# AIR-TO-AIR HEAT PUMPS EVALUATED FOR NORDIC CLIMATES- TRENDS AND STANDARDS

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**Abstract:** The number of sold air-to-air heat pumps in Sweden has increased over the last years. This paper presents the results from independent tests performed by SP on behalf of the Swedish Energy Agency of air-to-air heat pumps sold on the Swedish market during 2004-2013. The heat pumps were evaluated in terms of efficiency and capacity for space heating as well as noise emissions. The objective of the tests was to compare the performance of the different test objects. The results show that the efficiency of the best performing heat pumps have improved considerably since the year of 2004, but also that there is a large spread in the performance of the heat pumps sold today. In comparison to the requirements in the new Eco-design and energy labelling regulations within the EU, some of the tested heat pumps would probably not pass the requirements while others would obtain an A++ energy label (second best class).

**Key Words: air-to-air heat pump, efficiency, performance, eco-design,**

## 1 INTRODUCTION

During the past decade different air-to-air heat pumps sold on the Swedish market have been tested by SP Technical Research Institute of Sweden on behalf of the Swedish Energy Agency. The objective is to promote efficient products and to help consumers in choosing the best unit for their specific needs since the use of these heat pumps, mainly for heating purposes, has increased substantially in Sweden in recent years. The percentage of the total sales of heat pumps in Sweden that come from air-to-air heat pumps is estimated to be around 65 %. Figure 1 presents estimated sales volume multiplied by the rated capacity of each heat pump for the years 2006-2011. The estimation is made by SVEP, The Swedish heat pump association, which presents sales figures each year for heat pumps in Sweden. Not all sales of air-to-air heat pumps on the Swedish market are reported to SVEP and thus there is an uncertainty regarding these numbers. Interviews have been made with companies that import and sell air-to-air heat pumps. They estimate that approximately 50 000 - 60 000 units every year have been sold for the last decade.

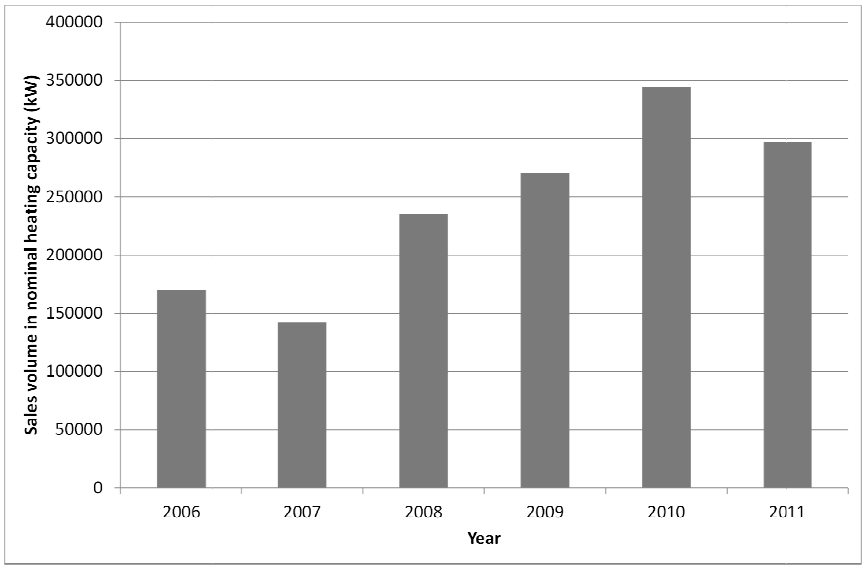



**Figure 1: Sales volume for air-to-air heat pumps in Sweden presented in rated (nominal) heating capacity (source: SVEP)**

In 2013, new Eco-design requirements were implemented within the EU. The objective of the Eco-design requirements is to increase environmental benefits by stimulation and implementation of advances in technology. How EUs Eco-design requirements will impact on the heat pumps is still uncertain. In the new Eco-design requirements, the heat pump manufacturers can choose the design heating demand that the heat pump is tested for. This may result in choosing a low such value in order to get high values of the seasonal coefficient of performance (SCOP) since less back-up heat by an electrical heater is then required. In addition it takes into account the electricity used by various auxiliary modes of the heat pump (see 2.2). Hence the new structure of this standard may contribute to changes of trends in technological development of these products. SP Technical Research Institute of Sweden has also performed tests on behalf of the Swedish Energy Agency based on the new Eco-design requirements. Four of these heat pumps have also been evaluated both by testing the units in accordance with the manufacturer's instructions and by using a compensation method.

## 2 METHOD

Heat pumps tested during the years 2004-2013 at SP Technical Research Institute of Sweden on behalf of the Swedish Energy Agency have been evaluated. The laboratory is accredited according to ISO 17025 for the test methods and the standards applied in these tests.

### 2.1 Test Method for Evaluation of Energy Performance

The heating capacity and coefficient of performance (COP) have been evaluated in accordance with the EN 14511 standard applicable at the time of the tests. The heating capacity and COP at part-load have been determined in accordance with CEN/TS 14825. The calorimeter room test method has been used and the total uncertainty of measurement is within ±5.0 % for the heating capacity and the COP. The calculated total uncertainty of measurement has been confirmed by using a heating fan with known capacity to perform an energy balance in the calorimeter room. Different capacities have as well been tested both in steady state and on/off operation to confirm the calculated total uncertainty of measurement. For the electric power measurements the uncertainty is less than ±0.5 %. The indoor air dry bulb temperature was +20 °C for all test points. The space heating performance tests as

specified in EN 14511 are referred to as 100 % (full-load) tests. Space heating performance tests at heating capacities less than 100 % are referred to as part-load tests and have been performed at 75 % and 50 % part-load. The tests were performed during 2004-2012.

**Table 1: Test points in space heating in accordance with EN 14511 and CEN/TS 14825.**

| Standard/ test method | Test point | Outdoor temperature (°C) dry bulb(wet bulb)[a] | Capacity (%) |
|---|---|---|---|
| EN14511 | 1 | 7(6) | 100 |
| | 2 | 2(1) | 100 |
| | 3 | -7(-8) | 100 |
| | 4 | -15(-) | 100 |
| CEN/TS 14825 | 5 | 7(6) | 50 |
| | 6 | 2(1) | 50 |
| | 7 | 7(6) | 75 |

a) The temperature in brackets shows the wet bulb temperature

## 2.2 Test Method for Evaluation of Energy Performance According to EU Eco-design

The Eco-design and energy labelling regulations for air conditioners came into force in January 2013. The heating capacity and COP have been evaluated in accordance with the EN 14825 standard applicable at the time of the tests performed during 2012-2013. The standard EN 14825 mainly refers to EN 14511 when describing the test method. EN 14825 lets the heat pump manufacturer choose the design heating demand that the heat pump is tested for. It also considers the electricity used by various auxiliary modes in e.g. thermostat off mode, stand-by mode, off mode and crankcase heater mode. The test points are presented in Table 2. The indoor air dry bulb temperature was +20 °C for all test points.

**Table 2: Space-heating test points for seasonal performance calculations (EN 14825)**

| Standard/ test method | Test point | Outdoor temperature (°C) dry bulb(wet bulb)[a] |
|---|---|---|
| EN14825 | 8 | -7(-8) |
| | 9 | 2(1) |
| | 10 | 7(6) |
| | 11 | 12(11) |
| | 12 | TOL[b] |
| | 13 | $T_{bivalent}$[c] |

a) The temperature in brackets shows the wet bulb temperature
b) Operation limit temperature
c) Lowest outdoor air dry bulb temperature at which the heat pump is capable of covering the total heating demand of the building

According to EN 14825, performance testing can be made for three different climates; Strasbourg (average), Helsinki (cold) and Athens (warm). For each climate there is a choice of a bivalent temperature ($T_{bivalent}$) for which the heat pump is capable of covering the total heating demand of the building. Tests have been performed for two climates, average and cold. The bivalent temperature has been chosen as presented in Table 3. In accordance with EN 14825 $T_{bivalent}$ can be chosen to be equal or lower than -7 °C for the colder climate and equal or lower than +2 °C for the average climate.

**Table 3: Choice of parameters in accordance with EN 14825.**

| Heat pump | Climate | $T_{bivalent}$ (°C) |
|---|---|---|
| A1 | Cold | -7 |
| A2 | Cold | -7 |
| B | Cold | -7 |
| A1 | Average | -7 |
| A2 | Average | -7 |
| B | Average | -7 |
| C | Average | -10 |
| D | Average | -5 |
| E | Average | -7 |
| F | Average | -10 |

Heat pumps C-F have been tested for market surveillance purposes in 2013 and have been tested in accordance with the manufacturer's instructions. For these heat pumps the compressor frequencies were set. $T_{bivalent}$ is as declared by the manufacturer. The heat pumps have also been tested on behalf of the Swedish Energy in accordance with EN 14825 for obtaining values as declared by the manufacturer but using a compensation method. For these tests the compressor frequencies were not set. The temperature value on the remote controller was set at the temperature which delivered an incoming air temperature of +20 °C to the indoor unit and at the same time the indoor test chamber was cooled to such extent that the heat pump delivered the target heating capacity. In this way, the heat pump's own control system adjusts the compressor capacity, such that the desired indoor air temperature is kept constant. The same tolerances, regarding the dry and wet bulb temperatures in both the outdoor and indoor test chamber, were applied as for transient tests according to EN14511.

## 2.3 Calculation Method for Evaluation of Seasonal Performance

For the tests performed in accordance with EN 14511 and CEN/TS 14825 the seasonal performance calculations were performed in accordance with SP method 0033. Calculations were made for two different type houses, one house having a loss factor of 109 W/K and another house having a loss factor of 199 W/K, both with an indoor temperature of + 20 °C. The gross energy requirements for these two houses are 11 000 kWh/year and 20 000 kWh/year respectively, excluding energy requirements for household electricity and hot water. The lowest operating temperature of the heat pump is assumed to be -15 °C and heating is assumed not to be required when outdoor temperatures exceed +17 °C. An annual average outdoor air temperature of +6 °C is used. Based on the average outdoor air temperature, the duration curve can be calculated. When the capacity of the heat pump is not sufficient, back-up with an electrical resistance heater (COP=1) is assumed to complement the heat pump. It is possible to determine the capacity provided by the heat pump for each time step since the heat pump capacity at different temperatures and loads is known from the measurements. The method is described by Fehrm and Hallén, 1981 and Karlsson, 2003. The calculations are made in steps of 30 hours. The equation below describes how the seasonal performance factor (SPF) is calculated and the definitions are described in the nomenclature list.

$$SPF = \frac{Q_{building}}{W_{heat\ pump} + W_{heater}} \quad (1)$$

The distribution of warm air during the verification testing points was ideal, which should be seen as differing from the conditions of a real installation, where air distribution can be affected by such factors as furniture, walls etc. This means that the actual thermal output power in a typical consumer installation could be less than the thermal output power values

as measured in the calorimeter chamber in these tests. The calculation does not take into account how other heating systems in the house operate.

### 2.4 Calculation Method for Evaluation of Seasonal Performance According to EU Eco-design

Tests performed to comply with EU Eco-design requirements for the seasonal performance calculations were carried out in accordance with EN 14825 which largely refers to EN 14511 regarding the test method. The calculations have been made according to EN 14825. The calculations in EN 14825 are based on a bin-method. In a bin-method all hours with a specific outdoor temperature for a given location are aggregated and sorted. For example, all hours with an outdoor temperature of 5 °C are collected in one bin and all hours with an outdoor temperature of 6 °C are collected in the next and so on. By calculating the performance of the heat pump for each outdoor temperature one can summarize how efficient the heat pump is over one year for a given climate. During hours when the heat pump capacity is lower than the heating demand it is assumed that backup by an electrical resistance heater (COP=1) covers the deficit. For test points where the heat pump heating capacity exceeds the load the coefficient of performance is corrected using a degradation coefficient (Cd) in accordance with EN 14825. According to the standard a default-value of Cd equal to 0.25 has been used. The equations below describe how the calculations are performed and the definitions are described in the nomenclature list (exact definitions of parameters and numbers can be found in the standard EN 14825),

$$SCOP = \frac{Q_H}{Q_{HE}} \tag{2}$$

$$Q_{HE} = \frac{Q_H}{SCOP_{on}} + H_{TO} \times P_{TO} + H_{SB} \times P_{SB} + H_{CK} \times P_{CK} + H_{OFF} \times P_{OFF} \tag{3}$$

$$SCOP_{on} = \frac{\sum_{j=1}^{n} h_j * Ph(T_j)}{\sum_{j=1}^{n} h_j \left( \frac{Ph(T_j) - elbu(T_j)}{COP_{PL}(T_j)} + elbu(T_j) \right)} \tag{4}$$

### 2.5 Test Method for Evaluation of Sound Power Level Measurements

The acoustic performance of the indoor and outdoor unit of the heat pumps was evaluated. The heat pumps were tested according to EN 12102 and ISO 3747 during the years 2004-2012.

## 3 RESULT AND DISCUSSION

The following section describes and summarizes results from the air-to-air heat pump tests. On the Swedish Energy Agency's webpage a more detailed presentation of the tests can be found (in Swedish).

### 3.1 Trends in Performance of air-to-air heat pumps

Every year SP Technical Research Institute of Sweden tests air-to-air heat pumps on behalf of the Swedish Energy Agency and the results are presented on the Swedish Energy Agency's webpage. 52 of the heat pumps tested by SP during 2004-2012 have a maximum heating capacity in accordance with the values presented in Figure 2. The figure also shows the rated capacity for the heat pumps tested. The rated capacity is normally the value

presented on the rating plates of the units but is often much smaller than the maximum heating capacity at the same temperature.

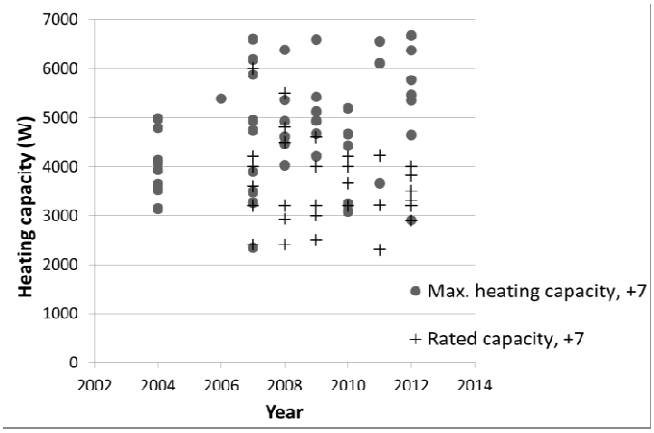



**Figure 2: Maximum and rated heating capacity for heat pumps tested for the Swedish Energy Agency during 2004-2012.**

The majority of the heat pumps that are tested by SP are being tested on behalf of the Swedish Energy Agency in agreement with a manufacturer or a distributor. During 2011 the Swedish Energy agency performed tests for market surveillance purposes on six air-to-air heat pumps. Figure 3 shows the COP as a function of heating capacity at +7 °C for different heating loads. The markings with a cross show the six heat pumps that were tested for marketing surveillance during 2011, the rest are from the tests in agreement with the manufacturer or distributor. The heat pumps tested for market surveillance purposes were tested at rated capacity at +7 °C which is the same as the value that was presented on the energy label at that time. These values are commonly not consistent with the maximum capacity of the units, but rather a part-load, and do not deviate from the values for the tests performed on behalf of the manufacturers or distributors.

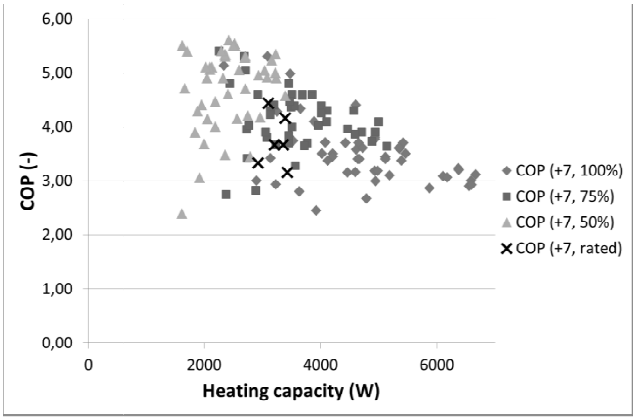



**Figure 3: COP as a function of heating capacity at +7 °C.**

Figure 4 presents the COP and SPF for the heat pumps tested during 2004-2012. The conclusion is that the units have improved since 2004 and that the trend continues to be positive. The conclusion is based on a limited selection of data with a wide spread and thus is somewhat uncertain. Also, for all heat pumps annual seasonal performance factors were calculated in accordance with the SP method 0033 described above under section 2.3 and these are also presented in Figure 4. Due to the differences in performance at different temperatures and part-loads, calculation of the seasonal performance factor (SPF) is a good tool for comparing the overall performance of these heat pumps. By comparing the SPF values over the years, the above conclusion that the units have improved over 2004 is affirmed. The weakness of this comparison is that the heat pumps included in the test are not

of equal capacity and thus cannot be directly compared, as the SPF value will depend on both capacity and efficiency. A large-capacity heat pump with a low efficiency can have a higher SPF than an efficient low-capacity heat pump. This, of course, is relevant to include in an analysis as it is important to match the heat pump to the load.

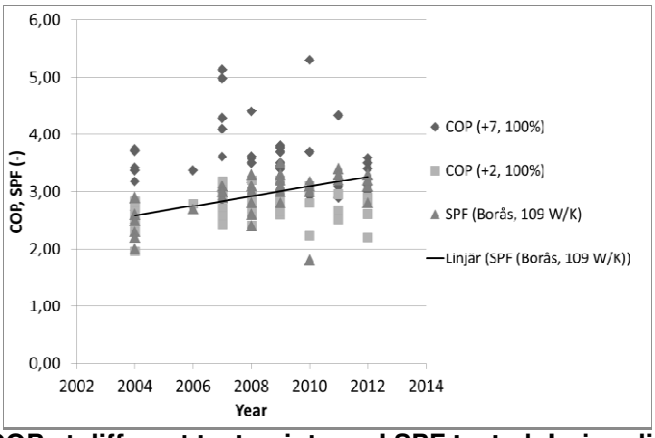



**Figure 4: COP at different test points and SPF tested during different years.**

## 3.2 Trends in Performance According to EU Eco-design Requirements

Figure 5 presents values for COP, SPF and SCOP for the heat pumps presented in Figure 4. Two of the heat pumps tested for market surveillance purposes in 2011 were also tested with the same test procedure as the heat pumps that are published on the Swedish Energy Agency's webpage. For this test the heat pumps with the highest and lowest performance at +7 °C were chosen. The latter of these two was an on/off type. As the SP method 0033 used to perform SPF calculations is adapted to be used for inverter type heat pumps, the method cannot be used for on/off types as it would not be comparable to the SPF calculations performed on the inverter types. Thus part-load tests was not performed and thus no SPF calculation. For these two heat pumps, (heat pump A1 and heat pump A2), calculations based on the standard EN 14825 and the climates average and colder were also performed using a bivalent temperature of -7 °C. Calculations based on the standard EN 14825 and the climates average and colder have also been performed for a third heat pump (heat pump B) using a bivalent temperature of -7 °C.

By studying the duration diagram for the average climate and the heat pump capacity curves one may conclude that for the tests that have been performed and published on the Swedish energy Agency's webpage the test point at +2 °C and a part-load heating capacity of 50 % is the test point that best correspond to the calculated SCOP values for the average climate when a bivalent temperature of -7 °C is used. In Figure 5 values at +2 °C 50 % and SCOP (average, -7 °C) for heat pumps A1 and B have been circled and confirm the conclusion. With this assumption 31 % of the heat pumps tested would not pass the Eco-design requirements of Tier 1 (EU, 2012, requirement 2013), which corresponds to energy label A. No heat pump would achieve A+++, 2 % would get A++, and 17 % would get A+. 17 % would get an energy label of a B and 13 % would get a C. 67 % of the heat pumps tested would not pass the Eco-design requirements, Tier 2 (2014). The conclusion is based on a limited selection of data with a wide spread and thus there is some uncertainty. The SPF values for Borås are a good representation of how a heat pump would perform in southern Sweden, where most heat pumps are installed, and coincide with SCOP for the colder climate and a bivalent temperature of -7 °C. A choice of bivalent temperature of -7 °C for the colder climate is assessed not to be realistic for future energy labelling of the heat pumps, this value will probably be lower.

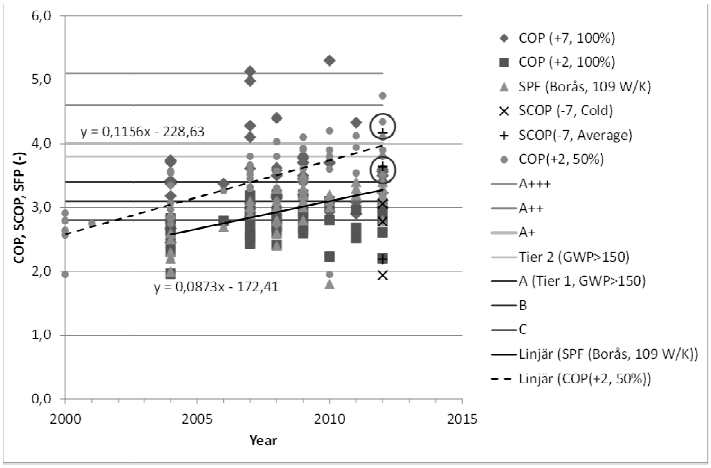



**Figure 5: COP at different test points and SPF and SCOP tested during different years.**

Four heat pumps were tested in 2013 for market surveillance purposes in accordance with the new EU Eco-design requirements. Calculations have been done for the average climate. In EN 14825 the bivalent temperature, i.e. the lowest outdoor temperature of which the capacity of the heat pump can cover the heating demand of the building, is not fixed, but was defined according to the manufacturer (or importer) of the product. However, there is a maximum value of +2 °C for the average climate. In this case the bivalent temperature was selected according to Table 4 below.

The system is based on self-declaration and thus is to be controlled by means of market surveillance performed by different authorities in the different member states. The Eco-design requirements are based on the performance at the average climate. The $P_{designh}$ value is the heating demand the coldest hour of the year for the imagined building. Hence, there is a risk that much focus will be put on improving the performance for an average climate, in order to obtain an A++ on the energy label, and less focus on improving the performance in a cold climate, in which the function during frosting and defrosting mode is very important.

**Table 4: Declared values for the heat pumps tested in 2013 for market surveillance purposes.**

| Heat pump | Climate | $T_{bivalent}$ (°C) | $P_{designh}$ | SCOP |
|---|---|---|---|---|
| C | Average | -10 | 2,80 | 3,90 |
| D | Average | -5 | 3,30 | 3,40 |
| E | Average | -7 | 2,70 | 3,40 |
| F | Average | -10 | 3,60 | 4,30 |

The table shows that for the average climate all values of bivalent temperature have been set lower than the maximum allowable value of +2 °C. The bivalent temperature as chosen by the manufacturer is even lower than -7 °C in some cases. This concludes that the percentage of heat pumps that would pass the requirements will be higher than the estimated values above. A lower $T_{bivalent}$ gives a smaller $P_{designh}$, which corresponds to a smaller building, and this normally results in a higher SCOP. On the other hand, a low value of $P_{designh}$ can result in much on-off operation which could have a negative impact on the SCOP value.

### 3.2.1 EN 14825 testing with and without setting the compressor frequency

The four heat pumps that were evaluated in 2013 for market surveillance purposes, in accordance with the new EU Eco-design requirements, were tested using two variations of EN 14825. In the first test the compressor frequency was set as specified by the manufacturer and in the second test a compensation method is used and the capacity of the heat pump is regulated by the heat pumps own control system (see description above in

section 2.2). Figure 6 presents a comparison of the calculated COP and measured heating capacity, as well as the target heating capacity at each test point.

When comparing the results one needs to keep in mind that if the tested heating capacity is within ±10 % of the target value then the test complies with the standard and it is assumed that the unit is capable of reaching the target value. Keeping this in mind the conclusion is that for test points 8, 12 and 13 the heat pumps were capable of reaching the same heating capacities with the compensation method as with the fixed compressor frequency method. For these test points the calculated COP values are very similar for the two different test methods. For some test points with defrosting cycles differences between the operations, such as cycle times, defrosting times and whether the operation was stable or not, could be seen for the different test methods. For heat pump E and test point 12 and 13 the unit defrosted after a certain time which was not the case when the compressor frequency was fixed. As a result of these variations the calculated COP differ between the test methods.

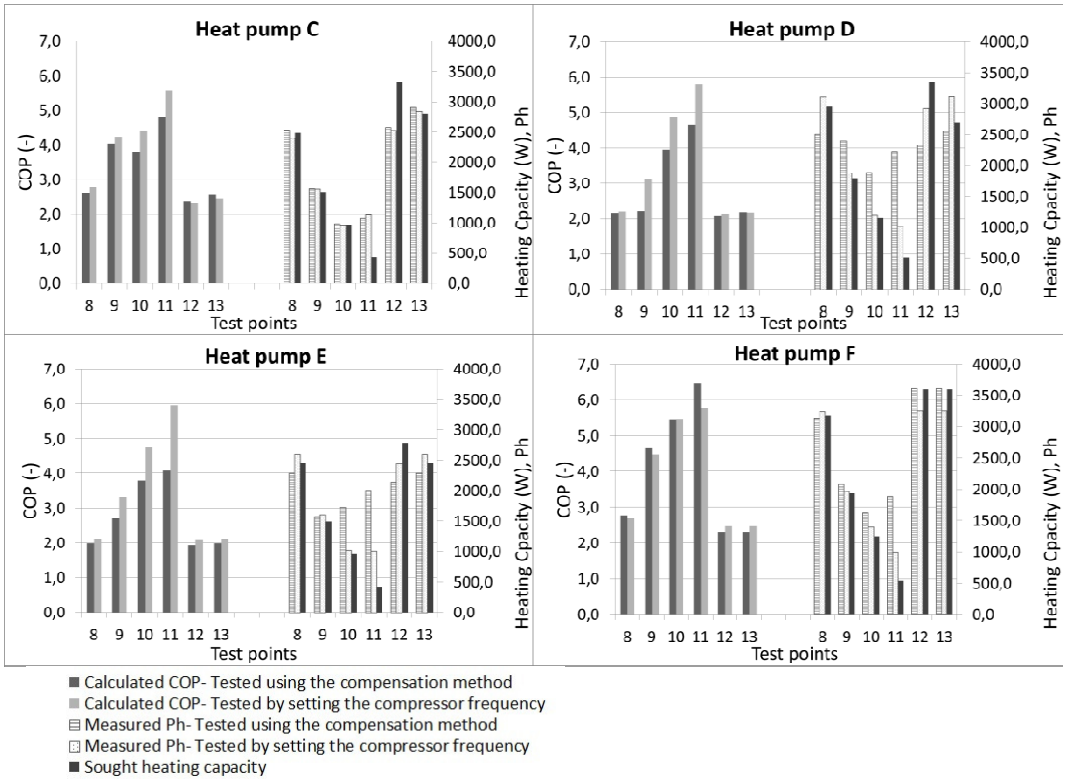



**Figure 6: Calculated COP and measured heating capacity at each test point with either a set compressor frequency or a compensation method.**

Heat pump C, when tested with the compensation method, cycled on/off at test points 10 and 11. However, the tolerances regarding the dry and wet bulb temperatures in both the outdoor and indoor test chamber were applied as for steady state tests according to EN 14511 and were met. Due to the cycling the COP calculated when tested with the compensation method is lower than the COP calculated when tested with a fixed compressor frequency (no on-off cycling). In both tests the measured heating capacity at test point 10 deviated less than 10 % from the target heating capacity, concluding that the unit is capable of reaching the target value. However when the intrinsic control system of the heat pump adjusted the compressor capacity, the tests showed that the unit did not work in the same manner as when the compressor frequency was set as it cycled on/off. At test point 11 the measured heating capacity deviated more than 10 % from the target heating capacity, although this deviation occurred in both tests. The heating capacities tested for the other test points were within ±10 % of the target capacities for both tests this indicates that the compensation method provides

similar results and that it is possible to test the units without setting the compressor frequencies.

When heat pump D was tested with the compensation method the unit was not able to adjust the compressor capacity by its own control system to achieve the same heating capacity as when the compressor frequency was fixed for test points 9, 10 and 11. The heat pump was not capable of achieving stable operation at the same low heating capacity as it was when fixing the frequency of the compressor. The test points were tested at the lowest possible stable heating capacity (closest to the target heating capacity) where also the tolerances in accordance with the standard were held. For the remaining test points the tested capacities were within ±10 % of the target heating capacity. The same conclusion could be drawn from the test of heat pump E with the exception of test point 9. At test point 9, heat pump E was capable of achieving the stable operation to meet the tolerances of the standard at the same heating capacity with the compensation method. Although with the set compressor frequency, the unit was able to work with a more stable electric drive power and thus achieved a higher COP.

Heat pump F, when tested with the compensation method, was not able to adjust the compressor capacity by its own control system to reach the same heating capacity as when the compressor frequency was set for test points 10 and 11. The heat pump was not capable of achieving stable operation at the same low heating capacity as with fixed frequency, but cycled on-off, and the standards tolerances were not met. The test points were tested at the heating capacity closest to the target heating capacity, where stable operation could be obtained (and where the tolerances were held in accordance with the standard). For the remaining test points the tested capacities were within ±10 % of the target heating capacity. However, for this heat pump the calculated COP values were similar and at test point 11 much higher than the values calculated when testing with the compressor frequencies set. This heat pump, however, was not a wall mounted unit like the others and thus the distribution of warm air during the testing points differed. This could result in the unit having a different feedback to its control system, ultimately achieving more efficient adjustment of the compressor capacity.

Figure 8 shows how the calculated SCOP for the different heat pumps differ when tested either with the compressor frequency fixed or when tested with the compensation method. The results vary and depend how the manufacturer declares that the heat pump shall be tested. For most heat pumps though the SCOP calculated from the tested values with the compressor frequency fixed is higher than with the compensation method where the intrinsic control system of the heat pump adjusted the compressor capacity.

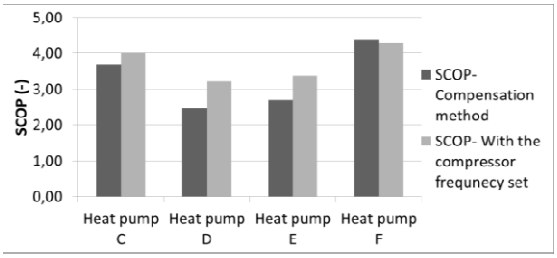



**Figure 8: Calculated SCOP with either a set compressor frequency or a compensation method.**

### 3.3 Results from Sound Power Level Measurements

The sound power levels for both the indoor and outdoor units were measured in the tests performed during 2004-2012. The minimum, average and maximum sound power levels for the indoor and outdoor units of the heat pumps can be seen in Figure 9. The average sound power level for the indoor units is 55.5 dB, which is comparable to a kitchen fan. The

difference between the highest and lowest sound power levels is almost 18 dB, which by the human ear is perceived as more than a doubled noise level. Note that the test is made with the fan on maximum speed, and that the actual sound pressure level will depend on installation conditions. The average value for the outdoor units was 61 dB. The Swedish Environmental Protection Agency prescribes that the sound pressure level at the garden boundary must be below 40 dB. This means that a heat pump outdoor unit with a sound power level of 60 dB should be placed at least 10 meters away from the neighbour's garden boundary. The spread in acoustic performance is large but most heat pumps on the market today will probably pass the requirements of the Eco-design regulations.

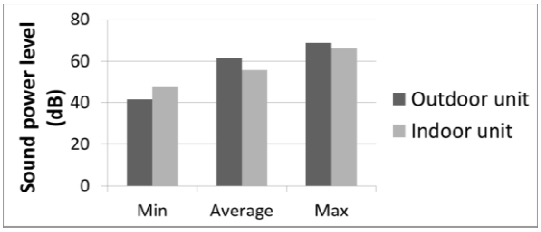



**Figure 9: Minimum, average and maximum sound power levels for the indoor and outdoor units of the heat pumps.**

### 3.4 Conclusions

By evaluating the test results for the different heat pumps tested by SP on behalf of the Swedish Energy Agency during the years 2004-2013 the following conclusions could be drawn.

- The heat pump performance (COP at different operating points) has increased significantly since 2004. However, the spread is large.
- In comparison to the requirements in the new Eco-design and energy labelling regulations within the EU, some of the tested heat pumps would probably not pass the requirements while others would obtain an A++ energy label (second best class).
- The tested heat pumps work often differently when testing in accordance with EN 14825 with fixed compressor frequency compared to when testing with a compensation method, where the control system of the heat pump is in operation, especially for low heating capacities but also at defrost mode. The result is that the SCOP declaration on the energy label may not represent how the unit will work in the real-world.
- The spread in acoustic performance is large but most heat pumps on the market today will probably pass the requirements of the Eco-design regulations.

## 4 ACKNOWLEDGEMENT

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**NOMENCLATURE**

Full definitions of the parameters can be found in standard EN14511 and EN14825

| | |
|---|---|
| COP | coefficient of performance (-) |
| $COP_{PL}$ | coefficient of performance at part load (-) |
| $elbu_{\mathrm{j}}$ | required capacity of an electric backup heater for the corresponding temperature Tj (kW) |
| $h_{\mathrm{j}}$ | number of bin hours occurring at the corresponding temperature Tj (h) |
| $H_{CK}$ | crankcase heater mode operating hours (EN14825 and EU, 2013c) (h) |
| $H_{OFF}$ | off-mode operating hours (EN14825 and EU, 2013c) (h) |
| $H_{SB}$ | standby-mode operating hours (EN14825 and EU, 2013c) (h) |
| $H_{TO}$ | thermostat off-mode operating hours (EN14825 and EU, 2013c) (h) |
| $n$ | number of bins (-) |
| $P_{CK}$ | crankcase heater power consumption (kW) |
| $P_{design}$ | full load heating demand (kW) |
| $Ph$(Tj) | heating demand of the building for the corresponding temperature Tj (kW) |
| $\mathrm{P_{OFF}}$ | off-mode power consumption (kW) |
| $P_{SB}$ | standby power consumption (kW) |
| $P_{TO}$ | thermostat off-mode power consumption (kW) |
| $SCOP$ | seasonal coefficient of performance (-) |
| $Q_{building}$ | annual heating demand (kWh) |
| $Q_H$ | reference annual heating demand (kWh) |
| $Q_{HE}$ | annual electricity use (kWh) |
| $T_{bivalent}$ | bivalent temperature (°C) |
| $Tj$ | outdoor temperature in bin j (°C) |
| $W_{heat\ pump}$ | power input to the heat pump (kW) |
| $W_{heater}$ | power input to the supplementary heater (kW) |