Analysis of data received from manufacturers and comparison with Eurovent database to derive proposed minimum requirements

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1 Methodology

1.1 Choice of a methodology

We need to evaluate the possible extension range of SEPR values by product type (capacity range matters because of different technologies, with distinction between air-cooled and water-cooled products).

Several methods were discussed with the manufacturers to reach this main objective :

1. To require manufacturers to submit performance and technological information on a sufficient number of chillers to cover most of the products sold today ; the key point is to make sure the limited information gathered (the time available for manufacturers to submit information is limited to about 1 month) leads to a representative data set.
2. To use a simplified modeling approach proposed by the JIEG; it consists in defining typical heat exchanger pinch, compressor efficiencies and auxiliary impacts at the four SEPR points to estimate SEPR values for typical air cooled / water cooled chillers of different capacity sizes. This requires however to make hypothesis on the real control and performance of chillers at low outdoor temperature knowing that no data is publicly available in those operating conditions and that most of the SEPR metrics energy weight is based upon those working conditions.
3. To base upon base cases and improvements options in Lot 6 and to estimate for these products the SEPR corresponding to the SEER values. This requires however the same speculations as for point 2 regarding chiller performances at low outdoor temperature. Whether it can also be argued that air conditioning and HT process chillers may be optimized differently, this is probably not the case today as most manufacturers sell chillers independently of their usage (except maybe in the case of very large capacity chillers). It may become the case whether different metrics and requirements are adopted for HT process and air conditioning applications.

Given the important weight of low temperature points in the SEPR calculation and the fact very little data is publically available regarding the performances of the chillers in those conditions, it was decided not to base the SEPR calculations on modelling only. **Conclusively, it was decided to require information from manufacturers on a set of chillers, as extended as possible, despite the short time to do so.**

The modeling approaches 2 and 3 could in principle be feasible after the first step of gathering data. A reverse engineering approach could help extracting parameters for a simplified model from gathered data, which in turn could be used to model base cases and improved products. Time is missing to pursue such an approach however for each category with several possible technological options.

In addition, it should be emphasized that there is no need to draw a LCC curve here to determine the LLCC improvement level. The average profile accounts for 7500 hours. This is 12.5 times the equivalent full load hours used in Lot 6 for the typical air conditoning profile. This means that **any**

possible improvement is profitable to the end-user on a LCC basis. The choice of the specific level is rather an industrial problem, raising other questions :

- Are the technology enabling to reach the highest performance levels available to all players on the market ?
- How long do manufacturers need to adapt these technologies ?

As a conclusion, this document builds upon data sent by manufacturers and expert insight from independent experts as well as from industry representatives to propose possible MEPS and BAT SEPR levels for high temperature process chillers.

1.2 Methodology steps

A limited data set has been supplied by manufacturers. This encompasses basic technical information (refrigerant fluid, heat exchangers types, compressor and compressor control types), the necessary performance data to compute SEPR values and available complementary energy efficiency indexes (EER – EN14511, SEER – EN14825, ESEER – Eurovent seasonal performance indicator for air conditioning use).

First, the data set is quantified by main technological types and compared to most common technology combinations on the market. This latter is established from expert insight and validated by manufacturers.

Second, in order to ensure that the data set represents correctly the performance spread, the performance indicators available in the data sent by manufacturers are compared to the available performance information available on the EU market. The same data used in Lot 6, Eurovent Certification catalogue, is used, to this purpose.

Third, sent data is used to compute the SEPR. The four performance points are shown. This gives an insight of the performance at low outdoor temperature for the different technologies and enables to make guess whether the SEPR values are representative of the technology potential or if the chiller underperforms because of a not optimized situation.

Four, possible minimum SEPR values are established and consequences on the chiller technologies banned and remaining on the market are discussed.

2 Database representativeness

Note that the focus is on electric chillers ; the absorption chiller segment is not covered in this document although products do exist on the market (with very low sales however). It is probably necessary to include those chillers in the regulation, at least to require information for future SEPR calculations. The same rationale applies to gas engine chillers (with still lower sales).

2.1 Technologies

The technologies of the chiller refer to the refrigerant type, compressor type and part load control and the types of heat exchangers. These were the information asked to manufacturers.

The information below is presented using the following capacity range :

- Air cooled < 100 kW
- Air cooled > 100 kW & < 400 kW
- Air cooled above 400 kW
- Water cooled < 400 kW
- Water cooled > 400 kW & < 1000 kW
- Water cooled above 1000 kW

These capacity ranges are the ones proposed by manufacturers, the initial capacity split being below 400 kW and above 400 kW, as in the Lot 6 study. The implications of the supplementary classes are discussed in part 4.

Table 1 shows the repartition of chillers in the data sent by manufacturers by capacity classes.

As compared to Lot 6 figures for chillers sales reported in annex 2 :

- For air cooled chillers, the intermediate and high capacity chillers are over represented in our data set as compared to the market sales in numbers.
- For water cooled chillers, the intermediate class is over-represented while the higher class is under represented.

This is of course important to notice as under represented classes will not show the same variety of different designs for the same technology and thus probably not the same performance dispersion. However, it is still more important to know whether all core technologies are covered in the data set. The reason is that some product categories are rather homogeneous : for instance AC chiller product ranges below 100 kW are mostly identical, the competition being rather on prices, compacity, sound power levels than on performance.

This technological analysis is led by component in the following paragraphs.

2.1.1 Refrigerant fluids

The refrigerant fluid type is the first choice to be made when designing a chiller. It conditions not only the efficiency at full load but also the efficiency at part load and above all the cost to reach a given level of efficiency as different fluids will require different machine size to reach the same level of capacity, different heat exchanger sizes to reach similar efficiency levels, and that safety for toxic or flammable fluids maya gain rise the cost to the end-user.

The table below shows the repartition of refrigerant types by capacity range.

Table 1. Refrigerant fluid versus chiller categories in the data set

	NH3	R134a	R407C	R410A	Total
1. AC < 100 kW			1	2	3
2. AC > 100 kW & < 400 kW	1	4		2	7
3. AC > 400 kW	1	11			12
4. WC < 400 kW	2	3		2	7
5. WC > 400 kW & < 1000 kW	1	10			11
6. WC > 1000 kW	1	4		2	7
Total	**6**	**32**	**1**	**8**	**47**

The main types of fluids in use today are :

- R410A for the lower capacity range, mainly with scroll compressors. However, in the past years, several compressors have developped R410A screw chillers.
- R134a for the middle and upper capacity range, mainly used with screw and centrifugal compressors (also they could be used in scroll compressors as well),

There are still some chillers using R407C, mostly of old designs or because these are reversible products, mainly inus the small capacity range.

Two manufacturers supplied data for ammonia (NH3) chillers, with models available for all capacity ranges with reciprocating or screw compressors. Only the air cooled chillers below 100 kW are not covered in our database.

Regarding refrigerant fluids, **it should be noticed that alternative refrigerants are available or being prepared to replace R410A and R134a** as they are amongst the most common refrigerants in use today. The alternative refrigerants will probably enable to reach equivalent performances, possibly with increased costs for the manufacturers and end users. Nevertheless, as explained before, the cost effectiveness of efficiency improvement is not a concern for industrial HT chillers so that **it is reasonable to base upon present machines to plan energy efficiency requirements**.

As a conclusion, most common fluids by capacity range are covered in the data set.

2.1.2 Compressor type and control

Compressor technology is an important parameter for efficiency and also regarding the ability of the machine to maintain performance over a large capacity range. Different compressor types also use different part load control strategies, modifying importantly the performance at low outdoor tmperature and reduced load ratio.

The table below gives an idea of the repartition of the types of refrigerant fluid, compressor type and compressor control for the data sent by the manufacturers.

Table 2. Refrigerant fluid, compressor type and control versus chiller categories in the data set

	NH3	R134a	R407C	R410A	Total
1. AC < 100 kW			**1**	**2**	**3**
Scroll			**1**	**2**	**3**
1. On Off			1	1	2
2. Cap Step				1	1
2. AC > 100 kW & < 400 kW	**1**	**4**		**2**	**7**
Centrifugal		**1**			**1**
3. Var Cap		1			1
Screw	**1**	**2**			**3**
3. Var Cap	1	2			3
Scroll		**1**		**2**	**3**
2. Cap Step		1		2	3
3. AC > 400 kW	**1**	**11**			**12**
Centrifugal		**1**			**1**
3. Var Cap		1			1
Screw	**1**	**10**			**11**
3. Var Cap	1	10			11
4. WC < 400 kW	**2**	**3**		**2**	**7**
Recip	**1**				**1**
3. Var Cap	1				1
Screw	**1**	**3**			**4**
3. Var Cap	1	3			4
Scroll				**2**	**2**
1. On Off				1	1
2. Cap Step				1	1
5. WC > 400 kW & < 1000 kW	**1**	**10**			**11**
Centrifugal		**3**			**3**
3. Var Cap		3			3
Screw	**1**	**7**			**8**
3. Var Cap	1	7			8
6. WC > 1000 kW	**1**	**4**		**2**	**7**
Centrifugal		**2**			**2**
3. Var Cap		2			2
Screw	**1**	**2**		**2**	**5**
3. Var Cap	1	2		2	5
Total	**6**	**32**	**1**	**8**	**47**

Most common compressor types in use on the chiller market are **scroll**, **screw** and **centrifugal**. Compressor types differ depending on the capacity ranges, scroll are reserved to the low and medium capacity range, screw and centrifugal to the intermediate and high capacity ranges.

Reciprocating compressors have been progressively left over for scroll and screw technologies as these technologies required much less maintenance and were more efficient under standard rating conditions. In the data set, only ammonia water cooled chillers are proposed with reciprocating compressors, also equipped with VFD (one of the best performing SEPR product with ratings between 11.5 and 12). This is mainly due to the fact that reciprocating compressors can work efficiently at very low load ratios (so chiller performance can continue to increase at low ambiant). However, this is unlikely to see this technology making again a significant share of the sales because of the maintenance issues, expecially with HFCs and mixtures with glide.

Rotary compressors are normally limited to very small capacity (typical for domestic refrigerators and air conditioners). However, the maximum capacity is extending over the range once reserved to scroll compressors. Two stage rotary with EC motor and VFD (typical of very high efficiency air conditioners) give better full load and part load performances, and are less sensitive to oil management. This should enable to reach very high performance levels at low ambiant, while scroll and screw compressors present performance are limited in those conditions. However, there are still very few chillers on the market, mainly limited to the small air to water reversible heat pump range for which manufacturers use the same outdoor units as for split air ocnditioners as chiller condenser. There was no data for this type of compressor in the data set.

Scroll compressors are still the dominant type for low capacity chillers. Part load control is either ON-OFF below about 40 kW, using several compressors in parallel between 40 and up to 750 kW about but have lower sales than screw chillers above around 400 kW. VFD scroll compressor are now available up to 50 kW, which should enable the development of variable speed solution over the full capacity range (combining parallel compressors and VFD). However, this is still uncommon and there is no such chiller in the data set. They mostly use R410A refrigerant fluid in chillers. They are slightly less efficient than screw compressors under rating conditions but the performances of parallel compressors deliver good efficiency levels under part load.

Screw chillers are the dominant type for intermediate capacity and in competition with centrifugal compressors at high capacities. They have intermediate efficiencies, more efficient than scroll compressors and less efficient than centrifugal, under standard rating conditions. Single screw type begins at about 100 kW, while twin screw type begins a bit higher, typically 300 kW. A tri rotor compressor have been developped by Carrier, it is reserved to the high capacity range and water cooled chillers, at the moment. Standard rating efficiency increases from single to twin and tri-rotor types. For all chillers in the data set, twin rotors are used. Traditional screw part load control uses a sliding valve to change the compressor swept volume, but this affects negatively the performances. So it is in general combined with parallel compressor and circuit operation. A variable Vi control is also available to screw compressors. This enables to optimize the performance at low ambiant (crucial for process chillers). Best vailable technologies combine this option with VFD. VFD is available for screw chillers (from about 100 kW until more than 1000 kW).

Centrifugal chillers, once reserved to capacities higher than 1000 kW now enters the intermediate capacity range thanks to the introduction of centrifugal chiller with variable frequency drive (VFD) and magnetic bearings. First models begin around 300 kW. Centrifugal compressors are the most efficient compressor type at full load. Their efficiency at reduced temperature and load depends on their specific control. Centrifugal chillers with VFD prove to be able to reach the highest SEPR levels, maintaining performance at very low ambiant (with SEPR values rangin between 11 and 12 for best products).

From the view point of compressors, there are technical reasons to have one or two capacity limits between 200 and 400 kW :

- Between 300 and 400 kW, it is the separation between scroll and screw respective dominating domains.
- Between 200 and 300, it is also the beginning of the centrifugal product range (between 200 and 300) and so of likely best performing products (in terms of SEPR) on the market. Interestingly, the other best performing product identified (water cooled chiller using reciprocating VFD with ammonia) product range also begins about 270 kW.

Conclusively, the data set in the study covers satisfactorily the most common combinations of compressors / refrigerant fluids and the associated part load controls. However, some of the promising compressor technologies are not covered. This regards two stage VFD rotary compressors, VFD scroll compressors,

2.1.3 Heat exchanger types

For chillers, there three types of heat exchangers to be considered :

- Refrigerant to water evaporators for both air cooled and water cooled chillers,
- Refrigerant to water condensers for water cooled chillers,
- Refrigerant to air condensers for air cooled chillers.

Evaporators

There two main technologies here, plate heat exchangers and tube and shell heat exchangers. The choice of the heat exchanger type is dependent mainly on capacity on also may be specific to the refrigerant choice (ammonia chillers do not use shell and tube evporators but plate heat exchangers).

What mainly affects the performance is the ability of the heat exchangers to reduce the temperature difference between water and refrigerant. Of course this is a question of heat transfer intensity and heat exchanger size. In that direction, plate heat exchangers have the benefit of much higher compacity than tube and shell.

What really makes a difference however, is the use of flooded evaporators because this enables to avoid the superheat temperature difference of direct expansion heat exchangers. In direct expansion shell and tube heat exchangers, the refrigerant evporates inside copper tubes while water circulates in the shell around the tubes. In flooded shell and tube evaporators, the refrigerant evaporates in the shell cooling water circulating inside the tubes. The refrigerant is aspirated at the top of the heat exchanger close to saturation conditions. Flooded shell and tube evaporators can work with temperature difference down to 1 to 2 K. Typical direct expansion heat exchanger work with 4 to 5 K temperature difference.

Flooded shell and tube heat exchangers are presently not available below about 300 kW. In our data set, the lower capacity is about 320 kW. Also it is not yet common, flooded plate heat exchangers are now available. They are only used in ammonia chillers in our data set (as an alternative to flooded shell and tube heat exchangers). This technology also begins about 300 kW on the data sent (and probably on the market too), although it is available to lower capacities from OEMs. This means that the present 300 kW capacity limit for flooded evporator is likely to decrease to lower capacities with the spread of flooded shell and plate heat exchangers.

Condensers of water cooled chillers

The technologies are the same as for evaporators regarding shell and tube heat condensers. There is no specific flooded type for plate heat exchanger but technologies do exist to control the subcooling to a minimum value in order to maintain the lowest possible condesning pressure.

Condensers of air cooled chillers

Condensers of air cooled chillers are almost exclusively round tubes with plate fins. For HFC, tubes are made of copper and fins are in aluminium. For ammonia, tubes are in aluminium.

Microchannels heat exchangers have already entered the market. They are more compact and thus enable either to reduce the costs for the same performance or to slightly increase the performance at comparable cost. In addition, air pressure loss are reduced. However, there is no significant difference due to the type of heat exchanger, performance is mainly a problem of size for standard rating performances, and of air flow and fan control at reduced load and low ambiant.

The different types of heat exchangers in the data set are shown in the table below. It is thought to be fully representative of present practices on the chiller market.

Table 3. Evaporator types versus chiller categories in the data set

	DX plate	DX S&T	Flooded plate	Flooded S&T	Total
1. AC < 100 kW	3				3
2. AC > 100 kW & < 400 kW	3	3	1		7
3. AC > 400 kW		7	1	4	12
4. WC < 400 kW	3	2	1	1	7
5. WC > 400 kW & < 1000 kW		2	1	8	11
6. WC > 1000 kW		2	1	4	7
Total	**9**	**16**	**5**	**17**	**47**

Table 4. Condenser types versus chiller categories in the data set

	DX plate	DX S&T	Flooded S&T	MicroChannel	RTPF	Total
1. AC < 100 kW					3	3
2. AC > 100 kW & < 400 kW					7	7
3. AC > 400 kW				1	11	12
4. WC < 400 kW	4	3				7
5. WC > 400 kW & < 1000 kW	1	4	6			11
6. WC > 1000 kW	1	2	4			7
Total	**6**	**9**	**10**	**1**	**21**	**47**

2.2 Comparison of the data set with available performance indexes

We have limited data supplied by manufacturers in the data set. Their statistical validity is limited. It can be increased by checking whether it covers main efficiency ranges by product type (air cooled, water cooled) and capacity size.

Available performance indexes to do so are the EER and the ESEER (Eurovent) indexes. The performance levels in the data set are tested against EER and the Eurovent ESEER metrics below.

As explained in the introduction, it is supposed that air conditioning and HT process chillers are not yet optimized differently, which may not be the case after different metrics and requirements are adopted for HT process and air conditioning applications.

2.2.1 Eurovent database

Eurovent on line catalogue gives the best source of performances for EU chillers for air conditioning application. Today, it can be supposed that most manufacturers do not differenciate their product range for the air conditioning and HT process applications (this affirmation will not be valid after separate requirements apply to both chiller ranges).

From the sent data, it appears that some manufacturers do not participate to the Eurovent programme (as Star Refrigeration) and that all chillers are not in the catalogue (for instance data was sent for ammonia chillers which are not listed in the Eurovent directory). In addition, the capacity ranges beginning over a certain capacity threshold are excluded :

- 1500 kW for water cooled chillers (above manufacturers are mainly adapting the chiller based on customers' specific needs) ; this means that large centrifugal chillers are under-represented ;
- 600 kW for air cooled chillers ; however, it seems that most manufacturers give all or almost all their product ranges in the catalogue.

Despite these limitations, the coverage of chiller product types is certainly higher than 90 % of sold products, which seems good enough to make sure all main product types (core sales) are covered in the directory. And supplementary information given by manufacturers enabled to add two ammonia water cooled product lines that were not covered.

2.2.2 Air cooled chillers, spread of performances of sent data

The comparison of EER values of sent data with Eurovent data (Figure 1) shows a relative good coverage, especially including the range extension of chillers using the same technological platform as the ones sent (indicated in dot lines around the chiller points on the graphic below). Below 400 kW, maximum EER value may reach 3.5 while sent data maximum EER is limited to about 3.1. Above 400 kW, almost all the capacity range is covered, with only one chiller for the higher end of the efficiency range.

The data set appears to have lower representation in the poorer performing EER range than the Eurovent data set. This is expecially true for low capacity chillers, that as already said, are under represented.

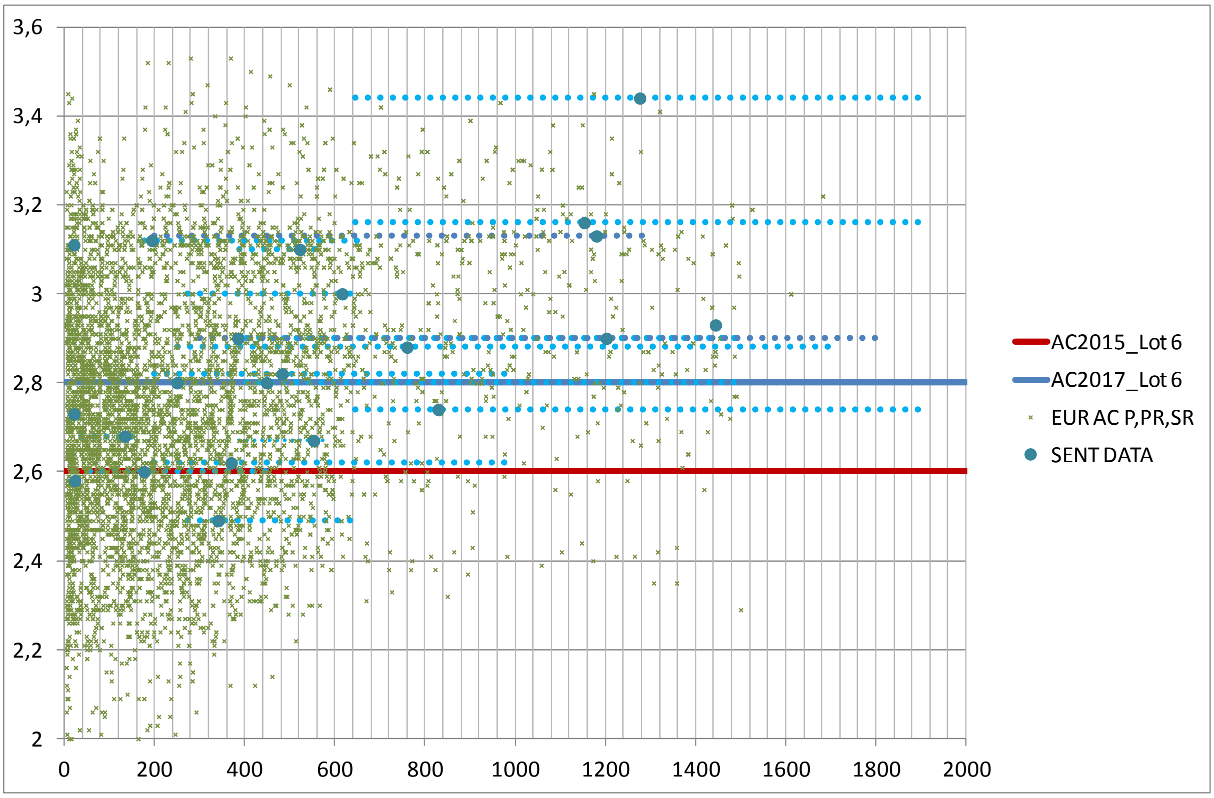
The proposed EER requirements from Lot 6 have been added on Figure 1.

Above 400 kW, most chillers in the data set are above the 2017 threshold (excluding about 40 % of models on the Eurovent directory in 2010) and all above the 2015 threshold (excluding about 20 % of models on the Eurovent directory in 2010).

Below 400 kW, most chillers in the data set are above the 2015 threshold (excluding about 35 % of models on the Eurovent directory in 2010), while only half would pass the 2017 threshold (excluding about 65 % of models on the Eurovent directory in 2010).

Hence the data set average EER value clearly appears to be higher than the average value in the Eurovent directory.

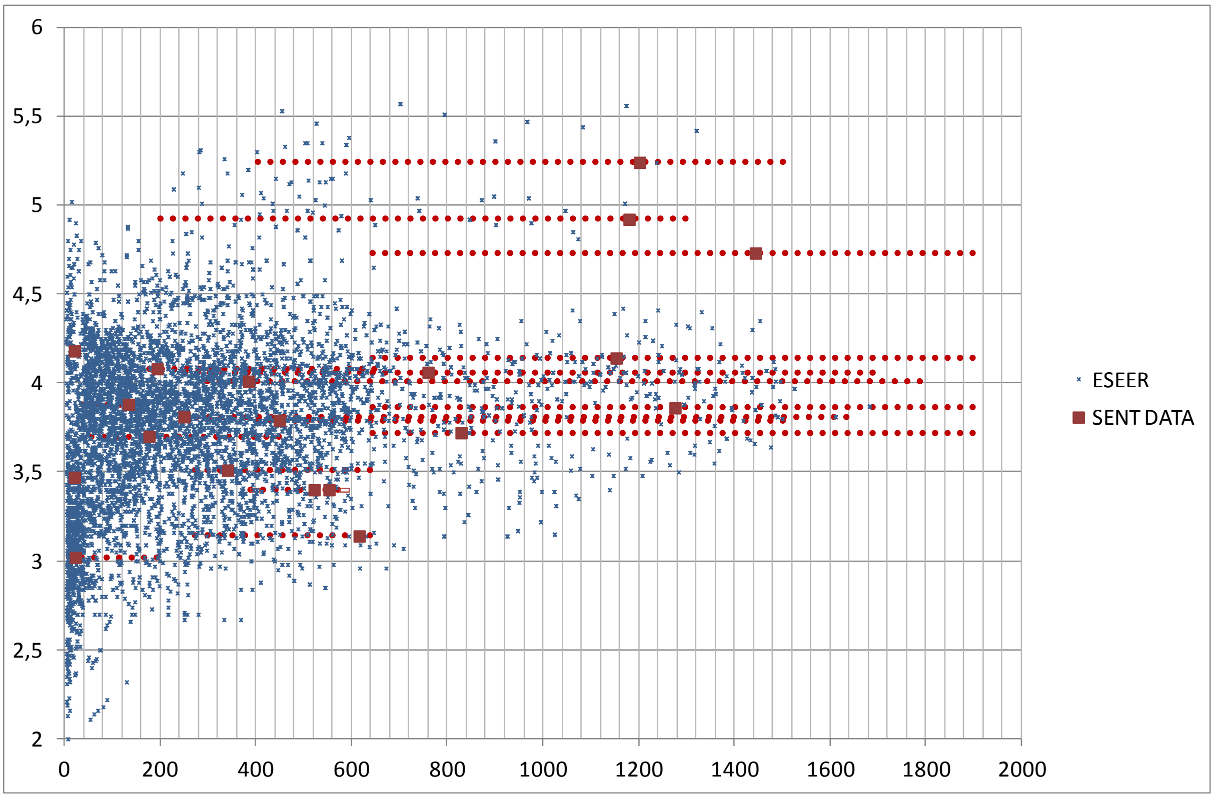
Figure 1. Air cooled chillers, net EER Vs net cooling capacity (kW)



The analysis of the ESEER graph confirms what has been observed for the EER. At the low capacity end of the range, the highest and lowest efficient chillers are missing, with ESEER values ranging between 3 and 4.1 while most efficient chillers may reach 5 below 100 kW and 5.3 starting at about 300 kW and lowest may reach 2.

The larger capacity range is relatively well covered. However, the high performance end of the range is represented by a single chiller (and its range extension), and the lower efficiency range is not covered (minimum ESEER 3.7 above 650 kW, versus 3.1 in the Eurovent directory).

Figure 2. Air cooled chillers, net ESEER Vs net cooling capacity (kW)



As a conclusion, the data set seems to cover most chiller in the graphs capacity / EER and capacity / ESEER, except :

- high and low EER and ESEER low capacity chillers,
- Low EER high capacity chillers
- And a low representation of high EER and SEER large capacity chillers

This tends to show that the data set supplied by manufacturers cannot be seen as fully representative of the market (i.e. not adequate on its own as a basis to judge minimum performance requirements) and that information is missing on low capacity high efficiency chillers. In order to compensate for this gap, the available technology options and their impact on efficiency have also been assessed to better inform the setting of minimum requirements and best available product efficiencies / benchmark levels.

2.2.3 Water cooled chillers, spread of performances of sent data

As compared to air cooled chillers, the coverage in terms of performances is better. All chiller performance types are represented including more efficient small capacity chillers. It should be noticed however that the Lot 6 study discovered that little performance improvements had occured in the small capacity range of water cooled chillers because of low market sales. As for air cooled chillers, the very high end of the EER range above 400 kW is represented by only one chiller.

The proposed EER requirements from Lot 6 have been added on Figure 3.

Above 400 kW, 40 % of chillers in the data set are below the 2017 threshold (excluding about 70 % of models on the Eurovent directory in 2010). This figures decreases to 25 % for the 2015 threshold (excluding about 25 % of models on the Eurovent directory in 2010).

Below 400 kW, one chiller (15 %) in the data set is below the 2015 threshold (excluding about 30 % of models on the Eurovent directory in 2010), while about 30 % would not pass the 2017 threshold (excluding about 70 % of models on the Eurovent directory in 2010).

Hence the data set EER values appears clearly to be higher than the average value in the Eurovent directory.

As for the EER, the data set shows a good coverage in terms of ESEER (Figure 4).

As a conclusion, the data set seems to cover most chiller in the graphs capacity / EER and capacity / ESEER, except :

- high and low EER and ESEER low capacity chillers,

This tends to show that the data set supplied by manufacturers cannot be seen as fully representative of the market (i.e. not adequate on its own as a basis to judge minimum performance requirements) and that information is missing on low capacity high efficiency chillers. In order to compensate for this gap, the available technology options and their impact on efficiency have also been assessed to better inform the setting of minimum requirements and best available product efficiencies / benchmark levels.

Figure 3. Water cooled chillers, net EER Vs net cooling capacity (kW)

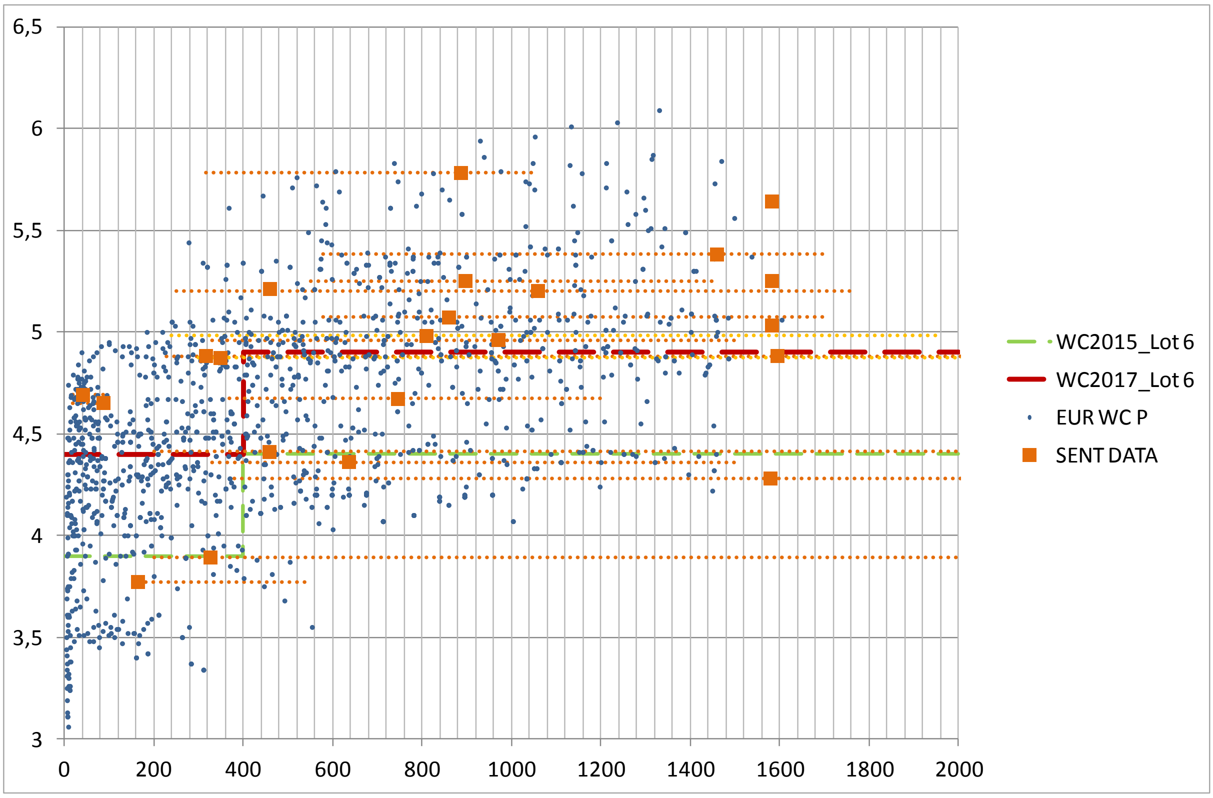
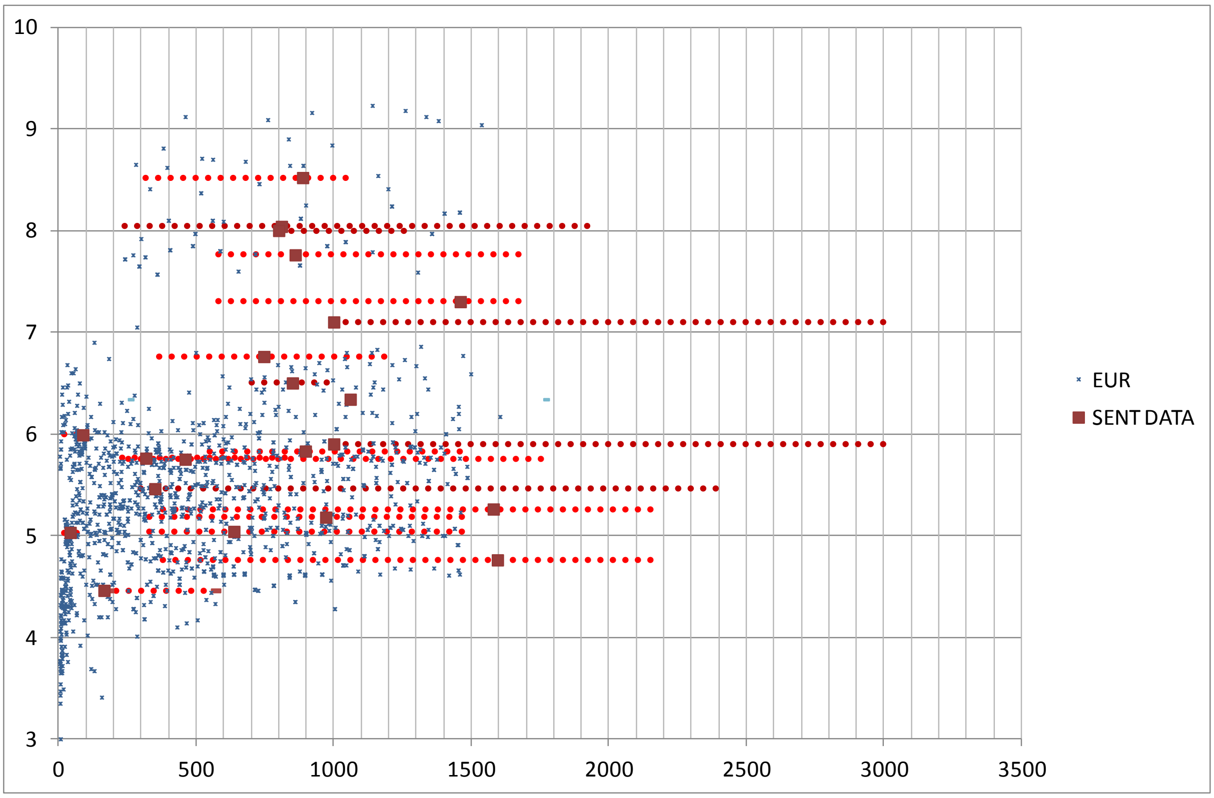


Figure 4. Water cooled chillers, net ESEER Vs net cooling capacity (kW)



3 SEPR values

3.1 Comparison of SEPR and other metrics

The question has been raised to know whether it was possible to use the SEER values from Lot 6 study in order to deduct likely ranges of SEPR figures with similar ambitions. The same question could be raised with other metrics, EER and ESEER.

To answer that question, the different indexes for the chillers on which information was available are gathered on the graphs below, for air cooled (Figure 5) and water cooled (Figure 6) chillers separately.

Note that on Figures 5 and 6, the SEER values are the EN14825:2012 SEER values which serve as a reference for Lot 6 study and proposed MEPS. Unfortunately, only a few manufacturers declared both SEER and SEPR values. Nevertheless, it clearly appears that best chillers (on a ESEER basis) fall in the MEPS zone proposed in Lot 6 study.

SEPR absolute values are clearly way above the SEER values for most chillers although it is not possible to distinguish clear trends only looking at the overall dataset. There is not a correlation to the ESEER or to the EER either.

This means that it is necessary to look into the details of the EER points supplied by the manufacturers in order to explain the SEPR variations from one chiller to another.

It is not possible to statistically deduce SEPR values from other metrics.

Figure 5. Air cooled chillers, comparison of the different performance indices

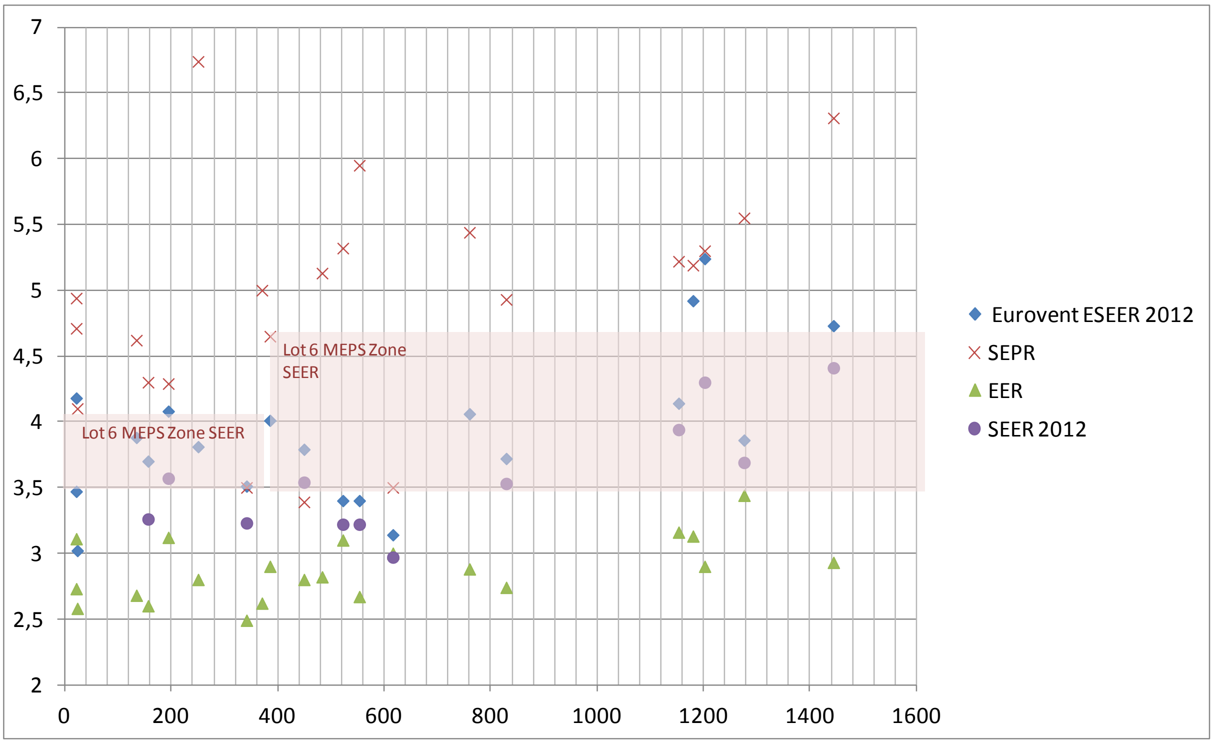
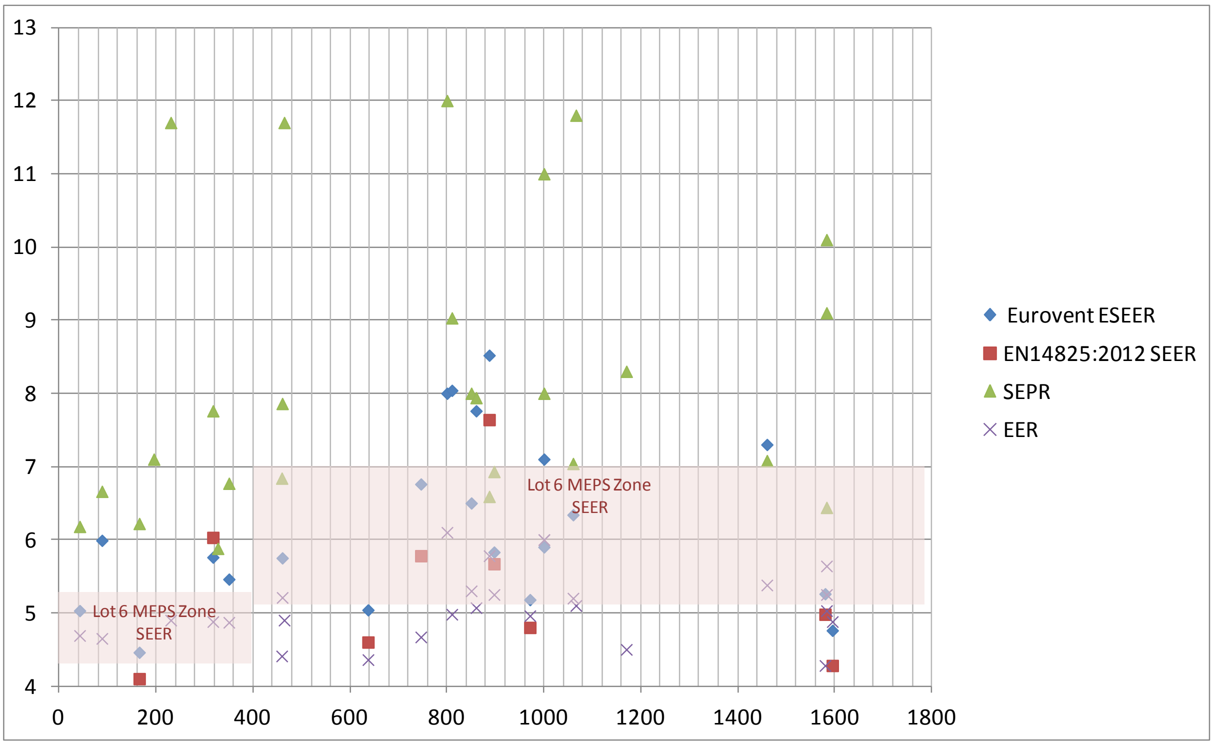


Figure 6. Water cooled chillers, comparison of the different performance indices



3.2 Detailed EER analysis

Is it possible to characterize typical SEPR to standard full load EER ratios by chiller category ?

In order to be able to estimate SEPR values for a given chiller with known technology and full load EER performance, sent data can be used to characterize typical EER evolution with reduced condenser inlet temperature and load.

The ratio of EER at reduced inlet temperature to stadard rating EER is influenced by several phenomenas. Factors explaining diffeent evolutions may include :

- The refrigerant fluid type,
- Compressor efficiency curve at reduced load ratio, which vary also with the type of unloading means being used,
- Compressor map security limitations imposed by compressor manufacturers as minimum condensing temperature or temperature difference between evaporating and condensing temperature to ensure a correct lubrification (when there is not a separate oil pump),
- The impact of fan energy consumption for air cooled chillers,
- The impact of the pumping energy which will varies with the pressure losses at both heat exchangers ; this makes a constant correction whose impact increases when the compressor electric power decreases (so at reduced inlet temperature air/water temperature at the condenser).

To do so, it is necessary analyze the data submitted by chiller category to to see whether it is possible to understand the EER variations with reduced air / water temperature inlet at the condenser and reduced load ratios, and if so, to estimate typical ratios relating SEPR to standard full load EER.

This is done by putting part load data of all chillers by category and checking that the available design characteristics given by manufacturers may explain the different part load EER evolutions.

This analysis is led hereafter in paragraphs 3.3 (air cooled chillers) and 3.4 (water cooled chillers) using the below chiller categories :

1. air-cooled, <400 kW and air-cooled >400 kW
2. water-cooled <400 kW, water-cooled >400 <1000 kW, water-cooled >1000 kW

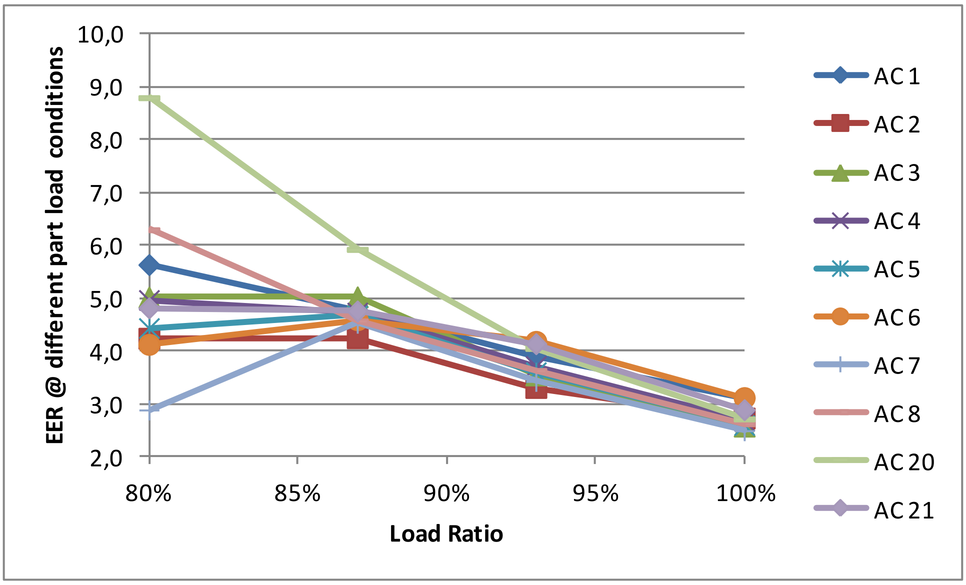
3.3 Air cooled chillers

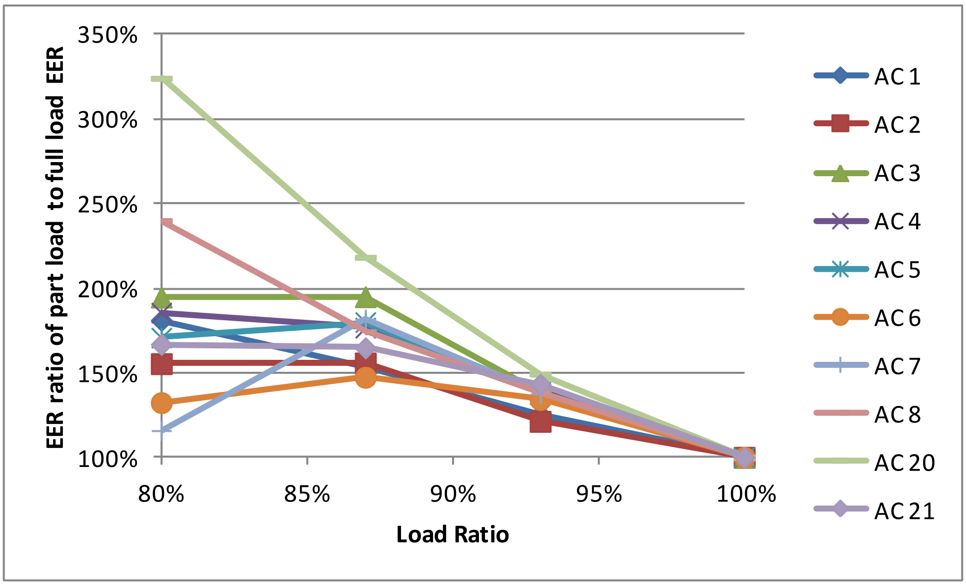
3.3.1 Air-cooled chillers <400 kW

Tab. 2 Design characteristics and performance of AC chillers below 400 kW

	Part load	Net cap kW	EER net	ESEER	SEPR	SEPR / EER	fluid	Evap	Cond	Comp	*range min cap (kW)*	*range max cap (kW)*
AC 1	On off	21	3,11	3,47	4,94	159%	R410A	BPHE	RTPF	Scroll	17	33
AC 2	Cap Step	21	2,73	4,18	4,71	173%	R410A	BPHE	RTPF	scroll		
AC 3	On off	23	2,58	3,02	4,1	159%	R407C	BPHE	RTPF	scroll	10	200
AC 4	Cap Step	134	2,68	3,88	4,62	172%	R410A	BPHE	RTPF	Scroll	39	160
AC 5	Cap Step	156	2,6	3,7	4,3	165%	R410A	DX plate	RTPF	Scroll	56	450
AC 6	Cap Step	194	3,12	4,08	4,29	138%	R134a	DX plate	RTPF	Scroll	178	672
AC 7	Var Cap	341	2,49	3,51	3,5	141%	R134a	DX S&T	RTPF	Screw	273	646
AC 8	Var Cap	370	2,62		5	191%	NH3	FX plate	RTPF	Screw	200	1000
AC 21	Var Cap	385	2,9	4,01	4,65	160%	R134a	DX S&T	RTPF	Screw	300	1800
AC 20	Var Cap	250	2,71	3,81	6,74	249%	R134a	DX S&T	RTPF	Cent. VFD, MB	250	1650

Fig. 7 Part load data of AC chillers below 400 kW





Regarding on-off machines, the SEPR / EER ratio is identical in both cases and is close to 160 %, with an EER varying from 2.6 to 3.1. This translates two different behavior at reduced temperature. AC1 chiller show a continuous performance improvement but steadier than for AC3 down to 15 °C. Below 15 °C, the EER of AC3 is limited (condensation temperature limit) while it continues improving for AC1, for which the EER at 5 °C is amongst the highest for R410A machines below 400 kW with a value of about 5.7. It is probably linked to a different management of the condensing pressure at low ambiant.

Except AC7, which shows a specific degradation at 5 °C, other scroll and screw HFC chillers typical EER at 5 °C inlet lie between 4 and 5. The impact of the maintained condensing pressure is clear. Fan management explains that in some cases the performance at 5 °C is even lower that the performance at 10 °C. **For standard R410A scroll chillers with capacity steps, and for R134a screw chillers with slide valve for continuous capacity variation (or enough step to adapt precisely the capacity), the SEPR / EER ratio lies between 160 % and 175 %.**

The **ammonia screw chiller SEPR / EER ratio** is relatively higher, about **190 %**, with an EER at 5 °C above 6.

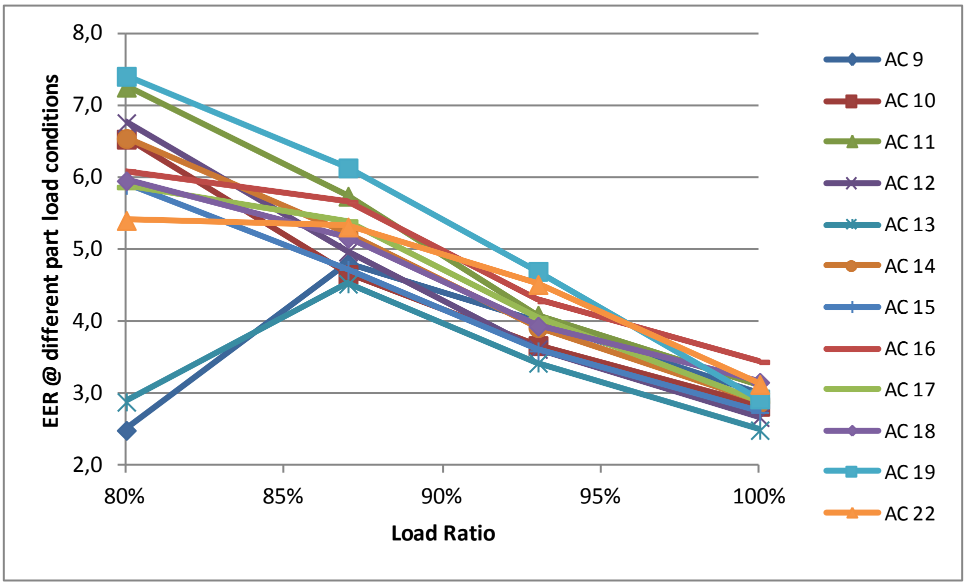
The centrifugal chiller with magnetic bearings and VFD enables to achieve much higher SEPR / EER ratio close to 250 %. It is not affected by condensing pressure control and additionally, the SEPR load / temperature curve is close to its optimal performances, which are very sensitive to load and temperature. The chiller performance reaches about 9 at 5 °C outdoor temperature.

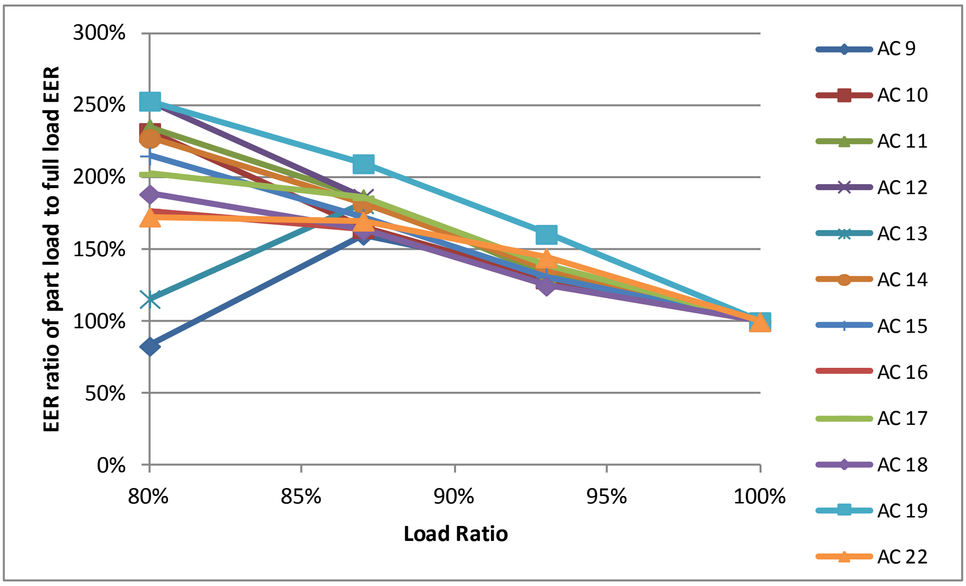
3.3.2 Air-cooled chillers >400 kW

Table 5. Design characteristics and performance of AC chillers above 400 kW

	Part load	Net cap kW	EER net	ESEER	SEPR	SEPR / EER	fluid	Evap	Cond	Comp	*range min cap (kW)*	*range max cap (kW)*
AC 9	Var Cap	449	2,8	3,79	3,39	121%	R134a	Flooded S&T	Ct, Al F	Screw	404	1511
AC 10	Var Cap	483	2,82		5,13	182%	NH3	FX plate	Al T, Al F	Screw	200	1000
AC 11	Var Cap	522	3,1	3,4	5,95	192%	R134a	DX S&T	Ct, Al F	Screw	388	575
AC 12	Var Cap	553	2,67	3,4	5,32	199%	R134a	DX S&T	Ct, Al F	Screw	388	575
AC 13	Var Cap	616	3	3,14	3,5	117%	R134a	DX S&T	Ct, Al F	Screw	273	646
AC 14	Var Cap	760	2,88	4,06	5,44	189%	R134a	Flooded	Micro Channel	Screw	252	1 702
AC 15	Var Cap	829	2,74	3,72	4,93	180%	R134a	DX S&T	Ct, Al F	Screw	645	1917
AC 16	Var Cap	1153	3,16	4,14	5,22	165%	R134a	DX S&T	Ct, Al F	Screw	645	1917
AC 17	Var Cap	1202	2,9	5,24	5,3	183%	R134a	Flooded S&T	Ct, Al F	Screw	404	1511
AC 18	Var Cap	1276	3,44	3,86	5,55	161%	R134a	DX S&T	Ct, Al F	Screw	645	1917
AC 19	Var Cap	1444	2,93	4,73	6,31	215%	R134a	DX S&T	Ct, Al F	Screw VFD	645	1917
AC 22	Var Cap	1180	3,13	4,92	5,19	166%	R134a	Flooded S&T	Ct, Al F	Cent. VFD, MB	200	1300

Figure 7. EER at the different SEPR points, AC chillers above 400 kW, Absolute and relative to standard full load EER values





From the figures above, it clearly appears that chillers AC9 and AC13 have peculiar behavior at reduced outdoor conditions (although from the data gathered it is not possible to know why), very different from the other products. They are not considered to derive typical SEPR / EER ratios.

R134a screw chillers, without VFD, have SEPR / EER ratio lying between 160 % and 200 %. Except the AC12 chiller, whose EER is relatively low, the ratio lies between 160 % and 190 %. It clearly appears that all chillers are not equal regarding condensation pressure control. Very performant chillers on a EER basis can have dispappointing SEPR because of the performance is blocked below 15 °C. The higher ratios, as compared to lower than 400 kW chillers, is difficult to apprehend, but could arise from better part load staging and management, and better air flow (and fan power) management at reduced temperature and load.

The screw ammonia chiller does not show a different behavior when compared to HFC screw chillers.

There is only one **screw VFD chiller** in the data set and it shows the best SEPR value of 6.3. It also has the highest SEPR / EER ratio. Its performance at 5 °C is comparable to the one of chiller AC1, suggesting that similar condensing temperature and fan control options have been chosen. Nevertheless, its relative performance at 25 °C and 15 °C increases faster as compared to other screw chillers. The **SEPR / EER ratio is 215 %**.

The centrifugal VFD chiller, also it has a relatively high ESEER value, only has a SEPR / EER ratio of 166 %, to be compared with the 240 % of chiller AC20. This chiller may not be optimal for the SEPR load curve (but rather optimized for the air conditioning conditions).

3.3.3 SEPR average and upper values

Median EER value for air cooled chillers is about 2.75 (Eurovent 2013 data), based upon categories kept in the analysis (as explained at § 2.2.1). This varies depending on the capacity as shown in the table below. Higher capacity chillers may be equipped with flooded heat exchangers, which increases significantly the EER in standard rating conditions. Besides, large screw compressors tend to be more efficient than scroll compressors at standard full load conditions.

Table 6. Median EER values by caapcity range for air cooled chillers (Eurovent 2013 data)

AC chillers categories	All	< 100	100-400	> 400
Median EER	2,75	2,73	2,71	2,87

The EERs are MEDIAN - not average, to remove influence of outliers and odd products (eg for some ducted units).

Maximum EER is about 3.4 for the whole capacity range.

This information can be combined with the analysis of SEPR / EER ratio variations with different technologies. This is of course a simplified approach, but alreay gives a good idea of potential SEPR values for different technologies and of the extension of SEPR values between mediane and higher values.

The results are shown in the table below.

Table 7. Estimates of average and high SEPR values bu product category

AC < 400 kW						
	EER ave	EER max	SEPR / EER ave	SEPR / EER high	SEPR ave	SEPR high
On-off scroll	2,7	3,4	160%		4,32	5,44
On-off scroll with extended HP range	2,7	3,4		190%	5,13	6,46
Capacity stage or VFD scroll	2,7	3,4	166%		4,48	5,64
VFD scroll / rotary with extended HP range	2,7	3,4	197%		5,32	6,70
Cap stage or var cap screw	2,7	3,4	166%	190%	4,48	6,46
Ammonia screw chiller	2,7	2,9	180%	190%	4,86	5,51
VFD screw	2,7	3,4	215%		5,81	7,31
Centrifugal VFD (MB)	2,7	3,4	203%	240%	5,48	8,16
AC > 400 kW						
	EER ave	EER max	SEPR / EER ave	SEPR / EER high	SEPR ave	SEPR high
Capacity stage or VFD scroll	2,87	3,4	166%		4,76	5,64
VFD scroll with extended HP range	2,87	3,4	197%		5,66	6,70
Cap stage or var cap screw	2,87	3,4	166%	190%	4,76	6,46
Ammonia screw chiller	2,87	2,9	180%	190%	5,17	5,51
VFD screw	2,87	3,4	215%		6,17	7,31
Centrifugal VFD (MB)	2,87	3,4	203%	240%	5,83	8,16

Below 50 kW, only information on on-off chillers was submitted. VFD is entering the market thanks to the introduction of double stage rotary compressors but the penetration for scroll compressors is still very low. Except improving the EER and adopting VFD compressors, on-off chillers can also be improved by extending the working range to lower condensing temperature and using VFD fan controls. One scroll manufacturer already qualified its scroll compressors at lower ambiant (down to 10 °C), thus this potential improvement is close to be available to chiller assemblers. This may lead to significant gains at 5 °C, estimated to lead to 190 % SEPR / EER ratios versus 160 % for standard on-off chillers.

There was no information submitted for chiller with capacity between 50 and 100 kW but there SEPR / EER ratio is likely to be similar to the ratio of larger scroll units, using 50 / 50 or 33 / 66 capacity staging.

The data set enables to identify possible benchmarks, with the meaning here of best available technologies not yet applied into products. We assume here that it would correspond to present technologies with associated SEPR / EER ratios, and best EER by product range. This leads to the following range of values :

- 0 – 200 kW : 6.5
- 200 – 400 kW : 8
- > 400 kW : 8

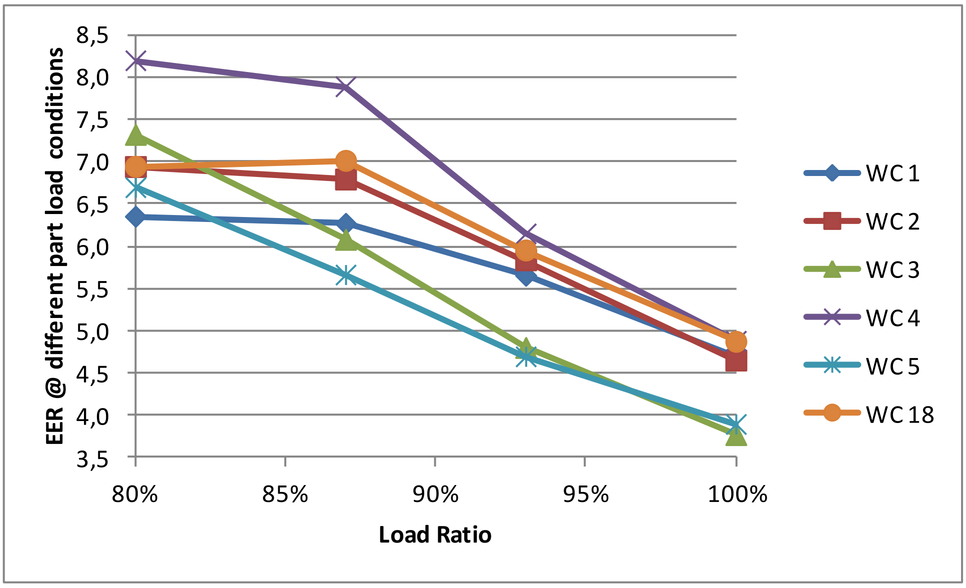
3.4 Water cooled chillers

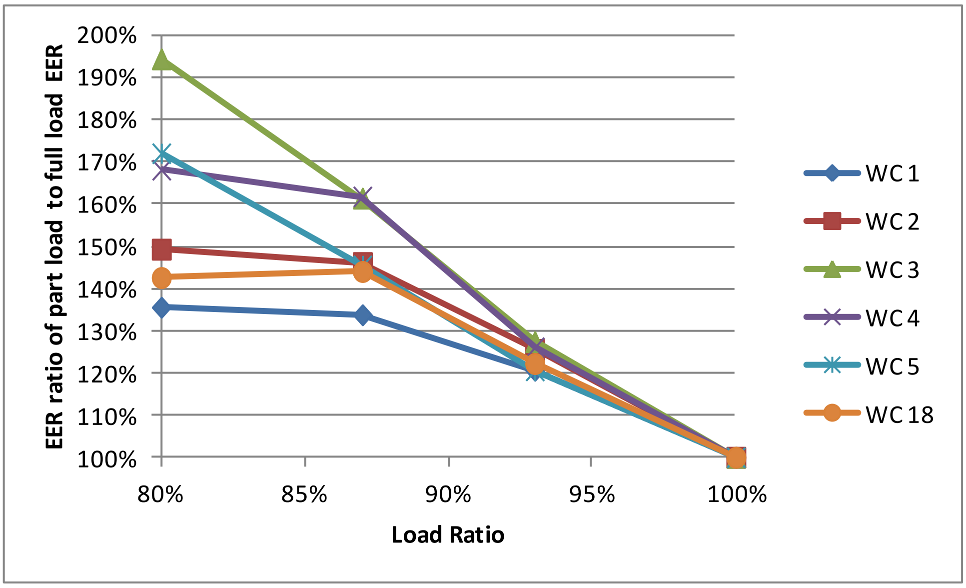
3.4.1 Water-cooled chillers <400 kW

Table 8. Design characteristics and performance of WC chillers below 400 kW

	Part load	Net cap kW	EER net	ESEER	SEPR	SEPR / EER	fluid	Evap	Cond	Comp	*range min cap (kW)*	*range max cap (kW)*
WC 1	On off	42	4,69	5,03	6,18	132%	R410A	BPHE	BPHE	Scroll	20	90
WC 2	Cap Step	88	4,65	5,99	6,66	143%	R410A	BPHE	BPHE	Scroll	20	90
WC 3	Var Cap	165	3,77	4,46	6,22	165%	NH3	DX S&T	DX S&T	Screw	165	554
WC 4	Var Cap	317	4,88	5,76	7,76	159%	R134a	Falling film	DX S&T	2 screw	230	840
WC 5	Var Cap	327	3,89		5,88	151%	NH3	FX plate	plate	Screw	200	8000
WC 18	Var Cap	350	4,87	5,46	6,77	139%	R134a	DX S&T	DX S&T	Screw	300	2400
WC 24	Var Cap	210	4,9		11,7	239%	NH3	BPHE	Plate	Recip VFD	200	1350
WC 31	Var Cap	195	3,4		7,1	209%	NH3	FX plate	Plate	Screw VFD Eco	200	3000

Figure 8. EER at the different SEPR points, WC chillers below 400 kW, Absolute and relative to standard full load EER values





SEPR to EER ratio are as follows :

- Around 130 % for the on-off chiller,
- Between 140 % and 160 % for HFC capacity step scroll chillers and screw chillers with multiple capacity steps and/or slide valve,
- Between 150 and 165 % for ammonia screw chillers with multiple capacity steps and/or slide valve (but, as compared to HFC chillers, they start with lower EER under standard rating conditions)
- About 210 % for ammonia screw with economizer and VFD,
- And about 240 % for the ammonia chiller with VFD reciprocating compressor.

It can be noticed that for HFC chillers, the EER at 9 °C (80 % load) appears to be limited to the value at 16 °C (87 % load). This is not the case for ammonia chillers. However, the EER at 9 °C for these chillers reach about the same value as for HFC chillers, so it is probably the reason why it is not observed (as i twas observed before for air cooled chillers). Hence, the lower EER value at 30 °C 100 % load probably explains for ammonia chillers why the SEPR / EER ratio is higher than for other HFC chillers above.

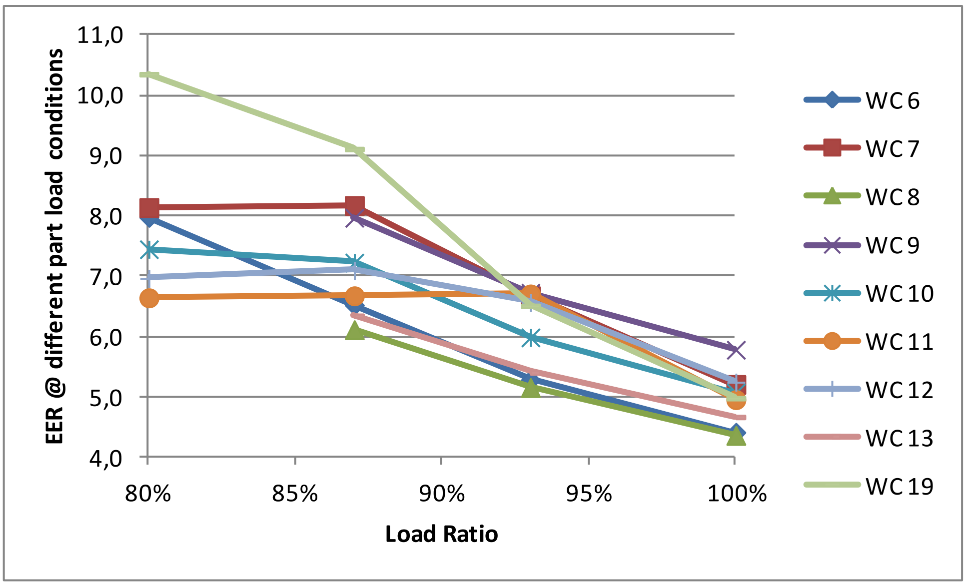
For water cooled chillers, the specification of pressure drop on both sides impacts importantly the EER evolution with temperature decrease. Whether manufacturers picked up high pressure loss chillers, this can lead to underestimate from 5 to 10 % the SEPR / EER ratio. This information was not asked for and is consequently generally not available.

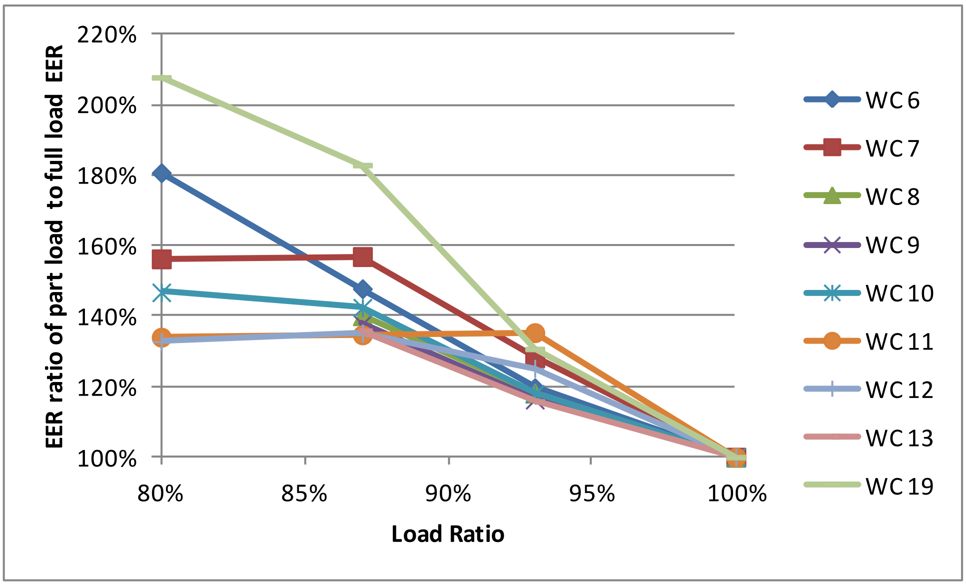
3.4.2 Water-cooled chillers >400 <1000 kW

Table 9. Design characteristics and performance of WC chillers between 400 kW and 1000 kW

	Part load	Net cap kW	EER net	ESEER	SEPR	SEPR / EER	fluid	Evap	Cond	Comp	*range min cap (kW)*	*range max cap (kW)*
WC 6	Var Cap	459	4,41		6,84	155%	NH3	FX plate	plate	Screw	200	8000
WC 7	Var Cap	460	5,21	5,75	7,86	151%	R134a	Flooded S&T	Flooded S&T	Screw	252	1762
WC 8	Var Cap	637	4,36	5,04			R134a	DX S&T	DX S&T	Screw	332	1503
WC 9	Var Cap	746	4,67	6,76			R134a	Flooded S&T	Flooded S&T	Screw	368	1212
WC 10	Var Cap	860	5,07	7,76	7,94	157%	R134a	Flooded S&T	Flooded S&T	Screw VFD	580	1710
WC 11	Var Cap	887	5,78	8,52	6,59	114%	R134a	Flooded S&T	Flooded S&T	Cent	316	1054
WC 12	Var Cap	897	5,25	5,83	6,93	132%	R134a	Falling film	DX S&T	1 screw	550	1460
WC 13	Var Cap	971	4,96	5,18			R134a	DX S&T	DX S&T	Screw	332	1503
WC 19	Var Cap	810	4,98	8,04	9,03	181%	R134a	Flooded S&T	DX S&T	Cent VFD, MB	240	1950
WC 22	Var Cap	800	6,1	8	12	197%	R134a	Falling Film	Flooded S&T	Cent VFD, MB	800	1300
WC 23	Var Cap	850	5,3	6,5	8	151%	R134a	Falling Film	Flooded S&T	Screw VFD Eco	700	1000
WC 29	Var Cap	464	4,9		11,7	239%	NH3	BPHE	Plate	Recip VFD	200	1350

Figure 9. EER at the different SEPR points, WC chillers above 400 kW and below 1000 kW, Absolute and relative to standard full load EER values





For chillers 8, 9 and 13, the performance point at 9 °C inlet water temperature at the condenser was not supplied. Probably, the evolution of the condensation pressure is blocked to the one of the (87 %, 16 °C inlet water temperature) EER. In that case, the water flow has to be reduced, which in turn reduces the pressure loss. This probably explains the performance improvement between 87 % and 80 % load for WC 10 chiller. And so i sis likely the performances of chillers 8, 9 and 13 at 80 % would be similar.

SEPR to EER ratio are as follows :

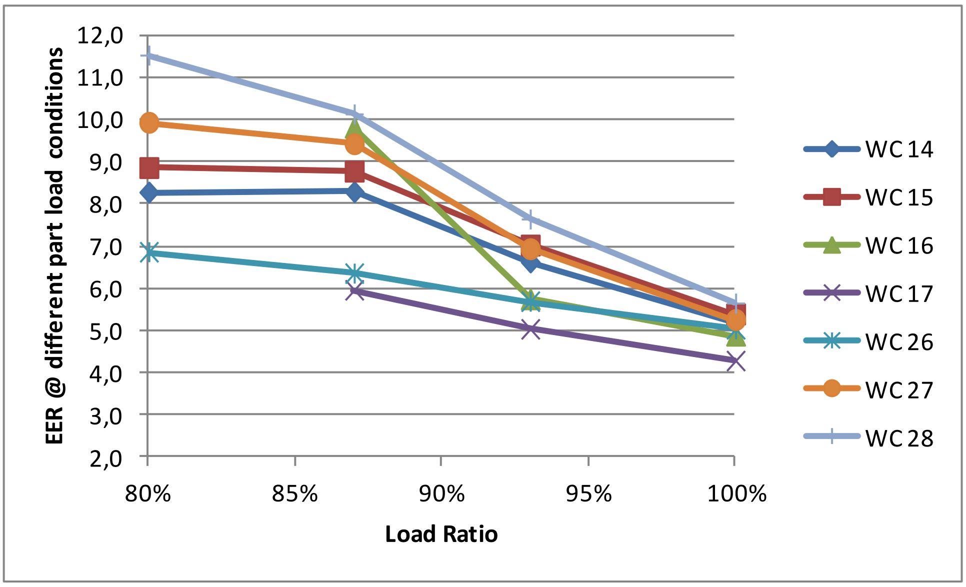
- Only 114 % for the non VFD centrifugal chiller ; however, the behavior is not common with efficiency blowked below 23 °C outdoor ;
- Between 130 % and 160 % for all screw chillers, the VFD screw controled chillers having ratios ranging between 150 and 160 %,
- Between 180 and 200 % for centrifugal VFD chillers (with magnetic bearings here),
- And about 240 % for the ammonia chiller with VFD reciprocating compressor.

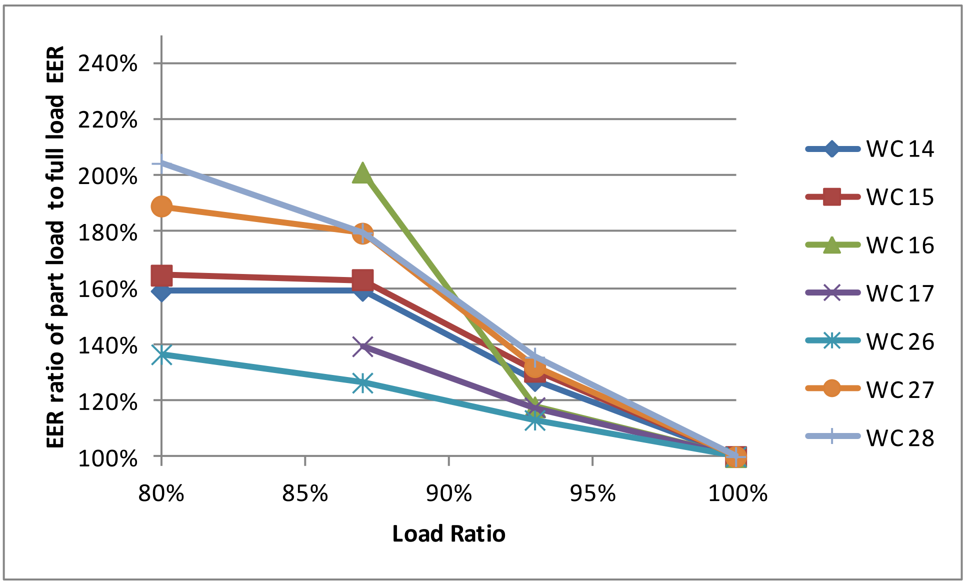
3.4.3 Water-cooled chillers >1000 kW

Table 10. Design characteristics and performance of WC chillers above 1000 kW

	Part load	Net cap kW	EER net	ESEER	SEPR	SEPR / EER	fluid	Evap	Cond	Comp	*range min cap (kW)*	*range max cap (kW)*
WC 20	Var Cap	1000	6	5,9	8	133%	R134a	Flooded S&T	Flooded S&T	Centrifugal	1000	3000
WC 21	Var Cap	1000	6	7,1	11	183%	R134a	Flooded S&T	Flooded S&T	Centrifugal, VFD	1000	3000
WC 14	Var Cap	1060	5,2	6,34	7,04	135%	R134a	Flooded S&T	Flooded S&T	Screw	252	1762
WC 30	Var Cap	1066	5,1		11,8	231%	NH3	Plate	Plate	Recip VFD	200	1350
WC 25	Var Cap	1000	4,5		8	178%	NH3	Flood. Plate	Plate	Screw VFD Eco	200	3000
WC 15	Var Cap	1460	5,38	7,3	7,08	132%	R134a	Flooded S&T	Flooded S&T	Screw VFD	580	1710
WC 16	Var Cap	1580	4,28	5,26			R410A	DX S&T	DX S&T	Screw	379	2156
WC 26	Var Cap	1583	5,03		6,44	128%	R134a	Flooded S&T	Flooded S&T	Centrifugal		
WC 27	Var Cap	1583	5,25		9,1	173%	R134a	Flooded S&T	Flooded S&T	Cent VFD		
WC 28	Var Cap	1583	5,64		10,1	179%	R134a	Flooded S&T	Flooded S&T	Tri screw VFD		
WC 17	Var Cap	1595	4,88	4,76			R410A	DX S&T	DX S&T	Screw	379	2156

Figure 10. EER at the different SEPR points, WC chillers above 1000 kW, Absolute and relative to standard full load EER values





Note : WC chiller 16 data point at 16 °C water temperature inlet and 87 % load is probably a mistake. The evolution should probably follow the same trend as for chiller 17 as both chillers 16 and 17 are from the same product range with simply different capacities and nominal EER.

SEPR to EER ratio are as follows :

- Between 128 % (with relatively high pressure losses at condenser and evaporator) and 135 % for the non VFD centrifugal chillers ;
- 135 % for the standard HFC screw chiller and 132 % for the VFD HFC screw chiller, clearly impacted by the high pressure condensation limit at 80 % load and 9 °C water temperature inlet,
- Between 173 % (with relatively high pressure losses at condenser and evporator) and 183 % for the VFD centrifugal chillers ;
- 178 % for the ammonia VFD screw chiller ;
- 179 % for the tri-screw VFD chiller (with relatively high pressure losses at condenser and evaporator),
- And about 230 % for the ammonia chiller with VFD reciprocating compressor.

3.4.4 SEPR average and upper values

Median EER value for water cooled chillers is 4.5 (Eurovent 2013 data), based upon categories kept in the analysis (as explained at § 2.2.1). This varies depending on the capacity as shown in the table below. Higher capacity chillers may be equipped with flooded heat exchangers, which increases significantly the EER in standard rating conditions. Although large screw and centrifugal compressors tend to be more efficient than scroll compressors and low size screw compressors at standard rating conditions. The mediane EER thus varies from 4.3 to 4.9, while the maximum EER in the eurovent directory waries from 5 to 6.1. Probably, the large size maximum EER could be higher (probably up to 6.3 based on Lot 6 findings) but all product ranges are not in the Eurovent database as the certify-all obligation is limited to range ending below 1500 kW. Above 1500 kW, chillers offer many design options, and are built on demand. Performances can be computed with selection softwares but all combinations cannot be published.

Table 11. Median EER values by caapcity range for water cooled chillers (Eurovent 2013 data)

	All	<100	100-400	< 400	400-1000	> 1000
Median EER	4,51	4,29	4,41	4,37	4,82	4,92
Max EER	6,09	4,95	5,61	5,61	5,94	6,09

This information can be combined with the analysis of SEPR / EER ratio variations with different technologies. This is of course a simplified approach, but alreay gives a good idea of potential SEPR values for different technologies and of the extension of SEPR values between mediane and higher values.

The results are shown in the table below.

Table 12. Estimates of average and high SEPR values by product category

WC < 400 kW						
	EER med	EER max	SEPR / EER ave	SEPR / EER high	SEPR med	SEPR high
On-off scroll	4,3	4,95	132%		5,68	6,53
On-off scroll / extended HP range	4,3	4,95	152%	158%	6,81	7,84
Capacity stage or VFD scroll / rotary	4,3	4,95	142%		6,11	7,03
VFD scroll / extended HP range	4,3	4,95	170%		7,33	8,43
Cap stage or var cap screw	4,4	5,6	130%	160%	5,72	8,96
Ammonia screw chiller	3,8	4,4	150%	165%	5,70	7,26
Ammonia screw chiller with VFD	3,4	4,5	210%	180%	7,14	8,10
Ammonia reciprocating VFD	4,9	5,1	240%	230%	11,73	11,76
Centrifugal VFD (MB)	4,4	5,6	180%	200%	7,92	11,20
WC > 400 kW and < 1000 kW						
	EER med	EER max	SEPR / EER ave	SEPR / EER high	SEPR med	SEPR high
Capacity stage or VFD scroll / rotary	4,3	4,95	142%		6,11	7,03
VFD scroll / extended HP range	4,3	4,95	170%		7,31	8,41
Cap stage or var cap screw	4,8	5,6	130%	160%	6,24	8,96
Screw VFD	4,8	5,6	160%	135%	7,68	8,96
Ammonia screw chiller	3,8	4,4	150%	165%	5,70	7,26
Ammonia screw chiller with VFD	3,4	4,5	210%	180%	7,14	8,10
Ammonia reciprocating VFD	4,9	5,1	240%	230%	11,73	11,76
Centrifugal VFD (MB)	4,8	6	180%	200%	8,64	12,00
WC > 1000 kW						
	EER med	EER max	SEPR / EER ave	SEPR / EER high	SEPR med	SEPR high
Capacity stage or VFD scroll / rotary	4,3	4,95	142%		6,11	7,03
VFD scroll / extended HP range	4,3	4,95	170%		7,31	8,41
Cap stage or var cap screw	4,92	5,6	130%	160%	6,40	8,96
Screw VFD	4,92	6,1	160%	135%	7,87	9
Ammonia screw chiller	3,8	4,4	150%	165%	5,70	7,26
Ammonia screw chiller with VFD	3,4	4,5	210%	180%	7,14	8,10
Ammonia reciprocating VFD	4,9	5,1	240%	230%	11,73	11,76
Centrifugal	5	6,3	115%	130%	5,75	8,19
Centrifugal VFD (incl. MB) and Tri-screw	5	6,3	180%	200%	9,00	12,60

Regarding ammonia chillers, only two manufacturers supplied data. As a consequence, it is dfficult to evaluate the EER range variation. On the other hand, this is probably relatively limited as flooded shell and tube heat exchangers are not used and given the comparatively lower performance of NH_3 at high condensing temperature.

Scroll HFC chillers presently extend to higher capacity ranges, with very few models and sales above 1000 kW. These are low cost options and that is the reason why the EER has been limited, both for the mediane and maximum values.

Regarding HFC screw chillers without VFD, the best products are rated just below 8 with EER between 5.1 and 5.4. The upper SEPR value is limited to a value between 8.5 and 9 because high EER chillers would be handicaped with the high pressure condensing limits more than less efficient chillers. The same occurs with VFD screw chillers.

The data set enables to identify possible benchmarks, with the meaning here of best available technologies not yet applied into products. We assume here that it would correspond to present technologies with associated SEPR / EER ratios, and best EER by product range. This leads to the following range of values :

- 0 – 200 kW : 8.5
- 200 – 400 kW : 12
- 400 – 1000 kW : 12.5
- > 1000 kW : 13

4 Discussion of possible MEPS levels

MEPS levels are proposed in two tiers with the ambition level to remove 33 % and 66 % of the products on the market. As discussed before, the database used to underpin this is not fully representative. Consequently, the available technologies and their impact on performance levels is also used to help judge the most appropriate MEPS levels.

Note also that a limited number of chillers is supplied while manufacturers may have many design options, noticeably on the heat exchanger design, to improve the performance. For categories above 400 kW and even more above 1000 kW, variations up to 5 - 10 % may occur depending on these design choices.

4.1 Air cooled chillers

Additional capacity threshold at 100 kW ?

Manufacturers plan to add a category below 100 kW for air cooled chillers in the frame of Lot 6. The reason behind is that this capacity range is reserved to scroll HFC chillers (screw chillers only begin between 100 and 200 kW, with no ammonia chillers either on this capacity range) and that scroll compressors have lower performances than screw (under standard rating conditions).

It can be seen however, that SEPR values for on-off units are comparable to the ones of chillers with several capacity steps. In that direction, probably the same values can be applied below 100 kW and above 100 kW, so that one single 0 to 400 kW range may be conserved for the SEPR metrics.

In addition, double stage VFD rotary compressors could enter the competition ; they have better full load and part load performances and have little limitations regarding condensation pressure at low outdoor temperature. In addition, some of the available scroll compressor operating range could be extended in order to improve the performances at low outdoor temperature, making the scroll compressors competitive with screw. So, **the 100 kW limit does not seem necesssary**.

However, as mentioned in the ENTR Lot 6 preparatory study, flooded evaporators begin above 200 to 300 kW, as well as VFD centrifugal chillers (with magnetic bearings) and this makes an important difference in terms of potential and of benchmark. Consequently, a possible benchmark capacity threshold would rather be 200 kW than 400 kW. The same issue in Lot 6 led to **propose different minimum requirements below and above 400 kW, and different benchmark levels below and above 200 kW**. **The same approach is proposed here.**

MEPS design below 400 kW

The table below shows the impact a MEPS level would have on the limited of chillers in our data set, with and without accounting for SEPR values below 4.2.

Table 13. Percentage of chillers passing MEPS thresholds, AC chillers below 400 kW (passing if one)

MEPS threshold	**4,2**	**4,3**	**4,4**	**4,5**	**4,6**	**4,7**	**4,8**	**4,9**	**5**	**5,1**
AC 1	1	1	1	1	1	1	1	1	-	-
AC 2	1	1	1	1	1	1	-	-	-	-
AC 3	-	-	-	-	-	-	-	-	-	-
AC 4	1	1	1	1	1	-	-	-	-	-
AC 5	1	1	-	-	-	-	-	-	-	-
AC 6	1	-	-	-	-	-	-	-	-	-
AC 20	1	1	1	1	1	1	1	1	1	1
AC 7	-	-	-	-	-	-	-	-	-	-
AC 8	1	1	1	1	1	1	1	1	1	-
AC 21	1	1	1	1	1	-	-	-	-	-
PASSING	80%	70%	60%	60%	60%	40%	30%	30%	20%	13%

Based on ambition levels to remove 1/3 and 2/3 of the market, minimum MEPS requirements should be about at least 4.3 for tier 1 and 4.8 for tier 2.

This is not of very high ambition ; for instance the on-off scroll unit is still passing at SEPR equal to 4.9 thanks to a lower limit for condensation pressure at low outdoor temperature and a two speed fan. Besides, available technologies even below 100 kW can help to achieve SEPR values above 6.5.

Hence it is proposed to raise tier 1 up to 4.5 and tier 2 up to 5.

MEPS design above 400 kW

Almost all SEPR values are above 5 in the sent data with maximum SEPR value of 6.31. They correspond to unloading screw chillers with DX or flooded shell and tube evaporators.

Based on ambition levels to remove 1/3 and 2/3 of the market, minimum MEPS requirements should be about at least 5.2 for tier 1 and 5.4 for tier 2.

Data supplied comprises one VFD centrifugal chiller with magnetic bearings but with disappointing low temperature and low load behavior. If it had been of standard behavior, MEPS threshold of 5.5 would have been 33 %. As the manufacturer is probably able to improve the SEPR just by adapting the control of the unit to SEPR conditions, it seems reasonable to have a tier 2 at 5.5, while the tier 1 should be between 5 and 5.2.

Table 14. Percentage of chillers passing MEPS thresholds, AC chillers above 400 kW

MEPS threshold	5	5,1	5,2	5,3	5,4	5,5	5,6	5,7	5,8	5,9	6
AC 9	-	-	-	-	-	-	-	-	-	-	-
AC 10	1	1	-	-	-	-	-	-	-	-	-
AC 11	1	1	1	1	1	1	1	1	1	1	-
AC 12	1	1	1	1	-	-	-	-	-	-	-
AC 13	-	-	-	-	-	-	-	-	-	-	-
AC 14	1	1	1	1	1	-	-	-	-	-	-
AC 15	-	-	-	-	-	-	-	-	-	-	-
AC 16	1	1	1	-	-	-	-	-	-	-	-
AC 22	1	1	-	-	-	-	-	-	-	-	-
AC 17	1	1	1	1	-	-	-	-	-	-	-
AC 18	1	1	1	1	1	1	-	-	-	-	-
AC 19	1	1	1	1	1	1	1	1	1	1	1
PASSING	75%	75%	58%	50%	33%	25%	17%	17%	17%	17%	8%

4.2 Water cooled chillers

Additional capacity threshold above 1000 kW ?

Above 1000 kW, it is common to find very efficient centrifugal chillers with VFD, while it is still rare below 1000 kW, mainly dominated by screw chillers. Having a threshold at 1000 kW enables to increase the MEPS levels higher than if a single category above 400 kW was kept. **So, the supplementary threshold of 1000 kW is adopted hereafter.**

MEPS design below 400 kW

Based on ambition levels to remove 1/3 and 2/3 of the market, minimum MEPS requirements should be about 6.5 for tier 1 and 7.0 to 7.2 for tier 2.

Table 15. Percentage of chillers passing MEPS thresholds, WC chillers below 400 kW

MEPS threshold	6,0	6,2	6,4	6,6	6,8	7,0	7,2	7,4	7,6	7,8
WC 1	1	-	-	-	-	-	-	-	-	-
WC 2	1	1	1	1	-	-	-	-	-	-
WC 3	1	1	-	-	-	-	-	-	-	-
WC 31	1	1	1	1	1	1	-	-	-	-
WC 24	1	1	1	1	1	1	1	1	1	1
WC 4	1	1	1	1	1	1	1	1	1	-
WC 5	-	-	-	-	-	-	-	-	-	-
WC 18	1	1	1	1	-	-	-	-	-	-
PASSING	88%	75%	63%	63%	38%	38%	25%	25%	25%	13%

MEPS design between 400 kW and 1000 kW

Based on ambition levels to remove 1/3 and 2/3 of the market, minimum MEPS requirements should be about 7.5 for tier 1 and 8.0 to 8.5 for tier 2. Regarding tier 2, SEPR 7 is the value of standard screw chillers with one compressor and flooded evaporator. SEPR 8 is the level of best screw chillers, with both heat exchangers flooded and or VFD screw compressor. It is proposed to keep 8 for tier 2 as it keeps the competition open to optimized standard screw design and to VFD.

Table 16. Percentage of chillers passing MEPS thresholds, WC chillers between 400 kW and 1000 kW

MEPS threshold	**6,0**	**6,3**	**6,6**	**6,9**	**7,2**	**7,5**	**7,8**	**8,1**	**8,4**	**8,7**	**9,0**	**9,3**
WC 6	1	1	1	-	-	-	-	-	-	-	-	-
WC 7	1	1	1	1	1	1	1	-	-	-	-	-
WC 29	1	1	1	1	1	1	1	1	1	1	1	1
WC 22	1	1	1	1	1	1	1	1	1	1	1	1
WC 19	1	1	1	1	1	1	1	1	1	1	1	-
WC 23	1	1	1	1	1	1	1	-	-	-	-	-
WC 10	1	1	1	1	1	1	1	-	-	-	-	-
WC 11	1	1	-	-	-	-	-	-	-	-	-	-
WC 12	1	1	1	1	-	-	-	-	-	-	-	-
PASSING	100%	100%	89%	78%	67%	67%	67%	33%	33%	33%	33%	22%

MEPS design above 1000 kW

Based on ambition levels to remove 1/3 and 2/3 of the market, minimum MEPS requirements should be between 7.2 to 8.0 for tier 1 and 9.0 to 10.0 for tier 2.

Regarding tier 1, in this capacity range, 8 is certainly a minimum, letting most efficient screw and VFD screw on the market.

Typical centrifugal VFD are rated around 9 while VFD centrifugal with magnetic bearings, variable tri-screw chillers and VFD reciprocating ammonia chillers may reach higher than 10 SEPR values. In order to keep centrifugal VFD chillers on the market, it is necessary to limit the ambition of SEPR between 9 and 9.5. So it is proposed to keep 9.

Table 17. Percentage of chillers passing MEPS thresholds, WC chillers above 1000 kW

MEPS threshold	**6,0**	**6,4**	**6,8**	**7,2**	**7,6**	**8,0**	**8,4**	**8,8**	**9,2**	**9,6**	**10,0**	**10,4**
WC 20	1	1	1	1	1	1	-	-	-	-	-	-
WC 21	1	1	1	1	1	1	1	1	1	1	1	1
WC 14	1	1	1	-	-	-	-	-	-	-	-	-
WC 30	1	1	1	1	1	1	1	1	1	1	1	1
WC 25	1	1	1	1	1	1	-	-	-	-	-	-
WC 15	1	1	1	-	-	-	-	-	-	-	-	-
WC 26	1	1	-	-	-	-	-	-	-	-	-	-
WC 27	1	1	1	1	1	1	1	1	-	-	-	-
WC 28	1	1	1	1	1	1	1	1	1	1	1	-
PASSING	100%	100%	89%	67%	67%	67%	44%	44%	33%	33%	33%	22%

4.3 Synthesis : proposed MEPS and benchmarks

MEPS levels

Table 18. Proposed MEPS levels

	Tier 1	Tier 2
Water cooled < 400 kW	6,5	7
Water cooled > 400 kW & < 1000 kW	7.5	8
Water cooled > 1000 kW	8	9
Air cooled < 400 kW	4,5	5
Air cooled above 400 kW	5	5,5

Benchmarks

Air cooled chillers

- 0 – 200 kW : 6.5
- 200 – 400 kW : 8
- > 400 kW : 8

Water cooled chillers

- 0 – 200 kW : 8.5
- 200 – 400 kW : 12
- 400 – 1000 kW : 12.5
- > 1000 kW : 13

As mentioned before, given the very high numbers of equivalent full load hours, benchmarks are already profitable for the SEPR profile. Nevertheless, only a few manufacturers produce these very high performance units. So it is likely that more than 10 years would be necessary so that the market average may reach these benchmark high efficiency levels.

Annex 1 : Tolerances

Tolerances on the SEPR value should be of maximum 6 % versus 10 % presently.

The necessary tolerances for rating chillers mainly come from the uncertainty on the water temperature difference to measure the cooling capacity at the evaporator. As the temperature difference between inlet and outlet is 5 °C and the measurement uncertainty is close to 0.1 °C, this gives about 2.5 % uncertainty for the water temperature measurement only.

When load is reduced, the average temperature difference at the evaporator falls, and the uncertainty increases as 2.5 % / (load ratio). The load ratios vary depending on the four testing points for the SEPR metrics :

- A : 100 % load, condenser inlet air/water 35 °C / 30 °C
- B : 93 % load, condenser inlet air/water 25 °C / 23 °C
- C : 87 % load, condenser inlet air/water 15 °C / 16 °C
- D : 80 % load, condenser inlet air/water 5 °C / 9 °C

Thus, the maximum measurement uncertainty on the cooling capacity is reached for testing point D, with a value of :

2.5 / 0.8 = 3.125 %

In order to estimate the total measurement uncertainty on the COP / SEPR value, the composed uncertainties of the measurement chain and of the electric power (1 % of the measured electric power) need to be added.

The following formula models the uncertainty of measurement level versus load with a reasonable level (accessible to most specialized testing laboratories in Europe, ie for Eurovent certification) :

Unc (%) = 2 + (3 / load ratio (%))

This leads to values of about 7.5 % for SEER conditions (the load ratio decreases down to 25 %). In the US (AHRI 550/590 chiller standard), the tolerance allowed to measure the IPLV is a bit larger and leads to values above 8 %.

However, in the case of the SEPR, the load ratio only decreases down to 80 %. The yearly average part load ratio is 85 %.

Using the above formula, this leads to a maximum uncertainty level of 5.5 %.

This can be used as a maximum tolerance level, rounded to 6 %. The working document figure of 10% is not justifiable because the above analysis shows that current equipment and test methods will reliably achieve repeatabilities far better than 10% and down to 6 %

As a conclusion it is proposed to modify the tolerance table of the impact assessment document(*) as follows :

(*) Working document on possible Commission Regulations, implementing Directive 2009/125/EC with regard to professional refrigeration products, Brussels, 09.12.2011, PART 4 – REFRIGERATION PROCESS CHILLERSImpact Assessment Final Report: Industrial Process Chillers

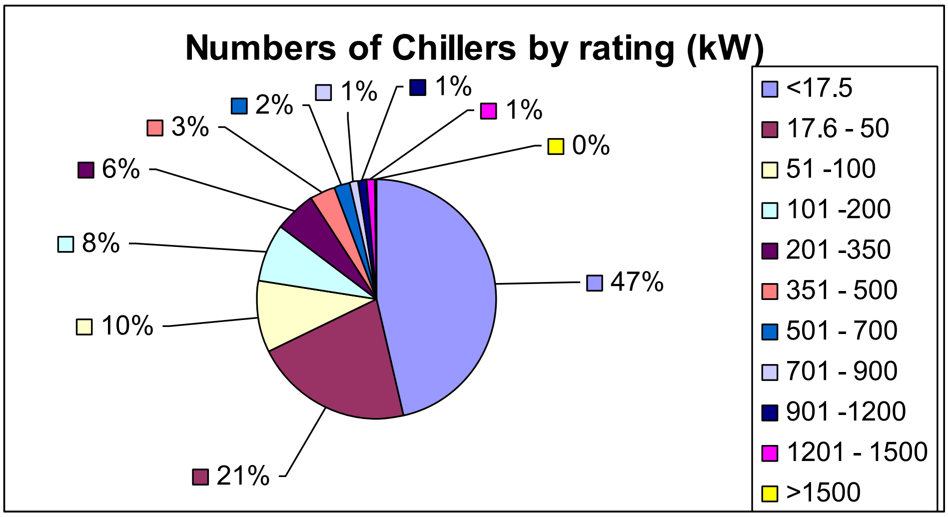
Annex IV, Table 1

Measured parameter	Verification tolerances
COP value (full load, +35°c ambient)	The measured value shall not be lower than the declared value by more than 10 % It shall not be lower than the minimum COP allowed in Annex 1 by 5% (was 10%) (Option 1)
Cooling capacity (full load, +35°c ambient)	The measured value shall not be lower than the declared value by more than 5% (was 10%)
Power input (full load, +35°c ambient)	The measured value shall not be greater than the declared value by more than 5 %
SEPR value	The measured value of SEPR at the declared capacity shall not be lower than the declared value by more than 6 % (was 10%) It shall not be lower than the minimum SEPR allowed in Annex 1 by 6 % (was 10%) (Option 2)
Cooling capacity at reference points A, B, C, D	The measured value shall not be lower than the declared value by more than 5 % (was 10%)
Power input at reference points A, B, C, D	The measured value shall not be greater than the declared value by more than 5 % (was 10%)

Annex 2 : Air conditioning chiller sales, extract from ENTR Lot 6 preparatory study (AC report, Task 2 report, pp 25-26)

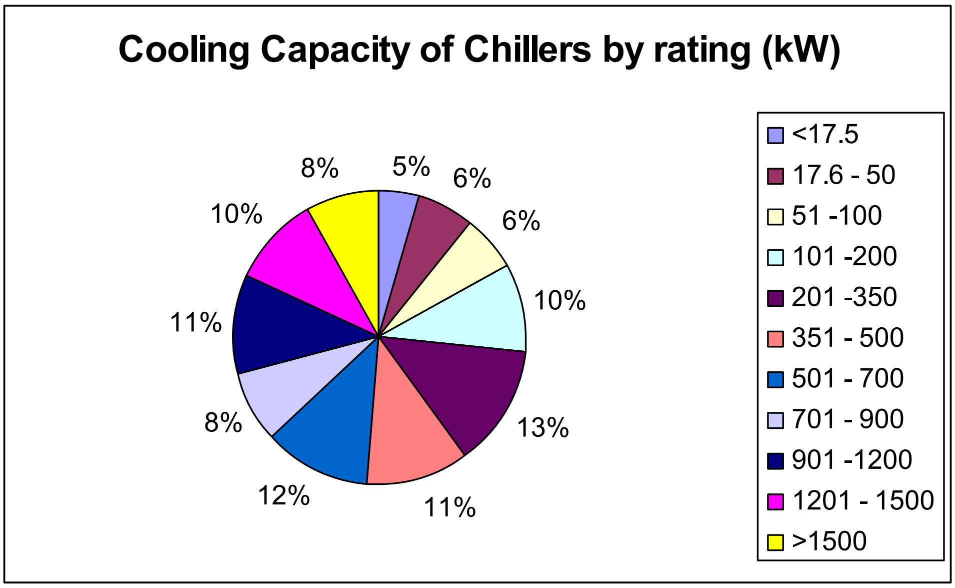
Distribution of sales by rated cooling capacity

Numbers of chillers by rated cooling capacity



Two-thirds of chillers are smaller than 50kW cooling capacity and 47% are smaller than 17.5kW.

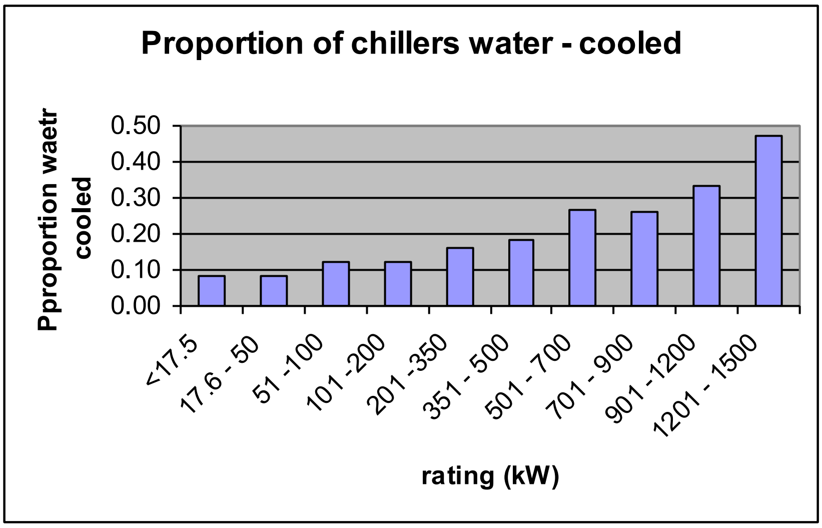
Cooling capacity of chillers by rating



In terms of the functional unit – kW of cooling capacity – the market is very evenly split between different ranges of capacity. No single range accounts for more than 13% of sales and the range that dominates numbers of sales (<17.5 kW) accounts for only 5% of total capacity.

Chiller heat rejection method

Proportion (kW cooling) of chillers that are water cooled



Overall, 23% of chillers are water cooled, but the proportion increases with the size of chiller.

Annex 3 : Accounting for the source pump/fan energy of water cooled chillers

In the present proposal, the SEPR for water cooled chillers only encompass the part of the source pump corresponding to the condenser pressure loss. In ENER Lot 1, a 5 % value is used to account for the source pump energy consumption not covered in the SCOP net value.

This 5 % has been computed for a heating profile where the average load ratio is 42 % (Strasbourg climate, sizing - 10°C) versus 85 % for HT process chillers. So the 5 % should be more or less divided by 2. Nevertheless, SCOP values of heat pumps are about 3 to 4 while SEPR values are rather between 5 and 10 so it makes sense to keep the 5 % for HT process chillers.

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