BRINE-TO-WATER HEAT PUMPS EVALUATED FOR NORDIC CLIMATE AND THE SWEDISH MARKET

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Abstract: A comparative test of eight brine-to-water heat pumps sold on the Swedish market has been performed at SP Technical Research Institute of Sweden on behalf of the Swedish Energy Agency. The test included measurements of performance for space heating (EN14511 and EN14825) and for heating of domestic hot water (EN16147). Similar tests were performed in 1998 and in 2005. The results from these tests show that the performance of the heat pumps has improved since 1998 and 2005, but also that the spread is significant. The seasonal coefficient of performance (SCOP) was calculated according to EN14825, which is the same measure that will be used in the eco-design and energy labelling directives for space heaters within the EU. A combined SCOP for alternating or simultaneous space and domestic hot water heating was also calculated by a method developed by SP. Results show that climate, heat demand and type of heating system of the house all have an impact on the SCOP, showing that heat pumps should be chosen with regard to the house and its location.

Key Words: brine-to-water heat pumps, efficiency, domestic hot water, SCOP, eco-design and energy labeling

1 INTRODUCTION

At the end of the last century the heat pump market started to grow considerably in Sweden. Today, Sweden has one of the most developed heat pump markets both in Europe and the rest of the world when it comes to using the heat pump predominantly for space heating and domestic hot water heating. Annual sales of brine-to-water heat pumps (mainly for ground source applications) in Sweden are shown in Figure 1.

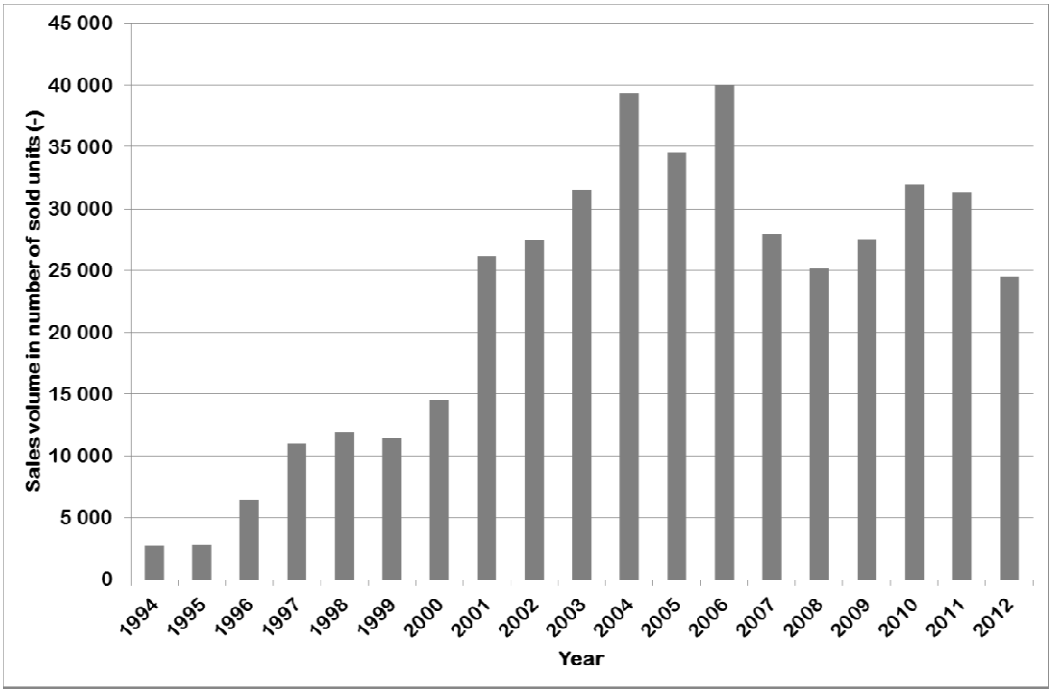


Figure 1: Annual sales of brine-to-water heat pumps in Sweden (SVEP, 2014 and EHPA, 2013)

From Figure 1 it can be seen that about 30 000 brine-to-water heat pumps have been sold annually in Sweden the last 10 years. Today it can be assumed that most houses that were previously using oil for heating have been retrofitted with other heat sources. Therefore the market will decline. However, brine-to-water heat pumps have been installed for so many years that the replacement market soon will become important.

In order to guide consumers regarding which heat pump to select, a number of brine-to-water heat pumps have been tested on behalf of the Swedish Energy Agency 2005 and 2012 (and the Swedish Consumer Agency in 1992-1998) and the results are published on their website. They are thereby the owners of the test results.

2 METHOD

The heat pumps have been evaluated in laboratory tests at SP Technical Research Institute of Sweden. The laboratory is accredited according to ISO 17025 for EN14511, EN14825 and EN16147, which are applied in these tests.

2.1 Test method for evaluation of energy performance

All the tested heat pumps were on-off controlled, and could provide both space heating and domestic hot water. 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 nine heat pumps performed in 1992-1998, EN 255 was applied. In 2005, when six heat pumps were tested, EN 255 had been replaced by EN14511 (year 2004) and therefore the heat pumps have not been tested at exactly the same test points and in exactly the same way. In the presented results in this article, only the performance at the rating point is compared. The major difference is that according EN255 the heating water and brine flow rates should be set according to the instructions by the manufacturer, while the heating water flow rate according to EN14511 should be set to reach a temperature difference of 5 K at rating conditions 0/35°C (inlet brine temperature / outlet water temperature), and the brine flow rate at the same conditions should be set to reach a temperature difference of 3 K.

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. When the following eight heat pumps were tested in 2012 the EN14511 standard had been revised again (2011) but this revision did not have any significant influence on the rating conditions 0/35°C for brine-to-water heat pumps. Also, a change had been made in the equation for correction of liquid pump power, but the change is assumed not to have a large impact on the COP.

A new feature in EN14511:2011 was that there were four rating conditions for brine to-water-heat pumps in the heating mode, to be applicable for different types of heating systems. The rating point 0/35°C was kept for low temperature application (floor heating). The heat pumps tested in 2012 were also tested for high temperature heating systems (radiator heating), with a rating point where the flow rates were set to reach a temperature difference of 8 K at the water side at 0/55°C (inlet brine temperature / outlet water temperature). The test results from both the low temperature application and the high temperature application have been used as input to calculate a seasonal coefficient of performance, as described in Chapter 2.2.

The expanded uncertainty of measurement is less than ±3% for the COP and the heating capacity.

2.2 Calculation method for evaluation of seasonal performance

Within the EU, eco-design (EU, 2013c) and energy labelling regulations (EU, 2013a) for space heaters have recently been approved and the first set of requirements come into force in September 2015. The seasonal space heating energy efficiency, η_s, is the key indicator that the eco-design requirements and energy label are based on. According to the regulations, the calculations shall be performed according to the newly published EN14825 standard and the tests shall be performed according to EN14825 and EN14511. The calculations have been performed according to EN14825 for the heat pumps tested in 2012. According to the regulations and EN14825, the seasonal space heating energy efficiency, η_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 climates.

Calculation of the seasonal space heating energy efficiency, η_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 °C, one for -9 °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 by an electrical resistance heater (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, 2013e) that are associated with the regulations.

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

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

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

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

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

The difference between SCOP and $SCOP_{on}$ is that $SCOP_{on}$ is the seasonal performance in on-mode, while SCOP includes electricity consumption in standby mode, off mode etc.
For explanation of the terms included, please see chapter "Nomenclature".

In those cases where data for the exact test points, required as input data to EN14825, are missing, interpolation and extrapolation based on adjacent test points have been performed.

The ecodesign requirements for heat pump space heaters, for high temperature application and average climate, are as follows (EU, 2013c):

Table 1: Ecodesign requirements

	Date:	η_s[1]
Tier 1	26 September 2015	100%
Tier 2	26 September 2017	110%

[1]Primary energy efficiency, including a conversion coefficient, which is set to 2.5 for electricity.

Heat pumps with poorer performance than the ecodesign requirements will not be permitted for sale on the European market.

The limits for the energy labels are shown in table 2 below (EU, 2013a).

Table 2: Energy labels

Seasonal space heating energy efficiency class:	**Seasonal space heating energy efficiency η_s**[1]
A^{+++}	$\eta_s > 150\%$
A^{++}	$125\% < \eta_s < 150\%$
A^{+}	$98\% < \eta_s < 125\%$
A	$90\% < \eta_s < 98\%$
B	$82\% < \eta_s < 90\%$
C	$75\% < \eta_s < 82\%$
D	$36\% < \eta_s < 75\%$
E	$34\% < \eta_s < 36\%$
F	$30\% < \eta_s < 34\%$
G	$\eta_s < 30\%$

[1]Primary energy efficiency, including a conversion coefficient, which is set to 2.5 for electricity.

2.3 Test method for domestic hot water

The heat pumps tested in 2012 were also tested for performance when heating domestic hot water according to EN16147. A coefficient of performance (COP_{DHW}) was calculated. The COP_{DHW} is calculated by comparing useful output energy of hot water and the energy input during one tapping cycle of 24 h. The tapping cycle L was used.

$$COP_{DHW} = \frac{Q_{TC}}{W_{EL-TC}} \quad (6)$$

An η_{WH} was calculated following the instructions in the transitional methods for eco-design (EU, 2013 f). The tapping cycle in the eco-design documents and in EN16147 is similar, but

not identical. The energy content is the same, but the EN16147 has fewer flow rates. Calculations were made on the results from the EN16147 tapping.

2.4 SP Method 4967: Combined heating of space and domestic hot water

In SP method 4967 the seasonal coefficient of performance combining both space heating and domestic hot water (DHW) is calculated. The calculations are made to reflect the yearly use of energy for heating and DHW for Swedish conditions. The calculations of $SCOP_{combi}$ and energy savings are based on the calculation method in EN14825, but the method has been modified in order to take into account also the heating of domestic hot water. Since the purpose of the method is to reflect the Swedish situation the cold climate is used. Input data to the calculations are taken from the test results of the space heating test and the domestic hot water heating performance test.

The calculation has been done for two types of house, described in Table 3 below:

Table 3: Summary of performance for type house 1 and 2

Quantity	Unit	House 1	House 2
Area	(m^2)	160	200
Heating demand (space heating)	(kWh/year)	19 965	30 070
Heating demand (DHW)	(kWh/year)	4 254	4 254
Design heat load at -22°C (P_{design}, space heating)	(kW)	8.1	12.2

3 RESULT AND DISCUSSION

The results shown are from comparative tests that have been performed on behalf of the Swedish Energy Agency and the Swedish Consumer Agency during the last two decades. The tests have been performed on brine-to-water heat pumps on the Swedish market.

The heat pump models tested were chosen in agreement with the manufacturers.

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). Since the aim of the article is to present general trends, and not results for specific manufacturers, the heat pumps tested in 2012 are referred to as heat pump 1-8 in the following figures.

3.1 Trends in performance of brine-to-water heat pumps

Since tests have been performed at intervals of a few years from 1992 to 2012, it is possible to study the development of the performance of the heat pumps. In Figure 2 below, COP is shown for an operating point with an inlet temperature of 0°C at the brine side, and an outlet temperature of 35°C on the water side (0/35°C). As described in Chapter 2.1, the tests were performed following two different standards, making the results not fully comparable.

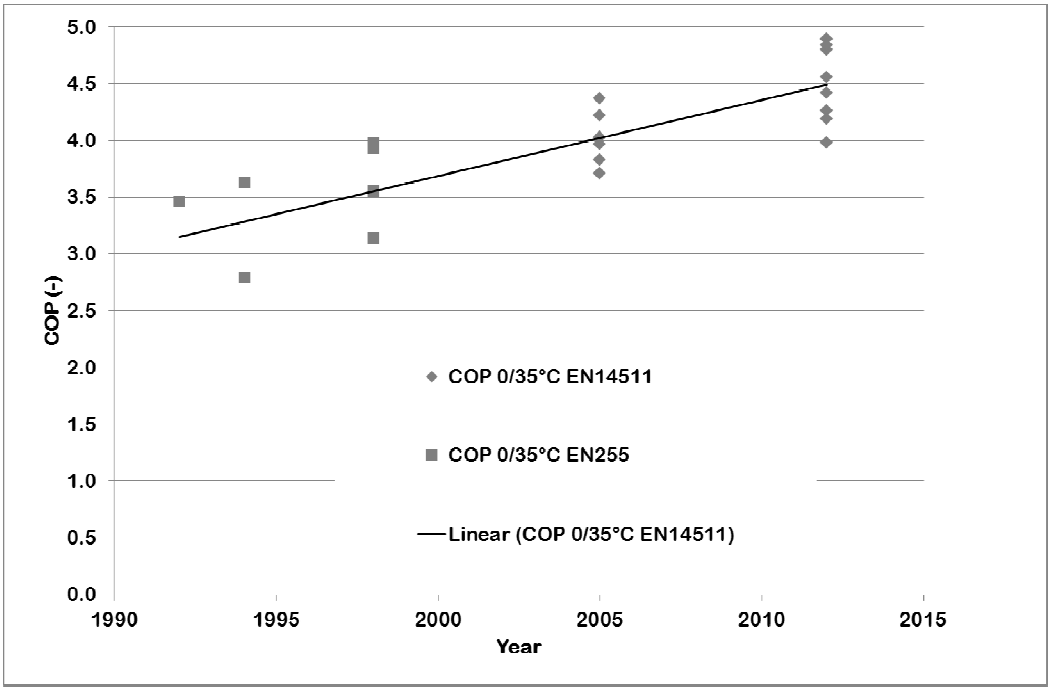


Figure 2: COP for brine-to-water heat pumps

The trend line drawn in the diagram is based on the results from 2005 and 2012. However, as seen in the diagram, it also represents the earlier tests reasonably well. It is clear that the performance of brine-to-water heat pumps is improving. All manufacturers that participated in both of the two latest evaluations have increased the efficiency of their products. The mean value of the COP at 0/35°C increased with around 10% from 2005 to 2012. Even though the tests from 1998 and 2012 are not fully comparable because of different standards used, it can be seen that the increase in COP at 0/35°C is more than 20%. Besides the improvements, it can also be seen that the spread is large between different heat pumps. Although figure 2 shows that there has been a significant improvement from 1998 to 2012, it cannot be used to predict the future development of the performance, since it is uncertain how the technical development will continue.

3.2 Performance in relation to the requirements in the eco-design and energy labelling regulations within the EU

For the heat pumps tested in 2012, a seasonal coefficient of performance (SCOP) was calculated according to EN14825 as described in Chapter 2.2. For the cold climate, calculations were made for a typical Swedish house with a P_{design} of 12.2 kW, having an annual heat demand of 30 000 kWh. Calculations were made both for low temperature systems (floor heating) and high temperature systems (radiator heating). The results are shown in Figure 3. As expected, the SCOP for the low temperature system is much higher than for the high temperature system.

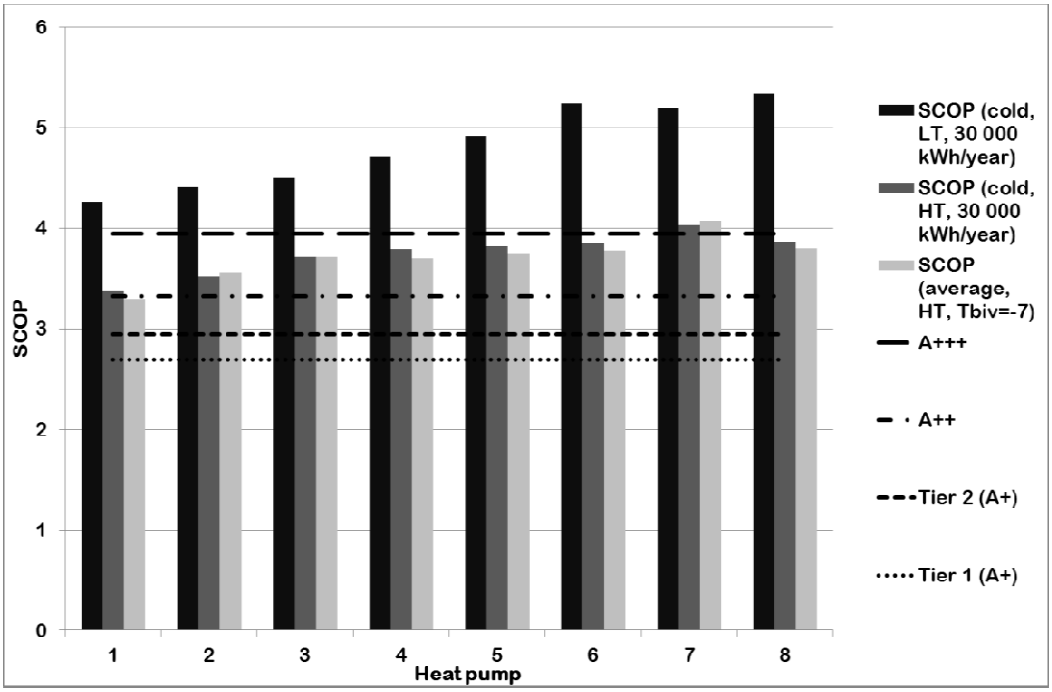


Figure 3: SCOP for brine-to-water heat pumps tested 2012

SCOP for the average climate was also calculated. For the average climate, calculations were made choosing a bivalent temperature instead of a specific house. 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. When marking the heat pump according to the EU eco-design directive, the average climate will be used. $T_{bivalent}$ is allowed to be between -10°C and +2°C. Heat pumps designed for the Swedish market will probably have the highest SCOP if calculations are made with a bivalent temperature where the heat pump is almost covering the total heating demand of the house, but not all. Therefore, SCOP for the average climate and a bivalent temperature of -7°C is shown in Figure 3. This is probably the SCOP that the energy labelling will be based on.

The limits for the energy labelling are shown in Figure 3, together with the tiers in the eco-design directive. The first tier will be implemented in 2015, and the second tier in 2017. Heat pumps with poorer performance than required by the eco-design directive will not be permitted for sale on the European market. As seen none of the tiers will affect the tested heat pumps. One of the heat pumps will have the highest possible energy label, A+++, while most of the others will have the second best energy label, A++. It might seem strange that almost all of the heat pumps already today reach label A++. But then it should be remembered that the energy labelling includes many types of space heaters, for example fuel boiler space heaters and electric boiler space heaters, and they are all in the same labelling system based on primary energy efficiency. For electricity, a conversion coefficient of 2.5 is assumed when calculating primary energy efficiency. This means that the highest possible theoretical value for an electrical boiler space heater is 40%, and for a fuel boiler space heater it is 100%. For a heat pump, as shown above, it is possible to reach the highest energy label even when using a conversion coefficient of 2.5.

If studying figure 3 again, it can be seen that the heat pump with the highest seasonal coefficient of performance for floor heating was not the heat pump with the highest seasonal coefficient of performance for radiator heating. Therefore, it is important that the heat pump should be chosen depending on the type of heating system in the existing house. In the energy labelling for combination heaters, only the SCOP for radiator heating will be showed.

There are not enough test data to calculate SCOP for the heat pumps tested previously. However, such data can be estimated. As shown in Figure 4, SCOP average for high temperature systems with $T_{bivalent}$ = -7°C is similar to the COP at the operating point with an inlet temperature of 0°C at the brine side, and an outlet temperature of 45°C on the water side (0/45°C), with the flow rates obtained at the high temperature rating point 0/55°C.

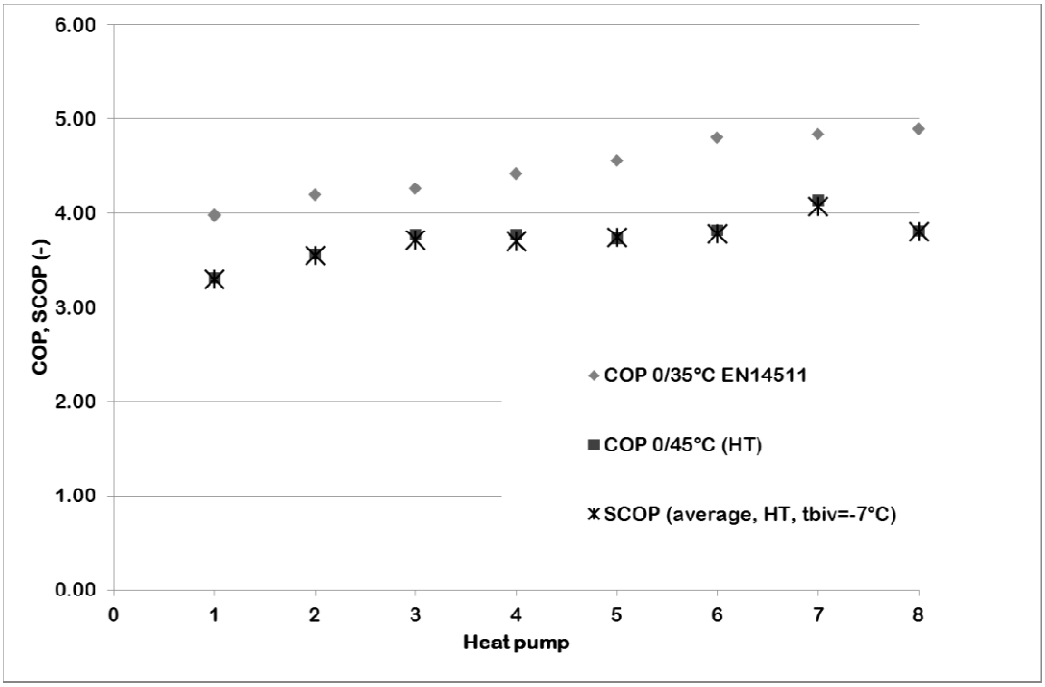


Figure 4: COP and SCOP for heat pumps tested 2012.

The mean value of the COP at 0/45°C is 17 % lower than the mean value of the COP at 0/35°C. Showing Figure 2 again, adding a line of a 17% lower trend line, gives an approximation of what the mean energy class would have been. This is found below in Figure 5.

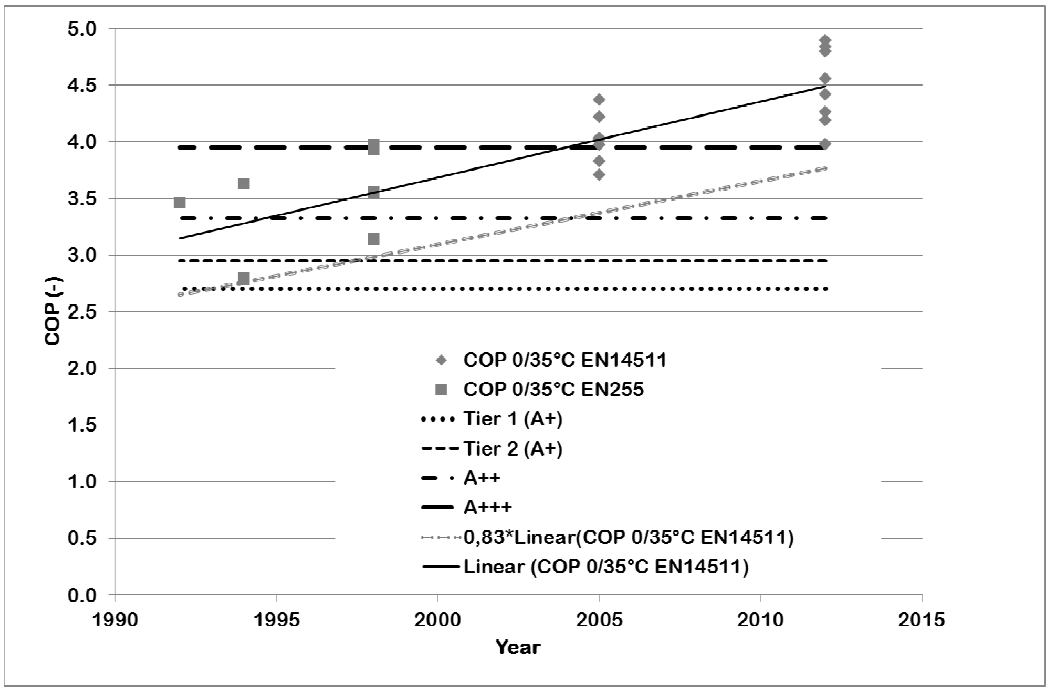


Figure 5: Approximated COP at 0/45°C

The dotted line 0.83*linear(COP at 0/35°C) can be expected to approximate the mean COP value at 0/45°C, and therefore the approximate mean SCOP value at the average climate. In 2012 it is A++ but close to A+++, in 2005 it is A++, and in 1998 is was approximately at the threshold for tier 2.

3.3 Performance including domestic hot water

The heat pumps tested in 2012 was also tested for domestic hot water (DHW) production according to EN16147, resulting in a COP for heating of DHW. Afterwards, η_{wh} was calculated according to the transitional methods for water heating (EU, 2013f). η_{wh} is expressed in terms of primary energy and therefore includes the conversion coefficient for electricity, which is set to 2.5. The results are shown in Figure 6, together with the thresholds in the ecodesign directive (EU, 2013 d) and the limits for the energy labelling classes (EU, 2013 b). The thresholds and limits are all for the η_{wh} -value.

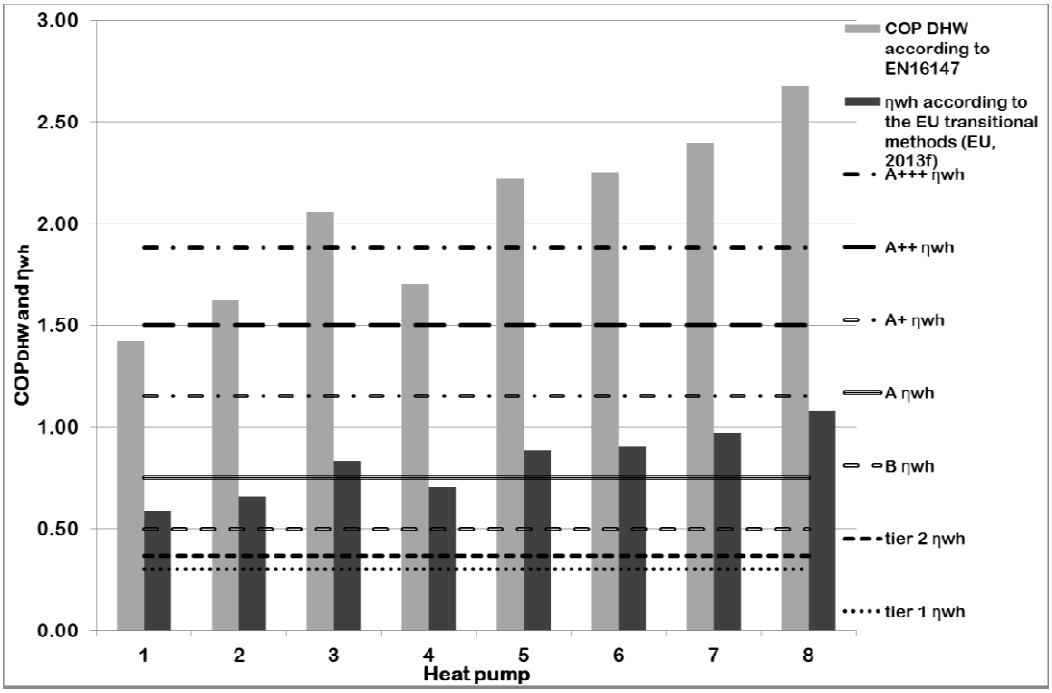


Figure 6: η_{wh} for heating of domestic hot water

In Figure 6, it can be seen that all heat pumps tested in 2012 will pass the thresholds both for tier 1 and tier 2. Most of the heat pumps will meet the requirements for energy label A, while the others will receive energy label B for domestic hot water heating. The spread is large in efficiency between the different models when it comes to heating of domestic hot water. The heat pump with the highest efficiency has almost twice as high efficiency as the heat pump with the lowest efficiency. However, the difference in energy label will only be one step (from A to B).

Including domestic hot water in the calculations of the seasonal performance, using a method developed by SP as described in Chapter 2.4, a combined seasonal coefficient of performance called $SCOP_{combi}$ is obtained. The results are shown in Figure 7.

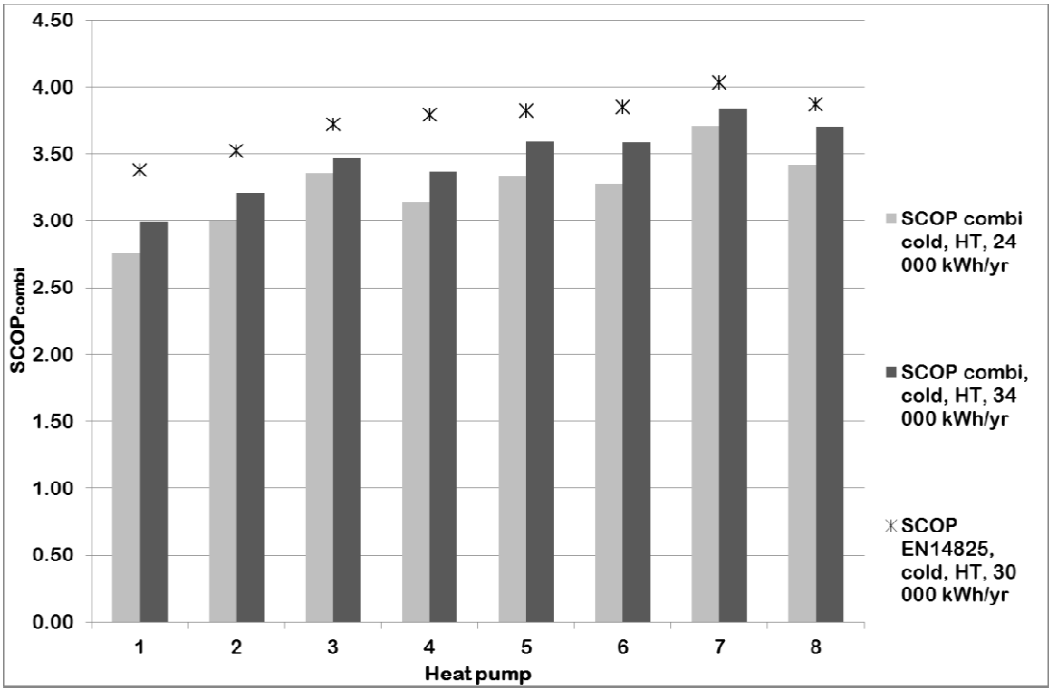


Figure 7: $SCOP_{combi}$, cold climate, high temperature application

The $SCOP_{combi}$ evaluated for an annual heating demand of 34000 kWh/yr is calculated for the same house as the shown SCOP according to EN 14825 for an annual heating demand of 30000 kWh/yr, but also including the domestic hot water. As seen in Figure 7, the SCOP is lowered when domestic hot water is included because of the high temperature needed all year around when producing hot water. For a customer installing a heat pump providing both space heating and domestic hot water heating, $SCOP_{combi}$ will be the seasonal coefficient of performance that best represents the reality.

Results are shown for two houses of different size. For the smaller house, the heat pumps cover all heat demand. For the larger house, a back-up heater has to be used to cover the peak load the coldest days of the year. Still, the best SCOP is obtained for the larger house. The reason for this is that for the smaller house, the heat pump has a surplus capacity during a larger part of the time, making it operate on/off and lowering the performance.

3.4 Conclusions

By evaluating the test results from 20 different heat pumps tested by SP on behalf of the Swedish Energy Agency and the Swedish Consumer Agency during the years 1998-2012 the following conclusions could be drawn.

- The heat pump performance (COP at different operating points) has increased significantly from 1998 – 2012. However, the spread is large.
- The spread is even larger when it comes to the COP for domestic hot water for the heat pumps tested in 2012. The heat pump with the highest efficiency had almost twice as high efficiency as the heat pump with the lowest efficiency. Still, the difference in energy label will only be one step.
- The brine-to-water heat pumps tested in 2012 will pass the tiers in the eco-design directive, both for space heating and domestic hot water.
- For space heating, most of the heat pumps tested in 2012 will obtain energy label A++ and one even A+++. For domestic hot water heating, however, they will only obtain the energy labels A and B.

- The heat pump should be chosen differently depending on whether the house uses floor heating or radiator heating. A heat pump covering the total heat demand of the house does not give the best SCOP.

4 ACKNOWLEDGEMENT

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5 REFERENCES

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EU, 2013c. Commission Regulation (EU) No 813/2013 of 2 August 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to the ecodesign requirements of space heaters and combination heaters

EU, 2013d. Commission Regulation (EU) No 814/2013 of 2 August 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to the ecodesign requirements for water heaters and hot water storage tanks

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EU, 2013f. Communication from the Commission (Transitional methods) for water heaters and hot water storage tanks, of 15 December 2013 (20131215_TRANS_WaterHeaters.doc)

SVEP 2014. Website of the Swedish Heat Pump Association, www.svepinfo.se

NOMENCLATURE

Full definitions of the parameters can be found in standard EN14511, EN14825, EN16147 and the eco-design requirements (EU 2013c and EU 2013d).

η_s	seasonal space heating efficiency (-)
η_{wh}	water heating energy efficiency (-)
CC	conversion coefficient equal to 2.5 (-)
COP	coefficient of performance (-)
COP_{DHW}	coefficient of performance for tapping domestic hot water (-)
COP_{PL}	coefficient of performance at part load (-)
$elbu_{\mathrm{j}}$	required capacity of an electric backup heater for the corresponding temperature Tj (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 (%) (EU, 2013e)
$F(2)$	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 (%) (EU, 2013e)
h_{j}	number of bin hours occurring at the corresponding temperature Tj (h)
H_{CK}	crankcase heater mode operation hours (EN14825 and EU, 2013e) (h)
H_{OFF}	off-mode operation hours (EN14825 and EU, 2013e) (h)
H_{SB}	standby-mode operation hours (EN14825 and EU, 2013e) (h)
H_{TO}	thermostat off-mode operation hours (EN14825 and EU, 2013e) (h)
n	number of bins (-)
P_{CK}	crankcase heater power consumption (kW)
Ph(Tj)	heating demand of the building for the corresponding temperature Tj (kW)
P_{OFF}	off-mode power (kW)
P_{SB}	standby-power (kW)
P_{TO}	thermostat off-mode power consumption (kW)
Q_{TC}	Total useful heat energy during the whole tapping cycle (kWh)
$SCOP$	seasonal coefficient of performance (-)
$SCOP_{on}$	active mode seasonal coefficient of performance (-)
Q_H	reference annual heating demand (kWh)
Q_{HE}	annual electricity use (kWh)
Tj	outdoor temperature in bin j (°C)
W_{EL-TC}	Total electrical energy consumption during a tapping cycle (kWh)