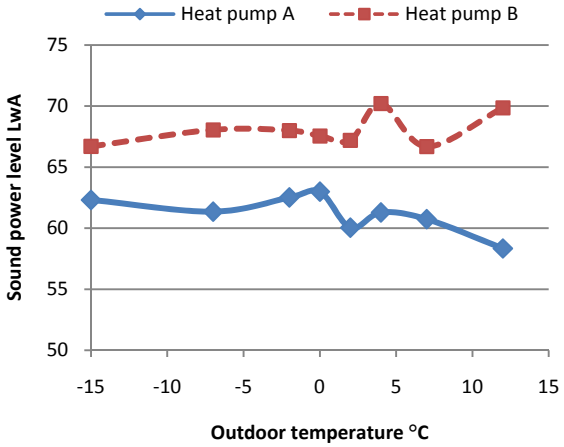


Figure 6. Outdoor unit sound power level, at full capacity.

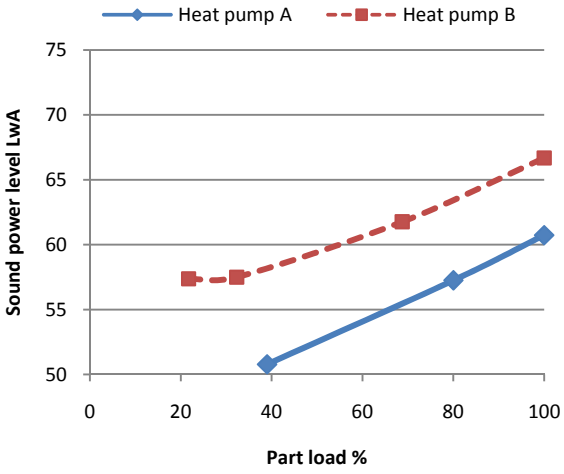


Figure 7. Sound power level of outdoor unit at part load.

The characteristics of the outdoor units are a bit different from the indoor units. Figure 6 presents the sound power level of the outdoor units for different outdoor temperatures. The noise level for the two heat pumps varies with temperature, but a strict correlation does not seem to exist. First, the variations in sound power level are relatively small and second, heat pump A shows a slight reduction of noise with increased temperature. Here, heat pump B radiates the highest sound power level (with a difference of 5-10 dB), but this heat pump also delivers approximately 500 W more than heat pump A. This might be the reason for some of the noise difference.

The measurements were performed without controlling the amount of frost on the heat exchanger of the outdoor unit. We suspect that the frost has an influence on the noise level since the air flow is altered with different amount of frost. We are planning to perform some sound power level measurements where the amount of frost is varied to investigate its influence. Before doing so we cannot draw any final conclusions from the measurements of the outdoor unit presented in this paper.

The influence of part load operation on the noise level of the outdoor unit is clearer. The sound level is up to 10 dB lower for part loads <50 %, compared to full load operation, as shown in Figure 7.

4 DISCUSSION

The results from the previously described measurements are discussed below. The discussion is divided into seven different parts; the noise levels of the indoor and outdoor units, dimensioning issues, noise measurements in laboratory environment and at frosting conditions, improved noise indicator and optimization of noise performance.

4.1 Noise levels of the indoor units

The noise levels from the indoor units, 53 dB and 59 dB respectively, are independent of the conditions of the outdoor units. The results show that the noise levels are constant no matter the outdoor temperature or what part load condition the heat pumps are operating at. Compared with former measurements conducted in 1990, no major improvements of the noise performance can be seen (Fahlén 1991). These measurements were conducted on air-to-air heat pumps with a thermal capacity of 1.6 – 3 kW and with sound power levels of the indoor units of 46 – 55 dB (at maximum fan speed). The difference in thermal capacity is most certainly a reason for the relatively high levels of the new heat pumps, but 20 years of development seem to have focused on other issues than noise performance.

The noise levels are dependent on the indoor fan speed (Johansson et al. 2011). Slightly simplified, minimization of the noise level is therefore a question about choosing a fan and a casing that is quiet and to optimize the control of the fan. It is important to operate the fan at the lowest possible speed without compromising the energy performance. At part load there may definitely be a potential for a lower fan speed. Knowing that the sound pressure level varies considerably with different fan speeds, sound rating with only the highest fan speed is not at all representative of the total noise performance of the heat pump.

4.2 Noise levels of the outdoor units

The two main sound radiation components of the outdoor units are the compressor and the fan. Since the noise levels are dependent on both the compressor frequency and the fan speed, proper control of these entities is one of the keys to a quiet heat pump. Results show that the outdoor temperature has a certain effect on the sound power level, but the influence, and the absolute level, is quite different for the two heat pumps. It is also worth noticing that operation at part load reduces the noise level considerably (~10 dB).

4.3 Dependence of dimensioning and energy performance on part load performance

In Sweden heat pumps often have been dimensioned to cover 50 % of the maximum heat demand (power) of the building. With this strategy up to 90 % of the annual heating load is covered by the heat pump. This results in a large number of hours where the heat pump is operating at full load, making the full load performance very important for the total performance. Another strategy is to let the heat pump cover the complete heating demand of the house, making an additional resistive heater redundant. Here the part load performance

is of greatest importance, allowing a poorer performance at full load without a large effect on the total performance. Looking at the heat pumps of this study, both heat pumps improve their COP significantly at part loads. Already at a part load of 80% the performance is increased with 30-40 %.

4.4 Noise measurements of heat pumps with frequent defrosts

The noise should be measured at stable conditions which is more or less impossible since the heat pump defrosts as frequently as every 50 minutes. According to the noise measurement standard, the outdoor unit should be free from frost at the occasion of measurement. The frost influences the air flow path through the heat exchanger which might affect the noise performance of the heat pump. Due to problem of achieving and maintaining frost free conditions, we will continue to investigate the impact of the frost load on the noise level from the outdoor unit.

4.5 Measurements of noise in laboratory environment

One parameter for achieving high quality sound measurements is low background noise levels. The only way to achieve these levels is to turn off the climate stabilizing functions of the climate chambers, causing the temperatures to drift during the measuring period. The noise measuring standard allows for certain deviations in the climate but the measurement period must be relatively short (<1 minute) in order to stay within these limits. Therefore it is complicated to measure variations in sound, such as at defrost operation.

4.6 Improved indicator of noise performance

Today, regular noise measurements are performed only at nominal operation (7 °C, 100 %) and one does not perform any measurements at part loads, which often represent a large share of the heat pump operation. This study shows that measurements at a larger number of operation conditions may be motivated, at least for the outdoor unit. The results from this study also give an indication of how much the noise is changed when the heat pump operates at different conditions (temperatures and part loads). This information, together with further investigation on frost load dependence, will be used when developing a seasonal performance indicator for the noise level of an air source heat pump.

4.7 Optimization of noise performance

One should strive towards low average sound power levels and limited top values to minimize disturbance. This requires a measure for average disturbance that includes how the sensitivity towards noise varies over the day.

The noise performance of the outdoor unit should be optimized for rather high operation temperatures, since you are seldom outdoors at winter time. However, the outdoor unit noise might also be disturbing indoors for example if it is placed close to a bedroom window. The noise performance of the indoor unit is more critical, since you spend most time indoors when the need for thermal capacity is large. The indoor unit should therefore be optimized for high air flows but one should also strive towards a minimization of the fan speed to reduce the noise level.

5 CONCLUSION

There are large differences in both energy and noise performance between two rather similar air-to-air heat pumps.

The noise of the indoor unit of an air-to-air heat pump is not dependent on the outdoor conditions. However, the noise depends strongly on the type and speed of the fan, as well as the geometry of the indoor unit.

The results from this study show no clear correlation between the noise level of the outdoor unit of an air-to-air heat pump and the operating conditions as such. However, the noise is reduced up to 10 dB when the heat pump operates at part loads which occur at high outdoor temperatures. Further measurements at different frost loads will hopefully give a clearer picture of the noise-performing characteristics of the outdoor unit.

An improved indicator of the noise performance of an air source heat pump is motivated since measurements at one operating condition do not represent the heat pump's total noise performance.

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