Nordic Council of Ministers

NORDSYN STUDY ON AIR-TO-WATER HEAT PUMPS IN HUMID NORDIC CLIMATE

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Caroline Haglund Stignor and Tommy Walfridson

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Caroline Haglund Stignor and Tommy Walfridson, RISE Research Institutes of Sweden AB

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Nordic Council of Ministers/Publication Unit
Ved Stranden 18
DK-1061 Copenhagen K
Denmark
Phone +45 3396 0200
pub@norden.org

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The Nordic Council of Ministers
Nordens Hus
Ved Stranden 18
DK-1061 Copenhagen K, Denmark
Tel.: +45 3396 0200
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Foreword

The study presented in this report has been performed on behalf of the Swedish Energy Agency within the Nordic cooperation project Nordsyn sponsored by the Nordic Council of Ministers. The study was performed by Caroline Haglund Stignor and Tommy Walfridson at RISE Research Institutes of Sweden AB, in cooperation with Nordsyn project leader Lovisa Blomqvist at Swedish Energy Agency.

The aim of this study was to analyse if the information given on the Energy Labels of air-to-water heat pumps give the consumer in Nordic countries sufficiently relevant information regarding the energy performance of the products. If this was found not to be the case, the reasons behind should be analysed and recommendations given. The methods used in the study are literature studies in open sources, browsing on the internet for product data available for consumers and interviews with relevant parties.

25 April 2019

Lovisa Blomqvist, Swedish Energy Agency

Executive summary

In 2015 Ecodesign and Energy Labelling regulations for air-to-water heat pumps were introduced in EU. Some of the Nordic market surveillance authorities suspects or have the perception that the declared efficiencies for the products on the energy labels and supporting data sheets are considerably higher compared to what have been measured in real installations in the field, especially in cold and humid climates, which in such case would give the consumer misleading information. The purpose of this study was to confirm or reject this suspicion and if confirmed, clarify the reasons for the divergences.

The Ecodesign regulations for air-to-water heat pumps stipulate minimum efficiencies for products placed on the European market. According to the Energy Label regulations air-to-water heat pumps must have an energy label showing efficiency class and rated heat output for an average climate. It is also mandatory to show the rated heat output on the label for cold and warm climate. Performance information for the other climates shall be possible to find in the product fiche but this study showed that is not always the case.

The test methods for determination of the capacity and efficiency for air-to-water heat pumps are described in the standard EN 14511. The standard EN14825 describes calculation methods to determine the averaged performance during the heating season, η_s – the seasonal space heating efficiency. In case frosting take place on the outdoor unit during the test, both the heating and defrosting period is included in the evaluation of the test. However, the evaluation period is limited to maximally three hours to limit the cost of the tests.

The rated heat output (with corresponding efficiencies) that are used in the η_s calculations can be defined freely (with some limitations) by the manufacturer. The efficiency of a heat pump normally increases with lower capacity, down to a certain limit. Therefore, to be able to declare the heat pump with a high efficiency on the Energy Label, it might be beneficial to declare the heat pump for a low capacity. In addition, according to the standards, if the manufacturer gives instructions for the setting of the frequency for the different test points, this setting shall be done.

Several air-to-water heat pumps have been tested by SP (RISE) between 1999 and 2011, before the present regulations and harmonized standards for this product were published. During these tests defrost strategies as well as the overall performance improved over the years.

It has been shown that frost growth takes place more rapidly at a higher relative humidity of the outdoor air and hence defrosting must take place more frequently. There are studies indicating that a high humidity will have a negative influence of the overall efficiency of the heat pump, but no clear trends have been found.

When reporting and evaluating results from field measurements it is important to relate to which system boundary that had been applied. The SEPEMO project defined four different system boundaries for SPF (Seasonal Performance Factors), which can be applied and the results presented in this report are related to them. There are several results from field measurements on air-to-water heat pumps reported in the open literature, with a large spread in SPF, ranging from 1,2 to 4,3 (SPF_{H3} or SPF_{H4}). However, it was not clearly defined in neither the SEPEMO project nor in the reported field measurements how to deal with possible heat losses from possible storage tanks in the heating system, a factor that can influence the performance measured.

All the heat pumps in the field measurements covered in this study, had been installed before the Ecodesign and Energy Labelling regulations went into force. It is likely to believe that there has been a shift towards more efficient air-to-water heat pumps on the market during the last years, especially after the regulations went into force. The reasons are probably a combination of the regulations and a rapid technology development for variable speed controlled heat pumps.

When comparing results from field measurements to performance data in Energy Labelling documentation, it shows that the declared values are usually a little better than the field data, especially in countries on the continent with a less humid climate. This is as can be expected, taking the considerations above into account. Hence, it seems like the Energy Label has the potential to give the consumer sufficiently relevant information about the performance, at least in the average climate, but there are discrepancies, particularly in some countries.

It was also clear that several heat pumps from the field measurements performed worse than could be expected, especially in some countries with a more humid climate. In some of these countries the experience among the heat pump installers is probably limited due to a non-mature market for air-to-water heat pumps.

Except for the fact that heat pumps sold and declared today, might be more efficient than the older heat pumps that had been evaluated in the field, there are several possible reasons for the experienced performance discrepancies between measured field performance (older heat pumps) and declared performance (for heat pumps sold today):

- Non-optimal installations, resulting in that the heat pump work with a very high heating water temperature, that that the back-up heater heats instead of the heat pump and large heat losses from storage tanks (not included in the measured SPF).
- The normal control system of the heat pump is by passed, and the compressor frequency is fixed, during the tests, resulting in different operation in the laboratory compared to in real installations.
- The test periods in the standards are not long enough to include a defrost period.
- Standard tests are performed at lower humidity than the real climate and at too few test points.

The first mentioned reason, regarding the installations, is probably the most important one that should be dealt with first.

No proof has been found in the study that the reasons for the deviation between performance data in the Ecodesign and Energy Label documentation (of heat pumps sold today) and the performance in real installations (of older heat pumps) should be that the standard tests do not take humidity sufficiently into account. However, this reason can on the other hand not yet be dismissed.

The following recommendations are given:

- To obtain as good performance as possible for an air-to-water heat pump in a real installation, it must be assured that appropriate system design and control setting are applied, and sufficient knowledge among the installers is critical.
- More data from continuous field measurements of air-to-water heat pumps during complete heating seasons, especially in a Nordic climate, would be valuable to get a better picture of the range of performance in the field for heat pumps in cold (and humid) climates.

- The methodology related to the definition of different system boundaries for presenting different SPF values should be further developed, to define how to take losses from storage tanks in the heating system into account. These system boundaries should be used when reporting performance results from the field, to assure a fair comparison.
- To evaluate if it is sufficient to test air-to-water heat pumps at the existing standard test points to obtain the performance during frosting conditions for a Nordic or cold climate, a study should be performed where several air-to-water heat pumps are tested at different temperatures and humidity levels in the range where frosting takes place.
- The performance of the heat pump in a cold climate should be visible on the Energy Label.
- It should not be allowed to give information about higher heating capacities of the heat pump than the declared P_{design} in the marketing information about the heat pump.
- Market surveillance authorities and consumer organizations should make sure that they are represented in the standardization work when developing new or revising standards to be used for Ecodesign and Energy Labelling regulations.

1. Nomenclature

EER	Energy Efficiency Ratio for air conditioners in cooling mode
COP	Coefficient of Performance for air conditioners in heating mode
SEER	Seasonal Energy Efficiency Ratio for air conditioners, cooling mode
SCOP	Seasonal Coefficient of Performance for air conditioners, heating mode
SPF	Seasonal Performance Factor for heat pumps
P_h	Heating capacity
P_{Design}	Heating capacity, according to manufacturer at lowest operating temperature of climate zone, T_{Design}
P_{Rated}	The cooling or heating capacity of the vapour compression cycle of the unit at standard rating conditions [2]
T_j	Temperature of bin in SCOP calculation
T_{Design}	Lowest operating temperature of climate zone, according to EN 14511
TOL	Operating temperature limit, below this temperature the heat pump will stop
H_{TO}	The number of hours the unit is considered to work in thermostat off mode for air conditioners
H_{SB}	The number of hours the unit is considered to work in standby mode for air conditioners
H_{CK}	The number of hours the unit is considered to work in crankcase heater mode for air conditioners
H_{OFF}	The number of hours the unit is considered to work in off mode for air conditioners
P_{TO}	The electricity consumption during thermostat off mode for air conditioners
P_{SB}	The electricity consumption during standby mode for air conditioners
P_{CK}	The electricity consumption during crankcase heater mode for air conditioners
P_{OFF}	The electricity consumption during off mode.
Q_{CE}	The reference annual cooling demand for air conditioners in cooling mode
Q_{HE}	The reference annual heating demand for air conditioners in heating mode
η_s	Space heating energy efficiency

2. Background

Ecodesign and energy labelling regulations for space heaters, including air-to-water heat pumps, were introduced in 2015 in EU and applies for all products that are put on the EU market. The regulations 813/2013 [1] and 813/2011 [2] applies for air-to-water heat pumps. Some of the Nordic market surveillance authorities suspects or have the perception that the declared efficiencies for the products on the energy labels and supporting data sheets are considerably higher compared to what have been measured in real installations in the field, especially in cold and humid climates, which in such case gives the consumer misleading information.

The purpose of this study was first and foremost to confirm or reject this suspicion. Thereafter, if confirmed, the reasons for the divergences should be clarified. Possible reasons for divergences and weaknesses that had been identified by the market surveillance authorities on beforehand are that:

- tests do not take humidity sufficiently into account; and
- unclear definition and use of P_{design}, P_{rated} and maximum capacity.

Which could mislead the consumer.

2.1 Scope of the study

The study is focused on air-to-water heat pumps used for space heating and combination heat pumps space and domestic hot water (DHW) heating, i.e. heat pumps covered by the Regulations 811/20123 and 813/2013. Air-to-water heat pumps only heating the DHW (covered by Regulations 812/2013 and 814/2013) are not covered in this study. The reasons are that DHW heat pumps using outdoor air as heat source are uncommon in the Nordic countries and no results from field measurements for such heat pumps were found in the literature study, regardless of location. Air-to-air heat pumps, regardless of size, are also excluded from this study.

2.2 Regulations 811/2013 and 813/2013 [1] [2]

In this section the purpose, content and requirements of the Ecodesign regulation for air-to-water heat pumps, 813/2013, and the corresponding energy label regulation, 811/2013, are summarized. Even though they apply for all space heaters for hydronic heating systems the main focus of the summary below are on air-to-water heat pumps. The regulations where approved in 2013 and now, five years later the process for review and possibly revision of the regulations has started.

The purpose of the Ecodesign regulations is to remove the less efficient products from the market. The Ecodesign regulation mentioned above include minimum efficiency requirements and requirements for maximum allowed sound power level. They also include requirements for product information in manuals for installers and users and on websites of the manufacturer.

From 26 September 2017 the seasonal space heating efficiency of air-to-water heat pumps shall correspond to the requirement in Table 1, 110% for all heat pumps except low temperature heat pumps and 125% for low temperature heat pumps. For all space heaters the requirements are based on η_s, the seasonal space heating efficiency, which is the SCOP (Seasonal Coefficient of Performance) divided by a primary energy factor of 2,5 and some smaller corrections for temperature control etc.

Table 1: Ecodesign requirements from Regulation (EU) 813/2013. The ηs values for heat pumps could approximately be compared to SPFH2 according to SEPEMO, Figure 5 on page 30, divided by 2.5

Type	26 Sep 2015	26 Sep 2017	26 Sep 2018
	(% = seasonal space heating efficiency)		
Fuel boiler space heating <70kW except type B1 (<10kW space heater / <30kW combination heater)	86%		max. NOx
B1 boiler <10kW if space heater / <30kW if combination heater	75%		max. NOx
Electric space/combination heater	30%	36%	
Cogeneration space heaters (Remark: no mentioning of cogeneration combination heaters)	86%	100%	max. NOx
Heat pumps space / combination heaters, except low-temperature types	100%	110%	max. NOx
Low-temperature heat pumps space / combination heaters	110%	125%	max. NOx
Combination heaters water heating efficiency (varies per class XXS-3XL)	22% – 32%	32%–64%	
All	Product information		

The energy labelling regulation aims to promote energy efficient heating by making the products energy efficiency class visible to the consumers in a standardised manner. The Ecodesign regulations alone could otherwise have resulted in that all products perform just above the threshold value.

The Energy labelling regulations requires that energy labels are displayed where products are sold and promoted. Climate zones is one important aspect of the energy labels for heat pumps and the heating mode. Information on the energy label directly refers to a specific climate zone and the figures are calculated based on the conditions of one. The European Reference for climate conditions divides Europe geographically into three zones: colder, average and warmer climate conditions. The simplest method to determine the climate zone of a country is to consult the map of climate zones, see Figure 1. A similar map is shown on the energy label of individual products. It can be seen from the map that Denmark is located in "average" climate zone, whereas Norway, Sweden, and Finland are located in "colder" climate zone. Iceland is in "colder" climate zone though not shown on Figure 1 [6]. A large portion of continental Europe is also in the colder climate zone, for example Estonia, Latvia, Lithuania, Poland, Czech republic, Slovakia, Hungary, Romania, Bulgaria, Austria, Slovenia, Croatia and parts of Germany and Italy.

Figure 1: European map of climate conditions [6]

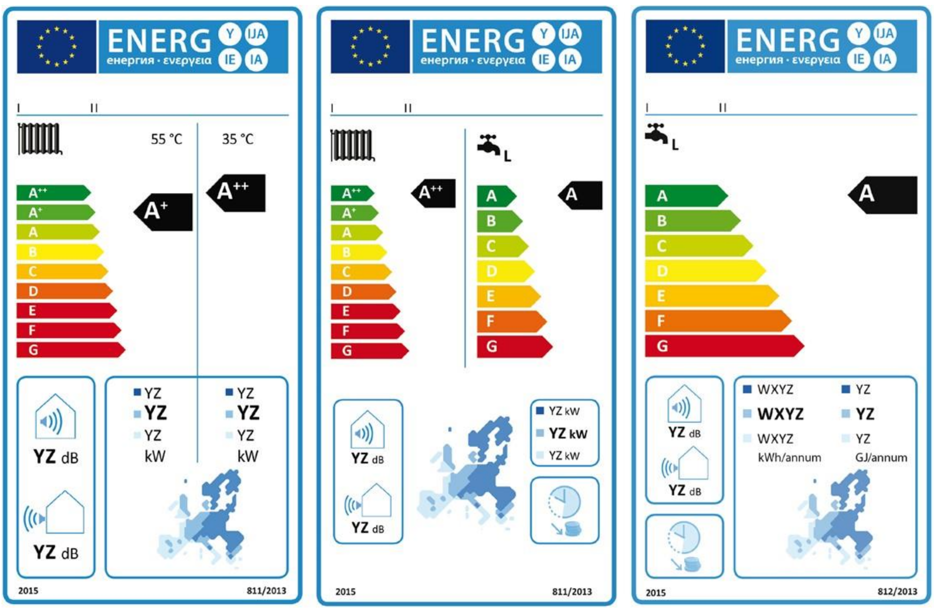
For different types of heat pumps and package products, the energy labels display different information, according to Viegand and Maagøe [6]. As shown in Table 2, it is usually mandatory to indicate information for average climate conditions, but for colder climate conditions it is either optional or less information on the label. On the energy labels of air-to-water heat pumps, it is mandatory to indicate the energy efficiency class and the rated output (i.e. the output the coldest hour of the year) for average climate conditions, but it is only possible (and mandatory) to indicate the rated heat output of the product for the other climates. Examples of air-to-water heat pump energy labels can be seen in Figure 2 [6].

Table 2: Information shown for colder and average climate conditions on energy labels

Information	Air to air HP	HP Space heaters	HP combi-nation heaters	HP Water heaters	Packages
SCOP – average	Mandatory	-	-	N/A	-
SCOP – cold	Optional	-	-	N/A	-
Efficiency Class – average	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory
Efficiency Class – cold	Optional	-	-	-	-
Rated output – average	Mandatory	Mandatory	Mandatory	-	-
Rated output – cold	Optional	Mandatory	Mandatory	-	-
Annual energy/fuel consumption - average	Mandatory	-	-	Mandatory	-
Annual energy/fuel consumption – cold	Optional	-	-	Mandatory	-

That the energy efficiency class is not given for the colder climate on the label is a minor problem, as this information can be found in the product fiche, according to Viegand and Maagøe [6].

Figure 2: Heat pump space heaters (left), heat pump combination heaters (middle) and heat pump water heater energy labels (right) [2] [3]



2.2.1 *Summary Regulations*

The Ecodesign regulations for air-to-water heat pumps stipulate minimum efficiencies for products placed on the European market. According to the energy label regulations the air-to-water heat pumps must have an energy label showing both efficiency class and rated capacity. There is a mandatory label the products for three different climates – cold, average and warm, but the efficiency class is only showed for the average climate. Only the rated heat output is shown for the other climates only mandatory to label them for the average climate.

2.3 European standards

There are so far no references of harmonized standards which have been published on the Official Journal of the European Union for:

- Hot water boilers (Directive 92/42/EEC [5])
- Water heaters and hot water storage tanks (Regulation (EU) No 814/2013 [4], Regulation (EU) No 812/2013 [3]
- Space heaters (Regulation (EU) No 813/2013 [1], Regulation (EU) 811/2013 [2])).

After the regulations had been approved by the EU member states, a mandate were issued by the EC to the European Standardization Organizations "M/535 – Mandate to CEN, CENELEC and ETSI for standardization in the field of space heaters". This mandate supported the development of harmonized standards regarding regulation 811/2013 and 813/2013 for space heaters and combination heaters.

The performance data presented in the Ecodesign and energy labelling documentations shall be produced according to pre described methods described in certain standards developed for that purpose, and accepted by the Commission, i.e. harmonized standards. Before there are any harmonized standards transitional methods apply.

As a consequence of the mandate above, the standards below were developed or revised to fulfil the mandate. However, there are not yet any references of harmonized standards which have been published in the Official Journal of the European Union for space heaters (regulation and 811/2013 and 813/2013), but they are under evaluation and are expected to be harmonized in a soon future.

The standards developed for the purpose of being harmonized are summarized below.

Standards regarding energy performance of EU Regulation 811/2013 and EU Regulation – 813/2013 are:

- *EN14511* [8] which defines the rated performance and measurement methods to be used for all electrically driven heat pumps in heating and cooling mode.
- The standard *EN14825* [9] defines the calculation and testing points to calculate the seasonal coefficient of performance (SCOP) and the seasonal space heating efficiency (η_s) and completes where required measurement methods defined in standard EN14511 are not sufficient.
- The standard *EN16147* [10] defines the testing methods and efficiency calculations for domestic hot water production for combination heaters, i.e. those heat pumps which produce both space and domestic hot water heating.

2.3.1 EN14511 [8]

EN 14511:2013 Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling.

The standard is divided in 4 parts which are: scope, terms and definitions, test conditions, test methods and requirements. This standard defines test conditions for rating the performances of the units at their rated or maximum available capacity for these operating conditions; only the tests in the standard conditions are mandatory, application conditions are facultative. The test conditions are defined in cooling mode and the heating mode following the classification by outdoor side and indoor side fluids. Rating conditions in heating and cooling mode are given in Table 3 and Table 4 [7].

Table 3: Air-to-water heat pumps , testing conditions for medium temperature applications in the heating mode (EN 14511:2018) [8]

		Outdoor heat exchanger		Indoor heat exchanger medium temperature application	
		Inlet dry bulb temperature °C	Inlet wet bulb temperature °C	Inlet temperature °C	Outlet temperature °C
Standard rating conditions	Outdoor air	7	6	47	55
	Exhaust air	20	12	47	55
Application rating conditions	Outdoor air	2	1	[a]	55
	Outdoor air	-7	-8	[a]	55
	Outdoor air	-15	-	[a]	55
	Outdoor air	12	11	[a]	55

Note: The test is performed with the fixed flow rate or with the ΔT obtained during the test at the corresponding standard rating conditions for units with variable flow rate. If the resulting flow rate is below the minimum flow rate then the minimum flow rate is used with the outlet temperature.

Table 4: Air-to-water heat pumps , testing conditions for low temperature applications in the heating mode (EN 14511:2018) [8]

		Outdoor heat exchanger		Indoor heat exchanger medium temperature application	
		Inlet dry bulb temperature °C	Inlet wet bulb temperature °C	Inlet temperature °C	Outlet temperature °C
Standard rating conditions	Outdoor air	7	6	30	35
	Exhaust air	20	12	30	35
Application rating conditions	Outdoor air	2	1	[a]	35
	Outdoor air	-7	-8	[a]	35
	Outdoor air	-15	-	[a]	35
	Outdoor air	12	11	[a]	35

Note: The test is performed with the fixed flow rate or with the ΔT obtained during the test at the corresponding standard rating conditions for units with variable flow rate. If the resulting flow rate is below the minimum flow rate then the minimum flow rate is used with the outlet temperature.

Rated capacity conditions for inverter air conditioners

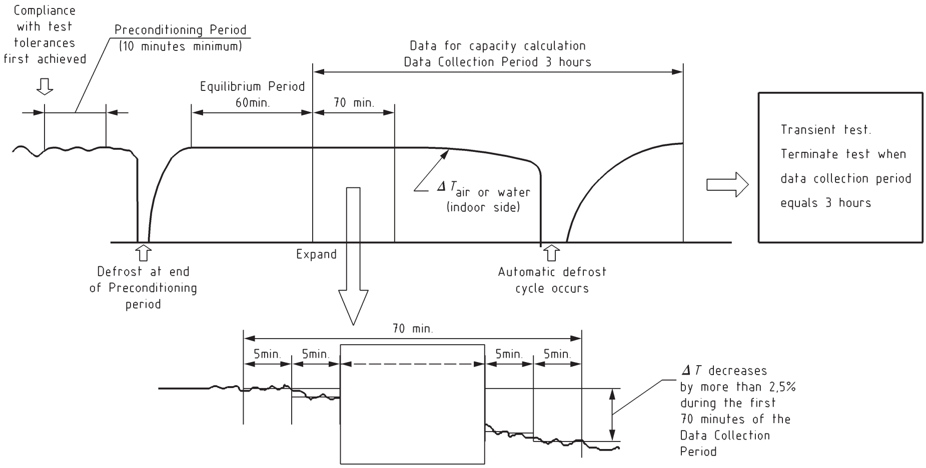
The rated cooling capacity of the unit is determined at standard rating conditions (outdoor air 7 °C / indoor heat exchanger, outlet temperature 35 or 55 °C (depending on temperature application/ chosen compressor frequency). For units with single speed compressors, this used to be the maximum capacity of the unit in heating mode. However, for inverter drive compressor units, this is a design choice made by the manufacturer.

Evaluation during frosting and defrosting

In real life air-to-water heat pumps defrost at certain combinations of air temperatures and capacities. Therefore, this must be taken into account when testing heat pumps in the laboratory, and the test periods must be sufficiently long to be able to evaluate if frosting take place on the heat exchanger surface or not. On the other hand, to keep down the cost for testing a heat pump, the evaluation periods are limited to a certain length.

The evaluation periods when evaluating an air source heat pump according to EN14511 is described below, see Figure 3.

Figure 3: Schematics describing the evaluation periods in EN14511:2013 [8]



To start with, the test room reconditioning apparatus and the heat pump under test shall be operated until the test tolerances specified in the standard are attained for at least 1 h, which is called the equilibrium period. After this the duration of measurement during the data collection period shall not be less than 70 min. To indicate if frosting occur on the heat exchanger surface, the difference between the leaving and entering temperatures of the heat transfer medium at the indoor heat exchanger (in this case air) shall be measured. For each interval of 5 min during the data collection period, an average temperature difference shall be calculated, ΔT_i (τ). The average temperature difference for the first 5 min of the data collection period, shall be compared to the temperature difference during the last 5 min period.

If a defrost occurs before the start of the data collection period, or if the difference between the 5 min periods in the start and the end of the 70 min data collection period exceeds 2,5%, the heating capacity test shall be designated a transient test. Likewise, if the heat pump initiates a defrost cycle during the equilibrium period or during the data collection period, the heating capacity test shall be designated a transient test.

If the above conditions do not occur and the test tolerances specified in the standard are satisfied during both the equilibrium period and the data collection period, then the heat capacity test shall be designated a steady state test. Steady-state tests shall be terminated after 70 min of data collection.

For a transient test, the data collection period shall be extended until 3 h have elapsed or until the heat pump completes three complete cycles during the period, whichever occurs first. If at an elapsed time of 3 h, the heat pump is conducting a defrost cycle, the cycle shall be completed before terminating the collection of data. A complete cycle consists of a heating period and a defrost period; from defrost termination to defrost termination. Hence, both the heating period and the defrosting period is included in the data evaluation period. Data used in evaluating the integrated heating capacity and the integrated power input of the heat pump shall be sampled more frequently during defrost.

2.3.2 EN14825 [9]

EN 14825:2016 Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling — Testing and rating at part load conditions and calculation of seasonal performance [9].

This European Standard describes how to calculate the Seasonal Coefficient of Performance ($SCOP_{on}$ and $SCOP_{net}$) and the seasonal space heating efficiency (η_s) for air-to-water heat pumps when they are used to fulfil the heating demands. It also gives the part load conditions and calculation methods. The overall methods and numerical values used are defined in the regulations above. However, the test methods are defined in this specific standard.

The version from 2016 is the latest published version of this standard. In that version, the standard has already been revised to satisfy the requirements of EU regulations 811/2013 and 813/2013, but it has not been accepted (approved) by the Commission yet and hence, it is not yet harmonized.

There is a Fpr-version from 2018 which has been approved by CEN and soon will be published. It will then satisfy the requirements of EU regulations 1095/2015 and 2281/2016 in addition to EU regulations 811/2013 and 813/2013.

Heating mode

For the purpose of reference SCOP and reference $SCOP_{on}$, there are 3 reference conditions: average (A), warmer (W) and colder (C). A supplementary $SCOP_{net}$, without backup nor consumption of the low power modes, is defined in view of the renewable energy directive (Commission decision 2013/114/EU)14.
For air-to-water heat pumps, the seasonal space heating efficiency in primary energy η_s [%], defined in regulations (EU) No 811/2013 and (EU) 813/2013 is included.

The Reference design conditions for heating (T_{Design})

The lowest ambient temperature conditions for average, colder and warmer climates:

- Average: -10 °C dry bulb outdoor temperature and 20 °C dry bulb indoor temperature.
- Cold: -22 °C dry bulb outdoor temperature and 20 °C dry bulb indoor temperature.
- Warm: +2 °C dry bulb outdoor temperature and 20 °C dry bulb indoor temperature [7].

P_{Design} is defined as the heating capacity declared by the manufacturer at T_{Design}. P_{Design} for each individual heat pump model type can be chosen more or less freely, see restrictions in 2.2.7 and description in Figure 4.

Bivalent temperature ($T_{bivalent}$)

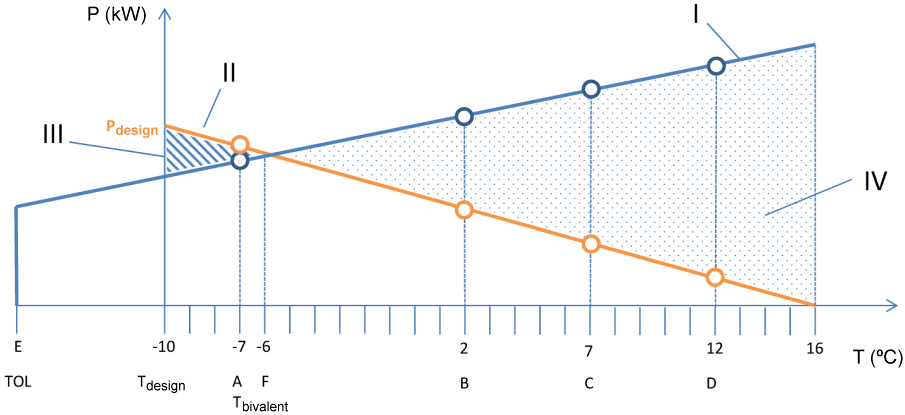
The bivalent point is the lowest outdoor temperature point at which the heat pump is declared to be able to meet 100% of the heating demand without additional backup. Note: Below this point, the unit may still deliver capacity, but additional back up heating is necessary to fulfill the heating demand.

The declared bivalent temperature can be any outdoor temperature (dry bulb) within following limits (this is defined in Regulation (EU) 813/2013:

- For the average heating season, the bivalent temperature is +2°C or lower.
- For the colder heating season, the bivalent temperature is -7°C or lower.
- For the warmer heating season, the bivalent temperature is +7°C or lower [7].

Figure 4 below gives an schematic overview of the part load ratios, test points and the bivalent temperature described in the standard EN14825. The description apply for an air-to-water on-off controlled heat pump where the capacity of the heat pump is larger than the heat load above the bivalent point . For an variable capacity heat pump (air-to-water or air-to-air) the capacity can be continuously lowered to follow the load curve (orange line) down to a certain limit. For relatively high outdoor temperatures, for example above 10°C, the minimum capacity will be higher than the load curve and the heat pump will in real life cycle on and off.

Figure 4: Schematic overview of the SCOPon calculation points (for an on-off cycling air to water unit, in EN14825:2016, Annex E, p 74) [9]



Note: T: outdoor temperature (°C).
P: capacity/load (kW).
I: declared capacity line and declared capacities at conditions A, B, C and D.
II: load curve and part load capacity at conditions A, B, C, and D.
III: electric back up heater.
IV: on off cycling.
T_{design}: reference design temperature.
$T_{bivalent}$: bivalent temperature.

The Operation Temperature Limit, TOL

The operation temperature limit, TOL, is the lowest temperature the heat pump can work at. According to the regulations [1] [2] the maximum values for TOL are according to below:

- For the Cold climate: -15 °C.
- For the Average climate: -7 °C.
- For the Warm climate: +2 °C.

The bin calculation

The calculation method described in EN14825 is based on a so called bin method, where the performance of the heat pump is determined, step by step, for the different conditions during the heating season. The heating bins (one for each degree outdoor temperature) are given hereunder. The load curve in heating mode is computed with 16 °C as the balance point temperature (ie outdoor dry bulb temperature with no heating load) with the following formula:

The heating demand, $P_h(T_j)$, for each bin can be determined by multiplying the full load value ($P_{designh}$) with the part load ratio % for each corresponding bin. This part load ratio % is calculated as follows:

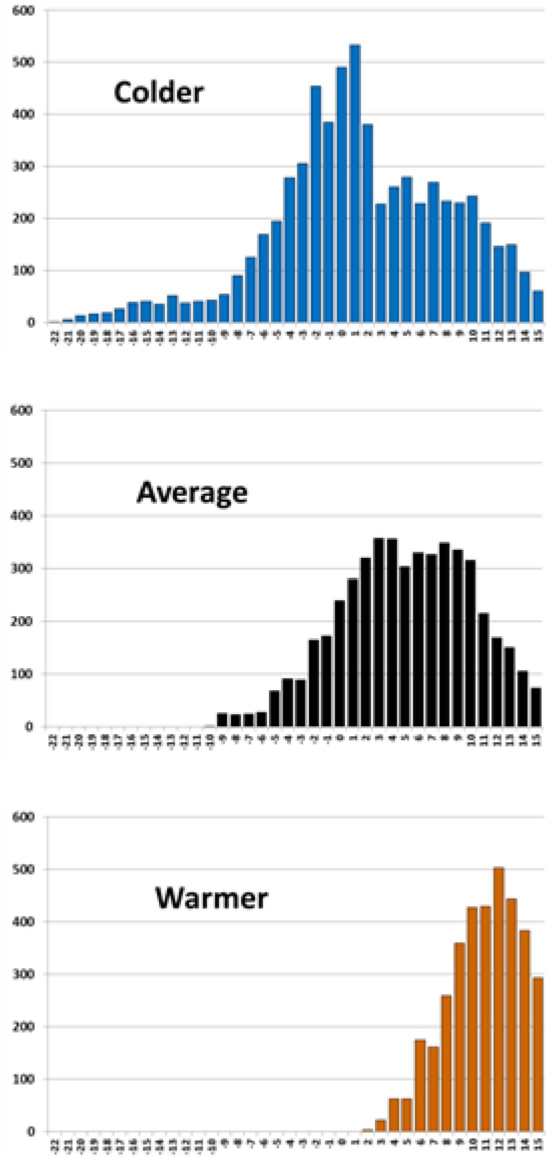
- For the average climate: Part load ratio % = $(T_j$-16) / (-10–16) %.
- For the warmer climate: Part load ratio % = $(T_j$-16) / (+2–16) %.
- For the colder climate: Part load ratio % = $(T_j$-16) / (-22–16) % [7].

Table 5. bin number j, outdoor temperature T_j in °C and number of hours per bin hj corresponding to the reference heating seasons —warmer, —average, —colder [7]. Blue shaded bins show declaration (test) points according to EN14825, were -15°C is mandatory, depending on lower operation limit for the heat pump.

Table 5: Bin number j, outdoor temperature Tj and number of hours per bin hj corresponding to the reference heating seasons: warmer, average and colder [4]. Blue shaded bins show declarations (test) points according to EN14825, were -15°C is mandatory, depending on lower operation limit for the heat pump

j #	T_j [°C]	Warmer (W) h_jW [h]	Average (A) h_jA [h]	Colder (C) h_jC [h]
1 to 8	-30 to -23	0	0	0
9	-22	0	0	1
10	-21	0	0	6
11	-20	0	0	13
12	-19	0	0	17
13	-18	0	0	19
14	-17	0	0	26
15	-16	0	0	39
16	-15	0	0	41
17	-14	0	0	35
18	-13	0	0	52
19	-12	0	0	37
20	-11	0	0	41
21	-10	0	1	43
22	-9	0	25	54
23	-8	0	23	90
24	-7	0	24	125
25	-6	0	27	169
26	-5	0	68	195
27	-4	0	91	278
28	-3	0	89	306
29	-2	0	165	454
30	-1	0	173	385
31	0	0	240	490
32	1	0	280	533
33	2	3	320	380
34	3	22	357	228
35	4	63	356	261
36	5	63	303	279
37	6	175	330	229
38	7	162	326	269
39	8	259	348	233
40	9	360	335	230
41	10	428	315	243
42	11	430	215	191
43	12	503	169	146
44	13	444	151	150
45	14	384	105	97
46	15	294	74	61
	Total	*3,590*	*4,910*	*6,446*

Figure 5: Outdoor temperature Tj and number of hours per bin hj for the reference heating seasons: warmer, average, and colder [4] as presented in table 5



The $SCOP_{on}$ are computed by summarising the heating demand for all the bins and electricity consumption for all the bins, separately, and then dividing the total heating demand by the total electricity consumption. The electric heating required to cover the heating load below the bivalent point is also considered and included.

To calculate the reference SCOP value, the equivalent full load hours and the performance and the number of hours the heat pump are in other modes than on mode (low power mode consumption), are also taken into consideration [7].

$$SCOP_{on} = \frac{\sum_{j=1}^{n} h_j * Ph(T_j)}{\sum_{j=1}^{n} h_j \left(\frac{Ph(T_j) - elbu(T_j)}{COP_{PL}(T_j)} + elbu(T_j) \right)} [9]$$

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

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

When calculating the $SCOP_{on}$, the input data for the bins between the test points are interpolated as described in EN14825 [9], quoted below.

"The COP_{bin} values and capacity values at each bin are determined via interpolation of the COP_{bin} and capacity values at part load conditions A, B, C, D, E, F and G where applicable" [9]. If looking at Figure 4, this means that for the bins representing the temperatures between the circles on the lines, P_h and COP_{PL} values are interpolated from the bins for which there are declared values (based on tests).

"Interpolation is done between the COP_{bin} and capacities of the 2 closest part load conditions (as mentioned in the tables of Clause 5). The COP_{bin} values and capacity values for part load conditions above D are extrapolated from the COP_{bin} values and capacity values at part load conditions C and D.

In case of the colder climate, and if the TOL (operation limit) is below −20 °C, an additional calculation point has to be taken from the capacity and COP_{bin} at −15 °C condition (condition G). However, if the capacity of the unit is lower than the value of $P_h(T_j)$, correction needs to be made for the missing capacity either with an electric back up heater with a COP of 1 or with the fossil fuel back up heater having an efficiency η_{sffbu} if the fossil fuel boiler is integrated in the unit. Below TOL (operation limit) the unit is not running. The capacity of the unit at outside air temperatures below TOL is 0 kW and correction needs to be made for the missing capacity either with an electric back up heater with a COP of 1 or with the fossil fuel back up heater having an efficiency η_{sffbu} if the fossil fuel boiler is integrated in the unit. [9]

The heating and cooling capacities measured on the liquid side shall be determined within a maximum uncertainty of (2+3/part load ratio) %. All uncertainties of measurement are independent of the individual uncertainties of measurement including the uncertainties on the properties of fluids. The maximum uncertainty of the measurement of the power input for off, thermostat off, standby and crankcase heater modes shall be ± 0,1 W up to 10 W; ± 1% for powers greater than 10 W. [9]

The seasonal space heating efficiency η_s [%] is defined in EN14825 [9] as

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

Where:

- CC is the conversion coefficient, equal to 2,5.
- SCOP is the seasonal coefficient of performance.
- ΣF(i) is the correction calculated as follows:
  - ΣF(i) = F(1) + F(2).

Where:

- F(1) is the 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) is the correction that accounts for the negative contribution to the seasonal space heating energyefficiency by electricity consumption of brine and water.

Setting of test objects to obtain required capacity ration

In the standard EN14825 it is stated that "The capacity ratio to be tested shall be set according to the instructions of the manufacturer. The manufacturer shall provide laboratories with the necessary information on the setting of the unit for operating at the required capacity conditions upon request. Contact information to obtain such information shall be provided in both user's manual and website of the manufacturer or importer" with the addition that "For inverter type control units, if the manufacturer gives instructions for the setting of the frequency for each rating condition, this setting shall be done."

2.3.3 EN16147 [10]

The European Standard EN 16147 [10] contains test methods for determining performance, but also requirements for labelling of heat pumps intended for domestic hot water production. The standard applies only to heat pumps with electrically driven compressors.

The test method specifies several draw-offs during a minimum period of 24 hours, measuring and evaluating the energy use, standby power, heating-up periods and COP_{dhw}. Maximum quantity of usable hot water and the reference hot water are measured during one single draw-off.

The performance tests are designed to determine the water heating energy efficiency when providing domestic hot water. The heat pump is installed and set according to the standard guidelines. After the storage tank is filled with water with a temperature of 10 °C, the test procedure starts. For heat pump combination heaters, the test consists of four principle stages.

Stage C which is the first, consists of a filling and heating up period. The goal is to determine the time it takes to heat the storage tank of water from the initial state until the compressor shuts off because of the thermostat sensing a high temperature.

Stage D is for determination of standby power input by measuring electrical power input over several cycles of the heat pump. 48 h or less, maximum 6 cycles. The cycles are initiated by the thermostat in the tank and measurements are made when no hot water draw-offs are done.

To proceed with step E, where the COP_{dhw} is determined, a load profile must be selected. The profile corresponds to the hot water requirement of the intended house. Load profile range goes from 3 XS up to 4 XL. The Water draw-offs in stage E lasts until all draw-offs are completed for the specific load profile and ends with the last shut off of the compressor. The load profile time is at least 24 h or more. If the compressor has shut off, before the 24 hours have elapsed, the test cycle is extended until the heat pump restarts and stops again. This to start the stage F which requires the tank to be charged with energy.

Stage F is the final stage where a continuous hot water draw-off is started and continues until the hot water temperature falls below 40 degrees Celsius. The maximum amount of mixed water at 40 degrees Celsius in one single draw-off shall be determined.

2.3.4 EN15316-4-2 [11]

This standard is part of a series of standards aiming at international harmonization of the methodology for the assessment of the energy performance of buildings, called "set of EPD standards". This standard specifies how to take into account the energy performance of heat pump systems used for domestic hot water and/or space heating.

The calculation method takes into account the following physical factors, which have an impact on the energy performance of the heat pump during the calculation period and thereby on the required energy input to meet the heat requirements of the distribution subsystem:

- type of generator configuration (monovalent heat pump, bivalent heat pump);
- type of heat pump (driving energy (e.g. electricity or fuel), thermodynamic cycle (VCC, VAC));
- combination of heat source and sink (e.g. ground-to-water, air-to-water);
- space heating and domestic hot water energy requirements of the distribution subsystem(s);
- effects of variation of source and sink temperature on thermal capacity and COP according to standard product testing;
- effects of compressor control in part load operation (ON-OFF, stepwise, variable speed units) as far as they are reflected in the thermal capacity and COP according to standard testing or further test results on part load operation exist;
- auxiliary energy input needed to operate the generation subsystem, if not considered in standard testing of thermal capacity and COP; and
- location of the generation subsystem.

Contrary to EN14825, which defines the SCOP, only for the space heating function, for a product in a general type house with a type heat distribution system, this standard defines the performance of the heating system for a specific heating system, taking all the losses, recoverable and non recoverable, into account. Both the space heating and heating of domestic hot water is included in the calculations. Test data for the standards EN14511, EN141825 and EN16147 is used as input data to the calculations.

A bin methodology, similar to the one in EN14825 is used for calculation of monthly and annual energy, which is based on the cumulative frequency of the outdoor air temperature. When constructing the bins the operating points (where the average performance of the bin is defined) shall be chosen at the test points of the test standards as far as possible, to be able to include the available information of the heat pump characteristics as exact as possible. Bin limits are to be set approximately in the middle of the operating points.

In this standard, 1 K bins (as in EN14825) can also be chosen. If no other data than test standard data is available, the heat pump characteristics is interpolated to the respective source/sink temperature from standard test data (in the same way as is done in EN14825).

2.3.5 Summary standards

The conditions and test methods for determination of the capacity and efficiency at standard rating conditions for air-to-water heat pumps are described in the standard EN 14511.

The standard EN14825 describes calculation methods and part load conditions (for the different outdoor temperatures during the heating season) for determination of the seasonal coefficient of performance, SCOP, and the seasonal space heating efficiency, η_s, which the efficiency class displayed on the energy label is based on.

The test methods described in EN14511 for determination of capacity and efficiency are used also in EN14825. In case frosting take place on the outdoor unit during the test, both the heating and defrosting period is included in the test. However, the evaluation period is limited to maximally three hours to limit the cost of the tests.

The capacities (with corresponding efficiencies) that are used in the SCOP and η_s calculations can be defined freely (with some limitations) by the manufacturer.

According to the standards, if the manufacturer gives instructions for the setting of the frequency for the different test points, this setting shall be done.

The test standard EN16147 is used for determining the performance during heating of domestic hot water, which the efficiency class displayed on the energy label is based on for combination heat pump heaters.

The standard EN15316-4-2 is a calculation standard for determination of the performance of a heat pump based heating system for a building. It includes both space and domestic hot water heating.

3. Literature study

3.1 Field measurements of air-to-water heat pumps

Field measurements of the performance of heat pumps can be made of different reasons and for different purposes, and therefore it can vary from case to case what has been included in the measurement results and what has been excluded. Because of this, when evaluating and comparing results from different field measurements for heat pumps, it is very important to relate to which system boundary that has been applied.

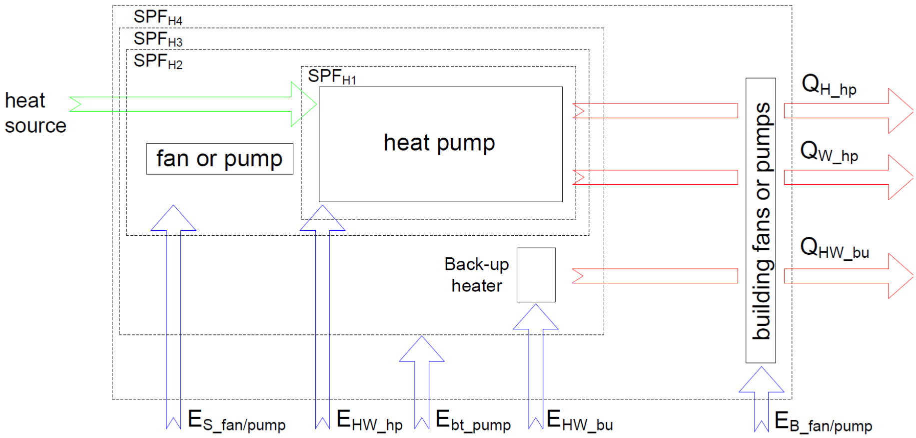
Several reports from field measurements have been found in the open literature, even some for the cold climate, see Chapter 3.1.1 to 3.1.6. Note that all the evaluated heat pumps in those field studies had been produced, put on the market and installed before the Ecodesign and Energy Label regulations went into force in 2015.

The SEPEMPO-Build project [12] elaborated guidelines for field measurements, for example for hydronic heat pumps (e.g. air-to-water heat pumps) [13] and defined four different system boundaries that could be applied and should be referred to when performing and reporting results from field measurements for heat pumps. These are shown in Figure 6 and can be concluded as follows. SPF is the abbreviation for Seasonal Performance Factor and is the average performance of the heat pump during a year or the heating season.

- SPF_{H1} includes only the heat pump unit itself. Thereby SPF_{H1} is similar to the average COP for the measured period.
- SPF_{H2} consist of the heat pump unit and the equipment needed to make the heat source available to the heat pump.
- SPF_{H3} represents the heat pump system SPF. SPF_{H3} includes the heat pump and the heat source pump or fan as in SPF_2, but also the backup heater.
- SPF_{H4} includes all parts related to SPF_{H3}, additionally SPF_{H4} also includes the pumps distribution of the heat.

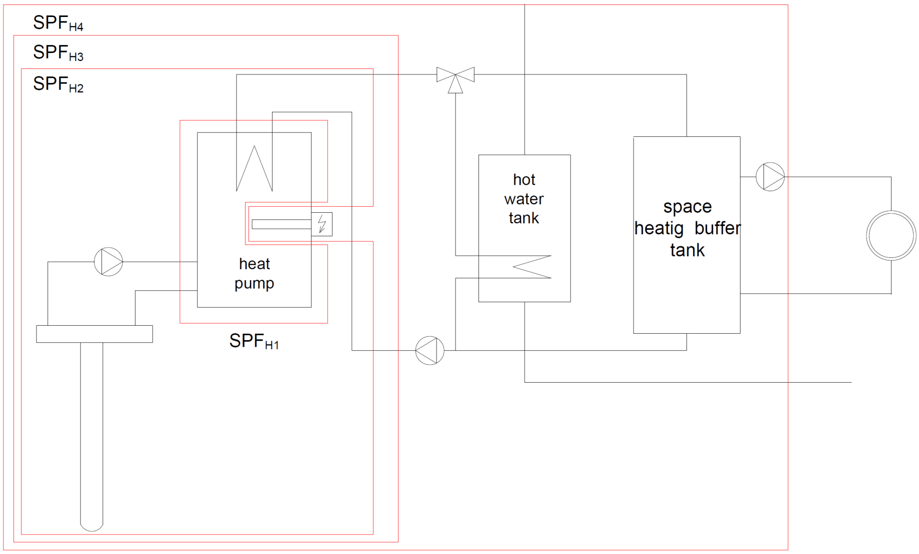
When comparing SPF values calculated from results from field measurements, to declared SCOP values for a heat pump, one should keep in mind that the SCOP value only applies to the product in an assumed "type" heating system, defined in the standard, while the SPF applies for a real system and the conditions there. However, H3 is the system boundary that is most comparable with the assumed system boundary when calculating SCOP according to EN14825. Hence SPF_{H3} is the SPF that give most fair comparison with SCOP even though it does not include the electric power for the pumps for the heat distribution system, while SCOP include a fraction of it (to overcome the pressure drop of the heat pump itself).

Figure 6: The system boundaries defined by the SEPEMO project [12]



According to Figure 4 it is not clear how to include losses in buffer tanks and DHW tanks in the various SPF values, since they are not defined within the system boundaries. However, according to Figure 6 it seems like the losses from the tanks are regarded as useful in SPF_{H3}, but not in SPF_{H4}, but this is not explained in detail and from the literature survey it has not been possible to assure that this principle was followed in the project when reporting about the field measurements. The same is true for many of the other reported field measurements – it is not clear to if and to what extent heat losses from tanks has been taken into account, when calculating the presented SPF values. Depending on if the system has any tanks at all, or several tanks, the influence on the SPF values will differ.

Figure 7: Alternative system boundaries defined in SEPEMO project [12]



3.1.1 SEPEMO field measurements

The SEPEMO project [12], published in 2012, reported results for air-to-water heat pumps from twelve sites in five different countries. The reported values are according to system boundary H3, i.e. SPF_{H3}, hence including also the back-up heater.

From analysing the data it can be concluded that all the Austrian sites used very little backup heating, being almost monovalent. All sites, except the Hoodland site in the Netherlands and the Mölndal site in Sweden, used underfloor heating, meaning low heating system temperatures. The Buchebach site in Germany used an exhaust air heat pump to produce DHW. The Hoogland site in the Netherlands was undersized as the houses were not fully insulated during the test period. Therefore the backup gas heater supplied the house with well over 50% of the heat. Faults in the control system of the buildings and the heat pump itself has also been fixed after the measurements were done at this site. These two reasons are the probable explanations for the low SPF value. Both the Swedish sites were measured during a very cold winter of 2009/10, which could be one of the explanations for the low SPF values for the Swedish sites, especially for the Mölndal site. Another explanation for the low SPF value for that site is that the DHW circulation pump are running all year along. Especially the DHW circulation, would result in a relatively large fraction of DHW heating compare to space heating, which would have a negative impact on the SPF. The Onsala site has underfloor heating and is coupled to a solar thermal system, which could counteract the effect of the cold outdoor temperature during the winter.

Figure 8: SPFH3 for the different air-to-water heat pumps in the SEPEMO final report. The SPF for the Mölndal site was estimated from monthly SPF-values

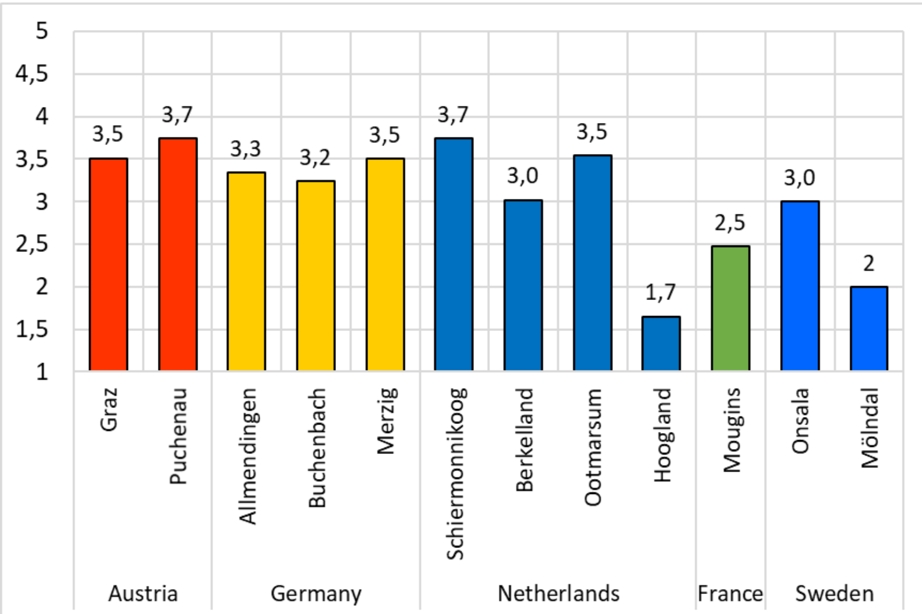


Table 6: Data on the sites in the SePeMo report. Blank = no information found

Site	Country	Building area [m2]	Heating capacity [kW]	Backup heater	House year	Heat pump year	DHW	Heating system
Graz	Austria	219	11,6	Electric	2009	2009	No	Underfloor
Puchenau	Austria	200	14	Electric	2010	2010	No	Underfloor
Allmendingen	Germany	127		Electric	2009	2009	Yes	Underfloor
Buchenbach	Germany	208		Electric	2008	2008	Yes	Underfloor
Merzig	Germany	161		Electric	2008	2008	Yes	Underfloor
Schiermonnikoog	Netherlands	115		Electric	2010	2010	No	Underfloor
Berkelland	Netherlands	181		Electric	2010	2010	Yes	Underfloor
Ootmarsum	Netherlands	309	11,2	None	1987	2010	Yes	Underfloor
Hoogland	Netherlands	96	4	Gas	1976	2011	No	Low temp. radiators
Mougins	France	203		Electric	2000	2008	No	Underfloor
Onsala	Sweden	280	14	Electric	1991	2010	Yes	Underfloor
Mölndal	Sweden	200	11	Electric	1963	2009	Yes	Radiators

3.1.2 IEA HPT Annex 37 field measurements

The final report of the IEA HPT Annex 37 project [29], published 2016, summarises six well described and 19 undescribed measurements on air-to-water heat pumps, Figure 9, Table 7 and Figure 10.

As seen in Figure 9 and Table 6, the SPFs vary to some extent. However the age of the heat pumps differ, some heat DHW, some are only used for space heating and the building area vary over a large range.

Figure 9: SPFH3 for six well described air-to-water heat pumps in IEA HPT Annex 37 final report [29]

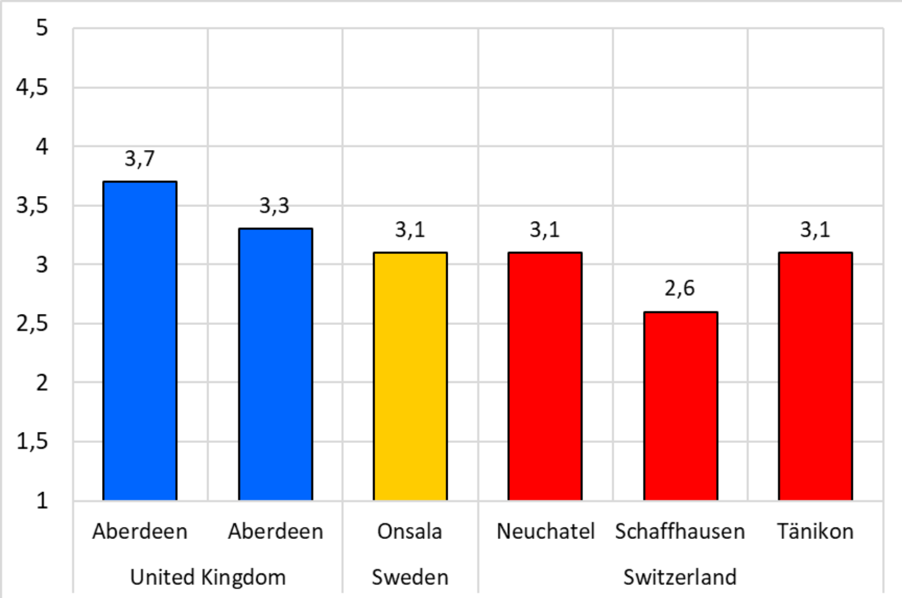


Table 7: Data on the more described sites in the IEA HPT Annex 37 report

Site	Country	Building area [m2]	Heating capacity [kW]	Backup heater	House year	Heat pump year	DHW	Average temperature
Aberdeen	United Kingdom	251	7		2008	2011	No	7,1
Aberdeen	United Kingdom	73	5		1992	2011	Yes	7,1
Onsala	Sweden	280	14	Electric	1991	2010	Yes	7,0
Neuchatel	Switzerland	123	7		1911	2009	Yes	9,5
Schaffhausen	Switzerland	160	9,6	Electric	1979	2003	No	9,3
Tänikon	Switzerland	275	8		2001	2001	No	10,0

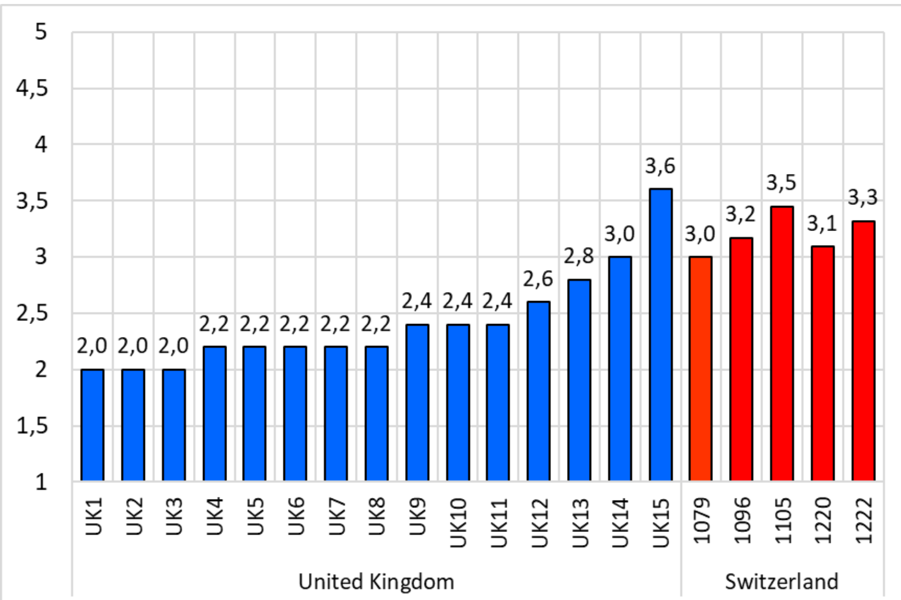
The Onsala field measurement

The Onsala site is covered in Tiljander [19], which gives some more details about the solar thermal part of the installation. The solar thermal supply was about 3800 kWh, but it is not clear if this heat is supplied to the heating system side or to the brine side of the installation. The report revealed that the heating system for this site is underfloor heating, i.e. a low temperature heating system.

The 19 undescribed sites of HPT Annex 37 field measurements

In Figure 10 below SPF values for 19 different sites presented in the IEA HPT Annex 37 report [29] can be seen. In this report they are not very well described. However, the UK sites are described in more detail by Dunbabin [33], see Chapter 3.1.6. The Swiss sites are all monovalent, meaning no backup heater is used. Designing a monovalent heating system is difficult, as any fault in the design involves a risk of giving dissatisfaction with low temperatures in the building during winter. Therefore, monovalent design must be performed with caution, and as a consequence the complete heating system is often better designed in such systems.

Figure 10: SPF values for 19 different air-to-water heat pumps in the IEA HPT Annex 37 final report [29]. The presented SPF values for United Kingdom are "similar to" SPFH4 and the ones from Switzerland are presented as SPFH3



3.1.3 Enova field measurements

In Norway field measurements have been carried out on five air-to-water heat pumps and the results are reported in the Enova report [14] published in 2015. The resulting SPF values from the evaluation can be seen in Figure 11. The details about the sites can be found in Table 8.

The Norwegian field measurements all show low or very low SPF_{H4}-values, the lowest of all field measurements investigated in this report.

By accessing and analysing the raw data behind the SPF-values it was first of all found that for the reported SPF values, the losses from the tanks have **not** been included as useful heat. In addition, several of the installations generally had high bivalent temperatures, meaning the electric backup heaters (several heaters in some cases) covered a large part of the heating. For site 2 the share of the heat from the electric backup heater could not be calculated, since it could not be separated from the electric drive power of the heat pump. For the others the annual energy share for backup heater heating was, 1% (Site 3), 14% (Site 26), 18% (Site 5) and 55% (Site 4).

The Norwegian sites all had high electricity consumptions, 27 000–50 000 kWh/annum. One clue to the high consumption is the age of the buildings, all being 50+ years old, which could be a reason why they were not well insulated and equipped with heating systems not adapted for heat pump heating.

All heat pumps supplied the houses with DHW, at least to some extent. The efficiency (COP) during DHW heating is normally lower compared to space heating, and therefore, the larger share of DHW, the lower SPF is obtained. However, in this case, no clear trend could be found.

In site 3 the heating system supply temperature set point was fixed at +65 °C during the winter, but the heat pump only delivered an average of 56°C during the period December to March (about 51 °C over the complete heating season), probably due to constraints in the control system. This is still very high temperatures for a heat pump to operate at and will most often result in very poor performance. Other heat pumps were operating at very high average supply temperatures as well. Site 2 had an average supply temperature of 54°C over the heating season, which is probably one of the reasons behind the low SPF value and Site 26 operated at an average heating water temperature of 48 °C even if the system seemed to be designed for maximum 42 °C.

Site 4 had very low SFP_{H4} (1,2) despite underfloor heating and thus low temperatures in the heating system. However, this heat pump system was equipped with three tanks, of which only one was heated by the heat pump. The others were heated by electric heaters. When analysing the raw data it was found that the heat losses from the tanks have not been regarded as useful heat in the SPF calculations, which could be one reason for obtaining such a low SPF_{H4}. This means that, if the house had been heated by resistant electricity only, the measured SPF had not been equal to one, but lower. How much lower depends on the magnitude of the losses, which is unknown. Another reason is the high share of back-up heating (55% of delivered heat). This finding suggests that the control of the heat pump system is not well working, as the heat pump seems to have spare capacity most hours of the year, even when the back-up heaters are in operation, according to the measurements. It seems like the DHW is heated mainly by electric heaters, and that the heat pump is only allowed to preheat the DHW, even though it has spare capacity. For this site there are still some remaining questions, i.e. has heat energy been correctly measured? Is the compressor damaged? Are the losses in this heat pump system larger than for other systems, due to the number of tanks in the system?

The Site 5 is operating at low average heating system temperature, about 37 °C over the heating season, but has a low SPF_{H4} of 1,8, despite the low temperatures of the heating system. According to the report the heat pump is oversized, but when producing DHW in the summer the heating system is only operating up to about 40–45 °C according to the raw data. The temperature of the DHW will, due to temperature losses in the heat exchanger be lower, thus the electric backup heater has to take a large portion of the DHW heating in order to obtain sufficient temperature of the DHW. The data on DHW is confusing, as more electricity is used in the electric heater in the DHW tank than the energy measure for the for the produced DHW. This indicate either an error in the measurements or could also be caused by high heat losses from the DHW tank.

No conclusion could be drawn from the raw data behind the report about the use of energy for defrosting, to be able to see if a malfunctioning defrosting strategy of the heat pumps was the reasons to the low SPF values or not. This could of course be the case but it could not be confirmed. The reason could also be the malfunctioning of the compressor caused by non-favourable operating conditions of the heat pump during a long time and that the heat losses are large in comparison to heat delivered from the heat pump.

However, when analysing the data and details about the Norwegian sites, it could be concluded that the selected system design and control settings were far from optimal for a heat pump system and the fact that the market for air-to-water heat pumps in Norway was still rather immature when the evaluated heat pumps were installed. Even though

Norway is the country in Europe with highest penetration of heat pumps among the population, most of the installed heat pumps are of air-to-air type and only 2–3000 air-to-water heat pumps are installed each year [34]. The corresponding number in Germany is at least tenfold [34]. Therefore, insufficient knowledge of the installers of the air-to-water heat pumps could be one of the reasons for the low SPF values.

One complicating factor in Norway is the 3x230V electric grid system, a system only also used in Albania in the rest of Europe. This makes it necessary for the manufacturers to sell special versions of the heat pumps on the Norwegian market, at least for the three phase heat pumps (most air-to-water heat pumps). This means Norway will likely get the latest released heat pumps later than other countries, as manufacturers will focus on the main 3x400V market of the rest of Europe first. What this really means for performance of the Norwegian heat pumps has not been investigated in this report.

Figure 11: SPFH4 for the different air-to-water heat pumps in Enova report [14]

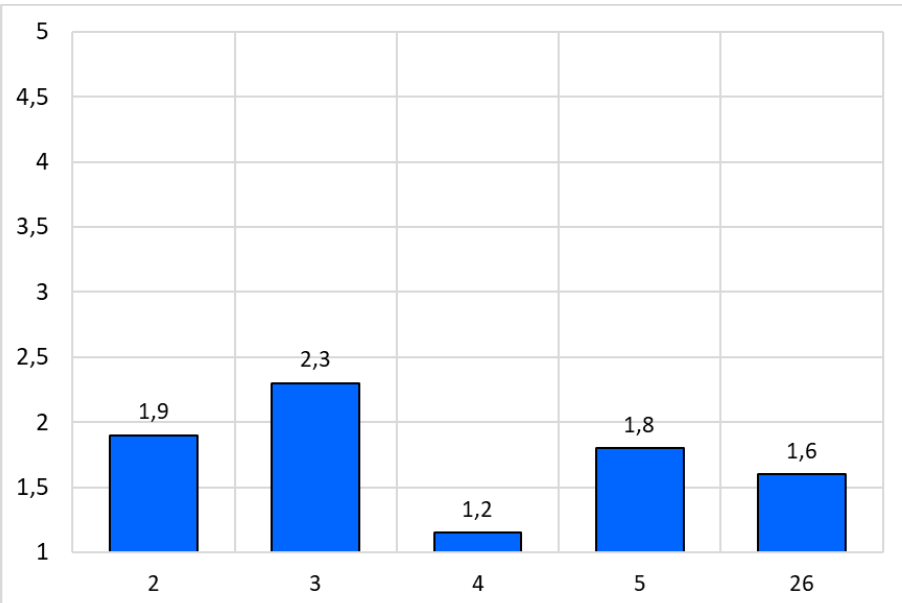


Table 8: Data for the sites in the Enova report [14]

Site	Heating capacity [kW]	Backup heater	House year	Heat pump year	DHW	Heating system	Average supply temp* [°C]
2	12	Electric	1900	2010	Yes	Radiator	54
3	16	Electric + oil (not used)	1938		Yes	Radiator	51
4	10	Electric + 5 (3?) electric radiators	2010 (1959)		Yes	Underfloor	~30
5	9	Electric + electric radiators + wood stove + AAHP (old part)	2009 (old part 1963)	2010	Yes	Underfloor	~35**
26	15	Electric	1964	2011	Yes	Radiator	~48

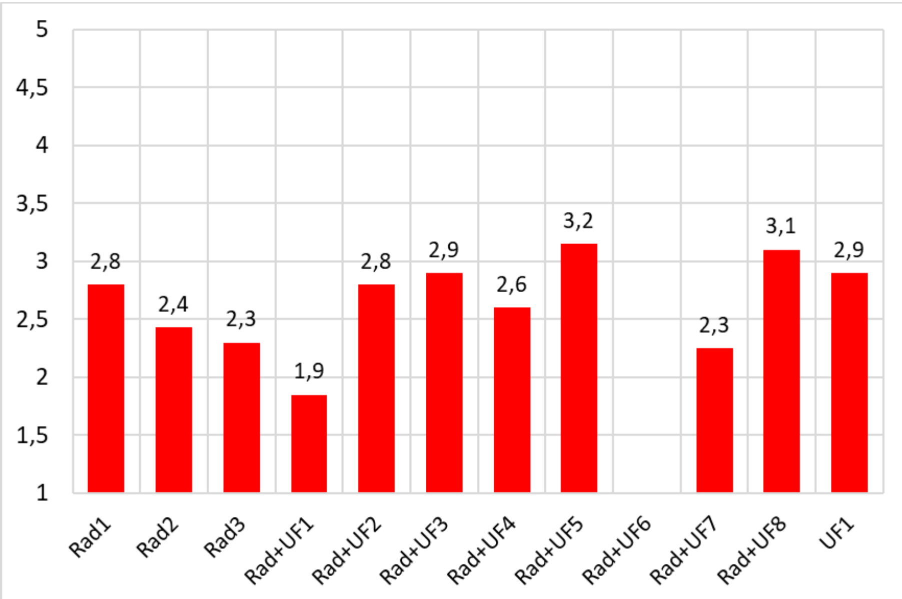
Note: Blank = no information found.
* During heating season.
** Heating seems to be on all year around.

3.1.4 Danish field measurements for approval for subsidies, DTI

The Danish Technological Institute, DTI, has performed field measurements on twelve air-to-water heat pumps in order to approve them for subsidies, see Figure 12. The results were reported in a report [27], published in 2013.

This report gives clear information regarding the heating system type for the installed heat pumps, but no clear conclusion could be drawn concerning how the type of heating system affected the performance. The underfloor heating system should have had the highest performance and accordingly, the SPF value of the one underfloor heating system is higher than the average of the others. However, two combined systems (both radiators and underfloor heating) had higher SPF values than the pure underfloor heating systems. Else very little information per site is available in the report. No information about how losses from tanks had been taken into account could be found. Note that SPF values around or below 2,0 are to be considered as low in this climate region. Also in Denmark the market for heat pumps connected to hydronic (water based) heating systems was very limited when this field measurements were performed. This means that the experiences among the installers were limited and might have been insufficient. The reason for this limited market could also be that the heating systems on the retrofit market are designed for high heating water temperatures, which in not ideal for a heat pump. Nevertheless, for many of the heat pumps the SPF had levels leading to considerable energy savings, even though the heating systems might not have been ideal for a heat pump.

Figure 12: SPFH3 for the different air-to-water heat pumps in DTI report

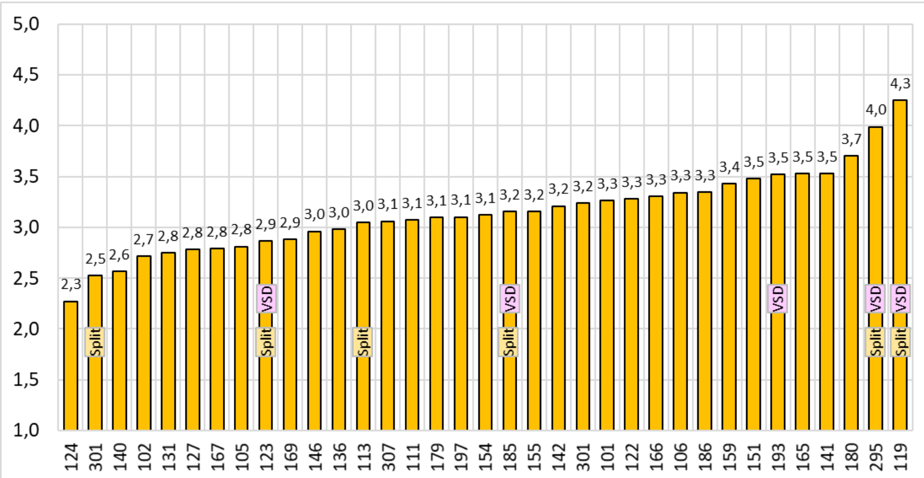


Note: Rad = Radiator heating system, UF = Underfloor heating system, Rad+UF a combination. On one of the sites the SPF-value was missing in the report.

3.1.5 German field measurements

In Germany the Fraunhofer ISH institute and the Internationales Geothermizentrum, GZB [20], [21], [22], [24], [25], [26] has performed a massive amount of field measurements from year 2007 and onwards. Some of their results are shown in Figure 13. SPF data is generally high in the German field measurements, compared to several other countries. One reason for this is that most of the sites, also the ones using On/Off heat pumps, have monovalent or near monovalent heat pumps system design. Another reason is of course a milder climate compared to Northern Europe.

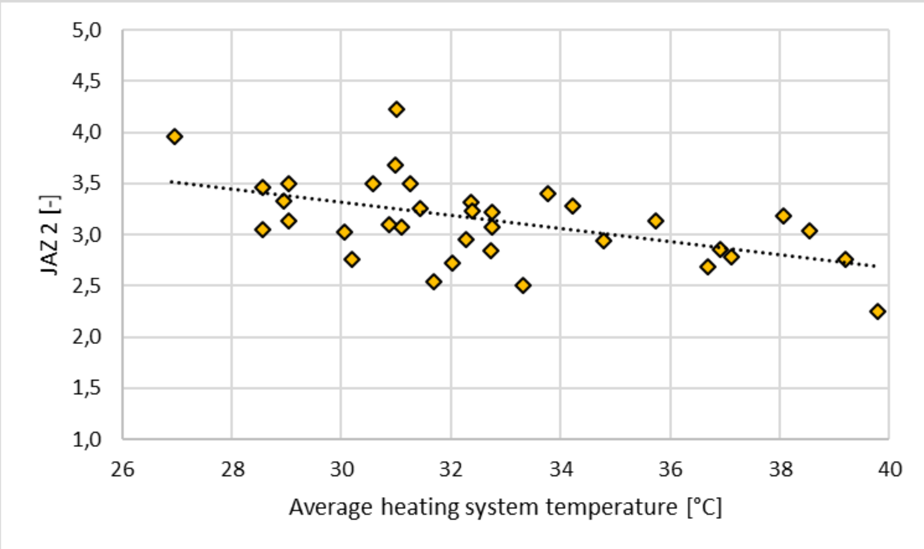
Figure 13: JAZ 2 (appr. SPFH3) for the different air-to-water heat pumps in the Fraunhofer 2014 report [25], showing data measured during 2012/13



Note: VSD = Variable Speed Drive, meaning the others are On/Off heat pumps. Split means that the refrigerant is condensed in the indoor unit, the others are Monoblock with water of the heating system passing through the outdoor unit.

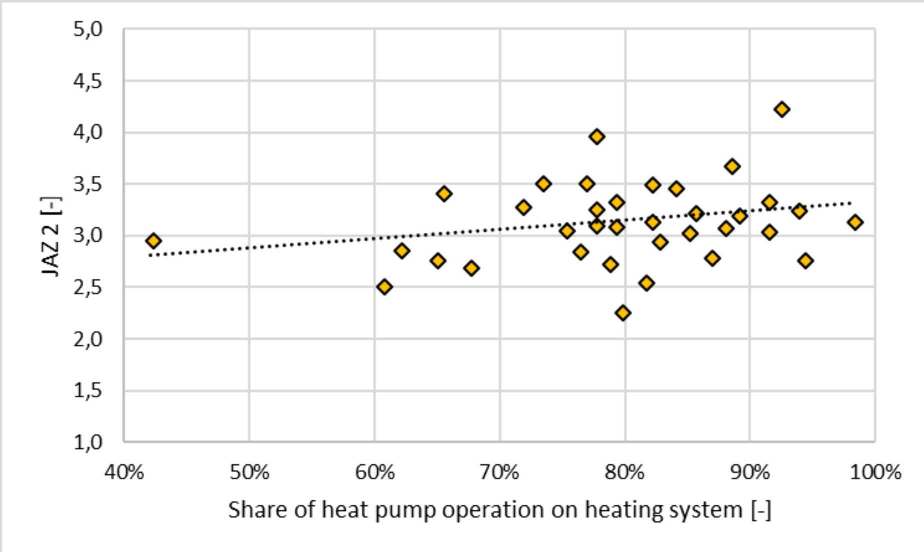
In the report there was also information given about average heating system temperature over the year for each heat pump, see Figure 14. The trend is clear, the lower temperature of the heating system, the higher SPF values (with some exceptions). It can also be concluded that heat pumps in Germany are generally installed in low temperature heating systems.

Figure 14: JAZ 2 (appr. SPFH3) as a function of average heating system temperature for the different air-to-water heat pumps in the Fraunhofer 2017 report, showing data measured 2012/13



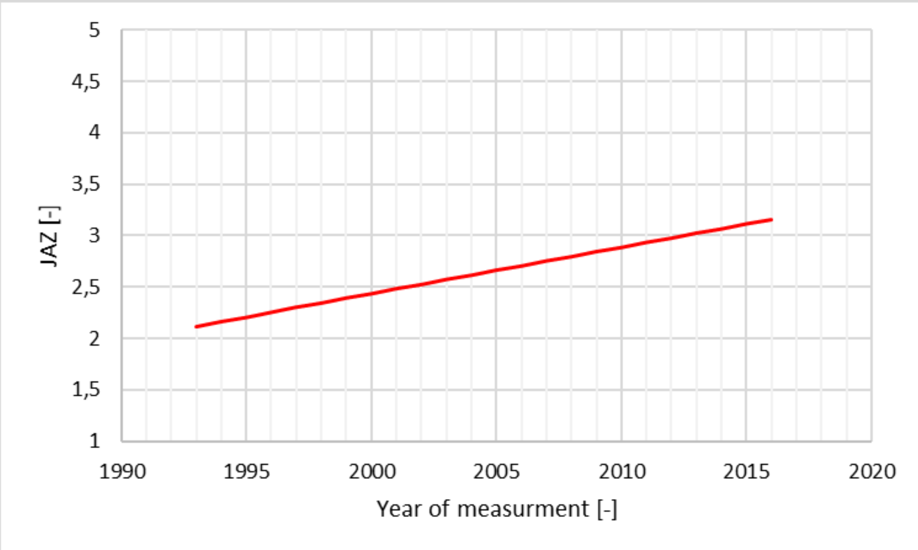
The presented data of the heat pumps also showed to what extent the heat pump operated in heating mode or in DHW mode, see Figure 15. The data show that a higher share of DHW will cause lower SPF values, with some exceptions.

Figure 15: JAZ 2 (appr. SPFH3) as a function of share of heat pump operation on heating system temperature for the different air-to-water heat pumps in the Fraunhofer 2017 report, showing data measured 2012/13. A high share means a low share of DHW



The Internationales Geothermizentrum, GZB [26] presents data showing that the SPF value of newly installed heat pumps increase every year, see Figure 16 The trend is very clear, according to them. The SPF values for air-to-water heat pumps in Germany has increased every year since 1993. The SPF difference between manufacturers declared performance and the field measurements is 0,77, but the calculation is not transparent, it is unclear how it has been calculated.

Figure 16: Trend of SPF (boundaries not clearly stated in the report) in installed air-to-water heat pumps in Germany from 1993 to 2016

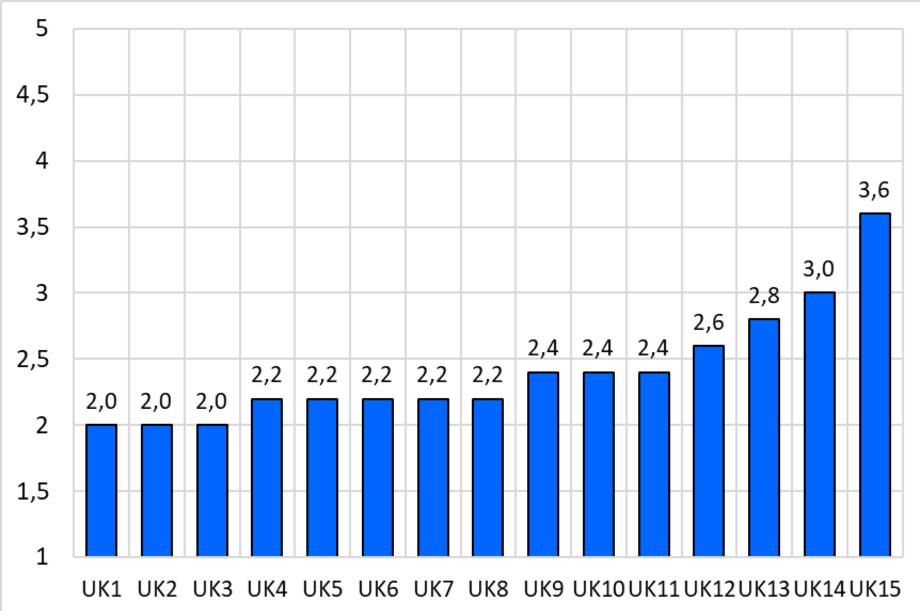


3.1.6 Energy Trust's heat pump field trial

The Department of Energy and Climate Change UK presented a report [33], published in 2013, which gives interesting information on SPF values after changes to the systems were made compared to the earlier field test [32] on the same heat pumps. The results showed that major and medium interventions gave most positive changes of SPF, on average an increase of 0,5 after the major changes had been done. The minor or no change gave both positive and negative change of SPF. The report does not clearly separate those findings, between ground source and air-to-water heat pumps, meaning results for air-to-water heat pumps cannot be extracted from the data.

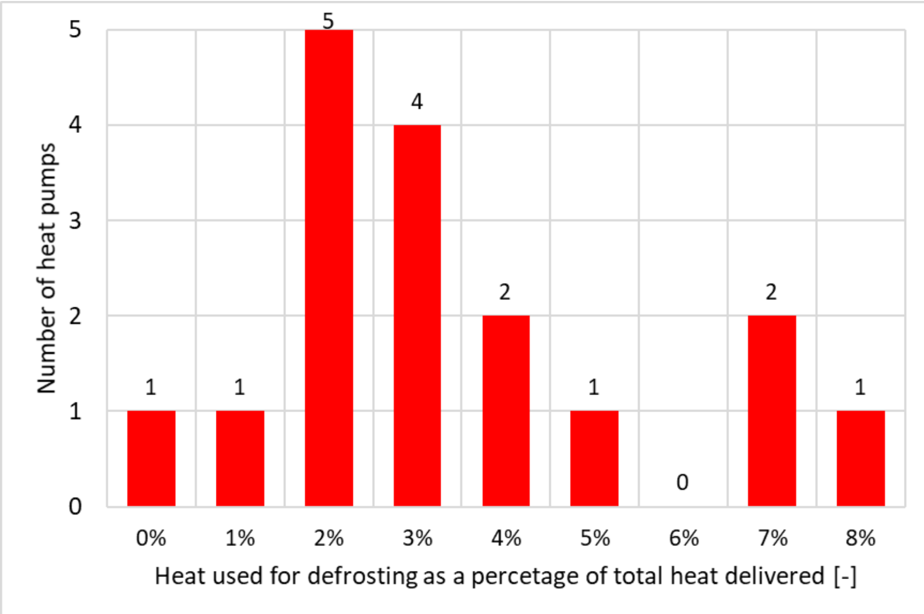
SPF_{H4} (not SPF_{H3}) data can be seen in Figure 17 for the sites after changes had been made to the systems (see above). There is no detailed site data available in the report.

Figure 17: SPFH4 (not SPFH3) for the different air-to-water heat pumps in UK report [33]



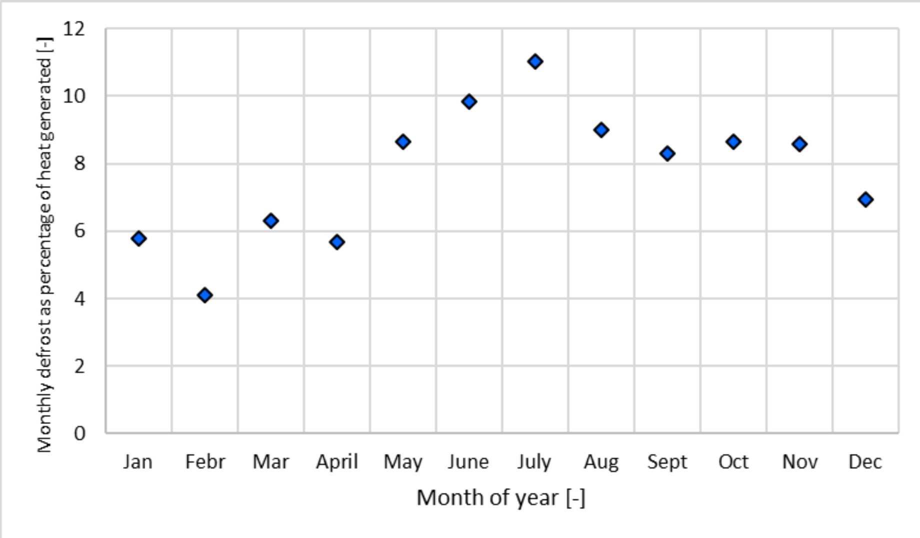
Defrosting percentage of total heat output was measured on the air-to-water heat pumps, see Figure 18. The amount of defrosting energy use is not nearly as high as for the German site, see Chapter 3.3 on page 60, were one of the sites in this report are discussed in more detail. The sites with highest percentage are not located in the coldest parts of the UK (the locations are: Belfast, Cheshire and Oxfordshire).

Figure 18: Heat used for defrosting as a percentage of total heat delivered from the heat pumps



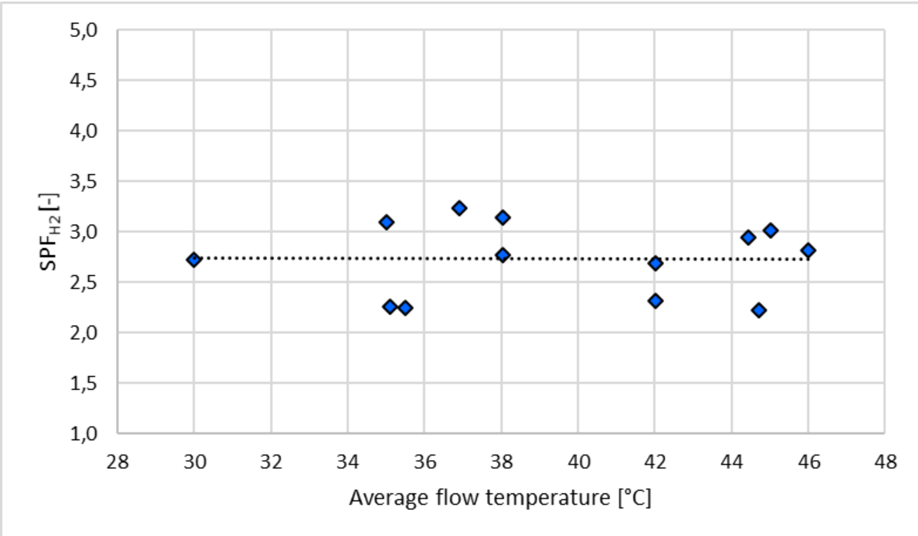
The heat used for defrosting was examined in detail for site 448. It used 544 kWh or 7% of the total delivered heat to defrost the evaporator. The defrost was done by reverse refrigerant flow and as seen in Figure 19 the defrosting function was operating all year around. During higher outdoor temperature operation period (summer) a well performing heat pump should not need to defrost. Therefore, this is an illustration on the importance of correct defrosting control. If the defrost control does not work properly, the total amount of energy used for defrost will be large.

Figure 19: Heat used for defrosting on site 448 over the year. The was one of the sites with largest percentage of heat used for defrosting



The study show that for the UK heat pumps the flow temperature does not affect the SPF_{H2} value, at least not on average, see Figure 20. As SPF should decrease with higher temperature lift, i.e. a higher flow temperature, this is unexpected. This is different from the German heat pumps, Figure 14, which showed a clear decrease in JAZ 2 as the average heating system temperature increased. This could be a result of that control of the heat pump let the heat pump work with a fixed high condensing temperature even if the temperature of the heating system is lower or varies.

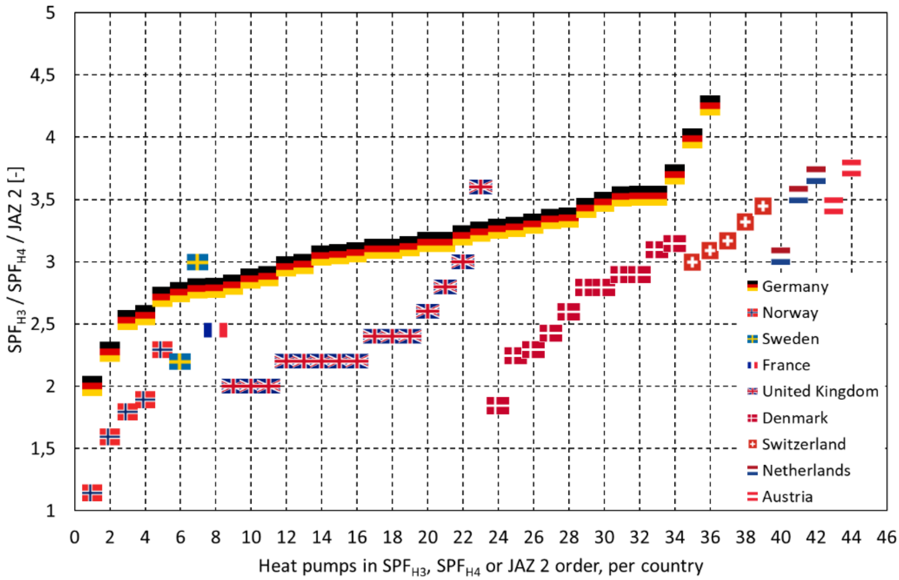
Figure 20: SPFH2, for heating only, as a function of the average flow temperature of the heating system



3.1.7 SPF for all field tested heat pumps

All field tested heat pumps in Chapter 3.1.1 to 3.1.6 are summarised in Figure 21. Almost half of the field tests are done in Germany, they represent 36 of the 78 found heat pump measurements.

Figure 21: All field measurements. Note that UK & Norway are SPFH4 and Germany are JAZ 2

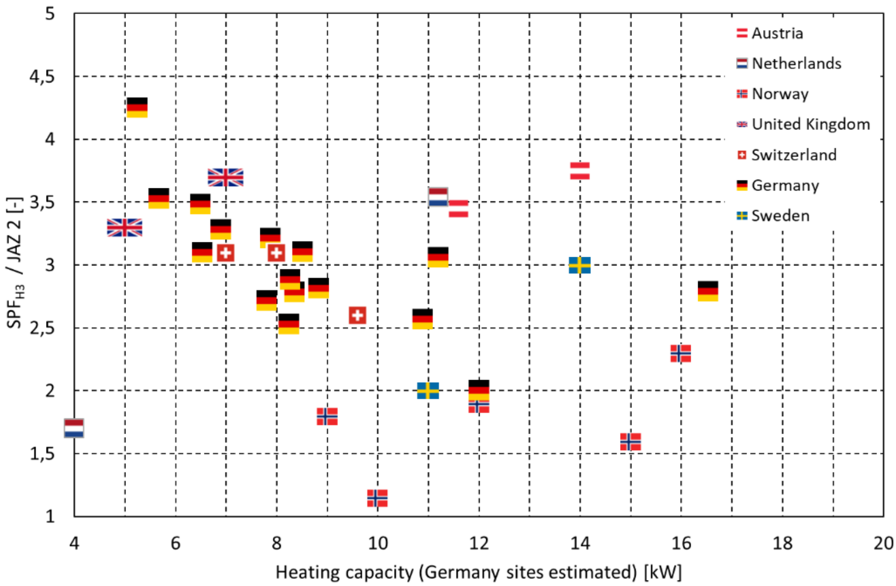


Note that even if SPF_{H3} or SPF_{H4} are reported for all the sites, the losses from possible storage or DHW tanks might have been treated differently in the different analyses and reports. It is clear that four Norwegian sites underperform compared to the heat pumps of the other countries, but also one Swedish, one Danish, one German and three UK perform worse than could be expected. Of course, the colder climate could be one explanation to the lower SPF values, but this is probably not the whole explanation. Many German, all Swiss, Dutch and Austrian heat pumps perform above average.

3.1.8 SPF as a function of heating capacity

Many of the reports from heat pump field measurements summarised in Chapter 3.1.1 to 3.1.6 have information on heating capacity available. The information is not stringent, since the manufacturers use capacities at different operating or test points when informing about heating capacity of the heat pumps. In Figure 22 the SPF values reported from different countries are shown as a function of heating capacity of the heat pumps. In most case the name plate information is used for the capacity of the heat pumps (if available), but for the German sites, the capacity was estimated from the data. However, no specific trend could be found.

Figure 22: SPFH3 as a function of heating capacity (JAZ 2 for the German sites and SPFH4 for the UK sites)



Source: Data from various sources. The German site's heating capacity are estimated from data on operating hours and electric consumption over the year.

3.1.9 Summary – Field measurements of air-to-water heat pumps

When reporting and evaluating results from field measurements it is important to relate to which system boundary that has been applied. The SEPEMO project defined four different system boundaries for SPF (Seasonal Performance Factors) values, SPF_{H1}-SPF_{H4}, which can be applied and the results presented in this report are related to them. However, neither the SEPEMO report nor several of the other reports are clear about to treat losses from storage tanks, i.e if such heat losses should or have been regarded as useful or not.

All reported field measurements found are performed on heat pumps developed and manufactured before the Ecodesign and Energy Label regulation went into force.

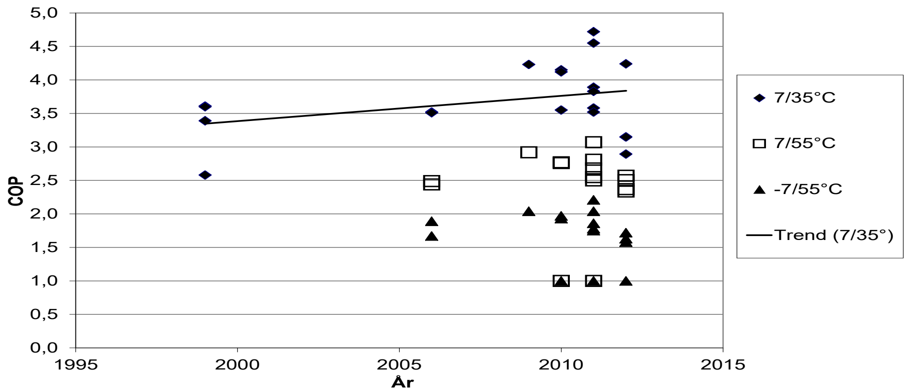
Many of them perform "as expected" but some of them underperform. The reasons for that are not clear, but in many cases it seems to be linked to a not very good selection of size, design and control parameters of the heat pump systems and/or high heat losses from tanks.

Some of the underperforming heat pumps are installed in Norway, UK and Denmark which have more humid climate compared to Germany and Switzerland. Therefore, mal performing defrost strategies could be a reason, but this cannot be said for sure based on the results found in the reports. The energy losses due to defrosting were measured separately in the UK sites. It was found that most of them used less than 5% of the heat output for defrosting. It is unlikely this will degrade SPF values significantly. Therefore, this is probably not the sole explanation to low SPF values.

3.2 Laboratory measurements of air-to-water heat pumps

Haglund Stignor *et al.* [18] presented the results from independent tests performed by RISE (former 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 had improved considerably since the year of 1999, but also that there was a large spread in the performance of the heat pumps sold today at that time (2014), see Figure 23. Note that the test points +7/55 °C and -7/55 °C were not tested in 1999 as they were not part of the earlier standards (before EN14511).

Figure 23: COP at different test points for air-to-water heat pumps tested during different years [18]

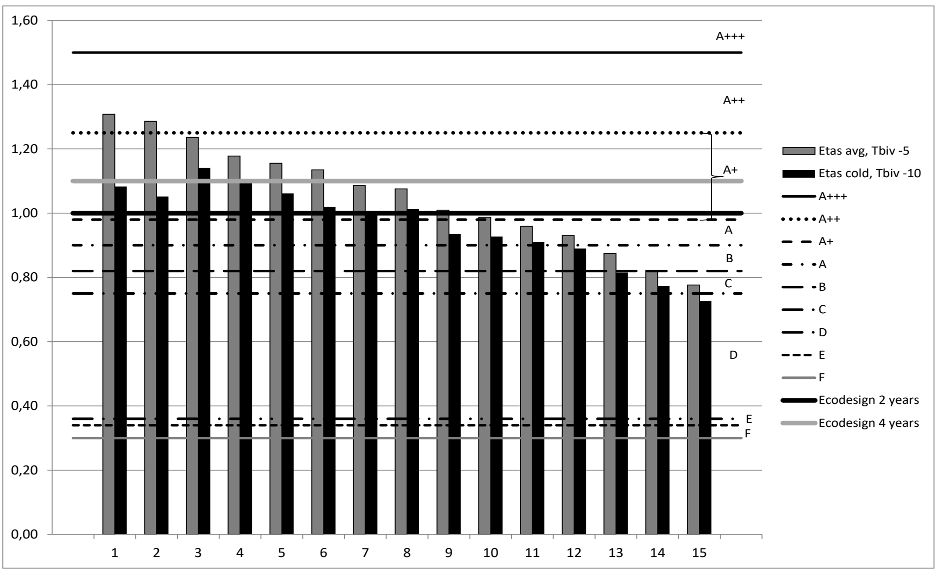


The performance of the heat pumps was compared to the requirements in the (by then) forthcoming ecodesign and energy labeling regulations for space heaters and combination heaters within the EU. It was found that some of the tested heat pumps would not pass the requirements while others would obtain an A++ energy label (second best class), see Figure 24. Of the evaluated heat pumps, all but two were on-off controlled. Since then, it seems like there has been a change to that almost all air-to-water heat pumps sold on the European market are variable capacity controlled. Since such a large fraction of the air-to-water heat pumps would not pass the ecodesign threshold values, ecodesign regulations have probably stimulated a technology development of this product category.

The space heating energy efficiency, η_s, (for a medium temperature, e.g. radiator heating system) shown in the figure below is approximately equal to SCOP divided by 2.5 and SCOP is comparable to SPF_{H3}, however not identical since the pumping power is included differently. The difference should not be more than a couple of percentage. In addition, in SCOP, all heat from the heat pump is regarded as useful, also the losses from possible tanks that the heat pump is connected to. Such losses are treated differently when reporting SPF_{H3}. Depending on site and placement of the tanks, this might lead to large differences.

If/when these heat pumps presented in the figure below had been installed and measured they would have ended up with SPF_{H3} between 2.0 and 3.2 in an average climate and 1,8 and 2,8 in the cold climate, if they had performed as well in the field as in the laboratory and all the heat losses from tanks are regarded as useful. Many of the results from field measurement reported in earlier sections are probably performed on heat pumps manufactured between 2006 and 2011 (which were the dates for the laboratory measurements) and many of the results are within the performance range above. However, if the operated to a large extent with a floor heating system, they should have ended up with higher performance numbers than presented in Figure 24. On the other hand, if they heated DHW (domestic hot water) in the field, that would result in lower SPF values. Nevertheless, some heat pumps evaluated in the field trials underperform compared to what they should perform according to laboratory measurements.

Figure 24: Approximate values of ␣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



3.2.1 Summary – Laboratory measurements of air-to-water heat pumps

The COP of the heat pumps tested at RISE (former SP) increase over the years according to the presented results. On average the COP increased about 15% from the first test in 1999 until the later test in 2012.

It was seen that a large fraction of the heat pumps tested before the introduction of the Ecodesign and Energy Labelling regulations, would not have passed the Ecodesign threshold value. At that time all but two tested heat pumps were on-off controlled. The introduction of the Ecodesign and Energy Labelling Regulations has probably resulted in that on-off controlled heat pumps to large extent has been replaced by variable capacity controlled heat pumps on the market. However, many of the heat pumps installed before the introduction of the regulations are still in operation.

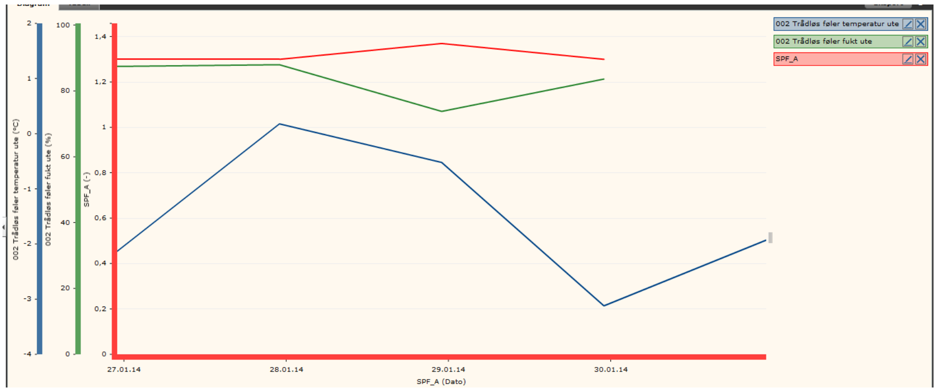
If/when these heat pumps presented above had been installed and measured they would have ended up with SPF_{H3} between 2.0 and 3.2 in an average climate and 1,8 and 2,8 in the Cold climate, if they had performed as well in the field as in the laboratory and all the heat losses from tanks are regarded as useful. Many of the results from field measurement reported in earlier sections are probably performed on heat pumps manufactured between 2006 and 2011 (which were the dates for the laboratory measurements) and many of the results are within the performance range above, but a few ones underperform.

3.3 Dependency of performance on the humidity of the climate

The efficiency (COP) of an air-to-water heat pump depends on the outdoor climate, both temperature and humidity. Therefore, those parameters are precisely defined in the test standards. At outdoor temperatures where frosting occurs the grade of humidity can have both a positive and negative effect on the performance of the heat pump. A high humidity means a higher enthalpy and thereby energy content of the heat source, i.e. the outdoor air, which can have a positive effect. On the other hand, the more water content of the outdoor air, the more likely it is that frosting takes place on heat exchanger surface and the larger is the magnitude of frost, that must be melted during defrost.

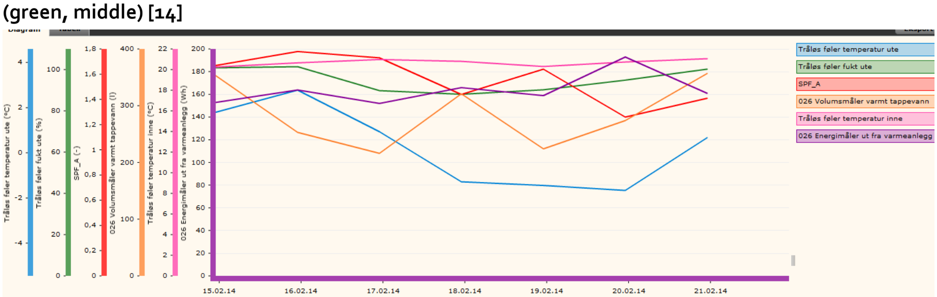
Haugerud *et al.* [14] reported results from field measurements of five air-to-water heat pumps, AWHP, in Norway, all installed between 2009 and 2011. The field measurements were analysed for the year 2014. A small increase in SPF can be seen for the heat pumps, when outdoor air humidity decreases, even if the outdoor air temperature is decreasing at the same time, see Figure 25. The increase is about 5% at one occasion, but another time a decrease is seen. As the AWHP produces domestic hot water, along with heating, it is difficult to compare different days, the variations are too large and cause disturbances in the result. Therefore there is a risk that the researcher to draws erroneous conclusions from the data set.

Figure 25: COP (red, top) as function of outdoor temperature (blue, bottom) and outdoor humidity(green, middle) [14].



In Figure 26 another week from the same study is shown, but it is very difficult to draw any certain conclusions regarding if COP is lower or higher at lower relative humidity.

Figure 26: COP (red, top) as function of outdoor temperature (blue, bottom) and outdoor humidity (green, middle) [14]

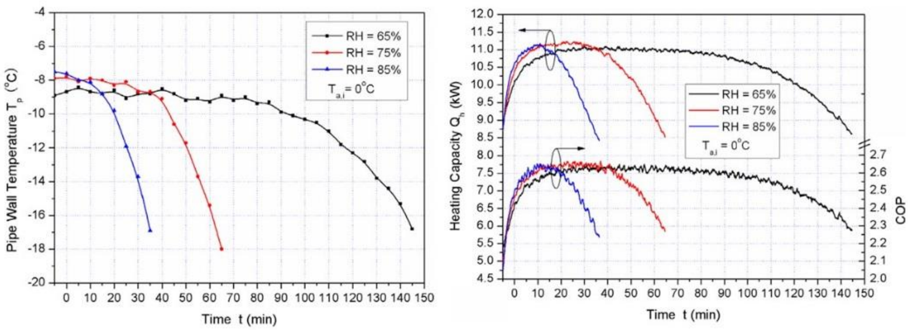


Klein [16] refers to performance tests of air-to-water heat pump system. According to them COP will decrease 0,3 to 1,0 if defrosting is accounted for, at a specific ambient temperature (not given in this article). They also state that frost normally does not form at higher ambient temperatures than +7 °C and that frost growth is lower at lower winter temperatures due to low absolute humidity, see below. This means that the Seasonal Performance Factor for the heat pump, SPF_{H2}, will possibly not decrease as much as Klein [16] states for the COP (if the heat pump is frosting and defrosting or not) since the SPF is an averaged COP of the heat pump over the whole heating season.

Stark [28] has measured defrosting energy on three different solar thermal coupled air-to-water heat pumps in Germany. One of the heat pumps were operating monovalent (without backup heater). In this system 3002 kWh were used for defrosting, but as no overall energy performance is presented for this system it is unknown how this defrosting energy correspond to overall heat production of that heat pump. Also it is noted that the defrost cycle is inefficient compared to one of the other heat pumps of the same type and manufacturer, since it used four times as high mass flow to melt the frost as the other do. Being at another location, and thus not fully comparable, the other heat pump used only 434 kWh for defrosting, or 12,6% of "overall energetic effort", likely meaning of all heat production, alternative heater included. The third heat pump used 727 kWh for defrost per annum, corresponding to 13,5% "overall energetic effort". This heat pump has a gas boiler taking over heating at -1,2 °C, below that temperature the heat pump seems to stop operating.

Dunbabin [33] presented more details on defrosting of one air-to-water heat pump. It used 544 kWh or 7% of total energy delivered from the heat pump. The heat pump used most energy to defrost in the winter, but compared to total delivered energy of the month the maximum ratio is actually obtained in July with 11% of total delivered energy. Defrosting during summer months seem illogical, as temperatures should be well above when defrosting should be needed. This finding shows that the heat pump control system is probably not correctly configured, or the heat pump design is poor, see Chapter 3.1.6.

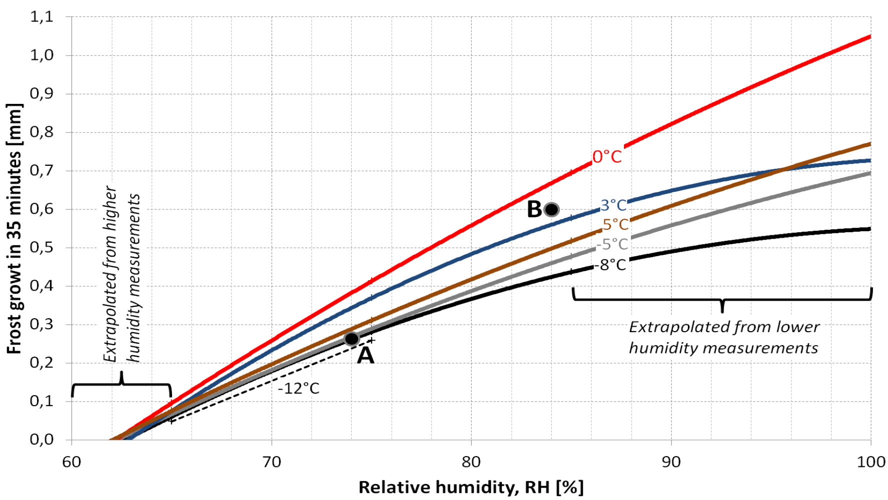
Figure 27: Evaporator wall temperature and Heating capacity/COP over time as frost accumulates on evaporator [15]



Formation of frost on the evaporator was studied and shown Guo *et al.* [15], see Figure 27 and Figure 28, where frost were found to form more rapidly at a higher relative humidity than at lower. When frost accumulates on the evaporator the temperature of evaporation decreases thus causing lower COP. The air-to-air heat pump used in the test has an evaporator temperature about 8 °C lower than the ambient temperature, which is somewhat low compared to a heat pump in real operation, as it will likely not operate at full heating capacity at 0°C ambient temperature. The frost growth shown in [15] should not be taken as general, since evaporator temperatures and thus frost growth will vary between heat pump brands and series.

The formation of frost has a maximum at ±0 °C according to the tests performed, see Figure 28. The curves are smooth and thus extrapolations, both to lower and higher humidity levels, were done (by the authors of this report). This should be seen as an indication of possible frost growth at humidity levels that were not tested. The test was done with a specific air-to-air heat pump (AAHP) and should be used with caution, as difference in evaporator sizes will cause different frost behaviours, as heat exchanger size will influence the evaporator temperature and thus frost growth.

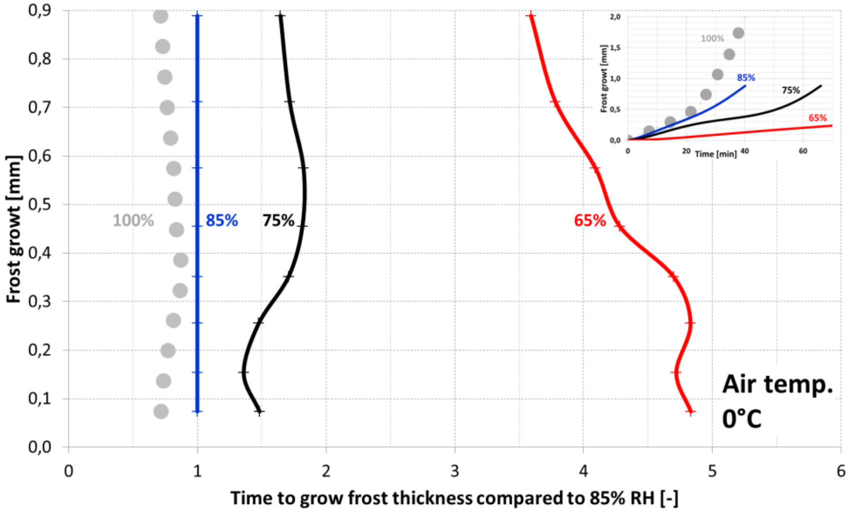
Figure 28: Frost growth at different relative humidity, with curves extrapolated up to 100% and down to zero frost growth. Data set from [14]



Note: Mandatory test points (A and B) used for the Ecodesign and Energy Labelling regulations, with temperatures within the test range of the study (defined in EN14825) are seen as large dots, see Table 13.

From a study presented by Guo *et al.* [15] the following diagram can be derived, see Figure 29, showing the relative time to grow a specific thickness of frost at 65, 75 and 85% relative humidity (RH). This shows clearly that the defrosting at 75% relative humidity will have to be done at an interval that is 1,3–1,8 longer than that at 85% (reference). At 65% RH defrosting has to be done at an interval being 3,6–4,8 times longer than the reference. The data set is extrapolated to 100% relative humidity, those values *indicate* that defrosting would have to be done at an interval of 0,7–0,9 of the interval at 85% RH (reference). This shows that defrosting should be initiated on demand, with shorter or longer intervals depending on ambient conditions. Using constant time intervals between defrostings risk poor performance.

Figure 29: Relative time to grow a certain frost thickness compared to growth time at relative humidity of 85%. Data set from [15]



Note: Absolute growth times are seen in the small diagram to the top right. The data for 100% RH is extrapolated and should be used only as an indication.

To further clarify what the frost growth means for the overall operation of the system see Figure 29. This means that there is likely no drastic increase in the number of defrostings above 85% relative humidity, at least not at ±0 °C ambient temperature.

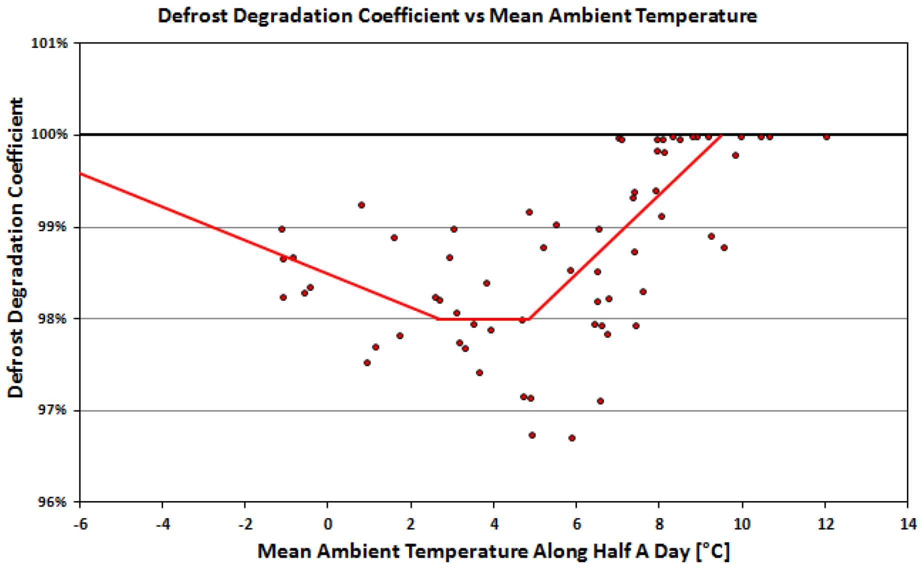
Table 9: Number of defrosting cycles per day, at an ambient temperature of ±0 °C, assuming 24 cycles at RH 85%

	Defrostings per day [-]	Time between defrostings [hh:mm]
65%	5–7	03:35–04:50
75%	13–18	01:20–01:50
85%	24	01:00
100%	27–34	00:40–00:55

Note: This is for a specific heat pump and that the values for 100% humidity is extrapolated.

In field tests performed by Dardenne *et al*. [17] on variable speed air-to-water heat pumps, the following degradation of COP was seen, see Figure 30. The heat pump setup was tested at twelve sites all situated in Belgium, Germany and Czech Republic, meaning all are within the Average climate zone. The Figure 30 is compiled of data from the twelve sites. The definition of HCOP is not clear from the report, but it is some kind of SPF measured and calculated within the controller of the compressor.

Figure 30: Degradation of HCOP (SPF) due to defrosting [17]



3.3.1 Summary regarding air humidity and performance of the heat pump

It has been shown that frost growth take place more rapidly at a higher relative humidity of the outdoor air and hence frosting must take place more frequently. There are studies indicating that a high humidity will have a negative influence of the overall efficiency of the heat pump, but no clear trends have been found. At conditions when frosting occurs higher humidity will cause more frost to form, giving lower COP, but this is necessarily not valid for the entire heating season, since no frosting generally occur at higher outdoor temperatures.

Four air-to-water heat pumps in the UK and in Germany are investigated in detail on defrosting showing around 10% of total heat output is used for defrosting. Compared to similar results from other heat pumps in the UK, these ratios of defrosting energy to total energy from the heat pumps are much higher.

4. Energy labelling of air-to-water heat pumps

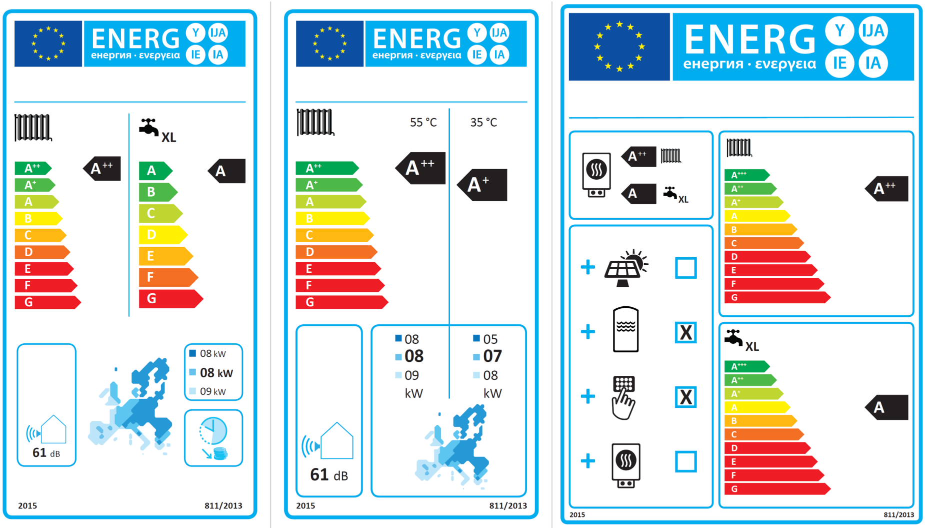
In this study, the internet has been browsed in order to find information about how performance data for air-to-water heat pumps are presented to the consumers. The Energy Labelling of air-to-water heat pumps is mandatory when putting a product on the European market. Hence, it should be possible for the consumer to find Energy Labels and associated data for air-to-water heat pumps. However, the results show that the magnitude and quality of presented data differ a lot. It should be noted, that from next year, it is compulsory for the manufacturer or importer to upload information related to the Energy Label in an Europea database, EPREL. Hopefully this will result in more homogenous data for the consumer.

4.1 Energy label and climates

The air-to-water heat pump Energy Label shows less detailed information than the Energy Label for air-to-air heat pumps (previous report). The Energy Label shows the following information, see Figure 31. The Nordic countries are mainly in the Cold climate zone according to the Energy Labelling Regulation [2], Denmark being the exception, while the Average climate zone is found mainly on the continent of EU and UK, see Figure 1 on page 18.

All information related to efficiency (energy efficiency class) is for the Average climate, although not clearly stated on the label, thus the Energy Label itself has rather low relevance in the Nordic countries. However, information regarding efficiency for the other climates should be possible to find in the mandatory product fiche.

Figure 31: Example of an anonymous energy labels for an On/off air-to-water heat pump



One series of heat pumps from one manufacturer found, provided detailed information for all climates and the efficiency classes could be calculated for the cold and the warm climates as well. The same threshold values for the seasonal space heating energy efficiency η_s as for the average climate was used in the classification, as there are no defined classes for the other climate zones.

Table 10: Efficiency class for different climates and temperatures of the heating system for the same anonymous on/off heat pump, calculated from background data in Energy Labelling documentation of the heat pump

Climate	Low temperature (35 °C)		High temperature (55 °C)	
	Class	SCOP	Class	SCOP
Cold	*A+*	*3,26*	*A*	*2,51*
Average	A+	3,70	A++	3,20
Warm	*A+++*	*4,71*	*A+++*	*3,55*

Note: The regulation does not acknowledge efficiency classes for the cold and the warm climate, thus these are italic and grey. SCOP values from the same data are also presented.

Table 11: Efficiency class for different climates and temperatures of the heating system for an anonymous variable speed control heat pump, calculated from background data in Energy Labelling documentation of the heat pump

Climate	Low temperature (35 °C)		High temperature (55 °C)	
	Class	SCOP	Class	SCOP
Cold	*A++*	3,96	*A+*	2,83
Average	A+++	4,41	A++	3,14
Warm	*A+++*	6,16	*A+++*	3,93

Note: The regulation does not acknowledge efficiency classes for the cold and the warm climate, thus these are italic and grey. SCOP values from the same data are also presented.

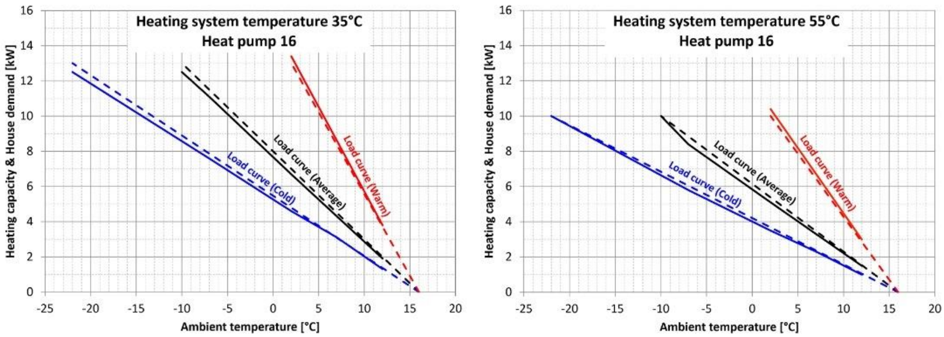
4.2 The heat pumps are declared at highest possible energy class

Most air-to-water heat pumps investigated through browsing marketing data are declared for a relatively low heating capacity (a low value of P_{design}). This means that they are declared to operate without any backup heater for most, or in some cases all, hours of the year in the SCOP bin calculation. Little data is found, except from one manufacturer, which give detailed data for the heat pump performance. From that data the manufacturers strategy could be understood:

- For heat pumps with variable speed drive control
  - Declare the heat pump as monovalent as possible, keeping highest energy class.
- For heat pumps with on/off control
  - Try to achieve as high energy class as possible.
  - Within that class, declare the heat pump with the highest as possible heating capacity, P_{design}

Figure 32 show how a variable speed heat pump is declared for different climates. It has been declared as monovalent, without any backup heater, for all climates. With variable speed drive compressors the heat pumps can run continuously from lowest ambient temperature up to +12 °C according to the declaration. This is a very wide span for the compressor, meaning that it can run continuously at a capacity which is less than 5% of maximum capacity (cold climate). Since, compressors normally can be regulated down to 15–25% of max capacity without lubrication problems, this declarations is somewhat concerning and surprising.

Figure 32: Anonymous variable speed drive heat pump (16 kW in name), rated at 12,5 kW for the cold climate at low temperature heating system (35 °C at Pdesign) and at 10 kW at a medium temperature heating system (55 °C at Pdesign). The heat pump is declared as monovalent, without backup heater, in all climates. Solid lines are actual heating capacity. As they are for a variable speed controlled and monovalent heat pump they are identical to the load curves

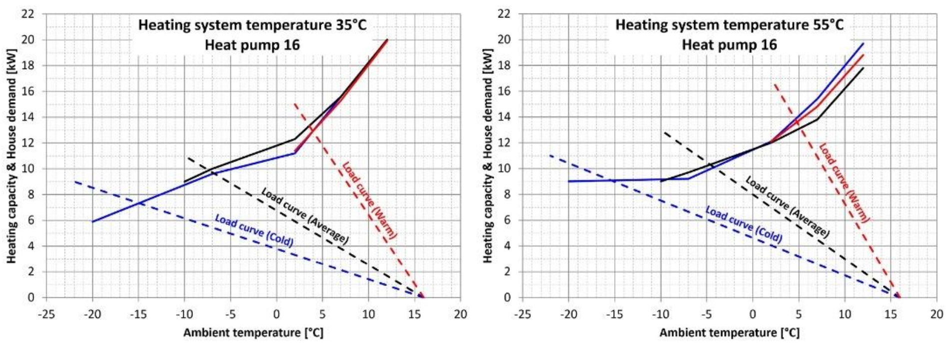


Another heat pump manufacturer claims that P_{Design} for the average climate is about 10% higher than the capacity in the product sheet at the same operating point. The product sheet has a passus: "*Maximum heating capacity at continuous operation*". Clearly the manufacturers are stretching the limits of the energy label.

Declaring the heat pumps as monovalent, meaning no backup heating is needed, as in Figure 32 is not at all incorrect. With variable speed drive compressors the heat pumps can run continuously from lowest up to high ambient temperature giving very good performance. This of course means higher cost of the heat pump compared to the smaller on-off heat pumps historically sold, at least in the Nordic countries. If this monovalent or near monovalent sizing is used nationwide, as it actually is in Germany (see Chapter 3.1.5), the peak power in the electrical grid could be reduced, since no electric back-up is needed, giving lower CO_2-emissions from the electricity production. Therefore, when installing a variable speed air-to-water heat pumps, a monovalent design should be encouraged and stimulated, if it can be shown that best efficiency can be obtained by such design.

Only few on/off heat pumps were found on the market. Figure 33 shows how an on/off heat pump is declared for different climates, and it is declared as almost monovalent. This is concerning. In a real system this means that the heat pump has very high capacity at higher ambient temperatures. Such a setup needs large tank volumes to operate well, else the result is short cycling which could be negative for the compressor in the long run. In addition, large capacity of the heat pump in relation to the heating demand, means that the heat pumps might work with unnecessarily high condensing temperatures during large parts of the year. Large tank volume in combination with a large heat pump also closes the cost benefit gap over ground source heat pumps or a variable speed air-to-water heat pumps, potentially making the installation uneconomical.

Figure 33: Anonymous on/off heat pump (16 kW in name), declared as a 9 kW for the cold climate at low temperature heating system (35 °C at Pdesign)



Note: Left figure, blue dashed line – and 11 kW for the cold climate at a medium temperature heating system (55 °C at Pdesign) – (right figure, blue dashed line. (This is well below the heating capacity in the name of the heat pump. Solid lines are actual (maximum) heating capacity for each climate according to the manufacturer. The black and red lines represent average and warm climates.

Generally the SCOP values are not communicated in marketing data, meaning there is a low incentive for the manufacturer to achieve highest SCOP within the energy class, see Table 12. This means that the Energy Labelling is holding back the development towards higher SCOP values, after a manufacturer has reached a competitive energy class for its heat pump series, for example A++. In the example not reaching energy class A+++ (4,45 and above, low temp.), there is no reason to strive for higher SCOP than 3,83 as it will be more costly still giving the same energy class.

Table 12: SCOP for different energy classes and different heating systems

Class	Low temperature (35 °C at P_{design}) SCOP	High temperature (55 °C at P_{design}) SCOP
A+++	4,45 & above	3,83 & above
A++	3,83 – 4,45	3,20 – 3,83
A+	3,15 – 3,82	2,53 – 3,20
A	2,95 – 3,15	2,33 – 2,52

4.3 Declared efficiency of heat pumps on the market

The internet was browsed in order to get a picture about declared efficiency for heat pump sold on the market today.

While it is easy to find information from some heat pump manufacturers others do not present any of energy performance data at all. One manufacturer's data was found, with a high amount of details, on their British site, while the Swedish site had little information.

All but one of the investigated manufacturers have a series of air-to-water heat pumps that have better performance than other series they are selling as well, meaning that they often have one premium series. Only one series of on/off heat pumps were found. Most of the heat pumps found are monoblock, meaning the entire heat pump circuit is in the outdoor unit. The others are split units, having the evaporator, expansion valve and the compressor in the outdoor unit, but the condenser in the indoor unit. The latter alternative is frost safe as no water is circulated out to the outdoor unit. On the other hand, the risk of refrigerant leakage might be higher and it requires higher refrigerant charges.

One manufacturer is not presenting any SCOP values at all, the values in the diagrams below are calculated from the η_s values in their data sheets. The two manufacturers of split heat pumps are not presenting any data at all for the Cold climate, despite the information is taken from their Swedish site. One of them is only presenting information for the Average climate and the low temperature heating system.

Regarding performance data for DHW production, no COP values were found at all, the COP values were calculated from the η_{wh} values instead, which is the measure that the energy labelling classes for water heaters are based on. In those cases the smart control (SCF) was assumed not to be used by the heat pump manufacturers, as no information for smart control of DHW production was available. For one heat pump series the standby power was not available, it was then neglected, as it on the other heat pumps, for those where it was declared, had little effect on the COP for DHW production.

For DHW production COP is measured at fixed outdoor temperatures, for the Average climate zone the outdoor temperature is set to 7 °C (6 °C) and for the Cold climate zone 2 °C (1 °C). According to EN 16147 [10] the COP value obtained for the evaluated load profile (S, M, L XL etc) should be considered the SCOP for DHW production.

4.3.1 Average climate SCOP values

SCOP for the Average climate are seen in Figure 34 to Figure 35. All the dots represent one heat pump model and the first figure in the description represents manufacturer and the second one the model. Figure 34 and Figure 35 show the SCOP for the low and high temperature heating systems, while Figure 36 show SCOP for DHW production. Note that the scaling is the same on all diagrams, for better readability.

Figure 34: SCOP from different air-to-water heat pumps declared for the Average climate with a low temperature heating system (35 °C at Pdesign). SCOP are ranging from 3,5 to 5,2, with the on/off controlled heat pump series in the bottom

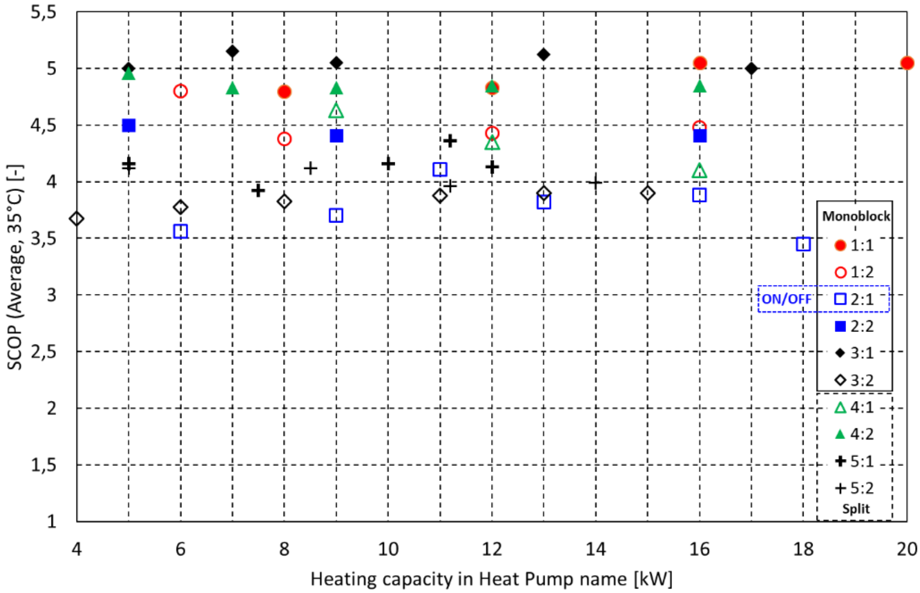


Figure 35: SCOP from different air-to-water heat pumps declared for the Average climate with a high temperature heating system (55 °C at Pdesign). SCOP are ranging from 2,8 to 3,9, for manufacturer 4 SCOP values are not found

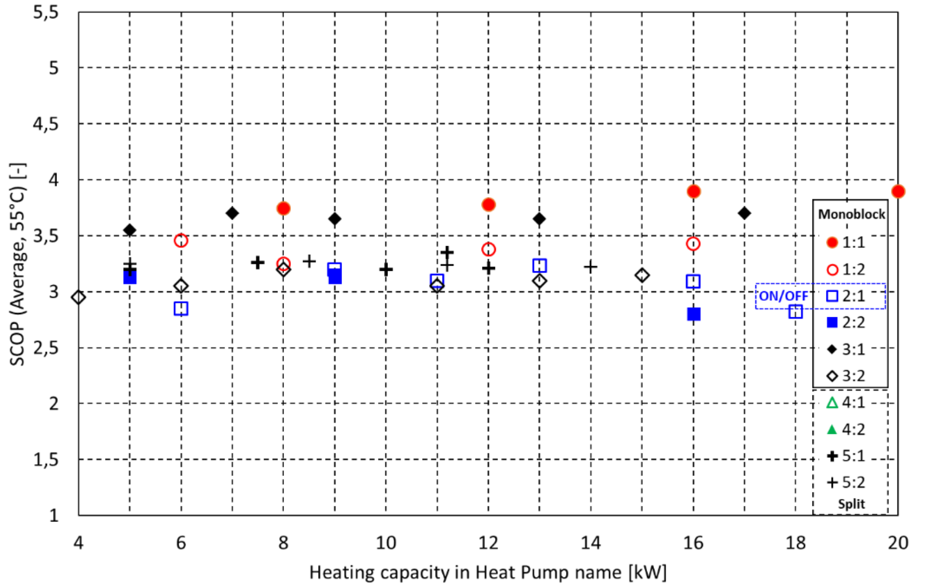
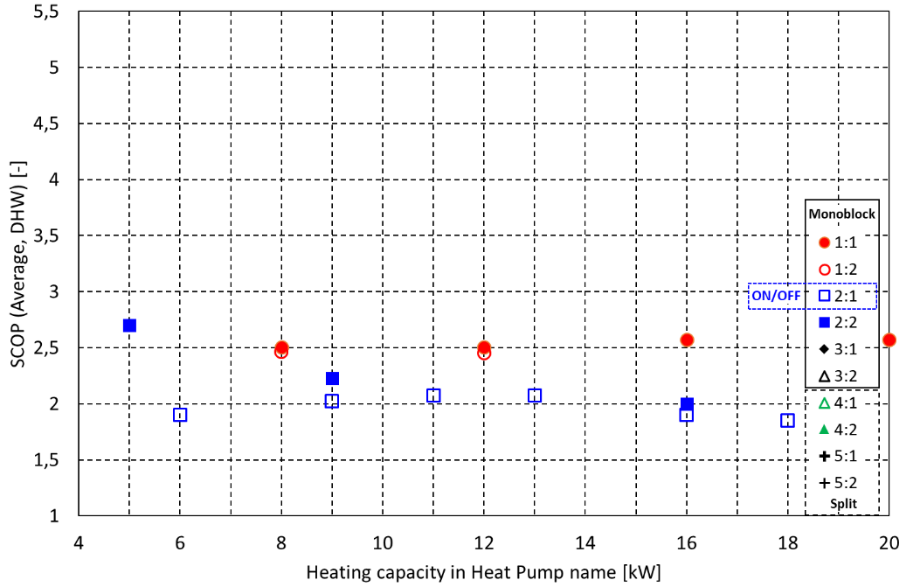


Figure 36: SCOP from different air-to-water heat pumps declared for the Average climate for DHW production. SCOP are ranging from 1,9 to 2,7. For manufacturer 3, 4 and 5 SCOP values could not be found



Cold climate SCOP values

SCOP for the Cold climate are seen in Figure 37 to Figure 39. Figure 37 and Figure 38 show the SCOP for the low and high temperature heating systems, while Figure 39 show SCOP for DHW production. Note that the scaling is the same on all diagrams, and the same as in Chapter 4.3.1.1, for better readability.

Figure 37: SCOP from different air-to-water heat pumps declared for the Cold climate with a low temperature heating system (35 °C at Pdesign). SCOP are ranging from 2,9 to 4,3, for manufacturer 4 and 5 SCOP values could not be found

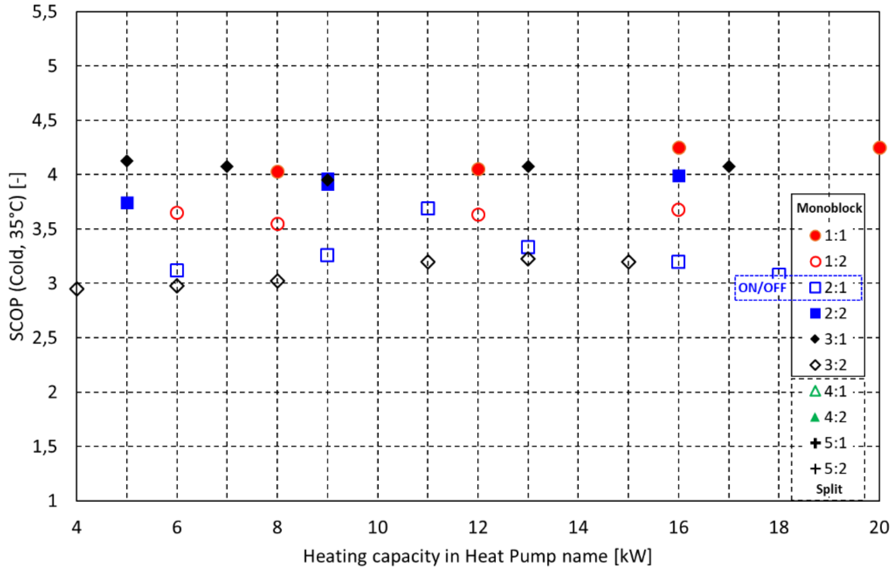


Figure 38: SCOP from different air-to-water heat pumps declared for the Cold climate with a high temperature heating system (55 °C at Pdesign). SCOP are ranging from 2,4 to 3,5, with the On/Off heat pump series in the bottom. For manufacturer 4 and 5 SCOP values could not be found

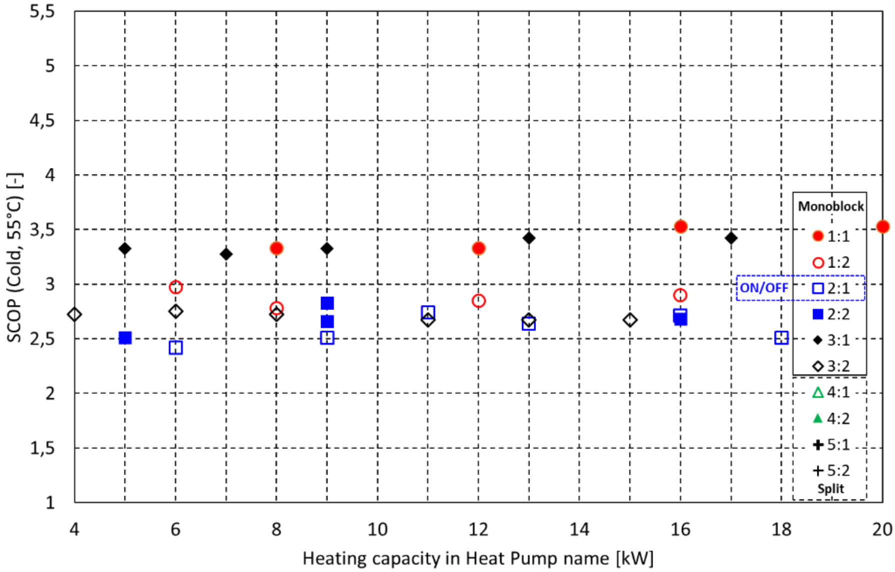
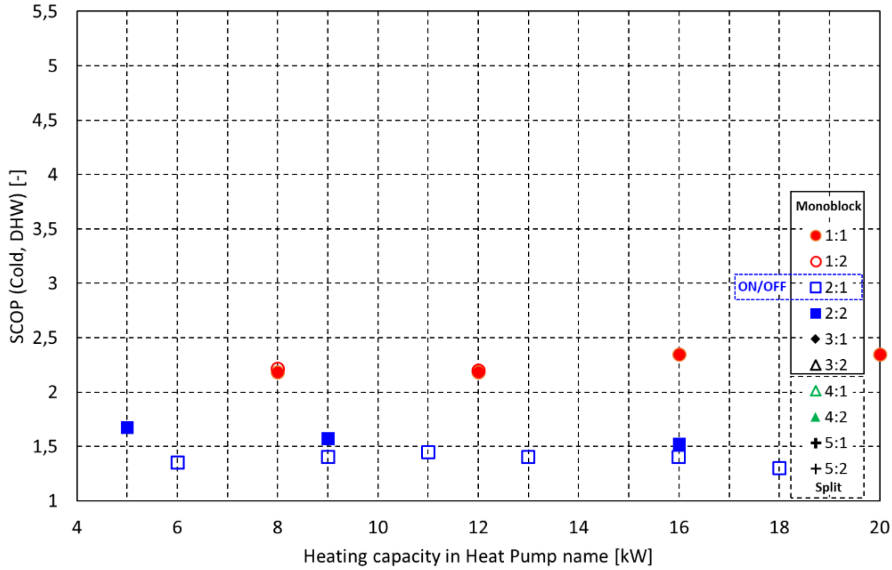


Figure 39: SCOP from different air-to-water heat pumps declared for the Cold climate for DHW production. SCOP are ranging from 1,3 to 2,4, for manufacturer 3, 4 and 5 SCOP values could not be found



Comparing the SCOP of Figure 34 (Average climate, underfloor heating system, 35 °C at P_{design}) with the SCOP of Figure 38 (Cold climate, radiator, 55 °C) there is a large difference in performance. While Figure 34 indicates a SCOP as high as 5,1 (low down to 3,5) the SCOP in Figure 38 for the same heat pumps are below 3,5 (low down to 2,4).

4.3.2 *Summary regarding Energy Labelling of air-to-water heat pumps*

Information about the efficiency of air-to-water heat pumps are only given for the Average climate on the Energy Label. Information for the other climates should be given in the product fiche. The heat pumps are normally declared at the highest possible energy efficiency class they can obtain and thereby high efficiency seems to be prioritized over high capacity. Variable speed controlled heat pumps are now dominant on the heat pump market (while this not was the case before the introduction of the Ecodesign and Energy Labelling regulations. Such heat pumps are often declared as monovalent (i.e. no back-up heating is needed during the coldest days) and such installations should also be encouraged. Not showing the efficiency of the heat pumps on the Energy Label could result in that the development of more efficient heat pumps are hold back since it weakens the incentives to reach as higher efficiencies when an efficiency class has been reached. By browsing the internet, it was found that the quality and magnitude of data declared for the consumer differ a lot between different heat pump brands.

The following SCOP ranges were found for heat pumps on the Nordic market:

- Average climate, low temperature heating system: 3,5 – 5,2
- Average climate, medium temperature heating system: 2,8 – 3,9
- Average climate, DHW heating: 1,9 – 2,7
- Cold climate, low temperature heating system: 2,9 – 4,3
- Cold climate, medium temperature heating system: 2,4 – 3,5
- Cold climate, DHW heating: 1,3 – 2,4

5. Comparison of results from field measurements with declared data

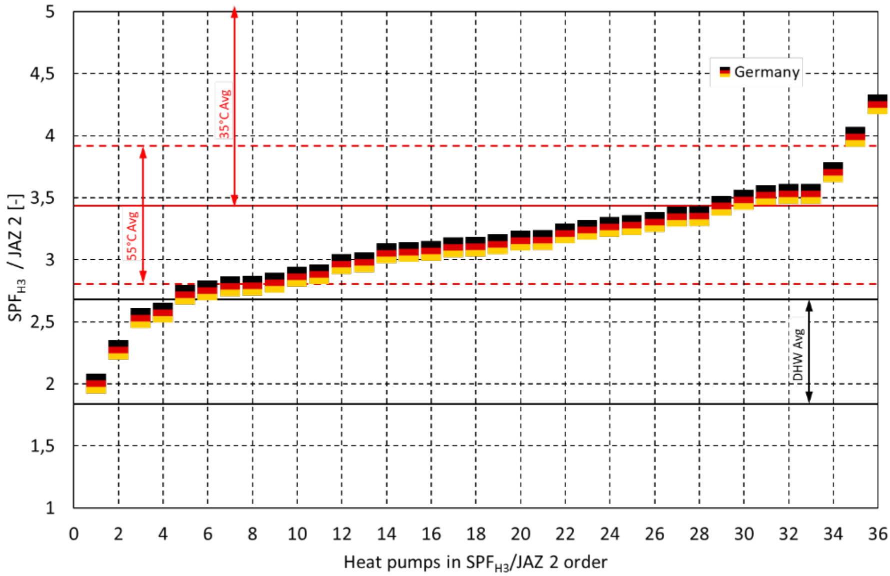
In Figure 40 to Figure 41 results from field measurements in different countries (SPF and JAZ), presented in section 3.1 are compared to declared performance (SCOP) in Energy Labelling documentation for a number of air-to-water heat pumps, presented in section 4 of this report, are compared. It should be mentioned that all the heat pumps monitored in the field had been installed before the Ecodesign and Energy regulations went into force. Therefore, the declared performances are for other products sold on the market today. In addition, the introduction of these regulations probably resulted in that the lowest performing products disappeared from the market and in a shift towards more efficient products.

Taking into account that:

- the products have probable been more efficient after the introduction of the regulations
- most air-to-water heat pumps are declared as monovalent, even though such system design was not very common before the introduction of variable speed control
- some of the heat pumps heat DHW to some extent
- it is not really clear to what extent and how the heat losses from tanks has been taken to account

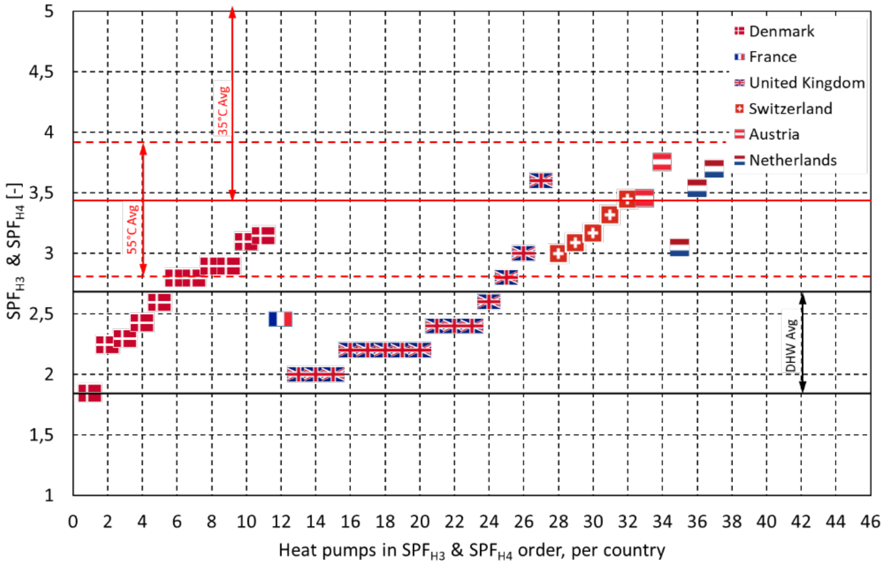
The measured performance of most of the heat pumps are as can be expected. However, there are some exceptions, with underperforming heat pumps in Norway, UK, Denmark, one each in Germany, Sweden and France. Possible reasons for the performance discrepancy are discussed on the following section.

Figure 40: Results from field measurements in Germany (SPF or JAZ) compared to declared performance (SCOP) in Energy Labelling documentation for a number of air-to-water heat pumps sold on the European market



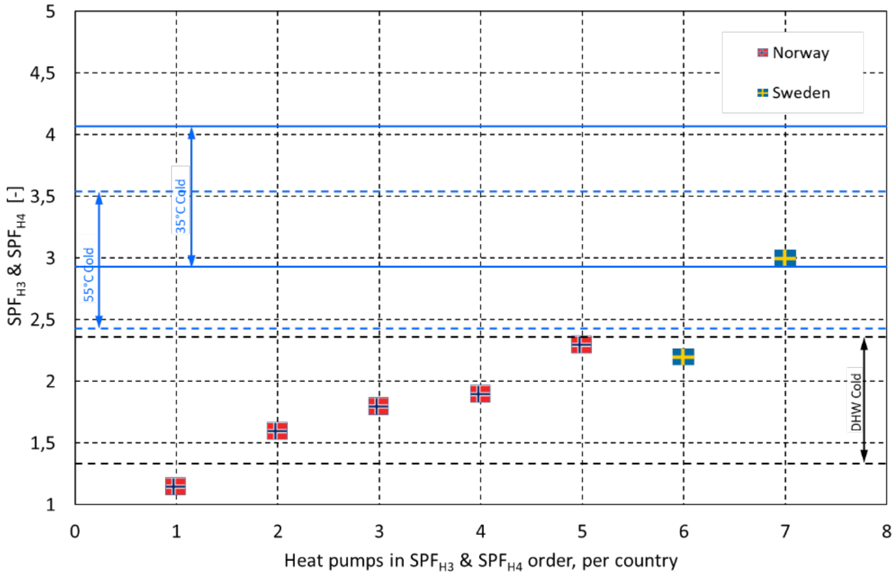
Note: The declared values are NOT for the heat pumps evaluated in the field.

Figure 41: Results from field measurements in different countries (SPF) compared to declared performance (SCOP) in Energy Labelling documentation for a number of air-to-water heat pumps sold on the European market



Note: The UK sites represent SPFH4 instead of SPFH3. Note that the declared values are NOT for the heat pumps evaluated in the field.

Figure 42: Results from field measurements in different countries (SPF) compared to declared performance (SCOP) in Energy Labelling documentation for a number of air-to-water heat pumps sold on the European market. The Norwegian heat pumps represent SPFH4 instead of SPF_{H3}



Note: The declared values are NOT for the heat pumps evaluated in the field.

5.1 Summary regarding comparison of results from field measurements with declared data

Taking the findings in this report into account, the measured performance of most of the air-to-water heat pumps are as can be expected. However, there are some exceptions, with underperforming heat pumps in Norway, some in UK and Denmark, one each in Germany, Sweden and France.

6. Reasons for performance discrepancy

There a several possible reasons why the performance displayed on the energy labels differ from the performance in real installations in a building. In the sections below the most obvious ones from this study are presented and explained.

6.1 Heat pumps installed before 2015 had lower efficiency

The introduction of the Ecodesign and Energy Labelling regulations, that went into force in 2015, probably resulted in that the lowest performing products disappeared from the market, see section 3.2. In addition, before the regulations went into force, normally just the COP value at one test point at +7 °C was declared for the consumer and there were low incentives for the manufacturer to develop efficient variable speed control of the heat pumps. However, after the introduction of the regulations, the declared performance was based on an average performance over the year (SCOP) and the incentives to develop (cost) efficient variable speed controlled heat pumps increased to a large extent. It is therefore likely to believe that the introduction of the regulation has resulted in a shift towards more efficient products.

6.2 Non-optimal installations and settings

When analysing the system design and measurement results in detail for some of the lowest performing heat pumps, it was found that in a number of cases the heating system design, the heat pump system design and the setting of control parameters were far from optimal for obtaining good heat pump operation. In many cases, it was found that the heat pump worked with very high heating water temperature, resulting in high condensing temperature with low efficiency as a consequence. In other cases it was found that the (mal functioning) control of the heat pump system made the electric back-up heaters heat by direct electricity even though there was still spare capacity for the heat pumps itself. In some of the installations, there were one or were several tanks for which the heat losses from the tanks could have been high (and had not been regarded as useful in the measurements, despite if they supported heating the house parts of the year or not). The reasons for the non-optimal installations are probably an unmatured market and not sufficient knowledge among the installers.

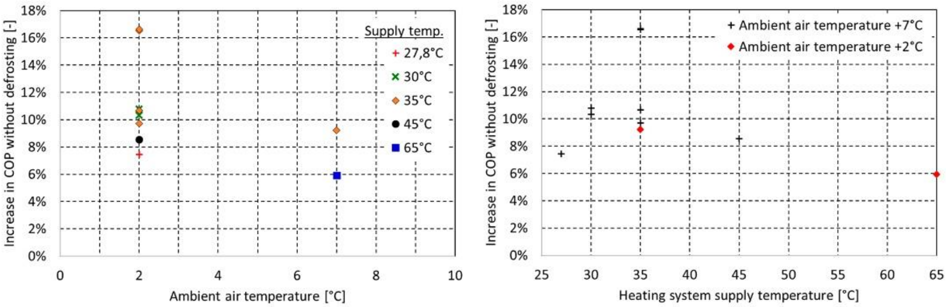
6.3 Performance difference due to test methods

Huang *et al.* [7] states that "It is important to keep in mind that for variable speed units, the test requires the manufacturer to supply information on how to fix (or lock-in) the frequency of the compressor (and probably of fans) according to European standards EN14825 and EN14511-3. Therefore, it could be the case that heat pumps work differently when evaluated in a laboratory compared to in real life. However, this report does not refer to any proofs that support this statement.

6.4 The test period in the standards are not long enough to include a defrost period

It has been seen in EN14825 and EN14511 tests performed at RISE on air-to-water from European heat pumps that all recently tested heat pumps are designed to handle the test cycles without need to defrost within the evaluation period. However, when measuring the heat pumps during a longer period, the heat pumps needed to defrost. Figure 43 shows the difference in COP of measurement on seven different heat pumps when no defrost period is included in the cycle compared to when it is included. The results show that excluding the defrost means in most cases COP that are 6–11% higher compared to including the defrost. These findings show that declared data could be based on tests where no defrosts are included in the evaluation period, while this takes place in a real installation. In most cases this would mean that the heat pump performance is overestimated by 6 to 11% for some of the test points. However, the difference on seasonal efficiency will be lower since the heat pump does not normally need to defrost at all at higher temperatures.

Figure 43: Increase in COP in laboratory tests of seven different air-to-water heat pumps when the heat pump does not defrost within the limited standard test period compared to when the heat pump is let run long enough for defrosting to occur



Note: Left: as a function of ambient air temperature. Right: as a function of heating system supply temperature.

6.5 Energy label tests performed at lower humidity than the real climate?

Since many of the low performing heat pumps can be found in countries with a relatively high humidity (Norway and UK) while the reported performance for heat pumps in countries with a dryer climate (Germany, Austria and Switzerland) perform closer to what could be expected, the humidity during laboratory tests could be one of the explanations to the discrepancies.

Running a heat pump at a more humid climate will cause the heat pump to defrost the evaporator more often than at a dryer climate according to Guo *et al* [15]. The following climates are applied in EN14825 [9], see Table 13.

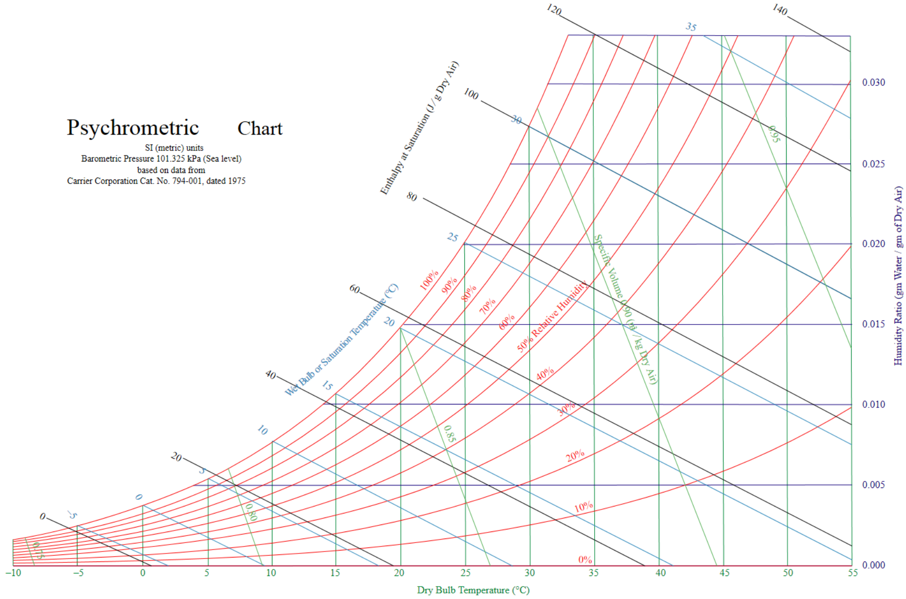
Table 13: Outdoor heat exchanger air conditions at test points used for the Energy Label measurements

	Dry temperature [°C]	Wet temperature [°C]	Relative humidity [%]	Dew point temperature [°C]	Absolute humidity [g/m3]	Maximum absolute humidity [g/m3]
A*	-7	-8	74	-10,4	2,0	2,8
B	2	1	84	-0,4	4,6	5,6
C	7	6	87	4,9	6,7	7,8
D	12	11	89	10,2	9,4	10,7
E	TOL	TOL - 1	<66	-	-	-
F	$T_{bivalent}$	$T_{bivalent}$ - 1	<90	-	-	-
G**	-15	-16	56	-21,2	0,8	1,4

Note: * Not used for the Warmer climate,
** Not used in Average and Warmer climate.

As seen, the relative humidity decreases with colder temperatures, even though the temperature difference between the dry and the wet temperature is fixed at all temperature levels. This is due to the lower absolute water vapour content in air at low temperatures. Maximum absolute humidity at all temperatures are shown as a reference, this is the amount of humidity in the air when the relative humidity is 100%.

Figure 44: Absolute water vapour content of air



Note: (right axis) By ArthurOgawa - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=2803863

To extract heat from the ambient air, the heat pump evaporator has to have a temperature that is lower than the air temperature. Typically a temperature difference of 5–8 °C could be assumed. This means that humidity can be condensed (or sublimized to frost) to that surface temperature. The surface will draw humidity out of the air, but only to an amount that corresponds to the difference between the dew point of the air and the temperature of the evaporator surface. The lower the ambient air temperature, the less heat the evaporator will draw from the air, as the performance of the refrigeration cycle degrades with temperature. This means that the evaporator will be more "oversized" at lower temperatures, causing the temperature difference between them to decrease.

6.5.1 Climates in examples of cities in Norway and Sweden

The following diagrams show the climate, from Meteonorm 6.1, in Malmö, Borås, Stockholm and Uppsala in Sweden and Oslo, Bergen, Stavanger and Trondheim in Norway presented as duration curves based on the dry outdoor temperature. Meteonorm uses the years 2000–2009 for their data climate (except for irradiation, but that is not used in this report). As seen in all diagrams the humidity varies a lot at the same dry outdoor temperature, but the test point for +2 °C (B) is near the real averaged curves. However, at lower temperatures the humidity for the test points (A and G) are lower than the averaged curve, meaning that the heat pumps likely will frost and defrost less in the tests than in the real climate.

For the higher temperatures (test points C & D), the tests are performed at higher humidity than the average humidity levels of the example cities. However, frosting is not likely to take place at any of them, not in the test nor in reality. The higher humidity at the test could in this case be beneficial for the performance, since the enthalpy of the air is higher. The opposite could apply, since condensation of water vapour could result in higher pressure drop through the heat exchanger. Note that the curves represent the average humidity, meaning that there are as many hours at higher humidity levels, as at lower humidity levels. These more wet hours will cause more defrosting, while the dryer hours will cause less. The defrosting pattern is not linear, as seen in Figure 28 and Figure 29.

The fact air-source heat pumps are tested at humidity levels that are sometimes lower than in a real installation could be a contributing reason for that the efficiency displayed on the energy label than what is experienced in real life. However, no real proof of this has been found since the test points where frosting generally is most severe (around +2 °C) seem to represent the average humidity in many parts of at least Sweden and Norway. However, there are trends reported that the humidity is increasing and this shall therefore be monitored in the future.

Common description of Figure 45 to Figure 52: The red lower lines are dry temperatures and the top thin black lines relative humidity. The top thick straight line is a 6th degree curve fit, the fuzzy line is 255 value moving average, both of the relative humidity. The blue dots show the test points according to EN 14825 [6], see Table 10.

Figure 45: Temperature and relative humidity profile of Malmö, Sweden

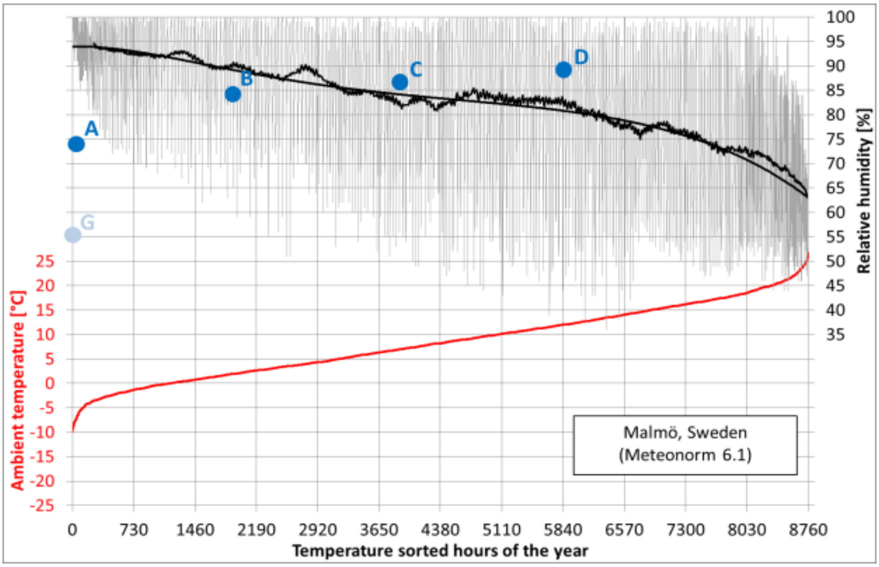


Figure 46: Temperature and relative humidity profile of Borås, Sweden

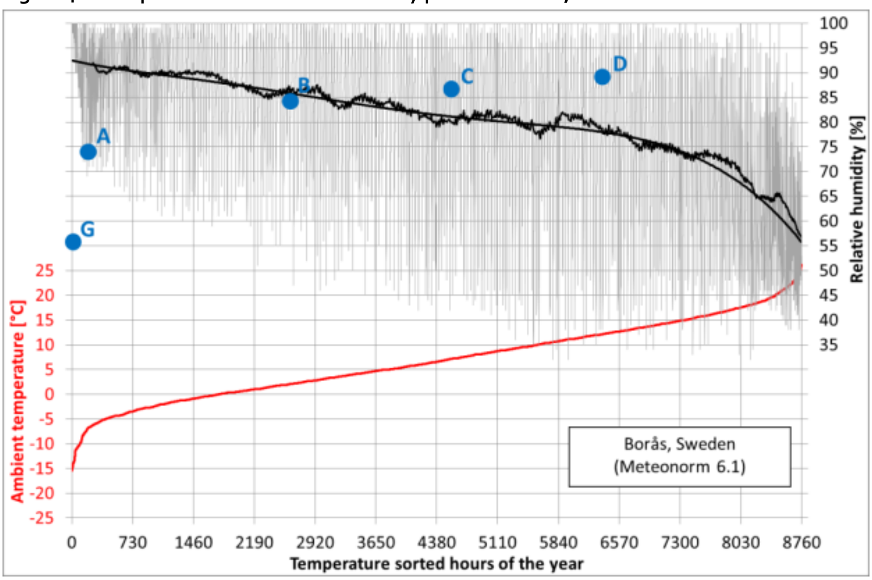


Figure 47: Temperature and relative humidity profile of Stockholm, Sweden

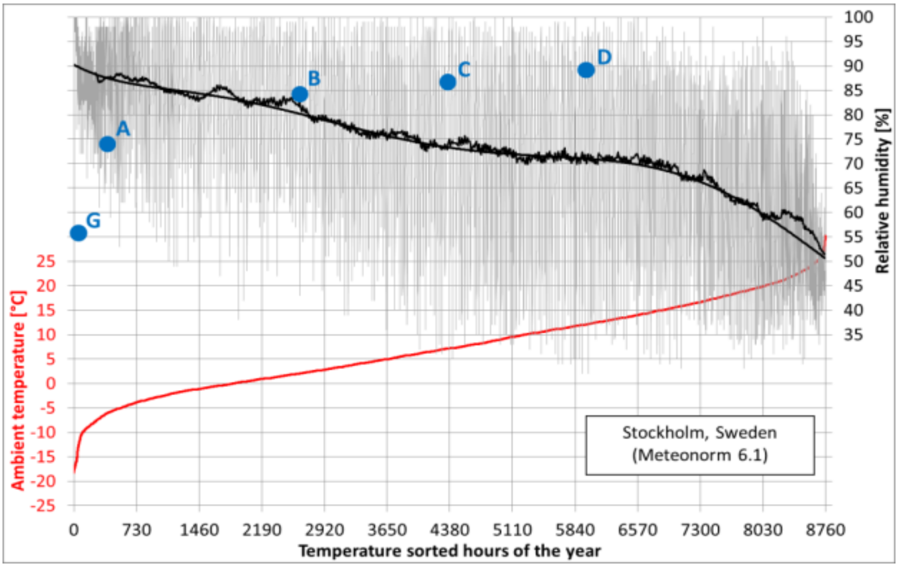


Figure 48: Temperature and relative humidity profile of Uppsala, Sweden

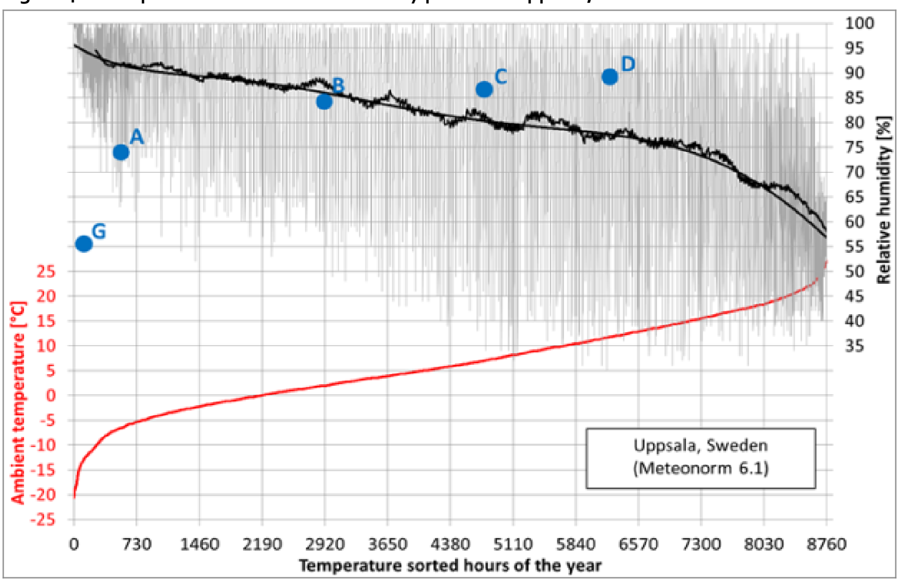


Figure 49: Temperature and relative humidity profile of Oslo, Norway

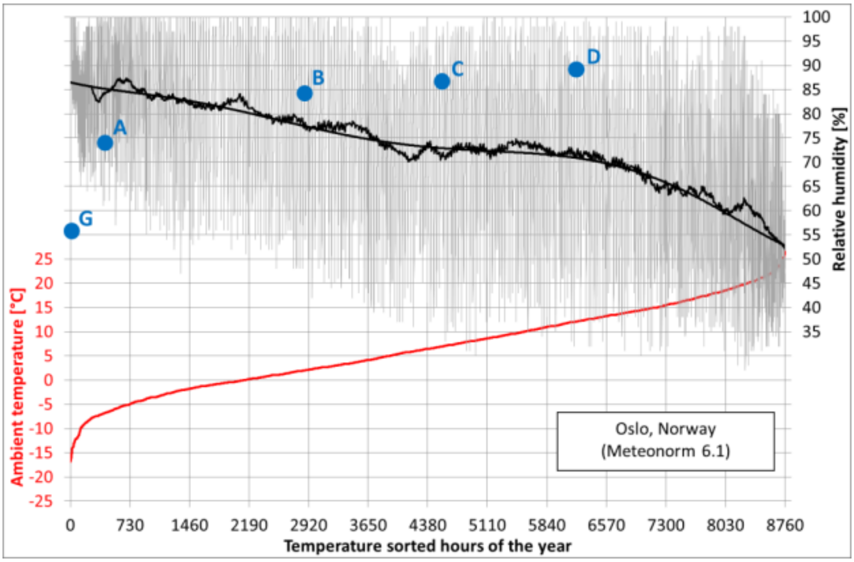


Figure 50: Temperature and relative humidity profile of Stavanger, Norway

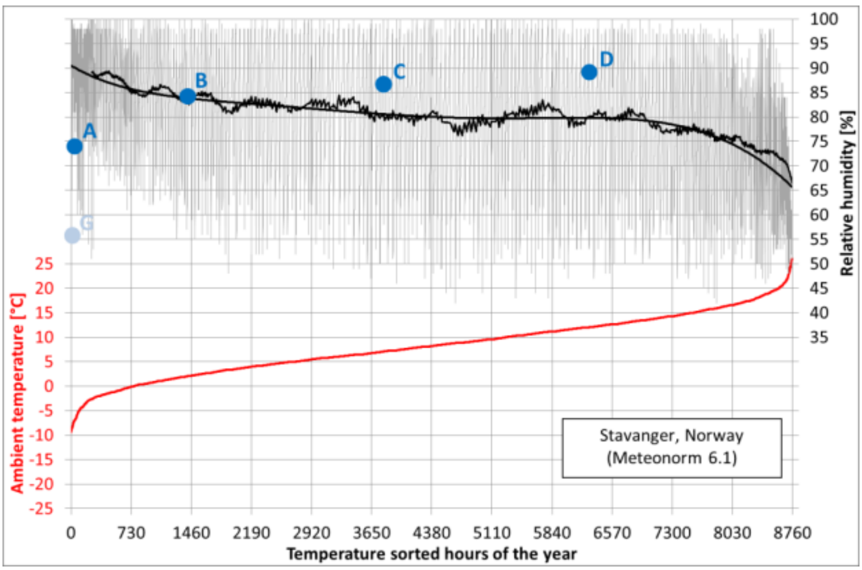


Figure 51: Temperature and relative humidity profile of Bergen, Norway

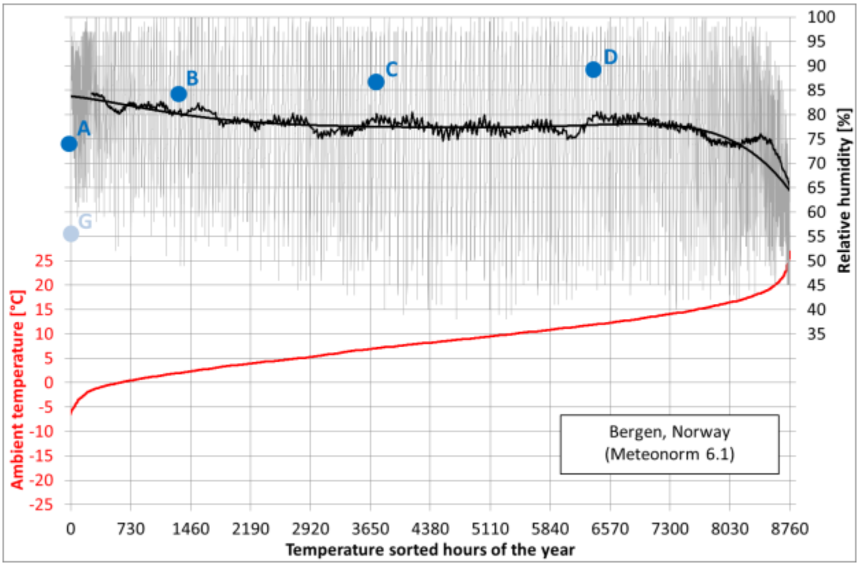
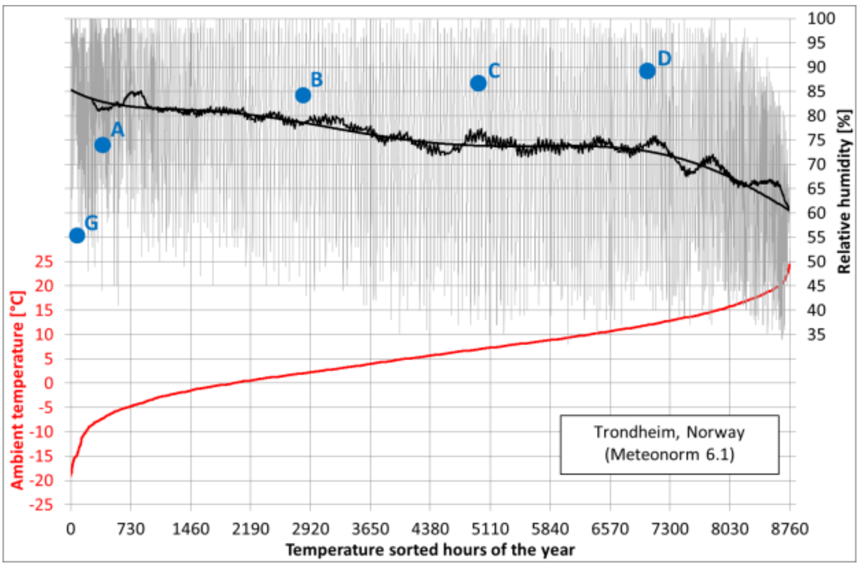


Figure 52: Temperature and relative humidity profile of Trondheim, Norway



Note that no more northern cities could be found in the Meteonorm 6.1 program.

6.6 Summary possible reasons for performance discrepancy

There are several possible reasons why the performance of air-to-water heat pumps presented on the Energy Labels are in many cases higher than the performance experienced in real life installations based on the results from the field measurement.

First of all, all the heat pumps evaluated by field measurements were installed before the Ecodesign and Energy Labelling Regulations for air-to-water heat pumps went into force in 2015 and it is likely that there has been a shift towards more efficient products on the market since then.

Another reason, is that the heating system design and the control strategies for the operation of the heat pump was far from optimal in several cases, especially for the lowest performing heat pump system. High settings for the heating water temperature has a negative influence on the performance, the same is true if the heat pump is too small in relation to the heating demand or if the control start the back-up heaters "too early" so they heat by directly used electricity instead of by the heat pump.

A further possible reason is that during laboratory measurements the frequency is normally set according to the manufacturers' instructions for the different test points and the normal control system, used in real life installations, is bypassed. This could result in the fact that the heat pump operates differently with different performance.

Since several of the lowest performing heat pumps from the field can be found in countries with high air humidity, differences in frosting and defrosting of the outdoor heat exchanger surfaces could be an explanation to the low reported SPF values. First of all, the evaluation time in the standard tests might not be long enough for enough frosting to be built up and thereby no defrosting to takes place during the standard tests. Secondly, the climates defined in the test standards might differ from the real climates where the heat pumps were installed.

However, the climates defined in the test standards that are the basis for the performance presented in the Energy Labelling documentation agree relatively well for the +2 °C (1 °C) test point for several example cities in Sweden and Norway. The frosting and defrosting is normally most severe at this test point during laboratory tests. For the -7 °C (-8 °C) test point the situation is opposite, the test conditions means lower humidity levels than real conditions. The fact that the climates during the laboratory tests are less humid than in real installations in some regions could still be a reason for the discrepancies, but no real proof for this has been found. Other explanations mentioned above are more likely.

7. Example of confusing advertising

One manufacturer is actually using the very high SCOP value for the Average climate in their marketing on the Swedish marketing (translated from Swedish):

> "With a SCOP exceeding 5,0* the heat pump is delivering more than five times as much heat compared to an electric boiler with the same electric consumption."

The explanation of the * is not found on the site itself, but the product sheet (pdf) needs to be opened to see it. The explanation reads (translated from Swedish):

> "…has a SCOP>5,0 (Average climate, Low temperature) and a SCOP of 4,3 (Cold climate, Low temperature) according to European standard…"

That the average climate is not relevant in Sweden is not explained, given the consumer basically incorrect information.

Other manufacturers are presenting SCOP values for both for the Average and the Cold climate in the product sheets, but without any explanation that the Average climate is not relevant in Sweden.

8. Conclusions

As explained in the beginning of this report some of the Nordic market surveillance authorities suspects or have the perception that the declared efficiencies for air-to-water heat pumps on the Energy Labels and supporting data sheets are considerably higher compared to what have been measured in real installations in the field, especially in cold and humid climates, which in such case gives the consumer misleading information. The purpose of this study was first and foremost to confirm or reject this suspicion.

The Energy Label for air-to-water heat pumps does only show efficiency class for the Average climate, even when sold and marketed in a Nordic climate, more similar to the Cold climate. Information about performance in other climates should be able to find in supporting data sheets. However, by browsing of internet it was found that the quality and magnitude of declared data differed between brands. However, this should be kept in mind when comparing data.

Results from quite a few field measurements on air-to-water heat pumps are available in the open literature. However, all of the evaluated heat pumps had been manufactured and installed before the Ecodesign and Energy Labelling regulations went into force in 2015. Before that year SCOP values were not presented in marketing information for air-to-water heat pumps. It has therefore not been possible to entirely either confirm or reject the suspicion or perception that air-to-water heat pumps are generally declared at much higher performance than is normally obtained in a real installation.

Based on the findings from this study, it is likely to believe that there has been a shift towards more energy efficient air-to-water heat pumps during the last years, especially after the regulations went into force in 2015. After the regulations went into force, there are almost only variable speed controlled heat pumps on the market, while on/off control was dominant before.

When comparing results from field measurements to performance data in Energy Labelling documentation, it shows that the declared values are usually a little better than the field data, especially in countries on the continent with a less humid climate. This is as can be expected, taking the considerations above into account. Hence, it seems like the Energy Label has the potential to give the consumer sufficiently relevant information about the performance, at least in the average climate, but there are discrepancies, particularly in some countries.

It was also clear that several heat pumps from the field measurements performed worse than could be expected, especially in some countries with a more humid climate. In some of these countries the experience among the heat pump installers is probably limited due to a non-mature market for air-to-water heat pumps.

Except for the fact that heat pumps sold and declared today, might be more efficient than the older heat pumps that had been evaluated in the field, there are several possible reasons for the experienced performance discrepancies between measured field performance (older heat pumps) and declared performance (for heat pumps sold today):

- Non-optimal installations, resulting in that the heat pump work with a very high heating water temperature, that that the back-up heater heats instead of the heat pump and large heat losses from storage tanks (not included in the measured SPF).
- The normal control system of the heat pump is by passed, and the compressor frequency is fixed, during the tests, resulting in different operation in the laboratory compared to in real installations.
- The test periods in the standards are not long enough to include a defrost period.
- Standard tests are performed at lower humidity than the real climate and at too few test points.

The first mentioned reason, regarding the installations, is probably the most important one that should be dealt with first. The second and third possible explanations could contribute to the differences, but more investigations should be made to be able to assess their impact.

No proof has been found in the study that the reasons for the deviation between performance data in the Ecodesign and Energy Label documentation and the performance in real installations should be that the standard tests do not take humidity sufficiently into account. However, this reason can on the other hand not yet be dismissed. This issue should be monitored in the future in order to take into account that climate change might lead to a more humid climate.

9. Recommendations

To obtain as good performance as possible for an air-to-water heat pump in a real installation, it must be assured that appropriate system design and control setting are applied. Therefore, the skills and knowledge of the installers are of uttermost importance. Training and certification schemes could be one tool to assure this. The installer shall at least be able to make sure that:

- the system work with as low heating water temperature as possible;
- that the heat pump has an appropriate capacity for the heating demand;
- that leakage from tanks are minimized;
- that the electric back-up heater does not heat instead of the heat pump, but as a complement;
- that unnecessary electricity is not consumed by circulation pumps and crankcase heaters; and
- that the air-flow around the outdoor unit is not blocked or hindered.

The manufacturer of air-to-water heat pumps shall provide laboratories performing market surveillance checks, upon request, the necessary information on the setting of the unit. This does not mean that the manufacturer is allowed to use a specific software or other means to activate a mode dedicated to standard tests, in which the control of the unit is bypassed (or partially bypassed e.g. in case of the need to defrost). However, this is very hard to control, by market surveillance authorities or test laboratories. Rules and guidelines related to such settings should be clarified to assure that:

- if frosting and defrosting take place for a heat pump at a certain condition in a real installations it will also do so in the standard tests
- the heat pump can work in the same capacity range in the field as during laboratory tests.

More data from continuous field measurements of air-to-water heat pumps during complete heating seasons, especially in a Nordic climate, would be valuable to get a better picture of the range of performance in the field for heat pumps in cold climates. Since there is a suspicion that the low recorded performances in some sites are linked to non-sufficient experiences of the installers, it would be of great interest to monitor a number of air-to-water heat pumps in the field in a country with a more mature heat pump market such as Sweden where about 9 000 air-to water heat pumps are sold every year. In addition, Swedish installers have long experiences from heat pumps in hydronic (water based) heating systems, since ground source heat pumps are installed to such a large extent in Sweden.

The methodology related to the definition of different system boundaries for presenting different SPF values should be further developed. The SEPEMO project did an extensive work elaborating the system boundaries H1, H2, H3 and H4. However, the project did not clearly specify how to deal with the leakage from different storage tanks in the system (if any). Nor was it always possible to find out how losses had been taken into account in the reported results from most field measurements in this study. There is a need for further definitions for the H3 and H4 system boundary, e.g,:

- H3 and H4 – all heat losses from the tanks have been regarded as useful heat, i.e. the heat meter is placed before the tank(s) and the magnitude of the losses are unkown
- H3' and H4' – the heat losses from the tanks have been regarded as useful partly, i.e. the tanks are placed in a heated space and there is a heating demand, the magnitude of the heat losses must be known, e.g. from laboratory measurements
- H3'' and H4'' – no heat losses from the tanks have been regarded as useful heat, i.e. the heat meter is placed after the tank(s) and the magnitude of the losses are unknown
  - These system boundaries should be used when reporting performance results from the field, to assure a fair comparison of field performance with declared data, of different heat pump installations, of heat pump systems with other heating systems.

To better understand real frosting and defrosting in the field, monitoring using an all day, all year, camera with sound recording could be used. Visual and audial data would be of great use to understand the process in forming frost at different temperatures and the efficiency of defrosting. As cost for data storage and camera equipment has gone done considerably during the last years, this could be performed at a reasonable total cost.

To evaluate if it is sufficient to test air-to-water heat pumps at -7 °C(-8 °C), 2 °C (1 °C) and 7 °C (6 °C) to obtain the performance during frosting conditions for a Nordic or cold climate, a study should be performed where several air-to-water heat pumps are tested at different temperatures and humidity levels in the range of those test points. In such a study the evaluations periods should be longer than the standard prescribes today. In case it is found that interpolation gives faulty results between e.g. -7 °C and +2 °C or between +2 °C and +7 °C one or two additional test point for the Cold climate should be considered, since the Cold climate defined in the regulations has many hours in that temperature range:

- The performance of the heat pump in a cold climate should be visible on the Energy Label. Today only the capacity is shown on the label, but no information is given about the efficiency.
- It should not be allowed to give information about higher heating capacities of the heat pump than the declared P_{design} in the marketing information about the heat pump.

Standardization work is costly since it requires a considerable amount of work hours to develop a standard. In the standardization committees today, normally manufacturers and test laboratories participate on their own expenses. Of course, both parties aim at fulfilling the mandate form the commission, when developing the standards and both have strong interest in that the test standards are robust, reliable and reproducible. The manufacturers are concerned that there is a level playing field among them and that the tests to perform are not too costly. However, the consumer side, is seldom represented in the standardization working group, nor is the market surveillance authorities. Therefore, to monitor and guarantee the interest from those parties, they should make sure that they are represented in the standardizations work when developing new or revising standards to be used for Ecodesign or energy label regulations.

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Sammanfattning

Studien som presenteras i denna rapport har utförts för Nordsyn och finansierats av Nordiska Ministerrådet. Syftet med denna studie var att analysera om informationen som ges på energimärkningsetiketterna för luft-vatten-värmepumpar ger konsumenterna tillräcklig information om energiprestanda. När resultat från fältmätningar jämförs med deklarerade värden, visar det att deklarerade värden ofta är bättre än fältvärden, särskilt i länder med fuktigt klimat. Det kan finnas flera anledningar till detta som icke optimala installationer, att kontrollsystem förbigås, att fältdata är äldre osv. Misstanken att skillnaden beror på att standardtestet inte hanterar fuktighet tillräckligt kan varken bevisas eller helt avvisas. Rekommendationer ges hur detta kan undersökas vidare och inkluderar fältmätningar i nordiska länder.

Nordic Council of Ministers
Nordens Hus
Ved Stranden 18
DK-1061 Copenhagen
www.norden.org

NORDSYN STUDY ON AIR-TO-WATER HEAT PUMPS IN HUMID NORDIC CLIMATE

The study presented in this report has been performed for Nordsyn sponsored by the Nordic Council of Ministers. The aim of this study was to analyse if the information given on the energy labels of air-to-water heat pumps give consumers in Nordic countries sufficient information on energy performance. When comparing results from field measurements to declared values, it shows the declared values are usually better than the field data, especially in countries with humid climate. There could be several reasons for this deviation as non-optimal installations, bypass of control systems, old field data etc. The suspicion that the deviation is due to that the standard tests do not take humidity sufficiently into account could not be proved nor fully dismissed. Recommendations are given on how this could be further investigated, including field measurements in Nordic countries.

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