

## AIR-TO-WATER HEAT PUMPS EVALUATED FOR NORDIC CIRCUMSTANCES

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**Abstract:** The number of sold air-to-water heat pumps in Sweden has increased to a large extent over last decade. This paper presents the results from independent tests performed by SP on behalf of the Swedish Energy Agency of air-to-water heat pumps sold on the Swedish market. Four heat pumps were tested during 2012, nine during 2010-2011, three during 2006-2009 and four during 1999. The heat pumps were evaluated in form of efficiency and capacity for space heating as well as noise emissions. The objective of the tests was to compare the different test object's performance. The results show that the efficiency of the best performing heat pumps has improved considerably since the year of 1999, but also that there is a large spread in the performance of the heat pumps sold today. In comparison to the requirements in the recently voted Eco-design and energy labeling regulations for space heaters and combination heaters within the EU, some of the tested heat pumps might not pass the requirements while others would obtain an A++ energy label (second best class).

**Key Words:** air-to-water heat pumps, efficiency, defrost, noise, heat exchanger area

### 1 INTRODUCTION

The heat pump market started to grow considerably in Sweden in the end of the last century and Sweden has today one of the most developed heat pump markets in both Europe and the rest of the world when it comes to using the heat pump predominantly for space heating and domestic hot water heating. Ground source, exhaust air and air-to-air heat pumps are commonly used heat pumps types in Swedish dwellings and in the beginning of the last decade also the market for air-to-water heat pumps started to grow rapidly. This heat pump type is especially attractive in the southern regions and in areas close to the coasts where the climate is milder. The heat pump type is also an attractive choice where drilling for ground source heat is not permitted. During the last years the number of sold heat pump units per year has dropped to a large extent, one of the consequences being that almost all oil burners in Sweden are now replaced. This effect can also be seen for the air-to-water heat pumps as shown in Figure 1. It is likely to expect the heat pump market will now stabilize on the level of today for a couple of years and then grow again when all the heat pumps sold during the top years in the middle of the last decade are to be replaced.

In order to guide consumers which heat pump to select, a number of air-to-water heat pumps have been tested on behalf of the Swedish Energy Agency (and the Swedish Consumer Agency in 1999) and the results are published on their website of. A number of reports and papers reporting results from field measurements have been found, e.g. Nordman (2014),

Dunbabin *et al.* (2013), Dunbabin and Wickins (2012), Tiljander (2012) and Miara (2008), but few publications summarizing results from laboratory tests of air-to-water heat pumps over the years have been found in the open literature. The only ones found are reports by Freymond (2013) and by Nano *et al.* (2005) showing performance of heat pumps over time in Switzerland. Laboratory heat pump test results are also published in a similar way as in Sweden at e.g. the website of the Danish Energy Agency.

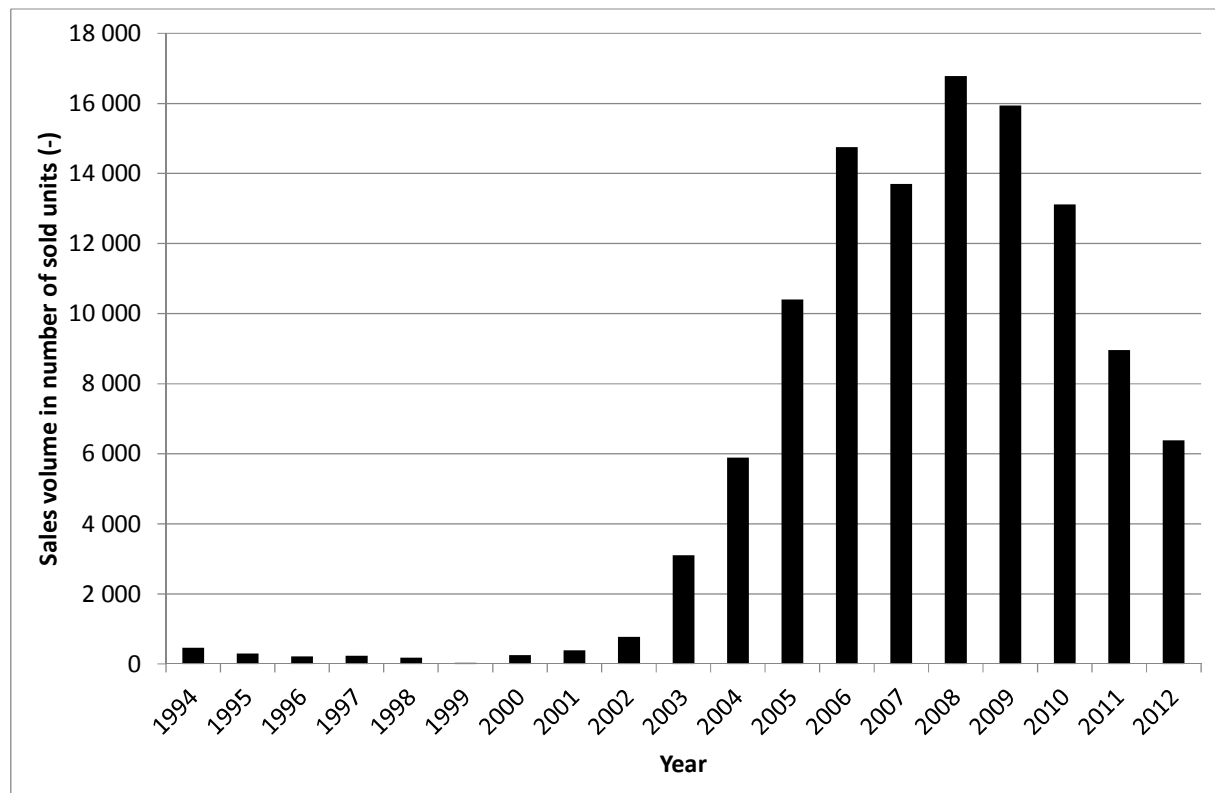


Figure 1: Number of sold air-to-water heat pumps per year in Sweden (SVEP, 2014)

## 2 METHOD

The heat pumps have been evaluated in laboratory tests at SP Technical Research Institute of Sweden on behalf of the Swedish Energy Agency who are the owner of the test results (the Swedish Consumer Agency in 1999). The laboratory is accredited according to ISO 17025 for the test methods and 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 existing EN standards for the time of the tests. Regarding the tests of four heat pumps performed in 1999, EN 255 was applied. At this time all the tested heat pumps were on-off controlled. In 2006 – 2008, EN 255 had been replaced by EN 14511 (year 2004) and therefore the heat pumps have not been tested at exactly the same test points and in exactly the same way. The test points are displayed below in Table 1. Except for the test-points also other things differ. The major issue is that according EN 255 the heating water flow rate should be set according to the instructions by the manufacturer, while this flow rate should be set to reach a temperature difference of 5 K at rating conditions, +7/35 °C or +7/45 °C (outdoor temperature/outlet water temperature) according to EN14511. These restrictions regarding the setting of the flow rate, resulted in somewhat lower COP values,

which should be kept in mind when comparing the results. At the tests conducted during 2006-2008 one of the tested heat pumps was equipped with variable speed control of the compressor. For evaluation of performance at part load conditions, CEN/TS 14825 was applied. The EN 14511 standard was revised again in (2007) but this revision did not have any significant influence on the test procedure for air-to-water heat pumps. At this stage three of the tested objects had variable speed control of the compressor and the other six were on-off controlled. In the tests performed during 2012, the same standards and methods were applied and all four test objects were variable speed controlled. The standard requires that the expanded uncertainty of measurement is less than  $\pm 5\%$  for the COP and the heating capacity which has been fulfilled in all tests.

**Table 1: Test points and applied standards/test methods**

Year of test (No test item)	Standard/ test method	Outdoor temperature (°C) dry bulb(wet bulb)	Outlet water temperature (°C)	Capacity (%)
1999 (4)	EN 255	7(6)	35	100
		2(1,5)	35	100
		7(6)	50	100
		2(1,5)	50	100
		-7(-8)	50	100
		-15(-)	50	100
2006-2012 (16)	EN 14511	7(6)	35	100
		2(1)	35	100
		7(6)	45	100
		2(1)	45	100
		-7(-8)	45	100
		-15(-)	45	100
		7(6)	55	100
		-7(-8)	55	100
	CEN/TS 14825	7(6)	35*	50
		2(1)	35*	50
		7(6)	45*	75

\*The inlet temperature and flow rate was the same as in the full capacity (100%) test. Hence, the resulting outlet temperature was lower than 35 and 45°C respectively

## 2.2 Calculation method for evaluation of seasonal performance

Within the EU eco-design (EU, 2013a) and energy labeling regulations (EU, 2013b) for space heaters and combination heaters have recently been voted and the first set of requirements comes into force in September 2015. In order to evaluate the relevance and levels of these requirements, the authors have, on behalf of the Swedish Energy Agency, calculated approximate values of the seasonal space heating energy efficiency,  $\eta_s$ , which is the key indicator that the eco-design requirements and energy label is based on. According to the regulations, the calculations shall be performed according to the newly published EN 14825 standard and the tests shall be performed according to EN 14825 and EN 14511. The calculations have been performed according to EN 14825, but since many of the tests were performed before the working documents of the regulations and new standards had been published, test results are missing for e.g. performance at off mode, thermostat off mode and at crankcase heater operation. For such modes, assumptions regarding the energy performance have been done. In addition, according to the latest versions of EN 14511 the heating water flow rate shall be set to obtain a temperature difference of 8 K when calculating the performance for a heating system requiring 55°C at design conditions (the coldest hour of the year). In this paper calculations have been performed, based on test results when the heat pump was rated with a temperature difference of 5 K. The effect of this

is probably that the results are somewhat underestimated (up to a couple of percent). According to the regulations and EN14825, the seasonal space heating energy efficiency,  $\eta_s$ , shall be calculated for three different climates; Strasbourg (average), Helsinki (cold) and Athens (warm). However, the efficiency displayed on the energy label is based only on the average climate. In this study calculations have been done for the average and cold climate.

Calculation of the seasonal space heating energy efficiency,  $\eta_s$ , is based on a bin method with one bin per degree of the outdoor temperature during the heating season, i.e. there is one bin for  $-10^\circ\text{C}$ , one for  $-9^\circ\text{C}$  and so on. For each bin a certain number of hours are defined for the different climates. For those hours of the year, when the capacity of the heat pump is not sufficient, back-up with an electrical resistive heat ( $\text{COP}=1$ ) is assumed to complement the heat pump. 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 EN14825 and in the transitional methods (EU, 2013c) that has been published together with the regulations.

$$\eta_s = \frac{100}{CC} SCOP - \sum F(i) \quad (1)$$

$$F(i) = F(1) + F(2) \quad (2)$$

$$SCOP = \frac{Q_H}{Q_{HE}} \quad (3)$$

$$Q_{HE} = \frac{Q_H}{SCOP_{on}} + H_{TO} \times P_{TO} + H_{SB} \times P_{SB} + H_{CK} \times P_{CK} + H_{OFF} \times P_{OFF} \quad (4)$$

$$SCOP_{on} = \frac{\sum_{j=1}^n h_j * Ph(T_j)}{\sum_{j=1}^n h_j \left( \frac{Ph(T_j) - elbu(T_j)}{COP_{PL}(T_j)} + elbu(T_j) \right)} \quad (5)$$

In those cases where data for the exact test points, required as input data to EN 14825, is missing, interpolation and extrapolation based on adjacent test points have been performed. Of course extrapolation introduces more uncertainty than interpolation, but was sometimes necessary, e.g. since performance for test points below  $35^\circ\text{C}$  was not available. The uncertainties introduced by inter- and extrapolation is largest for the variable speed controlled heat pumps.

### 2.3 Determination of heat exchanger area and fins spacing

The heat exchanger area and fins spacing was determined by visual inspection and measurement of different dimensions of the outdoor units.

### 2.4 Test method for evaluation of acoustic performance

The acoustic performance of the outdoor unit of the heat pumps were evaluated for the 16 heat pumps tested after 2005. The heat pumps were tested according to EN 12102 and ISO 3747 (engineering grade). The reproducibility of the A-weighted sound power when these methods are applied is assessed to be  $\pm 3.2$  dB (95% confidence interval) according to ISO 3747, provided that certain specified conditions are fulfilled. These conditions were fulfilled in the tests.

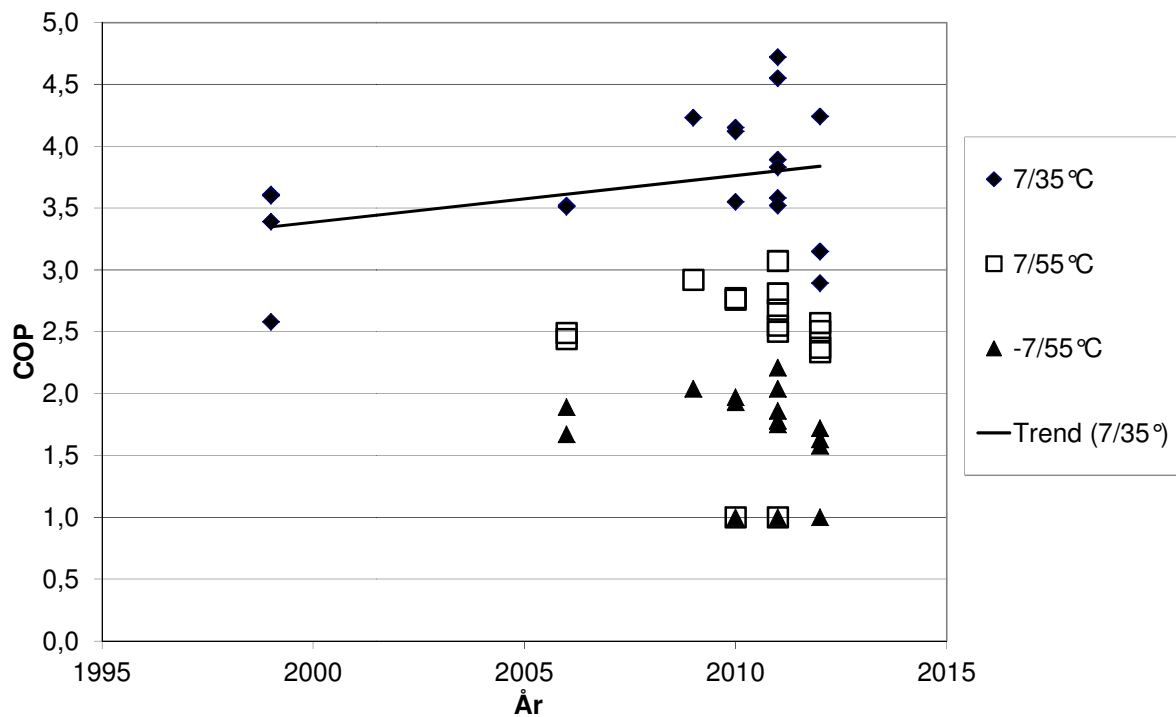
### 3 RESULT AND DISCUSSION

In the following sections summarized results are presented in a number of graphs. For the products still on the market, more detailed data regarding the test results can be found on the website of the Swedish Energy Agency (in Swedish).

#### 3.1 Trends in performance of air-to-water heat pumps

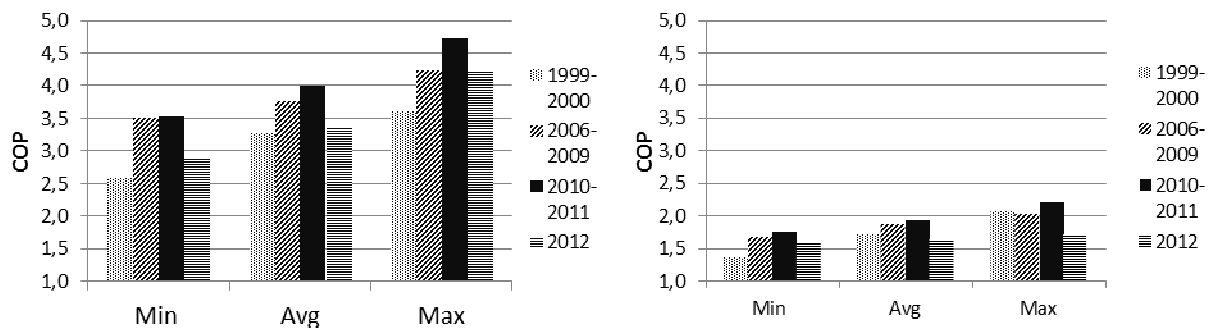
The COP is the common measure for energy efficiency for heat pumps and up to now the COP at the test points +7/35 or +7/45 have normally been the ones given at the marking plates of the heat pumps. In Figure 2 below, the COP (according to EN255 or EN14511) is shown for the heat pumps tested during different years. As mentioned above all the tests have not been performed according to identical standards, which could give the ones tested 1999 slightly higher values compared to if they had been tested according to EN14511. (The authors lack direct comparison of performance of heat pumps tested according to the two standards, but according to data presented by Freymond (2013), the COP at +2/35 is in most cases 5-10% better if the heat pump is tested according to EN255 compared to EN14511.) In addition, three of four of the objects tested during 2012 were selected for their considerably lower price. Nevertheless, a positive trend for the COP at +7/35 can be discerned (even though not statistically significant due to the limited number of test points). If the year of 2012 is excluded from the analyze, the performance of the poorest and the best performing heat pumps increase over time. The arrangement of comparative tests from which the results are published is probably one of the reasons for this development. However, there is a significant spread in the performance. There are still products on the market with lower performance than for some of those tested in 1999 (probably even taking the fact that different standards were applied into account). The data presented by Freymond (2013) and Nani *et al.* (2005), based on test data from the heat pump test center WPZ, do also show a positive trend in the performance at +2/35 over the years, even if the spread is large (Nani *et al.*, 2005). Test data is continuously published on the WPZ web site which well could stimulate the development of the products, at the same way as the comparative tests initiated of the Swedish Energy Agency.

When it comes to the test points at +7/55 and -7/55, they were not performed in 1999 and no direct comparison is available. By studying the results from 2006 and later for those test points a positive trend can be perceived, at least for +7/55, even though the spread is large. Some of the test objects could not deliver an outlet temperature of +55°C of the heating water at some outdoor temperatures (with a temperature difference of less than 5 K). In these cases the COP value has been given a value of 1,0. In real applications this does not necessarily have to be a severe problem, since in most cases the heat pump would need assistance from a supplementary heater at those hours of the year when such a high leaving water temperature is needed, and this heater is placed after the heat pump. However, if the heat pump cannot deliver high water temperatures as 55°C, there is always a risk that heat pump stops and the supplementary heater must then cover the whole heating demand.



**Figure 2: COP at different test points for air-to-water heat pumps tested during different years**

In Figure 3 below the test results have been grouped and minimum, average and maximum values are presented for the test points +7/35°C and -7/55°C. For the ones tested during 1999 results from the test point -7/50°C is shown. In the left figure a positive trend is seen for the minimum, the average and the maximum value when excluding the tests from 2012 which includes three “low-price” products. It is interesting to see that these products perform at approximately the same efficiency as the heat pumps tested in 1999 (except for the maximum COP value), but again the application of the different standards must be taken into account. In the right figure we can see the same pattern, even though the increase in performance is not as prominent. Note the maximum level of the heat pump COP tested during 1999 which is almost as high as for the more modern heat pumps, but this is to a large extent due to the fact that -7/50°C should result in higher COP values compared to -7/55°C. In this figure, the COP value has been excluded if the heat pump could not operate under the given test conditions.



**Figure 3: Minimum, average, and maximum COP at +7/35°C (left) and -7/55°C (right), -7/50°C for the heat pumps tested during the year 1999.**

### 3.1 Performance in relation to the requirements in the ecodesign and energy labeling regulations within the EU

Figure 4 below shows approximate values of  $\eta_s$  for 15 of the heat pumps tested during 2006 – 2012. One of the heat pumps tested during 2012 could not operate at several test points and calculation of  $\eta_s$  was not possible. Calculations have been done for the cold and for the average climate. In EN14825 the bivalent point, 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 shall be defined according to the manufacturer (or importer) of the product. However, there are maximum values,  $-7^\circ\text{C}$  for the cold climate and  $+2^\circ\text{C}$  for the average climate. In this case the bivalent temperature was selected to be  $-10^\circ\text{C}$  for the cold climate and  $-5^\circ\text{C}$  for the average climate. These values were assessed to be realistic values for a future energy labelling of the heat pumps. The threshold values for the ecodesign requirements 2 and 4 years after publication of the regulations (September 2015 and 2017) and threshold values for the different letters of the energy label are also shown. Two examples of energy labels are shown in Figure 5. The ecodesign requirements stated in the regulation (EU, 2013a) results in the fact that no heat pumps with poorer performance than the threshold values are permitted to be placed on the European market after the given date. The system is based on self-declaration and will be controlled by the means of market surveillance performed by different authorities in the different member states. The ecodesign requirements are based on the performance at average climate and as can be seen in Figure 4, 9 of the 15 tested heat pumps would most probably pass the requirements after 2 years (2015) but only 6 will fulfil the requirements after 4 years (2017). It is possible that the  $\eta_s$ -value can be increased to some extent by elaborating with the bivalent point for the declaration of the heat pumps, which might result in that some more of the heat pumps pass the requirements. For some heat pumps the  $\eta_s$  can be increased by declaring the heat pump for a lower bivalent temperature, but especially for on-off controlled products, the effect of lowering the bivalent temperature might have the opposite effect. It is necessary to mention here that the requirements for heat pumps are much higher compared to e.g. fuel boilers and electric boilers which need only to obtain a  $\eta_s$  of 86% and 36% respectively to pass the eco-design requirement. The  $\eta_s$  value for the cold climate is also shown and, as expected, these are lower for the cold climate. However, an interesting finding is that those heat pumps obtaining the highest  $\eta_s$  for the average climate (would obtain an A++ energy label) are necessarily not the ones obtaining highest values for the cold climate.

If the heat pump is only designed for space heating, both its performance in a  $55^\circ\text{C}$  heating system (i.e. as heating system requiring on outlet temperature of  $55^\circ\text{C}$  at design conditions, e.g. radiators) as well as its performance in a  $35^\circ\text{C}$  heating system (e.g. floor heating) can be displayed on the label. However, for a heat pump that is also designed for heating domestic hot water, a combination space heater, its performance at domestic hot water heating production shall be displayed on the label and hence there is not enough space for the performance for a  $35^\circ\text{C}$  heating system on the label. As can be seen in Figure 5 the energy performance class, based on the  $\eta_s$  value for the average climate, is shown by the arrow on the label. In addition the  $P_{\text{designh}}$  value is shown for the different climates. The  $P_{\text{designh}}$  value is the heating demand the coldest hour of the year for the imagined building for which the  $\eta_s$  has been calculated. Consequently, no information about the efficiency of the heat pump at neither the cold nor the warm climate is given on the label. 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 at cold climates, in which the function during frosting and defrosting mode is very important.

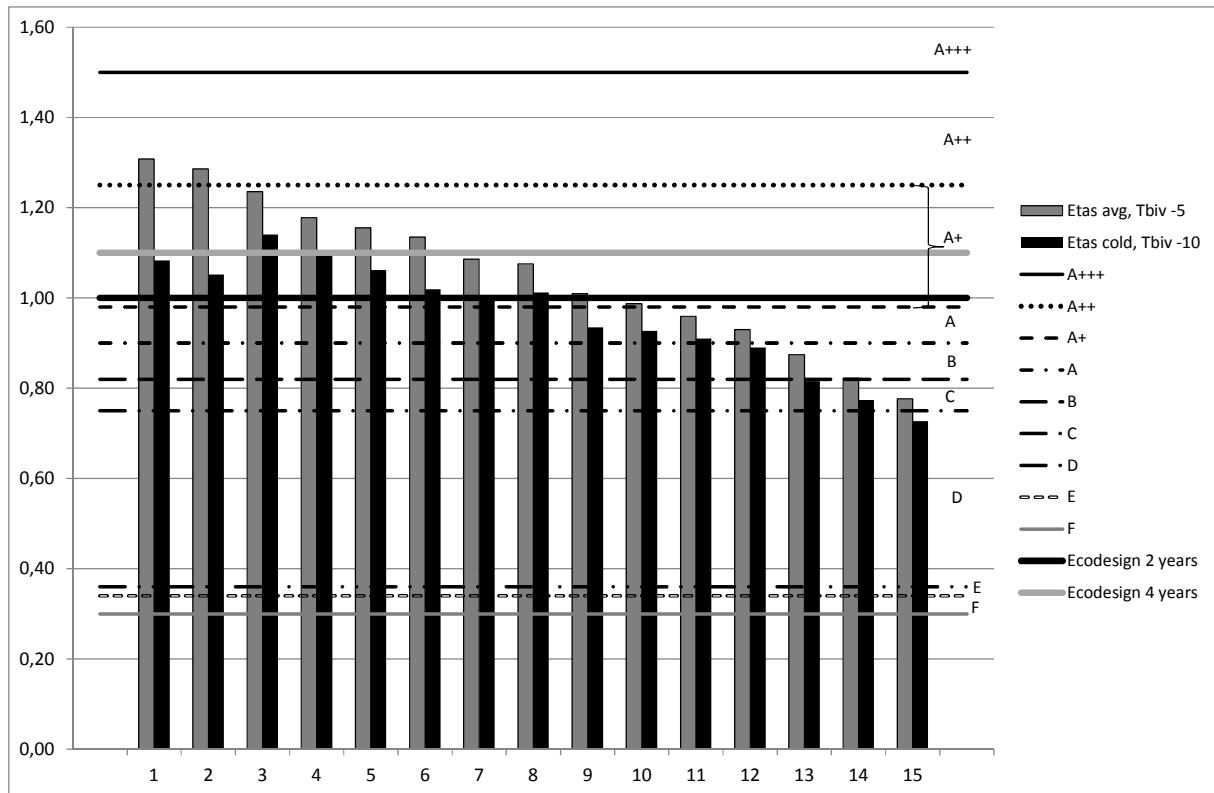


Figure 4: Approximate values of  $\eta_s$  for 15 of the heat pumps tested during 2006 – 2012 together with the threshold values for the ecodesign requirements 2 and 4 years after publication of the regulations (2015 and 2017) and for the different letters of the energy label (see below).

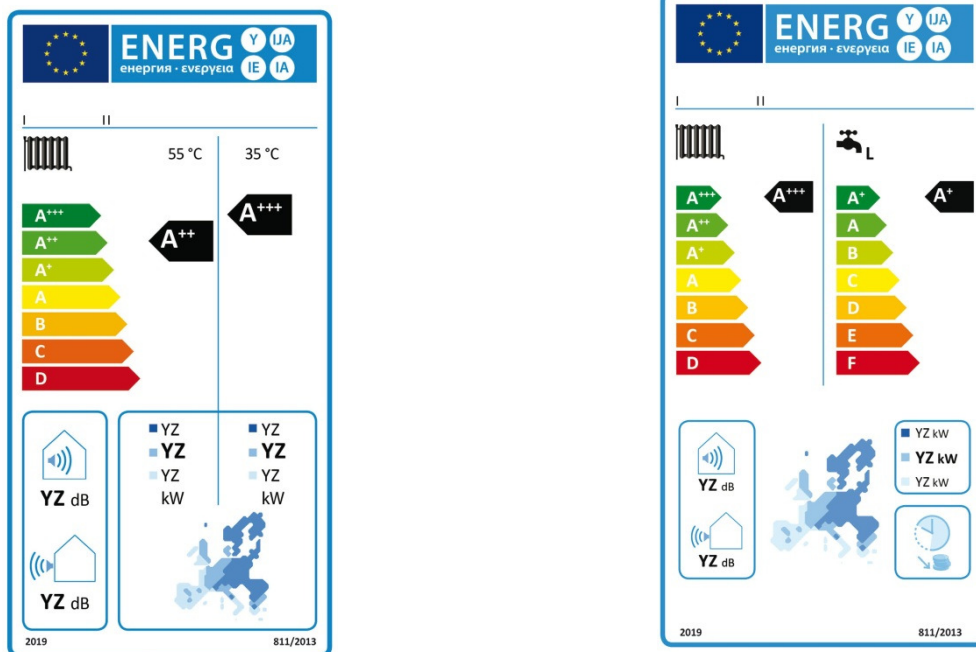


Figure 5: Examples of energy label for heat pump space heater (left) and space heater combination heater (right), except for low-temperature heat pumps, in seasonal space heating energy efficiency classes A+++ to D.

### 3.2 Influence of heat exchanger area and fins spacing on COP

The design and construction of the outdoor heat exchanger is important for the performance of the outdoor heat exchanger. Therefore, both the heat exchanger area and fin spacing were investigated and compared to the SCOP for the heat pumps tested during 2010-2011, see

Figure 6. When it comes to the area no real trend could be seen that the SCOPon increases with increasing normalized heat exchanger area (area divided by the capacity at the test point +7/35°C). Nevertheless, the lowest SCOPon values are obtained for those heat pumps with smallest normalized HX area. When it comes to the fin distance the results indicate that the seasonal performance is relatively independent on the fin spacing in the investigated range. Focusing on the performance of the heat pumps for the average climate, there is a vague trend indicating better SCOPon for smaller fin spacing. However, for the cold climate there is no such trend. This is probably due to the fact that other functions, such as control strategies for frosting and defrosting is probably of more significant importance than physical dimensions and as long as the control strategies are adapted to the physical dimensions these are of minor importance. It also proves the fact that measures leading to improved performance in an average climate do not necessarily lead to improved performance for the cold climate.

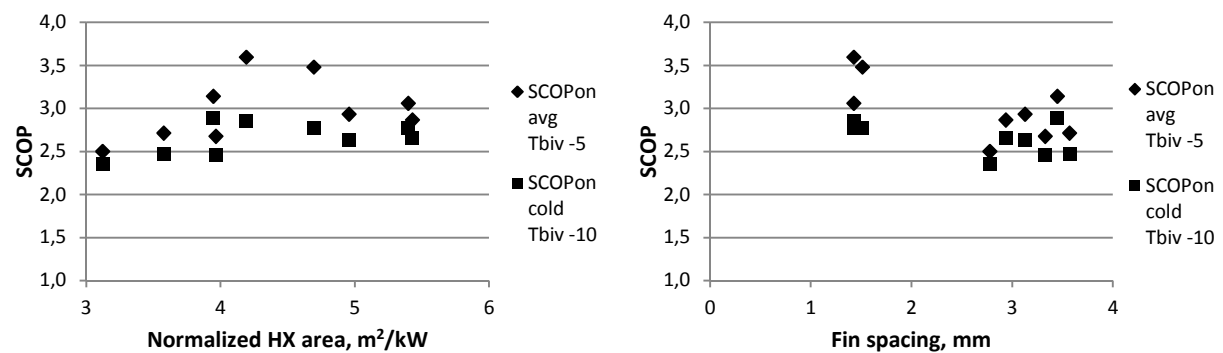
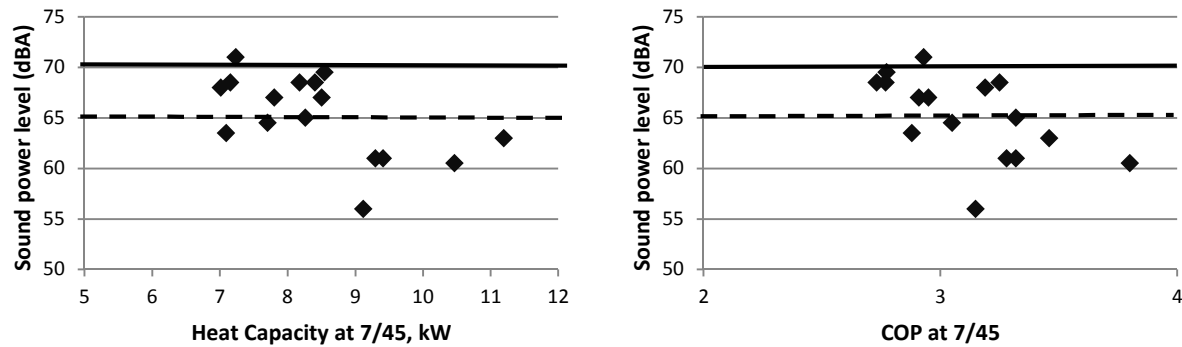


Figure 6: SCOPon versus normalized heat exchanger area (left) and fin spacing (right)

### 3.3 Results from acoustic tests

The acoustic performance of all heat pumps but the ones tested 1999 was evaluated. In figure 7 the sound power level of the outdoor units of the heat pumps operating at full load at 7/45 is shown versus heat capacity and COP at the test point 7/35 (outdoor temperature / leaving water temperature). The level differs considerably between the different heat pumps, the range stretches from 56 to 71 dBA with an average of 65 dBA as shown by the dashed line. There is only one heat pump that does not meet the sound power level requirement of 70 dBA set by the eco-design regulation (EU, 2013a) for heat pumps with a rated capacity 6-12 kW. As can be seen, there no trend indicating that the sound power level is higher for larger capacity or higher COP value for the tested heat pumps, rather the opposite.



**Figure 7: Sound power level of the heat pump tested 2006 and later (a) plotted versus heat capacity (b) plotted versus COP.**

### 3.4 Conclusions

By evaluating the test results from 16 different heat pumps tested by SP on behalf of the Swedish Energy Agency and the Swedish Consumer Agency during the years 1999-2012 the following conclusions could be drawn.

- The heat pump performance (COP at different operating points) has increased significantly from 1999 – 2012. The arrangement of comparative tests from which the results are published has probably contributed to this development. However, the spread in the performance is large.
- Some of the air-to-water heat pumps on the Swedish market will might not pass the soon coming eco-design requirements, if their performance is not improved, while others will obtain an A++ on the energy label. At the same time, it will be possible for other types of space heaters having lower primary energy efficiency to pass their ecodesign requirements (e.g. fuel and electric boilers).
- No information about the efficiency of the heat pump at neither the cold nor the warm climate is given on the soon coming energy label. Hence, there is a risk that much focus will be put on improving the performance for an average climate, and that less attention will be paid on the cold climate
- A larger heat exchanger results in a greater seasonal coefficient of performance to some extent. Decreased fin spacing (within the evaluated range) has the same effect for the average climate but not for the cold climate (defined in the ecodesign and energy labeling regulation).
- The spread in acoustic performance is large, but most heat pumps on the market today will probably pass the requirements of the ecodesign regulations.

## 4 ACKNOWLEDGEMENT

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## NOMENCLATURE

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

$\eta_s$	seasonal space heating efficiency (-)
$CC$	conversion coefficient equal to 2.5 (-)
$COP$	coefficient of performance (-)
$COP_{PL}$	coefficient of performance at part load (-)
$elbu_j$	the required capacity of an electric backup heater for the corresponding temperature $T_j$ (kW)
$F(i)$	total correction factor (%)
$F(1)$	correction that accounts for a negative contribution to the seasonal space heating energy efficiency of heaters due to adjusted contributions of temperature controls, equal to 3%. (%)
$F(2)$	correction that accounts for the negative contribution to the seasonal space heating energy efficiency by electricity consumption of ground water pumps. This factor is only for water-/brine to water and water-/brine to air units and is equal to 5%. (%)
$h_j$	is the number of bin hours occurring at the corresponding temperature $T_j$
$H_{CK}$	crankcase heater mode operation hours (EN14825 and EU, 2013c) (h)
$H_{OFF}$	off mode operation hours according to (EN14825 and EU, 2013c) (h)
$H_{SB}$	standby mode operation hours according to (EN14825 and EU, 2013c) (h)
$H_{TO}$	thermostat off mode operation hours according to (EN14825 and EU, 2013c) (h)
$n$	Number of bins (-)
$P_{CK}$	crankcase heater power consumption (kW)
$Ph(T_j)$	heating demand of the building for the corresponding temperature $T_j$ (kW)
$P_{OFF}$	off mode power consumption (kW)
$P_{SB}$	standby power consumption (kW)
$P_{TO}$	thermostat off mode power consumption (kW)
$SCOP$	seasonal coefficient of performance (-)
$Q_H$	reference annual heating demand (kWh)
$Q_{HE}$	annual electricity consumption (kWh)
$T_j$	outdoor temperature in bin $j$ ( $^{\circ}C$ )