# EXHAUST AIR HEAT PUMPS EVALUATED FOR NORDIC CIRCUMSTANCES

*Markus Lindahl, MSc, SP Technical Research Institute of Technology, Energy Technology, Box 857, 501 15 Borås, Sweden;*
*Caroline, Haglund Stignor, Head of Building Services Engineering, SP Technical Research Institute of Technology, Energy Technology, Box 857, 501 15 Borås, Sweden;*
*Kajsa Andersson, Head of Group Heat pumping technology and air treatment; SP Technical Research Institute of Technology, Energy Technology, Box 857, 501 15 Borås, Sweden*
*Stefan Thyberg, Test engineer, SP Technical Research Institute of Technology, Energy Technology, Box 857, 501 15 Borås, Sweden;*

**Abstract:** The exhaust air heat pump (EAHP) is a common heat pump type in Sweden. About 9% of the existing building stock is heated by an EAHP. For a long time, the maximal heating capacity of EAHP was normally just above 2 kW. During the last years a new type of EAHP has been common on the market. This type is inverter controlled and has a maximal heating capacity of 5-6 kW. A number of “new type” and “old type” heat pumps have been evaluated in independent laboratory tests at SP on behalf of the Swedish Energy Agency. The efficiency and capacity in both space heating and DHW production has been measured. Based on the test results SCOP and $\eta_S$ according to EUs ecodesign regulations has been calculated. The results shows that none of the “old type” exhaust air heat pump will pass the requirements in Tier 2. Thereby the evaluated “old type” of EAHPs will not be allowed to be placed on the European market from 2017 without an improved performance.

**Key words: exhaust air heat pumps, efficiency, domestic hot water, ecodesign**

## 1 INTRODUCTION

An exhaust air heat pump (EAHP) uses the ventilation (exhaust) air as a heat source. In an exhaust air ventilated house the fresh ventilation air is taken into the house via ventilators, this air is taken directly from the outdoor environment and is thereby unheated. The exhaust air heat pump normally delivers its produced heat to a water heating system as well as to the domestic hot water (DHW) system. EAHP delivering heat to the DHW system only exists as well.

In order to guide consumers which heat pump to select, a number of exhaust air heat pumps have been tested on behalf of the Swedish Energy Agency in 2011 and 2012, the results are published on their website (Energimyndigheten 2014). No publications summarizing results from laboratory tests of exhaust air heat pumps or how EUs ecodesign regulation will impact on the heat pump type have been found in the open literature. There are reports and papers related to the heat pumping technology in EAHPs, e.g. Fehrm (Fehrm 2005), focusing on technical issues and sales trend related to EAHPs without going into details about their heating performance.

### 1.1 Sales Trends of Exhaust Air Heat Pumps in Sweden

SVEP, the Swedish heat pump association, presents sales figures each year for exhaust air heat pumps in Sweden. Sales figures from 1994 until 2013 is presented in Figure 1 below. Based on reported data from installers to SVEP about heating capacity of installed units it can be seen that the absolutely main part of the sold EAHP has a nominal heating capacity of 0-6 kW and the average size is around 2-3 kW. It is only a few units sold, having a larger capacity than 6 kW (SVEP 2014a and 2014b).

The main part of the sold EAHP has been installed to new built houses. For a number of years exhaust air heat pumps was installed in 90% of all new built single family houses. Some significantly larger heat pumps have also been sold to multifamily houses for both new build houses and retrofit.

Figure 1 shows a steady increase in the number of sold EAHP from 1994 until 2006. From 2006 until 2012 the sales figures have decreased for each year, but 2013 an increase in sold units could be noticed again. The cause to the decreasing sales figures is due to a decreased building of new houses, but it is also likely that brine to water heat pumps or district heating has been chosen instead of exhaust air heat pumps.

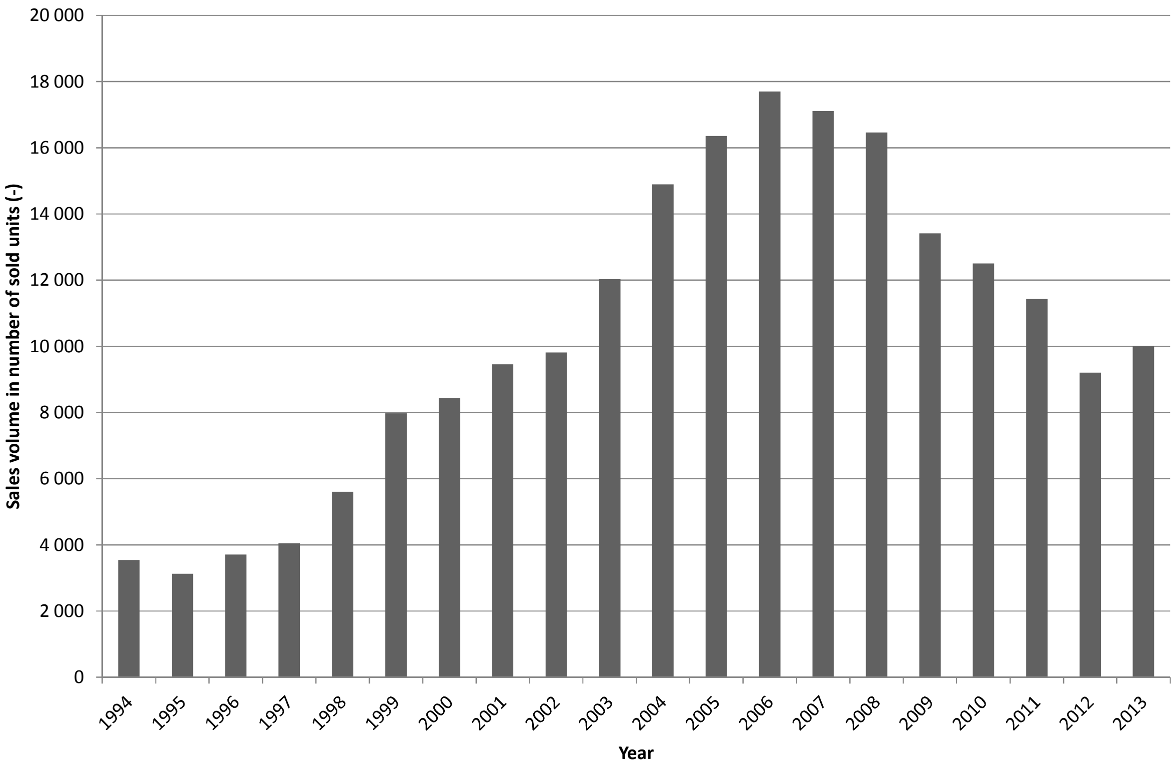


**Figure 1. Number of sold exhaust air heat pumps in Sweden 1994 – 2013 (EHPA, SVEP 2014b)**

## 1.2 Two Types of Exhaust Air Heat Pumps

In 2009 a new building code came into force in Sweden, BBR 16 (Boverket 2008), until then most of the exhaust air heat pumps had a fixed speed compressor working in an on/off operation. The heat pumps had a maximum electrical power of approximately 700 W and cooled down the ventilation air from 20 °C to between 5 and 0°C, which gives a maximal heating capacity of about 2 kW. The rest of the heating demand in the house was covered by an electric back-up heater. This type of heat pump is referred to as "old type" in this paper.

However, in order to fulfill the requirements regarding energy and maximum power demand in BBR 16, a new type of exhaust air heat pump has become more common on the Swedish market. This type is inverter controlled and is able to cool down the ventilation air from 20°C to -15°C. Thereby the heat pump can work efficient when the heating demand is low, due to its possibility to reduce the frequency of the compressor and in the same time it has the possibility to extract more heat from the exhaust air. For this heat pump type, with a maximum electrical power just below 2 kW, the maximal heating capacity is about 5-6 kW. This type is referred to as the “new type”.

After the Swedish building code, BBR 16, came into force the “new type” of EAHP is normally used for new constructions. But in the retrofit market the old type still has an important market share. Since the price for the “new type” is significantly higher compared to the “old type” (8 000-10 000 Euro compared to 4 500-5 500 Euro), it is likely to assume that the “old type” is many times chosen although its lower capacity and efficiency.

### 1.3 Efficiency, COP and SCOP

The capacity of the heat source of an exhaust air heat pump is limited by the ventilation air flow. This flow is specified by the minimum demands in the building regulations. From an energy point of view it is pointless to increase the ventilation flow above the required level in order to increase the heat source, since it will only lead to an increase in the heating demand of the house. The seasonal coefficient of performance (SCOP) for an exhaust air heat pump is strongly dependent of how much of the heat load the heat pump can cover at low outdoor temperatures without support from the back up heater. This in turn depends on the heat pumps capacity to use the heat in the exhaust air, namely cool down the exhaust air leaving the house. The “new type” of exhaust air heat pump described above can cool down the exhaust air from 20°C to -15°C, giving a higher heating capacity. COP values at single test points are therefor of less interest in this context.

## 2 METHOD

Three “new type” and one “old type” heat pump have been evaluated in independent laboratory tests at SP Technical Research Institute of Sweden on behalf of the Swedish Energy Agency during 2011-2012. 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) has been evaluated according to SP method 2800, using the test point specified in Table 1 below. Pump corrections and evaluation of the test points is made according to EN14511:2011.

**Table 1. Test point in space heating mode for EAHP**

| Test point | Temperature Exhaust air In to the heat pump [°C] | Flow, Exhaust air [$m^3$/h] | Frequency, compressor (Hz) | Outlet temperature, Water for space heating (°C) |
|---|---|---|---|---|
| 1 | 20 (12)[a] | 150 | Max | 55 |
| 2 | | | Max | 35 |
| 3 | | | Min | 55 |
| 4 | | | Min | 35 |
| 5 | | 230 | Max | 55 |
| 6 | | | Max | 35 |
| 7 | | | Min | 55 |
| 8 | | | Min | 35 |

a) The temperature in brackets shows the wet bulb temperature

The test of domestic hot water heating performance was made according to EN16147:2011 part A-D and an exhaust air flow of 230 $m^3/h$ were used. Tapping cycle Large (24 tapping's, totally 11,655 kWh/day) was used in part C. See Table 2 for details about the tap test.

**Table 2. Parts included in the domestic hot water heating test according to EN16147.**

| Part | Description |
|---|---|
| A | Heating up period |
| B | Determination of standby power input |
| C | Determination of the energy consumption and COP for heating domestic water by using the reference tapping cycle Large. |
| D | Determination of reference hot water temperature and the maximum quantity of usable hot water in a single tapping. |

### 2.2 Calculation Method for Evaluation of Seasonal Performance According to EU Ecodesign

The EU ecodesign (EU, 2013a) and energy labeling regulations (EU, 2013b) for space heaters have recently been voted and the requirements are planned to come into force in September 2015. In order to evaluate how the new requirements will affect the EAHP approximate values of the seasonal space heating energy efficiency, $\eta_s$, has been calculated. This is the key indicator that the ecodesign requirements and the energy label are based on. According to the regulations, the calculations shall be performed according to the EN14825 standard and the tests shall be performed according to EN14825 and EN14511. Since the performance test don't follow EN14825, test results are missing for e.g. performance at off mode, standby mode and thermostat off mode. For each mode, assumptions regarding the energy performance have been made.

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 of $\eta_s$ have been done for the average climate only.

The calculations in EN 14825 are based on a so-called bin-method. In a bin-method one have collected, calculated and sorted all hours with a specific outdoor temperature for a location. All hours with an outdoor temperature of 5°C is collected in one bin and all hours with an outdoor temperature of 6°C is collected in the next and so on. By calculating the performance of the heat pump for each outdoor temperature one can summing how efficient the heat pump is working over the year for a given climate.

For the hours when the heating demand of the house is lower than the lowest capacity of the heat pump, it is assumed that the heat pumps are cycling on and off. For these hours it is assumed that the warm heat transfer medium temperature is higher than the temperature given by the heating curve to compensate for the periods when the compressor is off. For the hours when the heat pumps capacity is lower than the heating demand it is assumed that the heat pumps are pre-heating the water and the backup with an electrical resistive heat (COP=1) finalizes the heating to the desired temperature. 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 EN14825 standard and in the transitional methods (EU, 2013c) that has been published together with the regulations.

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

$$F(i) = F(1) + F(2) \tag{2}$$

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

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

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

Data for the test points, required as input data to EN14825 has been extrapolated/interpolated from the test point specified in Table 1. First to correct temperature (the temperatures corresponding to part load A-F in EN14825), second to correct exhaust air flow. Finally COP for part load A-F is calculated.

### 2.3 SP Method 4964, $SCOP_{combi}$ Combining Space Heating and Domestic Hot Water Production

In SP method 4964 the seasonal coefficient of performance combining both space heating and domestic hot water (DHW) production is calculated. The calculations are made to reflect the yearly energy consumption for heating and DHW production 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 the production of the domestic hot water into account. Since the purpose with the method is to reflect the Swedish situation the cold climate is used. Input data to the calculations will be taken from the test results from the space heating test and the domestic hot water heating performance test.

The calculation has been done for two type houses, described in Table 3 below. Two different heating systems have been included in the calculations, a high temperature system with radiators and a low temperature system for floor heating.

**Table 3. Summary of performance for type house 1 and 2**

| | | Type house 1 | Type house 2 |
|---|---|---|---|
| Area | (m2) | 120 | 180 |
| Heating demand (Space heating) | (kWh/year) | 12 000 | 18 200 |
| Heating demand (DHW) | (kWh/year) | 4 200 | 4 200 |
| $P_{design}$, Full heating load at -22°C, (Space heating) | (kW) | 4,85 | 7,40 |
| Air flow ventilation | (m3/h) | 151 | 227 |

## 3 RESULT AND DISCUSSION

### 3.1 Trends in Space Heating Performance

In Figure 2 the test results regarding COP values for space heating from the independent test of four exhaust air heat pumps sold on the Swedish market are summarized. Since the “old type” 1 has a fixed speed compressor it has only been tested at the four test points where the heat pumps are working at maximum frequency (test point 1-2 and 5-6).

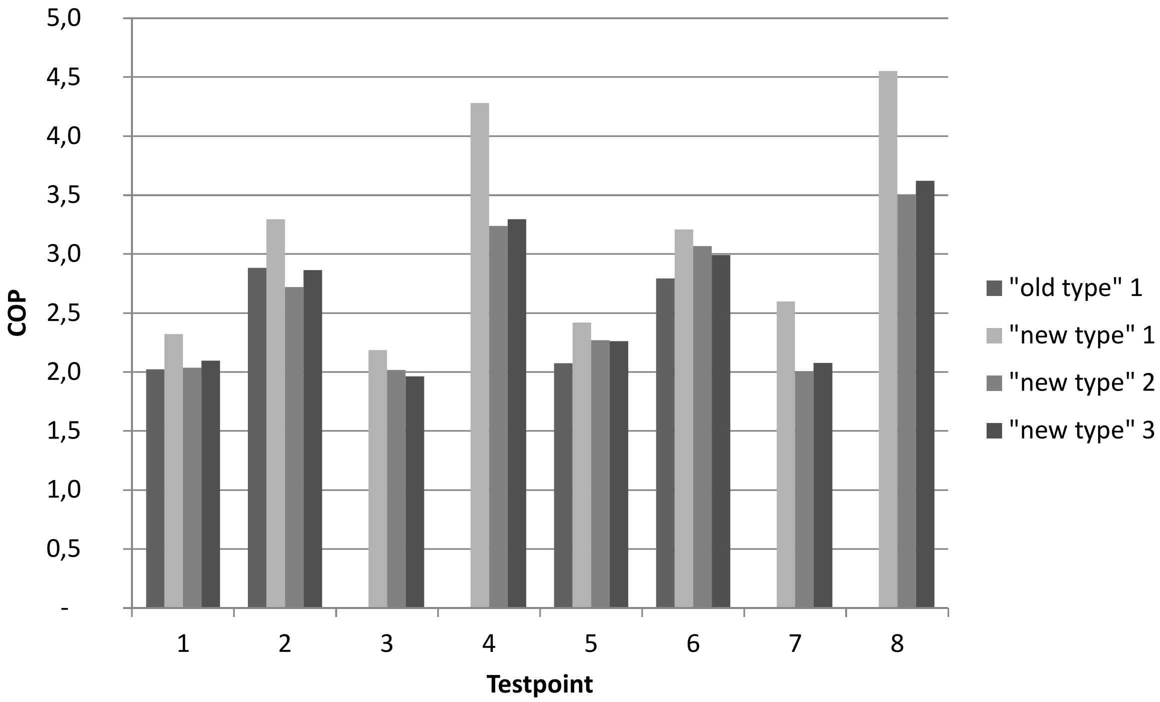


**Figure 2. COP for the EAHPs working in space heating mode at different test points from independent tests of exhaust air heat pumps. Test points according to Table 1.**

One can see that “new type” 1 in general has the highest COP value of the tested units, but despite from that it is hard to see any clear ranking between the heat pumps. Focusing on the test points where “old type” 1 has been included, there is no visible difference between the “old type” and the “new type” in the performance at single test points.

### 3.2 Trends in Performance of Domestic Hot Water Production

In Figure 3 below the $COP_{DHW}$ values from the domestic hot water production test is summarized, as for the performance test related to space heating the “new type” 1 has the highest COP value. Notable is that the “old type” 1 has the second highest COP in the test.

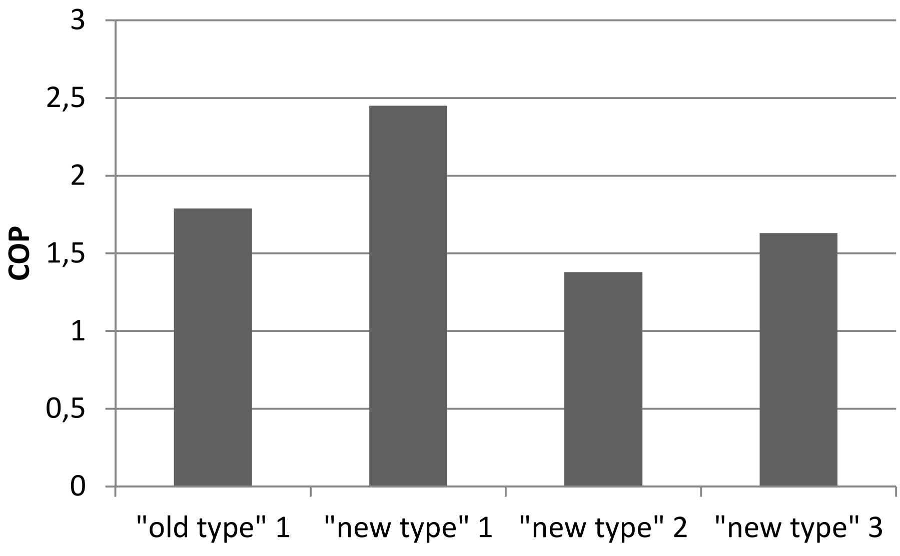


**Figure 3. $COP_{DHW}$ for the EAHP producing domestic hot water**

### 3.3 $SCOP_{combi}$ Combining Space Heating and Domestic Hot Water

For the exhaust air heat pumps tested and evaluated on behalf of the Swedish Energy Agency a seasonal coefficient of performance combining the production of space heating and domestic hot water ($SCOP_{combi}$) has been calculated. The calculations are made for both a high temperature system with radiators and a low temperature system for floor heating in two type houses of different size, see chapter 2.3 for details about the method.

Figure 4 below shows the results of the calculations, the $SCOP_{combi}$ values are between 1.5 and 2 for the old type and between 2.2 and 3.0 for the new type. Especially for the larger house (type house 2) there is a clear difference in efficiency between the old and the new type of heat pump. Note that although there were only small differences in COP between the heat pump types, there are large differences in $SCOP_{combi}$. This is mainly due to two things; First the small capacity of the “old type” giving a large demand of back up heat, second the “new type” has a variable speed compressor and thereby it can work more efficient compared to the “old type” when the heating demand is low.

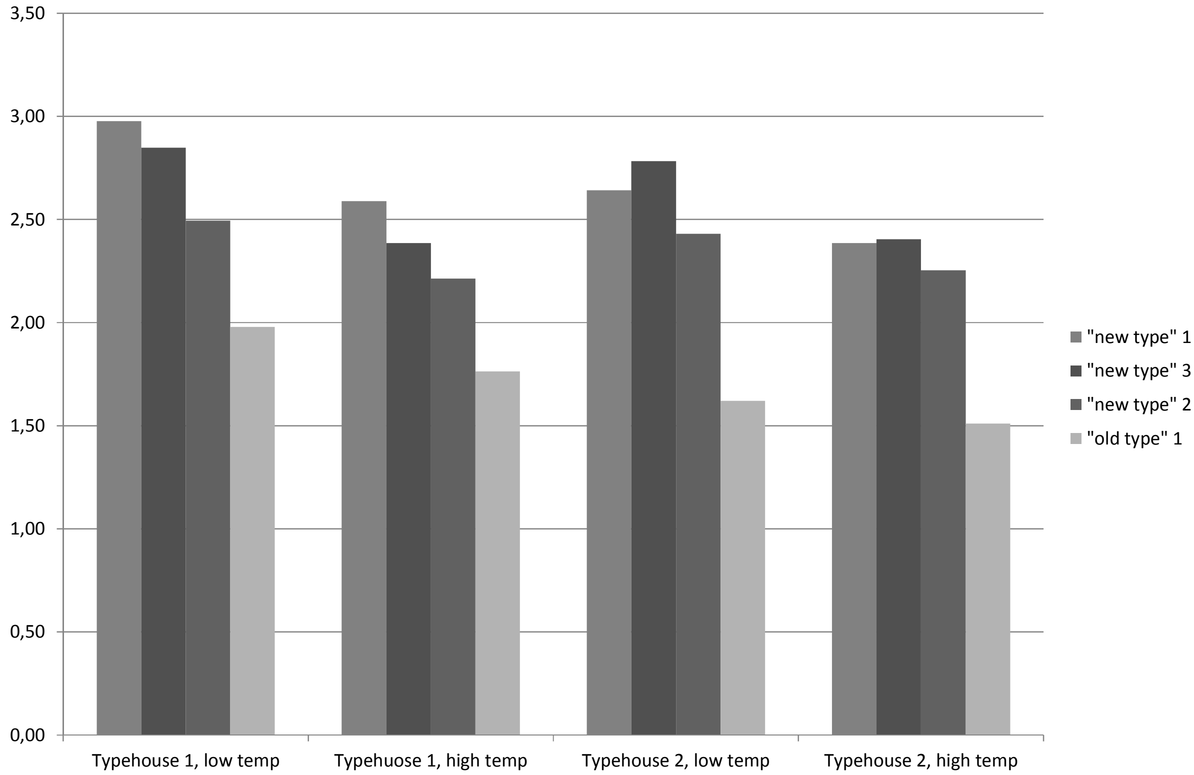


**Figure 4. Seasonal coefficient of performance combining space hating and DHW production, $SCOP_{combi}$, for four different exhaust air heat pumps**

### 3.4 Performance in Relation to the Requirements in the Ecodesign and Energy Labeling Regulations within EU

Figure 5 shows the $\eta_s$-values (seasonal space heating energy efficiency) for average climate for five heat pumps, three is “new type” and two is the “old type”. The data for three “new type” and one of the “old type” is based on test results from the independent tests performed at SP. For the heat pump called “old type 2” the calculated $\eta_s$ shown in Figure 5 is based on data from the producer.

The calculations are made for a high temperature system and for two different air flows at 150 and 230 $m^3/h$, the higher flow is close to the maximum flow of the heat pump. Different values of the bivalent temperature have been used in the calculation of $\eta_s$ ( +2℃, -2℃, -6℃ and -10℃) and the temperature giving the highest values of $\eta_s$ are shown in the Figure 5.

The bivalent temperature is the lowest outdoor temperature where the heat pump can cover the total heating demand of the house without any support from the back up heater. In Table 4 more details about the results are summarized.

The diagram shows that both the “old types” of exhaust air heat pumps will have difficulties to fulfill the demands for ecodesign tier 2 (2017), one of them will also have problem to reach the demands for tier 1 (2015). Thereby the evaluated “old type” of EAHPs will not be allowed to be placed on the European market from 2017 as it looks today. A product development focusing on improving the capacity and efficiency of the heat pump is needed to reach tier 2. The “old type” of EAHP has not been much developed during the last 12-15 years. One reason is that it has mainly been sold to house building companies, probably focusing more on price than a high performance of the heat pump. The heat pump has been included in the total price of the sold house and the future house owner, who will stand for the heating cost, has a small chance to influence the choice of product.

Note that for heat pumps the limit in tier 2 in EUs ecodesign is set to 110% (125% for low temperature applications), while the demand for fuel boilers are set to 86% and for electrical boilers to 36% (Official Journal of the European Union 2013). Thereby EAHP struggling to fulfill tier 2 for heat pumps still are very energy efficient compared to boilers for fuel or electricity which fulfills their demands for tier 2.

The new Swedish building code from 2009, BBR 16, forced the heat pump producers to focus the development on a new type of EAHP in order to be able to keep selling to the new construction market. The new type of heat pump will have no problem to fulfill the demands of neither tier 1 and probably nor tier 2. Two of the tested units might need some product development in order to fulfill tier 2, but this can probably be done by choosing more energy efficient pumps and fans. The most efficient of the exhaust air heat pumps tested would be labeled with an A++.

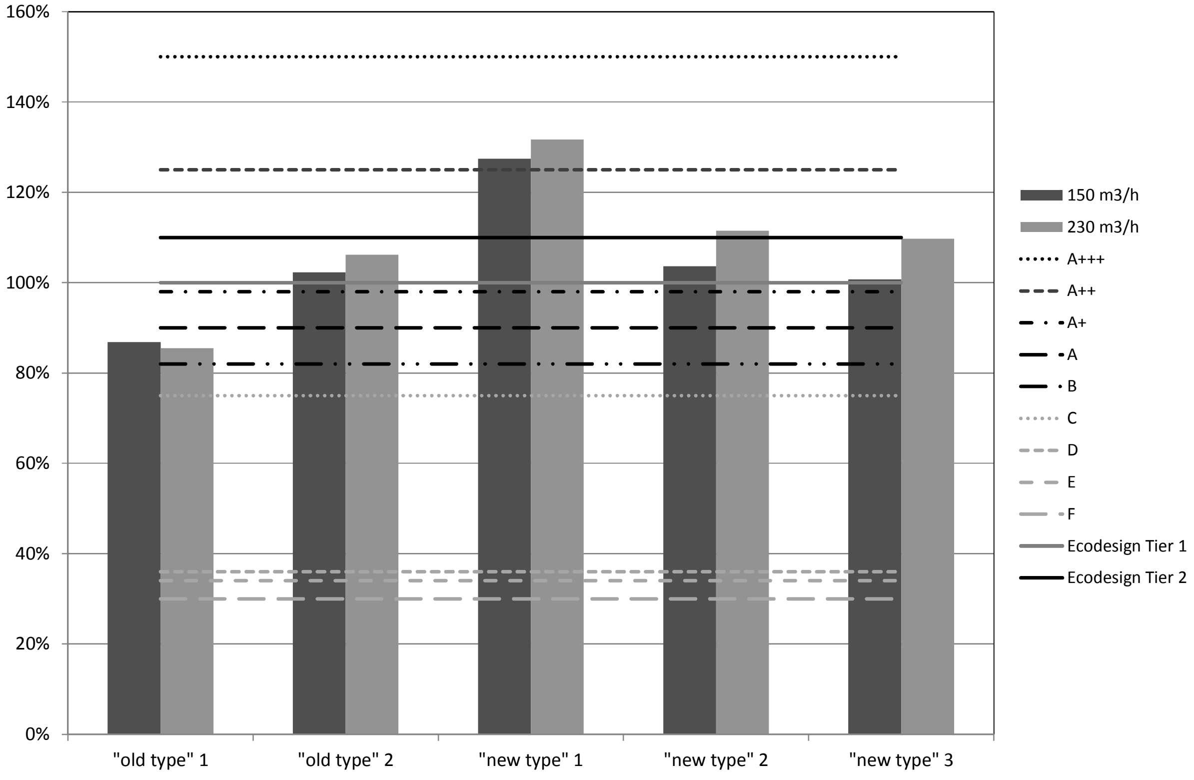


**Figure 5. Calculated values of $\eta_s$ for the EAHP tested on behalf of the Swedish Energy Agency 2011-2012 compared to Energy classes and eco design requirements. Calculations made at optimal bivalent temperature for a high temperature system**

**Table 4. Optimal values of the bivalent temperature ($T_{biv}$) and full load heating ($P_{design}$*) for the different heat pumps evaluated**

| | | Air flow: 150 m³/h | | Air flow: 230 m³/h | |
|---|---|---|---|---|---|
| **Name** | $T_{biv}$ | $P_{design}$ | $\eta_s$ | $P_{design}$ | $\eta_s$ |
| “old type” 1 | 2 | 2,6 | 87% | 3,2 | 86% |
| “old type” 2 | -2 | 2,4 | 102% | 2,6 | 106% |
| “new type” 1 | -10 | 2,7 | 127% | 2,7 | 132% |
| “new type” 2 | -10 | 3,6 | 104% | 3,4 | 112% |
| “new type” 3 | -6 | 3,9 | 101% | 4,9 | 110% |

* $P_{design}$ is the full load heating demand of the house the coldest hour of the year

### 3.5 Conclusions

By evaluating the results from the performance tests and calculations of SCOP and $\eta_S$ following conclusions can be drawn:

- The maximal heating capacity for an EAHP has increased from approximately 2 kW for an “old type“ to 5-6 kW for a “new type“. The increased heating capacity is due to an increased possibility to cool down the exhaust air. Combined with an inverter controlled compressor the “new type” has both a larger maximum capacity and can work more efficient when the heating demand is low.
- Since the maximum heating capacity of an EAHP is rather small, also for the “new type”, the exhaust air heat pump is most suitable for energy efficient houses with a low maximum heating demand.
- In order to increase the SCOP value for an EAHP it is most important to increase the maximum heating capacity in order to limit the use of back up heat. High COP values at a single test points are of less importance for the total SCOP result.
- EAHP of the “old type” will have difficulties to fulfil the demands of EUs ecodesign tier 2. One of the evaluated “old type” heat pumps will have problems to reach the demands for tier 1 as well. This indicates that the evaluated “old type” of EAHPs will not be allowed to be placed on the European market from 2017 without an improved performance. The “new type” is likely to fulfil the demands of ecodesign tier 2, even though some product development might be needed to reach the target.
- The requirements for ecodesign are all based on the average climate. Thereby there is a risk that future product development will focus on improving the product for the average climate in order to fulfil the requirements and get a high energy label. Hence there will be less focus on the performance of the heat pump in the cold and warm climate.

## 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 (-) |
| $elbu_j$ | is the 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% (%) |

| | |
|---|---|
| $F(2)$ | 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 Tj |
| $H_{CK}$ | crankase 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) |
| $n$ | Number of bins (-) |
| $P_{CK}$ | crankcase heater power consumption (kW) |
| $P_{design}$ | full load heating (kW) |
| $Ph$(Tj) | heating demand of the building for the corresponding temperature Tj (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) |
| $T_{bivalent}$ | bivalent temperature (℃) |
| $Tj$ | outdoor temperature in bin j (℃) |