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Calculation of SCOP for heat pumps according to EN 14825

The following document gives a general introduction to measurement points and the calculation method for SCOP according to European Standard EN 14825. SCOP is the parameter forming the basis for European minimum requirements and energy labelling for heat pumps.

This document was prepared in parallel with the document entitled, *"Energy labelling and minimum requirements for heat pumps in relation to the Ecodesign Directive"*, which describes requirements and energy labelling in adopted and expected regulations pursuant to the Ecodesign Directive.

Calculation of SCOP in general

SCOP (Seasonal Coefficient of Performance) describes the heat pump's average annual efficiency performance. SCOP is therefore an expression for how efficient a specific heat pump will be for a given heating demand profile.

Basically, the SCOP calculation method consists in dividing the heating season into a number of hours with different temperatures (called *bins),* which together are to reflect the variations in temperature over a heating season. Furthermore, a heating demand curve is determined for the temperatures, providing the heating demand that the heat pump is to meet for each set of temperatures. A COP value for each of the bins is found, and together these form the basis for calculating the average COP, i.e. the SCOP.

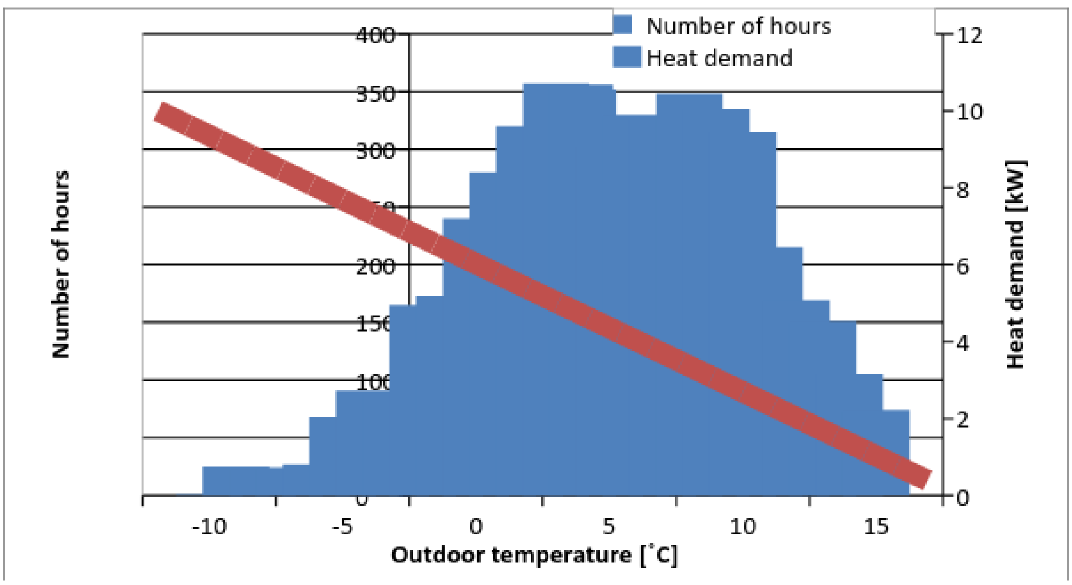

Figure1: Example of temperature distribution and heating demand pertaining to a heating season

The EN 14825 standard defines a *reference* SCOP to be used in energy labelling and legislation, in which the number of hours is determined and in which the heating demand curve is given on the basis of a single input parameter. Figure 1 shows an example of the distribution of hours for the climate zone, 'average'. The figure also shows how the heating demand falls with increasing temperature. The figure tells us, for example, that the heat pump must supply 6.2kW at 0 ˚C in 240 of the heating season's hours.

Climate zones (climate conditions)

Since the climate varies across Europe, SCOP can be calculated for three different climate zones (climate conditions). These are:

- ***Average*** corresponding to Strasbourg ”A”
- ***Warmer*** corresponding to Athens ”W”
- ***Colder*** corresponding to Helsinki ”C”

In European energy labelling, SCOP for the *Average* climate profile is mandatory, whereas the other two profiles are voluntary. The minimum requirement is also based on SCOP for the *Average* profile.

The number of hours in each bin for each of the climate zones is shown in the figure below:

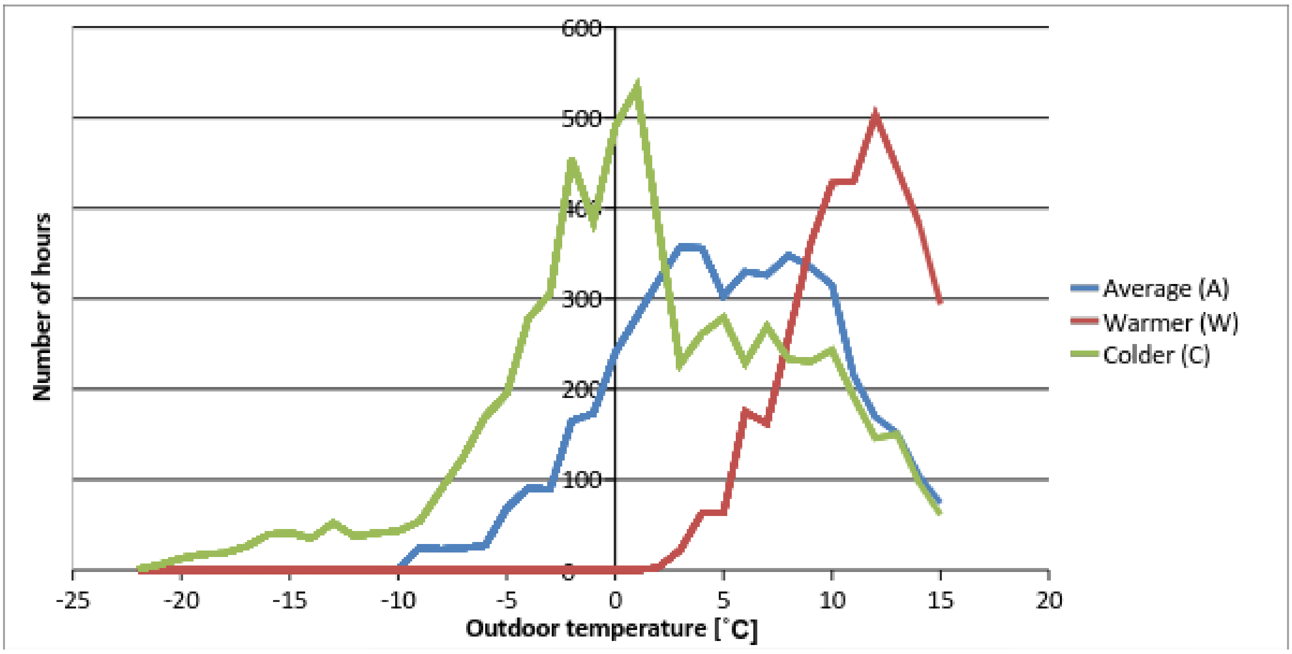

Figure 2: Distribution of temperature for the three climate zones Average, Warmer and Colder

The total number of hours in the heating season varies for each of the three climate zones, with *Average* having 4910 hours, *Warmer* 3590 and *Colder* 6446.

The climate zone best representing Danish conditions is *Average*, corresponding to Strasbourg. The following figure shows a comparison of Danish temperatures with temperatures in Strasbourg.

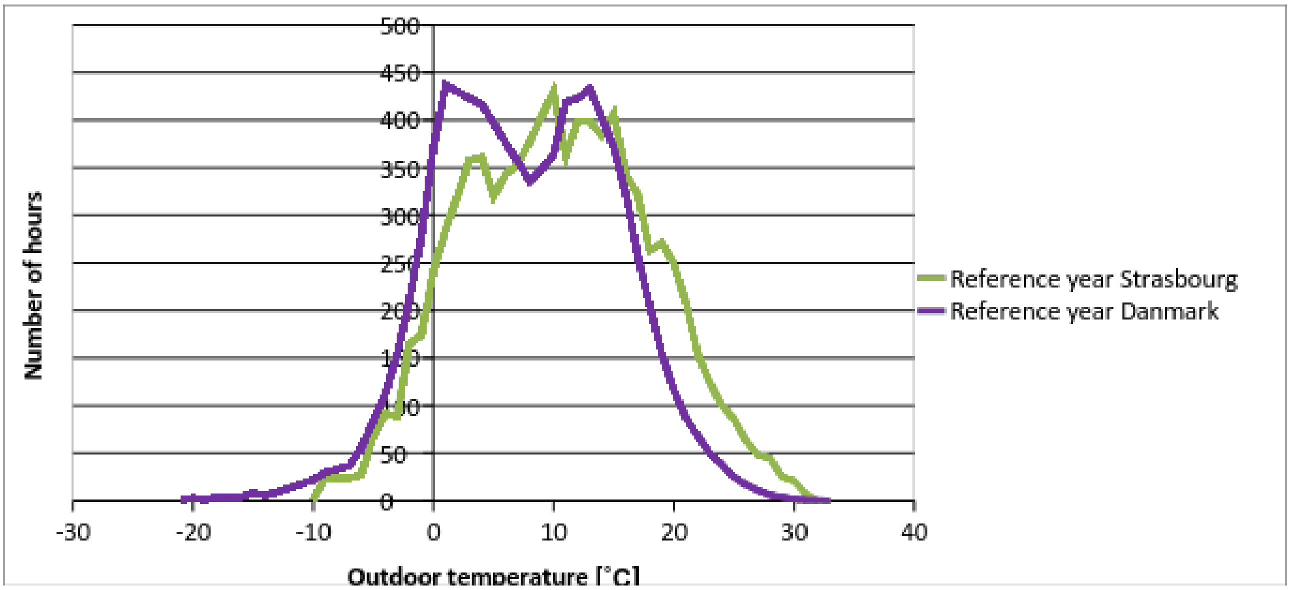

Figure 3: Standardised temperature variations for Strasbourg and Denmark

The climate zone *Average* has been designed on the basis of the temperature distribution for Strasbourg. Since temperature distribution in Denmark is very similar to that for Strasbourg, the *Average* temperature profile will therefore be representative of Danish conditions.

Test temperatures

For the calculation of SCOP according to EN 14825, the heat pump must be tested at a series of temperatures, corresponding to the temperatures in EN 14511. As an example, the test temperatures on the cold side of the heat pump for air-to-air heat pumps and air-to-water heat pumps for the different climate zones are given in the table below.

Point	*Average*	*Warmer*	*Colder*
			-15/20 ˚C*
A	-7/20 ˚C		-7/20 ˚C
B	2/20 ˚C	2/20 ˚C	2/20 ˚C
C	7/20 ˚C	7/20 ˚C	7/20 ˚C
D	12/20 ˚C	12/20 ˚C	12/20 ˚C
Tbivalent	The temperature at which the heat pump exactly meets the heating demand*		
TOL	The heat pump's lower temperature limit**		

Table 1: Test temperatures for the outside part of air-to-water heat pumps

* The test point for -15 ˚C only has to be performed, if SCOP is calculated for climate zone *Colder.*
** Tbivalent is described in more detail in the next section. The manufacturer has to provide this value.
*** *Temperature Operating Limit* describes the lowest temperatures at which the heat pump can function. Also to be provided by the manufacturer.

At each of these points, the heat pump can be tested for a more clearly defined part load, as described in the following.

Annex 1 shows a comprehensive overview of test temperatures for air-to-air, air-to-water and brine-to-water heat pumps, as they are to be used in relation to ecodesign regulation and European energy labelling.

Heating demand in the heating season for use in calculating SCOP

The heating demand curve, which determines the heating demand at a given temperature, and which the heat pump must meet in the SCOP calculation, is defined by the heating demand ($Pdesign_h$) at the design temperature ($Tdesign_h$), which in turn depends on the chosen climate zone. The design temperatures for the chosen climate zones are given in the table below.

Average	*Warmer*	*Colder*
-10˚C	2˚C	-22˚C

Table 2: Design temperatures for the three climate zones (climate conditions)

The heating demand at the design temperature can be set at will, and affects the calculated value of SCOP because the demand curve is moved up at a higher $Pdesign_h$ and down at a lower $Pdesign_h$. The demand curve is a straight line which runs through the determined heating demand $Pdesign_h$ at the design temperature and a heating demand of 0kW at 16˚C.
The applied heating demand $Pdesign_h$ will be shown on the future European energy labels along with the SCOP value, and could therefore become a guide for consumers with regard to choosing the right size heat pump. The manufacturer must therefore relate to the fact that $Pdesign_h$ is used to describe the size of the heat pump, and it affects the value of SCOP. This is described in more detail in the document, *"Energy labelling and minimum requirements for heat pumps in relation to the Ecodesign Direcitive".*

The desired capacity at the different test temperatures is determined by the demand curve and can be calculated using the equation

$$Pdesign_h\% = \frac{Test\ temperature - 16}{Tdesign_h - 16}$$

Therefore, with the *Average* climate zone ($Tdesign_h$ equal -10˚C) and test point A (test temperature equal -7˚C) the part load will be equal to 88.4% of the determined heating demand at the design temperature. These values are called *part load*.

The rounded percentages are given in the table below.

Point	*Average*	*Warmer*	*Colder*
			(82%)
A	88%		61%
B	54%	100%	37%
C	35%	64%	24%
D	15%	29%	11%

Table 3: Percentage share of determined heating demand at the design temperature for different test points, which describes the capacity to be applied when part-load testing the heat pump

It is important to stress that these percentages (part loads) do *not* describe the part load percentage of the heat pump's full load capacity. They instead describe a load percentage relative to $Pdesign_h$, independent of the heat pump's capacity.

The figure below shows a demand curve with the load percentages at the different test points.

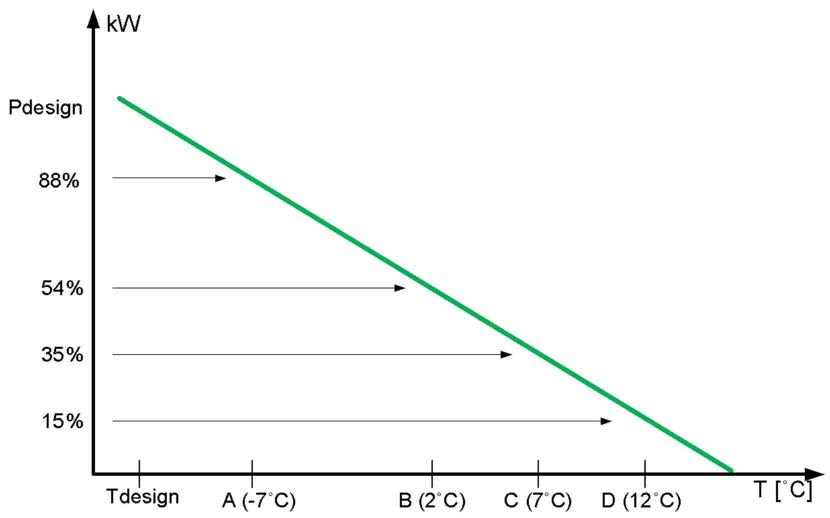

Figure4: Determining the heating demand curve from $Pdesign_h$

The heat pump will have a capacity curve independent of this demand curve. The point where the heat pump's capacity corresponds exactly to the heating demand is known as the bivalent point. At temperatures below the bivalent point, the heat pump's capacity has to be supplemented by backup heating. In the SCOP calculation this is included as pure electric heating with a COP value of 1, regardless of whether or not the heat pump has an electric heating element. For higher temperatures the heat pump will run in part load, which SCOP also takes into account. These conditions are illustrated in the figure below.

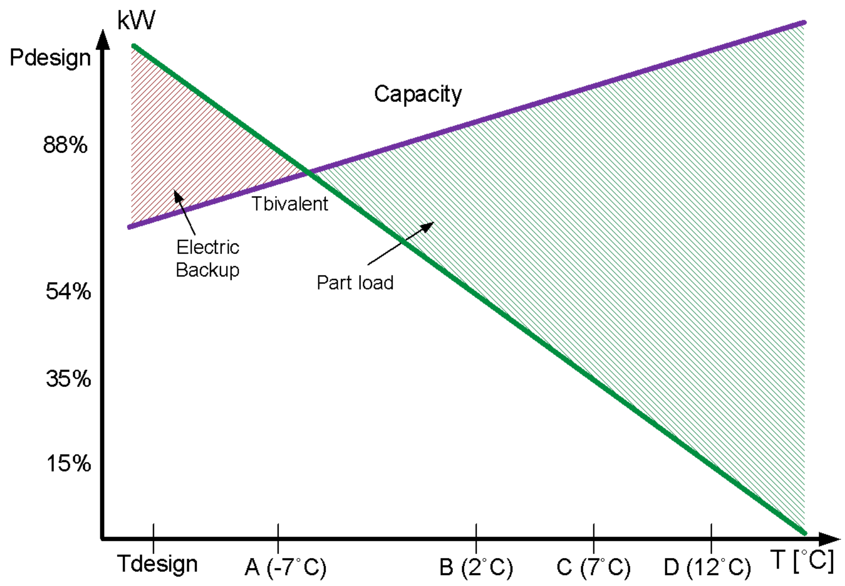

Figure 5: Heating demand curve and capacity curve

If, for example, $Pdesign_h$ is set at 10kW, the demand at 7 °C (point C) will be 3.5kW. If, for example, the capacity of the heat pump is 11kW at this temperature, the heat pump would have to supply 32% of its full load at this test point. This percentage is called capacity ratio (CR).

Since Pdesign$_h$ can be set at will, this value will also have significance for the electric backup heating percentage and for the part load percentages. This is illustrated in the following figure, in which the heating demand at the design temperature is increased compared to the previous figure, which results in a demand curve situated higher in the graph.

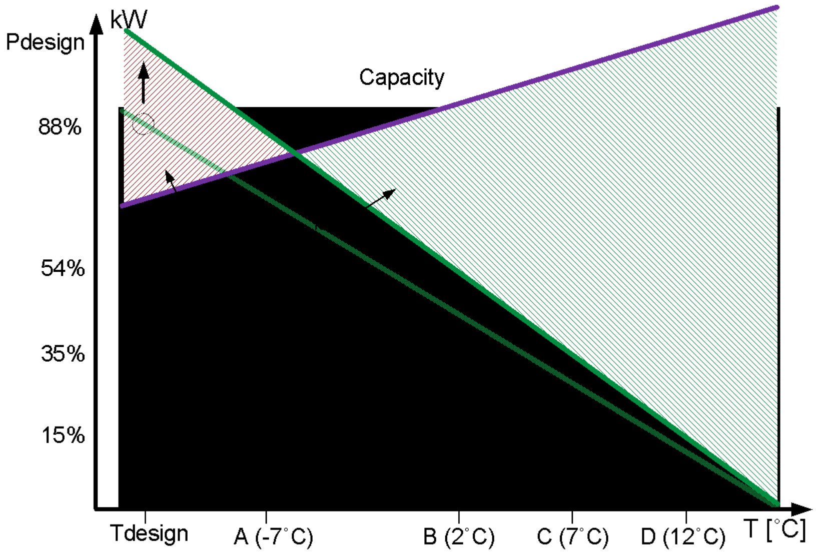

Figure6: Higher heating demand curve and capacity curve

If Pdesign$_h$ is set at 12kW, in this example the resulting heating demand in point C will be 4.2kW, and the heat pump will have to supply 38% of its full load capacity.

Part load efficiency values

The SCOP method can be used to calculate both fixed and variable-speed compressors. Similarly, full load data can be used to find the part load efficiency values, if no part load test results are available. The same temperature is applied when carrying out part load as well as full load tests. If a COP has been found by use of a test for a capacity within a maximum of 10% above the calculated demand, according to EN 14825 this COP value may be used for this point. If a COP has been found at a lower capacity, this same COP value can also be used.

For fixed-speed compressors, COP and capacity are given at full load operation. Part load is then adjusted using a degradation factor. This factor describes the reduction in energy efficiency at on/off operation. The factor can either be measured in a test or by using default values defined in EN 14825.

Air-to-air and brine-to-air heat pumps fixed-speed compressor

For heat pumps for heating air, the degradation factor (C_d) is found through a test, in which the compressor runs for 6 minutes and is subsequently turned off for 24 minutes, in order to reflect a part load of 20%. The degradation factor can be calculated from the accumulated heating capacity and the accumulated electricity consumption over the entire test period using a formula described in EN 14825. If this test has not been performed, a default value of 0.25 should be applied.

Part load COP for fixed capacity air-to-air and air-to-water heat pumps at the test points is found as follows:

$$COP_{part\ load} = COP_{DC} \cdot (1 - C_d \cdot (1 - CR))$$

Where COP_{DC} corresponds to COP at full load (declared capacity); C_d is the degradation factor; and CR is the capacity ratio, i.e. the heating demand in relation to the heat pump's capacity at this temperature. For example, if a part load of 50% is applied, and the degradation factor is the default 0.25, then part load COP will be 12.5% less, corresponding to if *full load* COP is 4, then *part load* COP will be 3.5.

Air-to-water and brine-to-water heat pumps fixed-speed compressor
For this type of heat pump, the EN14825 assumes that the only thing of significance for the degradation factor is the heat pump's remaining energy consumption when the compressor is turned off. Therefore, the energy consumption of the heat pump is measured after the compressor has been turned off for a minimum of ten minutes. The degradation factor is subsequently calculated on the basis of this consumption figure as well as the full capacity of the heat pump at a similar test point. If this test has not been performed, a default value of 0.9 should be applied.

Part load COP for fixed capacity air-to-water and brine-to-water heat pumps at the test points is found as follows:

$$COP_{part\ load} = COP_{DC} \cdot \frac{CR}{C_c \cdot CR + (1 - C_c)}$$

Where COP_{DC} corresponds to COP at full load (declared capacity); C_d is the degradation factor; and CR is the capacity ratio, i.e. the heating demand in relation to the heat pump's capacity at this temperature. For example, if a part load of 50% is assumed, and the degradation factor is the default 0.9, then part load COP will be 9.1% less, corresponding to if *full load* COP is 4, then *part load* COP will be 3.6.

Variable-speed compressors for all types of heat pump
For heat pumps with capacity control, COP can be measured by testing at the stated capacity within an interval of 10%. If the heat pump has step control, part load COP can be found by interpolation between COPs for the capacities above and below the desired capacity. If the desired capacity is below the minimum capacity of the heat pump, the calculation method for fixed speed compressors should be used.

Calculating SCOP

The calculated or measured part load efficiency values are used when calculating the SCOP value.

The calculation method includes finding a COP value for each temperature bin within the temperature interval of the climate zone. This COP gives the electricity consumption needed to meet the heating demand at each temperature.

Interpolated values are used for temperatures between the determined test points. For temperatures outside the test points, extrapolation is performed using the two nearest test points.

Electricity consumption is accumulated for all bins including any necessary electric backup heating. Add to this, electricity consumption for standby and similar modes, in which the heat pump consumes a limited amount of electricity but supplies no heating. These types of consumption are determined on the basis of a specific number of hours in each mode. This is described in more detail in the next section.

First $SCOP_{on}$ is calculated, which is the average seasonal efficiency of the heat pump in active mode. See example in the table below. The table shows the calculation of electricity consumption and heating demand for each temperature bin in an *Average* heating season. The yellow lines mark that COP has been based on measurements, while the white lines are interpolated/extrapolated values.

	Temperature [˚C]	Number of hours	Heating demand [kW]	Heat pump capacity [kW]	Electric backup heating [kW]	COP	Total electricity consumption per hour [kWh/h]	Total heating demand [kWh]	Total electricity consumption [kWh]
TOL	-10	1	11.46	7.80	3.66	2.60	6.66	11	7
	-9	25	11.02	8.28	2.75	2.82	5.69	276	142
	-8	23	10.58	8.75	1.83	3.04	4.71	243	108
A	-7	24	10.14	9.55	0.59	3.26	3.52	243	84
Tbiv	-6	27	9.70	9.70	0	3.30	2.94	262	79
	-5	68	9.26	9.26	0	3.35	2.76	630	188
	-4	91	8.82	8.82	0	3.39	2.60	802	237
	-3	89	8.38	8.38	0	3.44	2.44	746	217
	-2	165	7.94	7.94	0	3.49	2.28	1310	376
	-1	173	7.49	7.49	0	3.53	2.12	1297	367
	0	240	7.05	7.05	0	3.58	1.97	1693	473
	1	280	6.61	6.61	0	3.62	1.83	1852	512
B	2	320	6.17	6.17	0	3.67	1.68	1975	538
	Etc.	…	…	…	…	…	…	…	…
	15	74	0.44	0.44	0	2.72	0.16	33	12
								23,679	**6,611**

Table 4: Example of table with COP values, electricity consumption and heating demand for calculating $SCOP_{on}$. The values are taken from an example in EN 14825

By accumulating heating demand and electricity consumption for each temperature, $SCOP_{on}$ can be calculated as the accumulated electricity consumption divided by the accumulated heating demand. In this instance, $SCOP_{on}$ is 3.58.

Additional electricity consumption from various standby and off modes

In order to calculate *reference* SCOP, the heat pump's electricity consumption when deactivated has to be included. This includes thermostat off mode, standby mode, crankcase heater mode and off mode. In brief, electricity consumption for these modes is included in the calculation of the SCOP value as follows:

$$SCOP = \frac{Q_h}{\frac{Q_h}{SCOP_{on}} + H_{TO} \cdot P_{TO} + H_{SB} \cdot P_{SB} + H_{CK} \cdot P_{CK} + H_{OFF} \cdot P_{OFF}}$$

Where H signifies the number of hours in a year the heat pump is in the stated operating mode, and P is the energy consumption of the heat pump in this mode, which is an input parameter in the calculation. The number of hours in each operating mode is determined on the basis of whether or not the heat pump can be used for heating alone or for both heating and cooling.

The SCOP value forms the basis for labelling and minimum requirements in regulations under the Ecodesign Directive, see the document entitled *"Energy labelling and minimum requirements for heat pumps in relation to the Ecodesign Directive"*.

Annex 1 - Test points for European energy labelling and minimum requirements

For all the heat pumps, SCOP for the *Average* climate profile is mandatory, whereas it is voluntary for *Warmer* and *Colder.* The percentage of the design capacity $Pdesign_h$ is shown in brackets. Red fields describe test points about which there is uncertainty with regard to EN 14825. This is being investigated in more detail.

Air-to-air heat pumps

Point	Average	Warmer	Colder
			-15/20 ˚C *(82 %)*
A	-7/20 ˚C *(88 %)*		-7/20 ˚C *(61 %)*
B	2/20 ˚C *(54 %)*	2/20 ˚C *(100 %)*	2/20 ˚C *(37 %)*
C	7/20 ˚C *(35 %)*	7/20 ˚C *(64 %)*	7/20 ˚C *(24 %)*
D	12/20 ˚C *(15 %)*	12/20 ˚C *(29 %)*	12/20 ˚C *(11 %)*
$T_{bivalent}$	The heating demand can be met exactly		
T_{OL}	Lower temperature limit for the heat pump		

Table 5: Test temperatures for air-to-air heat pumps

Air-to-water heat pumps

Point	Average	Warmer	Colder
			-15/49 ˚C *(82 %)*
A	-7/52 ˚C *(88 %)*		-7/44 ˚C *(61 %)*
B	2/42 ˚C *(54 %)*	2/55 ˚C *(100 %)*	2/37 ˚C *(37 %)*
C	7/36 ˚C *(35 %)*	7/46 ˚C *(64 %)*	7/32 ˚C *(24 %)*
D	12/30 ˚C *(15 %)*	12/34 ˚C *(29 %)*	12/28 ˚C *(11 %)*
$T_{bivalent}$	The heating demand can be met exactly		
T_{OL}	Lower temperature limit for the heat pump		
Point	Average	Warmer	Colder
			-15/32 ˚C *(82 %)*
A	-7/34 ˚C *(88 %)*		-7/30 ˚C *(61 %)*
B	2/30 ˚C *(54 %)*	2/35 ˚C *(100 %)*	2/27 ˚C *(37 %)*

C	7/27 ˚C *(35 %)*	7/31 ˚C *(64 %)*	7/25 ˚C *(24 %)*
D	12/24 ˚C *(15 %)*	12/26 ˚C *(29 %)*	12/24 ˚C *(11 %)*
$T_{bivalent}$	The heating demand can be met exactly		
T_{OL}	Lower temperature limit for the heat pump		

Table 6: Test temperatures for air-to-water heat pumps. To the left: radiator heating; and to the right: underfloor heating

Brine-to-water heat pumps

Point	Average	Warmer	Colder
			0/49 ˚C *(82 %)*
A	0/52 ˚C *(88 %)*		0/44 ˚C *(61 %)*
B	0/42 ˚C *(54 %)*	0/55 ˚C *(100 %)*	0/37 ˚C *(37 %)*
C	0/36 ˚C *(35 %)*	0/46 ˚C *(64 %)*	0/32 ˚C *(24 %)*
D	0/30 ˚C *(15 %)*	0/34 ˚C *(29 %)*	0/28 ˚C *(11 %)*
$T_{bivalent}$	The heating demand can be met exactly		
$T_{100\%}$	Full load at design flow temperature. For "warmer" this point corresponds to point B		
Point	**Average**	**Warmer**	**Colder**

			0/32 °C *(82 %)*
A	0/34 °C *(88 %)*		0/30 °C *(61 %)*
B	0/30 °C *(54 %)*	0/35 °C *(100 %)*	0/27 °C *(37 %)*
C	0/27 °C *(35 %)*	0/31 °C *(64 %)*	0/25 °C *(24 %)*
D	0/24 °C *(15 %)*	0/26 °C *(29 %)*	0/24 °C *(11 %)*
$T_{bivalent}$	The heating demand can be met exactly		
$T_{100\%}$	Full load at design flow temperature. For "warmer" this point corresponds to point B		

Table 7: Test temperatures for brine-to-water heat pumps. To the left: radiator heating; and to the right: underfloor heating