Review of Regulation 206/2012 and 626/2011

Air conditioners and comfort fans

Task 4 report

Technologies

Final version

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Abbreviations

AC	Alternating current
BAT	Best Available Technology
BAU	Business as Usual
BC	Base case
BLc	Annual cooling load per square meter of room area (kWh/m2/year/)
BNAT	Best Not Yet Available Technology
BOM	Bill-of-Materials
COP	Coefficient of Performance for air conditioners in heating mode
DC	Direct current
DTLM	The logarithmic mean temperature difference between air and refrigerant
EER	Energy Efficiency Ratio for air conditioners in cooling mode
Eq	Equivalents
GWP	Global warming potential
HFO	Hydrofluro-Olefins (refrigerant)
LLCC	Least Life Cycle Costs
ODP	Ozone Depleting Potential
PCK	The electricity consumption during crankcase heater mode for air conditioners
POFF	The electricity consumption during off mode.
PSB	The electricity consumption during standby mode for air conditioners
PTO	The electricity consumption during thermostat off mode for air conditioners
Sc	Sizing coefficient for cooling
SCOP	Seasonal Coefficient of Performance for air conditioners, heating mode
SEER	Seasonal Energy Efficiency Ratio for air conditioners, cooling mode
SHR	Sensible Heat Ratio for air conditioners
UA	The global heat transfer coefficient multiplied by total heat exchange area
VRF	Variable Refrigerant Flow

Introduction to the task reports

This is the introduction to the interim report of the preparatory study on the Review of Regulation 206/2012 and 626/2011 for air conditioners and comfort fans. The interim report has been split into five tasks, following the structure of the MEErP methodology. Each task report has been uploaded individually in the project's website. These task reports present the technical basis to define future ecodesign and energy labelling requirements based on the existing Regulation (EU) 206/2012 and 626/2011.

The task reports start with the definition of the scope for this review study (i.e. task 1), which assesses the current scope of the existing regulation in light of recent developments with relevant legislation, standardisation and voluntary agreements in the EU and abroad. Furthermore, assessing the possibility of merging implementing measures that cover the similar groups of products or extend the scope to include new product groups. The assessment results in a refined scope for this review study.

Following it is task 2, which updates the annual sales and stock of the products in scope according to recent and future market trends and estimates future stocks. Furthermore, it provides an update on the current development of low-GWP alternatives and sound pressure level.

Next task is task 3, which presents a detailed overview of use patterns of products in scope according to consumer use and technological developments. It also provides an analysis of other aspects that affect the energy consumption during the use of these products, such as component technologies. Furthermore, it also touches on aspects that are important for material and resource efficiency such as repair and maintenance, and it gives an overview of what happens to these products at their end of life.

Task 4 presents an analysis of current average technologies at product and component level, and it identifies the Best Available Technologies both at product and component level. An overview of the technical specifications as well as their overall energy consumption is provided when data is available. Finally, the chapter discusses possible design options to improve the resource efficiency.

Simplified tasks 5 & 6 report presents the base cases, which will be later used to define the current and future impact of the current air condition regulation if no action is taken. The report shows the base cases energy consumption at product category level and their life cycle costs. It also provides a high-level overview of the life cycle global warming potential of air conditioners and comfort fans giving an idea of the contribution of each life cycle stage to the overall environmental impact. Finally, it presents some identified design options which will be used to define reviewed ecodesign and energy labelling requirements.

Task 7 report presents the policy options for an amended ecodesign regulation on air conditioners and comfort fans. The options have been developed based on the work throughout this review study, dialogue with stakeholders and with the European Commission. The report presents an overview of the barriers and opportunities for the reviewed energy efficiency policy options, and the rationale for the new material/refrigerant efficiency policy options. This report will be the basis to calculate the estimated energy and material savings potentials by implementing these policy options, in comparison to no action (i.e. Business as Usual – BAU).

The task reports follow the MEErP methodology, with some adaptations which suit the study goals.

4 Introduction to Task 4

Task 4 follows the MEErP methodology and entails a general technical analysis of current products on the EU market and provides general inputs for the definition of the Base cases (task 5) as well as the identification of part of the improvement potential (task 7), i.e. the part that relates to the best existing product on the market. It includes the following sections:

- Technical product description
- Technology roadmap
- Production and distribution
- End-Of-Life
- Conclusions and recommendations

4.1 Technical product description

4.1.1 Existing products

This section of the task assesses the general and technical parameters of existing products to represent 2 different product segments, portable air conditioners and fixed air conditioners: product types that could be used for base cases, capacities (section 4.1.1.1), SEER and SCOP efficiency levels (section 4.1.1.2) as well as parameters required to compute these values (sections 4.1.1.3 and 4.1.1.4), refrigerant charge information (section 4.1.1.5), sound power (section 4.1.1.6) and prices (section 4.1.1.7) are also presented.

As in the Preparatory study, the determination of existing products technical characteristics for split air conditioners is based on Eurovent Certita Certification (ECC[1]) information. More information was made available to the study team for this review study; the analysis builds upon three databases from ECC, the public ECC directory with main technical and seasonal metrics information, the database with all input to SEER and SCOP calculations, and a more detailed technical database with a limited number of anonymous ECC manufacturers) and results of information request directly sent to manufacturer under this revision study. The two complete databases from ECC are used as often as possible to ensure a better statistical representativeness.

Note also that following received comments from stakeholders, the initial figures identified based on the ECC information were corrected: this repertory of certified products does not contain information on the number of sales but only information on models declared. So, the statistics presented in sections 4.1.1.1 to 4.1.1.7 and in 4.1.1.8 (the synthesis of standard product characteristics) are model weighted, i.e. based on the number of available models rather than the sales that account certain models are sold more frequently than others. Stakeholders provided information enabling to correct main performance parameters (SEER and SCOP) to fit sales weighted values. This led to the final correct standard product characteristics in an additional 4.1.1.9 part.

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[1] http://www.eurovent-certification.com/. ECC is a certification company and includes a certification program for less than 12 kW air conditioners. ECC is the only public source in Europe to find technical information on a large number of products. The less than 12 kW certification program gathers 22 manufacturers, including all major brands; all their products have to be certified (this represented about 2200 models as per November 2016); representativeness is believed to be high: about 80 % of products sold in Europe according to the Preparatory study.

To select performance parameters as close as possible to real units, which helps ensuring data used are compatible, only the first two (complete) ECC databases are filtered to capacities close to the average products for split air conditioners.

4.1.1.1 Indoor unit type and cooling capacities

Regarding split air conditioners, the sales / stock model was based upon available capacity data and consequently built on the 0-5 kW and 5-12 kW capacity intervals. For these intervals, the average product was assumed to be of 3.5 and 7.5 kW.

As the (EU) Regulation 206/2012 capacity categories are 0-6 kW and 6-12 kW, it is necessary to adapt the global figures of sales of products by class, so the bottom-up approach of Task 5 may be based upon selected base cases representative of the 0-6 and 6-12 kW capacity classes. This is done by shifting about 15 % of total sales from "> 5 kW" class to "< 5 kW" class as this gives comparable weighted average kW to BSRIA sales data. This is higher than half the sales between 5 and 7 kW but enables to correct for bias in the sales / stock model, which overestimates number of units for > 5 kW. The final picture is given in Table 1: Repartition of product per class in number and capacity below.

Table 1: Repartition of product per class in number and capacity

	Sales number in 1000 units	**Average capacity in kW**	**Total capacity installed in GW (2015)**
0-6 kW	2468	3.5	8.6
6-12 kW	959	7.5	7.2
Totals	3427	NA	15.8
Weighted average	NA	4.6	NA

The sales per type also need to be adjusted following this modification and is based on BSRIA data. This is done in Table 2 below.

Table 2: Repartition of product per type on the 0-6 and 6-12 kW capacity ranges, adaptation from BSRIA data

	Single split					**Multi Split**	**TOTAL**
	Wall	**Ceiling type**	**Floor/vertical or consoles**	**Cassette**	**Ducted**	**All (mainly wall)**	
0-6 kW	72%	2%	2%	3%	4%	18%	100%
6-12 kW	32%	6%	1%	25%	19%	16%	100%

It appears that single split largely dominates the 0-6 kW range, with about 70 % of the sales by number, followed by multi split (whose indoor units are mainly wall units too), while other categories have much lower sales. For the 0-6 kW range, the average existing product will be a single split wall unit.

However, in the 6-12 kW range the repartition is more even between wall, cassette and ducted single split and multi split, even if single split wall units are more frequent. Thus, it is necessary to account properly for the differences in prices and efficiencies of these products in the LCC analysis. It has been seen however in Task 2 that despite having slightly lower maximum SEER values, single split wall units have lower added cost for improved efficiency. It is then likely that they have the highest SEER at LLCC point and, so it is required to keep these as the base case in order to estimate the improvement potential.

Regarding the average capacities, BSRIA data indicate weighted average capacities of 3.8 kW over the 0-6 kW range and of 7.8 kW over the 0-12 kW range. For smaller units, the most common type according to analysis of Eurovent directory is clearly the 3.5 kW model, which is kept as the reference value (it is also the median capacity of the capacity distribution in Figure 1). Regarding the 0-12 kW range, the most common products are 6.8, 7.1 and 10 kW. The 7.1 kW unit is the closest to the weighted average value; it is also close to the median capacity of all split models in the 6-12 kW range (Figure 2).

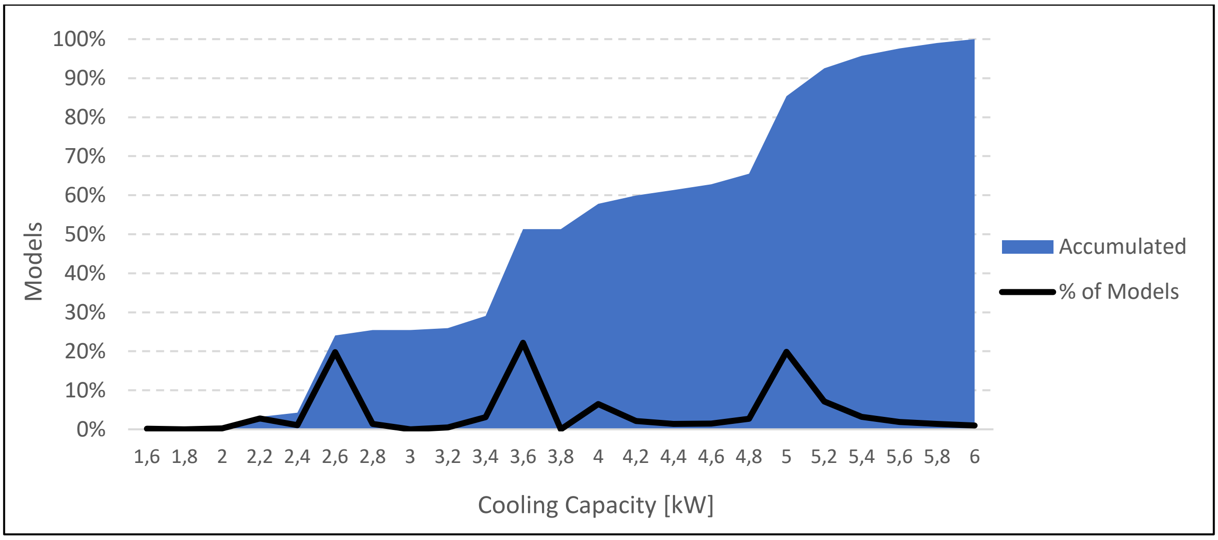

Figure 1: Distribution of models per size in the 0-6 kW range, adapted from ECC directory[2]

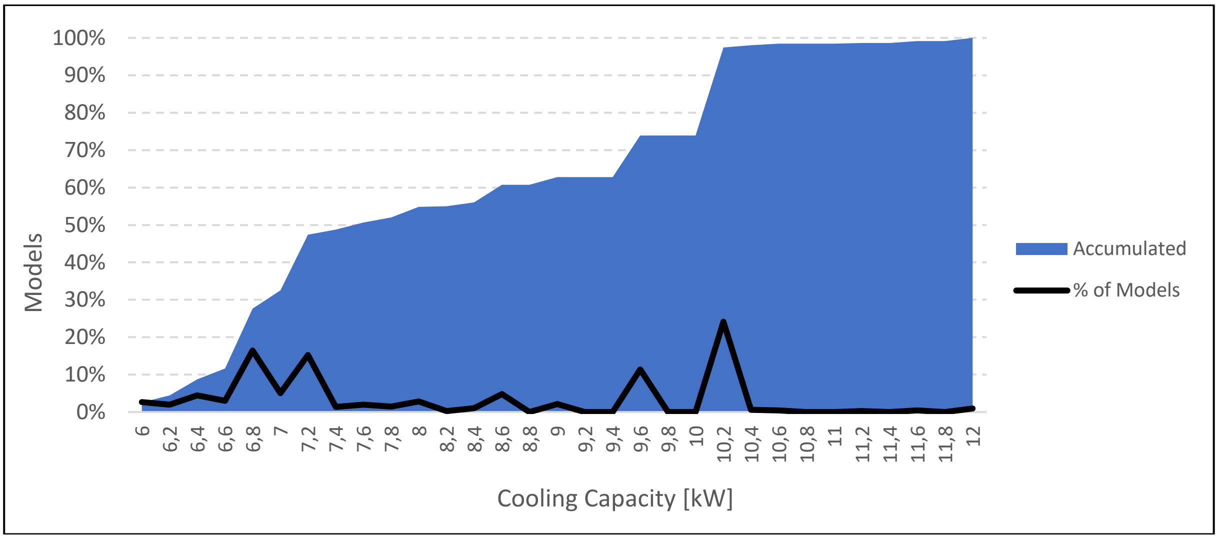

Figure 2: Distribution of models per size in the 6-12 kW range, adapted from ECC directory

Regarding portable air conditioners, average product has been defined in Task 2. The exact market share of double duct products is not known; however it is believed to be small. Hence a single duct product is considered for a base case. Single duct products are usually not reversible, but if they are, around 5 % use electric heating and 10 % thermodynamic heating. The average cooling capacity is 2.6 kW.

4.1.1.2 SEER, SCOP, EER, COP

GfK data (which are sales weighted data) indicate average efficiency figures as follows: SEER=5.7 (A+) and SCOP=4.0 (A+). Nevertheless, there is no product technical

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[2] http://www.eurovent-certification.com

characteristics or input for energy performance calculation corresponding to GfK SEER 5.7 and SCOP 4.0 weighted average values, and so the ECC directory was used for finding average product technical characteristics and also to inform on possible parameter distribution.

Table 3 and Table 4 below give the distributions of SEER and SCOP for 0-6 kW and 6-12 kW cooling product ranges in ECC directory (W: high wall; S: ceiling suspended; L: floor mounted; C: cassette; D: ducted) It should be noted that SEER and SCOP of ducted units should increase with the change in EN14511-3:2018 standard for fan power correction (see Task 1, part 1.2.1.1 - Standard EN14511). Stakeholders estimate this change will lead to 0.2 to 0.3 SEER value increase and between 0.1 and 0.2 SCOP value increase for standard ducted units.

Table 3: Distribution of SEER and SCOP over the 0-6 kW range, source ECC directory and own calculation

Type	Single split						Multi split	All
Mounting	All	W	S	L	C	D	All	All
No. of products	962	685	84	38	88	67	255	1217
SEER min	4.6	5.1	4.9	4.7	4.8	4.6	5.1	4.6
SEER 25%	5.8	5.9	5.2	6.1	5.7	5.2	5.7	5.8
SEER median	6.2	6.5	5.8	6.5	6.2	5.6	6.2	6.2
SEER 75%	7.0	7.2	6.1	7.0	6.4	5.7	6.6	7.0
SEER max	10.5	10.5	7.2	8.5	8.5	6.6	8.6	10.5
SEER average	6.5	6.7	5.8	6.7	6.2	5.5	6.3	6.5
Type	Single split						Multi split	All
Mounting	All	W	S	L	C	D	All	All
No. of products	962	685	84	38	88	67	255	1217
SCOP min	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
SCOP 25%	3.9	4.0	3.8	4.0	3.9	3.8	3.9	3.9
SCOP median	4.0	4.1	3.9	4.2	4.1	4.0	4.0	4.0
SCOP 75%	4.4	4.6	4.1	4.3	4.3	4.1	4.2	4.3
SCOP max	6.2	6.2	5.0	4.7	4.9	4.5	4.6	6.2
SCOP average	4.2	4.2	4.0	4.1	4.1	4.0	4.1	4.2

Table 4: Distribution of SEER and SCOP over the 6-12 kW range, adapted from ECC directory

Type	Single split						Multi-split	All
Mounting	All	W	S	L	C	D	All	All
No. of products	652	154	164	32	180	22	249	901
SEER min	4.3	4.7	4.3	4.6	4.3	5.0	4.6	4.3
SEER 25%	5.4	5.9	5.4	5.1	5.6	5.1	5.5	5.4
SEER median	5.9	6.1	5.8	5.5	6.1	5.6	5.7	5.8
SEER 75%	6.3	6.4	6.1	5.7	6.7	6.0	6.1	6.2
SEER max	7.9	7.6	7.0	6.4	7.9	6.5	8.0	8.0
SEER average	5.9	6.1	5.8	5.5	6.1	5.6	5.9	5.9
Type	Single split						Multi-split	All
Mounting	All	W	S	L	C	D	All	All
No. of products	652	154	164	32	180	22	249	901
SCOP min	3.4	3.8	3.4	3.8	3.8	3.8	3.8	3.4
SCOP 25%	3.8	3.8	3.8	3.8	4.0	3.8	3.8	3.8
SCOP median	4.0	4.0	3.9	3.9	4.1	3.9	3.9	3.9
SCOP 75%	4.1	4.0	4.1	4.0	4.3	4.0	4.1	4.1
SCOP max	4.8	4.7	4.8	4.2	4.8	4.3	4.4	4.8
SCOP average	4.0	4.0	4.0	3.9	4.1	3.9	3.9	4.0

Task 2 explained that the Gfk data under-represents large units, and it can be seen in tables above the GfK values are close to the first quartile of the SEER and SCOP distribution (SEER 5.8 in last column of table 3 versus 5.7 for GfK, and SCOP 3.9 versus 4 for GfK). This shows that product reference weighted values tend to overestimate performances (less efficient and less costly models have more sales per product reference).

For other than energy parameters, like sound power or refrigerant charge, values representative of the whole capacity range are indicated in later subsections.

However, in order to get coherent data sets to characterize existing average products, the study team has also been looking for the median characteristics (efficiency values and technical parameter) required to compute SEER and SCOP for machines whose capacity is close to the cooling capacity of the existing average products. This gives slightly different, but coherent, parameters to explain SEER and SCOP values.

The average SEER value of split units in the product capacity range 3.4-3.6 kW (Figure 3) is close to 6.2. Distributions for SEER of larger units are shown in Figure 4. The median product characteristics of products around the average existing product capacity in the ECC database are as follows:

- *Reversible 3.5 kW wall single split: SEER 6.25 (SEERon 6.9), EER 3.35, SCOP 4.1 (SCOPon 4.1; SCOPon/SCOP ratio varies between 1.001 and 1.005), COP 3.8, Pdesignh= 3.0 kW, Tbiv = -7, COP(Tbiv) 2.6, Ph(Tbiv) 2.7*
- *Reversible 7.1 kW wall single split: SEER 6.05 (SEERon 6.9), EER 3.2, SCOP 4.0 (SCOPon 4.0 with same remark as for 3.5 kW unit), COP 3.6, Pdesignh= 5.7 kW, Tbiv = -10, COP(Tbiv) 2.5, Ph(Tbiv)5.6*

Note that focusing on capacities around the average products tend to create small biases as compared to the complete ECC database although with limited impacts: slight changes in SEER and SCOP values, over the 0-6 kW range EER would rather be of 3.5 and on the 6-12 kW range T_{design} would rather be of -7 °C.

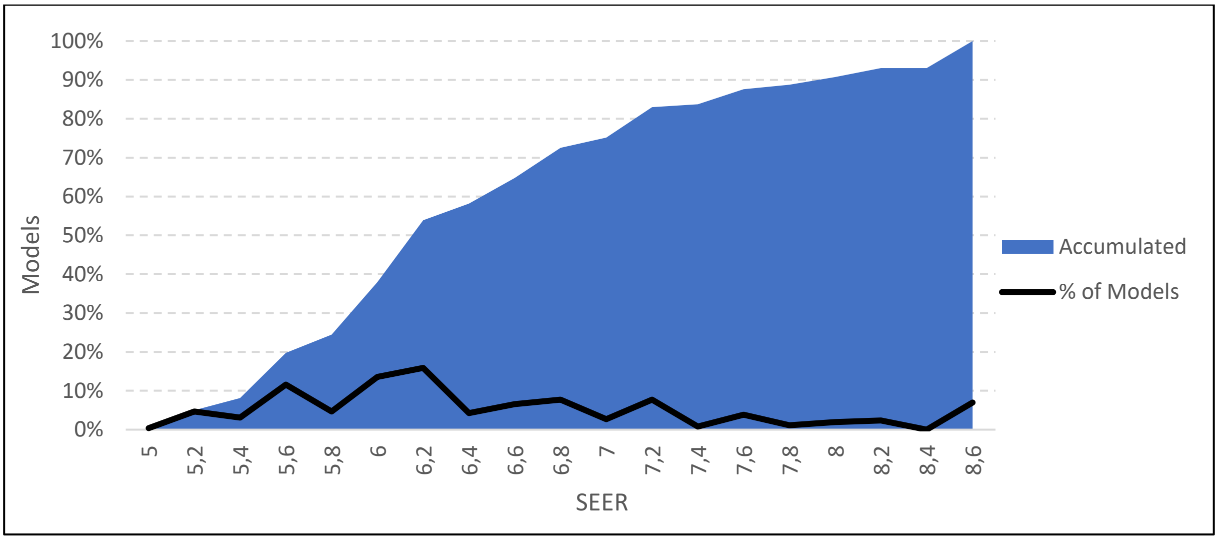

Figure 3: SEER distribution by model between 3.4 and 3.6 kW, adapted from ECC directory

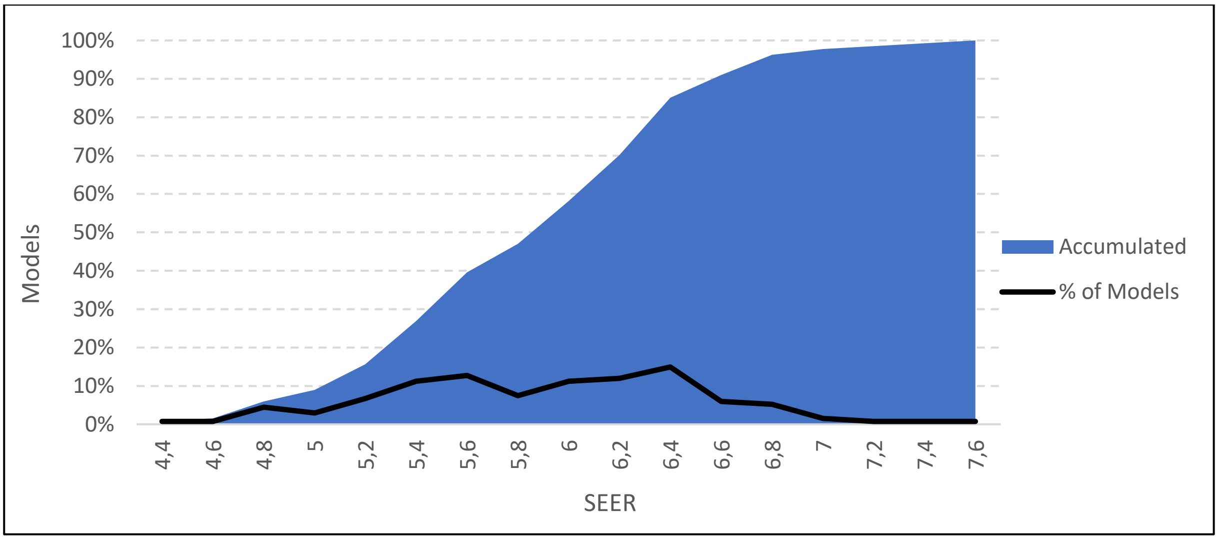

Figure 4: SEER distribution by model between 7.0 and 7.2 kW, adapted from ECC directory

Average portable EER in this review study is of EER= 2.65 (35°/35°)/ SEER= 2.09 ((against EER 2.3 kept in the preparatory study in 2006 for the base cases and an EER of 2.67 was estimated market average at the time but probably biased by faulty declarations). For reversible products, average COP is found 2.53 in this study, but no base case is proposed for reversible portable air conditioners.

4.1.1.3 Part loads

To complete the SEER and SCOP information, it is useful for modelling in Task 6 to know the parameters to compute the metrics. This includes part load EER and COP (respectively in cooling and heating mode) and auxiliary power modes. This section focuses on the EER and COP values.

Eurovent Certita Certification manufacturers supplied the declared part load performances and capacities required to compute SEER and SCOP figures. The distribution shown in Figure 5 to Figure 8 is for products with cooling capacities around the existing average product sizes of 3.5 and 7.1 kW. Note these lines (based on median and quartiles of separate distributions) do not give the performances of real units but rather indicate the general evolution of EER and COP at part load and its likely spread for best and poorest efficiency levels. However, because of the large number of units in the database, the shape of the median part load performances is close to the one of existing units and it is proposed to keep it for the base case part load values in Task 5.

In cooling mode, median part load ratio reached at 20 °C is 35 % and thus higher than the 21 % of the standard, which means cycling correction has to be applied on the 20 °C point (and EER used for SEER calculation is then lower than appears on graph). The same is true in heating mode, where this value is 36 %.

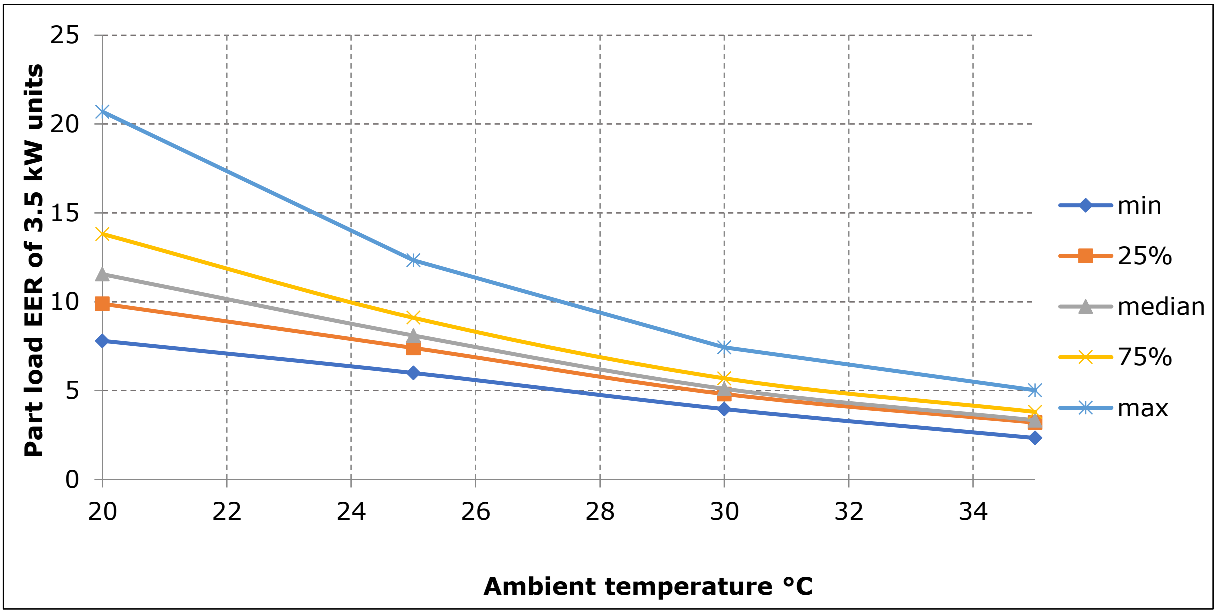

Figure 5: Part load EER of 3.5 kW units distribution in cooling mode, source Eurovent Certita Certification

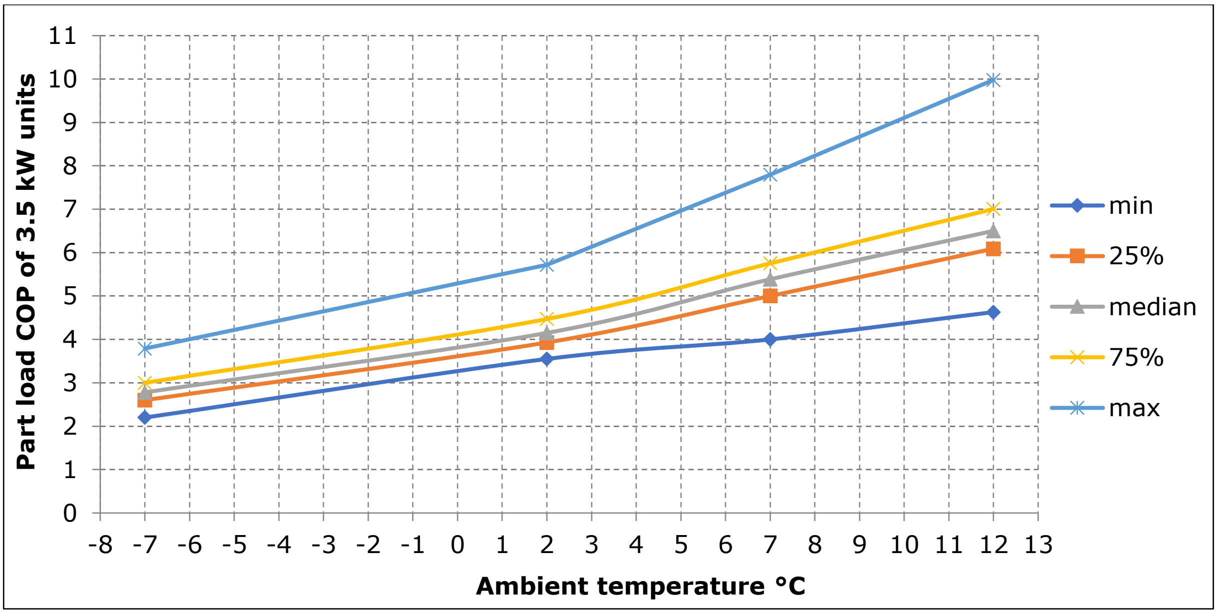

Figure 6: Part load COP of 3.5 kW units distribution in heating mode, source unknown manufacturers part of Eurovent Certita Certification

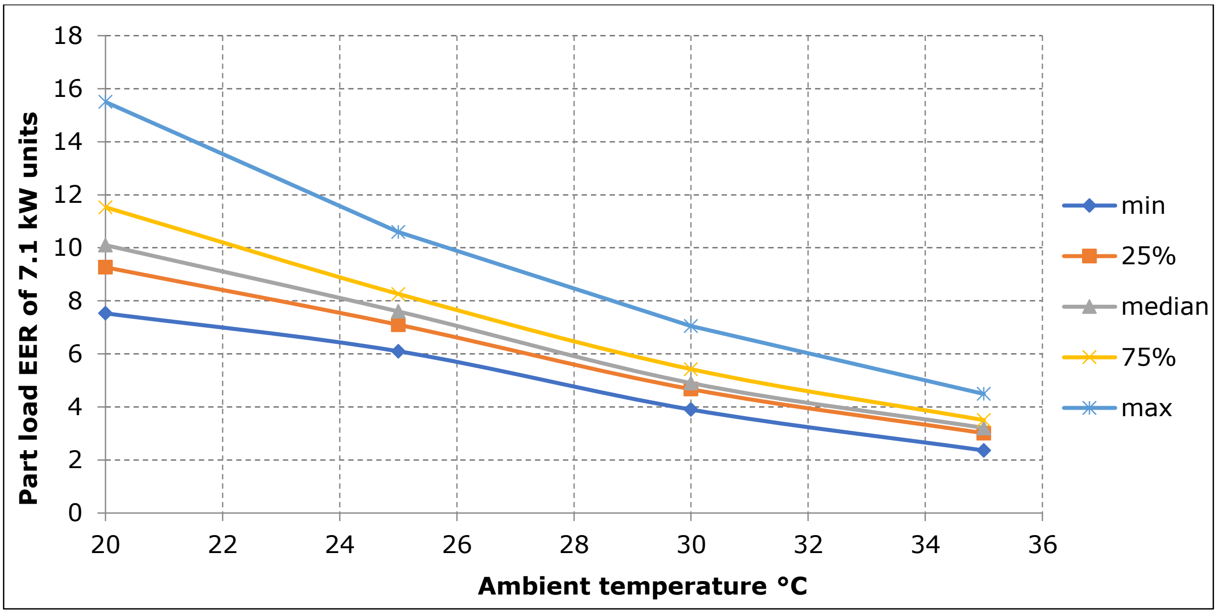

Figure 7: Part load EER of 7.1 kW units distribution in heating mode, source unknown manufacturers part of Eurovent Certita Certification

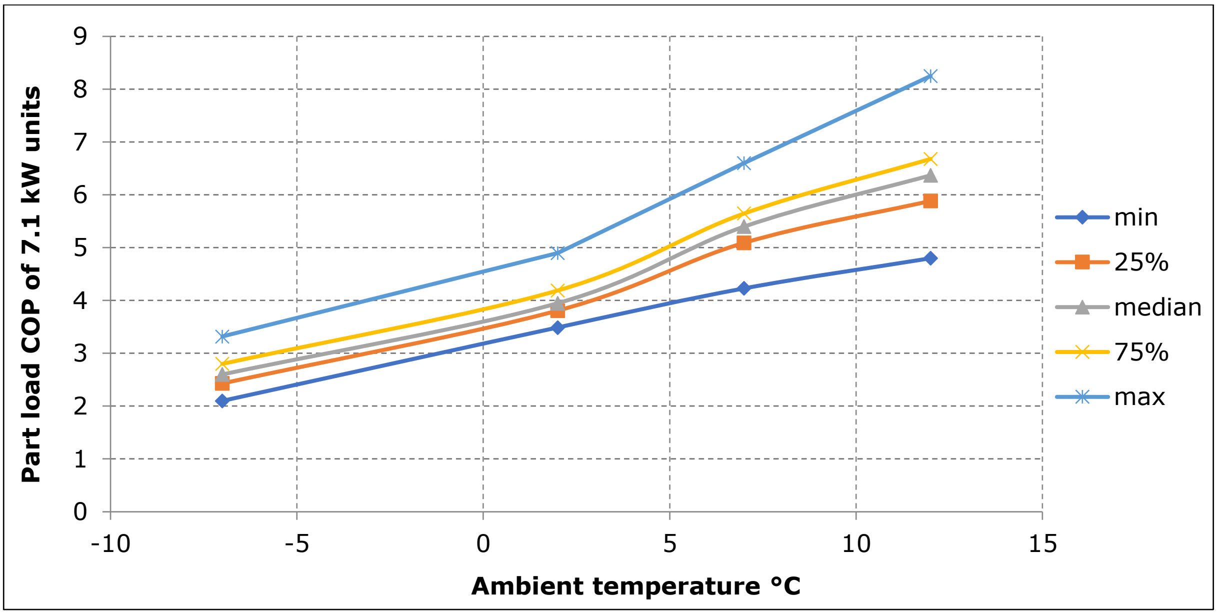

Figure 8: Part load COP of 7.1 kW units distribution in heating mode, source unknown manufacturers part of Eurovent Certita Certification

4.1.1.4 Crankcase, thermostat-off and standby values

The distributions of power by mode are shown in Table 6 below.

Off-mode power and standby power values are almost identical, and differences are not meaningful as most units are fitted with remote control (i.e. most units are in standby when not used). Standby power values are relatively high (median values of 6 W for smaller units and 12 W for larger units). The maximum values in the horizontal standby (EU) regulation 1275/2008 for products in scope (air conditioners and comfort fans are not in scope) are of 0.5 W in off mode and 1 W in standby mode.

Even if most units have no built-in networking capability, most of them can be equipped with this capability, so networked standby should also be considered. However often with the network capability, they consequently do more than just waiting an activation signal through the network but also monitor continuously outdoor and indoor air temperature, and possible other parameters, this will per definition no longer be "networked standby" according to regulation (EU) 1275/2008. If the product has networked standby as defined by regulation 1275/2008, and it is the default mode when product is not in use, it is proposed that the networked standby should be measured and used for the performance calculation instead of standby.

The standby consumption of air conditioners could be optimized, as is shown by the best possible values of 0.4 W that can be reached independently for both wall units of 3.5 and 7.1 kW. The main reason for the typically relatively high values is probably due to low focus on this point as it has limited impact on the metrics (no impact at all in heating mode, and limited, but not negligible, in cooling mode). Standby impact related to SEER metrics lies between about 1 % SEER loss per W of standby power for average products (SEER close to 6) and close to 2 % SEER loss per W of standby power for best products (SEER close to 10.5). Thus, focus on standby should increase with higher SEER values. Interestingly, there is a dependence of off mode and standby mode power to the unit size (0-6 kW range, standby is 6 W, and 6-12 kW range, 12 W standby), which is logical from a metrics point of view as the relative impact of these modes decreases when the size of the unit increases.

For large capacity units (6-12 kW), the minimum and the median of standby power are respectively 0.4 W and 12 W. Although it is not possible to go so low as 0.4 W for all unit types according to some stakeholders, still there is at least 9 W difference between mean and minimum values.

Table 5: Standby power of air conditioners

	6-8 kW	8-10 kW	10-12 kW
Min	0.4 W	0.7 W	1.0 W
Median	10.0 W	10.0 W	16.0 W
Average	10.0 W	12.2 W	14.6 W

Note also that with suspected high oversizing in real life, this impact on performance in real life is probably more important in both heating and cooling modes, because cooling/heating energy delivered by the product decreases with oversizing, while the electricity consumption in these auxiliary low power modes remain constant and so their weighting increases. However, this real life effect could only be incorporated in metrics by accounting properly the oversizing coefficient discussed in Task 3 section 3.1.2.2, which seems not yet possible because oversizing data is too scarce.

Regarding thermostat-off power, the median values are of 19 and 35 W respectively for the 0-6 and 6-12 kW ranges. This value is the addition of the power electronics consumption and of the electric consumption of the indoor fan minus the standby power value. In general, the fan has to remain on, even if working at lower speed, in order to sense the indoor air temperature variations. According to measurement standard EN14825:2016, measurement is done starting 10 min after the unit stops in test condition D (20 °C indoor in cooling mode) and runs for one hour. Good control of the fan in this mode (reduced speed, part time operation) enables to decrease thermostat-off value to about 1/3 of consumption. Best values of 2 W can be reached by using an external room temperature sensor; the remaining 2 W consumption is thus the Printed Circuit Boards (PCBs) power consumption minus the standby power consumption. Note that there can be up to several PCBs in an air conditioner. Ducted units can both have very high and 2 W values: worst case values, as their indoor fan power consumption is the highest and as for some products, the fan probably remains on at full speed (80 W worst case for 0-6 kW and 188 W for 6-12 kW), and best-case values, suggesting that some units probably cut the indoor air flow to rely only on an indoor thermostat.

It should be noted that the crankcase power values in Table 6 are not representative (because of very few data in ECC directory). Statistics are derived here on non-zero values only.

Table 6: Distribution of off mode, standby, thermostat-off and crankcase power for the 0-6 kW and 6-12 kW cooling capacity ranges, crankcase values in italic are highly uncertain because of a very low number of declared values and probably not representative, adapted from ECC directory

	0-6 kW				**6-12 kW**			
	Off mode power (W)	Standby power (W)	Thermostat-off power (W)	Crankcase power (W)	Off mode power (W)	Standby power (W)	Thermostat-off power (W)	Crankcase power (W)
Min	0.4	0.4	2.2	0.0	0.4	0.4	2.0	0.0
25% quartile	2.0	2.0	10.0	15.0	8.0	7.0	13.0	6.0
Median	6.0	6.0	18.0	19.0	12.0	12.0	35.0	19.0
75% quartile	10.0	10.0	30.0	23.0	16.0	16.0	63.0	25.0
Max	20.9	20.9	80.0	41.3	40.0	40.0	188.0	42.7

According EN145825:2016 standard, the "crankcase heater operates, when the compressor is off and the outdoor temperature is lower than a given value". In addition, the measurement for reversible units is done at 20 °C. This suggests that worst units stop crankcase operation above 20 °C or have no temperature control, while best units have temperature control lower than 20 °C, and hence have 0 W power in this mode.

Some of the product descriptions were sent by manufacturers in this review study, stakeholders indicated two sets of values for crankcase heater power, respectively measured in test condition D in heating mode (12 °C outdoor) and cooling mode (20 °C outdoor). Amongst these units, standard performance ones have crankcase starting temperature between 12 and 20 and consequently have no crankcase heater for cooling mode operation (following EN14825 calculation) but do have crankcase consumption at 12 °C. On the other hand, many units have 0 W crankcase heater values, which at the moment are measured at 20 °C. But the difference is not representative as the control could just start the operation below 19.9 °C. Thus, it tends to confirm it is necessary to refine the inclusion of crankcase heater consumption by requiring 2 distinct crankcase power values, one for heating and one for cooling in (EU) regulation 206/2012 (see Task 3 for more detail).

Estimate of low power mode values has to be adapted for the average products in order to fit with the overall base case parameters later. To that purpose, the SEERon/SEER is used as this ratio is relatively constant all over the efficiency distributions around the existing average products:

- For 0-6 kW units: SEER/SEERon median value is 0.9, increasing to 0.94 for highest efficiency units; median standby power (Psb) is 3 W, median thermostat-off (Pto) is 17.5 W. By difference, this leads to a crankcase power (Pck) value of 3.3 W (this in line with statistics for less than 6 kW wall units, the Psb = 3 W, Pto =19 W, which would lead to Pck of 3.1 W). Therefore, for the base case, the following values will be used: Psb of 3 W, Pto of 18 W, Pck of 3.2 W.
- For 6-12 kW: SEER/SEERon median value is 0.93 decreasing to 0.9 for higher efficiency units; median standby is 10 W, median thermostat-off is 40 W but this is too much to reach the SEER/SEERon ratio. Single wall values are used instead which leads to: Psb of 6 W, Pto of 30 W, Pck of 2.5 W.

Regarding portable air conditioner average products, standby power is regulated to 1 W (2 W in standby mode with a status display) and this value is thus kept as a reference, although stakeholders have indicated lower values (down to 0.7 W). For thermostat-off, stakeholders have indicated values of 25 W. Note also that portable units are not fitted with crankcase heaters, as their compressor is located indoors (where temperature normally does not decrease significantly below 15 to 20 °C).

4.1.1.5 Refrigerant type and charge

About 95 % of split products still used R410A refrigerant in 2016.

Refrigerant charge for R410A 0-12 kW split units (all types, including multi-split) is shown in Figure 9. Values identified in this study are higher than the ones in Lot 10 study, but the units are also more varied as they contain not only inverter wall split units but all types of units. Refrigerant charge varies with product efficiency (as far as efficiency increment is due to larger heat exchangers requiring more refrigerant). Refrigerant charge can then be correlated to the cooling EER rated at T1 conditions (Figure 9). Using the regression curve to set refrigerant charge of split products versus EER gives:

- 3.5 kW unit (EER=3.5): 0.30
- 7.1 kW unit (EER=3.3): 0.32

For single duct unit, information supplied gives a lower value of 0.2 kg/kW, which seems coherent with the fact that heat exchanger area per kW is lower than for an equivalent 2.5 kW split unit.

According to (UNEP, 2014)[3], the average refrigerant charge of air conditioners in scope is between 0.25 and 0.3 kg/kW, which seems coherent with the above values.

Refrigerant charge of alternative refrigerants used are lower:

- R32 charge is 10 - 20% lower than for equivalent split units charged with R410A according UNEP. Comparing R410A and R32 single split wall units in Figure 9, following respectively "Lot 10, 2006 R410A inverter split wall units" and "R32 wall single split units 3.5", although varying with EER, the difference is close to 0.05 kg/kW in average. The charge increase in kg/kW with EER is similar to the one of R410A unit (about 0.085 kg/kW added for each point EER added).

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[3] UNEP, Report of the refrigeration, air conditioning and heat pumps technical options committee, 2014 assessment.

- Propane charge is estimated to be approximately 40 % of the one of R410A for single duct units or about 0.08 kg/kW (also in line with UNEP: 0.05 – 0.15 kg/kW of rated cooling capacity).

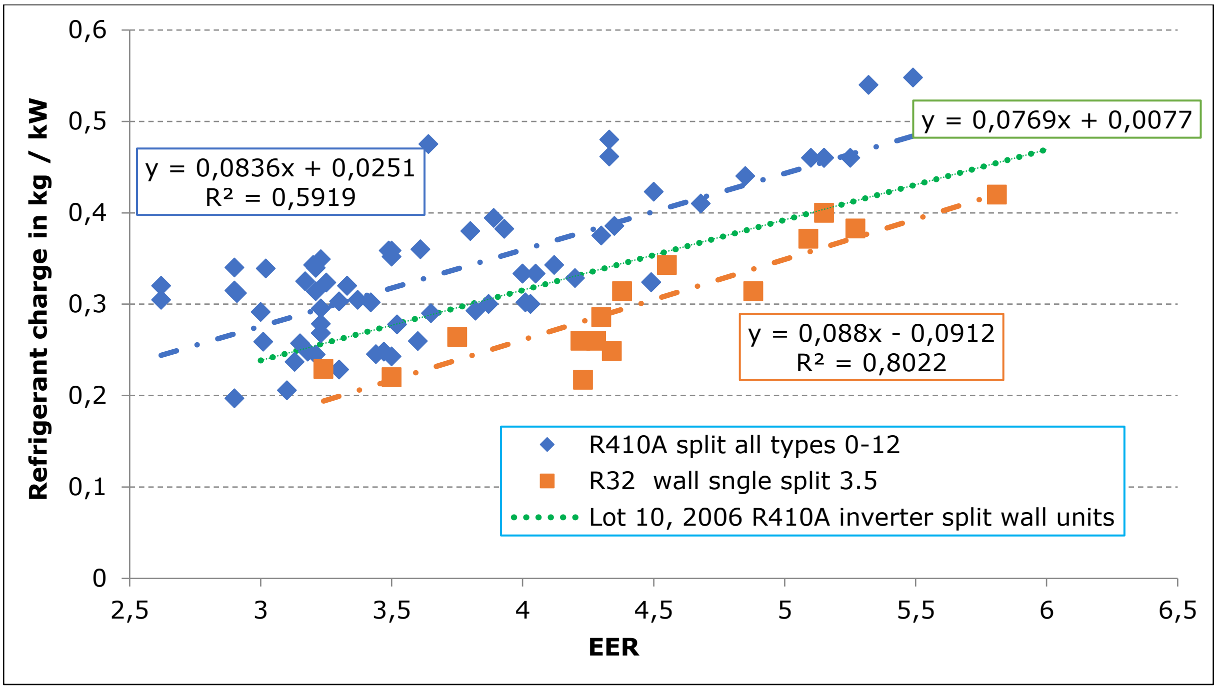

Figure 9 EER versus specific refrigerant charge in kg/kW (capacity and EER at T1 condition), 5 m piping length

4.1.1.6 Sound power

Sound power values are available in the ECC directory. Median values were searched for split units with sizes around the existing average products (3.4-3.6 kW range and 7.0 to 7.2 kW range).

Median sound power values for the 3.5 kW split products are:

- 62 dB(A) outdoors
- 57 dB(A) indoors

Median sound power values for the 7.1 kW split products are:

- 66 dB(A) outdoors
- 60 dB(A) indoors

Sound power is linked to both energy efficiency and unit price, but unit price is not available in technical databases. The link between performances and sound power was assessed. There did not appear to be a clear link between seasonal performance metrics and sound power level for capacities close to the identified average products. The analysis was then extended to the 0-6 kW and 6-12 kW capacity ranges. Looking at average SEER and SCOP values versus sound power levels indoor and outdoor for both product ranges, the link between sound power and efficiency is not completely clear; however, in the 0-6 kW range for indoor units, the SEER decreases with lower sound power value.

Table 7: Average SEER and SCOP values by sound power bin, adapted from ECC directory

0-6 kW					6-12 kW				
Sound power dB(A)	Outdoor		Indoor		Sound power dB(A)	Outdoor		Indoor	
	SEER	SCOP	SEER	SCOP		SEER	SCOP	SEER	SCOP
50	-	-	6.3	4.1	56	-	-	6.0	4.0
52	-	-	6.2	4.0	58	-	-	5.9	4.0
54	-	-	6.2	4.1	60	-	-	6.0	4.0
56	6.7	4.2	6.5	4.2	62	6.7	3.9	6.0	4.0
58	6.7	4.2	6.7	4.2	64	6.1	4.1	5.9	3.9
60	7.0	4.3	6.7	4.2	65	-	-	5.8	4.0
62	6.4	4.1	-	-	66	5.8	4.0	-	-
64	6.4	4.2	-	-	68	6.0	4.0	-	-
65	6.4	4.1	-	-	70	5.6	3.9	-	-

For single duct air conditioners, sound power is only measured indoors. This single value is higher than for split air conditioners of equivalent capacity because the compressor and two fans are inside. 63 dB(A) has been indicated by stakeholders for products similar to the average products (note that for these products, maximum authorized values as per Regulation (EU) 206/2012 is of 65 dB(A).

4.1.1.7 Prices

The prices of existing products have been investigated in Task 2, therefore the average price per kW from Task 2 is used here and corrected to account for higher efficiency to obtain the prices for the average product ranges.

Task 2 price (including markup) of 3.5 kW single split wall air conditioner is:

- 209 euro/kW x 3.5 = 732 Euros
- It must be corrected because of higher efficiency (SEER is 6.25 here for average product versus sales weighted average SEER of 5.7 indicated in Task 2) by 3.5% according to price efficiency curve given in Task 2, which gives 754 Euros. Task 2 price (including markup) of 7.1 kW single split wall air conditioner is:
- 272 euro/kW x 7.1 = 1929 Euros
- it must be corrected because of higher efficiency (SEER is 6.05 here for the larger split average product versus sales weighted average SEER of 5.7 indicated in Task 2) by a bit less than 2 % according to price efficiency curve given in Task 2, which gives 1964 Euros.

Task 2 price (including markup) of 2.6 kW portable single duct unit with EER of 2.65 is of 358 Euros, there is no need for correction of price.

4.1.1.8 Existing products main characteristics (model weighted)

In Table 8 and Table 9 a summary of the existing products characteristics previously identified in sections 4.1.1.1 to 4.1.1.7 is presented for both fixed air conditioners and portable air conditioners. These are model weighted average characteristics, in section 4.1.1.9, sales weighted characteristics are presented.

Table 8: Fixed air conditioners existing product main characteristics (model weighted)

	Type	Reversible split [0-6kW]	Reversible split [6-12kW]
General description	Mounting / type	Wall single split	Wall single split
	Current information	230V-1 phase- 50Hz	230V-1 phase- 50Hz
	Price (Euros)	754	1964
Refrigerant fluid	Type	R410A	R410A
	Charge	1.05 kg	2.27 kg
Cooling performances	Cooling capacity kW	3.5 kW	7.1 kW
	SEER	6.25	6.05
	EER//Pc 100% capacity, air at 35°C	EER 3.3/Pc 3.5 kW	EER 3.2/Pc 7.1 kW
	EER/Pc 74% capacity, air at 30°C	EER 5.1/Pc 2.6 kW	EER 4.9/Pc 5.2 kW
	EER/Pc 47% capacity, air at 25°C	EER 8.1/Pc 1.7 kW	EER 7.6/Pc 3.4 kW
	EER/Pc 21% capacity, air at 20°C	EER 11.6/Pc 1.2 kW	EER 10.1/Pc 2.5 kW
Heating performances	Pdesignh kW	3.0 kW (-7°C)	5.6 kW (-10°C)
	SCOP	4.1	4.0
	COP/Ph Air at -7°C and part load	COP 2.7/Ph 2.7 kW	COP 2.6/Ph 4.9 kW
	COP/Ph Air at 2°C and part load	COP 4.1/Ph 1.6 kW	COP 4/Ph 3 kW
	COP/Ph Air at 7°C and part load	COP 5.3/Ph 1.1 kW	COP 5.4/Ph 2.4 kW
	COP/Ph Air at 12°C and part load	COP 6.4/Ph 1.1 kW	COP 6.4/Ph 2.1 kW
	T_tol °C	-15 °C	-20 °C
	COP/Ph at T_tol	COP 2.3/2.5 kW	COP 2.0/4.5 kW
	T_biv °C	-7 °C	-10 °C
	COP/Ph at T_biv	COP 2.7/2.7 kW	COP 2.5/5.6 kW
Other power values	Crankcase Heater	3.3 W	2.5 W
	Thermostat-off	18 W	30 W
	Standby	3 W	6 W
Sound power values	Outdoor	62 dB(A)	66 dB(A)
	Indoor	57 dB(A)	60 dB(A)
Weight	Total kg	41 kg	96 kg

Table 9: Portable air conditioner existing product main characteristics

	Type	Portable
General description	Mounting / type	Single duct
	Current information	230V-1 phase- 50Hz
	Price (Euros)	358
Refrigerant fluid	Type	R410A
	Charge	0.64 kg
Cooling performances	Cooling capacity kW	2.6 kW
	EER (35°/35°)/ SEER	2.65 /2.09
Other power values	Crankcase Heater	0 W (no crankcase)
	Thermostat-off	25 W
	Standby	1 W
Sound power values	Outdoor	63 dB(A)
Weight	Total kg	32 kg

4.1.1.9 Final existing products main characteristics (sales weighted)

For split base cases, the study team received comments from stakeholders on the chosen method to determine efficiency levels of base cases, suggesting to use sales weighted instead of models weighted method. The 2 base cases were adjusted based on the new data received as follows:

Base case 1: SEER 6.00/ SCOP 4.00
Base case 2: SEER 5.80/ SCOP 4.00

In addition, the crankcase power value has also been changed to 0 W, and is thus not accounted in the improvement options. Indeed, it was made clear by stakeholders that missing crankcase power values in the data are in fact to be understood as 0 W values.

Prices are adapted for these changes:

- Base case 1/ 3.5 kW: The base case must be corrected because of higher efficiency (SEER is 6.00 here for average product versus sales weighted average SEER of 5.7 indicated in Task 2) by 1.5% according to price efficiency curve given in Task 2, which gives **743 Euros**.
- Base case 2/ 7.1 kW: Same correction as the base case 1 (SEER is 5.8 here for average product versus sales weighted average SEER of 5.7) by 1%, which gives **1948 Euros**.

Table 10:Fixed air conditioners existing product main characteristics (sales weighted)

	Type	Reversible split [0-6kW]	Reversible split [6-12kW]
General description	Mounting / type	Wall single split	Wall single split
	Current information	230V-1 phase- 50Hz	230V-1 phase- 50Hz
	Price (Euros)	743	1948
Refrigerant fluid	Type	R410A	R410A
	Charge	0.98 kg	2.01 kg
Cooling performances	Cooling capacity kW	3.5 kW	7.1 kW
	SEER	6.00	5.80
	EER//Pc 100% capacity, air at 35°C	EER 3.1/Pc 3.5 kW	EER 3.1/Pc 7.1 kW
	EER/Pc 74% capacity, air at 30°C	EER 4.8/Pc 2.6 kW	EER 4.8/Pc 5.2 kW
	EER/Pc 47% capacity, air at 25°C	EER 7/Pc 1.7 kW	EER 6.7/Pc 3.4 kW
	EER/Pc 21% capacity, air at 20°C	EER 11.2/Pc 1.2 kW	EER 9.9/Pc 2.5 kW
Heating performances	Pdesignh kW	3.1 kW (-7°C)	5.6 kW (-10°C)
	SCOP	4.0	4.0
	COP/Ph Air at -7°C and part load	COP 2.6/Ph 2.7 kW	COP 2.6/Ph 4.9 kW
	COP/Ph Air at 2°C and part load	COP 3.9/Ph 1.6 kW	COP 3.9/Ph 3 kW
	COP/Ph Air at 7°C and part load	COP 5.3/Ph 1.1 kW	COP 5.1/Ph 2.4 kW
	COP/Ph Air at 12°C and part load	COP 6.25/Ph 1.1 kW	COP 6.1/Ph 2.1 kW
	T_tol °C	-15 °C	-20 °C
	COP/Ph at T_tol	COP 2.2/2.5 kW	COP 2.1.93/4.5 kW
	T_biv °C	-7 °C	-10 °C
	COP/Ph at T_biv	COP 2.6/2.7 kW	COP 2.6/5.6 kW
Other power values	Crankcase Heater	0 W	0 W
	Thermostat-off	18 W	30 W
	Standby	3 W	6 W
Sound power values	Outdoor	62 dB(A)	66 dB(A)
	Indoor	57 dB(A)	60 dB(A)
Weight	Total kg	41 kg	96 kg

4.1.2 Products with standard improvement (design) options

The following section describes the possible improvement options of air conditioners and comfort fans. The improvement options are first described at component level, this explains how products are improved, then best available technology levels are discussed.

4.1.2.1 Improvement options

Heat exchanger

Efficiency of air conditioner (or heat pump) increases when the temperature difference between the evaporating and the condensing temperature decreases. This temperature difference depends mainly on hot and cold source temperatures. Nevertheless, for heat to be exchanged with both sources, there is a necessary temperature difference between cold source and evaporation temperature and between hot source and condensing temperature. These temperature differences are proportional to the thermal capacity to be exchanged; nevertheless, it can be reduced by improved heat exchangers.

The power of the heat exchanger can simply be written as:

$$Q = U \times A \times DTLM$$

Where:

- Q (W) is the capacity of the heat exchanger

- U (W/m²/K) is the global heat transfer coefficient (accounting for air and refrigerant side thermal convective resistances) and divided by the total heat exchange area
- A (m²) the total heat exchange area (air side)
- DTLM the logarithmic mean temperature difference between air and refrigerant

Efficiency of the air conditioner in heating and cooling modes is directly a function of the compression ratio, the pressure ratio between the high and low-pressure sides. The lower the difference the higher the efficiency. With inverter technology, refrigerant flow rate is reduced at part load. This decreases the temperature difference between air streams and refrigerant temperatures and thus the pressure ratio and the work to be supplied by the compressor. When reducing the refrigerant flow rate by half, there is twice as less capacity to exchange through the heat exchanger and the temperature difference between the air stream and the refrigerant fluid decreases. To get about this level of efficiency at rated capacity, global heat transfer coefficients at both heat exchangers (UA) have to be increased by a factor of 2. The simpler way to do it is to oversize both heat exchangers and to increase air flow rates consequently. Strategies developed by manufacturers vary depending on the technologies used to reach highest efficient EER and COP. According to the Preparatory study, increasing both heat exchanger UA values by a factor 2 without increasing the air flow rate still leads to about 40 % savings. Increasing heat exchange area at both heat exchangers is the main improvement option available to all manufacturers. There are however physical and cost limitations to oversizing heat exchangers. For instance, portable air conditioners compete on size for the same capacity, cassette air conditioner indoor units have to fit in standard sizes of ceiling panels, suspended ceiling indoor units cannot be too heavy (as they have to be suspended).

Increasing the heat transfer performance

The resistance to heat exchange between refrigerant fluid and air can be decreased by improving refrigerant tube design or fin design or increase the fin density. For refrigerant tubes, high quality copper tubes with internally grooved design to maximize heat exchange intensity is used, and conduction and convection are very high already.

Still it is possible to optimize tube diameter. Refrigerant tube typical sizes vary between inside tube diameter of 4 mm and 9 mm depending on unit size, efficiency and heat exchanger type. High efficient units have lower internal diameter. This allows for higher refrigerant heat exchange coefficients and then to use less copper quantity (cost reduction), but also implies higher pressure losses. Best available technologies then use two different tube sizes in the same heat exchanger to optimize heat transfer, pressure loss and cost (e.g. 4 and 6 mm instead of 5 mm for best 3.5 kW units).

Regarding the air side heat transfer, no recent evolutions on the fin pattern could be identified. Best available units still use complex fin designs of slit or grooved type. Fin density is limited for reversible units because of frost and in both modes by pressure losses and the air side which imply larger fan power consumption.

Further improvement could come from the adoption of microchannel heat exchangers; these are made of flat tubes with rectangular cross section with dimensions of 1 to 3 mm. Fins pass between the tubes and are brazed to the tubes. The resulting microchannel coil transfers more heat per unit of face area than present heat exchanger of comparable capacity. According to stakeholders, microchannel heat exchangers can improve SEER (SCOP) by 3-5% compared with tube and fin Cu/Al at equivalent heat exchanger size because of higher heat transfer area for the same outdoor unit size and equal flow rate; this figure is coherent (right order of magnitude) with the 20 % UA performance increase mentioned in the Preparatory study ; our own simulations in Task 6 give 2 % increase in SCOP and 3.5 % in SEER for 20 % UA increase at condenser thanks to microchannel adoption.

Figure 10: Micro Channel Heat Exchanger4

In the literature (e.g. Cremaschi (2007)[5]) it was suggested that microchannel heat exchangers would primarily be used for the indoor heat exchanger and not for the condenser since they were likely to decrease COP in frost conditions because of refrigerant fluid distribution problems and condensate draining issues. Nevertheless, it seems these problems could be solved (first product with microchannel heat exchanger at the outdoor heat exchanger of VRF air conditioners was put on the market in 2014). And so micro channel heat exchangers should now be considered in the best available technologies, although these are not yet used in the 0-12 kW range, probably for cost reasons. However, on the indoor side of split units, in order to increase the heat exchanger area, coil designs are much more complex. For instance, in single split wall units, the coil is wrapped around the cross-flow fan. Designing equivalent area that fit in the indoor units with microchannel heat exchangers is a challenge because of the manufacturing process of micro-channel heat exchangers. Thus, it is not an option for manufacturers at the moment to increase the performance for indoor unit, and is thus rather to be classified as a BNAT option.

It is important to note that inside tube diameter reduction or use of microchannels are also important as these options allow to reduce the refrigerant charge of air conditioners. (RTOC, 2014)[6] proposes a review of charge reduction thanks to microchannel heat exchangers, and the charge reduction potential is of the order of magnitude of 30 % when both heat exchangers are converted.

Portable air conditioners use water condensed at the evaporator side to increase the heat exchange performance at the condenser side. Evaporator is located above condenser, so that condensates may fall by gravity on the condenser coil. At the bottom of condenser coil, a wheel pump located in a condensate tray works permanently to spray water droplets on the condenser coil. Part of the condensates thus evaporate on the hot surface of the condenser coil and probably part of it is extracted also with the exhaust air outdoors. Heat is then transferred from the coil to water droplets by evaporation, and then without temperature increase. Condensate evaporation represents about 15 to 20 % of the heat to be released at condenser side for the identified average product, hence enabling to

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[4] http://airconditioning.danfoss.com/products/heat-exchangers/mche/#/

5 Cremaschi, 2007, HPC, 2007, Heat pump Center, Newsletter n°3, 2007.

6 REPORT OF THE REFRIGERATION, AIR CONDITIONING AND HEAT PUMPS TECHNICAL OPTIONS COMMITTEE, Montreal Protocol on Substances that Deplete the Ozone Layer UNEP, 2014

reduce the size of the condenser of this same amount. This value varies with the SHR ratio of the unit, and then as a function of air flow rate and evaporation temperature.

For portable air conditioners, coil design is simpler than in indoor units of split systems (standard horizontal copper tubes with vertical aluminium fins) and so microchannel heat exchangers could be an interesting option for both heat exchangers. Single duct manufacturers have reported however disappointing performances at the condenser due to refrigerant fluid distribution issues and to the specific requirement of proper condensate evaporation at condenser side for this coil. Hence for portable, it seems water condensation at evaporator and water evaporation at condenser side makes it difficult to use microchannel heat exchangers for now.

Compressor

The compressor is the component that consumes the most energy in an air conditioner system. Its energy consumption depends directly on the high and low pressure which are fixed by heat exchangers; still, at given low- and high-pressure conditions, the compressor efficiency is crucial for the overall system efficiency. Once the temperature difference between evaporation and condensation temperatures has been fixed by the heat exchanger designs, this directly gives evaporating and condensing pressures and the pressure ratio (ratio of the condensing to the evaporating pressure). Delivering a given cooling capacity in these conditions requires a particular refrigerant mass flow. This set of conditions enables to choose a compressor, and it can be more or less efficient to deliver this flow against the operating pressure ratio. Compressor efficiency is defined by its efficiency value at standard operating conditions, which enables to compare efficiency for one single performance point. However, in seasonal performance metrics, the outdoor temperature and capacity to be delivered vary, which in turn influences the pressure ratio and the compressor efficiency.

Air conditioning compressor technologies have evolved over the past several years. Regulatory efforts worldwide (introduction of seasonal metrics in largest markets) have contributed to the phase out of single speed compressors and introduction of higher efficiency variable speed DC compressors in split air conditioners. As reported in Task 2, DC inverter compressor penetration is now close to 100 % for split air conditioners in Europe. For these compressors, required system capacity can be matched by adjusting the frequency and then the mass flow for a given temperature difference between evaporating and condensing temperatures. This also affects efficiency.

Units in the scope only use rotary (also named rotary vane) compressors. Information on compressor performances of these products is limited, despite more than 100 million split units fitted with rotary vane compressor being sold each year. Information can be found at standard rating conditions (AHRI standard conditions) for some compressor manufacturers, with fragmentary information only to explain the differences in performances. Air conditioner manufacturer also supplied rating compressor performance in standard conditions or at cooling/heating rating points. Non nominal performance values could be found for single speed AC compressors but not for DC inverter rotary compressors and information on the impact of frequency variation on performances is also limited.

In the preparatory study, the standard AHRI EER (Efficiency in standard AHRI conditions, named COP when in SI units in US standards) was evaluated to be of 2.8 for AC single speed rotary compressor. Several options were simulated with best DC inverter rotary compressor having EER of 3.4, mainly because of much more efficient motor (these figures include inverter losses, i.e. AC to DC conversion, which are very low nowadays).

For the purpose of defining improvement options, rotary compressors can be classified as follows:

- Single speed AC motor rotary compressor; common performance ranges are of 2.7 to 3.1 at best; here Figure 11 curve can be used to assess compressor efficiency variation for different operation at different pressure ratios (only useful for portable air conditioners, which are still using single speed AC motors);
- Variable speed DC motor rotary compressor; commercial models with performances in the range of 3.1 to 3.4 (3.1 to 3.3 for R32 compressors nowadays) can be found; above that only little improvement is possible, a few percent's but only in part load conditions, according to stakeholders;
- Improved 3.4 DC rotary compressor with ability to operate at slightly lower compression ratios thanks to incorporation of specific lubrication design enabling more oil flow at low speed and pressure ratio.

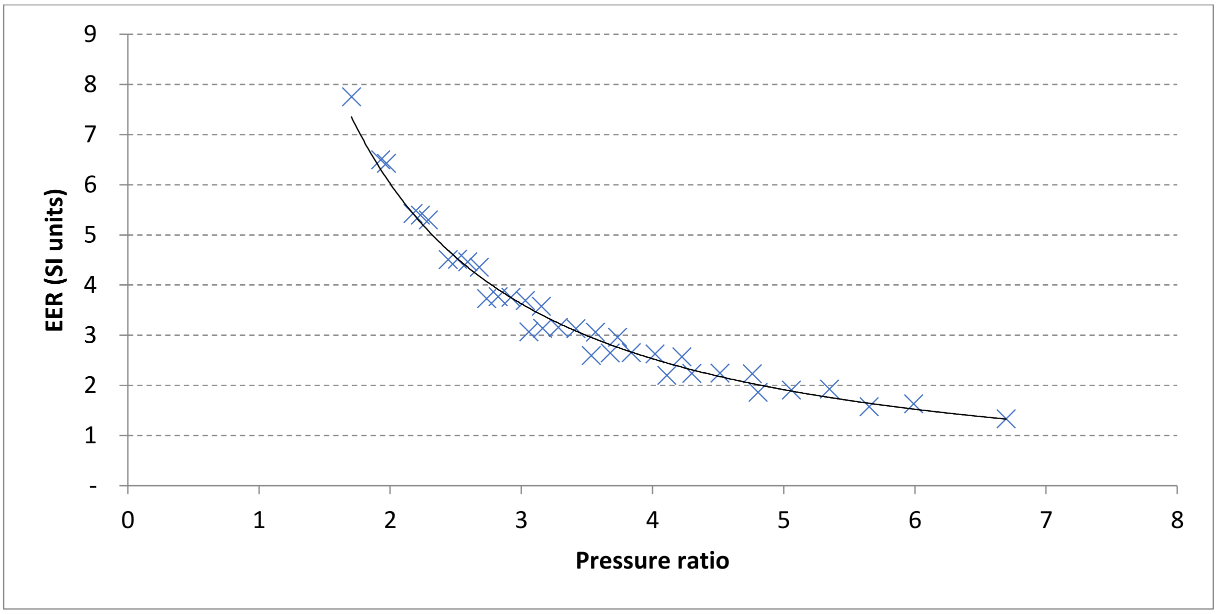

Figure 11: R410A single speed AC motor rotary compressor EER plotted against pressure ratio, source (Lei et al, 2013)[7]

Looking at the shape of the compressor EER evolution versus pressure ratio at low pressure ratio values (Figure 11), it can be seen a strong compressor EER increase at low pressure ratio (EER 8 for compression ratio close to 1.7). EER_C and EER_D point in SEER metrics (resp. at 25 °C/47 % load and 20 °C/21 % load) can lead to compression ratios as low as 1.1 to 1.3 and these EER values strongly impact the final SEER values. In addition, ideal EER compressor, continues increasing to very high values at these low pressure ratios. Hence, it is crucial to know what are the minimum condensing temperature or minimum pressure ratio at which DC inverter compressor can operate and at what efficiency levels.

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[7] Zhang Lei, Zhu Yanting, Qin Chao, TEST REPORT #26, Compressor Calorimeter Test of Refrigerant R-32 in a R-410A Rotary Type Compressor. Air-Conditioning, Heating, and Refrigeration
Institute (AHRI) Low-GWP Alternative Refrigerants Evaluation Program (Low-GWP AREP), October 13, 2013

This can only be done by the study team on the basis of reverse engineering from performance and technical characteristics of best units available to the study team. A first evaluation (to be refined in Task 6) is that minimum operating compression ratio can go down to about 1.1 for best twin rotary DC inverter compressor versus typically 1.2 to 1.3 for standard DC inverter rotary compressors.

According to stakeholders, it is difficult nowadays to find good DC inverter compressor for hydrocarbon units. Hence, for portable units, present products cannot benefit of the performance gain of using both propane (higher EER by 5 to 10 %) and DC inverter compressor. This will probably be possible in the near future, but that depends on the general trend to adopt hydrocarbons as refrigerant fluid in Europe or in other large AC countries.

As for non-nominal performances, there is little information regarding the consumption required by the power conversion from AC to DC for DC inverter compressor. In any case, stakeholders have indicated that improvement potential was possible, although limited to 1 W constant gain (when compressor operates).

Compressor heat losses at low ambient is thought to be significant and because most units are reversible, compressors are fitted with elastomeric (polymer with rubber-like properties) insulation. One option here is to recover part of this heat for heating. This may be done through phase change material/combination of dense enough material with refrigerant piping inside. In any case, the energy quantity recovered is thought to be low and it is used only for short periods for space heating during defrost cycle. As defrost cycle impact on the performances of these units is thought to be low (about 5 % loss at 2 °C on the capacity and COP), this option is not considered here.

A supplementary option used by some manufacturers in heating mode already is refrigerant vapor injection. At the outlet of the condenser, liquid and vapor are separated; vapor is injected at an intermediate suction port in the compressor; liquid enters the evaporator which allows for larger capacity to be exchanged with outdoor air. Main injection types are with intermediate heat exchanger or with flash tank (Heo et al., 2011)[8]. These technologies enable to increase the capacity at low ambient in heating mode and to increase COP. Published values by (Heo et al., 2011) give COP gain of 10 % and heating capacity gain of 25 % at -15 °C. SCOP benefit is however limited to 0.5 to 1 % as the gain is mainly at low ambient which has low weight in SCOP average metrics. There is however an economic interest if the unit is selected for heating as it enables, for the same basic component sizes, to have larger thermodynamic capacity at low ambient and then higher Pdesignh without increasing the resistive heating part. It is then an option of high interest for Northern Europe.

Standby, thermostat off and crankcase power

Units with standby power down to 0.4 W are available for both split units (see section 4.1.1.2) and for portable air conditioners. For portable units, indeed DOE's test sample[9] shows standby values down to 0.46 W.

For base case 7.1 kW, the median standby value is 6 W. Adopting the best technology gives a maximum reduction of 5.6 W. However, it might not be possible for all products

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[8] J. Heo, M.W. Jeong, C. Baek, Y. Kim, Comparison of the heating performance of air-source heat pumps using various types of refrigerant injection, Int. J. Refrigeration, 34 (2) (2011), pp. 444-453

[9] TECHNICAL SUPPORT DOCUMENT: ENERGY EFFICIENCY PROGRAM FOR CONSUMER PRODUCTS: Residential Central Air Conditioners and Heat Pumps, US Department of energy 2016

to reach a 0.4 W value, such as for multi-split units or due to electromagnetic compatibility tests etc. according to stakeholders, but usually for these products the difference between the median and min value of standby power is higher than 5.6 W due to the different sizes than our base cases. A standby power cut of 5.6 W is thus a conservative view of the gains that can be reached thanks to a better design of standby (see Table 5).

Thermostat-off consumption is the addition of the unit control power consumption plus the fan average power over a 60 mins measurement period minus the standby power. Lowest value for thermostat off power is of 2 W for split units currently on the market as per ECC databases. This value leaves no place for fan consumption, and this can be reached by using an external room temperature sensor. There are other possible design choices, like operation at reduced fan speed of the indoor unit, or part of the time; this leads to reductions of fan power consumptions by 1/2 to 1/3 at best.

Refrigerant charge reduction and alternative refrigerant fluid

Regarding split air conditioners, most products are still using R410A, the conversion from R410A to R32 already started (R410A is banned in single split air conditioners from 2025 onwards), because manufacturers are already anticipating this change. So R32 is the candidate replacement fluid for R410A. However, it may not be the long-term choice. There has been extensive search for alternate fluids these last years and final solution to reach low GWP (below 150) presently contemplates HFO mixtures and hydrocarbons. Recently, Godrej developed high efficiency propane split air conditioners with DC inverter compressor and fan in India[10]. In 2018, a Midea propane split unit was awarded the Blue Angel Ecolabel in Germany[11]. Hydrocarbons are a potential long term solution but manufacturers need to be convinced on its safety before engaging their liability in manufacturing such units, which is not the case yet for most split air conditioner manufacturers in Europe.

For best split products in Europe, almost all manufacturers now offer R32 and no longer R410A.

For portable products, propane has been used for some years already by one manufacturer[12], while other manufacturers still use R410A. At the moment, there is no other fluid envisaged, but any replacement fluid also used for split or car air conditioning (like R32) could also be a solution if it does not lead to large product size increase (as with HFOs), as it guarantees to find parts to build a product (particularly compressors). Hydrocarbons can be used to meet 2020 ban requirement for products using fluids with GWP > 150. However, it may not be the unique solution, and it is difficult to anticipate right now in which direction the market will go. However, it is believed that there will probably be a mix of hydrocarbons and of mixtures based on HFO on the market.

Indoor and outdoor fans

Larger-Diameter Fan

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[10] http://www.godrejnxw-ac.com/

[11] https://www.businesswire.com/news/home/20180320006123/en/Midea-Launches-World%E2%80%99s-Eco-Friendly-Air-Conditioner-Certified

[12] Interview with Delonghi, 2017

Larger fans can provide the same air flow as smaller fans at their best efficiency point, due to the lower air velocities associated with their larger flow passages. Using larger DC motors run at reduced speed also enables to use more efficient motors. So, it is an option to increase the size of the fans to reduce their consumption, although it may imply important costs if there is no margin for this in indoor/outdoor casings.

Higher-Efficiency Fan Motors

The average split air conditioner is supposedly fitted with DC inverter fan motors for both indoor/outdoor unit. This is not the case for average portable air conditioner; only best products are fitted with DC inverter fan motors (at both heat exchangers).

Electronically commutated motors (ECM) are brushless permanent magnet motors with design-speed efficiencies between 70 and 80 (even over 80 % for split air conditioner fans) percent, making them more energy efficient even over their broader range of operating speed than AC motors.

4.1.2.2 Best available technologies (BAT)

This part aims at estimating BAT levels that are basically best available products with the highest efficiency on the market. According to the MEErP, "the Best Available Technology benchmark should be a robust benchmark for market pull measures, e.g. the ‘A’ energy class and/or the level for public procurement, Eco-labels, etc.".

This section will present the best available products (BAT levels) and discuss further improvement options that might be added to the BAT to achieve BNAT (Best Not yet-Available Technology) target values, that could be reached within 5 or 10 years. The intent of these BNAT target values is the new EU labelling scheme that requires that A and B classes be empty at its beginning.

Characteristics of best available products in Europe as per November 2016 for splits (ECC directory) and as indicated by stakeholders for portable are given for the 3 average product categories. As highest efficient products are not forcedly in the exact same product category as the average product we defined, therefore several BAT products with different technical specifications are presented (e.g. best 0-6 kW unit has smaller capacity than the average product). See Table 11 for the BAT products main characteristics.

Table 11: best available products main characteristics[13]

	Split 0-6 kW		**Split 6-12 kW**			**Portable**
	2.5 kW	**3.5 kW**	**6.8 kW**	**7.1 kW**	**7.1 kW**	
Mounting	Wall	Wall	Wall	Wall	Cassette	Single duct
	single split	single split	bi-split	single split	single split	
Refrigerant	R-32	R-32	R-32	R-410A	R410A	Propane
PdesignC	2.5 kW	3.5 kW	6.8 kW	7.1 kW	7.1 kW	2.5 kW
SEER	10.5	10	8.02	7.6	7.40	EER 3.6
SCOP	6.2	5.9	4	4.7	4.9	NA

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[13] Note that these best products base upon ECC database as per January 2018.

0-6 kW split range

BAT level for SEER is presently of 10 (3.5 kW unit) and of 10.5 (2.5 kW unit). BAT level for SCOP is of 5.9 (3.5 kW unit) and 6.2 (2.5 kW unit). These are real units. They have already been designed with R32 instead of R410A.

For BNAT, SEER levels could be higher because there are more efficient units on a SEERon basis, up to 12.2 for 2.5 kW units, but that still suffer a high contribution of standby and thermostat-off power consumption. By altering thermostat-off value to half the value (reduced indoor fan speed) and standby value to 0.4 W, best SEER of about 10.9 could be reached. Note however that these more efficient units on a SEERon basis are also less efficient in heating mode. The only left option on top would be micro channel heat exchangers to be used at the condenser, which could still increase SEERon by maximum 3.5 %, which would push SEER BNAT value close to 11.3. It should however be[14] acknowledged that there is high uncertainty on the evaluation of EER_C and EER_D points and, if rotary compressor designs may decrease the minimum compression ratio above which these compressors can operate efficiently, this can significantly increase the maximum SEER levels that can be reached. Unfortunately, we have no information here.

BNAT SCOP level could be higher than BAT levels by 2 % using microchannel heat exchanger at outdoor heat exchanger and thus BNAT level comes to 6.3, a value which is believed to be more robust than the maximum SEER level because rotary compressor efficiency at low pressure ratio has less impact than in cooling mode. Note that these levels leave no margin for noise reduction of 3.5 kW units and only 2 to 3 dB(A) maximum for smaller 2.5 kW units. It also means that for 4 to 6 kW units, sound power level present requirements may prevent to reach such performance levels.

To conclude, for the 0-6 kW range:

- BAT levels are SEER 10.5 and SCOP 6.2
- BNAT levels are SEER 11.3 and SCOP 6.3

6-12 kW split range

On this capacity range, best products have SEER levels of 8 (existing bi-split wall unit and BAT seen by stakeholders for cassette) and SCOP level of 4.9 (single split cassette unit) ; note that highest SEER and SCOP values cannot be reached for the same unit. There is no physical limitation to explain why wall units of 7.1 kW could not be as efficient as 3.5 kW units. This is only probably a cost issue. However, regarding cassette, in addition to costs there may be physical limitations (size of ceiling panels in which indoor units have to be mounted).

To conclude, for the 6-12 kW range:

- BAT levels are SEER 8 (SCOP 4) and SCOP 4.9 (SEER 7.4)
- BNAT levels are SEER 11.3 and SCOP 6.3

Portable

Best available portable product is right over the A++ energy label class, with EER of 3.6 (at 35/35). SEER is of 2.82. For BNAT targets, it is possible to reach higher performance levels by increasing evaporator heat exchanger size but not with propane (because of refrigerant charge limitation), the fluid used for the best product presently available. This

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best product uses a standard AC motor rotary compressor amongst the few available for propane; there could be significant gains at maximum capacity (using present metrics) and much more with the newly proposed SEER metrics.

Micro channel heat exchangers on both sides is presented as a best non-available technology by stakeholders in this product range, although it seems to be the way forward, as it enables both to gain heat exchanger area at same product volume and to decrease refrigerant charge (and so to potentially further increase heat exchanger area and efficiency as it would allow to alleviate the refrigerant charge maximum limit).

BNAT EER basing on propane unit could be higher than 3.6 (BAT level) using highest efficiency DC inverter compressor, and if microchannel heat exchanger can be used. As manufacturers indicate that microchannel heat exchanger is not available, BNAT is derived from modelling an improved propane unit in Task 6, by considering the combination of all other options. BNAT EER (measured at 27/27) levels are of 5.45 (about 4.9 at 35/35) and SEER of 4.3 with the proposed metrics (Cf Task 3).Regarding standby power mode, BAT value for existing products is 0.7 -0.8 W according to stakeholders, and BNAT value of 0.4 W is feasible.

To conclude, for portables:

- BAT levels are EER of 3.6 (35/35) and SEER of 2.82
- BNAT EER levels (determined in Task 6) are of 5.45 (27/27) (or about 4.9 at 35/35) and SEER of 4.3

4.2 Technology roadmap

Current product technologies including best available technologies (BAT) have been presented in the previous section, this section aims to show technological development into the near future, an outlook of technologies yet to enter the market (BNAT).

Efficient heating and cooling is an important topic to reach climate objectives as heating and cooling together represents 50 % of the EU energy consumption and is still mainly based on fossil fuels[15]. Regarding systems, EU research funding is thus mostly focalized on developing heating and cooling systems mobilizing renewable energy, which includes heat pumps but with little technological developments[16]. However, there is Research & Developments (R&D) funded by the EU, via non-EU R&D programs (like regional funds) and by Member States in the heat pump field, even if not regarding directly air-to-air products.

Looking abroad, the US DOE recently published a technology roadmap of emerging and future air conditioning technologies, that is used as a basis to identify best non available technologies for air conditioners (Goetzler et al., 2014 and 2016)[17], together with the

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[15] An EU Strategy on Heating and Cooling, COM(2016) 51 final

[16] European Commission, Overview of support activities and projects of the European Union on energy efficiency and renewable energy in the heating & cooling sector. Horizon 2020, Framework Programme 7 and Intelligent Energy Europe programmes of the European Union, Luxembourg:
Publications Office of the European Union, 2016 © European Union, 2016.
https://ec.europa.eu/energy/sites/ener/files/documents/overview_of_eu_support_activities_to_h-c_-_final.pdf

[17] Goetzler et al. 2014. “Energy Savings Potential and R&D Opportunities for Non-Vapor-Compression HVAC Technologies.” https://energy.gov/eere/buildings/downloads/non-vapor-compression-hvac-technologies-report
W. Goetzler, M. Guernsey, J. Young, J. Fuhrman, O. Abdelaziz, The Future of Air Conditioning for Buildings, Prepared for: U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Building Technologies Office, July 2016. http://eere.energy.gov/buildings

Ecodesign refrigerator technology roadmap[18] as some emerging technologies for fridges are common for air conditioners, and reports regarding heat pump research needs[19] and alternative technologies to high GWP vapor compression technologies[20]. More information is then presented on highlighted technologies.

The technologies are presented in 2 different categories:

- Best Not yet Available Technology (BNAT) with the same product archetype (electric vapor compression cycle)
- Alternative technologies to electric vapor compression cycle

In each case, the technology is described; research and development stage are assessed as well as potential improvement potential and indications on costs when available.

4.2.1 BNAT based on same product archetype

Field performance measurement

On-board performance measurement method was already described in Task 3 as a way to measure the real life performances and operating conditions of air conditioners. The technology is mature, and several methods are available to every manufacturer that can be used with very limited cost. The compressor or the expansion valve performance maps can indeed be used as refrigerant flow meter, which combined with measurements that are already done for controlling the capacity of the unit gives access to the unit capacity.

These methods can also be used to improve fault detection[21] and then to help to maintain the performances of the units along their lifetime.

Standardization work could help ensuring their reliability. This could include methods to correct performance evaluation for dynamic conditions and the way faults are filtered, as well as possible checks of on-board measurement capabilities by third parties.

Refrigerant fluid with lower environmental impacts

There is not yet a consensus on the future refrigerant fluids that will be used for air conditioners after the bans of 2020 for portable air conditioners (GWP lower than 150) and of 2025 for split air conditioners (GWP lower than 750 for single split units) following Regulation (EU) 517/2014. For split air conditioners, the immediate solution is R32 with a GWP of 675. But it may be a temporary solution. For portable air conditioners, even if propane is already used, it is only by one manufacturer in Europe nowadays and other solutions may be preferred after 2020.

The fact that automotive industry already adopted the HFO R1234yf makes it a potential candidate for air conditioners too because it means that optimized components are readily available. However, size increase is probably too important, and this would tend to

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[18] http://www.ecodesign-fridges.eu/Documents/Household%20Refrigeration%20Review%20TECHNOLOGY%20ROADMAP%20FINAL%2020160304.pdf

[19] BRGP, CETIAT, CSTB, EDF, GDF SUEZ, Armines/Mines ParisTech, Besoins en R&D pour le développement des pompes à chaleur, Rapport final Convention ADEME : 1105C0043, Responsables du projet: David Canal et Michèle Mondot, Janvier 2014.

[20] S. Barrault, D. Clodic, E. Devin, T. Michineau, X. Pan, Alternatives to high GWP in refrigeration and air-conditioning applications, final report, study funded by Ademe, Afce and Uniclima, December 4 2013

[21] Kim, Woohyun and Braun, James E., "Evaluation of Virtual Refrigerant Mass Flow Sensors" (2012). *International Refrigeration and Air Conditioning Conference.* Paper 1245. http://docs.lib.purdue.edu/iracc/1245

decrease performances of air conditioners significantly as compared to R410A or R32. At similar performance levels than R32 and lower than 150 GWP, only hydrocarbons could be a solution in the future, but manufacturers are presently reluctant to use them because of the risks associated to their high flammability.

The low-GWP AHRI AREP program helps HVAC manufacturers in qualifying new fluid performances and in highlighting component required adaptation to use new fluids[22]. Besides R32, other alternatives to R410A have been tested with lower GWP[23]. This includes several blends of R32 and HFO with performance similar to the ones of R410A and GWP ranging from 272 to 482.

In parallel, research is still on-going to define possible refrigerant alternatives to replace R410A. NIST (USA National Institute of Standards and Technology) made an extensive research of all possible pure fluids[24] and added new molecules to the list of potential candidates screening all known molecules for low GWP, low ODP, high COP values and considering stability, toxicity and flammability criteria, see Figure 12. There appears only a limited choice, which includes already known solutions - R32, HFO, hydrocarbons, ammonia and CO2 - but also new molecules to be tested as single components or in blends -new HFO or similar substances, fluorinated oxygenates and fluorinated nitrogen and sulfur compounds, the safety parameters of the latter two families are still to be determined.

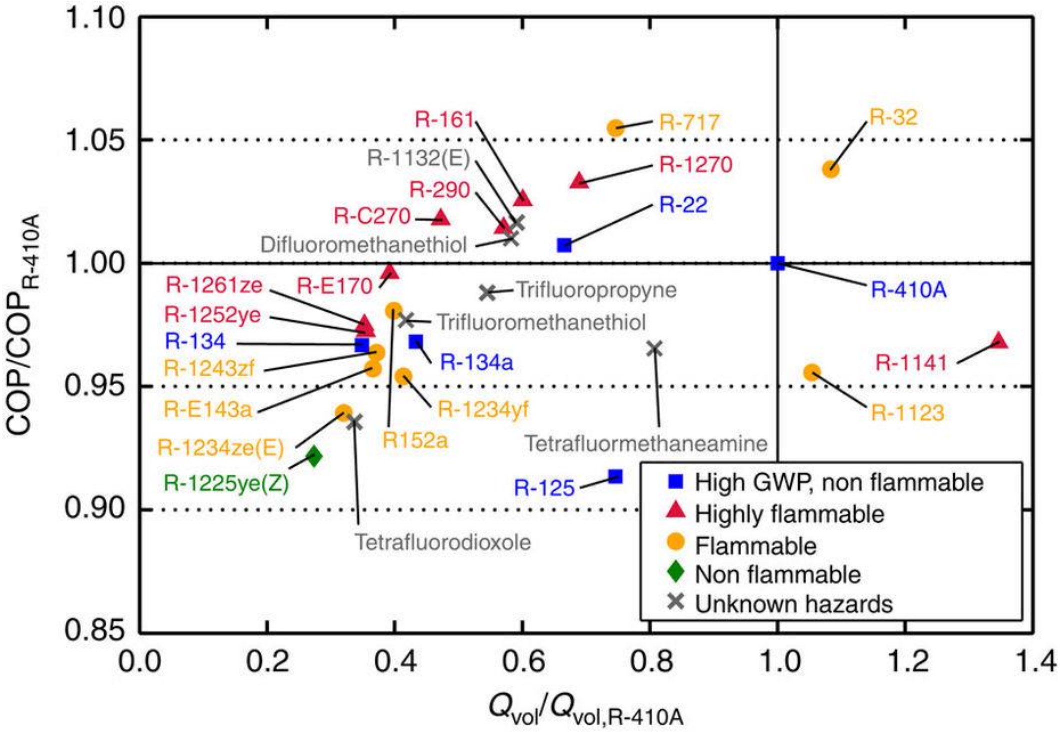

Figure 12: Coefficient of performance and volumetric capacity of selected low-global-warming-potential fluids[24]

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[22] http://www.ahrinet.org/arep.aspx

[23] http://www.ahrinet.org/App_Content/ahri/files/RESEARCH/AREP_II/CC-I-1_Bristol.pdf

[24] Mark O. McLinden, J. Steven Brown, Riccardo Brignoli, Andrei F. Kazakov & Piotr A. Domanski, Limited options for low-global-warming-potential refrigerants, Nature Communications 8, Article number: 14476 (2017). https://www.nature.com/articles/ncomms14476

Improved compressor efficiency

Air conditioner compressor use rotary vane compressors with DC inverter and very high efficiency motors. Research is still active to propose solutions to improve the performances of these compressors. This includes for instance improved compressor design such as rotary spool compressor[25], control of twin rotary intermediate pressure[26] and optimization of injection design and control.

Research is still on-going on small oil free centrifugal compressors, with working prototypes using gas lift bearings. The first advantage is to avoid the need for oil lubrication, which is useful to reach high temperature levels, but present limited improvement potential to improve efficiency above rotary compressor efficiency levels as oil circulating ratios are thought to be relatively low already (less than 0.5 % as a mass fraction of mass plus oil mass flow). Targeted isentropic efficiency levels are between 75 % and 79 %[27], which would present a small improvement only over best rotary compressor efficiency levels.

The overall potential impact of this on-going research which improves SEER or SCOP for air conditioners beyond present best efficiency levels is thus limited, although significant savings could be obtained for larger temperature differences and larger systems. Time to market is supposedly low.

Improved heat exchanger designs

Micro channel heat exchanger is now a mature technology with large OEMs already proposing market solutions. Research is still active however to optimize their design. For instance, the US DOE funded a project to develop miniaturized air-to-refrigerant heat exchangers that are 20% better, in size, weight and performance, which could then lead to 20 % more surface available at equivalent air conditioner outdoor unit size. Figure 13 below gives a view of proposed new designs to achieve such savings.

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[25] http://toradengineering.com/wp-content/uploads/2012/06/Torad-Rotary-Spool-Compressor-White-Paper.pdf

[26] Gang Yan, Qinglei Jia, Tao Bai, Experimental investigation on vapor injection heat pump with a newly designed twin rotary variable speed compressor for cold regions, In International Journal of Refrigeration, Volume 62, 2016, Pages 232-241.

[27] Cordin Arpagaus, Frédéric Bless, Stefan S. Bertsch, Adeel Javed, Jürg Schiffmann, Heat Pump driven by a Small-Scale Oil-Free Turbocompressor, System Design and Simulation, 12th IEA International Heat Pump Conference, Rotterdam, 2017.

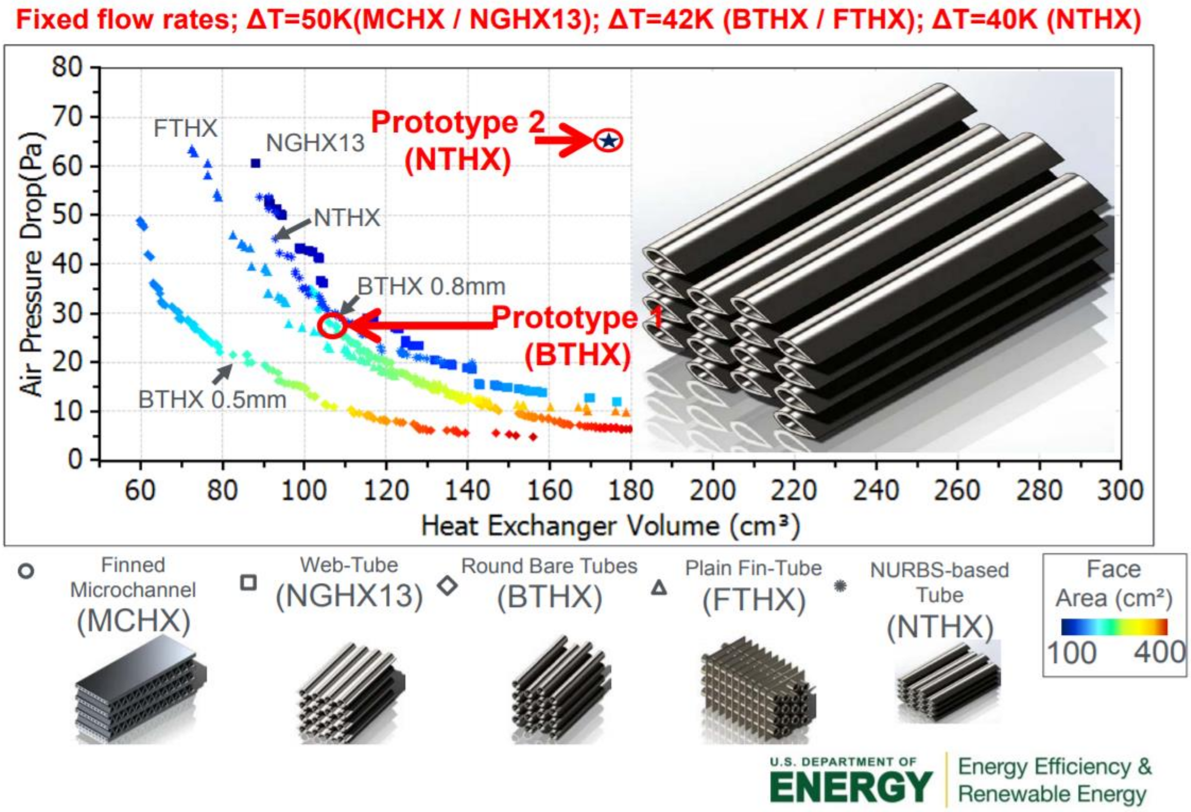

Figure 13: Miniaturized Air -to-Refrigerant Heat Exchangers research project findings illustration[28]

Higher fan motor efficiency

Most residential and smaller commercial HVAC units contain low efficiency induction fan motors. Higher efficiency Electronically Controlled Motors (ECM) that have become available have low power factors and thus give up much of their efficiency advantage. Moreover, ECM efficiency is limited due to the continual power conversions and electronic commutation required during operation.

Several technologies are in development to develop advanced motors with higher efficiency and power factor than available Induction or Electronically Controlled Permanent Magnet motors.

DOE has funded a project[29] to develop Parallel Path Magnetic Technology (PPMT). This technology promises to provide significant efficiency and upfront cost advantage compared to incumbent solutions for almost all electric motor compressor and fan applications for air conditioners.

Solar cooling

Most promising solar cooling option is the coupling of solar photovoltaic panel, DC electric air conditioner, with the very low cost of solar panels.

HVAC systems designed for DC-power would reduce the losses normally incurred from conversion of PV and battery electricity to AC power. Additionally, the systems would significantly offset the building's peak electrical demand since the peak solar resource generally coincides with highest space cooling demands. DC HVAC systems already exist

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[28] https://energy.gov/sites/prod/files/2016/04/f30/312103_Radermacher_040616-1505.pdf
[29] https://energy.gov/sites/prod/files/2017/04/f34/5_31296_Nichols_031517-1330.pdf

for specialized markets such as telecommunications, electronics, and transportation systems. The preparatory study already noted the will to market such products in 2007:

"*Sanyo announced the release of a product coupling solar panels and a classical air conditioner plus batteries. Cooling loads being high when electricity can be produced a small battery is advertised to be enough for the product to be almost independent from the grid.*"[30] But still limited options exist for building-scale HVAC systems.

Research studies show an interesting solar contribution for southern EU countries (e.g. 64 % of electricity coming from solar panels for an office building in Alicante, using 235 W photovoltaic panel, and a split with EER of 4.05 and 3.5 kW cooling capacity at nominal ratings[31]).

This is thus a quite interesting option for Southern EU countries in the present context of the development of renewable energies, with less subsidies and more self-consumption, with very low time to market if the right electricity tariffs and/or incentive conditions appear.

4.2.2 Alternative technologies to electric vapor compression

Vapor compression systems using electrically driven compressors are operated as Rankine cycle while utilizing refrigerant liquid–vapour phase change, and it has become the dominant use in heat pumps and air-conditioners around the world due to its scalability, reliability, the availability of nontoxic and non-flammable refrigerants, use of electricity (widely available), and relatively compact size.

Many alternative technologies to vapor compression have shown promising results in laboratory studies, but most have yet to be tested as full-scale prototypes. Further research and development is required to demonstrate the viability of alternative technologies, including demonstrating their ability to compete with conventional vapor compression products on cost, efficiency, reliability, maintenance requirements, occupant comfort, and safety.

There are a large number of technologies which, on the short to long term could reach the air conditioning market and compete with air conditioners. Figure 14 shows different alternative cooling technologies identified in (Goetzler et al., 2014)[17]. A focus is made for most promising ones according to existing roadmaps.

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[30] NYT, 2007, Sanyo Uses Sun to Cool Air, The New York Times, September 3, 2007.

[31] F.J. Aguilar, S. Aledo, P.V. Quiles, Experimental analysis of an air conditioner powered by photovoltaic energy and supported by the grid, In Applied Thermal Engineering, Volume 123, 2017, Pages 486-497.

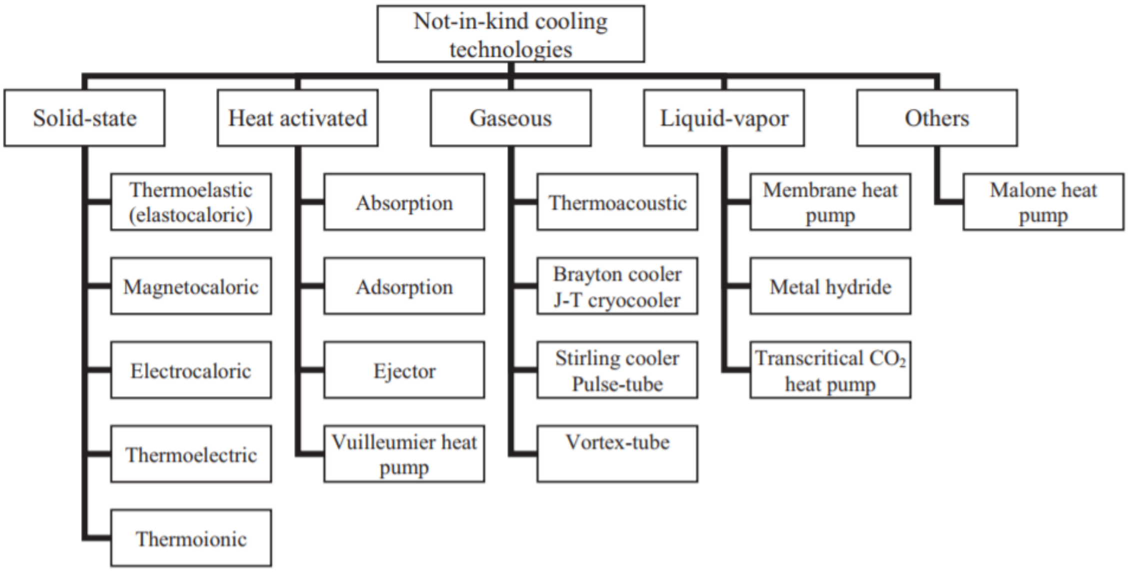

Figure 14: Alternative cooling technologies identified in (Goetzler et al., 2014)

Magnetic cooling

The operation principle of magnetic refrigerators is based on the magneto-caloric effect (MCE). The MCE is the ability of the material to change its bulk temperature when undergoing changes in the applied external magnetic field. Key points in the development of magnetic air conditioners are the cost of rare earth and that the exploitation of MCE around the desired temperature is limited by the fact that existing MCE materials do not achieve high temperature differences. Research projects aiming at finding new materials adapted to air conditioning appliance could be supported.

According to the US DOE, magnetocaloric air conditioning is an emerging technology with the potential for efficiency improvements of up to 25% over conventional vapor compression systems (when compared to minimum SEER requirements in the US)[32]. US DOE plans for magnetocaloric air conditioning market introduction over the period 2019-2023.

Elastocaloric or thermoelastic cooling

Elastocaloric cooling, also known as thermoelastic cooling, has been recognized as one of the most promising alternative to vapor compression cooling systems. It is based on the latent heat associated with the martensitic phase transformation process, which has been found in shape memory alloys (SMAs) when they are subjected to cyclic uniaxial loading and unloading stresses[33]. Efficiency potential is thought to be similar to the one of magnetic refrigeration.

Research is at the stage of designing commercial size prototype, including material choice, reliability of SMAs submitted to a large number of phase transformation cycles and heat exchanger design (heat recovery heat exchangers is of particular importance).

US DOE does not plan for magnetocaloric air conditioning market introduction before 2023.

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[32] Magnetocaloric Refrigerator Freezer, 2014 Building Technologies Office, US DEPARTMENT OF ENERGY

[33] Manosa, L., Planes, A., Vives, E., 2009. The use of shape-memory alloys for mechanical refrigeration. Funct. Mater. Lett. 2, 73–78.

Electro-chemical compression

Developing electrochemical compressors could offer scalable operation, utilize low GWP refrigerants, and operate with minimal noise, but their success ultimately depends on cycle efficiency and cost compared to electromechanical compressors. In place of a motor-driven compressor, electrochemical compressors raise the pressure of a hydrogen working fluid using a proton exchange membrane and electricity source. The pressurized hydrogen gas combines with water, ammonia, or another refrigerant, raising its pressure and driving the combined working fluid through condenser, expansion valve, and evaporator in a standard vapor-compression cycle. Prototypes have already been developed and tested by Xergy Inc. however; it remains system integration (developing compatible heat exchangers, controls and seals with this new system compression). US DOE plans for market introduction over the period 2019-2023.

Thermal compression

Stirling cycle has been the subject of numerous energy researchers for decades as being theoretically the most efficient cycle. This is a motor cycle that uses hot and cold source to produce mechanical work which can be used to run the mechanical compressor of a standard vapor compression cycle. The hot source can be gas or other fossil or renewable fuel. A recent variation of this cycle using thermal compression and a CO_2 supercritical cycle has been developed[34]. Burning gas, designed as a high temperature air-to-water heat pumps, η_s value of close to 2 (according Regulation N (EU) 813/2013) are foreseen, which would make it the best available technology on this segment. Development of such a system in an air-to-air version could allow reaching higher SCOP values than present BAT levels, but with however lowering efficiency levels in cooling mode. Note that there is no planned development of such system for now which means that it most likely could not reach the market before 2020 to 2025.

Electro-caloric heat pump

Electrocaloric cooling is a recent technology. When exposed to an electric field, electric (dipole) moments in the material become oriented and the entropy is reduced. This is similar to the magnetic field induced magnetic moment change in Magnetocaloric materials. Quite a few materials candidates have been developed so far, most of which are polymers or ceramics. P(VDF-TrFE) and P(VDF-TrFE-CFE) have shown superior latent heat to other materials. One challenge for this technology is the limitation in the shape of the materials. Only thin films can be applied since a high electric field is needed (hundreds of MV/m). However, no power efficiency, parasitic pump power and other losses were included. More studies are on both materials level and system level prototype development is still needed to fully understand the potential for this NIK technology. This is thus a potential technology for the long-term.

Summary and development status

Based on the above, the Table 12 below presents a summary comparing the status of the different alternatives to vapor compression technologies, as well as energy efficiency improvement potential, expected cost, complexity and barriers.

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[34] http://www.boostheat.com

Table 12 Summary and status of the different alternatives to vapor compression technologies

	Potential	Development status	Expected cost	R&D barriers
Magnetic cooling	+25% MEPS US	Emerging	Moderately higher	Cost of rare earth + low temperature difference
Elastocaloric cooling	+25% MEPS US	R&D	Equal or lower	Reliability of material to a very large number of cycles
Electro-chemical compression	-	Available prototypes	Moderately higher	Integration of all components
Thermal compression	Lower cooling efficiency	Emerging (heating mode only, air-to-water segment)	Higher	Lower cooling efficiency
Electrocaloric heat pump	-	R&D	Higher	Shape of the materials

4.3 Production and distribution

The production and distribution provide a quick overview of the material composition and distribution of air conditioners and comfort fans. The inputs will be used to model the environmental footprint in later task. The material composition also gives valuable inputs to the discussion on resource efficiency.

4.3.1 Bill-of-Materials (BOM)

This section the BOM of air conditioners and comfort fans are presented. The presented values will be used as inputs in the EcoReport Tool for Task 5.

Bill-of-Materials (BOM) of air conditioners

The material composition and weight of air conditioners are expected to be very similar to the values presented in the preparatory study. The preparatory study assumed an average weight of 14 kg/kW. These numbers cover an indoor unit of 4 kg/kW and an outdoor unit of 10 kg/KW. These values seem a little high compared to the values presented in Table 8. The updated existing average products suggest the following correlation between the weight and capacity:

- Reversible split (0-6 kW): 11.8 kg/kW
- Reversible split (6-12 kW): 13.5 kg/kW
- Portable air conditioner: 12.3 kg/kW

The above presented values will be used in the current study.

The material composition of air conditioners is expected to be unchanged since the preparatory study why the assumptions from the preparatory study are adopted to the current review study. The preparatory study based the average material composition on 32 bills of materials received from stakeholders. The average expected material composition of air conditioners is presented in the table below.

Table 13: Average material composition of air conditioners

Material Type	Monosplit		Multi-split % (4 units only)
	Average %	Modal %	
Bulk Plastics	16	(14)	13
TecPlastics	2	(0)	0
Ferrous	45	(47)	57
Non-ferrous	24	(25)	23
Coating	0	(0)	0
Electronics	3	(<1)	2
Misc.	11	(13)	6

These assumptions are consistent with values stated by a manufacturer[35] on their homepage and presented in Figure 15. The main materials in air conditioners are ferrous and non-ferrous which constitutes more 65 % of the weight. The composition presented below shows that steel is the dominant material followed by copper.

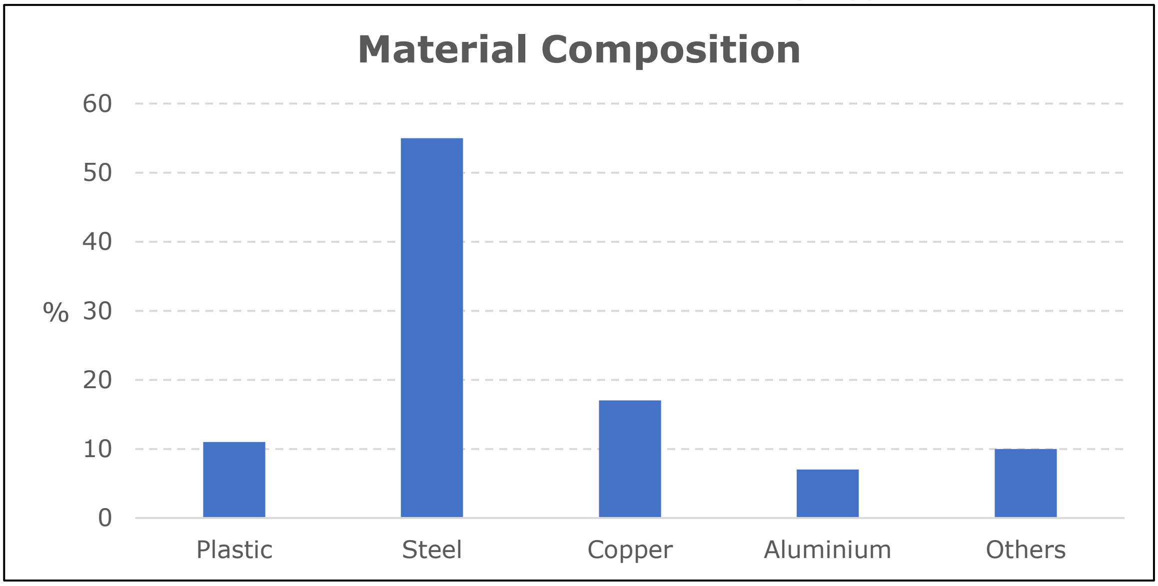

Figure 15: Material composition of fixed air conditioners based on information from a manufacturer's homepage.

Regarding portable air conditioners and VRF systems the material composition will be modelled based on the average material composition of split air conditioners presented in Table 13.

Bill-of-Materials (BOM) of comfort fans

The material composition of comfort fans is also based on the preparatory study as there is no evidence showing significant changes to the design and material use for comfort fans since preparatory study. The material composition is presented below:

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[35] https://panasonic.net/eco/petec/process/

Table 14: Material composition of comfort fans

Material Type	Tower fan	Pedestal fan	Table fan	Box fan
Bulk Plastics	50%	15%	29%	50%
TecPlastics	0%	0%	0%	0%
Ferrous	23%	54%	35%	28%
Non-ferrous	12%	20%	19%	2%
Coating	0%	0%	0%	0%
Electronics	0%	0%	0%	0%
Misc.	14%	12%	17%	19%

Depending on the type of fan the share of plastic varies greatly from 15 % to 50 %.

4.3.2 Primary scrap production during manufacturing

The primary scrap production is estimated to be negligible in. It is assumed that cuttings and residues are directly reused into new materials. So, the actual losses of materials are low.

4.3.3 Packaging materials

Cardboard, plastic and expanded polystyrene are used to protect the products during transport. More packing materials are sorted by the end user and recycled. Cardboard are easily recyclable for the next purpose while the plastic likely is burned or recycled otherwise. Regarding the expanded polystyrene it can be compressed and recycled into polystyrene. The problem is the density and volume of the expanded polystyrene. It must be compressed to make it both affordable and environmentally sound. It could also be burned.

4.3.4 Volume and weight of the packaged product

The combined volume of the indoor and outdoor unit is presented in the below table. Data are based on air conditioners from TOPTEN[36].

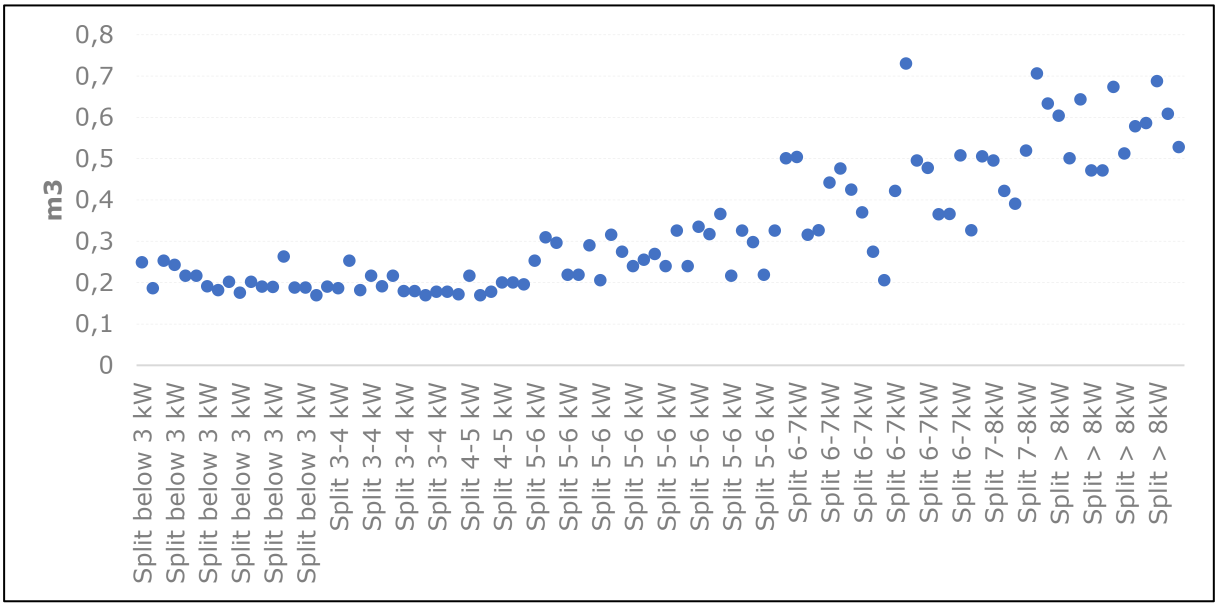

Figure 16: Combined size of indoor and outdoor unit

The presented values are the dimensions of the outdoor and indoor unit without packaging. For an average product with a size in the range of 3-4 kW it can be assumed the volume of the two packages roughly corresponds to 0.25 m^3.

The following assumptions from the preparatory study are adopted to the current review regarding comfort fans:

- Table fan: 0.06 m^3
- Pedestal fan: 0.15 m^3
- Tower fan: 0.08 m^3
- Box fan: 0.06 m^3

4.3.5 Means of transport

The means of transport are often negligible in life cycle assessments since the impact often is small compared to the environmental impact of the rest of the product. Most air conditioners are assumed to be shipped by freight ship or by truck. Both means of transport have in general a low impact in the final assessment.

4.4 End-of-Life

Resource efficiency is a growing concern within Europe. More raw materials are categorised as critical and the dependency of these materials are increasing. More manufactures are actively working with take-back schemes and recycling of products:

- Daikin started a national scheme in Belgium for collecting and recycling air conditioners in 2008. The air conditioners collected in Belgium are both Daikin units and units of other brands when the reach the end of their working life. This scheme

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[36] http://www.topten.eu/english/recommendations/policy-recommendations-room-air-conditioners.html&fromid=

has increased the mass of collected units in Belgium from 42.5 tonnes to 73.40 tonnes in 2012. Daikin has also introduced different schemes or participated in existing take back schemes in Greece, Italy, Spain and in Netherlands[37].

- Toshiba has a case study in Japan investigating the use of plastics in air conditioners recycled from decommissioned air conditioners. They collect glass fiber-reinforced AS resin from old air conditioners. When the old air conditioners arrive at the facility the unit is dismantled, and the selected plastic parts are crushed, cleaned and the contaminants are removed. Afterwards are the processed plastic shipped to another company for recycling. The recycled plastics are then used as materials for outdoor unit fans in home and industrial air conditioners[38].

Most of the air conditioners and comfort fans are though expected to be collected through national collection schemes. The following sections describe the current collection rate and the pre-processing of the equipment. Furthermore, different options to improve the resource consumption are discussed.

4.4.1 Technical product life

The technical product life is described in task 3. The average lifetime of air conditioners varies between 10 and 15 years (12 years used in later tasks). The estimated lifetime of comfort fans is 10 years.

4.4.1 Materials flow and collection at end-of-life

Air conditioners and comfort fans are collected at end-of-life and send suited facilities for reprocessing. Illegal trade and sales of scrap challenge the collection rate for some product categories. The statistics from Eurostat shows products put on the market and waste collected for large household equipment[39]. This statistic does not refine the actual number of air conditioners collected so the actual collection rate can be difficult to quantify. This is also the case for comfort fans.

From 2019 onwards, the minimum collection rate to be achieved annually shall be 65% of the average weight of Electrical and Electronic Equipment (EEE) placed on the market in the three preceding years in each Member State, or alternatively 85% of Waste Electrical and Electronic Equipment (WEEE) generated on the territory of that Member State. Below in Table 15 is the collection rate for large household appliances calculated based on the WEEE collected in 2014 and the average weight of EEE placed on the market in the three preceding years:

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[37] http://eu.daikineurope.com/corporate-home/environment-leadership/initiatives-throughout-the-product-life-cycle/end-of-life/

[38] https://www.toshiba.co.jp/env/en/products/homeappliance.htm

[39] http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_waselee&lang=en

Table 15: Calculated collection rate of large household equipment in Europe, 2014[40]

	Average EEE put on the market 2011-2013	WEEE collected 2014	Collection rate
Austria	77,662	31,199	40%
Belgium	107,115	50,781	47%
Bulgaria	38,664	30,286	78%
Croatia	23,445	5,275	22%
Cyprus	8,350	1,222	15%
Czech Republic	72,575	27,828	38%
Denmark	65,210	32,890	50%
Estonia	8,223	1,854	23%
Finland	71,690	33,917	47%
France	918,570	292,730	32%
Germany	748,121	239,662	32%
Greece	86,162	27,317	32%
Hungary	45,004	28,682	64%
Iceland	3,305	1,696	51%
Ireland	38,306	23,797	62%
Italy	501,190	142,666	28%
Latvia	8,728	2,490	29%
Liechtenstein	36	75	208%
Lithuania	15,352	12,429	81%
Luxembourg	4,690	2,586	55%
Malta	6,206	971	16%
Netherlands	112,119	64,496	58%
Norway	70,451	49,402	70%
Poland	244,980	81,082	33%
Portugal	73,738	33,154	45%
Romania	75,341	20,465	27%
Slovakia	25,087	11,590	46%
Slovenia	17,030	4,535	27%
Spain	355,992	101,827	29%
Sweden	107,447	71,306	66%
United Kingdom	708,172	296,520	42%
Total	4,638,962	1,724,730	37%

The collection rate for large household equipment at EU level was just below 40 % in 2014. This value should be improved to 65 % in 2019. The low collection rate of products cannot be directly addressed in the Ecodesign regulation, but should be addressed by each Member State how they will fulfil their obligation regarding the WEEE directive.

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[40] http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_waselee&lang=en

4.4.1 Recyclability of air conditioners and comfort fans

After collection, air conditioners and comfort fans are treated at suited facilities. Air conditioners are handled together with other appliances containing refrigerants such as refrigerators. These appliances are treated at specialised facilities which can handle the refrigerants. The waste process flow[41] for commercial refrigerants appliances (CRA) are visualised in Figure 17.

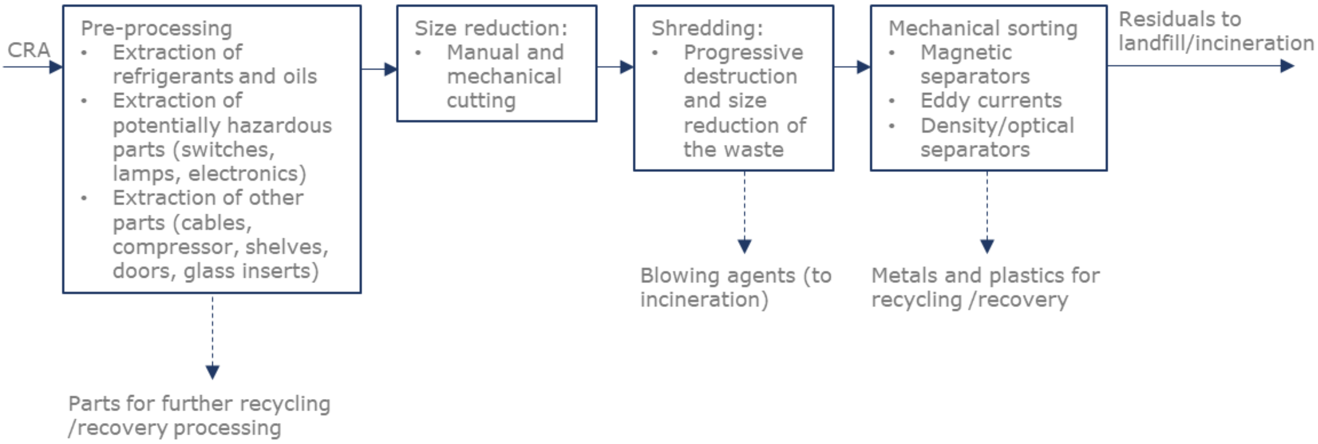

Figure 17: The waste process flow for commercial refrigerants appliances

The pre-processing[42] is the first step in the recycling process of air conditioners. This first step often consists of manual removing of targeted components and/or materials for further treatment. The pre-processing is very important in connection with an effective recycling process by reducing the risk of contamination, quickly recover selected valuable materials and allow compliances with current legislation on hazardous substances and waste and prevent damage to the facility in the following steps. It is also during the pre-processing the refrigerants and oils are removed by piercing the tubes followed by suction to safely remove these substances (for split systems the refrigerants are also often removed during the dismounting on site). The heat exchangers of air conditioners are likely to be removed since they contain a lot of copper. According to the WEEE-directive components such as electronic components (e.g. printed circuit board, capacitors, switches, thermostat, liquid crystal displays) and lighting systems (gas discharge lamps) are additionally dismantled when present. Equipment with large dimensions might be cut to smaller pieces before shredding.

Next step[43] is shredding, which reduces the air conditioners in smaller pieces. These facilities also handle insulation foams which may contain different hydrocarbons so these are removed in an initial shredding in closed atmosphere. These foams are usually burned.

When the equipment is shredded into smaller pieces (approximately 1 cm to 10 cm) different technologies handles the sorting. These technologies are often:

- Magnetic separation removing ferrous metals
- Eddy current separators removing non-ferrous metals such as copper, aluminium, and zinc
- Density separators for different types of plastic.

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[41] http://www.sciencedirect.com/science/article/pii/S0921344915300021
[42] http://www.sciencedirect.com/science/article/pii/S0921344915300021
[43] http://www.sciencedirect.com/science/article/pii/S0921344915300021

Comfort fans are assumed to be recycled at regular shredders which are very similar to the above description except the handling of refrigerants.

The effectiveness or recycling rate of the shredder (the share of recovered, recycled, and reused materials) is based on the EcoReport tool[44] but updated regarding plastics[45]. The values used in the current study are presented in Table 16.

Table 16: Recycling rates from EcoReport Tool adopted in the current study

	Bulk Plastics TecPlastics*	Ferro Non-ferro Coating	Electronics	Misc.	refrigerant
EoL mass fraction to re-use, in %	1%	1%	1%	1%	1%
EoL mass fraction to (materials) recycling, in %	29%	94%	50%	64%	30%
EoL mass fraction to (heat) recovery, in %	40%	0%	0%	1%	0%
EoL mass fraction to non-recov. incineration, in %	0%	0%	30%	5%	5%
EoL mass fraction to landfill/missing/fugitive, in %	31%	5%	19%	29%	64%
TOTAL	100%	100%	100%	100%	100%

**Adjusted values compared to the EcoReport tool*[46]

With these numbers the total recycling rate (including incineration) is above 85 % which is in line with information provided by stakeholders[47]. The numbers also express high recycling rates for metals and lower rates for plastic. Traditionally is it also easier for recycling facilities to recover the value of metals than plastic. Plastic are often mixed with other types of plastics which challenge the quality of the recycled plastic. Often recycled plastics are downgraded if it is not properly separated.

4.4.2 Design options regarding resource efficiency

Different approaches can be implemented towards improved resource efficiency at End-of-Life. Several options are available for design improvements and covers both more holistic guidelines and product specific suggestion.

Common "design for X" practices which cover all types of EEE products could be[48]:

- Minimise the number and type of fasteners, so fewer tools are needed during disassembly and repair
- The fasteners should be easily accessible and removable

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[44] http://ec.europa.eu/growth/industry/sustainability/ecodesign_da

[45] Plastic Europe, Available at: http://www.plasticseurope.org/documents/document/20161014113313-plastics_the_facts_2016_final_version.pdf

[46] Plastic Europe, Available at: http://www.plasticseurope.org/documents/document/20161014113313-plastics_the_facts_2016_final_version.pdf

[47] Data collection from stakeholders, September, 2017

[48] Chiodo, J., 2005. Design for Disassembly Guidelines. Available at: http://www.activedisassembly.com/strategy/design-for-disassembly/.

- Easy to locate disassembly points
- If snap fits are used, they should be obviously located and possible to open with standard tools to avoid damaging the product during repair.
- It is beneficial if fasteners and materials are either identical or are compatible with each other in the recycling process
- The use of adhesive should be minimised
- Minimise the length of cables to reduce the risk of copper contamination, or connection points could be designed so they can break off
- Simple product design is preferable

These suggestions are not specifically targeting air conditioners or comfort fans, they are suggestions for all EEE products, which need to be evaluated on a case by case basis. Some of these suggestions are targeting manual disassembly which not is assumed to be the preferred recycling technology within EU. Though, if air conditioners are easy to disassemble more people might consider repairing the product. The possible effect of these suggestions is difficult to quantify.

Guidelines based on resource criticality

The awareness of resource criticality is increasing, and the Commission carries out a criticality assessment at EU level on a wide range of non-energy and non-agricultural raw materials. In 2017, the criticality assessment was carried out for 61 candidate materials (58 individual materials and 3 material groups: heavy rare earth elements, light rare earth elements and platinum group metals)

The following main parameters are used to determine the criticality of materials[49]:

- Economic importance - the importance of a material for the EU economy in terms of end-use applications and the value added of corresponding EU manufacturing sector.
- Supply risk - reflects the risk of a disruption in the EU supply of the material. It is based on the concentration of primary supply from raw materials producing countries, considering their governance performance and trade aspects.

The updated list of critical raw materials is presented in the below table.

Table 17: List of critical raw materials

Critical raw materials 2017			
Antimony	Fluorspar	LREEs	Phosphorus
Baryte	Gallium	Magnesium	Scandium
Beryllium	Germanium	Natural graphite	Silicon metal
Bismuth	Hafnium	Natural rubber	Tantalum
Borate	Helium	Niobium	Tungsten
Cobalt	HREEs	PGMs	Vanadium
Coking coal	Indium	Phosphate rock	

*HREEs=heavy rare earth elements, LREEs=light rare earth elements, PGMs=platinum group metals

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[49] https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_da

Both air conditioners and comfort fans may contain several raw materials categorised as critical. Raw materials like vanadium and phosphorous are in some designations of steel used as alloying elements. These alloying elements are not included in this assessment as they are very difficult to quantify and more obvious choices are present such as:

- Printed circuit boards which may contain several critical materials such as gold, silver, palladium, antimony, bismuth, tantalum etc.[50]
- Compressor and heat exchangers which may contain copper
- Wires which may contain copper
- Motor (comfort fans)

The composition of printed circuit boards is difficult to quantify but it is estimated as low grade for air conditioners and comfort fans. The product development of air conditioners indicates higher grades of boards in the future due to the implementation of more functions.

Printed circuit board are already targeted components according to the WEEE-directive and compressors, heat exchanger and wires are already target due to their high amount of copper. Copper is also very important to remove before shredding to minimise the risk of copper contamination in the iron fraction since it directly can influence the mechanical properties of the recycled iron/steel[51]. Avoiding contaminants is one of the key points of design for recycling guidelines. Design for recycling mainly focuses on the recycling compatibility of different materials avoiding losses at End-of-Life. This can be done by respecting a few common guidelines such as minimising the use of non-reversible adhesives. See more details in Annex 1.

Guidelines supporting the WEEE directive

The WEEE directive contains several parts supporting resource efficiency and selective requirements. How the directive is interpreted and adopted to the member states can vary greatly. Based on WEEE-directive special articles and annexes are highlighted below to pinpoint which design improvements which could comply with the directive:

- <u>Article 4, Product design:</u> *"Member States shall, without prejudice to the requirements of Union legislation on the proper functioning of the internal market and on product design, including Directive 2009/125/EC, encourage cooperation between producers and recyclers and measures to promote the design and production of EEE, notably in view of facilitating re-use, dismantling and recovery of WEEE, its components and materials."*
- <u>Article 8, Proper treatment:</u>
    - Member states shall ensure that all separately collected WEEE undergoes proper treatment including the removal of the following components following substances, mixtures and components:
        - Mercury containing components, such as switches or backlighting lamps
        - Batteries

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[50] http://www.wrap.org.uk/sites/files/wrap/Techniques%20for%20recovering%20printed%20circuit%20boards%2C%20final.pdf

[51] http://www.rmz-mg.com/letniki/rmz50/rmz50_0627-0641.pdf

        - Printed circuit boards of mobile phones generally, and of other devices if the surface of the printed circuit board is greater than 10 square centimetres,
        - Plastic containing brominated flame retardants,
        - Chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC) or hydrofluorocarbons (HFC), hydrocarbons (HC),
        - External electric cables,
    - The following components of WEEE that is separately collected have to be treated as indicated:
        - Equipment containing gases that are ozone depleting or have a global warming potential (GWP) above 15, such as those contained in foams and refrigeration circuits: the gases must be properly extracted and properly treated. Ozone-depleting gases must be treated in accordance with Regulation
- Article 15 Information for treatment facilities: *"In order to facilitate the preparation for re-use and the correct and environmentally sound treatment of WEEE, including maintenance, upgrade, refurbishment and recycling, Member States shall take the necessary measures to ensure that producers provide information free of charge about preparation for re-use and treatment in respect of each type of new EEE placed for the first time on the Union market within one year after the equipment is placed on the market."*

Design for re-use, dismantling and recovery of WEEE all fits in the category of design for repair. Design for repair is described in Annex 1. The overall purpose of design for repair is to ease the repair process by allowing easy access to critical components. Based on stakeholder inputs printed circuit boards and compressors are among the most bought spare parts. These parts should ideally be easily located and changed if possible. If printed circuit boards are located and removed easily it also fits with the proper treatment definition if this information also are available for the recycling facilities. Regarding refrigerants pump-down systems may be beneficial in the recycling process and preventing leakage before the equipment is handled at the facility.

Resource efficiency requirements in other ecodesign regulations
Some of the above-mentioned suggestions for addressing resource efficiency of air conditioners are already part of the most recent suggestions for other household appliances(dishwashers, washing machines, refrigerators).

The overview of requirements in other ecodesign regulations shows that the emphasis is placed on repair information, ease of dismantling and the availability of spare parts. The effect of such requirements may have little impact in each regulation vertically as the energy consumption often is the most important factor in relation to emission of CO_2. However, if material efficiency requirements are aligned across several regulations, the impact can be much greater, and it ensures regulatory consistency within ecodesign framework. In Table 18, different resource efficiency requirements in other regulations are presented.

Table 18: Alignment with other regulations

	Information requirements for refrigeration gases	Requirements for dismantling for the purpose of avoiding pollution, and for material recovery and recycling	Spare part availability	Spare part maximum delivery time	Access to repair and maintenance information
Dishwashers (Not yet adopted)	x	x	x	x	x
Washing machines (Not yet adopted)	x	x	x	x	x
Domestic refrigerators and freezers (Not yet adopted)		x	x		
Water Heaters					x
Domestic and commercial ovens, hobs and grills					x
Residential Ventilation					x
Circulators and pumps					x
Ventilation Fans					x
Electric motors					x
Vacuum cleaners					x
Local room heating products					x
Domestic and commercial ovens, hobs and grills					x
TVs					x
Personal computers and portable computers		x			

Dishwashers and washing machines may have the most ambitious requirements regarding resource efficiency and requirements that support the circular economy. These regulations are not yet adopted but they received general support[52]. Previously there have been different requirements regarding information relevant for the disassembly, but one of the greatest barriers towards increased repair and refurbishment is the lack of available spare parts[53]. Though these requirements are difficult to quantify with the current methodology, a study from Deloitte[54] suggest that the following options might have a positive effect on the environment and these are to a large extent the same requirements proposed for ecodesign regulations for white goods as presented in table above:

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[52] Industry stakeholders did not strongly oppose resource efficiency requirements, however proposed change of wording in the current formulation of a few requirements, stakeholder comments 2017.

[53] Deloitte (2016) Study on Socioeconomic impacts of increased reparability – Final Report. Prepared for the European Commission, DG ENV.

[54] Deloitte (2016) Study on Socioeconomic impacts of increased reparability – Final Report. Prepared for the European Commission, DG ENV.

- Measures to ensure provision of information to consumers on possibilities to repair the product
- Measures to ensure provision of technical information to facilitate repair to professionals
- Measures to enable an easier dismantling of products
- Measures to ensure availability of spare parts for at least a certain amount of years from the time that production ceases of the specific models
- Different combination of the above-mentioned options

The effect of these options and the study from Deloitte are further described in Annex 2.

Based on the above considerations it is therefore recommended to consider aligning with resource efficiency requirements regulations for dishwashers/washing machines or domestic refrigerators and freezers.

Recommendations regarding resource efficiency

The low collection rate of air conditioner and comfort fans can challenge the improvement potential of any suggestions regarding resource efficiency since many products does not reach the desired recycling facility. The collection rate is expected to increase and fulfil the WEEE directive in 2019. The current low collection rates cannot be directly addressed in the Ecodesign regulation since it is not related to the design of the product.

Based on the list of critical raw materials and the WEEE directive the following components and materials are of special interest:

- Printed circuit boards
- Compressor and heat exchangers

These components should follow some of the common “design for X” practices described in the beginning of section 4.4.2 so these targeted components could easily be repaired or removed at End-of-Life supporting the WEEE directive and improving the recycling of critical resources.

The possible points to be considered and discussed with stakeholders for improving resource efficiency of air conditioners:

- Requirements of availability of spare parts (selected parts)
- Requirements of exploded views and instructions for disassembly
- Requirements regarding the number of operation to remove targeted components (e.g. printed circuit boards greater than 10 square centimetres)
- Requirements of pump-down systems to minimise leakage of refrigerants End-of-life

All the above suggestions should be carefully discussed since the impact can be difficult to quantify, but also difficult for the market surveillance authorities to check. The improvement potential is also difficult to quantify since the improvement potential is calculated in CO_2-eq. Though, the study from Deloitte[55] indicates that some of these

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[55] Deloitte (2016) Study on Socioeconomic impacts of increased reparability – Final Report. Prepared for the European Commission, DG ENV.

requirements may have a positive impact on the environment. The best solution could be alignment with other regulations that already have some of these requirements.

4.5 Conclusions and recommendations

Based on above presentation of existing products, BAT, improvement options to achieve BAT levels, technology roadmap showing the different future paths for cooling technologies in air conditioners, typical production and distribution processes and end-of-life aspect issues, key conclusions have been presented in this section.

Technical product description

The technical analysis leads to propose 3 air conditioner average products to represent the 0-12 kW product range. Weighting coefficients to represent the global environmental impacts of the product segments for Task 5 have been assessed. The existing products main characteristics are summarized in Table 19, these can be used for defining base cases in Task 5.

Table 19: Existing average products main characteristics

	Type	Reversible split [0-6kW]	Reversible split [6-12kW]	Portable
General description	Mounting / type	Wall single split	Wall single split	Single duct
	Price (Euros)	743	1948	358
Refrigerant fluid	Type	R410A	R410A	R410A
	Charge	0.98 kg	2.01 kg	0.5 kg
Cooling performances	Cooling capacity kW	3.5 kW	7.1 kW	2.6 kW
	SEER	6.00	5.80	2.65 (35/35)/ SEER 2.09
Heating performances	Pdesignh kW	3.1 kW (-7°C)	5.6 kW (-10°C)	NA
	SCOP	4.0	4.0	NA
Other power values	Crankcase Heater	0 W	0 W	0 W (no crankcase)
	Thermostat-off	18 W	30 W	25 W
	Standby	3 W	6 W	1 W
Sound power values	Outdoor	62 dB(A)	66 dB(A)	NA
	Indoor	57 dB(A)	60 dB(A)	63 dB(A)
Weight	Total kg	41 kg	96 kg	32 kg

Available improvement options have been screened. The main ones are to increase heat exchanger size and to improve compressor efficiency. These are the options used today to reach **BAT levels**, for which estimations have been given:

- Split 0-6 kW range: SEER 10.5, SCOP 6.2

- Split 6-12 k range: SEER 8 (SCOP=4), SCOP 4.9 (SEER=7.4)
- Portable: EER= 3.6 (35°/35°)/ SEER= 2.82

In view of a possible **revision of the EU energy label**, **BNAT** target values that can typically be used to define the A energy class efficiency level have been assessed, with values slightly above BAT levels:

- Split 0-6 kW range: SEER 11.3, SCOP 6.3
- Split 6-12 k range: SEER 11.3, SCOP 6.3
- Portable: EER of 5.45 (27/27) (or EER 4.9 at 35/35) and SEER of 4.3

All these units will have to use new refrigerant fluids by 2020 for portable air conditioners and most of them by 2025 for split air conditioners below 12 kW (the ban does not apply to multi-split units) according F-gas Regulation (EU) 517/2014. For split units, the conversion to R32 (GWP 675) instead of R410A is already well advanced and best available products, close to BAT levels, already use R32. However, for portable units, only one manufacturer is starting to use refrigerant with lower than 150 GWP. In addition, since it is proposed to change the metrics for a seasonal performance metrics, there are more uncertainties on the technical options available to manufacturers to supply products in the coming years. It is one of the reasons why the BAT level has been limited to EER of 3.6 (35°/35°) (present A++ existing product).

It is also to be noted that present BAT level split units in the 0-6 kW range and portable air conditioners have sound power levels close to the maximum sound power requirements in Regulation (EU) 206/2012. So, for these units, further limitation of sound power level may come at a cost that is to be accounted for in life cycle cost evaluation. There is however a larger margin for 6-12 kW split units, although it varies significantly depending on the indoor unit mounting type.

Technology roadmap

There are ongoing R&D works to improve the efficiency and decrease the environmental impact of HVAC systems in general which may affect the future of air conditioners. Urgent research regards the refrigerant fluids to be used in a few years to replace present HFC is also going on. Solar photovoltaic electric air conditioner could be developed in the coming years, which can offer an interesting solution to consume more renewable electricity and limit grid impact of air conditioning in southern EU countries. Several alternative technologies to electric vapor compression could also reach the market before 2023 and they can compete with present air conditioners; this includes magneto-caloric cooling and electro-chemical compression.

Production and distribution

The BOM of air conditioners and comfort fans are largely maintained the same as presented in the preparatory study as there is no evidence showing significant changes to the design and material use for these products since the preparatory study.

End-of-life, resources criticality and efficiency

Total EU collection rate for large EEE equipment is 37% in 2014. The collection rate is expected to increase to 65 % in 2019. The current low collection rate of these products cannot be directly addressed in the Ecodesign regulation, but should be addressed by each Member State how they will fulfil their obligation regarding the WEEE directive.

After collection the air conditioners are shredded at specialised facilities with an assumed recycling rate above 85 % as most of the air conditioners consist of iron. The recycling rate of iron is expected to be high. Though, the critical resources are mainly located in the heat exchanger, compressor, and the printed circuits boards as they all contain platinum group metals. It should therefore be investigated how the recycling of these components can be improved. This can be done by simple design guidelines which improve the liberation or removal at End-of-Life. Some of these suggestions are already included in other regulations and it could prove beneficial to align with these regulations.

These suggestions should be properly discussed with stakeholders.

Annex 1: Design guidelines

The following design guidelines are common design guidelines improving the recycling and repair process of EEE products and are not only specifically targeting air conditioners or comfort fans. The guidelines provide a number of ideas of simple operation which improves the resource efficiency of products either in the recycling process or by a prolonged life.

Design for recycling

Design for recycling is quite complicated due to the mix of products at End-of-Life. Different products are discarded together which increases the complexity and risk of contamination. Even within the same product group contaminant can appear. To prevent contamination End-of-Life and to improve the quality of the recycled product it is important to consider the material mix and how the different materials are liberated at End-of-Life. For design for recycling, it is important to consider[56]:

- To reduce the use of materials, and especially the use of materials that will cause loss or contamination in the recycling process. It should be considered how the materials would behave in the sorting and processing End-of-Life
- To identify materials in assemblies combined in an inappropriate way so resources are lost during recycling. E.g. the connection between a metal screws and plastic, where one of them may be lost due to incomplete liberation. Also, some mix of metal are problematic, and the different types om smelters cannot handle all types of metal. In Figure 18 the metal wheel is shown which explains which resources can be recovered by the different smelters. In Table 20 a rough guideline for plastic recyclability is shown.
- Proper labelling both on plastic, but also general futures such as marking of tapping points of generators
- Minimise the use non-reversible adhesives, and avoid the use of bolt/rivets to obtain maximum liberation at End-Of-Life

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[56] Reuter, M.A. & Schaik, A.V.A.N., 2013. 10 Design for Recycling Rules , Product Centric Recycling & Urban / Landfill Mining. , pp.1–15.

🟦 **Society's Essential Carrier Metals: Primary Product** Extractive Metallurgy's Backbone (primary and recycling metallurgy). The metallurgy infrastructure makes a "closed" loop society and recycling possible.

🟦 **Dissolves mainly in Carrier Metal if Metallic (Mainly to Pyrometallurgy)** Valuable elements recovered from these or lost (metallic, speiss, compounds or alloy in EoL also determines destination as also the metallurgical conditions in reactor).

☐ **Compounds Mainly to Dust, Slime, Speiss, Slag (Mainly to Hydrometallurgy)** Collector of valuable minor elements as oxides/sulphates etc. and mainly recovered in appropriate metallurgical infrastructure if economic (EoL material and reactor conditions also affect this).

🟩 **Mainly to Benign Low Value Products** Low value but inevitable part of society and materials processing. A sink for metals and loss from system as oxides and other compounds. Comply with strict environmental legislation.

El **Mainly Recovered Element** Compatible with Carrier Metal as alloying Element or that can be recovered in subsequent Processing.

El **Mainly Element in Alloy or Compound in Oxidic Product, probably Lost** With possible functionality, not detrimental to Carrier Metal or product (if refractory metals as oxidic in EoL product then to slag/slag also intermediate product for cement etc.).

El **Mainly Element Lost, not always compatible with Carrier Metal or Product** Detrimental to properties and cannot be economically recovered from e.g. slag unless e.g. iron is a collector and goes to further processing.

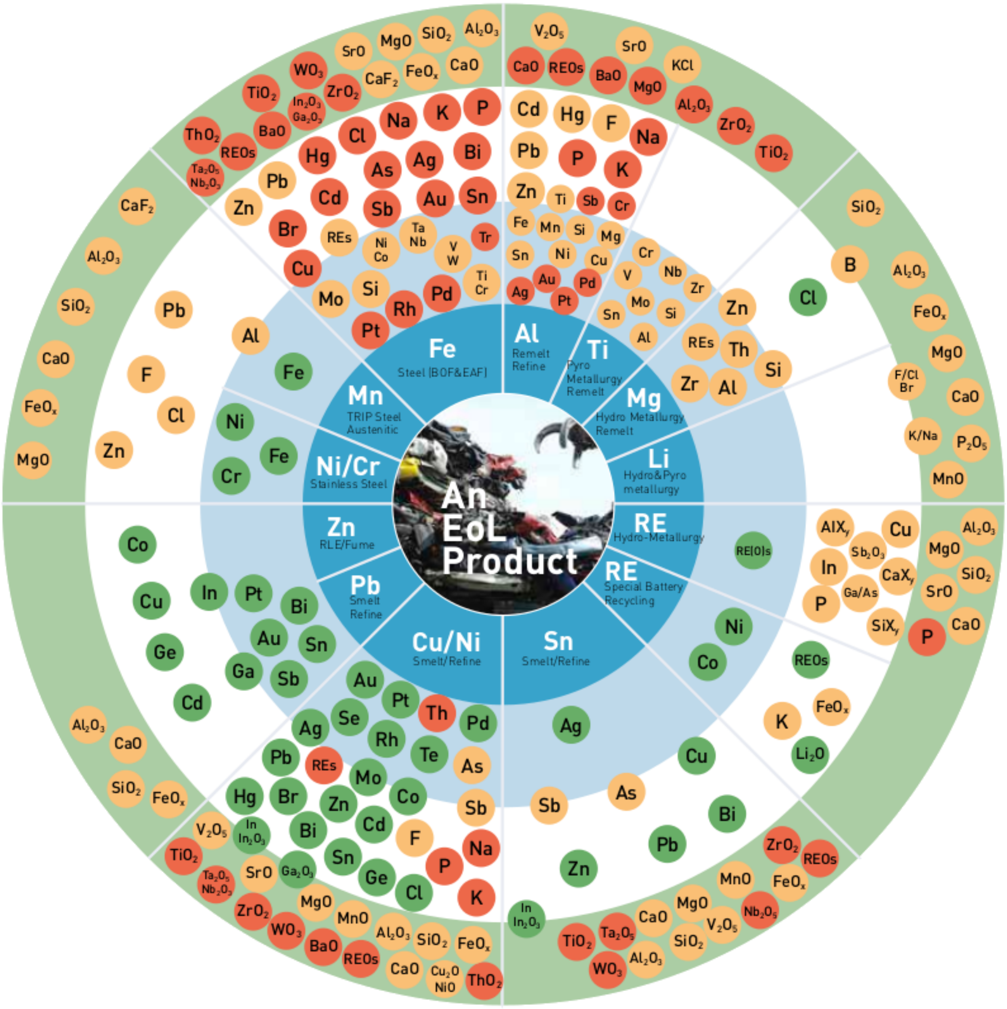

Figure 18: Metal wheel. The metal wheel shows which resources that can be recovered at the different types of smelters[57]

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[57] http://wedocs.unep.org/handle/20.500.11822/8423

Table 20: Recycling compatibility of different types of plastic. 1= Compatible, 2 = Compatible with limitations, 3 = Compatible only in small amounts, 4 = Not compatible[58]

Important Plastics	PE	PVC	PS	PC	PP	PA	POM	SAN	ABS	PBTP	PETP	PMMA
PE	1	4	4	4	1	4	4	4	4	4	4	4
PVC	4	1	4	4	4	4	4	1	2	4	4	1
PS	4	4	1	4	4	4	4	4	4	4	4	4
PC	4	3	4	1	4	4	4	1	1	1	1	1
PP	3	4	4	4	1	4	4	4	4	4	4	4
PA	4	4	3	4	4	1	4	4	4	3	3	4
POM	4	4	4	4	4	4	1	4	4	3	4	4
SAN	4	1	4	1	4	4	4	1	1	4	4	1
ABS	4	2	4	1	4	4	3	4	1	3	3	1
PBTP	4	4	4	1	4	3	4	4	3	1	4	4
PETP	4	4	3	1	4	3	4	4	3	4	1	4
PMMA	4	1	3	1	4	4	3	1	1	4	4	1

Design for repair

Design for repair and design for maintenance is design strategies to minimise the downtime of products. During the warranty period producers can benefit from a quick service, by reducing the labour cost of the repair. When adopting the approach for design for repair there are some general rules that support the ease of repair[59]:

- That parts can be easily removed without damaging other parts in the process
- Minimise the need for specialised tools for repairing the product
- Make part identification visible for easy clarifications of part origin and suited replacements
- Different form factors might be helpful in the reassembly process, and guiding pins can help the process of proper location
- For heavy parts handles or other features for ease of handling should be considered
- Avoid sharp edges of parts that can cause injury during the disassembly
- Provide clear access to components and parts. Especially if the product contains a line of replaceable units
- Provide clear access to the connectors and provide cables with codes throughout the whole cable for easy identification

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[58] Chiodo, J., 2005. Design for Disassembly Guidelines . Available at: http://www.activedisassembly.com/strategy/design-for-disassembly/.

[59] Mital, A. et al., 2014. Product Development, Elsevier. Available at: http://www.sciencedirect.com/science/article/pii/B9780127999456000144.

Annex 2: Impact of resource requirements

A recent study on the impacts of increased reparability[60] concluded that simple measures could have neutral to positive impact on the environment, but with some clear gains of resources. The study assessed the environmental impact on 7 different measures related to reparability. These four measures are briefly described below:

- Option 1 – Measures to ensure provision of information to consumers on possibilities to repair the product
- Option 2 – Measures to ensure provision of technical information to facilitate repair to professionals
- Option 3 – Measures for the provision of technical information to consumers to facilitate simple self-repairs
- Option 4 - Measures to enable an easier dismantling of products
- Option 5 – Measures to ensure availability of spare parts for at least a certain amount of years from the time that production ceases of the specific models
- Option 6 – Combination of option 5 and option 2 presented in the above section about repair and maintenance (measures to ensure provision of technical information to facilitate repair to professionals)
- Option 7 – Combination of scenarios 5 & 4 presented in the above section about repair and maintenance (measures to enable an easier dismantling of products)

These options are connected with a range of assumption but common for all options is their ability in some degree to support the ideas of the circular economy and stimulate more repair of products and prolong the lifetime. The impacts on the energy consumption, emission of CO_2-eq and consumption of resources (used for the production of appliances and spare parts) of the four measures are presented in Table 21.

Note that the baseline is described as:

"The baseline corresponds to the business as usual scenario where a new product is bought when the previous fails unless it is repaired according to the current repair rates. Products are replaced by new more efficient ones at the end-of-life. A certain share of the products at the end-of-life is repaired and changes ownership. Disposed products are treated as waste with some materials being recycled and other materials landfilled or incinerated."

Please note that the results mostly can be used as an indicator to show whether each measure has a negative, neutral or positive impact on the environment and the presented findings are based on washing machines.

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[60] Deloitte (2016) Study on Socioeconomic impacts of increased reparability – Final Report. Prepared for the European Commission, DG ENV.

Table 21: Impact of different measures to increase the reparability of washing machines

Washing machines									
	Baseline		**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Option 6**	**Option O7**
Energy	7,173.9 mil. GJ	Min	-0.1%	-0.1%	0%	-0.1%	-0.2%	-0.2%	-0.2%
		Max	-0.3%	-0.3%	0%	-0.5%	-0.7%	-0.8%	-1%
Emission of CO_2-eq	1319.4 mil. tonnes	Min	0%	0%	0%	0%	0%	0%	0%
		Max	0%	-0.1%	0%	-0.1%	-0.1%	-0.2%	-0.2%
Resource consumption	26.4 mil. tonnes	Min	-0.1%	-0.1%	0%	-0.2%	-0.2%	-0.3%	-0.3%
		Max	-0.4%	-0.3%	0%	-0.7%	-0.9%	-1%	-1.2%

The findings in the study indicates that option 1, option 2, option 4, option 5, option 6 and option 7 all have a positive effect on the environment with reductions in energy consumption and resource consumption. Option 2, option 4, option 5, option 6 and option 7 may also have a positive effect on the emission of CO_2-eq. Option 3 which is the measure for the provision of technical information to consumers to facilitate simple self-repairs has neutral impact, as the consumers are considered to perform only simpler repairs.

In Figure 19 all options are compared with each other and it seems like that the most beneficial single option is the measure to ensure spare parts for a certain amount and years (Option 5). However, both of the combined options (option 6 and option 7) may have even greater impact (positive impact) on the environment. It should be noted that both of these combined options also include option 5.

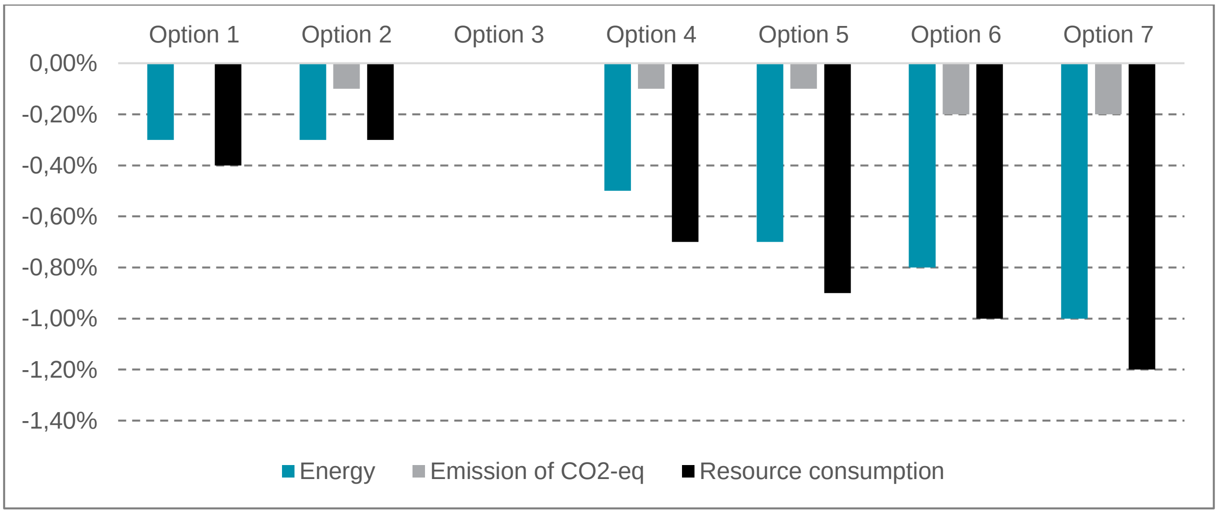

Figure 19: Impact of all options towards increased reparability

Different approaches can be implemented towards improved reparability, reusability, recyclability, dismantlability and a prolonged lifetime as discussed above. The lifetime is not solely dependent on break downs or malfunctioning components as more consumers are replacing functioning appliances due to a desire for an improved model with e.g. improved efficiency.